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Closing Remarks on Reliability of Geotechnical Instrumentation

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ABSTRACT

In the closing remarks delivered at the Symposium on Reliability of Geotechnical Instrumentation, three subjects are discussed: a "recipe" for reliability, the parameters that can be measured most readily, and a plea to users of instrumentation.

These closing remarks will address three topics: First, a recipe for reliability. Second, which parameters can be measured most reliably? Third, a plea to users of instrumentation.

A RECIPE FOR RELIABILITY

When this symposium was being planned, I wrote a recipe for reliability. Having now read the six papers that have been presented, I have made a few changes and will define what I believe are the major ingredients. There are two types: instrument ingredients (three of these) and people ingredients (five of these).

Instrument Ingredients

Simplicity

Follow the KISS (keep it simple, stupid) principle. For example, mechanical and hydraulic devices are generally more reliable than electrical devices.

Self-Verification

This term means that instrument readings can be verified in place. For example:

- Telltales on a rod extensometer with a method of disconnecting the rod from the anchor, so that a check can be made for free sliding;
- Duplicate transducers (e.g., a vibrating wire and a pneumatic transducer packaged within the same housing to create a piezometer with two independent methods of reading); and
- Checking remote-reading borehole extensometers with a dial gauge at the head.

Durability in the Installed Environment

The transducer must have proven longevity to suit the application. Cables, tubes, or pipes that connect the transducer to its readout must be able to survive imposed pressure changes, deformation, water, sunlight, and chemical effects such as corrosion and electrolytic breakdown.

People Ingredients

Thorough Planning

Details of planning requirements are given by Dunnicliff (1). The ingredients include

- McGuffey's "System Design," (see paper by McGuffey in this Record) including development of the best predictive model.
- Use of the best contract practices. Abramson and Green (see their paper in this Record) say, "Many owners effectively encourage low survivability rates by using low-bid procurement procedures." That is a succinct statement about a very large and serious problem.
- Rawnsley, Russell, and Hansmire (see their paper in this Record) address backup and redundancy, in their discussion of Harvard Square Station: "Redundancy existed, with key parameters being measured by more than one instrument." Hannon and Jackura (see their paper in this Record) say in their summary, "When feasible, alternative procedures should be used for backup to estimate soil stress conditions."
- Comprehensive factory calibration and quality assurance are important. Note that this is a people ingredient not an instrument ingredient. Hannon and Jackura say, "All instruments should also be subject to bench or calibration testing, or both, to ensure performance and specification compliance."

Installation Care

Planning for installation usually includes gaining the cooperation of the construction contractor. Without this, reliability is hard to achieve.

Regular Maintenance and Calibration

The need for regular maintenance and calibration is well demonstrated in the paper in this Record by Bordes and Debreuille. For example, portable readout units should be calibrated frequently.

Care During Data Collection

For example, in the field the person reading an instrument should always study changes with respect to the previous reading. Substantial changes may indicate a reading error or the need for rapid remedial action.

Care During Data Processing and Interpretation

This ingredient includes McGuffey's "Engineering Interpretation Methodology."

Summary

In summary, experience and knowledge are vital to the people ingredients. Rawnsley, Russell, and Hansmire say:

> The key to the reliability of the instrumentation program was the people involved. Instrumentation installation was done by experienced professionals. Instrument monitoring was performed by trained people who were on the job for extensive periods of time, were interested in the results, and were responsible for interpreting the measurements.

In their summary Hannon and Jackura say,

> Instrumentation personnel should be experienced and knowledgeable about potential problems associated with the placement and monitoring of the particular instruments selected for use.

McGuffey had operator knowledge as one of his five major items contributing to reliability. It is therefore agreed that experience and knowledge are vital. But perhaps even overriding these is motivation. Discussing responsibility for instrumentation, Baker (2) said:

> Who has the motivation? Who cares about the data? The person with the greatest vested interest in the data should have direct line responsibility for producing it accurately.

Conclusion to a Recipe for Reliability

In my view, unreliability can more often be attributed to the people ingredients than to the instrument ingredients. The message is clear: We, the users, need to make a strong effort to improve the state of the practice.

WHICH PARAMETERS CAN BE MEASURED MOST RELIABLY?

The four parameters, pore pressure, total stress, deformation, and load and stress in structural elements, need to be rated. They will be rated here in order of increasing reliability.

Total Stress in Soil

The difficulties are well illustrated by Hannon and Jackura. They divide them into two groups, first the ability of the cell to measure the stress around it (cell design) and, second, underregistration because the cell is in a soft cocoon of backfill (cell placement). I believe the larger problem is the second one. S.D. Wilson (personal communication, 1984), on the basis of his extensive experience measuring total stress within embankments dams, states:

> When earth pressure cells are installed in a horizontal plane in compacted fills for embankment dams, the cells typically register only 50 to 70 percent of the added vertical stress as embankment construction continues.

There is a need to develop a method of hand compaction around the cells that prestresses the soil to match the prestress in the remainder of the fill without damaging the cells. This is, of course, extremely difficult to do. The Comision Federal de Electricidad at experimental laboratories in Mexico City has constructed a large laboratory facility to test the response of embedment earth pressure cells to applied loads. It is hoped that improved installation techniques will result from tests now in progress.

Finally, I rate total stress as the least reliable parameter because of one other fundamental factor: Measurements are point measurements in a heterogeneous environment, and therefore a small number of measurements may not be representative of overall conditions.

Pore Pressure

The instruments are satisfactory. Installation problems are difficult, but they can be solved. The main problem, well illustrated by McGuffey, is the same as the one mentioned last for total stress: Measurements are point measurements in a heterogeneous environment. The problem is not as severe with pore pressure measurements, but is still significant.

I want to say a few words about the paper by Bordes and Debreuille, in this Record, because their conclusions apply to pore pressure measurements. A most believable and impressive case for vibrating wire instruments is presented in their paper. I have been looking for such a paper for more than 10 years and welcome this clear and convincing information. However, I am going to disagree with their Parisian graciousness. They say:

> Although the instruments discussed in this paper come from the same manufacturer, the conclusions drawn therefrom have a much wider scope. They apply to all vibrating wire instruments, provided of course that construction is of a high standard.

I will mention briefly two experiences with vibrating wire instruments from another "leading manufacturer," from whom "construction of a high standard" might be expected.

1. During first filling of the reservoir behind an embankment dam, a vibrating wire piezometer indicated a piezometric level that caused concern. Filling was stopped. The piezometer reading continued to rise. When the indicated piezometric level rose above pool level, everybody discounted the measurements and filling continued.
2. Vibrating wire pressure transducers have recently been used to measure oil level in oil tankers. Many have been unreliable, and several hundred have been returned to the manufacturer.

I truly believe that the conclusions drawn by Bordes and Debreuille do not necessarily apply to all vibrating wire instruments. How do users know whether all the details discussed by the writers are handled with similar care by all manufacturers? As one example, is the aging issue raised by Bordes and Debreuille handled adequately by other manufacturers?

Load and Stress in Structural Elements

I rate this parameter more reliable than pore pressure because it is measured on or in a material made and controlled by people. Discussion of this parameter is subdivided into use of three types of instrument: load cells, strain gauges on elastic elements, and strain gauges in or on concrete.

1. Load cells serve extremely well. Abramson and Green indicate the need for good bearing plates and taking care of eccentricity. Rawnsley, Russell, and Hansmire talk about problems with using hydraulic jacks for load measurement and confirm what many others have found:

- Up to 20 percent overregistration during loading and
- Up to 5 percent underregistration during unloading.

The problem is caused by friction between the piston and the cylinder, and hydraulic jacks should not be relied on for load measurement.

2. Strain gauges on elastic elements also serve well. Measurements on structural steel, for which a reliable conversion from strain to stress can be made, have a long and successful history.
3. Strain gauges on or in concrete cause problems in converting strain to stress, and the problem is aggravated if measurements are other than extremely short term. Horvath and Abramson and Green discuss this problem, and Abramson and Green recommend three methods of dealing with it:

- Controlled laboratory tests;
- Dummy no-load gauges; and
- Measuring the load directly, where possible (e.g., across a concrete pile).

My experience has been that

- Controlled laboratory tests rarely model field conditions adequately and
- Dummy no-load gauges are of little use because they do not account for strain caused by creep under load. This leaves three options:
- Measure load directly, as suggested by Abramson and Green;
- Where possible, use concrete stress meters instead of strain gauges, taking great care to ensure intimate contact between the instrument and the concrete, either by following the installation methods recommended for the Carlson stress meter or by using a poststressing tube as provided in the Gloetzl stress meter; and
- Create, as part of the structure in the field, an "unconfined compression test specimen," under known load, and measure strain with strain gauges or multiple telltales in this part of the structure, to determine modulus. This can be done at the top of piles and drilled piers during test loading, sleeving if necessary below the ground surface to create the "specimen."

Deformation

Deformation can be measured with greatest confidence. Instruments can often be simple. A single instrument can provide data for a large and representative zone. If you can answer your geotechnical question with deformation measurements, please do so.

The extensive topic of deformation measurements has not been covered in this symposium, and at first this seems to be a shortcoming. However, I do not think its inclusion would alter my view that the main impediment to reliability is the people ingredient of inadequate experience, knowledge, and motivation.

MY PLEA TO THE USERS OF INSTRUMENTATION

Hansmire says, in his introduction to this Symposium, "The negative experiences, the failures, are not often reported." Abramson and Green say, when talking of the failure of instrumentation schemes: "The distilled experience of many engineers who have suffered the consequences of instrument or program failures should help reduce the incidence of future occurrences."

It is clear that we learn from our mistakes and the mistakes of others. I have described about 20 mistakes, of which I have been guilty or with which I have been associated, in a series of three articles to be published in Geotechnical News (published quarterly by Bitech Publishers, Ltd., 801-1030 West

Georgia Street, Vancouver, British Columbia, Canada, V6E 2Y3, and distributed to registered members of the Canadian Geotechnical Society and the United States National Society of ISSMFE; others may subscribe by contacting the publisher). My purpose in writing these articles, entitled "Lessons Learned from Imperfect Field Monitoring Programs," was to help others to avoid making the same mistakes. In each case the mistake and the lesson learned are stated. This is planned as an ongoing section in Geotechnical News. The ball will soon be rolling; please keep it rolling by contributing lessons learned from your mistakes so that I may avoid adding them to my already long list.

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