# Instrumentation Today and Tomorrow

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**Summary** The geotechnical engineer has today a wide range of sensors, data loggers and computer software to assist in carrying out both laboratory and field testing, data gathering and the analysis of results. With component miniaturisation, better telecommunications networks and the internet many further improvements are possible and it is indeed a field where imagination and an heuristic approach can be very rewarding. The development by the authors of a low cost micro-balance for use with the filter paper technique for soil suction measurement is described as an example of such an approach.

## 1. INTRODUCTION

The geotechnical engineer can today choose from a range of testing and monitoring equipment which is suitable for, or can be adapted to, a wide range of applications. The proving rings, dial gauges and mechanical balances have now been replaced in most laboratories with load cells, displacement sensors and electronic recording and programmable balances. The development of these devices has, with the aid of the PC, enabled almost complete and automatic control in the laboratory and the field, of the testing, the data logging and the reduction of the results. This has in turn led to more reliable and accurate measurement, increased resolution, easier manipulation of data and lower running costs. Even so further technological advances are possible and the sophistication of both laboratory and field instrumentation and measurements can now be said to be only limited by the imagination and the programming ability of, or available to, the developer.

## 2. RECENT DEVELOPMENTS

### 2.1 Collecting and Analysis of Data

During the past decade the main improvements in instrumentation in the field of geomechanics have been in the monitoring and measurement techniques using commercially available equipment and sensors. This has arisen due to great advances in the development of the personal computer which is now much smaller, faster, has reduced power consumption and uses input/output boards which are faster and have greater resolution. This has made the PC adaptable to practically any laboratory or field application. The portability and memory capacity has allowed more sensors to be monitored, more data to be collected and analysis to be carried out, as the results are obtained. The latter facility has proven particularly valuable with field instrumentation where faulty transducers can be immediately detected and checking programmes can be run before data acquisition commences.

However, the use of the computer in these applications must be carefully checked as errors can arise which may go unnoticed. Not uncommon are errors resulting from the reliance on proprietary software to carry out an analysis when the user has little basic knowledge or understanding of the procedure. This can result in incorrect results, conclusions or designs. Another common source of errors stems from the acquisition of incorrect data through the use of an incorrect sampling frequency, the incorrect scaling of signals, or insufficient resolution on the data aquisition card. It is wise whenever possible to run a checking program for the full range of the data which might be collected to test the limits of the software.

Many improvements have also been made to the stand-alone data logger in this period. Loggers can now be thought of as small computers as they incorporate microprocessors, E proms and EE proms which allow software programs to be installed and changed after the logger has been purchased. Loggers can thus be used not only to collect, hold and to transmit data but their behaviour can be modified either automatically or during use. A more recent development is the ability of the logger to transmit data directly to a printer either as it is obtained or on command. This avoids the need for a PC in the data logging equipment. The logger still has a memory which allows the data to be stored and then downloaded into a portable PC on command.

Although most field sensors are still wired to data loggers at some distance equipment is now being designed which will allow the logging of data at a site and the transmittal back to the home office with a solar operated mobile phone. Changes to the logger settings can also be altered and checks made from a remote location to ensure that the equipment is operating satisfactorily. Thus the equipment designer and other parties interested in the data can have immediate access to the results.

### 3.2 Purchase and Design

When considering the purchase of equipment it is important that the engineer now look not only at the initial cost, but also consider the long term stability, the security of the power supply, the software available, the amount of data being accumulated and the cost of staffing. If after consideration it appears that there are decided advantages to be achieved in:

-automatic control of testing functions

-increased accuracy and sensitivity of data recording

-automatic reduction of results

-reduced personnel time and increased output

-reduced possibility of reading errors

then, after due allowance for the often considerable time required for setting up and maintenance, an informed decision can be made regarding its purchase.

Very similar considerations must be kept in mind by the designers of the equipment. Firstly there must be a market for the equipment which implies that if it is not a "one-off," for a particular application, that it:

-might automate, replace or assist a testing program already in place,

-allow the determination of parameters currently only possible by indirect methods

-provide software which allows equipment to be used in a way not possible by conventional means.

The transistor psychrometer and a micro-balance for use with the filter paper technique for soil suction measurement are two instruments with which the authors have been involved and which have attempted to follow some of these principles. The ideas behind the development of the latter can be used to illustrate some of the processes.

## 3. THE GALVANOMETER BALANCE

The development of the galvanometer balance for use with the filter paper technique for the measurement of soil suction is a typical example of how the instrumentation process can be used to save time, to answer some questions about a process and to obtain more accurate results. Since its development further questions have arisen regarding the filter paper technique for soil suction measurement which, with further research, the balance may also be used to answer.

### 3.1 The Filter Paper Technique

The filter paper technique involves allowing a piece of filter paper to come to moisture equilibrium in a sealed chamber with a soil sample. If the filter paper is touching the soil sample it is said to equilibrate at the matrix suction of the sample. If it is suspended within the air space above the sample, then it equilibrates at the total suction of the soil sample. The technique has been used for many years and has been assessed by a numbers of researchers. To find the matrix or total suction involves obtaining the moisture content of the filter paper at equilibrium. Calibration curves have been obtained for a number of standard laboratory filter papers and these relate, in the case of total suction, the moisture content of the filter paper to the relative humidity of the air space in the sample chamber. When measuring matrix suction, the calibration is obtained using filter papers in either the pressure plate apparatus or with soil samples at a known suction.

At the time of development of the balance the test had been recently accepted as a method for obtaining soil suction (ASTM 1993). It was known however that it suffered from at least three disadvantages. These were (i) the time taken to reach equilibrium which was not known, a period of 7 days normally being allowed, (ii) the effect of temperature variation during the period of the test and (iii) the requirement for very accurate measurement of the mass of both the dry and the moist filter paper, which commenced to change immediately it was withdrawn from the controlled environment. The effect of each of these on the final result had not been precisely determined and data was still being obtained by ASTM who, in their Section on Precision and Bias, stated "data are being evaluated to determine the value and precision of this test method".

As the authors were involved in the development of equipment for soil suction testing it seemed that the problems associated with this test could be overcome by some appropriate instrumentation. One obvious solution was to design a balance to weigh the filter paper within the soil sample container and to write appropriate software for the balance to enable constant monitoring of the mass, thus giving an indication of the time required for equilibrium to be reached.

### 3.2 The Development Methodology

Normally 5cm diameter filter papers weighing about 0.2 gm are used in the technique. The filter paper has to be weighed using an electronic balance accurate to 0.0001 gm. This balance itself is rather expensive, costing around $2000. It was thus also deemed desirable to design a balance and monitoring equipment that would cost significantly less than that amount.

By weighing the filter paper within the sample container it was realised the technique would be suitable only for total suction measurement. This was not considered to be a disadvantage as most of the analysis carried out by engineers use this suction variable. It was also decided for convenience that the balance should be mounted either on the lid or under the lid of the container and that a piece of filter paper should be suspended from it. As sometimes the amount of soil sample obtained is rather limited it seemed that a container between 300 and 500 cc would be appropriate. It then followed that if the sample was to be arranged around the wall of the container to create a central void then a piece of filter paper approximately 2x2.5 cm should be able to be suspended without touching the sample. This paper size was considerably less than that used in the conventional technique. It meant that the filter paper when dry would weigh approximately 0.05 gm and that it would increase to about 0.09 gm with the wettest soils. For the same order of accuracy required by the ASTM Standard the balance would have to weigh to about 0.00001 gm - i.e. 10 times the accuracy of balances currently being employed. There was no such micro-balance known to the authors which could be adapted for use, all being too large to fit within the proposed soil container. The decision was thus made to develop our own micro-balance. It was probably a good thing that neither author knew much about the mechanics of balances and particularly micro-balances.

### 3.2.1 Possible Weighing Methods

Initially three possible ways of continuously weighing the filter paper were examined. These consisted of:

-a strain gauge on a lever arm supporting the filter paper

-a loudspeaker coil and cone which would deflect under load and which could be restored to its original position by supplying a restoring voltage

-the moving coil of a galvanometer using the indicating needle as the lifting arm.

Tests were carried out with all of these and after various trials the third was selected as that showing the most promise.

### 3.2.2 The Mechanism

Generally, with a moving coil meter such as that used in a multi-meter the internal coil and the needle rotate in a fixed magnetic fieldaccording to the amount of current, voltage or resistance being measured. The instrument itself is however a current meter, various components and switching being used to make it more versatile.

If a weight is hung from the needle then a restoring current is required to bring the coil supporting the needle back to its original or zero position. For extreme sensitivity the current must be applied, and be able to be measured, in very small increments which indicated the use of a pulse modulation technique. In this technique the current is supplied in pulses, each pulse being one "standard" pulse width greater that the previous pulse. The pulse width is measured by basically counting the number of pulses applied. As more pulses are applied to the coil the magnetic field surrounding it becomes stronger and it is able to rotate against the magnetic field of the fixed magnet . Any weight hung on the needle applies a restraining torque which requires a larger current to raise the needle to a predetermined position.

To define the zero or horizontal position of the needle a small infra-red light source and receiver were fixed to the sides of the balance frame. When the lever arm rises with the filter paper attached it intersects the light source and the current source is cut off. The number of pulses required to achieve this position is noted.

The balance can be calibrated using known weights and a straight line calibration is obtained. It can weigh to $10^{-6}$ gm per count but is adjustable. For the purpose of filter paper weighing each count was adjusted to measure approximately 0.00001 gm. The balance does not appear to be affected by the relative humidity within the soil jar which can often be above 99%. Calibration lines for individual balances vary slightly due to the mass of the counterweight and the length of the needle and hook used to support the filter paper.

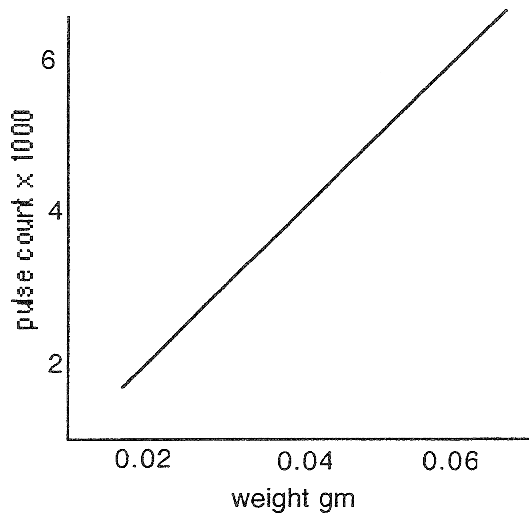


Figure 1. Typical balance calibration

## 3.3 Soil Suction Determination

### 3.3.1 Calibration

After designing a simple and low cost balance which more than met the specification required for accuracy and sensitivity a number of calibrations were attempted for the standard Whatmans No. 42 using salt solutions in the container. This follows standard practice for both the psychrometer and filter paper techniques which use salt solutions of known vapour pressures to control the relative humidity. The results obtained indicated that to achieve the moisture contents obtained by other researchers for the same Whatmans No 42 filter paper that a large surface area of salt solution saturated filter paper had to be placed within the container to obtain the correct relative humidity. More recent work reported at the First International Conference on Unsaturated Soils has shown that the equilibrium filter paper moisture content is dependent on the distance between the filter paper and the soil or solution surface It is now proposed as part of the test procedure for the galvanometer balance that a standard void is formed within the container when measuring the soil suction and that calibrations are made using soils at a range of suctions.

3.3.2 Technique

To determine the total suction with the balance the filter paper is initially hung within a container containing silica gel. This gives an initial pulse count for a dry filter paper. The lid containing the balance and filter paper is then transferred to an identical jar containing the soil sample. The filter paper then gains in weight until it reaches moisture equilibrium with the relative humidity inside the jar. It has been found using this technique that equilibrium for samples was generally reached in less than 24 hours and that an indication of soil moisture suction could be obtained in one hour from the rate of gain of weight of the filter paper-Figure 2.

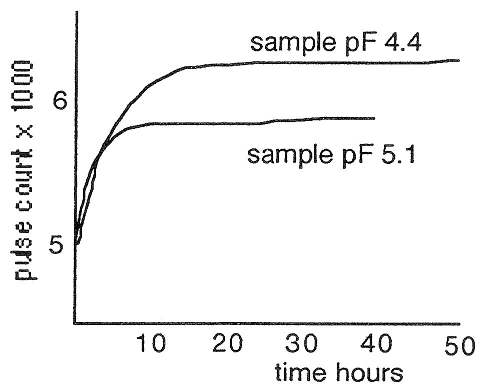


Figure 2. Equilibration of filter papers

### 3.4 Balance Controller

Although the balance was designed as a basic piece of equipment it was realised that it might be an advantage to be able to run a number of balances together using the same power source and data monitoring system. Consequently a balance controller was designed to support up to 8 balances. These are arranged in series with only the number 1 balance being plugged into the controller. The controller prints directly to a dot matrix printer or to a text file in a PC, the order of operations being:

1. a command to all of the balances to start weighing
2. a command to each balance in turn to transmit its result
3. transmission of the results to a printer and/or a PC.

Printing can be in either numeric or graphical form, the latter being useful as it shows the rate at which equilibrium is achieved.

### 3.5 Adoption for Use as a Field Sensor

Adoption of the balance to turn it into a field sensor for the down-hole determination of total soil suction is the next step. Other similar sensors using filter papers have already been used with mixed success, the main problem being the recovery and accurate weighing of the moistened paper. With down hole weighing these difficulties should be overcome. It is recognised that there is likely to be difficulty in recovering the balance itself: however, as the cost of the balance is of the order of some of the more expensive sensors it could be regarded as disposable after a number of years of service.

## 4. FUTURE DEVELOPMENTS

Today much work is taking place by instrumentation companies on the development of the next generation of testing and monitoring equipment. The "wireless" electronic cone and other in situ testing equipment will be soon followed by other wireless sensors for long term monitoring of groundwater, loads, displacements, soil suction and pollutants. The miniaturisation of components and reduction in power consumption must mean that eventually sensors fitted with R. F. links will be available not only for field monitoring of soil suction, volume change, temperature, moisture content and salinity but will also be available for use in the laboratory for the monitoring of loads, pore pressures and soil suction during shear strength and other testing. With this type of instrumentation the prediction of the behaviour of designs should become more accurate due to the extent of monitoring and feedback that will be available.

For further sensor development there are many existing materials whose characteristics change with changes in stress or strain. A number of piezo electric cables and films could possibly be used as load cells for measuring soil pressures as they are small and very flexible. There are also carbon coated plastic films which exhibit a change in resistance when two sheets are placed together with the carbon surfaces touching and loaded. The resistance of a number of the thermally responsive papers are also known to be extremely moisture sensitive and work is being carried out to determine whether these have an application in the in situ measurement of soil suction. They are indeed interesting times for the geotechnical engineer involved in this field and it can be said that there are many challenges and possible rewards for the designers of instrumentation equipment in this field.

## 5. REFERENCES


ASTM Standard D5298-92 (1993). Standard Test Measurement of Soil Potential (Suction) Using Filter Paper.