Geotechnical Instrumentation NEWS

Geotechnical Instrumentation News

John Dunnicliff

Introduction

This is the forty-sixth episode of GIN. There are four articles, and we have an international flavor this time, as all the authors are from outside North America!

New E-mail Address

I have changed my e-mail address to ***john@dunnicliff.eclipse.co.uk.*** If you have a record of my old attglobal address, would you please change it?

Some Disappointing Total Stress and Pore Water Pressure Data

The article by Ali Mirghasemi describes measurements of total stress and pore water pressure at Karkheh Dam in Iran. I met Ali last year at an instrumentation course in the Netherlands, where he told us about some disappointing data, and he agreed to share this with us in GIN—it's refreshing when someone is willing to publish something that didn't work out well. He tells us about his experiences with 510 earth pressure cells installed in the core of the embankment dam, and concludes that "no consistent data were achieved". He also describes pore water pressure measurements with both open standpipe and vibrating wire piezometers which are inconsistent, and says, **"The author will welcome any comments and discussion that may help to explain the differences". Over to you!** Discussions will be in the June 2006 episode of GIN.

Comparison among Various Methods of Measuring Settlement

Ton Peters, of GeoDelft in the Netherlands, compares settlement data obtained with four systems: a horizontal in-place inclinometer chain with electrolevel sensors; a liquid level system with vibrating wire sensors; a robotic total station; and a robotic digital level. For his application he concludes that only the liquid level system and robotic digital level system were adequate.

On a point of detail, but an important one, Ton indicates that for the selected liquid level system the **inside** diameter (i.d.) of the liquid-filled tubes is 18 mm. This caused me to re-read my attempt to summarize views on the required tubing diameter for liquid level gages (red book, page 84). At that time the consensus appeared to be that the i.d. should be 6 mm. If less than 6 mm, it appeared that there is a possibility of incomplete pressure equalization because of surface tension effects in the event that **any** air finds its way into the tube—and in the field it is difficult to avoid this. If more than 6 mm, there appeared to be a possibility of air being trapped in crests in the tubing, which also may lead to incomplete pressure equalization. Also, if the i.d. is larger than 6 mm, there has been experience of difficulties in displacing any such trapped air while flushing—the new liquid just passes below the trapped air, and does not remove it (however, it should be noted that if the trapped air does not occupy the full diameter of the tube it does not effect the pressure transmission).

Continuing the consensus gathering, when reviewing a draft of this article, I asked the manufacturer of the liquid level gage (Geokon) to indicate the basis for choosing an i.d. of 18 mm. They replied, "The volume of water in the chambers is large compared to that of the connecting tube, and the larger diameter liquid-filled tubes have proved to be more stable in changing temperature environments, probably because of faster equalization. It is important that the complete filling of the tubing is verified visually, and that the tube is always lower than the inlet fitting on any chamber. Once you've filled these large diameter tubes and chambers properly, the possibility of air causing problems in the liquid later are nil". So here is an experience that adds to our knowledge of this detail. **If anyone has anything more to add, will you please let me know?**

The consensus for the vent tube appeared to be that the i.d. should be more than 5 mm. The i.d. for this liquid level gage is 9 mm.

Judgment

The article by Elmo DiBiagio and Kaare Høeg of the Norwegian Geotechnical Institute is a pungent discussion about one of my favorite subjects—judgment. The title, "Where Has All the Judgment Come From" has its origin in the Fifth Laurits Bjerrum Memorial Lecture which was delivered by Ralph Peck in Oslo, Norway in 1980. The title of the lecture was "Where Has All the Judgment Gone?" and in the lecture Ralph Peck "both raised and answered the question embedded in the rather unusual title".

Read the masterful nine-point recommendation on pages 42 and 43.

Summary of Articles in GIN

The fourth and final article is a summary of articles that have appeared in GIN—several of you have asked me to assemble this.

FMGM-2007. A Reminder

The next international symposium, *Field Measurements in Geomechanics (FMGM),* will be held in Boston in September 2007. When dates are finalized, details will be on *www.geoinstitute.org.* For more information about these symposia, please visit *www.fmgm.no.*

Next Instrumentation Course in Florida

This will be on March 18-20, 2007 at St. Petersburg Hilton *(www.stpetehilton.com).* Details of the course will be on *www.doce-conferences.ufl.edu/geotech* as soon as they are available.

Toasts

I'm running short of new toasts again. If you don't send me some, I'll have to start repeating! **So—action please!**

Closure

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

Prozit! (Latvia). Thanks to Lap-Yan Chan for this.

Karkheh Dam Instrumentation System - Some Experiences

Ali Asghar Mirghasemi

Introduction

Karkheh Dam is the largest dam, in terms of reservoir capacity and volume of fill placed, that has been constructed in Iran. It is a central core, zoned embankment dam 127m (416 feet) high, 3030 m (9940 feet) long, with an embankment volume of 32 million cubic meters (344 million cubic feet) (Figure 1). The reservoir is 60 km (37 miles) long and has a volume of 5.6 and 7.3 billion cubic meters (60.3 and 78.6 billion cubic feet) at normal and maximum water level, respectively. The foundation water-tightness is achieved by a plastic concrete cut-off wall (Mirghasemi et. al, 2005).

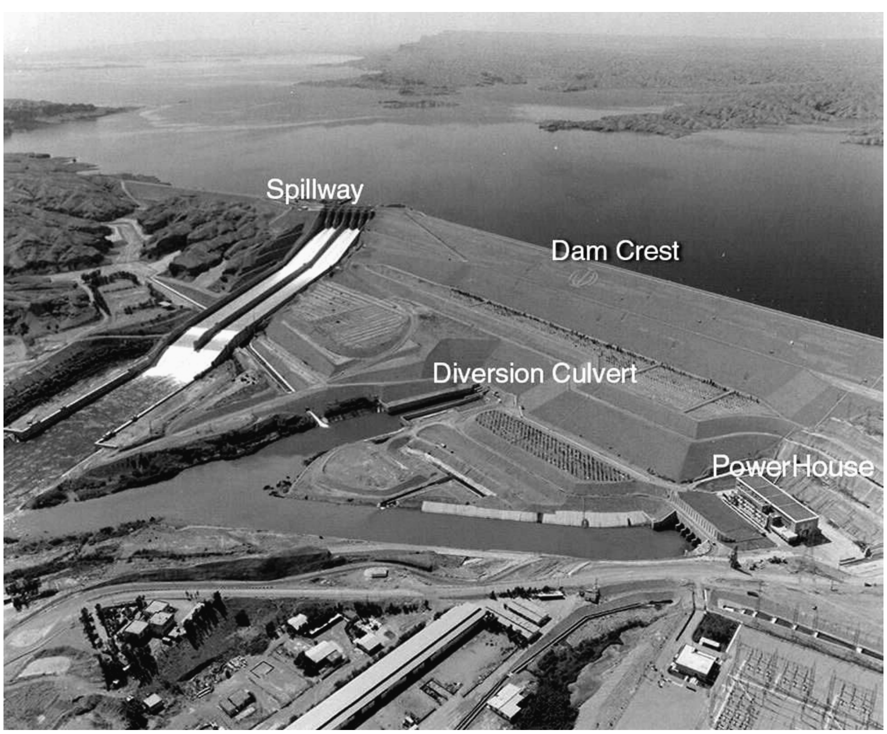

Figure 1. Karkheh Dam.

The dam is constructed on Karkheh River located 250 km (155 miles) northwest of Persian Gulf in southwest Iran. The construction of Karkheh Dam started in 1993 and its impounding was started in mid-February 2000 (Mirghasemi et. al, 2002). The dam and its foundation are extensively instrumented to provide data required for monitoring of the dam and its appurtenant structures. The purpose of instruments in the dam is to measure the following parameters:

- External displacement of the dam, abutments and appurtenant structures, using surveying methods.
- Internal deformation of the body of the dam and its foundation, using inclinometers (horizontal deformation) and anchor magnets with a

portable reed switch probe used with the inclinometer casing (vertical deformation).

- Total soil pressure at different directions to define the stress distribution and possible arching effect, using total earth pressure cells.
- Foundation and embankment pore pressure, using standpipe and vibrating wire piezometers.
- Seepage through the embankment and its foundation, using flumes and weirs.
- Water level at abutments, using observation wells.
- Reservoir water level
- Climatic parameters
- Earthquake
- Foundation treatment performance, using standpipe and vibrating wire piezometers at both sides of the cut-off wall.

In this article the instrumentation scheme is briefly described and the article then focuses on two aspects of the measured data that indicate shortcomings in the instrumentation.

Overview of Monitoring System

In order to monitor the performance of Karkheh Dam, geotechnical instruments have been installed in the embankment and foundation. Considering the conditions associated with the embankment and foundation, 14 primary sections along the dam axis are instrumented. Based on observations made during the trial impounding in 1997, complementary instrumentation was installed in nine secondary sections. It was observed that permeability of the foundation rock was higher than anticipated; therefore only foundation pore pressure measurement devices were installed in secondary sections, to track the possible seepage paths. The secondary sections are located between primary sections.

Figure 2 shows the instruments installed at Section 5, which is the highest section of the dam.

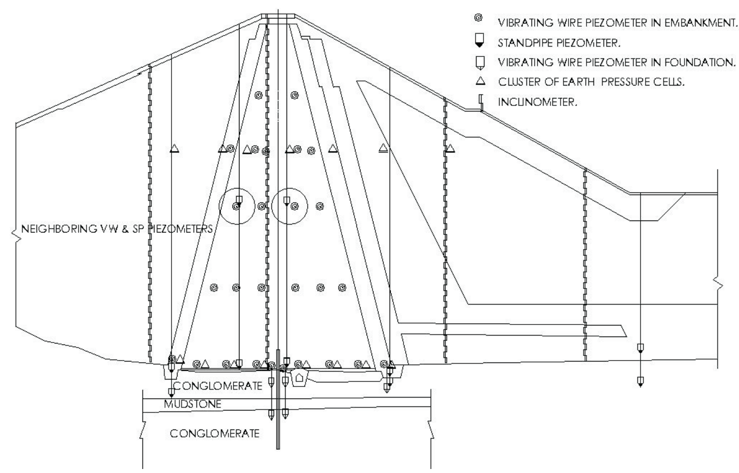

Figure 2. Instruments installed in Section 5 (1+230 km).

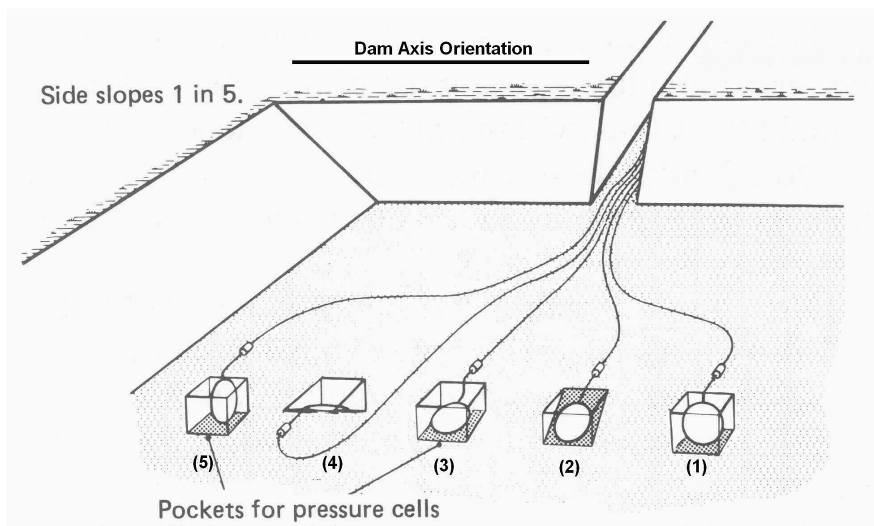

Figure 3. Layout of embankment earth pressure cells (Dunnicliff, 1993)

Uncertainties in Earth Pressure Measurements

A total of 102 clusters, each of five earth pressure cells, have been installed to determine the total stresses in the embankment at various locations. For each cluster, the cells are installed in the following orientations: horizontal (Figure 3-3), vertical parallel to dam axis (Figure 3-1), vertical normal to dam axis (Figure 3-5), 45 degrees upstream (Figure 3-2) and 45 degrees downstream (Figure 3-4). The cells have a diameter of 229 mm, and are Roctest Model TPC-0.

Figure 4 shows the excavated trench in which the cells are installed. Four of five measured stresses (1-4 of Figure 3) in each cluster are in vertical and parallel planes oriented normal to the dam axis. The other stress measured by the cell installed vertical and normal to the dam axis (Figure 3-5) is located in a plane which is vertical and parallel to the dam axis. Since the pocket of pressure cells are enough close to each other, these four mentioned stresses can be considered as stresses at different directions in one plane for a single point in the embankment. Having two stresses in two different directions, the others can be calculated using Mohr circles.

At the end of construction, there is no horizontal force acting on the em-

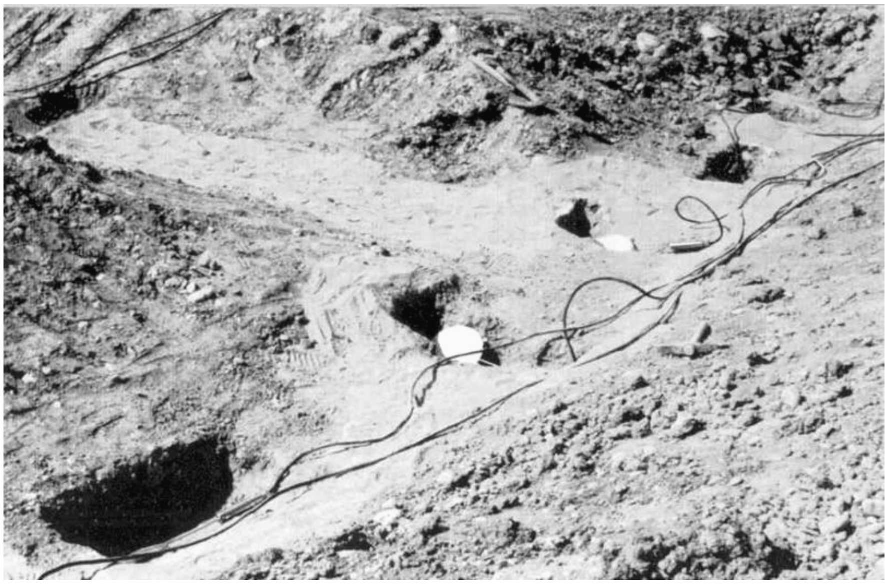

Figure 4. Excavated trench for installation of one cluster of earth pressure cells.

Table 1. Comparison between computed and measured stresses at 45 degree planes.

Pressure cell number	Differences between measured and computed stresses for the cell oriented 45 degrees downstream (in percent)	Differences between measured and computed stresses for the cell oriented 45 degrees upstream (in percent)
PC5-4	17	no measurement
PC5-5	23	no measurement
PC6-4	21	11
PC6-5	17	115
PC7-3	48	70
PC7-4	23	22

Table 2. Comparison between computed and measured horizontal stresses.

Pressure cell number	Differences between measured and computed stresses for the vertical cells (in percent)
PC5-4	266
PC5-5	33
PC6-4	120
PC6-5	41
PC7-3	70
PC7-4	64

bankment due to water in the reservoir. Also the dam cross section is almost symmetrical. Thus, at the centre of the clay core the maximum principal stress direction is near-vertical. Therefore the vertical and horizontal stresses at the center of clay core can be considered as principal stresses.

Using Mohr circles, with the known principal stresses measured by means of horizontal and vertical cells, stresses at 45 degree planes have been calculated, and the results compared with the stresses measured in those planes. However, there is no consistency between calculated and measured stresses. Table 1 shows the error found between the measured and calculated stresses at two 45 degree planes. The difference varies between 11 and 115%.

In another calculation, the stresses at 45 degrees and in horizontal planes have been used to calculate the stresses at vertical planes (horizontal stresses). The results are compared in Table 2. As can be seen, the differences are generally greater than in Table 1, varying between 33 and 266%.

Based on the above analyses, clearly the measurements cannot be used to determine real earth pressures. It is believed that the differences result from at least three issues. First, the inherent 'inclusion' effect when placing a measuring device within compacted fill, such that the presence of the earth pressure cell changes the stresses around it. Second, the difference in the elastic properties of the surrounding backfill and the mass fill, created because of the different methods of compaction. If the compaction method used for the mass fill was used immediately above the earth pressure cells, it would damage the cells; therefore a lighter compaction method has to be used. Third, the possible rotation of the earth pressure cells during compaction of the mass fill. It should be noted that these three issues are generic issues, not attributable to the particular commercial version of earth pressure cell used.

Comparison of Vibrating Wire and Open Standpipe Piezometers

Two types of piezometers are used in Karkheh dam: open standpipes (Roctest Model CP1.1) and vibrating wire (Roctest Model PWS). Standpipe piezometers are simple and reliable, and therefore are sometimes used to

Table 3. Locations of installed pairs of open standpipe and vibrating wire piezometers.

Piezometer Number	Piezometer Type	Elevation (meters)	Distance from dam axis (meters)
EP5-17	Vibrating Wire	165.15	15.09 Upstream
SP5-5	Standpipe	165.00	13.78 Upstream
EP5-19	Vibrating Wire	165.09	6.05 Downstream
SP5-6	Standpipe	165.00	3.29 Downstream

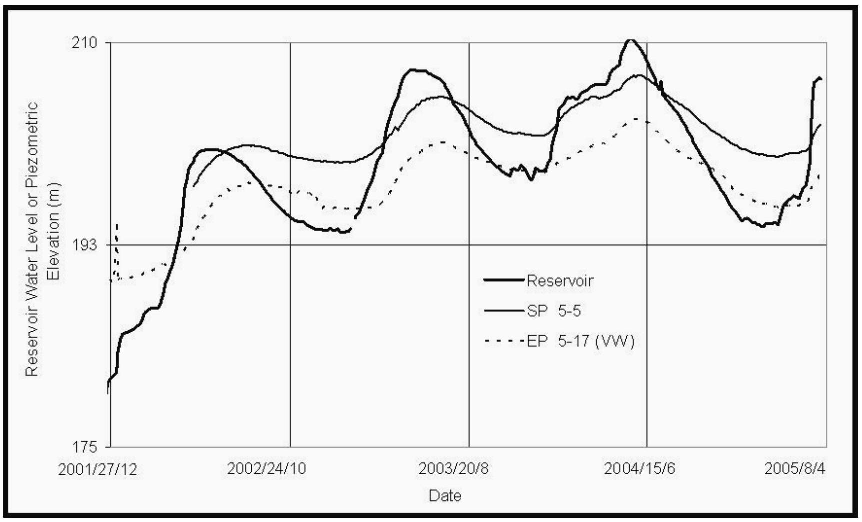

Figure 5. Comparison between measured data from open standpipe (SP5-5) and vibrating wire (EP5-17) piezometers.

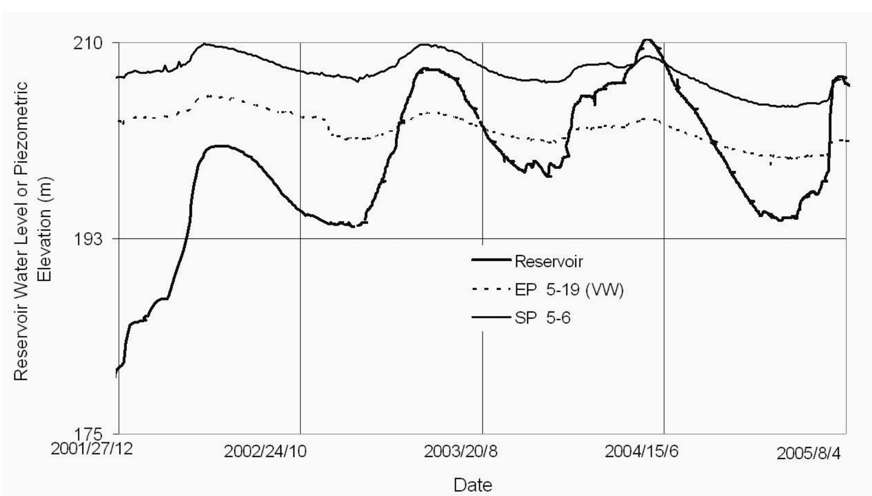

Figure 6. Comparison between measured data from open standpipe (SP5-6) and vibrating wire (EP5-19) piezometers.

substantiate data from other types of piezometers. In impervious soils they have a longer time lag than vibrating wire piezometers because a large volume of water is required to register a change in head. At selected locations in the clay core, for double-checking and also for verifying and evaluating any unusual readings, a standpipe and a vibrating wire piezometer have been installed close to each other (see Figure 2). Table 3 shows the locations of two pairs of open standpipe and vibrating wire piezometers. The core material is a mixture of 60% clay and 40% gravel. The clay materials are highly plastic with LL = 40-80 and PL = 15-45. The gravel that was added to clay was reconstructed sandy gravel (GW), obtained from conglomerate rocks.

Data from each first pair of piezometers are compared in Figures 5 and 6. The construction pore pressures have not yet dissipated; thus the data show piezometric elevations above reservoir level. It is to be noticed that there is no significant time lag or delayed response in the open standpipe piezometer data in comparison with the vibrating wire piezometer data. The Penman (1960) equation was used to calculate the response time of Karkheh open standpipe piezometers. The computation shows that a delay of about 3 days is required for the response. Due to the large surface area of Karkheh reservoir the changes in lake water level elevation in a period of 3 days is not significant enough to create noticeable time lag in pore pressure measurements.

On the other hand, almost constant differences in measured pore pressure between vibrating wire and standpipe piezometers are observed in both cases. Penman (2002) explains the role of gas bubbles in unsaturated soils when monitoring pore water pressure. He indicates that the gas must be at a higher pressure than the pore water. If this were the case at Karkheh Dam, and vibrating wire piezometers were measuring pore gas pressure as opposed to pore water pressure, the readings would be higher than those from nearby open standpipe piezometers, whereas the opposite is the case. Therefore this phenomenon cannot explain the differences. High air entry filters were used for the vibrating wire piezometers, saturated by manufacturer, carried to the installed location in a bottle of water and installed in intimate contact with the clay core.

For standpipe piezometers low air entry filters were used. The filters were saturated by 24 hour immersion in water and installed in a sand pocket with a diameter of 15 cm (6-in.) and length of 150 cm (5 ft). A seal was formed above the pocket using bentonite pellets and cement–bentonite grout. A riser pipe with internal diameter of 20.6 mm (0.8 in.), protected with a 15-cm (6-in.) PVC pipe was used.

Barometric pressure differences between the place of calibration (Montreal, Canada) and the place of installation (Karkheh Dam) might be a reason for the differences in measured pore pressure between vibrating wire and standpipe piezometers. Atmospheric pressure is influenced by geography and elevation above mean sea level and decreases with increasing altitude. However, this cannot explain the differences, for the following reasons:

- The piezometers were checked before installation by using them to measure a known water surface in an observation well.
- The altitude at Karkheh site is about 150-200 meters above sea level, which cannot cause a significant barometric pressure change with respect to the place of calibration.

The real reason for these differences is still under investigation. **The author will welcome any comments and discussion that may help to explain the differences.**

Conclusion

In this article the instrumentation scheme of Karkheh embankment dam is briefly described. The uncertainties found in measurement of earth pressure in the clay core are discussed. A total of 102 clusters, each of five earth pressure cells, have been installed to determine the total stresses in the embankment – a total of 510 cells. This number is about half of total number of instruments installed in the dam. No consistent data was achieved from the earth pressure cells. However, valuable information was gained from the other half of the instruments, indicating satisfactory performance of the dam.

Finally a comparison is made between the readings from standpipe and vibrating wire piezometers installed at the same location in the core of the dam. It is found that there is no time lag between the responses of the two types of piezometers. Measurements show unexplained differences of about five meters between the piezometric levels obtained from the two types of piezometers.

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Ali Asghar Mirghasemi, Assistant Professor, School of Civil Engineering, College of Engineering, University of Tehran, Enghelab Ave.
P.O. Box 11365-4563, Tehran, Iran, Also senior geotechnical engineer for Karkheh Dam project, Mahab Ghodss Consulting Engineers.
Tel: (+9821) 61112273
Fax: (+9821) 66461024
email: aghasemi@ut.ac.ir

Comparing Surface Settlement Systems for On-Line Monitoring

Ton Peters

Introduction

When tunnels are driven in urban areas, engineers are challenged to control the impact on the environment. Today, in Amsterdam and Rotterdam in the Netherlands, control of the process is achieved using information derived from measuring the influence of tunneling activities. An important control parameter is surface settlement, which can be measured using various geodetic and sensor-based systems.

A field test was performed during drilling of the Botlek Rail Tunnel, part of the new Betuwe railway route. On this site state-of-the-art techniques for monitoring on-line surface settlement were installed and tested. This article describes the test set-up, measurement results and conclusions in terms of accuracy, sensitivity to vibrations and temperature change.

Requirements and Selection of Systems

In a previous study the requirements were defined for these types of on-line measurement systems. In addition to requirements for the measurements themselves, a number of practical requirements for proper functioning in an urban area have to be considered, such as protection from vandalism and the exposure to traffic, the tunnel boring

Table 1. Measurement requirements for surface settlement systems.

Characteristic	Requirement
Measurement accuracy	+/- 0.5 mm
Measurement range	100 mm
Measurement frequency	Minimum of one measurement every five minutes per measurement point
Availability of data	Results in engineering units within one minute

and other construction activities. The requirements are given in Table 1.

After investigating the market and consulting with manufacturers, the following state-of-the-art measurement systems were selected—they appeared to satisfy the given requirements:

1. Horizontal in-place inclinometer chain with electrolevel sensors
2. Liquid level system with vibrating wire sensors
3. Robotic total station
4. Robotic digital level.

Horizontal In-place Inclinometer Chain with Electrolevel Sensors

The in-place inclinometer installation comprised a number of uniaxial electrolytic tilt sensors, placed at predetermined intervals inside an inclinometer casing. The inclinometer casing was installed horizontally over the crown of the tunnel at a depth of approximately 0.5 meters below ground level.

All tilt sensors are mounted on steel beams which connect directly with each other in a continuous hinged chain, therefore allowing determination of the complete profile of vertical deformation. The total system measures 20 meters in length, consisting of ten interconnecting tilt sensors. Each tilt sensor indicates the inclination at its own position. When settlement occurs, a change in inclination of tilt sensors is converted to a measurement of vertical displacement.

The in-place inclinometer system is installed in a standard inclinometer 85 mm diameter casing, which provides enough space for sensors and cables. The signal cables for the tilt sensors lead out of the casing and are connected to a data-acquisition system for on-line monitoring.

Liquid Level System with Vibrating Wire Sensors

The liquid level system is based on the physical principle of communicating tubes. This states that the level of a liquid in two reservoirs connected by tubes are at the same datum line. The liquid level system consists of a series of vessels containing liquid level sensors interconnected by a liquid-filled tube. Differential settlement or heave between the vessels results in a rise or fall of the liquid level in that vessel.

Each vessel contains a cylindrical weight suspended from a vibrating wire force sensor. The common liquid level inside each vessel partially submerges the suspended weight. Settlement of a vessel causes a rise in the water level in that vessel, leading to a reduced force acting on the weight due to increased buoyancy, and a reduction of the force that acts on the vibrating wire sensor. This is monitored with an automatic data acquisition unit.

A total of nine settlement vessels were placed at 2.5 meter intervals, interconnected with 18 mm inside diameter liquid-filled tubing. In order to avoid the influence of barometric fluctuations

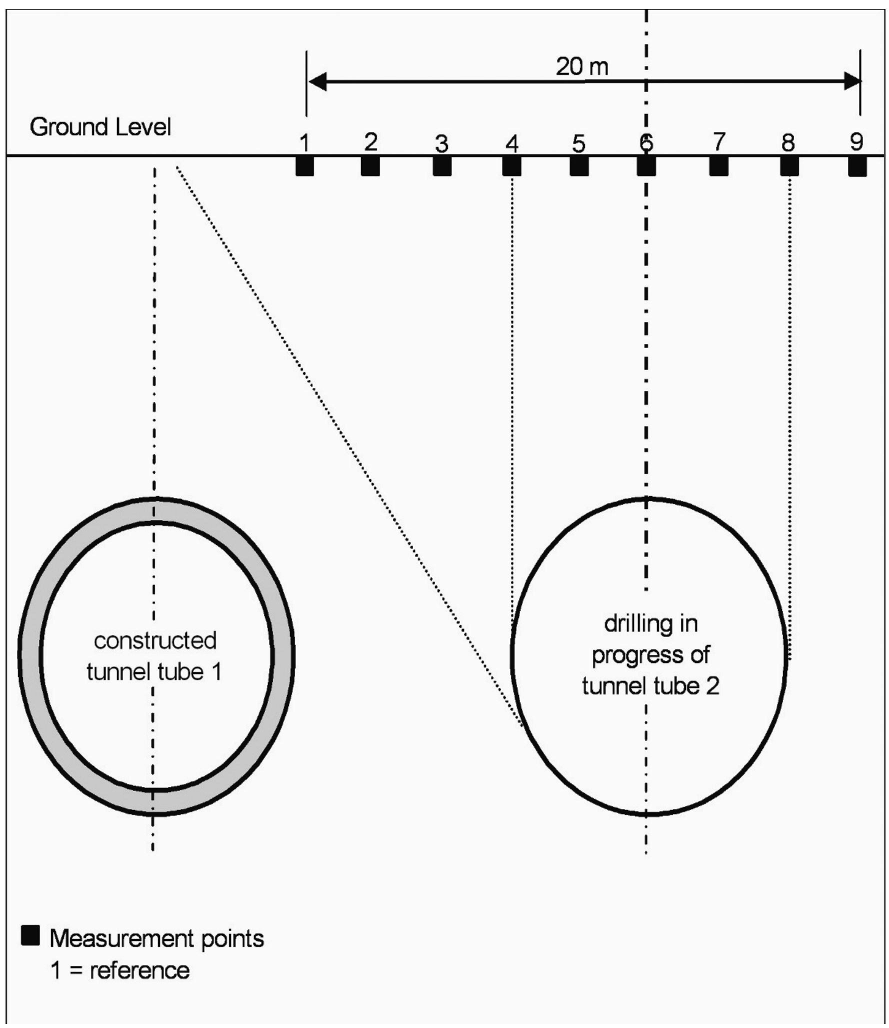

Figure 1. Test set-up at the Botlek rail tunnel

Table 2. Evaluation of accuracy.

Tested System	Random error	System-atic error	Total accuracy related to +/-0.5 mm criterion
Horizontal in-place inclinometer chain with electrolevel sensors	+	-	-
Liquid level system with vibrating wire sensors	+	0	+
Robotic total station	-	-	-
Robotic digital level	0	+	+

Legend:
+ System meets criteria well
0 System meets criteria
- System does not meet criteria

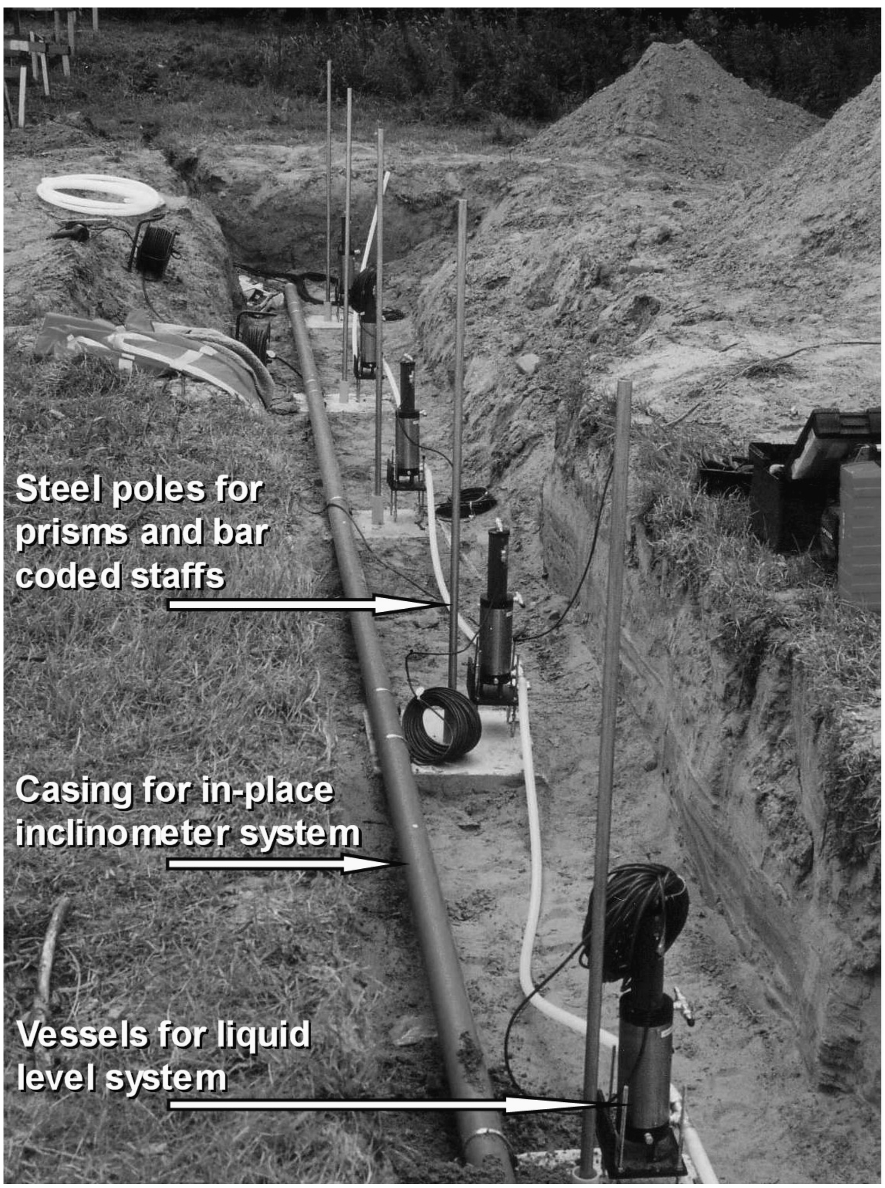

Figure 2. Instruments and measurement points during installation

on the liquid levels, a venting tube with an inside diameter of 9 mm interconnects the air above the liquid in each vessel.

Robotic Total Station and Robotic Digital Level

Two types of geodetic systems were available for the field test: a total station, and a digital level. Both instruments are robotic, enabling the entire measurement process to be performed automatically once the measurement cycle had been set up.

A total station consists of a theodolite and a laser distance measurement device. The measurement principle is based on determining the direction and distance of fixed, passive reflectors. The angle between the total station instrument and each reflector is measured in two directions. Using the measured distance between instrument and reflector, the position in three dimensions (x, y and z) can be calculated. To provide accurate measurements, a prism is used as reflector. The reflectors and instrument can be placed at different levels in the field. During a measurement cycle, the instrument aims at the last known position of a target, focuses, performs the actual measurements, and aims at the next target, and so on. In addition to the measurement points, several reference points are needed to correct for measurement errors such as displacement of the instrument itself.

A second type of geodetic system is motorised digital leveling. Instrument and measurement points must be at approximately the same level in the field. Digital levels work on an optical principle, and use invar bar-coded staffs mounted on the measurement point for automated measurements. The software instructs the instruments to locate a bar-coded staff, focus the optics and carry out the measurements. For these optical measurements the staffs must be illuminated during night.

Installation and Measurements

The test set-up is shown in Figure 1. Nine measurement points were constructed on a traverse over the crown of the tunnel. Each point consists of an underground concrete block at a depth of

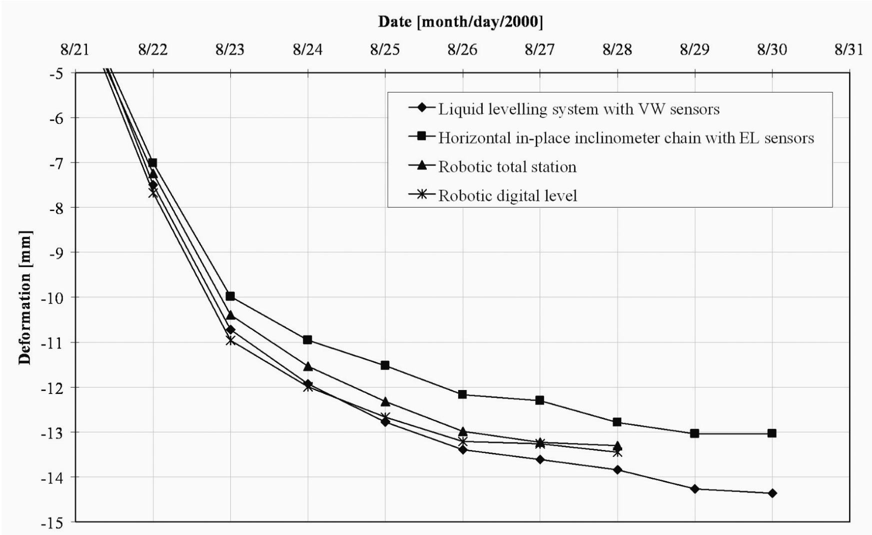

Figure 3. Results of settlement measurements at point 5 over a time period of nine days

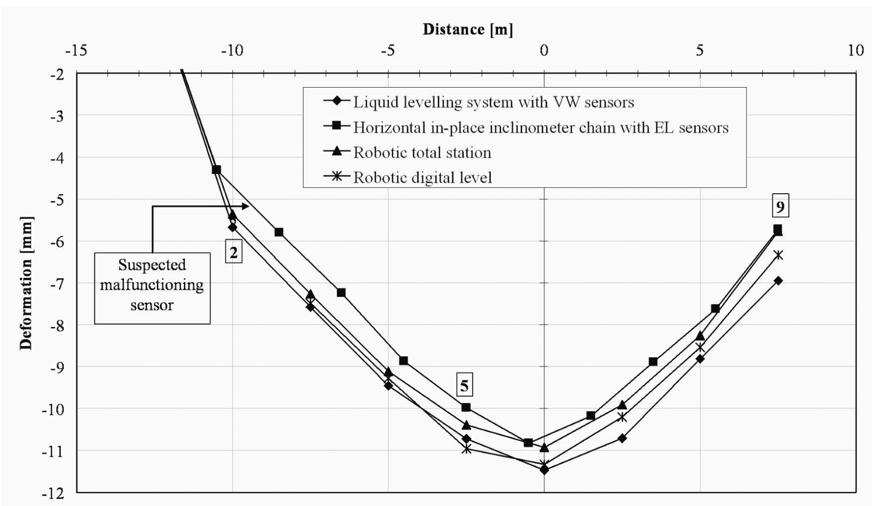

Figure 4. Results of the settlement profile over point 2 to 9 on August 23rd 2000

approximately 0.5 meters below ground surface. The blocks are fitted with the necessary liquid level vessels, inclinometer casing and a steel pole that sticks approximately one meter out of the ground. The prism and invar bar-coded staff for the geodetic measurements are connected to this pole. This set-up ensures that all measuring systems will experience exactly the same settlement, as shown in Figure 2. After completion of instrument installation, the trench was backfilled.

Position number 1 includes a reference point for all measurements. It incorporates a deep level reference datum, established at approximately 10 m below the invert of the tunnel.

Zero readings were taken prior to passage of the tunnel boring machine. Measurement frequencies ranged from one sample per minute (sensor-based systems) to one sample per 15 minutes (geodetic systems) during passage of the machine.

Discussion of Results

The measured results from the tested systems are shown in Figures 3 and 4. To evaluate the data, it should be noted that the inclinometer system uses gauge lengths of 2 m and the other systems use intervals of 2.5 m. On Figure 4, zero distance indicates the center line of the tunnel. The settlement of the subsoil influences the whole length of the inclinometer casing, whereas the other systems measure only at discrete points, i.e. the concrete blocks and poles.

Figure 3 shows settlement versus time, at measurement point 5, during passage of the tunnel. All measurements were averaged to one sample per day. After passage of the tunnel boring machine, the total settlement is approximately 14 mm. Figure 4 shows the settlement profile on 23 August 2000, when approximately two-thirds of the settlement had occurred.

Three systems show similar results, whereas the in-place ineter system measures approximely 1 mm less settlement. It seems that the inclinometer at -10.5 meters (see Figure 4) shows correct results, but after that an error is introduced over the rest of the profile. The most likely explanation is that this inclinometer sensor is malfunctioning, introducing an error that is consequently included in all the other determinations of settlement further along the chain.

Conclusion

After the test all four systems were evaluated for their total accuracy. The total accuracy is determined from the random error and systematic error. Systematic errors originate from nonlinearity, malfunctioning, hysteresis and change of the calibration over time. The random errors are mainly caused by environmental effects, in this case temperature and vibration by the tunnel boring machine. The random error is evaluated by the ‘noise level’ determined from the observations. The settlement of the soil due to the tunneling is a gradual process (days) which is measured here at high frequencies up to 1 sample per minute. The mean value of settlement was calculated for each system over a certain time period, and compared with the individual measurements within that time period. This gives an impression of the noise level, and therefore the random error of the systems under field conditions. The results of these analyses are shown in Figure 5. It appears that the geodetic systems show significantly

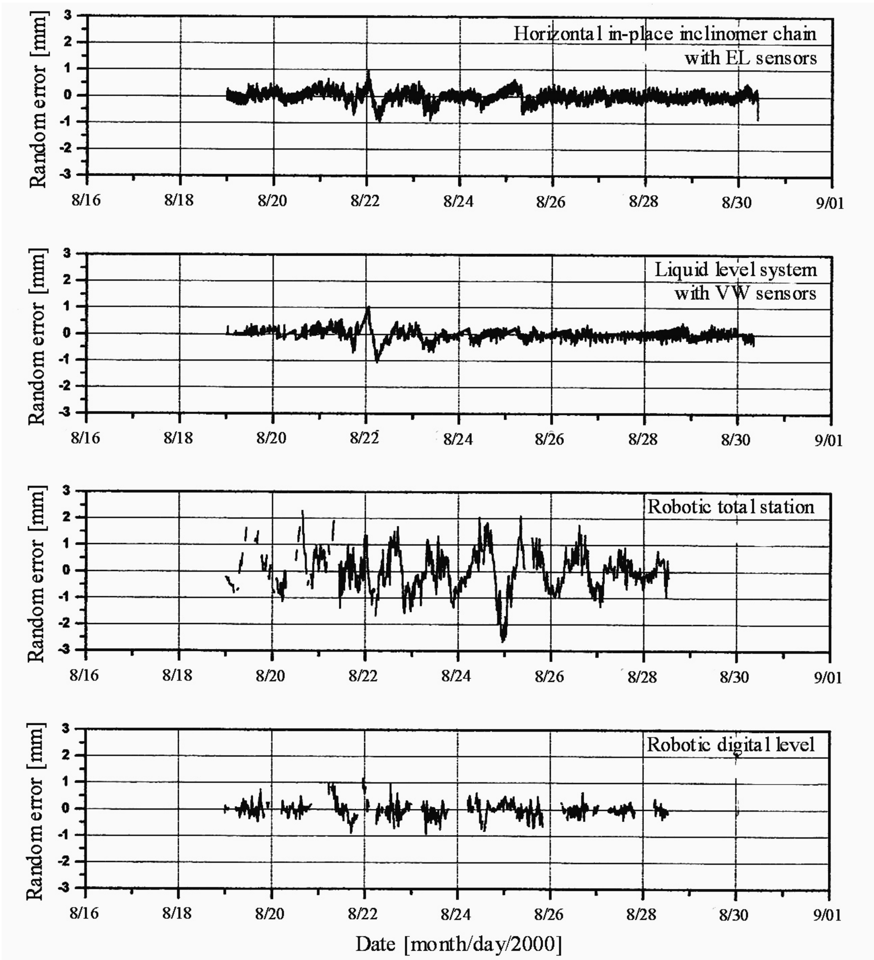

Figure 5. Evaluation of the random error of the tested systems

more random error than the sensor-based systems, as could be expected because of the operating principles. It can be concluded that under these circumstances the sensor-based systems are less sensitive to vibration of the tunnel and temperature effects.

Systematic and random errors have been compared with the required accuracy of +/- 0.5 mm, and the results are shown in Table 2. Based on the data in the table, only the liquid level system and robotic digital level system met the accuracy criteria under actual field conditions.

Acknowledgements

The field test was part of the research program carried out at the Botlek Rail Tunnel by the Dutch Center for Underground Construction. Test set-up, installation, measurements, and evaluation were carried out by GeoDelft, in close cooperation with Fugro. We would like to give our thanks to those companies who supplied the instruments and provided assistance during installation and measurements: Boart Longyear Interfels, Bad Bentheim Germany *(horizontal in-place inclinometer chain with electrolevel sensors)*; IV-Infra, Papendrecht, the Netherlands *(robotic total station)*; Koenders Instruments (representing Geokon), Almere, the Netherlands *(liquid level system with vibrating wire sensors)*; and Solexperts, Mönchaltorf, Switzerland *(robotic total station and robotic digital level).*

Ton Peters, Manager, Field Measurements Unit, GeoDelft, Delft, The Netherlands,
e-mail: A.J.M.Peters@GeoDelft.nl,
tel. +3115 2693 571,
fax. +3115 2610 821

frame is 42 x 17

possible spot inviting contributions

Where Has All the Judgment Come From?

Elmo DiBiagio
Kaare Høeg

I've been re-reading some of the papers that were published in the proceedings of a symposium held at the University of Illinois at Urbana-Champaign, Urbana, Illinois, in April 1987, titled "The Art and Science of Geotechnical Engineering at the Dawn of the Twenty-first Century". The symposium was in honor of Professor Ralph B. Peck, and the proceedings include 31 papers that were prepared by his colleagues and former students. One paper particularly appealed to me and, with the permission of the authors and the publisher of the proceedings, part of it is reprinted below. The original publication included three "Instrumentation Examples" before the "Closing Remarks" illustrating, for each example, "Where Did the Judgment Come From".

John Dunnicliff

Prelude

"Where has all the judgment gone? It has gone where the rewards of professional recognition and advancement are greatest—to the design office where the sheer beauty of analysis is often separated from reality. It has gone to the research institutions, into the fascinating effort to idealize the properties of real materials for purpose of analysis and into the solution of intricate problems of stress distribution and deformation of idealized materials. The incentive to make a professional reputation leads the best people in these directions" (1)

Background

The title of this paper has its origin in the Fifth Laurits Bjerrum Memorial Lecture which was delivered by Ralph Peck in Oslo, Norway on May 5th, 1980 (1). The title of the lecture was "Where Has All the Judgment Gone?" and in the lecture Dr. Peck both raised and answered the question embedded in the rather unusual title.

Although the title of Peck's Memorial Lecture sounded a little strange at first, it was no great surprise that he had selected judgment as the central theme. Throughout his professional career, he has stressed the importance of judgment in engineering practice. He has expressed this opinion loudly and clearly, time and time again, to audiences in all parts of the world. As a result, the name Ralph Peck has become synonymous with engineering judgment in our profession. This recognition is clearly manifested, for example, in the book published in his honor: *Judgment in Geotechnical Engineering. The Professional Legacy of Ralph B. Peck* (2).

Peck used the occasion of the Fifth Laurits Bjerrum Memorial Lecture to warn us that engineering judgment is in danger of vanishing from the scene as an acknowledged contribution to problem solving (or to avoiding problems) in foundation engineering. In the lecture Dr. Peck voiced his concern over the present trend to emphasize and give more professional recognition to work based on complex analytical methods or sophisticated research and laboratory tests performed on idealized materials. He addressed the problem both philosophically and through examples taken from the area of dam safety. He did not oppose the increased interest in modem analytical and experimental methods. What he did criticize was their misuse or excessive use. He contended that this was being done in such a way that the role of engineering judgment was being degraded, and he was concerned about the effect of this trend on geotechnical engineering in the future.

The roots of this paper go back to that day in 1980 when Peck gave his lecture on "Where has all the judgment gone?" However, the authors take a different approach and raise instead the question, "Where has all the judgment come from?"

The philosophy and approach of applying engineering judgment has served us well. If we are to maintain this philosophy, it is important that we have an understanding of how good judgment is generated and cultivated so that these sources can be further strengthened. Where it comes from is important in order to establish the credibility of the sources. This is a prerequisite to a professional recognition of engineering judgment as an acceptable approach to engineering practice.

By focusing on where the judgment comes from, the authors will identify and illustrate by example one of the most important sources of information used as a basis for engineering judgment—performance monitoring.

What Is Engineering Judgment?

How do you define engineering judgment? Even Ralph Peck admits that it is difficult to do that. In one of his lectures directed to a group of young engineers, he illustrates the differences of opinion that exist (2, p. 192):

> *To the engineering student, judgment often appears to be an ingredient said to be necessary for the solution of engineering problems, but one that the student can acquire only later in his career by some undefined process of absorption from his experience and his colleagues.*
>
> *To the engineering scientist, engineering judgment may appear to be a crutch used by practicing engineers as a poor substitute for sophisticated analytical procedures.*
>
> *To the practicing engineer, engineering judgment may too often be an impressive name for guessing rather than for rational thinking.*

In the same lecture Peck continued by giving his own working definition of engineering judgment, ". . . let us call it a good sense of proportion..." Even this definition leaves much to the imagination unless it is illustrated by examples as Peck did in the lecture.

An authoritative definition of the word *judgment* that seems to be appropriate in the context of engineering judgment may be found in *Webster's New Collegiate Dictionary.* It is as follows:

> ***Judgment*** *The operation of the mind, involving comparison and discrimination by which knowledge of values and relations is mentally formulated.*

To the authors, this definition is a good one, but again, it is not immediately obvious. An important point with respect to the definition is the wording "comparison and discrimination," which implies that knowledge from more than one source is dealt with. This point will be developed further later on.

Engineering Judgment and the Foundation Engineer

Engineering judgment is not unique to geotechnical engineering. It is essential to successful practice in all fields of engineering, but it is more important in some fields than others. Why is the concept of engineering judgment so important in foundation engineering?

In certain fields such as hydraulics and electronics, for example, many of the processes that are dealt with seem to follow well-defined natural laws, and reliable predictions can be made on the basis of theory or physical experiments alone. The same is true for many civil engineering applications involving man-made materials like steel and concrete because their properties can be controlled or estimated reliably. The geotechnical engineer has an enormous disadvantage in comparison, as he must work with natural geologic materials. The properties of these materials are generally variable and often unpredictable or even unknown. Getting a true picture of the actual conditions at a site is often impossible or impractical to achieve. Thus, it is frequently necessary to make assumptions regarding the real behavior of the materials or of important details such as drainage conditions, the degree of rock fissuring, the magnitude of in situ stresses in the ground, and so on. Because of this, many geotechnical engineering problems do not lend themselves to solution strictly on the basis of mathematical analyses and physical experiments alone. Other sources of information and other approaches to problem solving are required. This is where judgment comes into the picture.

Where Has All the Judgment Come From?

Where does judgment come from? The immediate response to this question is to say that it is something that comes from exceptional engineers like Ralph Peck, from the teaching and examples set forth by him throughout his professional career.

This is true of course, but there is more to it than that. Judgment comes from the human mind and it is based on what you yourself know; it comes from knowledge of all kinds and from many different sources.

To be good at their work engineers must be knowledgeable. Judgment is based on knowledge, and knowledge is familiarity gained by actual experience, directly or indirectly through others. It does not really matter so much where the knowledge comes from, provided it is correct, adequate and properly used, and that all sources of information that are judged to be significant are taken into consideration. An engineering decision can be made on the basis of information from one source alone, but an engineering judgment entails the broadest possible frame of reference. This is an essential difference. An engineering judgment can only be made after considering the information that is available from all the sources. The comparison and discrimination of this information by the human mind constitutes judgment.

In the engineering world, our knowledge of what is important to our work is based on information derived from theoretical concepts, experimental methods, measurements, observations and past experience. These are the sources of information and knowledge that are the basic building blocks upon which engineering judgment is founded. They are so obvious that exposure to them can hardly be avoided, but they have to be recognized, assembled and evaluated collectively before judgment can be rendered. Engineering judgment comes from being able to fit all the available information together to get a complete picture and on this basis be able to evaluate what is reasonable and what is not. This is what practicing engineers must learn to do if they are to become persons of judgment.

How do we insure that in the future we continue to cultivate the philosophy of engineering judgment that has served us so well in the twentieth century and bring it with us into the twenty-first century? We must somehow get this across to the new generation before it "goes out of style," as Peck warned.

Instead of trying to lay down a set of instructions on how to "cultivate" judgment from these sources, it is perhaps equally as illustrative to describe how to "avoid" it. To achieve this, one should follow the recommendations and guidelines for professional development that follow.

1. Be one-sided. Do your best to avoid a balanced education. Choose an educational program that allows you to specialize at an early stage, and do the same when it comes to accepting employment. (After all, a specialist commands more professional respect and compensation than a gen-

eral practitioner.)

2. Do not overly concern yourself with theoretical concepts and analytical methods because they serve no useful purpose in the real world.
3. Do not be critical of information received from other sources unless it conflicts with your own ideas.
4. Do not discuss your problems with your peers; just talk to your computer.
5. Do not try to become an integrated and independent thinker; develop a one-track mind and follow the crowd. Do not ask a lot of questions as this may indicate uncertainty on your part. Assume that you have been given all the pertinent information needed to solve the problem on hand.
6. Do not be critical of your own work. If you admit that there are uncertainties in your work, this will cast suspicion on your professional reputation.
7. Do not attempt to follow up your work to see how things turned out. If you are a designer, confine your work to the office and stay away from the site. After all, you are only responsible for the part of the job assigned directly to you. And by adhering to the axiom that "no news is good news," you will perhaps be spared a lot of unnecessary or unpleasant discussions.
8. Do not read the literature. Nothing of great value to the particular projects you are concerned with can be learned from the success or misfortunes of others. In particular, do not read the book *Judgment in Geotechnical Engineering* (2).
9. Do not become an observer. Do not recommend or engage in field instrumentation and performance observation programs. Anyway, the instruments are malfunctioning unless they give data in accordance with the theoretical predictions.

Performance Data: The Link between Theory and Practice

The world is becoming digital, whether we like it or not. If the present trend continues, we may soon arrive at the stage where nothing can be evaluated or communicated unless it can be done numerically.

Engineering judgment, by nature of what it is and where it comes from, is necessarily both qualitative and quantitative. Obviously, the quantitative part is more readily accepted because, being numerical, it is easier to interpret, use and communicate than the qualitative part. This fact is undoubtedly what prompted Dr. Peck to close his Bjerrum Memorial Lecture with the plea: ". . . at least equal professional prestige and responsibility should be accorded men of judgment, even when the judgment is not expressed in numerical form."

To dispel the attitude maintained by some that only what can be calculated constitutes engineering, we need to build a bridge between the quantitative world and the qualitative world. Many of our modem-day performance monitoring programs do just this. That is what instrumentation is all about, and this is why engineers and scientists have traditionally relied heavily on the use of instruments and instrumentation techniques to make quantitative measurements. The need for this is not a new one. Lord Kelvin expressed it most eloquently a long time ago:

> *When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you can not measure it, when you can not express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of the knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever matter may be.*

Numerical data, the end product of measurement, provides a basis for judgment and a quantitative link between the two worlds of theory and practice. This is why instrumentation and performance monitoring have come to be such an important part of geotechnical engineering, and this trend will continue into the twenty-first century. For, as our analytical capability will undoubtedly continue to increase in the future, so will our need for performance data. With field instrumentation we can provide a check on these more advanced analytical predictions and herein lies the promise of real improvements in the state of the art in geotechnical engineering.

Closing Remarks

As we enter the twenty-first century and artificial intelligence is coming in fast, it is essential that we identify and mark the sources of engineering judgment and bring these with us into the new world of artificial intelligence.

In this new world, **judgment**—the process of comparison and discrimination of information by the human mind—will be even more important to successful engineering practice than it is now.

References

1. R. B. Peck, "Where Has All the Judgment Gone?" The Fifth Laurits Bjerrum Memorial Lecture. *Canadian Geotechnical Journal,* 17, 4 (1980), pp. 584-590. Also published in *Norwegian Geotechnical Institute Publication 134.*
2. J. Dunnicliff, and D. U. Deere, eds., *Judgment in Geotechnical Engineering. The Professional Legacy of Ralph B. Peck,* John Wiley & Sons, New York, 1984 and BiTech Publishers, Vancouver, B.C., 1991.

Elmo DiBiagio, Kaare Høeg,
Norwegian Geotechnical Institute (NGI), P.O. Box 3930 Ullevaal Stadion, N-0806 Oslo, Norway,
Tel.: (+47) 22 02 30 00,
Fax: (+47) 22 23 04 48, email: Elmo.DiBiagio@ngi.no
Kaare.Hoeg@ngi.no

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Articles in Geotechnical Instrumentation News March 2003 – March 2006

John Dunnicliff

In the December 2005 episode of GIN I listed some articles that have appeared in GIN about recent technologies. Several of you have asked me to provide a summary of other articles, to make it easier to find what you want.

Articles from the start of GIN in 1994 until 2002 are listed on *www.fmgm.no*, together with a key worded search function for subject and author. Open the Publications page and scroll down to "Articles Published in Geotechnical News".

A chronological listing of articles subsequent to 2002 is given below.

GIN Episode	Date	Pages	Author(s)	Title
34	March 2003	47-50	Andrew M. Ridley	Recent Developments in the Measurement of Pore Water Pressure and Suction
		50-53	Thomas Thomann, Aaron Goldberg, Richard Napolitano	Are Those Pore Pressure Readings Correct?
		53-58	Daniel Naterop	Some Recently Developed Instrumentation Technologies
35	June 2003	41-51	Barrie Sellers, John Dunnicliff, P. Erik Mikkelsen, Martin Beth	Discussions of "Measurement of Pore Water Pressures in Embankment Dams", by Arthur D. M. Penman. Also Author's Reply
		51-59	Charles H. Dowding, Matthieu L. Dussud, William F. Kane, Kevin M. O'Connor	Monitoring Deformation of Rock and Soil with TDR Sensor Cables
37	December 2003	29-30	Ralph B. Peck	The Power of Observation
		30-31	Youssef M.A. Hashash, Camilo Marulanda	Temperature Correction and Strut Loads Interpretation in Central Artery Excavations
		32-37	A. Tyson Kaempffer	Update on Bentonite Chips and Pellets for Sealing Piezometers in Boreholes
38	March 2004	31-34	Jostein Aasen, Robert D. Holtz	A New Geotextile Strain Gage
39	June 2004	29-31	W. Allen Marr, Barry Christopher	Test Your Knowledge of Geotechnical Instrumentation
40	September 2004	21-27	Michael Long, Chris Menkiti, Ben Follett	Some Experiences in Measuring Pore Water Pressure in Dublin Glacial Till
		27-28	John Dunnicliff	Discussion of "Some Experiences in Measuring Pore Water Pressure in Dublin Glacial Till" by Long, Menkiti, Follett
		28-31	Beto Ortigao, Maria G. Justi	Rio-Watch: the Rio de Janeiro Landslide Alarm System
41	December 2004	33-35	R. K. S. Chan, W. K. Pun	Landslip Warning System in Hong Kong
		35-40	Robert Farrell, Pedro de Alba, Jean Benoît	Piezometer Design and Installation for Earthquake Pore Water Pressure Measurement

GIN Episode	Date	Pages	Author(s)	Title
42	March 2005	26-27	Michael Long, Chris Menkiti, Ben Follett	Authors' Closure, "Some Experiences in Measuring Pore Water Pressure in Dublin Glacial Till"
43	June 2005	30-32	Barrie Sellers	The Truth About Accuracy
		32-35	John Dunnicliff	Reminiscences of a Director of Instrumentation Courses
		35-36	Gord McKenna	Erroneous Readings from a Vibrating Wire Piezometer With a Broken Signal Wire
		37	Simon Cornwallace, Barrie Sellers	Discussions of "Erroneous Readings from a Vibrating Wire Piezometer With a Broken Signal Wire" by McKenna
44	September 2005	27-31	Matthew Spriggs, Neil Dixon	The Instrumentation of Landslides Using Acoustic Emission
		32	Gord MeKenna	Protecting Instruments from Damage
45	December 2005	44-47	David R. Rutledge, Steven Z. Meyerholtz	Using the Global Positioning System (GPS) to Monitor the Performance of Dams
		48-51	Claus Ludwig, Etienne Constable	Wireless Tiltmeters Monitor Stability during Trench Excavation for Reno Transportation Rail Access Corridor
		51-55	Lyne Daigle	Temperature Influence on Earth Pressure Cell Readings
46	March 2006	32-36	Ali Asghar Mirghasemi	Karkheh Dam Instrumentation System - Some Experiences
		36-40	Ton Peters	Comparing Surface Settlement Systems for On-Line Monitoring
		41-43	Elmo DiBiagio, Kaare Høeg	Where Has All the Judgment Come From?
		44-45	John Dunnicliff	Articles in Geotechnical News, March 2003 - March 2006

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