Geotechnical Instrumentation News

John Dunnicliff

Introduction

This is the twenty-seventh episode of GIN. Four articles this time, and some book reviews.

More on Temperature Sensitivity of Earth Pressure Cells

The June 1997 GIN column (page 42) had some comments about this subject, and in the March 2000 episode there was an article by Barrie Sellers (page 23) that looked at the topic from a theoretical standpoint. The following article by Yang et al pursues the topic, with a 'hands on' case history.

Locating Underground Features by Dowsing (Water Divining)

The article by Greenwood and Price was first published in the January 2001 issue of the English magazine *Ground Engineering*. Although somewhat outside the normal range of topics for GIN, I thought it would be worthwhile to spread the word. Try it!

For non-British English speaking readers (which includes most of you folks on the west side of the Atlantic), here's a translation of some terms used in the article:

- 'Delegate'. Someone who attends a course or conference, a registrant, participant, or attendee. Doesn't make any sense, does it? But it's the standard word here, implying that the person really doesn't want to be there, but has been delegated by the boss to attend!
- 'DIY store'. Do-it-yourself store. One of those wonderful places where engineers go to buy all their fix-it needs.
- 'Having a go'. Checking it out.
- 'Pullover'. Sweater. Also called a 'jumper' on this side of the Atlantic.

This reminds me of the many times when, while living in USA, someone said to me "I **do** love your accent". My frequent response was "Thank you, but what language are we speaking?" Usually a long and suspicious pause, then rather anxiously, "English". Then the punch line — "Okay, then **who** has the accent?"

Telltales

Here's another article by Bengt Fellenius, this time about use of telltale measurements in piles for determining load. No, I haven't forgotten my promise (March 2001 GIN) to twist his arm further, in the hope of an article about his method for offsetting the uncertainly of both residual stresses and of strain gage drift.

Errata

In the article by Bengt Fellenius "From Strain Measurements to Load in an Instrumented Pile" that was published in the previous issue of GIN (Vol. 19, No. 1, March 2001, pp. 35-38), Equation 2 contains a typographical error. It should read:

$$(2)\ \sigma = \left(\frac{A}{2}\right)\varepsilon^2 + B\varepsilon$$

Moreover, the value of 217 microstrain given in the example (on page 37, "...Gage Level 5 at a depth of 12 m registered a strain of 217 $\mu\ \varepsilon$") should be 271 $\mu\ \varepsilon$.

Thanks to Barrie Sellers for pointing this out. I suggest you mark these corrections on pages 36 and 37 of the March 2001 GIN.

An Enjoyable Evening

I've written an introduction, on page 34, to Peter Vaughan's article/speech, so nothing additional is needed here.

Book Reviews

After the four articles you'll find reviews of three recent ASCE publications.

Update on Tests of In-place Inclinometers

In the last episode of GIN there was an article (pages 33 and 34) about testing of eight commercial versions of in-place inclinometers in France. These tests are now in progress, and are expected to be completed by the fall of this year.

Installation of Inclinometer Casing

In the last episode of GIN I promised that this current episode would include an article telling about experience with using barite-bentonite weighted mud inside inclinometer casing to counteract buoyancy. There has been a 'production delay', but I hope to have it for the September issue.

Recent Instrumentation Courses

Two recent instrumentation courses were well attended, and we expect that they will both be updated and given again. 61 participants came to the course in Florida, with a provisional repeat date of March 2003. 45 participants came to Delft in The Netherlands, with a provisional repeat date of either April 2002 or April 2003. I'll give more exact information in GIN later.

Corps of Engineers Publications on the Web

At the course in Florida I learned that Corps of Engineer Manuals and other publications can be downloaded from the web. These include:

- EM 1110-2-1908. Instrumentation of Embankment Dams and Levees, June 1995.
- EM 1110-2-4300. Instrumentation of Concrete Structures, Sept. 1980 and Nov. 1987.

The URL is:
www.usace.army.mil/inet/usace-docs/eng-manuals/em.htm

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. +44-1626-836161, fax +44-1626-832919.*

A votre santé! (France)

Temperature Effects on Contact Earth Pressure Cells: Inferences from Long Term Field Instrumentation

Michael Z. Yang
Eric C. Drumm
Richard M. Bennett
Matthew Mauldon

Earth pressure cells were installed on a cast-in-place concrete box culvert to measure the pressures during construction and during the service life. The double cell culvert was surrounded with crushed stone, and had a final embankment height of about 12 meters. Hydraulic contact pressure cells, 230 mm in diameter and 6 mm thick (Geokon 4810 - vibrating wire transducers) were installed, three on the roof and three on the wall as shown in Figure 1.

To eliminate direct contact between the 0.5 m thickness of #57 crushed limestone and the pressure cells, a buffer of medium sand was placed around the cells. A geosynthetic fabric was used to separate the sand and gravel. The backfill material was clayey weathered shale, with a field measured unit weight of about 22.0 kN/m^3.

Pressure cells with vibrating wire transducers were selected because they are generally recognized as having excellent long-term stability characteristics (Weiler and Kulhawy, 1982; Dunnicliff, 1988, 1993; McRae and Simmonds, 1991). These devices have an internal thermistor such that the recorded signals can be corrected for temperature effects on the transducer. Because the inside of a box culvert is exposed to changes in air temperature, the temperature variations in a box culvert are likely to be greater than that experienced in many buried structures.

Observed Field Earth Pressure

Nearly four years of field earth pressure data were collected after completion of the earth embankment. Figure 2 illustrates the variation in measured vertical earth pressure with time at the three roof locations. The results from cell 4A (over the stiff external wall) indicate consis-

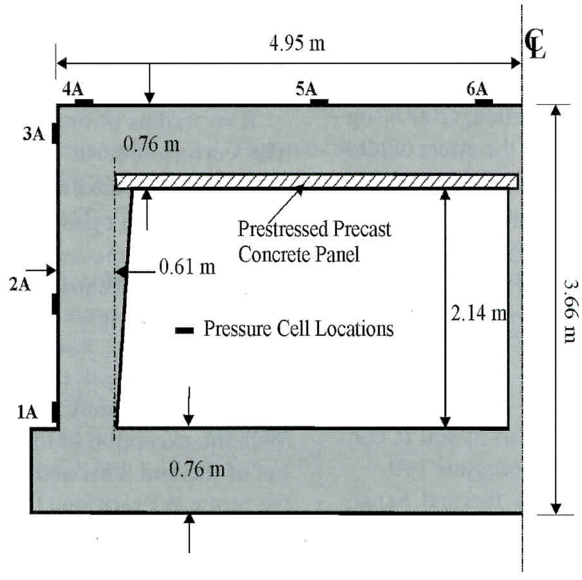

Figure 1. Box culvert dimensions and pressure cell locations

tently higher earth pressures than that recorded the other two locations. Although it would typically be assumed that the earth pressure would be constant after reaching the final embankment height, the measurements suggest a seasonal variation in earth pressure at each of the three locations on the roof. Also shown in Figure 2 is the variation in the mean temperature recorded from the internal thermistors in each of the pressure cells. The pressure readings shown in Figure 2 were temperature-corrected based on the recommendations of the manufacturer. In spite of the temperature corrections, the vertical earth pressures appear to follow the seasonal variation in temperature, with higher summer temperatures correlating with higher earth pressure readings. The recorded variation in earth pressure was approximately 100 kPa, or 30% to 40% of the mean measured pressure. This seasonal variation in pressure may be related to factors other than the temperature, such as fluctuations in the water table elevation, the water content of the backfill, and the volume of streamflow through the culvert. Regardless, the pressure variations recorded by these instruments must be understood and corrected to properly interpret the results, and the apparent temperature-induced pressure variations should be evaluated.

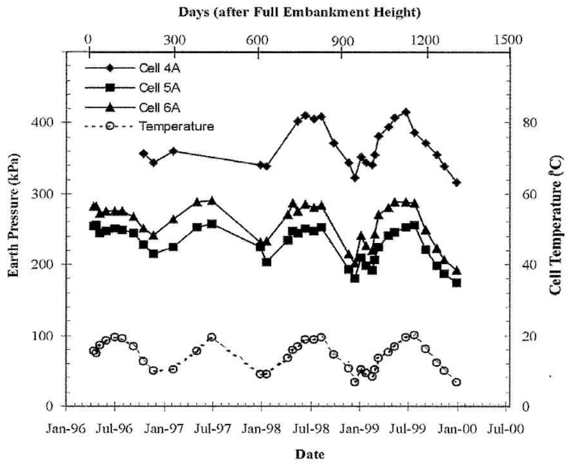

Figure 2. Measured earth pressures and temperature

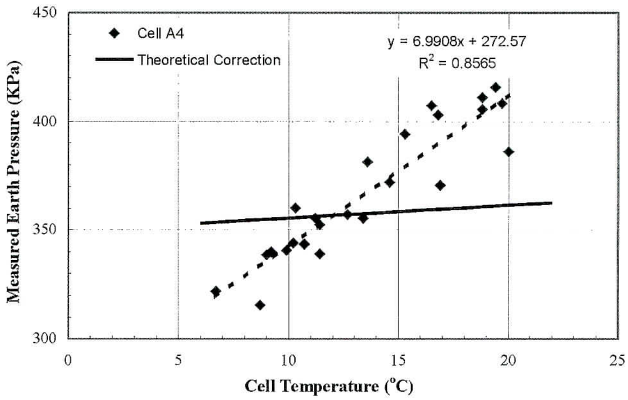

Figure 3. Illustration of temperature coefficient determination

Temperature Correction — Theoretical Approach

The manufacturer's recommended temperature correction is intended to account for the effect of temperature on the pressure transducer response, and does not consider temperature effects on the fluid inside the cell. Sellers (2000) suggested a correction for the effect of temperature changes on the fluid inside hydraulic earth pressure cells. For contact pressure cells installed at the surface between soil and concrete, the temperature correction coefficient *k* (units of stress/degree C) is given by:

$$k = 3EKD/R \qquad (1)$$

where:

E = elastic modulus of soil in contact with the pressure cell

K = coefficient of thermal expansion for the fluid in the cell diaphragm

D = thickness of oil inside the cell

R = radius of the pressure cell

The corrected earth pressure, P'_1, at temperature T_1 can then be obtained by:

$$P'_1 = P_1 + k(T_1 - T_0) \qquad (2)$$

where:

T_1 = thermistor-measured temperature in pressure cell

T_0 = baseline temperature

P_1 = measured earth pressure at temperature T1

With the exception of the elastic modulus of the soil surrounding the cell, all the terms in Equation (1) are a function of the pressure cell design. For the pressure cells installed on the buried culvert, $K = 700\times10^{-6}$ /°C (oil filled cell), D = 0.51 mm, and R = 115 mm. The initial elastic modulus for the soil was estimated from a series of drained triaxial shear tests performed on the crushed stone at the in-situ dry unit weight of 21.0 kN/m^3. For confining pressures ranging from 69 to 275 kPa, an average initial elastic modulus of 62.6 MPa was obtained assuming a hyperbolic (Duncan and Chang, 1970) stress-strain relationship. Thus, the theoretical temperature correction coefficient from Equation (1) for the pressure cells installed on the buried culvert is 0.582 kPa /°C (0.084 psi/°C), which is consistent with the value for a contact cell in medium stiff soil reported by Sellers (2000). For the measured temperature variation of 13 °C, this produces a maximum pressure correction of only 7.6 kPa (1.1 psi). Clearly, this correction is insufficient to remove the apparent temperature effect from the pressure measurements, and if the pressures were corrected using this relationship, the resulting graph would be indistinguishable from Figure 2. Since the modulus of the weathered shale backfill is smaller than that of the crushed stone, an even smaller correction factor would have been obtained if the shale were used to calculate the correction. Using the modulus of the small amount of sand surrounding the cell, the correction would increase by a factor of about 3.

Temperature Correction — An Empirical Approach

Assuming that the vertical earth pressure is constant under a uniform embankment height, a relationship between the measured cell temperature and the recorded earth pressure can be developed. Figure 3 shows the relationship between the recorded temperature in the cell (corrected in accordance with the manufacturer's transducer recommendation) and the observed earth pressure for Cell 4A. Similar results were obtained for the other cells on the roof, cells 5A and 6A. The slope of the "best-fit-line" is the "observed temperature correction coefficient", assuming that the vertical pressure in fact remains constant over the range of observed temperature. Also shown in Figure 3 for comparison is the theoretical fluid temperature correction, Equation 1, which has a much smaller slope (one order of magnitude). For the three cells (cells 4A, 5A, and 6A), the observed temperature coefficients ranged from 5.62 to 6.99 kPa /°C, as summarized in Table 1. For comparison, Table 1 also includes the theoretical fluid temperature coefficient, the manufacturer's transducer coefficient, and the corresponding range of soil pressure change for the measured change in temperature. The observed temperature coefficient yields pressure changes ranging from 25 to 32% of the measured average earth pressure.

Figure 4 illustrates the variation of recorded earth pressures after correction using the correction coefficients developed from the observed temperature/pressure response. Although a seasonal variation in pressure is still observed in Figure 4, the temperature-induced variation has been reduced significantly.

Discussion and Conclusions

As indicated in Table 1, the temperature coefficient given by the manufacturer for transducer temperature effects acts in an opposite sense as the temperature correction applied to the fluid, and is very small. The theoretical fluid temperature correction results in a pressure change that is correct in sign, but more than one order of magnitude too small to correct the temperature fluctuations observed in the contact cells on the culvert.

Sellers' theoretical approach improved the understanding of temperature effects on the measurement of earth pressure with hydraulic pressure cells. However, based on the empirical temperature correction obtained directly from the field measurements, the theoretical formula underestimated the actual temperature effects, providing an insufficient correction. The theoretical temperature correction (Equation 1) is dependent on the elastic properties of the surrounding material, which is assumed to be linear elastic. The value of Young's modulus for soil is strongly dependent upon the strain magnitude, and small strain modulus values may exceed large strain values by more than an order of magnitude (Ng et al., 2000). Depending upon the soil, five to ten times larger modulus values are likely under the small strain magnitudes associated with dynamic loads, and the effects of these modulus differences on stress cell measurements has been recognized (Weiler and Kulhawy, 1982). In addition, the constraint conditions in the laboratory triaxial test used to measure Young's modulus are not the same as the constraint conditions in the material surrounding the pressure cell in the field.

Table 1. Comparison between Different Termperature Coefficients

Cell	Average measured earth Pressure kPa (psi)	Measured temperature variation at cell, °C	Empirical or observed correction coefficient		Theoretical fluid correction coefficient		Manufacturer's transducer coefficient	
			Correction coefficient, kPa /°C (psi/°C)	Range of pressure change kPa (psi)	Correction coefficient, kPa /°C (psi/°C)	Range of pressure change, kPa (psi)	Correction coefficient, kPa /°C (psi/°C)	Range of pressure change kPa (psi)
4A	367 (53.2)	6.7 - 20.0	6.99 (1.01)	93.0 (13.5)	0.582 (0.084)	7.56 (1.1)	-0.113 (-0.016)	-1.50 (-0.217)
5A	229 (33.2)	7.2 - 20.2	5.62 (0.816)	73.1 (10.6)			-0.048 (-0.007)	-0.62 (-0.089)
6A	258 (37.5)	7.2 - 20.3	6.18 (0.897)	81.0 (11.8)			-0.115 (-0.017)	-1.52 (-0.221)

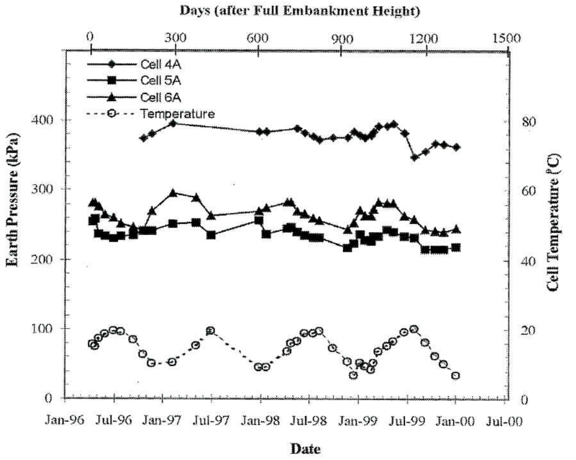

Figure 4. Earth pressures after correction

Dunnicliff (1997) suggested that significantly different temperature effects may be observed between calibration studies conducted in the laboratory and cells embedded in field, due to different boundary and constraint conditions.

It is suggested here that the theoretical fluid temperature correction approach described by Sellers may provide a suitable temperature correction provided care is taken to choose an appropriate value for the modulus of the surrounding material. In this example, the empirical model and the theoretical model would agree very well if the gravel modulus was increased by a factor of 10. The deformations in the material surrounding the earth pressure cell mounted in contact with the culvert roof are expected to be very small. Therefore, the initial modulus measured in the triaxial test may not have been appropriate representation of the small strain response of the gravel adjacent to the pressure cell. A constrained modulus test may have been a more appropriate measure of the gravel modulus under these loading conditions, and would likely yield a substantially greater modulus.

The results for this study also suggest that even under constant embankment height significant variations in earth pressures may be recorded, in this case variations of 30 to 40 percent. The nature of these variations must be understood to properly interpret the earth pressure data. The variations in earth pressure may be attributed to factors other than temperature, but the data reported here suggests that changes in temperature may be significant and that these effects on the measured pressures should be evaluated for good geotechnical engineering practice.

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Locating Underground Features by Dowsing

John Greenwood
Robert Price

Abstract

A light-hearted look at the ancient art of dowsing during a Masters course on Site Investigation has led to some surprising findings with most of the course participants able to detect underground features with little prior tuition. An explanation of the phenomenon is provided in terms of electrostatic forces. It is considered that the technique may be of considerable value as an initial, very cost effective, non-intrusive method for estimating the location of certain underground services, water and voids prior to the use of conventional geophysical and intrusive exploratory techniques.

Rob Price (centre left) helps delegates develop their dowsing skills to detect the presence of underground services in the university grounds.

Introduction

The ancient powers of dowsing using divining rods have been observed over the years and have either been dismissed as some sort of black art or trickery or perhaps accepted as being available only to those possessing a special sensitivity. Little credibility has been attached to the results because of lack of scientific explanation.

During the part time MSc module on Site Investigation delivered in June 2000 at the Nottingham Trent University, England, the authors and the delegate group investigated the phenomenon of dowsing and came up with some surprising findings. It was confirmed that the use of divining rods can be an effective, low cost, method of detecting the presence of underground features such as services, water and voids.

The Divining Rods and Their Use

Traditionally dowsers have used forked rods cut from hazel or other wood which deflect when the dowsers body reacts to a particular underground feature. However most dowsers today use simple bent metal rods which cross when a reaction occurs. A historical review of the application of dowsing was presented by Grounds, (1996).

The authors made their rods from 4mm brass rods obtained from the local DIY store for around £3 and bent to the approximate dimensions shown in Figure 1 on the following page. The rods are simply held, not too tightly, with the long arm horizontal. The sketch shown in Figure 1 illustrates the holding of the rods, the walking action and the crossed position of the rods when a reaction occurs. Experience has shown that many people have a strong reaction in only one rod - often the right hand - and therefore a single rod is often adequate.

Dowsing Demonstration

During the Site Investigation course, the second author, Robert Price was able to demonstrate his dowsing ability to a group of 15 delegates by locating the position of a service duct running from a manhole in the grounds of the University. The group was initially sceptical but, after 'having a go' for themselves, discovered that two thirds of the group experienced a similar reaction in the divining rods at the same location.(See photo on page 29).

Each delegate was then invited to walk along a 15m tape laid on the ground and record any reactions in their rods. The location of a reaction was taken to be the position of the delegate's toes at the point of strongest reaction. The results are plotted in Figure 2. The locations detected by the inexperienced delegates who did have a reaction compared well with the locations picked up by Rob (participant 16). It is of interest to note that the four females in the group (participants 5,7,8 and 10) all had positive reactions at very similar locations along the tape. All those present had their initial scepticism removed and were satisfied that dowsing had some merit as an aid to site investigation.

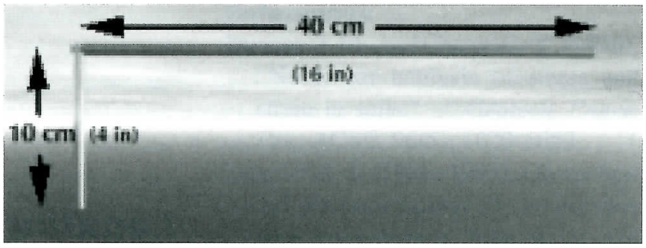
Other Evidence of the Value of Dowsing

Whilst there is some documented evidence of dowsing success (Killip, 1984, Wilcock, 1994) it has tended to be regarded as a gift of special individuals. It is encouraging that a high proportion of people, perhaps 60 - 80 % of those introduced to the technique, have a measure of success. The 'in-house' National Coal Board guidance notes on 'The Treatment of Disused Mine Shafts and Adits' (1982) refer to the use of the services of water diviners and the success of some NCB engineers in detecting underground discontinuities with purpose made rods. It is believed that many water company workers carry divining rods to help locate positions of pipes and leaks but there is perhaps a slight embarrassment for such staff who seem to possess this mystical power.

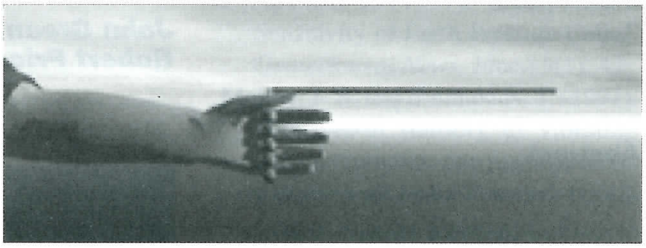
Possible Causes

Once the existence of the dowsing phenomenon is accepted, the next question has to be 'what is causing it?' Wilcock lists the various force fields which might affect the sensitivity of the human body and rods: - Gravitational, Magnetic, Electric, Electromagnetic, Radioactive, Seismic (The stress field around fractures, fissures and faults), Geothermal,

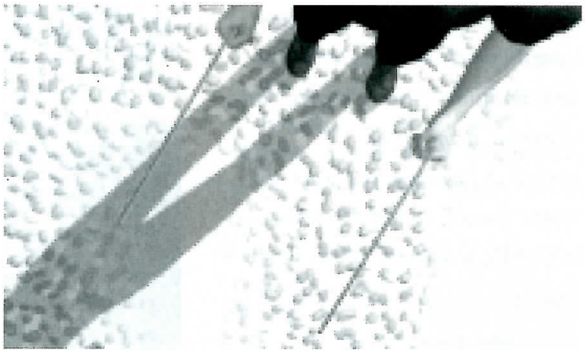
The Divining Rods - Two brass rods, typical 4mm diameter and bent to the approximate dimensions as shown



Rods positioned in palm of the hand



Hands closed, but not too tightly, on to the rods, and rods held parallel to the ground



Rods held loosely, parallel to each other, and operator walks slowly forward

Rods indicate a reaction by crossing, and often end up at 90° to the direction of walking

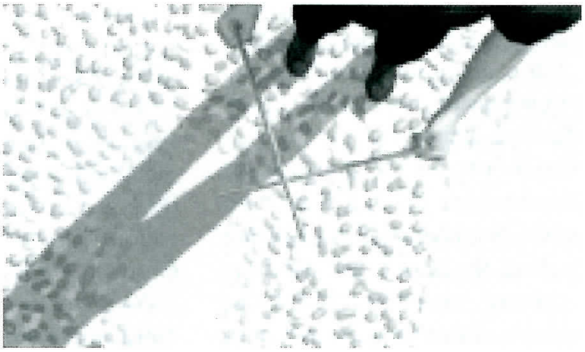


Figure 1. Typical divining rods and their use(Diagrams courtesy Slawek Wojtowicz)

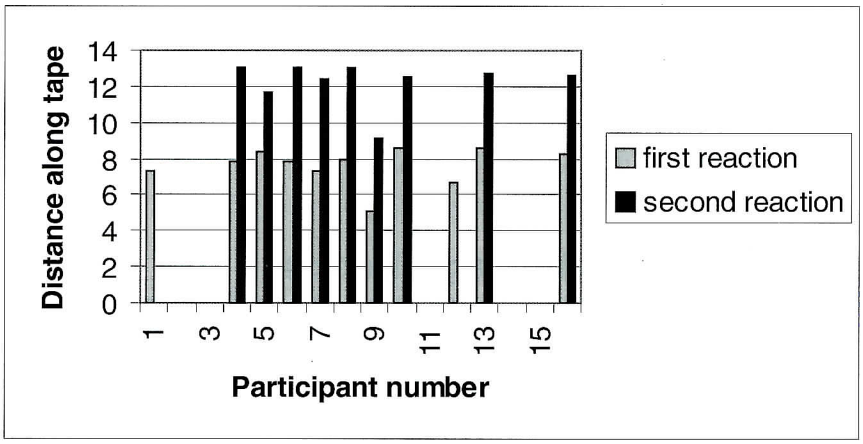


Figure 2. Reactions recorded by the participants in the dowsing trial

and Geochemical. Of these he considered the electric, magnetic and electromagnetic fields to be the most probable candidates with the skin conductivity of the dowser playing a part.

An Explanation

Whilst working with the divining rods, the first author, John Greenwood, became overheated and on removing his acrylic pullover discovered that the rods were particularly sensitive to the electrostatic field that surrounded it. When the pullover was placed on the ground, the rods responded very positively as his body passed over it. The effect was even more pronounced when the rods were rubbed on the acrylic jumper prior to dowsing. A similar response in the rods was found when dowsing over a bowl of water placed on the ground.

The electrostatic explanation ties in with the likely presence of varying electrostatic fields around pipes, cables, voids and bodies of water. It may be that forward motion will also play a part in the response of the rods to the fields that are present.

The divining rod is performing a similar function to the gold leaf electroscope experienced during school physics to demonstrate electrostatic effects. The charges on the rods cause a response in relation to the charges on the object. Like charges repel and opposite charges attract to influence the alignment that the rods are trying to take up. It was noted that removing the shoes often increased the dowser's sensitivity indicating the importance of electrical continuity with the ground

Some work has been published (http://www.connect.ab.ca/~tylosky/) supporting the electrostatic explanation and providing a convincing argument as to why one hand (the right) is sometimes more responsive than the other. The existence and detection of electrostatic fields associated with underground features is being further researched at the Nottingham Trent University with the intention of developing a scientific instrument, operating independently from the human body, which will be of assistance to the geotechnical engineer in locating the features.

Conclusions

The majority of people, but not all, are able to generate a reaction in divining rods relating to the presence of certain underground features such as cables, metal and plastic pipes, buried tanks, foundations, trenches, large tree roots, voids/cavities and bodies of water. The control and understanding of the response seems to improve with practice.

The reaction is explained in terms of electrostatics and the rods aligning themselves with the various electrostatic fields present around the underground features.

The limitations of the technique must be recognised with its dependence on operator 'sensitivity' and the presence of electrostatic fields to relate the object to the divining rods. The technique should not be used as a substitute for establishing the location of services in consultation with the statutory authorities prior to any excavation. However it is a very cheap, and often a remarkably effective (and entertaining!) way of making a preliminary geophysical appraisal of a site prior to more detailed geophysical and intrusive investigation work.

Acknowledgement

The enthusiastic participation and support of the delegates on the part time MSc programme in Geotechnical Engineering Design and Management at Nottingham Trent University was much appreciated. The authors are grateful to the Editor of 'Ground Engineering' for permission to reproduce this article which was first published in January 2001.

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Where to Plot Average Loads from Telltale Measurements in Piles

Bengt H. Fellenius

Introduction

A static pile loading test is sometimes instrumented with one or several telltales to measure the shortening of the pile during the test. The measurements are used to determine the average load in the pile. Two telltales placed with tips at different depths in the pile provide three values of average load: each gives an average load over its length and the third value is the shortening over the distance between the telltale tips (as the difference between the two full-length values).

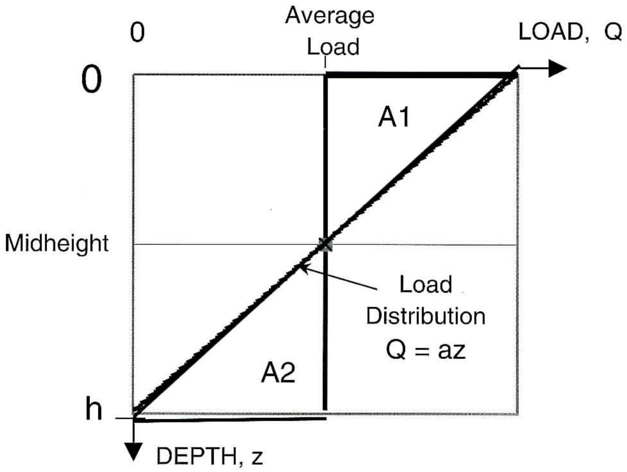

Figure 1. Load distribution for constant unit shaft resistance.

Similarly, three telltales provide six values. The most important telltale is the one that has its tip placed at the pile toe, because it provides the pile toe movement (by subtracting the shortening of the pile from the pile head movement). If the telltale dial gage is arranged to measure shortening directly and the length considered is at least 5 m, the usual 0.001 inch dial-gage reading gradation normally results in an acceptably accurate value of strain over the telltale length.

When using a telltale value for determining average load, the shortening must be measured directly and not be determined as the difference between movement of telltale tip and pile head movement. This is because extraneous small movements of the reference beam always occur and they result in large errors of the shortening values. If you don't measure shortening directly, forget about using the data to estimate average load.

Load Distribution

The main use of the average load in a pile calculated from a telltale, or of the average loads if several telltales are placed in the pile, is to produce a load distribution diagram for the pile. The distribution is determined by drawing a line from the load applied to the pile head through each value of average load calculated for that applied load. Case history papers reporting load distribution resulting from the analysis of telltale-instrumented pile loading tests invariably plot the average loads at the mid-point of each telltale length considered. But, is that really correct?

Although several telltales are usually placed in the pile, even with only one telltale in the pile (provided it goes to the pile toe) we can determine a load distribution line or curve for each load applied to the pile head. As the toe telltale supplies the pile toe movement for each such distribution, the data establish the load-movement curve of the pile toe, which is much more useful than the load-movement curve for the pile head.

If the average load is determined in a pile that has no shaft resistance — it acts as a free-standing column — the load distribution is a vertical line down from the applied load; the applied load goes undiminished down to the pile toe. In a pile, however, the load reduces with depth due to shaft resistance. Assuming that the unit shaft resistance is constant along the pile, then, the load distribution

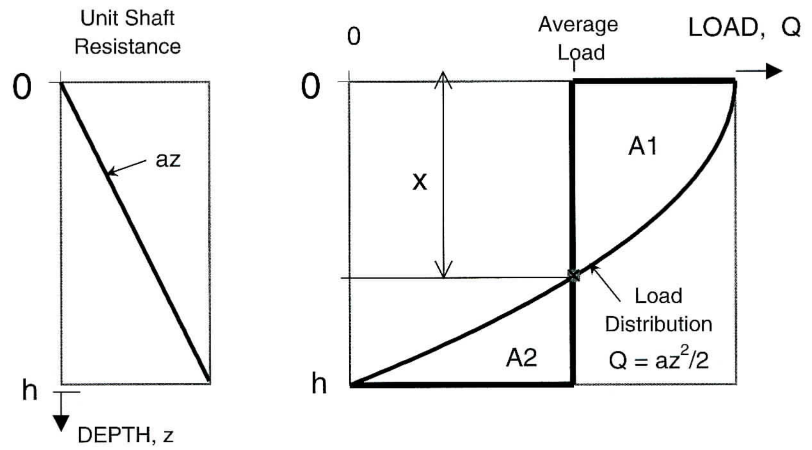

Figure 2. Linearly increasing unit shaft resistance and its load distribution.

is a straight line from the applied load to the pile toe, as shown in Fig. 1 (in order to make the figure more clear, it is assumed that the pile has no toe resistance).

The straight-line load distribution line crosses a vertical line drawn through the average load at midheight of the pile, the midheight of the telltale length, rather. To be five, clearly, a straight-line distribution must have equal areas, A1 and A2, between load-distribution line and the vertical through the average load over the telltale length. This "equal-area-condition" means that, for the case of constant unit shaft resistance, the average load should be plotted at midheight of the telltale length. Actually, a load-distribution of any shape must satisfy an "equal-area-condition". However, this does not mean that the average load must always be plotted at midheight.

Let us assume a more realistic distribution of the unit shaft resistance, for example, linearly increasing with depth, such as a unit shaft resistance proportional to the effective overburden stress. Fig. 2 shows two diagrams, one with unit shaft resistance (az) versus depth and one with load distribution versus depth (z). The shaft resistance is a line proportional to the effective overburden stress and the load distribution curve is the result of the integration of the unit shaft resistance. Fig. 2 also shows a vertical line through the average load and two areas, A1 and A2. For A1 and A2 to be equal, obviously, the average load must be plotted below the midheight of the telltale length.

The exact location can easily be found, as shown in Figure 2.

Assume that

h = height (length) of pile considered (distance from pile head to telltale tip, or distance between two telltale tips)
x = height of area A1
z = depth
az = unit shaft resistance (proportional to effective overburden stress)

we can determine

$$A1 = \frac{\alpha x^3}{3}$$

Similarly, we can determine that Area A2 is

$$A2 = \frac{a(h^3 - 3x^2h - 2x^3)}{3}$$

The "equal-area-condition" of A1 equal to A2 gives

$$A1 = \frac{h}{\sqrt{3}} = 0.58h$$

When the shaft resistance is not constant but proportional to the effective stress, as shown above, plotting the value of average load at midheight of the telltale length, h, is then not correct. The value should be plotted at a distance down from h = 0 of 0.58h. This is not trite matter. The incorrect representation of the average load implies more shaft resistance in the upper portion of a pile and less in the lower portion. The error has contributed to the "critical depth" fallacy.

Conclusions

The possibility, and often also the probability, of the data having been incorrectly plotted and analyzed is a good thing to keep in mind when consulting old case histories. When producing results to go into new case histories, use vibrating wire strain gages rather than telltales for determining load — and limit the telltale instrumentation to one telltale at the toe for determining the pile toe movement.

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Peter Vaughan's 'After Dinner' Speech

Imperial College, London, September 1999

Introduction

Professor Peter Vaughan has been teaching soil mechanics at Imperial College in London since 1963 and is currently Senior Research Fellow within the Soil Mechanics Section of the Department of Civil and Environmental Engineering. In September 1999 Imperial College celebrated the 50th anniversary of the first DIC/MSc course (DIC is "Diploma of Imperial College") with a three-day symposium titled "Symposium on Geotechnics in the New Millennium, An Imperial College Perspective". The symposium celebrated the achievements of the past 50 years, reviewed the state-of-the-art of geotechnics, and speculated on its future.

On the second evening the attendees gathered for a symposium dinner, at the end of which Peter Vaughan gave the following speech. There are several references to geotechnical instrumentation. My purpose in including it here is to share the fun with you. With Peter's approval, I've done some editing, and have added subtitles to make the written version more readable.

John Dunnicliff

Auntie

I had an auntie, not long departed, who took an interest in my career. Once, many years ago, I tried to explain what I did. Auntie thought about it and said, "you mean you play with dirt? At your age? Don't you think you ought to get a proper job?"

To the end, she retained the view that a career in geotechnics was a clear demonstration of arrested development.

It is difficult to make what we do look glamorous. I sometimes think it best not to talk about it too much in front of strangers. It is difficult to reconcile the fact that we had nuclear power before we had a viable theory to explain the long-term strength of London Clay.

In the past I've explored the alternative theories that:

1. Our subject must be unusually difficult, or
2. It has an extraordinary ability to attract thick people.

Among such a gathering I must support the first explanation.

Meta-physics with Numbers

What started my career in geotechnics, probably more than anything else, were some inspirational remarks by Professor Skempton in the saloon bar of the Cleveland arms in Middleton in Teesdale in 1957. As a very junior engineer I had been delegated to supervise the excavation of a deep trial shaft in glacial sediments in Upper Teesdale, an uncomfortable duty which I had accepted rather grudgingly. I should say that perhaps I had not paid all the attention that I should have to my undergraduate soil mechanics lectures. Perhaps, as undergraduates do, I had scrubbed out my mind on completion of the course to remove any dangerous residues of technical information that might confuse my future. Towards the end of things Prof Skempton came to inspect what was going on and to issue testing instructions. He required various tests and made clear that they were to be done at several different soul pressures. I have a romantic nature and I was impressed by this. This business must be like metaphysics with numbers, I thought. I went home to the office and wrote a letter to Wimpey's Central Laboratory instructing that the tests be carried out. It was signed by Percy Partner, who was really a very nice man, but who seemed never to be at one with life, which caused him to spend a lot of time standing on one leg and shouting. Several days went by. Then the door slammed and in stomped Percy. "Man on the phone from Wimpey's", he said (they always speak to the man who signed the letter), "can't understand your testing instructions. Speak to him". I spake. "We can't understand your testing instructions", said a voice. "We think there may be a typing error", it said. "When you say soul pressure do you really mean cell pressure?" Dim memories of lectures returned. I immediately rejected the option of returning to Prof Skempton for further instructions and I said that, taking everything into consideration, I probably did mean cell pressure. I must admit I was saddened by this return to ordinariness, but I decided to hang on to my new interest, and here I am.

Plate Loading Tests

That trial shaft in Yorkshire started a process of lifetime learning that still goes on. My principal duty was to perform plate loading tests on the boulder clay by placing a strut across the pit and jacking the plate off the end of it. The trouble was the boulders were nearly all in contact with other boulders, leaving little space into which to push the plate. After no successful tests and several visits to the blacksmith to straighten out the strut, I bought some steel knitting needles. I pushed these in first to find out where there was enough room for the plate. I could not help wondering about the relevance of the test to the overall performance of the boulder clay as a dam foundation, whether it had a soul or not. Indeed, I began to wonder what a stress was in such a material.

The crew were mostly old-fashioned public works men from the emerald isle. When we started they all had digs [rented rooms] within a ten-mile radius. When we finished after 2 months no-one had digs nearer than forty miles because of their tendency to set fire to their beds with their cigarettes. The boss man, small but with an incredible ability to split a whinstone boulder with a 12 pound hammer, used to work two weeks continuously, take the weekend off, go down to Darlington, buy a new suit, drink Guinness for three days, return to site in his new suit, work two weeks in it, go back to Darlington, buy another new suit, spend three days drinking Guinness, etc, etc.

The first attempted plate test was a disaster, with all the equipment ending in a splintered heap in the mud on the floor within minutes. Being idle, I sent two of the crew for replacements, remaining in the pit with the final member, an absolutely charming man - the only Irishman I have ever met with a stutter. I think he got it from being torpedoed too often in the second world war. He seemed to think that you always finished a journey across the Atlantic in a rowing boat. After a while we fell into conversation. "You know", he said, after a few pleasantries, "if you put a plate on both ends of the strut you could do two tests at once". I thought - he thought. "Ah, he said, "I can see why you can't do that. You'd need two jacks, and you've only got one." I'm still thinking!

no-one had digs nearer than forty miles because of their tendency to set fire to their beds with their cigarettes

Twin-tube Hydraulic Piezometers

Our Irish friends rather dominated construction forty years ago. Shortly after the pit, I worked on Selset Reservoir. This was the first dam to incorporate drainage blankets in its design. It was also one of the last with a puddle clay core. It was full of hydraulic piezometers - incorrectly designed as it turned out, with polythene connecting tubes rather than nylon ones. A problem with hydraulic piezometers is that it is very difficult to identify which tube is which when the contractor digs them up again accidentally, as he will. Soil Mechanics Ltd., who were the sub-contractors, cracked this problem. They had got twin tubes extruded from polythene of many different colours. They were very jolly and could be identified easily. One day we had laid out a number of piezometers and their tubes but had not had time to bury them. We came back in the morning and pushed water through the tubes to make sure that the systems were full of water when we buried them. No water came through one piezometer. We walked back down the trench. Half way along we discovered a gap neatly cut in one tube, with about 2 metres missing. A short time later the missing length of tubing was found supporting the trousers of one of the workman placing the core. Somewhere I should have a copy of the letter from the Agent to the Resident Engineer, saying that Balfour Beatty deeply regretted the damage done to the instrumentation that morning by a Mr Joseph O'Rourke, "who is no longer in our employ".

a short time later the missing length of tubing was found supporting the trousers of one of the workman placing the core

Space Considerations

Not long after, I first met John Burland at the international conference in Paris. We shared an interest in partly saturated soil. I was going back to Teesdale after the conference. Somewhere, I suspect, in a Parisian pavement café (the conference sessions were a bit boring), I suggested to John hat he might like to come with me and see what we were doing. He accepted. Accommodation was in short supply and I had to book two rooms in a pub that I had not used before, although it was much used by the contractor. We arrived and were shown to our rooms. John found that his cupboard was full of someone else's clothes. Assuming, reasonably, that he had been misdirected, he reported this to the landlady. "Oh", she said, "That's all right, he's on night shift".

Dancing

That conference in Paris brought to an end Skem's four years as President of the ISSFE. The conference dinner was a magnificent affair at the Orangerie at Versailles. The top table was half-way down this very long room, where Skem sat with the French Minister of Culture. For reasons that I cannot quite remember I was late, but received a message that a seat had been saved for me at the far end of the room. Everyone else was seated. I set off. I didn't notice that a small and highly polished dance floor had been prepared opposite the top table, at least that is until I trod on it and did the next ten metres on my backside. I looked up to from a supine position to see the French Minister of Culture looking down in a very disapproving way, and (I lip-read on such an occasion) saying to Skem "oo is zat ide-ert?" I have always wondered what Skem said. At least I had the presence of mind not to say "Hi, Skem".

Index Test

A life in geotechnics has many successes and failures, triumphs and disasters, examples of heroism and rank cowardice, and many uncompleted projects. I recall a perhaps inadvertent discovery which Nordie Morgenstern made at this time. If you form a small cylindrical sample of remoulded clay in a tube, as for the triaxial test, extract it and drop it vertically on the floor (after imparting a little off-spin to keep it axially stable), it adopts on impact a shape rather like a child's drawing of an elephants foot - in fact, exactly like a child's drawing of an elephants foot. Through the application of some sophisticated plasticity theory (or an empirical correlation) this can be related to the undrained strength of the clay. I am sad that this fundamental discovery has not been developed as one of those empirical index tests which we soils engineers so much enjoy. The apparatus is very simple and the science is certainly sounder than that of the moisture condition value. Would it not be more satisfying to say - not "this soil has a moisture condition value of thirteen", but "its all right, chaps, its Elephant 3"? There is still work to be done.

Full-scale Testing

As an example of raw courage I recall John Hutchinson on a field trip to Sheppey, to view the large coastal landslides there. He was accosted by the local resident in a house clearly ordained to be the next but three to join the big drop. The resident waxed heatedly on the gross inadequacy of the local council for not building a seawall to prevent this happening. "Oh no", said John, "this is the last piece of undefended London Clay sea cliff that there is, and it is vital to science that they should do no such thing". Some people will go all the way to the wire for a principle.

Computers

Our work is now much changed by electronics and computers. I welcome this but find relationships difficult. Imperial College will not network me on the grounds that I am a virus. Two weeks ago I took delivery of a new and very sophisticated deaf aid with no less than four programmes. After five days it emitted a squawk and withdrew co-operation. I thought it had gone to join the great acoustic laboratory in the sky, so I took it back, in a state of modest dudgeon. The man plugged it into his computer. He said, "it's not broken, but somehow all the programmes have disappeared. That's never happened before".

Auntie Again

Anyway, the night passes. Enough of idle chatter. Perhaps it is time to follow Auntie's advice at last and go away and get a proper job. But if I do I doubt if it will be anything like as much fun as the one I have had so far. I hope that will be as true of the future as the past.
Goodnight

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Reviews of Some Recent ASCE Publications

John Dunnicliff

Introduction

These reviews are intended to be part of GIN and, as such, address only the aspects of the following publications that relate to geotechnical field instrumentation.

Even though it has little relevance to these reviews, I thought it was worth reminding you of the superb advice of Joseph Pulizer:

> *Put it before them briefly so they will read it,*
> *clearly so they will appreciate it,*
> *picturesquely so they will remember it*
> *and, above all, accurately so they will be guided by its light.*

A goal for us all!

Guidelines for Instrumentation and Measurements for Monitoring Dam Performance (2000). ASCE Stock #40531, 712 pp. Price $65.00.

This volume has been written by the ASCE Task Committee on Instrumentation and Measurements for Monitoring Dam Performance, Foster Pelton, Chairman. There are 12 chapters and 5 appendices:

PART I. MONITORING DAM PERFORMANCE

1. The Purpose of a Measurement System
2. Factors Affecting Dam Performance

PART II. MEANS AND METHODS OF MONITORING

3. Measurement Instruments and Techniques
4. Geodetic Monitoring Techniques

PART III. MONITORING PROGRAMS

5. Planning and Implementing Measurement Systems
6. Developing an Instrumentation and Measurement Plan
7. Automated Data Acquisition Systems

PART IV. RESULTS OF MONITORING ACTIONS TAKEN

8. Data Evaluation and Reporting
9. Decision Making and Taking Action

PART V. TYPICAL MONITORING APPLICATIONS

10. Concrete Dams
11. Embankment Dams
12. Other Dams and Appurtenant Structures

Appendix A.
Case Histories

Appendix B.
Instrument Details, Performance Specifications and Lightning Protection

Appendix C.
Standard Operating Procedures

Appendix D.
Typical Data Collection Forms and Plots

Appendix E.
Glossary of Terms

Review

The members of the Task Committee are affiliated with architect/engineer companies, public agencies, instrument manufacturers and geotechnical consulting firms, and some are individual consultants. Thank you, to these 26 people, for giving your time and energies to produce this guide. The above listing of contents indicates the very comprehensive coverage of topics relating to performance monitoring of dams. I was particularly pleased to see the significant content on "why?", which is much more difficult to write than "how?"

Section 3.2, on the origins of modern dam instrumentation, is important, even to those of us with grey hair. It has photos of Roy Carlson and André Coyne, and tells about unbonded resistance strain gage instruments and the history of vibrating wire instruments.

In general, there are many aspects of this book that will help the rest of us, and anyone who is involved with instrumentation of dams should have a copy. But there are significant shortcomings, and it is the duty of a reviewer to tell about the not-so-goods as well as the goods.

In the many pages on means and methods of monitoring, I looked for the authors' views on "which ones to use when", but found little, and this is a very significant omission. As an example, I'd hoped for their opinions on what types of piezometers to select for long-term performance monitoring.

There are mis-statements about piezometers: "Piezometers buried in the ground or grouted into boreholes are surrounded by a sand envelope" (page 3-67). This is incorrect for piezometers installed in cores of embankment dams, which require high air entry (HAE) filters, complete saturation, and intimate contact between the filter and the compacted core material. Also, "HAE filters are used in unsaturated soils of low permeability to prevent soil particles from entering the piezometer".

There are also major shortcomings that result from multi-authorship. Where was the conductor of the orchestra? For example, means and methods of monitoring are both in Chapters 3 and Appendix B (e.g. both Figures 3.37 and B.14 show similar schematics of a vibrating wire jointmeter/crackmeter, and there are many other examples of overlap between these two parts). I'm not clear why the two haven't been combined into one chapter. Also, I'm not clear why Chapters 5 and 6 are not combined into a single chapter. Another example of the problems with multi-authorship is the inclusion, in **four** places (Sections 1.3, 3.4, 5.3 and B.2) of definitions for accuracy, precision etc. And some of the definitions are different!

Regular readers of GIN will appreciate my delight on finding clear and excellent recommendations for procurement practices. Table 5.2 indicates that the following are **generally not true** when the contract for instrumentation is between the owner and the general contractor:

- Contract is issued to entity most familiar with dam instrumentation
- Technical issues involving instrumentation system are resolved directly between owner and instrumentation specialists
- Staff are skilled in instrumentation issues
- Instrumentation issues are given top priority
- No additional markup on instrumentation system cost

All the above five factors are **generally true** when the contract for instrumentation is between the owner and an instrumentation company. Right on!

In summary, despite the substantial shortcomings, this is a "should have" for all who are involved with monitoring the performance of dams.

Performance Confirmation of Constructed Geotechnical Facilities (2000).

ASCE Stock #40486, 568 pp. Price $65.00.

This volume contains the proceedings of a specialty conference held in Amherst, MA on April 9-12, 2000, published as ASCE Geotechnical Special Publications No. 94, and edited by Alan J. Lutnegger and Don J. DeGroot. There are 37 papers, in seven categories:

- Invited plenary papers (3)
- Shallow and deep foundations (9)
- Fills, embankments and slopes (6)
- Statistical analyses (3)
- Roadways and railways (6)
- Grouting (3)
- Tunnels, excavations and retaining structures (7)

There is an excellent index (a rarity and a luxury, thanks to the editors), that indicates seven papers under "Instrumentation", three of which have only minor content on this subject. The following are a few comments on the remaining four:

- Marr, A.W., "Managing Large Amounts of Geotechnical Performance Data for the Central Artery/Tunnel Project", pp 41-63. An excellent paper, with valuable practical guidelines and lessons learned.
- Fellenius, B.H., Brucey, W.G. and Pepe, F., "Soil Set-up, Variable Concrete Modulus, and Residual Load for Tapered Instrumented Piles in Sand", pp 98-114. Another excellent paper - this is the one referred to in Fellenius's article in the March 2001 episode of GIN, "From Strain Measurements to Load in an Instrumented Pile", pp.35-38, and is a 'must read' when interpreting strain data from a test of a concrete pile.
- Hajduk, E.L. and Piakowsky, S.G., "Performance Evaluation of an Instrumented Test Pile Cluster", pp 124-147. This paper describes a research project to investigate time-dependent gain in pile capacity, involving a cluster of **very** heavily instrumented piles. Some very useful conclusions about instrument performance. But one that I've heard many times before — "The majority of electrical resistance gages did not withstand the testing program"!
- Farrar, J.A., "Bureau of Reclamation Experience with Rolled Earth Fill Dams", pp 240-252. A crisp and useful summary of reports written by Jim Gould in the 1950s

In summary, although the title of the conference had led me to believe that I'd find more instrumented case histories, there are some valuable contributions. Apart from the non-instrumentation papers (and indeed there may be some very valuable ones amongst them), the two by Marr by Fellenius et al are extremely worthwhile practical contributions.

Geotechnical Measurements, Lab and Field (2000).

ASCE Stock #40518, 200 pp. Price $48.00.

This volume contains the proceedings of a session of GeoDenver, held in Denver, CO on August 5-8, 2000, published as ASCE Geotechnical Special Publications No. 106, and edited by W. Allen Marr. There are 14 papers, 10 of which describe field measurements. In the view of this reviewer, the following three stand out:

- Anderson, N. and D. Welch, "Practical Applications of Time Domain Reflectometry (TDR) to Monitor and Analyze Soil and Rock Slopes", pp 65-79. The paper describes five case histories and includes useful practical guidelines.
- Dowding, C.H. and K.M. O'Connor, "Comparison of TDR and Inclinometers for Slope Monitoring", pp 80-90. Four more case histories, with useful practical information.
- Myers, B.K., Squier, L.R., Biever, M.P. and R.K.H. Wong, "Performance Monitoring for a Critical Structure Built Within a Landslide", pp 91-108. A useful case history of landslide monitoring, particularly the long-term monitoring program.

Sources of the Publications

In USA the books can be ordered from ASCE Book Orders, PO Box 79404, Baltimore, MD 21279-0404, email:marketing@asce.org

In Europe, order books from American Technical Publishers, Ltd., 27-29 Knowl Piece, Wilbury Way, Hitchin, Herts SG40SX, England, email:ATPLTD@compuserv.com

Clay Membrane Barriers for Waste Containment

Charles D. Shackelford
Michael A. Malusis
Harold W. Olsen

Introduction

Clays that restrict the passage of solutes are referred to as clay membranes. Restricted movement of charged solutes (ions) through the pores of a clay is attributed to electrostatic repulsion of the ions by electric fields associated with the diffuse double layers (DDLs) of adjacent clay particles. Non-electrolyte solutes (uncharged species) also may be restricted from migrating through clays if the size of the solute molecule is greater than the pore size. This latter type of restriction commonly is referred to as *steric hindrance*, and occurs more often in the case of the relatively large molecules associated with organic compounds. The existence of clay membrane behavior also results in chemico-osmosis, or the movement of liquid in response to a solute concentration gradient. Since the purpose of many clay soil barriers used in waste containment and *in situ* remediation applications is to restrict the migration of aqueous miscible contaminants, the existence of membrane behavior in clay soils represents a potentially significant beneficial aspect that presently is not considered in the use of clay soil barriers for such applications. Thus, the objectives of this article are to describe briefly the basic characteristics of clay membranes, and to illustrate the potential benefits resulting from the use of clay membrane barriers (CMBs) for waste containment applications.

Quantifying Clay Membrane Behavior

The extent to which a clay soil acts as a membrane in the presence of a concentration gradient is termed chemico-osmotic efficiency, and often is expressed quantitatively in terms of a chemico-osmotic efficiency coefficient, ω, also referred to as a reflection coefficient, σ (Barbour and Fredlund 1989, Olsen et al. 1990). The theoretical chemico-osmotic efficiency coefficient of an "ideal" or "perfect" membrane that completely restricts the movement of solutes is unity (i.e., $\omega = 1$), whereas $\omega = 0$ for a material that exhibits no solute restriction (e.g., Mitchell 1993). Thus, clay membranes may be defined as clay soils in which $\omega > 0$. In most cases, the pores in clay soil membranes vary over a range of sizes such that the degree of restriction in the pores also varies. As a result, ω typically falls within the range $0 < \omega < 1$, and the clay soil membranes are referred to as "non-ideal" or "leaky" membranes. The term "semi-permeable membrane" also is frequently used to describe clay soils that behave as membranes; however, this term strictly refers to the relative ability of water (solvent) to pass through the membrane and, therefore, also applies in the case when $\omega = 1$.

Factors Affecting Clay Membranes

The sizes of the pores in a clay soil and, therefore, the value of ω, are affected by several factors, including the state of stress on the soil, the types and amounts of clay minerals in the soil, and the types (species) and concentrations of the solutes in the pore water (Olsen et al. 1990, Mitchell 1993). In general, ω increases with an increase in stress (lower porosity), an increase in the amount of high activity clay minerals, and a decrease in the valence and concentration of the solute.

In particular, the results of several studies suggest that membrane behavior is significant in clay soils containing an appreciable amount of sodium montmorillonite (see Keijzer et al. 1997 and references therein). Clay soils containing a significant amount of sodium montmorillonite, such as sodium bentonite, also are frequently used in waste containment applications (e.g., soil-bentonite cutoff walls, geosynthetic clay liners, sand-bentonite liners), due to the low hydraulic conductivity (e.g. $\leq 10^{-9}$ m/s) typically required in these applications. Thus, the existence of clay membrane behavior in such materials should not be surprising.

For example, consider the effects of salt concentration and ion valence on the chemico-osmotic efficiency coefficient, ω, shown in Fig. 1. The results shown in Fig. 1a are from Kemper and Rollins (1966) for specially prepared, < 2-µm sodium bentonite specimens subjected to NaCl and $CaCl_2$ solutions, whereas the results in Fig. 1b pertain to recent tests performed at Colorado State University on GCL specimens using KCl solutions, as described by Malusis et al. (2001). The data in both Figs. 1a and 1b indicate that ω decreases approximately semi-log linearly as the average salt