

# New Developments in On-line Monitoring of Geotechnical Data

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## ABSTRACT

*Improvements in sensor designs over the past 20 years have generally only been marginal, except in the case of those which now employ micro-electronics. On the other hand data acquisition systems, communications and data handling have changed dramatically, having passed through several generations of development in the same time frame. The net result has provided reliable and simpler monitoring systems, with more features and, due to improved manufacturing productivity, all at lower cost.*

*This paper focuses on recent developments in on-line monitoring systems and, in particular, the way in which the data can be handled. It follows the path set in previous papers by the same authors who both work on the subject: How to handle, display and work with geotechnical data in a modern on-line monitoring system.*

## 1 PHILOSOPHY

The benefits of automated data acquisition systems and data visualizations are now generally well understood (Marr, A 2005), providing, stakeholders and contractors alike, a convenient and near real-time means of assessing instrument data and, in turn, the performance of the structure. It also provides a means to verify the design of the structure, develop maintenance strategies and a means to advance the state of the art.

Essentially, the main purpose of the data acquisition system is to supervise the behavior of the structure being monitored, through a system of on line instruments and sensors. In general, various groups of sensors are connected to strategically placed dataloggers, in which the readings are processed, stored and then transmitted, quickly and securely, to a centrally located

Automatic Data Acquisition System (ADAS) (Fiorini, As et al, 2007), which can, when necessary, promptly alert alarm conditions if pre-set threshold criteria are met.

The data obtained at the ADAS is typically stored in a data base where analyses and actions based on sensor specific data can be initiated, and the performance of the ADAS itself be assessed. Sensor data can be processed to determine trend lines, max. min. and mean values, accelerations, cumulative displacement, and even to output in engineering units, for example; if the Young's Modulus and cross sectional area of a structural member is known, readings of strain can be presented in terms of stress or load. At the same time, built in diagnostics can report the status of the data acquisition system itself,

including battery voltage, capacity, etc. and send alarms when necessary.

## 2 OVERVIEW OF SENSORS, DATA ACQUISITION SYSTEMS

Generally, the most important parameters required by the geotechnical engineer are Physical Parameters which include the following; deformation, strain, load, pressure, pore water pressure, earth pressure, inclination, temperature, precipitation, soil moisture and corrosion. There are hundreds of different sensors available for geotechnical monitoring, based on a wide variety of technologies, some of which have been in use for more than 80 years.

The ultimate selection of any sensor must consider that its output is directly proportional to the quantity being measured and that it is reliable and repeatable. The sensors must also be capable of providing the required accuracy and sensitivity and, where long term monitoring is required, exhibit excellent long term stability. Finally, no matter which type of technology is chosen, the sensor must be durable and capable of withstanding the environment in which it will be installed. Today, the most widely used technologies include, Wheatstone Bridge, MEMS, DCDT, Potentiometric, Vibrating Wire, 4-20mA and, most recently, fiber optic.

The past 20 years have witnessed huge advances with respect to data acquisition systems (Thorarinsson, A et al 2007). Now they are available with sophisticated processing and error checking capabilities, operate from low power supplies, and have communications devices built in to allow for remote data collection via a variety of means (hard wire, fiber optic cable, telephone, Ethernet, satellite, and wireless). They have become more affordable, even for small scale projects, and most are designed in a modular way which better facilitates housing in small,

field ready, enclosures and, moreover, allows them to be easily customized (and expandable) for the type, number, and location of sensors being monitored.

The widespread availability (and relative low cost) of sensors and data acquisition systems has greatly improved the ability to retrieve data from geotechnical monitoring sites (including those in remote locations) reliably, and in a timely manner. On top of this, the Internet, as a communications tool, has provided a highly reliable and inexpensive link to show data from a sensor located anywhere in the world to a user located anywhere else, at any time.

## 4 ROLES IN MONITORING SYSTEMS

Important in every data monitoring system today is the need to identify certain roles that must be managed in order to ensure the integrity of the system. From a data handling point of view the main roles are those of the Designer, Maintenance Manager, On-duty Manager and Analyst. As a data monitoring system becomes bigger and more complex it is vital to identify those roles, and to assign each role to an individual who is capable of handling all the requirements.

### 4.1 *The Designer*

Although data monitoring systems can be planned in a number of different ways, let's consider the data part of the monitoring system, where the designer must decide which information he needs, how it should be presented and reported and then decides on the appropriate sensors, data loggers and communications.

An important part of any design is the decision as to how alarms should be handled to allow for reasonable response time and to minimize the possibility of false alarms, (Thorarinsson, A 2015). A

typical false alarm can arise when, for some reason, the data logger returns an out-of-range (high or low) value caused by electrical noise or a voltage spike. One method to facilitate this, is to adjust the protocol such that an alarm will not be triggered unless the data logger returns at least two consecutive readings which fall outside the alarm limit(s).

This leads to another important consideration (and decision); how long after an alarm event should an alarm be made? Keep in mind that all alarms do not require rapid response, common are alarms which warn about slow moving process like low battery voltage, seepage or gradual movements (accelerations) in an active slope.

Finally, the designer should also be aware that too much data may not be helpful, it may over load the communication link, the data storage and all the data handling. To illustrate, consider a data acquisition system monitoring every 10 minutes (52.000 readings per year) versus one monitoring every 0.1 second (320 million readings per year).

#### 4.2 *The Maintenance Manager*

The responsibility of the maintenance manager is to ensure that the monitoring system is operational and performing as expected. A well designed monitoring system will incorporate “health indicators” which will indicate if parts of the system need maintenance or replacement (see Thorarinsson, A et al 2011). Two important health indicators are update and power, but there may be others including those related to individual sensors or to the internal life of the sensor. Health indicators greatly simplify the task of the maintenance manager who now only needs

to spend a short amount of time to check if all is well

If data is no longer being updated from a monitoring system then something is clearly wrong. It would be very time consuming to always be checking update status, better if this task is automated and to receive a notification. The main reasons why data may not be updated are no power (or power has been removed), failed communications, or there a network problem. If automated update notifications are set in a reasonable way, for example as 5 to 10 times the scheduled update, then the operator can rest assured that he will be notified if data is not updated in a timely manner

The duties of the Maintenance Manager become a lot easier when key data is organized in such a way that, in a single glance (on one screen), it can be shown all is well.

#### 4.3 *The On-duty Manager*

The purpose of a monitoring system is to collect data. The role of the on-duty manager is to review the data at regular intervals to ensure correctness and to decide if it indicates a need for some action. The larger the system the more important it becomes to organize graphs and overviews such that the daily workflow of data browsing becomes as easy as possible. The tools to facilitate this include naming of sensors, trend lines, overviews, setting alarm thresholds and the creation of groups of data such that differences can be more clearly seen. It must also be possible that the layout of data be adaptable to changing situations as time passes, and areas of interest shift from one aspect to another.

On most occasions the On-duty manager is in contact with several clients, each with different needs; for example the contractor, the owner, the engineer, and the regulatory body; as such, the on-duty manager has to be able to create the various requirements by tweaking the web interface to the data. This may include automatic forwarding of data into another data system or to allow an external system to retrieve data from his, and it may well require the assistance of the maintenance manager to create the necessary views and associated data handling.

#### 4.4 *The Data analyst*

Everyone who works with data becomes a data analyst. Data analysts use data to get results, whether it be the sum or average for a time period, correlation of data, comparing one period to another, identifying trends or creating reports. Originally the input for the data analyst was a series of data in which each reading had its own time stamp, and the analysis tool of choice was a spreadsheet program. This process was a major task and very time consuming to. Nowadays, however, it is expected that data monitoring systems incorporate an arsenal of d tools which makes it possible to perform a variety of analyses and to achieve deterministic results with just a few keystrokes. However the old, classic, and fundamental problem is always present; “Can I trust the result?” After all, the result is only as good as the integrity of the data being used as input. The data can be suspect to a variety of errors; incorrect units, spikes,

drift, gaps and so on. And as the amount of data collected is constantly rising the role of the data analyst, to validate the results are correct, becomes increasingly important. This leads to the conclusion that an important part of the data analyst’s work is to check it for integrity and to make corrections where necessary such that the data being used for the analyses is correct.

## 5 DATA VISUALIZATION AND REPORTING

To see is to understand! How true it is. But what one person sees (or wants) may not be the same for another. Now, however, are many tools available that can be used as quick reports and, by a few simple key-clicks, it is possible for the analyst to reveal hidden information that is not immediately obvious from the sensor data alone. Let's look at few examples.

### 5.1 *XY graph*

Let's first look at what the classical XY graph can do for us.

Figure 5.1.1 shows 6 months of data from an extensometer installed in a slope close to a main road. The graph shows some movement, the sensor returns a low of 2.7 inches and a high of 4.7 inches. The question is, of course, “Is this is true?” In this case there is a temperature sensor inside the extensometer, see figure 5.1.2.

Now, what is interesting is to plot the extensometer data as a function of the temperature on a XY plot, see figure 5.1.3.

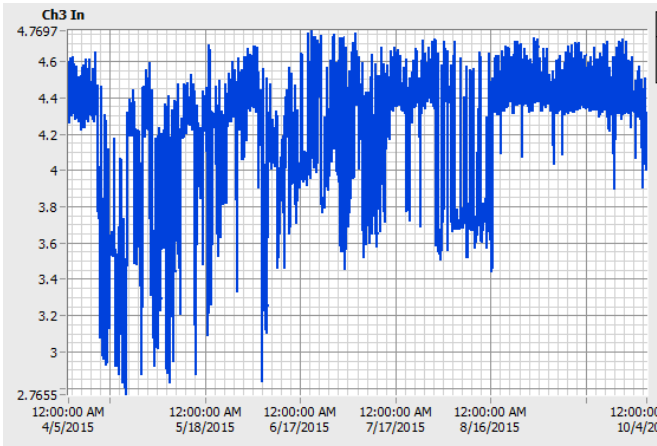


Figure 5.1.1: 6 months of extensometer data

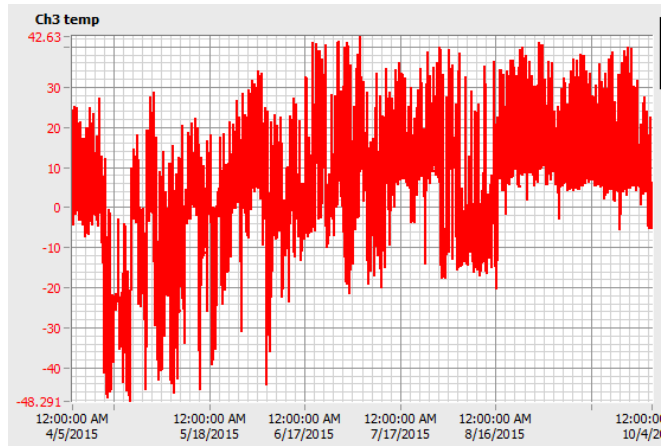


Figure 5.1.2: Temperature readings from the extensometer sensor in fig. 5.1.1

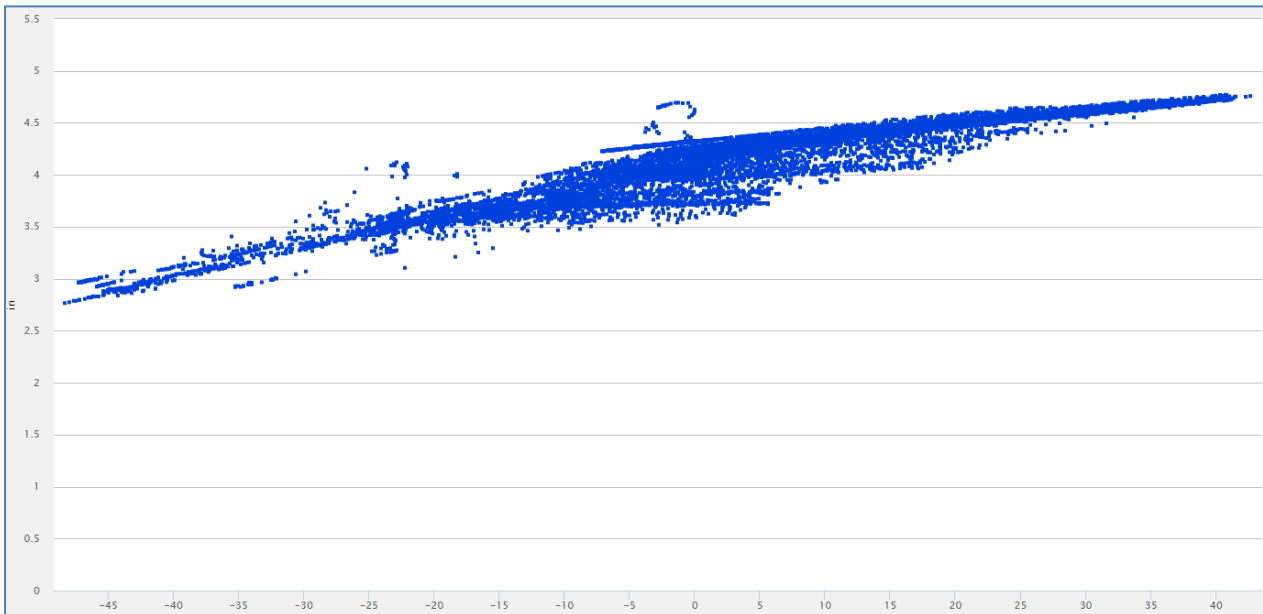


Figure 5.1.3: XY plot of 6 months of extensometer sensor data. X-axis is sensor temperature, Y-axis is extensometer sensor readings.

As it turns out, there is a linear relationship between the extensometer readings and the ambient temperature. Is it possible that there are movements at the site and that they are greater when the temperature gets higher? Or it is equally possible that the current temperature correction of the extensometer is incorrect or that the AD conversion of the data logger is

temperature sensitive which, in either case, would lead us to believe that there is actually no movement at all! The final conclusion is that if such a correlation between a sensor reading and temperature is discovered the real cause must be investigated via an on-site inspection and possibly additional instruments.

### 5.2 Overlay graph and intensity plot

Overlay graphs and Intensity plots are great tools for investigating trends in sensor readings. If there are trends it is of utmost importance to understand if they are the result of actual changes or if there is some kind of an instrumentation error

that one should be aware of. The following example shows data from a piezometer in borehole at the edge of a landfill, close to a pond and few miles from the sea.

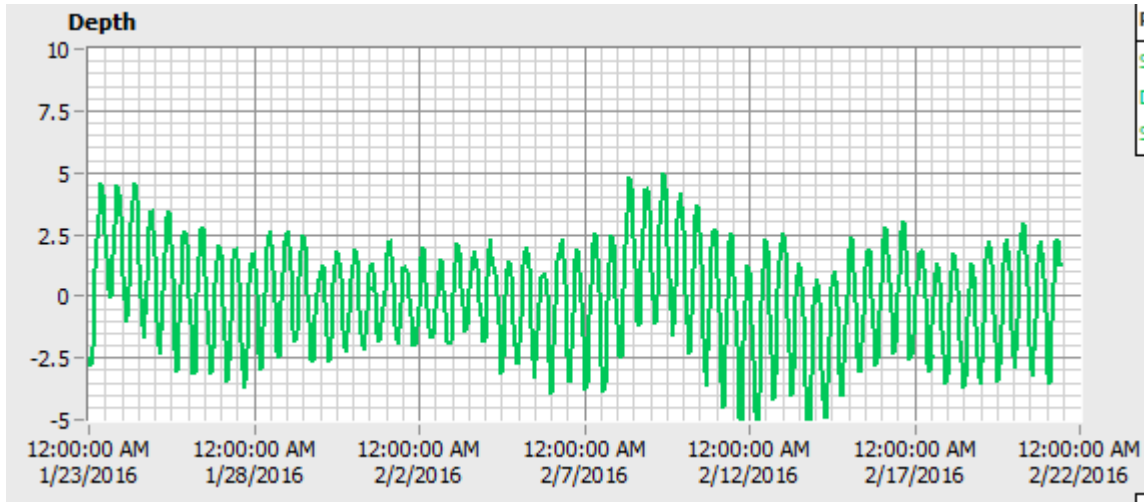


Figure 5.2.1: One month of groundwater level sensor readings

Clearly there are regular swings in the water level readings. The operator could ask if this is true and if so, why? Or is this some kind of an instrumentation error? In

order to find the answer the operator could start by plotting the data on Overlay graph reporting tool.

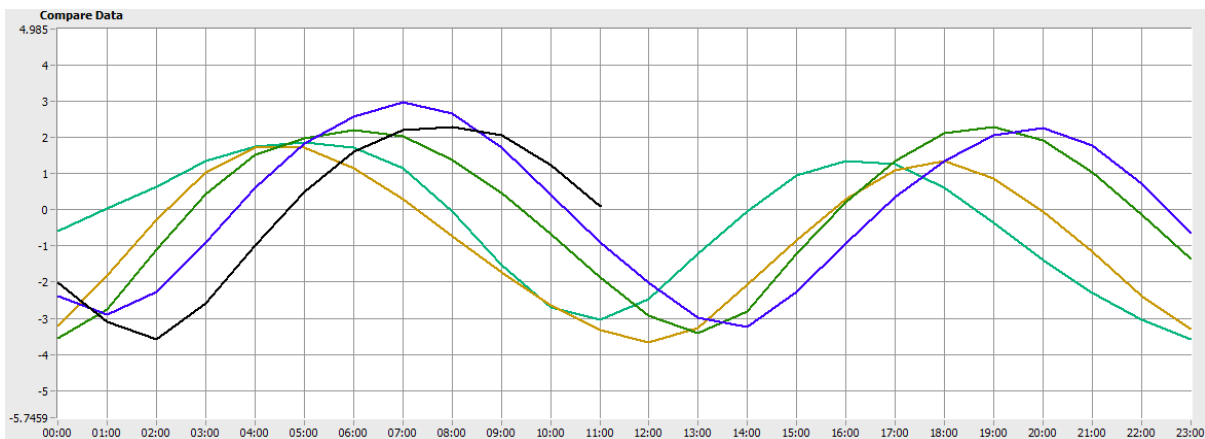


Figure 5.2.2: Overlay graph, four and a half days, of water level readings on top of each other.

The Overlay graph reveals that the maximum and minimum of the sensor readings occur almost every 12 hours but not always at the same time of day, and

that they move slightly forward in time every day.

Now let's plot the same data in the Intensity plot reporting tool:

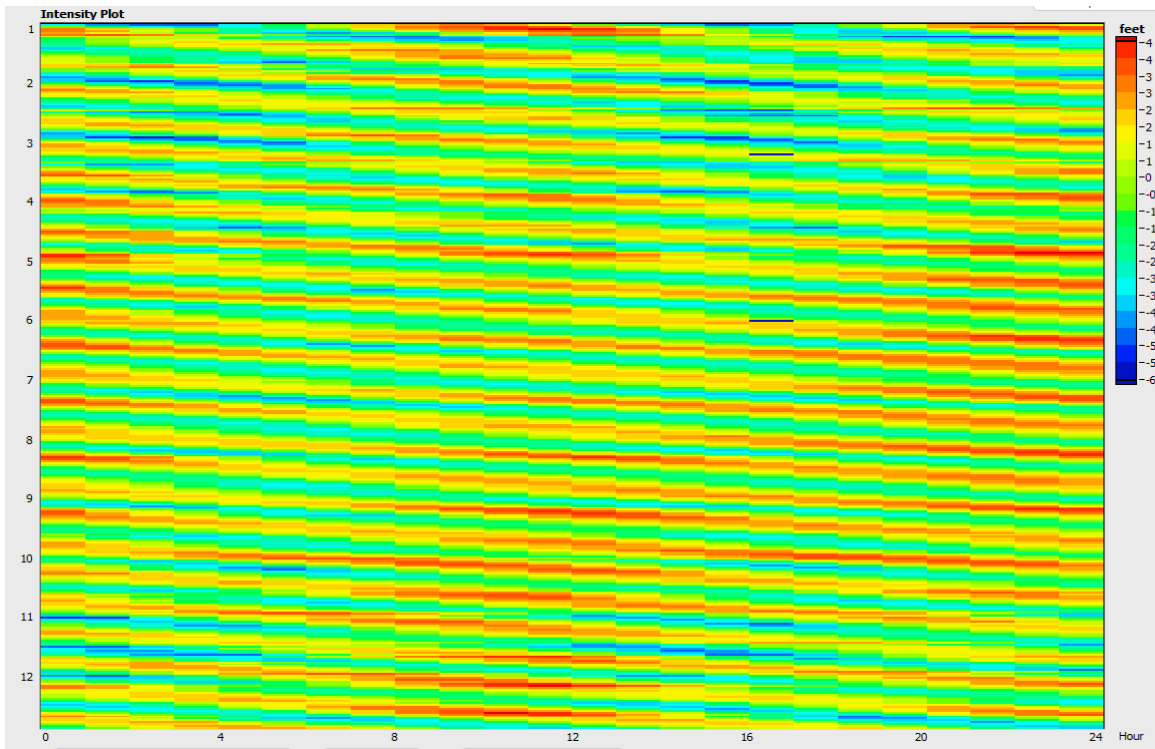


Figure 5.2.3: One year of water level sensor readings. Y-scale is the months, starting on month 1 (January) and ending on month 12 (December). X-scale is hours of the day.

The Intensity plot reveals the answer; the water level correlates with the tide, which influences the ground water even though is some miles away.

### 5.3 Wind rose

Weather data can give information which is useful when planning work at a building site, and one reporting tool that can be

extremely helpful is the wind rose reporting tool. The wind rose reporting tool not only shows the wind speed as function of the wind direction but also other variables as a function of the wind direction. In the following example check from which direction the heaviest rain hits the site and from which direction the highest wind speed comes.

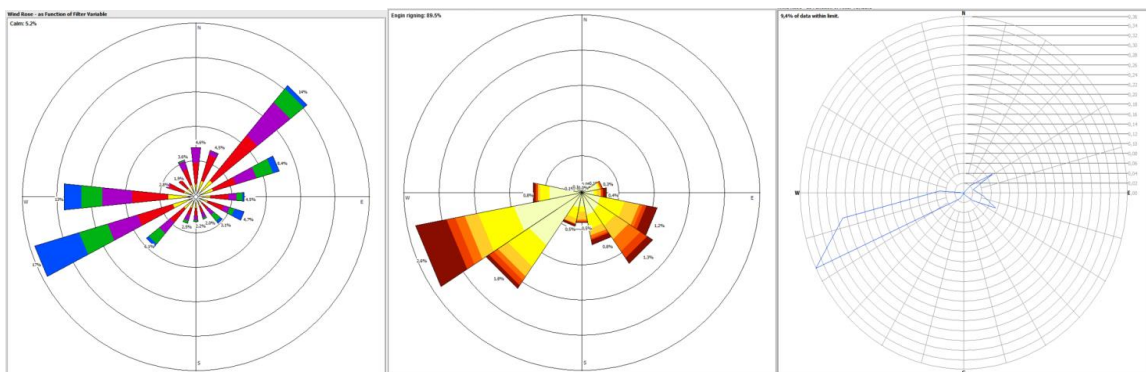


Figure 5.3.1: Three "wind" roses: a) Classic wind rose, b) Precipitation as function of wind direction, heaviest from WSW and ASA, c) Strongest wind is blowing from WSW.

### 5.5 *Automatic reports*

Automatic reports are just that; sent automatically to the recipient daily, weekly or monthly, or however the requirement may be. Automatic reports may include just the raw sensor data, or all the text, photos, data sets, graphs, alarms and notes for the preceding period and therefore greatly simplifies the task of providing reports to the client. Other types of reports can send data automatically from the on-line monitoring system to another system, or receive and store data from another data system.

### 5.6 *Dashboard*

While graphs with trend lines are the traditional method of displaying data there are other tools now available which can show a mix of latest data *and* trend lines which gives a great overview of the entire project. In this way, the operator only needs to select the work site and he then has, at his fingertips, all the information for that site, including latest readings, alarm status, trend lines and data all presented in quick reporting tools.

## 6 DATA FROM VARIOUS INSTRUMENTS

### 6.1 *Wireless instrument systems*

Wireless transmission of data from sensors connected to data acquisition systems is not particularly new, as far as data communications are concerned, but what is becoming increasingly popular of late, is the use of wireless sensor networks, where one sensor (or a small group of sensors) are connected to a wireless nodes which, in turn, transmit data to one common base station.

Communication protocols in wireless networks can be rather complex, but essentially comprise a header, identifying its source node, destination node and the data content. When multiple nodes desire to transmit, protocols are needed to avoid collisions and lost data. Similarly, in a distributed network, there may be multiple paths from the source to the destination and so message routing becomes very important. Routing can be Fixed, which dictates the destination (and so cannot take into account failed links, or congested queues) or Adaptive (which can take into account various performance measures and take into account link or node failures).

The database/data visualization software used to handle data from wireless systems must take into account all of the abovementioned and, more often than not, integrate it along with data from larger data acquisition systems, to which a larger number of sensor are connected.

### 6.2 *Vibration recorders*

In order to capture vibrations caused by blasting, or any other event, a vibration recorder is used. A typical vibration recorder uses three sensors in the x, y and z planes, and samples all three constantly, at high sampling rate, 500Hz or higher, even up to 5kHz, and stores these data in a buffer. If there is a vibration that is higher than a preset trigger value the vibration recorder stores a data set starting few seconds before, and up to 30 seconds, after the event. This set of data is called event data and is sent to the on-line monitoring system for handling. Sometimes a microphone is part of the vibration recorder, returning some metrics for the sound and sometimes full audio sampling for the period. In order to show the background vibration it is not uncommon that the vibration recorder to store one



sample every couple of minutes which may then be plotted on a graph.

### 6.3 *Automatic motorized total station (AMTS)*

Increasingly being used to detect even the smallest surface movement with high precision are automatic motorized total stations (AMTS) which uses a laser beam to measure the distance and angle to a target prism. Often the AMTS is programmed to wake up every hour, make its measurements to the group of prisms and return the readings to a central data base storage along with data from all the other sensors on the project site..

### 6.4 *Tunnel boring machines (TBM)*

The TBM is a major piece of equipment used for boring underground tunnels, and is loaded with various control systems and collects data from a wide variety of on-board sensors. Now, instead of using an outside system to connect and read the data, a more efficient method is to have the TBM output a set of its sensor readings into a text file for other systems to read. The data being output may include forward movement, pressure on head, direction, location and much more. A special forward program forwards the data to a FTP site to be input to the on-line monitoring system and therefore the vital information about the TBM may be presented together with other data in the on-line monitoring system.

### 6.5 *Other systems*

With each passing year, new field devices are being developed and deployed in geotechnical projects. Common with many of these devices is their wireless

capability and automatic forwarding of data to a FTP site or by sending its data to an email address. This remarkable feature means that no centralized call engine is needed for data collection. Therefore, all the on-line monitoring system needs to be able to do is to monitor a FTP site for new data and to monitor an email account for the same purpose, and to import all new data into its data base.

## 7. WHAT'S NEXT?

In recent years, remote sensing methods, such as Interferometric Synthetic Radar (InSAR), Automated Motorized Total Stations, 3D laser scanners, etc., have seen more widespread use and acceptance in the geotechnical community. The various techniques allow macroscopic evaluations of surface data to be made which, in turn, can be used to identify localized zones where conventional contact sensors should be used for more detailed (real time?) observations, or to correlate those surface measurements with measurements from subsurface sensors; for example settlement resulting from dewatering.

Recent interest in remote sensing techniques has not gone unnoticed by the geotechnical research community who are now starting to better assess how these technologies can be gauged against widely-accepted standards, such as extensometers and piezometers. Clearly this initiative will require more complex and sophisticated data bases and visualization platforms, and will undoubtedly require interactive 3D representations and animations to visually demonstrate how subsurface and surface measurements are related. Exciting times indeed.

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