

# AUTOMATION OF TRADITIONAL GEOTECHNICAL INSTRUMENTATION

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**SUMMARY :** The rapid growth in automation of traditional Geotechnical Instrumentation is causing new technologies to be used in conjunction with standard traditional applications. Instant access to information about a particular monitored site makes automation an attractive proposition.

In order to understand the developments of instrument automation, the paper will discuss automation generically and then focus on how existing probe extensometers were automated to a user's specifications. The development of Geotechnical Systems Australia Pty.Ltd.'s AMEC (Automatic Magnetic Extensometer Controller) system illustrates a working example of a traditional instrument, in this case a probe extensometer, undergoing the metamorphosis of automation.

## 1 GEOTECHNICAL INSTRUMENTATION

The need, use and application of Geotechnical Instrumentation has created a highly specialised field of its own within the broad spectrum of Geotechnical Engineering. In order to gain a better understanding of the behaviour and conditions of a particular field site, engineers employ the appropriate instrumentation.

A Geotechnical Instrument can be defined as a device that measures and monitors geotechnical parameters, in the field, relative to the initial reading upon installation. Typically the parameters are displacement, pressure and temperature which can be redefined from an engineering perspective, as stress, strain and shear. To measure these parameters instruments rely on various types of optical, mechanical, hydraulic, pneumatic and electrical transducers.

The most attractive feature of Geotechnical Instrumentation is that it monitors what is actually happening on site. It is therefore extremely important that an instrument be reliable in producing an output of high repeatability and resolution. The vital information provided by these instruments can be interpreted in many ways, ultimately assisting in project design, management and safety.

Instrumentation, however, is only of benefit if the user is clear about the instrument's application. Selection of suitable instrumentation requires that the user :

- Knows geotechnically what is trying to be achieved.
- Knows which geotechnical parameters are to be assessed.
- Can roughly predict the magnitude of change in relation to the operating range of the instrument.
- Pre-determines the location of the instrument taking into consideration existing and future hazards.
- Is aware of installation procedures.
- Is aware of instrument's limitations.

## 2 DEVELOPMENTS IN INSTRUMENTATION

The development of Geotechnical Instrumentation is an ongoing process. Although the basic operating and measurement principles of the instruments have not changed with time, the applications and variety have.

Initially instruments were simple in operation and application. They were very expensive, sporadically reliable, were of poor resolution and from a reading perspective were manually exhaustive. These instruments also required well-trained technicians to operate the systems to obtain a reading. To some users these apparent deficiencies are only of minor concern. To the greater majority they are totally unacceptable.

The market demands instruments to be of a high quality. As such, users play a significant role in the development of Geotechnical Instrumentation. Often products custom built by a manufacturer to meet a client's particular specifications have been further developed to the point

where the once state-of-the-art instrument has now become a standard off-the-shelf item. Since the user constantly wants instruments that are better, easier to use and cheaper, it is up to the manufacturer to supply. A healthy, cooperative relationship between user and manufacturer is vital to the development of new instruments.

Without doubt the advent of computer technology and complex electronics have made the largest impact on Geotechnical Instrumentation. Instrumentation parameters are being constantly stretched, even redefined, with most instruments now being able to provide an electronic output. Where instruments once had to be read with dial gauges, they can now be accurately read with electronic readout devices.

The most useful contribution associated with computer technology has been the introduction of data acquisition systems. These systems automate instrumentation allowing vast quantities of instrument data to be monitored, logged, analysed and finally presented in an easy to understand format. Geotechnical Instrumentation is finding itself immersed in a new frontier that is being driven by the user demands of wanting more but physically doing less.

### **3 AUTOMATED GEOTECHNICAL INSTRUMENTATION**

#### **3.1 Datalogging**

The automation of Geotechnical Instrumentation is steadily creating an environment where users will have full access to all on-site information at their fingertips. To be able to have vast quantities of data displayed in a graphical form at the press of a button is highly attractive to any user.

In the most straightforward cases, instrument automation consists of an instrument with an electronic output capacity connected, usually by hardwiring, to a datalogger. It is the datalogger that allows intelligent automation to take place. In the last 10 years dataloggers have progressed enormously. They are capable of monitoring all types of sensors associated with temperature, frequency, pressure, period, flow, voltage, strain, current and resistance, as well as digital functions outputs. Depending upon sensor types, a datalogger can typically monitor 10 sensors, but can be expanded to cater for 100 sensors. The actual storage capacity of some dataloggers is 30 000 individual readings that can be further increased to 1 000 000 readings if used in conjunction with a memory expansion data card. The data from all dataloggers is readily downloaded into a spreadsheet format, where it can then be more closely scrutinised and manipulated.

#### **3.2 Datalogger Software**

The various software packages associated with dataloggers have been constantly revised in order to make a product more user friendly. The improvements in both dataloggers and software have created systems capable of performing functions of higher complexity than just simply recording data to memory.

Many sensors require calibration and scale factors to be applied to the raw data output in order to obtain readings in engineering units. Software allows these factors to be applied automatically and can also allow the user to apply various statistical evaluation techniques to the data; for example calculating and displaying the average of the output readings. The most powerful feature associated with the software is being able to raise event-triggered alarms. These allow the logger to make logical decisions based on whether a particular event is true or false. The alarm can then be implemented to initiate functions such as increasing the logging rate, read a second instrument or even activate another system (e.g. pump system).

Graphical or virtual interface software is starting to replace the traditional line command software. In the past line command software meant that a whole new language had to be learned prior to programming a datalogger. Learning the system software was very time consuming and even writing a simple program proved to be an arduous task. However, the introduction of graphical software allows new users to use and configure dataloggers more easily, quickly and confidently.

#### **3.3 Remote Automation**

The greatest time and cost savings associated with automating instrumentation is that a remote site many kilometres away can be easily and quickly accessed. In many cases Geotechnical Instrumentation is located in very difficult to physically access regions, or a vast quantity of instruments to be monitored are spread over a large area. Using a remote automation system means that all instruments can be read, or recorded data downloaded, at one conveniently accessed location.

The simplest way to network instruments is to hardwire them all at a central location to a datalogger. Understandably not all sites allow hardwiring of instruments. In many cases the distance between instrument and datalogger makes hardwiring not feasible. To counter this radio and telephone modems provide a more than suitable alternative.

Telemetry automation of Geotechnical Instrumentation is a popular alternative. A fully automated telemetry system can be configured so that a particular event (e.g. flooding in a monitored flood plain) triggers a message is sent via modem to a designated number, to confirm the event occurrence. By using a telemetry system such as this an event hundreds of kilometers away can be almost instantly accessed and assessed by personal computer.

### 3.4 Advantages and Disadvantages

The advantages and disadvantages of automating geotechnical instrumentation are summarised below.

#### Advantages.

- Fast and easy to use with almost instant access.
- Reduces the need for manual reading therefore saving time and money.
- Gives an option to increase frequency of data collection.
- Can be left alone and read/downloaded as required.
- Can monitor instruments in regions of difficult access.
- Can monitor a large number of instruments over a large area in a short time.
- Easily networked.
- Easily powered including solar power option.
- Can be set to trigger other electronic systems.
- Reduces reading discrepancies associated with individual user collections of data.
- Easily adapted to suit previously existing electronic instrumentation that was manually read.

#### Disadvantages.

- Initially very expensive.
- Difficult to set up, usually requiring experienced personnel to install.
- Requires user to be fully familiar with system.
- Reduces user awareness, such that an instrument may be faulty for months without being noticed until downloaded.
- Reduces physical inspection of site conditions.
- Can be prone to total data loss.

## 4 EXTENSOMETER APPLICATION AND BACKGROUND

### 4.1 Extensometer types

The generic term extensometer covers a broad range of geotechnical instruments. Essentially an extensometer can be simply defined as being an instrument that measures and monitors differential movement between a minimum of two points. The applications of the various extensometers and their hybrids are enormous. Although in some applications highly complex instruments are utilised, the basic operation concept still remains. Extensometers can be easily categorized into three groups, they being: surface extensometers, borehole extensometers and probe extensometers.

### 4.2 Surface Extensometers

Surface extensometers as the name implies, measure the change in movement between two points on a given surface, such as ground surface or even the surface of a particular structure or excavation. Surface extensometers once were further divided into two categories; crack monitors and convergence monitors. Logically a crack monitor measures the expansion between two fixed points

as opposed to a convergence monitor that measures contraction between the points. However, the development of extensometers has meant that many instruments are quite capable of performing the dual role of a crack and convergence monitor. An excellent example of a surface extensometer is a tape extensometer.

In many cases surface extensometers can be easily automated by linking to a data logger providing the instrument is capable of producing an electronic output. In general surface extensometers are relatively cheap, easy to install and are quite often reusable.

### 4.3 Borehole Extensometers

Borehole extensometers consist of steel rods or wires, which are anchored at specific levels within a borehole. As movement occurs within the borehole, the relative positions of the rods/wires change. The changes are determined with respect to the instrument's collar head, which is used as a datum. The physical measurement changes can be measured manually using calipers or an electronic readout provided the extensometer head is designed by the manufacturer to provide a suitable output. Once an extensometer has an electronic output capability it can easily be automated by linking it to a data logger.

The maximum number of anchor points to be measured is dependent upon the length and diameter of the borehole in which the instrument is to be inserted. In most cases anchor capacity is restricted by the particular instrument manufacturer's extensometer specifications.

The difference in operation between the wire and rod extensometers is that wire extensometers operate on the basis of measuring axial movement within the borehole using either springs or complex pulley systems to keep the wire between the anchor and head in tension. The rod extensometers rely on the tensile spring nature of the steel rods to maintain tension between the anchors and head. Each of the extensometers has their own advantages and disadvantages. Rod extensometers have been used to measure over 200m with a rod extension range of 0-150mm. They are easily installed and transported and can also be installed horizontally and vertically inverted if desired. Rod extensometers usually have a monitoring capacity of 6 anchors and over long depths have a very limited ability to accurately monitor borehole settlement. Wire borehole extensometers can measure over 500m with an extension range of up to 4m and can monitor up to 20 anchors. Since wire extensometers employ complex wire tensioning techniques they are quite expensive and require extreme care when installing. In most cases installation by the manufacturer is recommended. Both borehole extensometers can readily be automated.

#### 4.4 Probe Extensometers

Probe extensometers operate by allowing anchors to slide along a central access tube, loosely sheathed in a collapsible outer tube, within a borehole. The anchors which are usually spring loaded are placed at the critical points to be monitored within the borehole. The anchors are free to move with the vertical settlement or heave associated with the adjacent-to-the-borehole soils. Once the anchors, access tube and collapsible outer tube are placed, a probe with an attached tape is fed down the central access tube. Each anchor consists of a material that triggers an audible alarm within the probe. If a magnetic sensing reed switch is used the triggering anchors will contain magnets but if an inductance type probe is used the triggering anchors will contain stainless steel rings. To use the magnetic probe as an example, once the magnetic sensitive probe enters the magnetic field produced by the target, the audible alarm is triggered and the corresponding depth is read from the tape. It is extremely important that this depth is referenced to a surveyed datum.

The advantages of probe extensometers are their relatively low cost, ability to monitor an infinite number of anchors, easy to install and are capable of monitoring up to 2m of anchor displacement in either direction (settlement or heave). Although the depth range of a probe extensometer is about 100m, the real disadvantages are associated with the precision in readings due to the instrument being quite labor intensive.

The need to automate probe extensometers in an effort to increase precision and repeatability and eliminate the manual operation became apparent. However, a reliable instrument to perform this task has not yet been available.

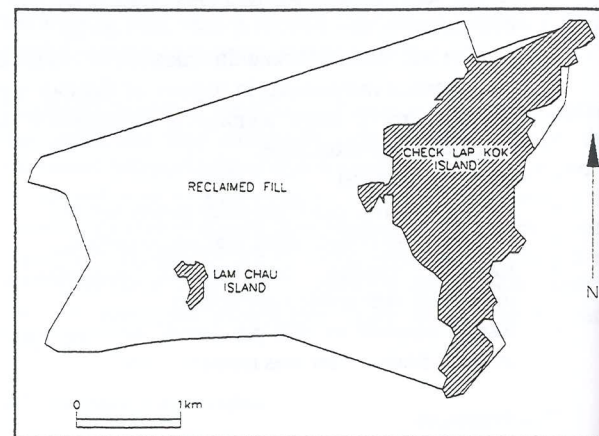
### 5 HONG KONG APPLICATION

#### 5.1 Brief history and site overview

Hong Kong's Kai Tak Airport currently deals with 28 million passengers a year and as a result suffers from an overburden on existing services. In order to satisfy Hong Kong's extreme air traffic congestion and maintain its status as the pivotal trade focus in Asia, Kai Tak Airport will make way for a new airport at Chek Lap Kok island which is 25kms west of Hong Kong's Central Business District. The Airport Authority of Hong Kong (AAHK) oversees the current construction of the new airport, which is considered to be one of the largest construction projects worldwide.

The airport platform was created by removing the top off Chek Lap Kok island, reclaiming 75% of the platform mostly from the sea and capping the entire area with a 2 metre layer of compacted sand or completely decomposed granite and in effect joining the island of Chek Lap Kok with Lam Chau island (see Figure 1.). The airport occupies 1248 hectares. Prior to any filling taking place it was necessary to dredge the soft marine muds from the site in order to reduce settlement. The dredge level of the mud had to satisfy a minimum cone resistance ( $q_c$ ) of 500 KPa, equivalent to an undrained shear strength of about 25Kpa. The reclaimed part of the site consists of a combination of

the mined Chep Lap Kok and Lam Chau islands, imported rock and marine sands obtained from nearby contracts and marine sands obtained from nearby designated borrow areas. The remaining 25% of the platform lies on the levelled granitic base of the original islands of Chep Lap Kok and Lam Chau. The reclamation is protected by a seawall consisting of up to 5 tonne in mass of Chek Lap Kok blasted rock. The compacted sand/decomposed granite cap is separated from the fill material using a geotextile separator.



(Figure 1. Hong Kong Airport Platform)

#### 5.2 Settlement

Settlement with respect to the reclaimed platform is a issue of much debate. Initially settlement estimates, based upon an analytical evaluation of the platform, were between 1-1.5metres. As construction has progressed settlement predictions have been monitored to check the settlement predictions.

As outlined earlier, the platform comprises of various fill and existing material. These vary from solid rock to up to 20 metres of reclaimed fill overlaying 30 metre beds of lightly overconsolidated alluvial sediments. In some regions of the platform bedrock is at depths of up to 60 metres. Understandably the various fills during the completion of construction phases have been placed at different times. As a result different stages of settlement are experienced on the platform at any given time. This is compounded by the fact that the various fill material types will also have differing stiffnesses further affecting consolidation, compression, creep and ultimately settlement.

#### 5.3 Instrumentation

AAHK's observational approach to settlement meant that instrumentation was to play a leading role in understanding the issues regarding the settlement of the platform. To gain a clear insight of the total settlement profile, subsurface instrument clusters and surface monitoring points have been used. The clusters were placed specifically, taking into account geology, settlement prediction and the planned positions of temporary and permanent structures. Each cluster typically comprises of a Sondex (inductance extensometer and to a lesser extent magnetic extensometer.

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together with a combination of pneumatic, vibrating wire or Casagrande piezometers. The settlement rate, particularly of the alluvial deposits, can be measured taking into account excess pore pressure and pore pressure dissipation rates determined by the piezometers and comparing these with the settlements obtained from the extensometers.

The data obtained from the instrumentation is placed into a spreadsheet program where it is appropriately 'massaged' and stored. Of the 60 existing instrument clusters it is anticipated that 20-25 of these will be retained. Ideally these retained clusters are to be automated in order to provide and create a unique database showing the settlement behaviour of the reclamation fill materials within the platform.

#### 5.4 Existing Magnetic Extensometer System

Each cluster is arranged so that the Sondex extensometer acts as the central instrument surrounded by three to four piezometers within a 20 metre radius. About half of the clusters include a magnetic extensometer placed next to the central Sondex extensometer. On average a space of 400-500 metres exists between the clusters. In regions where greatest settlement is envisaged the cluster spacing is reduced to about 200-250 metres.

The operation of magnetic extensometers is relatively simple. The ring magnets slide along a central access tube ( $\phi 70\text{mm}$  O.D., ABS) and within a collapsible outer tube. The magnets act as targets and are fixed within the borehole, using spring supports, at locations where expected movement is to be monitored. The central access tube, collapsible outer tube and targets are all installed then backfilled with a bentonite/cement grout and gravel fill. During installation all extensometers had a datum target placed at a minimum of 2 metres into Grade III rock. The extensometer boreholes are up to 90 metres deep with up to 11 target points. The location of the targets is determined by using a magnetic probe, connected to a tape, which is then lowered through the central access tube. Each magnetic target triggers an audible probe signal whereby the depth of the target can be measured from the tape relative to the top of the extensometer central access tube.

The readings are taken manually and are then placed in a spreadsheet format. Data and data plots are then presented in the following ways :

- Accumulated settlement against depth for all survey dates.
- Accumulated settlement for all targets against time.
- Absolute settlement of any one target against time.
- The distance between any two targets plotted against time.

#### 5.5 Automation of Magnetic Extensometer

It has been AAHK's plan to continue monitoring well into the operational phase of the Airport. Understandably the access to the instrumentation clusters would be extremely limited given the obvious frequency of aircraft activity

expected within the settlement monitored region. To address this problem it has been proposed to employ an automated settlement monitoring system. However, of all the instrumentation in current use, only the vibrating wire piezometers can be readily adapted to remote automation. Historically there has been no evidence of a fully functioning magnetic extensometer with automotive capabilities.

## 6 AMEC SYSTEM

### 6.1 Description

The Automatic Magnetic Extensometer Controller (AMEC) is, as the name implies, an automated magnetic extensometer. Currently conventional magnetic extensometers operate by manually lowering a calibrated sensor and cable assembly down a borehole to detect magnetic targets positioned at various depths. To enable regular and repeatable long term measurements, at a site with limited accessibility, an alternative to manual measurement had to be found. Therefore, an automated magnetic extensometer was developed to meet the perceived needs of long term, repeatable and high resolution measurement.

The new airport being built in Hong Kong was the catalyst in creating AMEC. With many manual magnetic extensometers already in operation, the need to automate for the future was apparent. AAHK wanted to make use of the existing boreholes with magnetic targets, therefore a system had to be designed to conform with and utilise what was already in place. As no such automated system existed, the challenge, to create a state-of-the-art automated magnetic extensometer, evolved. It was an Australian company, Geotechnical Systems Australia Pty. Ltd., that designed a system satisfying AAHK's requirements.

### 6.2 Development

AMEC took 6 months to design. The initial design parameters were emphasised by AAHK and as a result, it was important that AMEC satisfied the following criteria.

- Make use of the existing magnetic extensometer installations.
- Be fully automated.
- Have a remote power supply.
- Able to be controlled and monitored via a personal computer.
- Output to be expressed in text file format to be easily imported into a spreadsheet file.

### 6.3 Finished Product

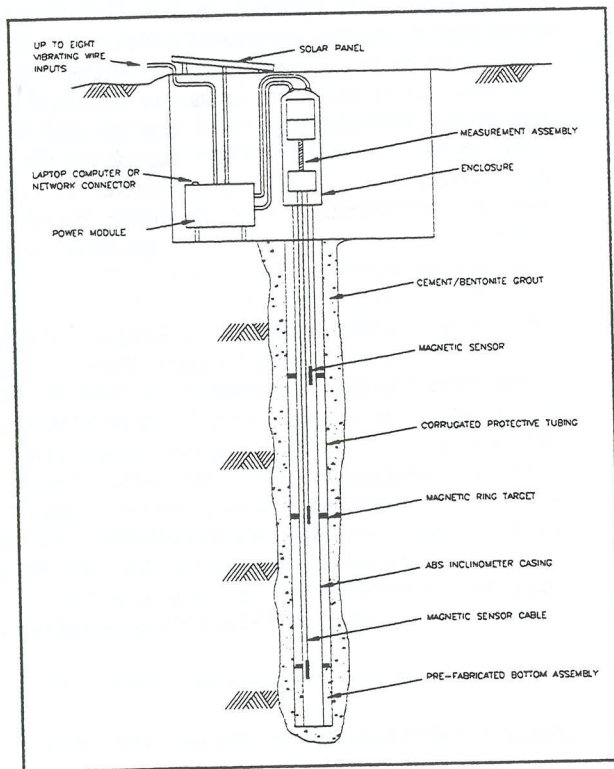
AMEC consists of four distinct parts; sensor assembly, measurement assembly, enclosure and power module (see Figure 2.).

The sensor assembly allows a maximum of 8 sensors to be suspended in close proximity to specific targets. During the measurement cycle, sensor outputs are continuously interrogated and each of their trigger points is logged against the vertical displacement of the head assembly.

The measurement assembly's on-board microprocessor manages all measurement, control and data storage processes. These include sensor monitoring, displacement, log time intervals, data storage, data retrieval and transmission, programmable functions, power optimisation and self-diagnostic checking.

The controller is housed inside a cylindrical stainless steel enclosure that is hermetically sealed to IP68 waterproof standard. The enclosure provides access to power and RS232 communication links.

The power module is housed in a powder coated aluminium case sealed to IP68. Powering can be from mains power, D.C. power or internal battery with solar charger.

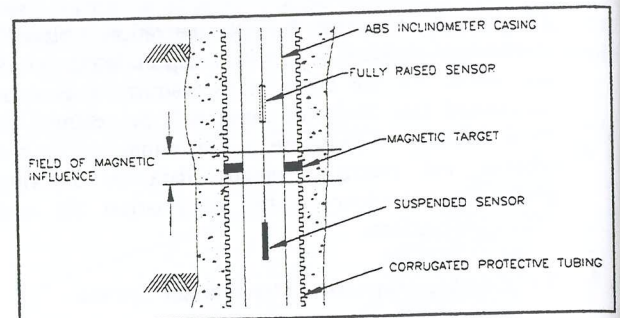


(Figure 2. AMEC Profile)

#### 6.4 Operation

Once fully installed, AMEC is programmed to take readings at a fixed time interval. When operating, the stepper motor, via a threaded drive shaft, slowly raises all 8 sensors at the same time. Each of the sensors contains a reed switch that closes once in contact with the magnetic field created by the magnetic targets within the borehole. The vertical position of the sensor is recorded once the reed switch has initiated a closed circuit (see Figure 3.). The sensor positions, which are measured only during the raising of the sensors, are referenced to the bottom anchor, which is positioned in rock. Once the threaded drive shaft is fully extended, the stepper motor reverses and lowers all 8 sensors back to their initial pre-scanning positions. The sensors are not read during the lowering cycle. If a particular sensor indicates no reading, it means that the amount of either settlement or possibly heave has exceeded the drive shaft's full extension range of 200mm during

scanning. Where excessive settlement has occurred, either the borehole casing collar on which AMEC is housed can be cut lower, or new sensors with longer cables may be fitted. For excessive heave sensor cables may be shortened to bring the sensors back into the magnetic field range of the targets.



(Figure 3. Operation detail)

#### 6.5 Features

The features of AMEC are:

- It is a stand-alone measurement system.
- Monitors up to 8 targets.
- Has high resolution readings.
- Has non-volatile data storage.
- Can be removed for manual reading.
- Waterproofed to IP68.
- Microprocessor controlled.

The following tables (see Table 1. & Table 2.) detail the physical and electrical specifications of AMEC.

#### 6.6 Installation

The installation of AMEC is a relatively simple process. Prior to installation the depth of the borehole and anchor positions must be known. The sensor cables are cut to the appropriate depth and fixed with locking ferrules to the head assembly. The wires of the cables are stripped and attached to terminals. Once the cables with sensors have been fed down the hole, the enclosure is placed over the head assembly and locked into position. The power module is then fixed into position and communication cables are attached. The system is checked with a personal computer running AMEC through several scans to make sure that a full set of repeatable readings is obtained.

Since AMEC is a new product, installation by the manufacturer is recommended. However, detailed installation and operation manuals accompany each unit.

PHYSICAL SPECIFICATIONS	
<b>Controller:</b>	
Size:	800mm long×φ150mm
Weight:	17kg
Material:	Stainless Steel
Sealing:	IP68
<b>Power Module:</b>	
Size:	350mm long×160mm wide×100mm high
Weight:	8kg
Sealing:	IP68
<b>Sensor Cable:</b>	
Size:	φ5.1mm
Material:	Polyethylene with nylon jacket
Construction:	4 core, jelly filled
Weight:	2.9kg/100m
<b>Sensors:</b>	
Size:	200mm long×φ19mm
Material:	Stainless Steel
Weight:	450gm
Accuracy:	± 0.1mm

(Table 1. Physical Specifications)

### 6.7 Software

It was important to create a user-friendly software that can be quickly learnt. To achieve this AMEC was designed to work in conjunction with a Windows 95 based custom software interface. With this software the user controls how often and at what time scanning will occur. Each scan is recorded with the corresponding date and time, with displacement relative to the vertical displacement of the head expressed in millimetres. The scanned data can then be downloaded into a spreadsheet file for further analysis. Other software specifications are listed in Table 2., under datalogging and communications.

## 7 CONCLUSION

The automation of traditional Geotechnical Instrumentation is steadily increasing in popularity amongst users. With the barriers to what can and cannot be automated eroding, the application for instrument automation have been dramatically enhanced.

The development of AMEC has shown the evolution of an automated probe extensometer from conceptual origins to a fully functional system. For AMEC to be an advantageous benefit, cooperation between user and manufacturer (AAHK and Geotechnical Systems Australia Pty. Ltd.) was vital. The result is a state-of-the-art instrument available to the global geotechnical industry.

## 8 ACKNOWLEDGEMENTS

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ELECTRICAL SPECIFICATIONS	
<b>Controller:</b>	
Inputs:	Up to a maximum of 8
Index Accuracy:	± 0.1mm
Index Repeatability:	± 0.1mm
Index Resolution:	0.014mm
System Accuracy:	± 0.5mm
<b>Power Module:</b>	
Mains:	240V, 120V, 50-60Hz, 50Watts Peak (optional)
Battery, D.C. Supply:	Sealed lead acid, 10W Solar charger
Backup:	2 × Sealed lead acid, 12V, 1.2Ah
<b>Data Logging :</b>	
Storage Capacity:	500 measurements of 8 inputs (Inc. Date, Time & Status information)
Data backup:	10 years without primary power
Logger Timing:	Real-time clock, non-volatile operation, 10 year count without primary power
Scanning Intervals:	Choice of scanning intervals from 1hour to daily
<b>Communications:</b>	
Baud Rate:	9600 Baud, 8data, 1 start, 1 stop, no parity
Data Format:	8 Data points, Time, Status data
Data Separator:	Tab separated columns, text format
Data Recovery:	Customized WIN95 Interface Software
Networking:	Optional linking of up to 10 sites for data. Recovery from a single access point

(Table 2. Electrical Specifications)

## 9 REFERENCES

- Dunnicliff, J. (1988), "Geotechnical Instrumentation for Monitoring Field Performance." John Wiley and Sons Inc. New York.
- Dunnicliff, J. (1995), "The Practical Use Of Geotechnical Instrumentation : Some Problems and Solutions." Proc. 4<sup>th</sup> International Symposium on Field Measurements in Geomechanics, Bergamo Italy. 239-256.
- Hanna, T.H. (1985), "Field Instrumentation in Geotechnical Engineering." Trans Tech Publications. Clausthal-Zellerfeld. Germany.
- Ground Engineering/AAHK Chek Lap Kok Supplement (December 1996), Published by Emap Construct. London.