# Management, training and education in geotechnical engineering

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ABSTRACT
This paper examines the state-of-the-art associated with the management of geotechnical data and processes; training of geotechnical engineers in the private and public sectors; and attempts to predict the future of geotechnical engineering education. The paper also explores issues related to the awareness of the importance of geotechnical engineering by owners, engineers and the public at large, and how this awareness might be enhanced in the future.

RÉSUMÉ
Ce document examine la situation actuelle liée à la gestion des données et des processus géotechniques; formation des ingénieurs géotechniques dans les secteurs publics privés et; et tentatives de prédire le futur de l'éducation géotechnique de technologie. Le papier explore également des issues liées à la conscience d'importance de la technologie géotechnique par des propriétaires, des ingénieurs et le public dans son ensemble, et comment cette conscience pourrait être augmentée à l'avenir.

Keywords : Management, data bases, training, education, engagement

## 1 INTRODUCTION

Geotechnical engineering is a dynamic, exciting and evolving discipline. In this state-of-the-art paper, the authors have been directed to examine the following geotechnical engineering issues, with the lead author for each particular aspect indicated in parentheses: (i) management of geotechnical data and processes (Ken Ho); (ii) training of geotechnical engineers in the private and public sectors (Marc Woodward); (iii) the future of geotechnical engineering education (Mark Jaksa); and (iv) owner, engineer and public awareness of the importance of geotechnical engineering (all authors). Each of these issues is presented in the order given above.

## 2 MANAGEMENT OF GEOTECHNICAL DATA AND PROCESSES

Considerable advances have been made in recent years in geotechnical practice and risk management, which are knowledge based as well as technology based. Geotechnical practice encompasses investigation, analysis and design, construction and maintenance. Some of the key components of geotechnical processes in practice include data acquisition and data interpretation, use of new tools, materials and advanced technology and expert input, all of which need to be properly managed for enhanced integration of skills, knowledge and technology. In the present context, management refers to the structured coordination of activities with a view to enhancing the geotechnical processes and achieving the desired outcome.

Examples of geotechnical processes range from a risk management system (e.g. a landslide risk management system operated by a control authority), to a specific project or geotechnical operation, such as subway construction using the New Austrian Tunnelling Method, use of instrumented rigs with built-in computer control systems for pile construction or ground improvement works, use of compensation grouting to minimize potential tunnelling-induced damage to vulnerable structures, control of ground movements associated with construction of deep basements, etc.

This part of the paper deals with the management of geotechnical data and application of improved knowledge and advanced technology to enhance the management of geotechnical processes.

### 2.1 *Data, knowledge, technology and risk management*

All geotechnical processes are invariably fraught with uncertainties and risks. Judicious management of the available geotechnical data and the associated geotechnical processes constitutes a key part of risk management, as well as asset management. Data management encompasses the consideration of data collection, storage, processing, interpretation, presentation, dissemination, etc. The management of geotechnical processes involves a holistic consideration of selection and installation of suitable instruments for data collection, judicious data processing and interpretation, risk analysis and implementation of the necessary corrective actions. The availability of improved data provides a basis for enhancing knowledge and advancing understanding. For example, monitoring has contributed to insights into the dynamics of landslide initiation and movement (Reid et al. 2008).

Adequate and good quality ground investigation data for the construction of representative geological and hydrogeological models and the characterization of relevant engineering properties constitute an important starting point for hazard identification under the context of risk management. Timely acquisition and feedback of actual performance data during construction form an essential part of the observational approach as advocated by Peck (1969), which is an integral element of the geotechnical risk management process. This is vital for construction control and verification of design assumptions, and provides a basis for optimizing the design in the face of uncertainties.

Post-construction monitoring of geotechnical structures also plays a key role from an asset management point of view. Such ‘health monitoring’ provides important data on the actual

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performance of geotechnical structures during their service lives. This allows a review of the applicability of the design assumptions and a better understanding of the limits of predictions.

In addition to the above, insights from studies of geotechnical failures (e.g. Duncan 1988, Ho & Pappin 2007) provide another important source of reference for identifying key lessons to be learnt as well as areas that warrant improvement.

Recent advances in geotechnology have included improvement in instrumentation sensors, construction tools, data acquisition and transmission systems, engineering analyses, quantified risk assessment, etc. The advances have come about as a result of improved access to good quality data, together with an improved understanding of the geotechnical processes, particularly our insights in respect of failure mechanisms. In addition, improvements in digital technology, information technology, space technology, together with application of material science in the development and use of new engineering materials, have all played a key role in enhancing the geotechnical practice (Ho 2004).

The successful implementation and management of a geotechnical process hinges on the availability of good quality data, a proper understanding of the potential hazards and failure mechanisms, together with the appropriate application of the state-of-the-art technology. Improved data, advancing technology and enhanced knowledge combine to constitute the prime assets of the geotechnical community.

### 2.2 *Data acquisition*

The first step in any engineering assessment consists of collecting all the available information. One important source of data is via monitoring by means of geotechnical instruments. Monitoring may have the following objectives:

(a) to improve the understanding of the actual behaviour for research and technical development purposes (e.g. to enhance design procedures and construction control);
(b) to verify design assumptions and assess the need for refinement of design and construction procedures (e.g. to allow back analysis of operational parameters and the implementation of corrective measures);
(c) to assist in construction quality control (e.g. to improve construction management);
(d) to provide input to the implementation of a public warning system (e.g. to enhance risk management and public safety); and
(e) to support long-term health monitoring of geotechnical structures during their service lives (e.g. for asset management purposes).

Proven monitoring techniques, with continuous measurement and data logging capabilities, are now becoming available at more affordable costs. Instrumentation tools and sensors that are sufficiently robust and give accurate results with little drift are essential for timely data collection. A range of off-the-shelf hardware and software systems are now available for system integration on a tailor-made basis.

A reliable power supply (e.g. use of AC power for urban sites or air-alkaline batteries or solar panels for remote sites) is essential for data acquisition systems.

Recent developments in electronic instrumentation and telecommunication have made it possible to undertake continuous monitoring remotely, by means of dataloggers and telemetry, in a reliable manner. Continuous and real-time monitoring is becoming more commonplace in many places, particularly for critical structures (e.g. dams) or where public safety is at stake (Olalla 2004, Froese et al. 2005, Flantje et al. 2005, Chang et al. 2008). In the operation of an early warning system, data reliability and redundancy are some of the key considerations.

Automated monitoring system based on a wireless network generally comprises the following components:

(a) instrumentation sensors;
(b) data acquisition system and wireless network (to sample and control the sensors);
(c) data transmission system (to relay data from the field to base stations or the internet directly); and
(d) data management system (software for data analysis and visualisation).

Considerable advances have been made in respect of various instrumentation devices and sensors, such as fibre optic technology, smart sensors, MEMS technology, time domain reflectometry, multi-antenna differential GPS, etc. Reference should be made to the State-of-the-Art Paper No. 3 by Negro et al. (2009) for details of the recent advances in geotechnical instrumentation.

### 2.3 *Data processing and verification of data quality*

The vast amount of data needs to be processed, typically by means of fairly complicated data processing and numerical algorithms. Quality assurance procedures for regularly checking the overall functionality of the system, including sensor operation, are of paramount importance. It is of the essence to build in regular manual field inspections and automated internal system diagnostic checks (e.g. consistency checks), or cross-checking using other systems, in order to detect and prevent inconsistent and anomalous information, and verify data accuracy. The compilation of GIS datasets should preferably be done in accordance with the GIS geo-referenced data standards and metadata should be provided as a standard good practice to enhance quality control and inform the users regarding the source and quality of the data.

It is important to bear in mind that the information should be homogeneous in the sense that data of different scales and resolution must not be combined together. Considerable care and sound judgement are called for in the selection of sufficiently reliable data from what may be available, the quality of which can be highly variable. The reliability and accuracy of the data should continue to be critically reviewed from time to time as more information becomes available.

An important consideration is the type of information to be provided to the users or decision-makers. Dataloggers may collect a vast amount of readings but these are useless unless and until they have been properly processed and presented in an appropriate and user-friendly manner that is easy to understand. Also, some judicious extrapolation of the data based on an assumed model is often needed in order to predict the likely behaviour using a suitable model. This calls for input from suitable experts and the exercising of sound engineering judgement.

### 2.4 *Data transmission*

The monitoring data may be "pushed" from site, "broadcast" from site or "pulled" from a central (or base) station. Such considerations will have a bearing on the selection of the most appropriate means of data transmission.

Data transmission may be done either via cabled connections or wireless connections. Cabled connections include land-line transmission, dial-up connection, together with ADSL (asynchronous digital subscriber line) and DSL (digital subscriber line) connections. Data transmission using cables is prone to lightning strikes and damage from other factors such as human activities, roaming animals and fires. Suitable protection is warranted to preserve data integrity and prevent data loss (Chang et al. 2008).

Strout et al. (2008) reviewed the range of telemetry solutions involving wireless transmission. Mobile telephone technology supports reliable data telemetry from remote sites where mobile telephone coverage is available. The mobile communication services may include GSM, GPRS, EDGE, CDMA, 3G and HSDPA. Modems provide communication for a serial device that provides a digital signal. Alternatively, radio modems can be used but these would require a line-of-sight connection and are not practical for more than short- to medium-length transmissions of data between two fixed points up to a few hundred metres apart.

A number of wireless protocols are now available which allow networking. The instrumentation network may involve the use of Bluetooth and WiFi (both being radio solutions), or 'self-organizing' wireless networking protocols for digital communication to enhance system reliability. For example, under a self-organizing wireless network each node (i.e. the wireless dataloggers and the base station) acts as a receiver or a transmitter and can communicate directly with any other nodes (Solomon et al. 2008). In this set-up, each node will only communicate with the nearest neighbouring nodes. Data received by a node that is intended for another node will be forwarded to a neighbouring node closer to the intended destination, until that destination is reached. Self-organizing wireless networks of this type are very robust, because when a node is taken out of service, the data will automatically find a different route. Also, as the data will hop from node to node, it is not necessary to have a direct line-of-sight connection between each datalogger location and the base station, as is the case in many conventional wireless data acquisition systems.

Being generally of limited range, self-organizing systems are typically more appropriate for connecting different pieces of equipment on the same site, rather than connecting a remote site to a central server.

Other possible data telemetry solutions include satellite transmission and use of meteor vaporization trails as a reflector for radio waves. For wireless underground sensors such as those used in boreholes, the use of low frequency electromagnetic waves for data transmission is a possibility (Strout et al. 2008).

### 2.5 *Data management*

A well-planned and well-defined data management strategy is critical in ensuring long-term data integrity. The data management system is to collect, store, analyse and display the data. A typical 3-tier application architecture comprises data tier, application tier (logic and processing) and presentation tier. Normally, a database system is used to process and archive the data, based on which graphs and tables can be created. The system should have the capability of performing validation checks on the monitoring data to examine if there are any data inconsistencies.

An appropriate user interface of the data management system is of critical importance, as this will form the main access portal through which the data are to be retrieved. The database server can be designed to facilitate internet accessibility and combine platforms that are compatible with Geographic Information System (GIS) in order to allow the data to be presented and viewed in text and graphical form and reports to be generated. The data can be accessed through dedicated homepages and exported in a variety of formats, such as Excel tables or PDF reports. The web server may be configured to provide two user interfaces, say, one for a conventional desktop computer, and one with limited functionality and small page size, intended for a PDA or smart phone with internet browsing capability. Part of the data management system includes an FTP server for storage and downloading of the generated reports.

The primary control mechanism for the collection, storage and transmission of field monitoring data is achieved with the use of dataloggers that are connected to a cluster of instruments in accordance with the technical specifications. In practice, the use of multi-user database solutions combined with dedicated software or on-demand webpage based graphical user interfaces has greatly enhanced data flow and availability (Strout et al. 2008).

Software options include commercially available software packages (e.g. based on Open Process Control (OPC) protocols that can handle real-time data flow and proceedings), or custom-written base station software controlled by automated batch processing (Reid et al. 2008). The key is to ensure that the data management system is user-friendly and able to meet end-users' needs.

Various geotechnical organizations, such as the Geotechnical Engineering Office of the Hong Kong Government, have built up their own information infrastructure as a hub of geotechnical information and applications, to serve as the essential backbone for the management of their geotechnical processes, operations and businesses, as well as for the dissemination of geotechnical data and information to different users. In addition to compiling core datasets for data management and data dissemination, the current trend is to incorporate specific GIS functionalities and geotechnical application modules (with web-based applications). Other examples of comprehensive GIS-based geotechnical information systems include the slope management system in Malaysia (Mahmud 2004), the Geotechnical Database Management System and Geotechnical Information System in Singapore (Dasari & Tang 2004), the National GIS Program in Taiwan (Hwang 2004), the Geotechnical Information System in Korea (Sun et al. 2004), etc. Case histories of application of geo-informatics are given in a report prepared by the Asian Regional Technical Committee No. 10 (2004).

### 2.6 *Data dissemination*

The availability and accessibility of the data to the end users is a critical component. The commonly adopted approach is to use a database for organizing the data and a graphical user interface for presentation in dedicated systems. The use of a database in conjunction with an internet web page allows the delivery and dissemination of data in accordance with specific requests, or as the information becomes updated with time. Such database-to-web solutions are compatible with the improved graphical user interfaces. The 'middle-ware' for managing data access and dynamic web page generation may range from a custom-designed solution for a specific application, to the use of a commercial software system.

Through the internet, databases can effectively be linked, thus making very large quantities of information available to the users. Suitably developed computational processes are needed to locate the relevant data for a particular situation, to categorize the data quality, and to interpret them (Simpson & Tatsuoka 2008).

There has been an increasing drive to make geotechnical and geoscientific data more accessible to the wider geotechnical community. For example, the aim of the OneGeology project, which is supported by UNESCO amongst others under which more than 80 countries have signed up as of end of 2008, is to provide internet access to the available geological map data worldwide. This will accelerate the interoperability of geoscience data and sharing of knowledge and expertise in the delivery and dissemination of digital geological maps. The target is to introduce a Web Feature Service interface standard, which will enable more detailed interrogation of the digital geological maps.

### 2.7 *Standardisation of geotechnical data*

In recent years, much effort has been made in striving to achieve consistency and compatibility amongst the different geo-engineering data schemata and data structures, particularly for the 'high level' attributes (Toll 2007a). These cover ground investigation data, laboratory and insitu test data as well as data on geotechnical assets (e.g. foundations, retaining structures, slopes, etc.). There has also been an enormous movement around the world to adopt GIS technology for geoscience data management and dissemination. Coupled with this is an international collaborative effort to establish global standards for the storage, dissemination and exchange of internationally standardized geoscience data and information.

At present, different schemata such as AGSML, GeotechML, DIGGSML, eEARTH, SlopesML, etc. have been proposed by different organizations. As yet, there is some divergence in relation to the definitions of certain data and terms, the use of different forms of languages, as well as the means adopted in defining some of the entities and nomenclature, etc.

The initiatives on standardization of geotechnical data format are overseen by the Joint Technical Committee 2 (JTC2) of the ISSMGE, IAEG and ISRM, which is entitled 'Representation of Geo-Engineering Data in Electronic Form'. The objective of JTC2 is to come up with an internationally agreed form of representation of geo-engineering data in order to facilitate data interchange and transfer amongst various organizations and different computer systems. This will allow the electronic data to be made available on the internet for improved data accessibility and in the form of sustainable data records for future use by practitioners and researchers. Apart from improving the data handling procedures as well as data storage, the common file formats for geo-engineering data are also intended for importing or exporting data to and from other software, such as databases, GIS, analysis packages, etc. (Toll 2007b). The ongoing development of Geography Markup Language (GML) (www.opengis.net/gml/) and Geoscience Markup Language (GeoSciML) (www.opengis.net/GeoSciML/) is expected to provide the underpinning for such a reference scheme.

Sufficient flexibility needs to be built in to represent the data at various levels of detail in order to best suit the needs of a wide range of end-users. Toll (2007a) advocated the use of extensible markup language (XML), which will become the main form of data representation on the World Wide Web. XML allows simple text files to be marked up by including tags in the files, which can be recognized by an XML compliant web browser. One advantage of XML is that the data (stored in an .xml file) is separated from the formatting information, which is provided by means of a stylesheet (.xsl) file. As a result, the data can be formatted in different ways for presentation without the need to change the data file. In essence, the use of XML tags to search for files on the internet will make web-based searching much more efficient and focused as compared to the currently available keyword searching options.

A Java program can be used to display graphically the contents of the XML file in order to produce borehole logs, cross sections and data plots. For example, DIGGS (Data Interchange for Geotechnical and Geoenvironmental Specialists), which was first released in 2006, is a proposed international standard interchange format for geotechnical and geoenvironmental data that incorporates an XML schema and the associated data dictionaries (DIGGS 2006). These data are GML (geography markup language) compliant and can cover, for example, piling data as well as data on any linear construction features. DIGGS has the backing of major US and UK organizations, including the Association of Geotechnical and Geoenvironmental Specialists (AGS). The use of GML allows DIGGS data to be processed by GIS, as well as to be served and displayed over the internet using web services.

As far as geotechnical monitoring data are concerned, a separate standard format needs to be developed. For example, the current AGS format, which was primarily designed for ground investigation data, is not particularly suited to instrumentation and monitoring data. In view of this, the AGS has launched the AGS-M format for electronic transfer of monitoring data. This was promoted as an add-on module to the AGS format, which may be used either on its own or in conjunction with the AGS format.

The current lack of a standard data transfer format and unified definition of geo-engineering data will hamper the sharing of data. The potential disadvantages of a new standard format include unfamiliarity with the new look of the format, possible need for larger files, modification or upgrading necessitated by some existing software systems, etc. To date, some progress has been made in moving towards a common file format as a result of the various initiatives as highlighted above, but consensus is yet to be achieved. Also, issues regarding promoting enhanced awareness of the potential benefits including time and cost savings and enhanced integration of data in standardized electronic format into the geotechnical practice are pertinent.

### 2.8 *Use of advanced technology in data acquisition and geotechnical applications*

As a result of significant advances made in recent years, information technology and digital technology have become more readily accessible, with improved capability for geotechnical applications at reduced costs. This has led to enhancement in data capture and data analysis, hence resulting in improved efficiency in the management of geotechnical processes. Some examples in relation to landslide risk management are outlined below with a view to illustrating the advances made in practice.

#### 2.8.1 *Application of Digital Photogrammetry*

Conventional aerial photograph interpretation (API) using stereoscope and stereo-plotter is increasingly being replaced by digital photogrammetry in geotechnical practice. The advantages of digital photogrammetry include improved efficiency, enhanced resolution and extended analytical capability. As a result of recent developments including the use of airborne Global Positioning System (GPS), inertia navigation systems and automated techniques provided by modern software packages, digital photogrammetry can be applied at more affordable costs.

Digital photogrammetry involves digitizing a pair of aerial photographs with the use of a high-precision and high-resolution scanner, processing the digitized data together with the available control points by means of digital photogrammetry algorithms, and displaying the stereo-images and processed data on a computer monitor. Standard off-the-shelf hardware and software packages are available for digital photogrammetry analysis and presentation of the results. Upon setting up, the system is neither costly nor difficult to operate, especially for personnel with API experience.

Apart from aerial-based digital photogrammetry, terrestrial-based digital photogrammetry is also gaining acceptance by the profession as an efficient means for, say, producing a digital elevation model (DEM) and capturing geological structures of rock slopes. Related GIS datasets that can be derived from the DEM include shaded relief maps, slope gradients maps, etc.

Digital photogrammetry has a number of practical applications to geotechnical work, which include the following:

- <u>Stereo visualisation and API</u>: With the ability to display 3-dimensional stereo images on a computer monitor, stereo views of the present as well as past conditions of a site can be generated by means of the available aerial photographs for stereo visualization. It is feasible for API to be done and evaluated collectively by a team, which can greatly facilitate communication and discussions. Good resolution can be achieved, e.g. up to about 0.1 m for vertical aerial photographs taken at about 1.2 km (4,000 feet).
- <u>Surveying and measurement</u>: Comprehensive data on topography and feature dimensions can be obtained from a pair of aerial photographs through digital photogrammetry, without the need for detailed and labour-intensive land surveying work. A spatial accuracy of 0.5 m to 1 m can be achieved, which can be further improved with low-flight

photographs and additional ground control points. Thus, it provides an efficient and inexpensive means of remote surveying and measurement. This is particularly useful for geotechnical work that covers a large area, e.g. assessment of natural terrain landslide hazards, and for circumstances where field measurement is hazardous (e.g. new landslide scars), or not credible (e.g. in areas with access problems).

- Movement monitoring: Subtracting DEMs from different epochs is a useful tool to quantify landform changes. However, quantitative use of DEMs may be limited by their accuracy whereby measurements of vertical displacements are subject to larger errors than that of horizontal displacements. Movement monitoring would normally require a higher degree of accuracy than that commonly required for visualization and measurement purposes. Hence, digital photogrammetry using conventional aerial photographs tend to have limited use in movement monitoring, unless where the movement to be measured is large. Use of low-flight aerial photographs or terrestrial photogrammetry can, however, give better accuracy (e.g. Hansen & Lichti 2002) and there is scope for further technological development in this area.
- Digital terrain model: The results of digital photogrammetry can be used to compile a DEM that has important 3-dimensional GIS and virtual reality applications. This can provide accurate DEM data and is particularly useful where the DEM of the past site condition is required. In generating a DEM by means of digital photogrammetry, care should be taken to map the ground surface in areas where dense vegetation is present, as otherwise the terrain model for vegetated terrain would not be sufficiently accurate to support the subsequent geotechnical analysis, e.g. assessment of landslide debris runout paths and 3-D debris mobility modelling (Kwan et al. 2008).
- Production of ortho-rectified images and 3-dimensional ground models: Conventional aerial photographs can be converted into ortho-rectified images by means of digital photogrammetry (with resolution up to about 0.2 m). Such images are true to scale and position accurate, and hence they can supplement survey plans. For example, ortho-rectified images contain rich visual details of the ground and they are suited for use in field reconnaissance and field mapping (Figure 1). As ortho-rectified images are in digital and geo-referenced format, they can be integrated into a GIS, together with other digital data, for a range of GIS and remote sensing applications such as geotechnical field mapping, GIS data mining, feature recognition and extraction, change detection and monitoring, and visualization through virtual reality. Sequential images can be combined in animations to provide a clear visualization of the progressive change of the ground surface. 'Fly-through' animations, created by draping an orthophoto over a DEM, can also provide realistic impressions of the geomorphology of a site.
- Rock slope mapping and rock joint survey: Digital photogrammetry can be used in conjunction with image processing analysis and artificial neural network algorithm to map the discontinuities in rock exposures. Automated digital discontinuity mapping systems, which are efficient and can overcome access problems, are available in the market. However, the resolution of the raw and interpreted data needs to be reviewed carefully and verified in the field.

### 2.8.2 *Improved remote sensing technology*

Van Westen (2007) summarized the use of remote sensing imagery in creating landslide inventories and noted that medium-resolution satellite imagery such as LANDSAT, SPOT, ASTER, etc. are increasingly being used to create land-use maps and landslide inventories. SRTM can resolve features up to 30 m in size and have been used to assess areas of global landslide susceptibility. In practice, however, the limited resolution of the associated DEM and a lack of information on subsurface conditions can severely constrain the application of such remote sensing information, which should be used with caution.

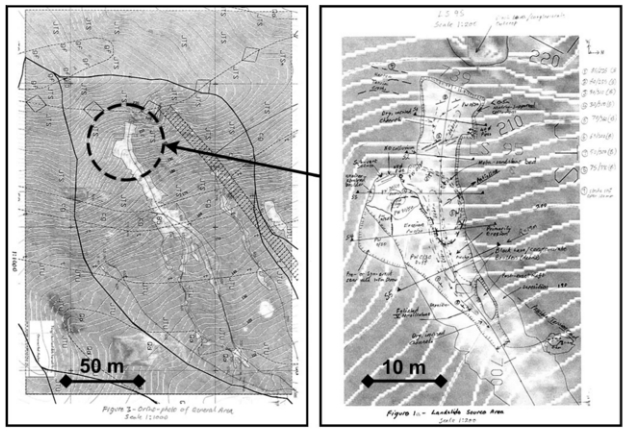


Figure 1. GIS-based ortho-images of a landslide with digital contour overlay used as base plan for mobile field mapping.

High-resolution satellite imagery (e.g. IKONOS, Quickbird, etc.) has proved to be more useful for the interpretation of landslide morphology as well as for landslide emergency preparedness and emergency response. High-resolution imagery, together with 3D capabilities and zooming functionalities, is available in Google Earth. The latter also has the facility for drawing polygons on an image, which can greatly facilitate interpretation and field mapping of landslides. In addition, the information can be transported into GIS for storage and further manipulation.

In recent years, much use has been made of the Light Detection and Ranging (LiDAR) technique and the Interferometric Synthetic Aperture Radar (InSAR) technique for data acquisition over a large area, e.g. for mapping of natural terrain and slope monitoring. These are descried further in the following sections. For a discussion of the potential use of other technology such as airborne multi-spectral imagery technique and application of image textural analysis in the detection of landslides through the use of filters to enhance areas of image roughness, reference may be made to Whitworth et al. (2005) and Mason et al. (1998).

### 2.8.3 *LiDAR*

LiDAR is a promising remote sensing technology for scanning the surface topography by measuring the direction and time of sending and receiving laser beams to the objects of interest. The strengths and weaknesses of LiDAR mapping are discussed in detail by Schulz (2007).

Land-based LiDAR system (sometimes referred to as a laser scanner) has the capability of measuring three-dimensional point clouds of objects within about 300 m along the line of sight. The laser scanner emits thousands of laser beam pulses per second for measuring a window of three-dimensional surfaces. The positional accuracy is within 6 mm in a 50 m range. Apart from providing spatial information on their x, y and z coordinates, the point clouds contain an intensity signal of the laser reflection, which presents a three-dimensional digital model of the scanned object.

Laser scanners are increasingly used in the following geotechnical applications:

(a) Topographic surveys – this is of particular use where physical access to the survey site is difficult or dangerous (e.g. new landslide scars).
(b) Construction of high resolution DEM – given the high sampling density, DEM produced by LIDAR can enhance

the quality and supplement the DEM produced from topographic maps or via digital photogrammetry.

(c) Compilation of three-dimensional digital models of geotechnical assets – this functionality assists construction monitoring and provides an accurate and detailed virtual reality record for use in future maintenance and modifications.

(d) Movement monitoring of geotechnical assets – movement can be detected by comparing the LIDAR results obtained at different times.

(e) Rock slope mapping and rock joint survey – this can be done by judicious analysis of the LIDAR point clouds. Examples of such applications are described by Martin et al. (2007) and Sturznegger et al. (2007). Rosser et al. (2005) presented the use of land-based LiDAR for direct monitoring of coastal cliff erosion and degradation. Hutchinson et al. (2008) evaluated the performance of three different LiDAR systems for rock joint mapping for a site in Ontario. In this instance, it was established that the resolution and quality of the surveys depended on the type of equipment used, the distance from the object and the type of software used to process the data. As compared with conventional geomechanics face mapping, Hutchinson et al. (op cit) reported some differences in the data scatter and in the orientations of the discontinuities as interpreted using the above data by the algorithms.

Airborne LiDAR, which can survey a large area efficiently at competitive cost, has shown great promise for application in geotechnical practice. The survey is performed by mounting a high-powered LiDAR at the bottom or sides of a plane (or helicopter) to scar the ground features along the flight path. The instrument is bundled with accurate on-board differential GPS (DGPS) to register the flight position during the LiDAR survey. A noteworthy development in recent years is the multi-return LiDAR system, which can be used in conjunction with an advanced data processing algorithm to extract the ground profile and produce a bare-earth DEM in vegetated terrain (Figure 2). This is done by filtering away the vegetation using a process known as 'virtual deforestation' (e.g. Haugerud & Harding 2001, Ng & Chiu 2008), highlighting the underlying morphological features that would otherwise be concealed by the vegetation and not observable by means of conventional aerial photograph interpretation or field mapping.

The above capability of mapping the ground surface of vegetated natural hillsides has been used to produce fine-scale topographic maps and DEM, typically with a grid size of about 1 m. This allows the landslide geomorphology (e.g. degraded relict landslide depressions) to be mapped and interpreted (see Figure 1a). Landslide inventory maps and hazard maps can be produced to a resolution that cannot otherwise be achieved using conventional aerial photographs. The capacity to view LiDAR data as contours of differing (self-specified) intervals also enables a more refined interpretation of terrain morphology, which further aids the identification of breaks in slope.

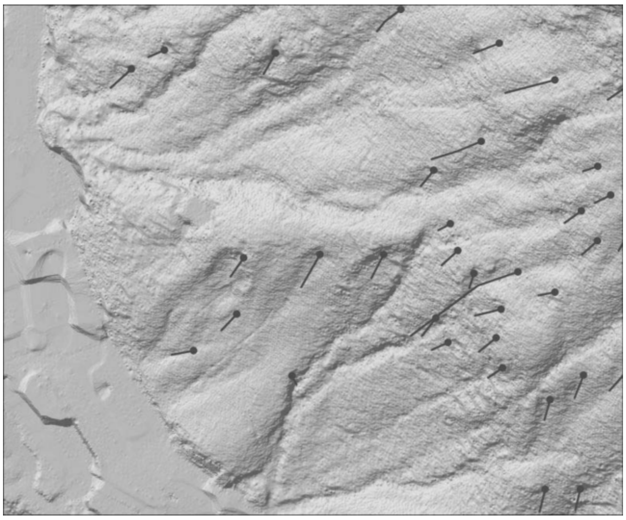

Figure 2. DEM generated using LiDAR data overlain with ENTLI records.

In general, some caution is warranted when using LiDAR data, as the precise accuracy of the entire dataset that contains a vast amount of data cannot be critically evaluated easily and sufficient validation and calibration are called for. Also, it is possible that different LiDAR systems (with different data pre- and post-processing algorithms which are complex and not standardized) could give rise to data of different resolution.

2.8.4 *INSAR*

InSAR, or differential InSAR, is an emerging remote sensing technology that is able to measure ground displacements with millimeter level accuracy. Each pixel of a Synthetic Aperture Radar (SAR) image contains information on the phase of the signal backscattered from the terrain surface. By applying interferometry to a pair of SAR images of an area, the geometry of the two slightly displaced, coherent observations of the surface will give their phase difference, which is a function of the surface height. Through repeated observations, it is possible to measure the surface displacement where ground movement has occurred. It is a potentially promising low-cost, high-accuracy remote sensing technology for geotechnical application, particularly for slope and ground movement detection in sites with a significant areal extent. The system is capable of operating under all weather conditions, such as night time, fog, rain, etc. The general limitations of InSAR are associated with the availability and resolution of SAR images, potential distortions due to a steeply inclined terrain, loss of coherence due to presence of vegetation, ground moisture and atmospheric effects, etc.

Successful applications of InSAR have been reported for the monitoring of movement of extensive flat ground (such as reclamations), and of complex slow-moving landslides (e.g. Froese et al. 2005). Success was also reported by Tarchi et al. (2002) and Noferini et al. (2008) in using ground-based InSAR to monitor slow-moving landslides.

The application of the Permanent Scatter (PS InSAR) technique in airborne and land-based InSAR, together with the use of suitable filters and corner reflectors, is capable of reducing the noise effects and enhancing the accuracy and spatial resolution of InSAR results. With such applications, both the view direction and the frequency of the radar images can be controlled. Falorni et al. (2008) described the use of an Advanced PS Analysis (APSA) for monitoring the displacement of a slow-moving landslide in Italy to verify the effectiveness of landslide stabilization works. The above suggest that PS InSAR is suitable for regional-scale and local-scale engineering geological investigation of ground instability. However, the interpretation of the exact significance of small, radar-sensed ground surface deformation on a steep terrain, especially in heavily vegetated terrain, is posing a significant challenge to the geotechnical profession.

Trials of InSAR technique with the use of radar data acquired by the Envisat satellite for monitoring of slopes subjected to tropical weathering have shown that the available satellite SAR images are not suitable for a densely developed urban setting with steep terrain, such as in Hong Kong (Ding et al. 2004). The limitations are thought to be due to geometry distortions associated with the steep terrain and a relatively humid environment and presence of thick vegetation that tends to accentuate noise due to atmospheric and temporal decoration effects (Wong 2001). The results were slightly improved with the use of corner reflectors and based on the application of the CR-InSAR technique or interferometric point target analysis. Radar satellites equipped with systems to acquire higher resolution SAR images than those acquitted by Envisat have recently been launched by Italy, Japan and Germany. However, it should be noted that most of these are deployed with short wavelength radar system (e.g. X-band), and hence are not suitable for penetrating foliage.

Recent developments of airborne InSAR system have shown great potential in terrain mapping and slope monitoring. In particular, some systems are able to acquire data using dual wavelengths, e.g. short wavelength (X-band) and long wavelength (P-band). The latter bandwidth allows the penetration of foliage and can reveal subtle ground features. The corresponding resolution of the DEM generated is in the order of 3 m to 5 m.

Advances in ground-based InSAR have improved the precision for monitoring ground features (e.g. mountainous terrain or rock slopes), without the need to install reflectors. Some systems have reported results with an accuracy of better than 0.1 mm. Harris & Roberts (2007) described the use of differential interferometry with a real-aperture radar on a stationary platform, referred to as a Slope Stability Radar (SSR), located about 50 m to 100 m away to monitor a rock slope. In the case of ground-based InSAR, the type of radar may comprise the use of a single antenna, one antenna array or sliding antenna, two antenna arrays, a rotating array (which may determine the 3-dimensional positions of the monitoring points), etc.

A realistic appreciation of the current limitations of the InSAR technique and an awareness of the areas for improvement are of the essence for successful practical applications. The potential application of InSAR to landslide mapping and slope monitoring requires careful consideration on a case-by-case basis in determining the suitability of this technique to a particular set of site conditions. Whilst the available resolution of the SAR sensors and the number of satellites have in the past been a limitation, the launching of new, high resolution satellites provides an opportunity to overcome some of these limitations. In particular, the emergence of systems that acquire both short and long wavelengths appears promising. Further work is needed to evaluate the use of such systems in monitoring the movement of vegetated terrain.

2.8.5 *Image processing and pattern recognition techniques*

Image analysis has been used in conjunction with digital face mapping using photogrammetry to characterize the rock mass and map the discontinuities (Lemy & Hadjigeorgiou 2004). A semi-automated method is developed which incorporates a detection algorithm that involves the use of artificial neural network.

Image processing and pattern recognition analyses have been applied to map boulders perched on natural hillsides (Shi et al. 2004). By integrating digital photogrammetry, image enhancement and image analysis techniques, together with a technique known as 'human-machine interaction', the data can be used to compile statistics on boulder sizes, shapes and heights, which are some of the essential input parameters for assessing boulder fall hazards. An example of such application in the mapping of boulders on natural hillsides is depicted in Figure 3.

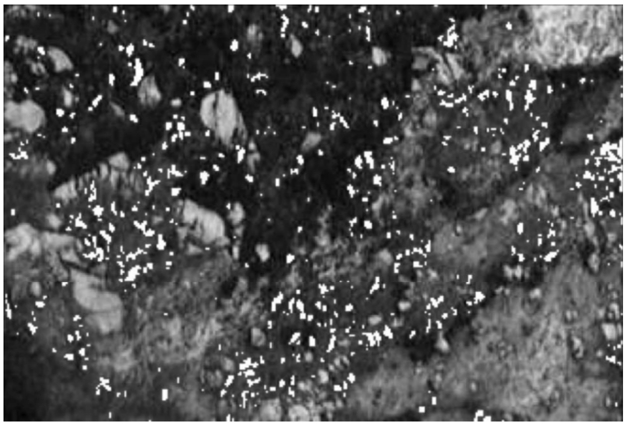

Figure 3. Boulders (white specks) extracted by image processing techniques.

2.8.6 *Applications of GIS in geotechnical practice*

By their nature, most geotechnical data contain spatial attributes on their geographic locations (x, y and z), together with the geometry of the ground/object (e.g. point, line or polygon) represented by the data. Managing the data in GIS would register the spatial attributes and permit the use of the attributes in GIS-related applications, with improved capability and efficiency. There has been a growing recognition of the importance of the use of spatial data that support spatial analyses (or spatial-temporal analyses). As a result, GIS tools are increasingly used by the geotechnical profession in recent years.

Practical GIS applications require the compilation of appropriate GIS datasets of the required quality, deployment of GIS systems, together with development of GIS capability. In the past, GIS was used primarily for data management and information services, with basic GIS search and browsing functionalities provided to users, without the need for a GIS software to interact with the systems. Notable developments of GIS systems and GIS capability have been made in recent years. As a result, more advanced GIS analyses (e.g. landslide susceptibility analysis, rainfall-landslide correlation, etc.) and GIS modelling (e.g. modelling of runout of landslide debris or boulder trajectories, quantitative landslide risk assessment) and being undertaken very efficiently on a GIS platform.

There have also been developments in 3D modelling and visualization of digital data and virtual reality functionality by combining the DEM and other elevation data with ortho-rectified images. These are useful in direct visualization of the landform, together with identification of geotechnical features, such as past landslides (Figure 4). Virtual reality animations and computer fly-through can also be produced for presentation and evaluation purposes (see Figure 4). An example of such application is the GSI3D software developed by the British Geological Survey, which is used to produce systematic 3D geological models. The GSI3D software is programmed in JAVA and can be run on any standard operating systems. Its file import and export formats are open and extensible and the main model file is written in Extensible Markup Language (XML). The software is directly compatible with GIS systems and other 3D packages. The models are suitable for interrogation using GIS-based analytical tools to produce thematic and bespoke outputs.

As a result of continued improvement in information technology, the latest GIS systems can provide better data management functionality (e.g. direct support of LiDAR data format, improved Structured Query Language (SQL), etc.), improved rule-based symbololgy for cartography, and tight integration with Microsoft .NET technology, which facilitates development of web-based applications.

The trend in recent years has been to adopt more advanced GIS functionalities to address geotechnical problems. Some examples of such advanced GIS applications in geotechnical practice are given in the following.

(a) Advanced GIS search, browsing, editing and publication: Functions involving advanced GIS data search, browsing, editing and publication can be performed by skilled GIS personnel via the use of GIS tools, for example, in a geotechnical desk study to examine the available geotechnical data and assimilate key data for presentation.

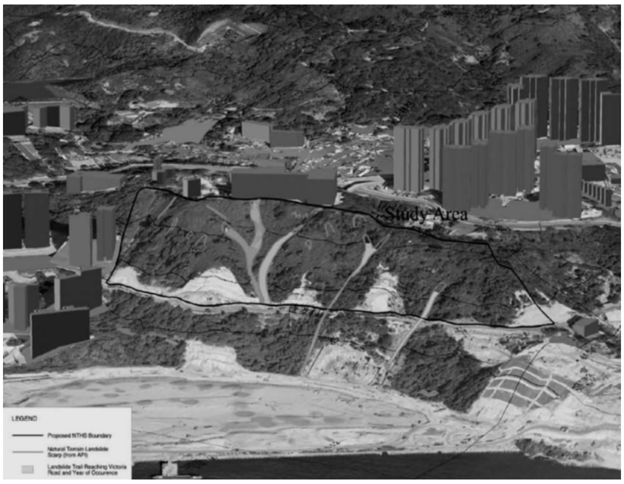


Figure 4. 3-dimensional visualisation of historical landslides.

An advanced GIS search would enable users to undertake suitable spatial queries and retrieve data that meet certain prescribed criteria or geographic relationships. Data manipulation and assemblage can be carried out using appropriate GIS software, both for presentation and analysis purposes. For example, recent landslides and new building and infrastructure developments can be identified from overlays to ortho-rectified images of different vintages (Figure 5).

(b) GIS analysis: GIS analysis can be performed efficiently to examine the spatial relationship and correlation amongst different spatial data (e.g. landslide susceptibility analysis), which are otherwise very cumbersome to analyse using conventional means. Spatial analysis using GIS has also proved to be very useful in geotechnical and geo-environmental research and development work. Many of the landslide susceptibility analyses are now routinely undertaken on a GIS platform (Chacon et al. 2006; van Westen 2007). There is a tendency to incorporate increasingly complex statistical methods in such landslide susceptibility analyses. In practice, spatial validation is essential for practical application in order to test the applicability of the empirical relationships against actual data.

Another example of the value of GIS analysis in geotechnical practice is the use of GIS-based geostatistics on a GIS platform to establish the correlation between natural terrain landslide density and rainfall intensity (Ko 2003), see Figure 6.


Figure 5. NTLI records overlaid to ortho-rectified images in 1963 (upper) and in 2000 (lower).

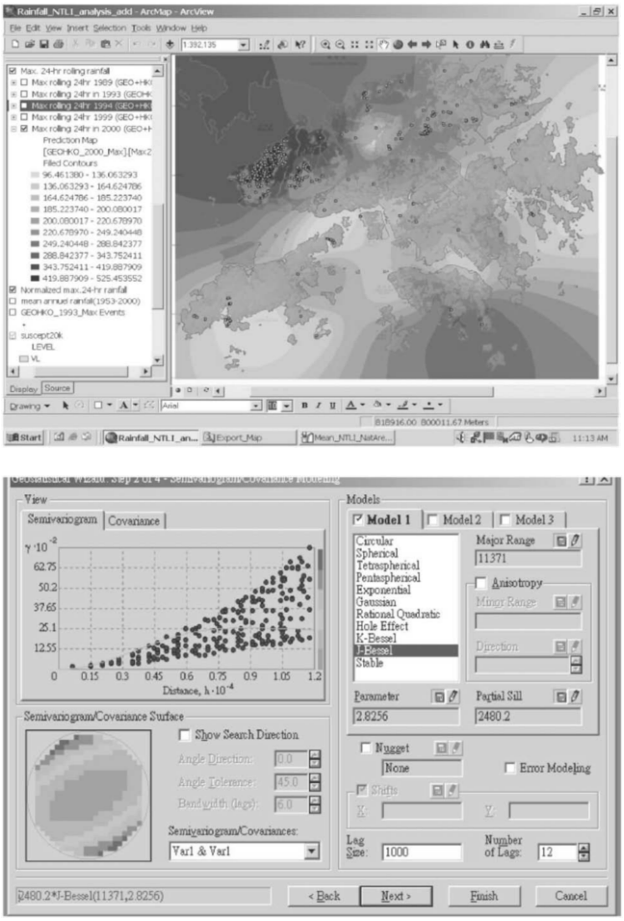


Figure 6. GIS analysis of natural terrain landslide-rainfall correlation: (upper) year 2000 maximum rolling 24-hr rainfall and natural terrain landslide locations; (lower) GIS-based geostatistical analysis.

(c) GIS modelling: The potential of GIS-based geotechnical analysis and numerical modelling based on application of engineering principles and governing physical laws has been exploited in recent years. Such applications integrate engineering analysis with GIS, thereby providing a powerful modelling tool, particularly for cases involving the analysis of the geographic and engineering attributes of a large amount of spatial data. The development of GIS modelling applications requires GIS programming input from skilled personnel. Examples of such geotechnical applications include the 3-D modelling of the runout of landslide debris as shown in Figure 7 (Wong 2004), quantitative risk assessment of natural terrain landslides (Wong 2007) as shown in Figure 8, compilation of boulder

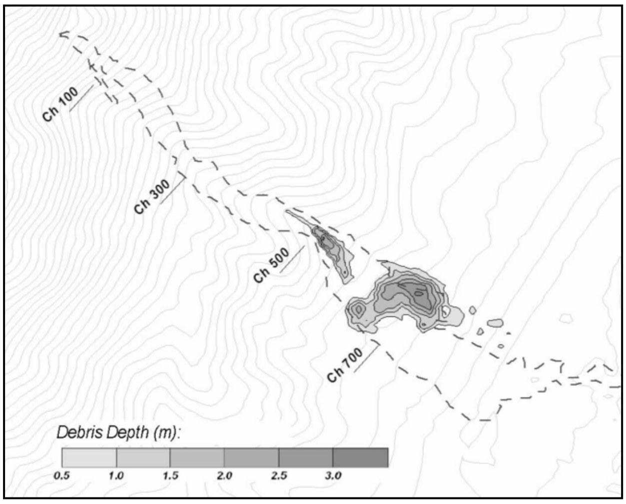


Figure 7. 3-dimensional landslide debris runout modelling.


Figure 8. GIS-based landslide quantitative risk assessment.

fall hazard map based on modelling of boulder fall trajectory (Morgenstern & Martin 2008), etc.

Morgenstern & Martin (op cit) opined that the developments in 3-dimensional GIS are currently not sufficient in meeting the needs of the geotechnical profession and they highlighted the need to make GIS geotechnically ‘smarter’ for the purposes of applying GIS in geotechnical modelling and analyses. These authors demonstrated how the integration of GIS analysis software and geological modelling, together with geotechnical numerical modelling, would lead to a more complete 3-dimensional spatial model of shallow landslides. This enabled geotechnical modelling and analysis to be carried out on a GIS platform in an efficient manner.

In order to fully exploit the value of GIS, geotechnical analyses as well as data management on a GIS platform are likely to be the future trend given further improvement of 3-dimensional visualization and modelling capabilities.

(c) Mobile, location-based applications of GIS: Geotechnical professionals spend considerable time and effort doing mapping work in the field, which is one of the key components of geotechnical practice. GIS can now be brought to site to assist and enhance the fieldwork. This is done by uploading the relevant datasets onto a mobile GIS platform that operates on a pocket computer. When integrated with GPS for detecting the spatial location on site, a mobile GIS system can guide on-site navigation to the point of interest, such as suspected tension cracks based on aerial photographic interpretation (Wong 2001), see Figure 9. In addition, the spatial data relevant to the points of interest can be retrieved for location-based applications. The GIS-GPS mobile mapping unit, which incorporates the use of ortho-imagery and is equipped with wireless telecommunication via the internet for GIS data transfer, is now commercially available on a ARC-pad system using a palm PC and has been successfully integrated into routine geotechnical practice in various places. Details of such system and its application are given by Ng (2004) and van Westen (2004).

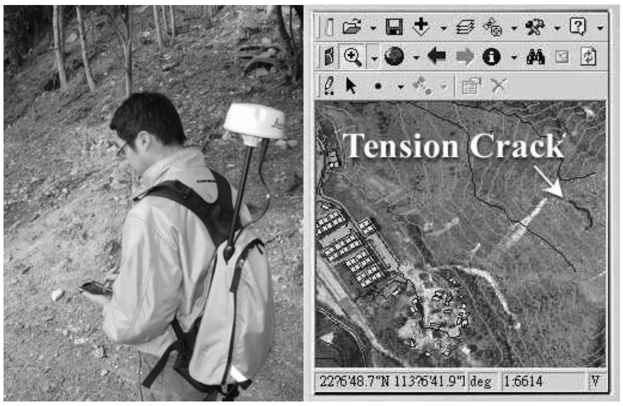


Figure 9. Mobile field mapping using a hand-held pocket PC on a GIS platform.

In recent years, various organizations (including Geological Surveys) are moving towards implementing digital field data capture systems and more and more geological maps are being produced on a GIS platform. For example, the British Geological Survey (BGS) has recently introduced a mobile field data capturing system, which has been developed for geological mapping. This system is incorporated into a Tablet PC platform that is adaptable to working in diverse and rough environments. The system enables the capture of complex spatial data during field observations, and allows interpretive interpolations to be done in a flexible and structured manner. It provides access to a suite of baseline data in the field and features touch screen technology and menu driven pull-down data dictionaries, GPS-enabled functionality to aid navigation, uploading of digital photographs taken on site for annotation and adding of sketches and notes, field visualization of 3-dimensional models and swift transfer of data from site to office for manipulation.

### 2.9 *Data analysis in management of geotechnical process*

In managing a geotechnical process, the available data must be interrogated in a timely manner, on a regular basis, by suitably qualified personnel that are knowledgeable of what can go wrong and the risks involved. The decision-maker must regularly review the situation by examining the updated data and implement the necessary corrective measures in order to reduce the risk of non-performance. Where feasible, threshold values should be pre-set in the case of real-time monitoring, and a suitable protocol set up for automatic alert by means of various communication channels (e.g. SMS text messages, emails, etc.).

Sound geotechnical input is called for in designing the instrumentation (i.e. considering what to monitor and how, the key questions that need to be addressed by the monitoring scheme, etc.), interpreting the data against the likely bounds of performance established by analysis using appropriate models, deciding on the suitable threshold limits as well as action and alarm levels, together with establishing the range of possible corrective actions in advance for risk management and optimal performance. Such a risk management framework is embodied implicitly in the observational approach (Peck 1969), which is essentially a continuous, managed, integrated process of design, construction control, monitoring and review that enables previously defined modifications to be incorporated during or after construction (Nicholson et al. 1999). A similar framework may also be applied to early warning systems, incorporating a reliable monitoring system, response plan, timely and effective dissemination of warnings to those potentially at risk, as well as good risk communication.

It should be emphasized that the mere acquisition of improved data only constitutes the starting point. It is essential that the data are interpreted properly and used to the full. There have been reports of major collapses or problems of geotechnical constructions (e.g. tunnels, deep excavations, dams, etc.), whereby a considerable amount of instrumentation data is available, but somehow the decision-maker failed to make the best use of the data and did not implement timely and appropriate corrective actions. Some of the problems encountered in practice were related to the improper implementation of the observational approach, such as the adoption of a poor quality monitoring scheme, inadequate data interpretation, etc.

Data interpretation and risk assessment done without a proper understanding of the likely collapse mechanisms are liable to lead to highly variable and unreliable predictions. The practical difficulties posed by the inherent uncertainties and spatial variability associated with geological complexities and the groundwater regime, together with the inevitable idealizations that have to be made for analysis purposes, should never be under-estimated. A structured risk management framework, supported by adequate and good quality data together with the application of appropriate technology, is of the essence.

### 2.10 *Discussion*

As a result of major advances made in information technology and digital technology, the emphasis in recent years has shifted from the provision of conventional data management and information services to the development of systems for geotechnical applications, including spatial modelling and spatial-temporal analysis as well as management of geotechnical processes. The geo-informatics and related digital capabilities constitute important assets of the geotechnical profession, and their scope of application is likely to continue to expand as technology improves further and becomes more accessible to professional users.

Enhanced data acquisition and management, together with improved management of geotechnical processes using advanced technology, have led to more efficient and robust geotechnical processes and safer geotechnical constructions. Advancing technology has helped to continually push the boundaries of geotechnical engineering with a view to further enhancing geotechnical practice.

It should be emphasized that improved data acquisition and application of advanced technology are complementary to, but are no substitute of, critical thinking, fundamental understanding, proper geotechnical and engineering geological input and sound engineering judgement. To capitalize on the technological advances made in enhancing geotechnical practice, data management and risk management, it is important to have a thorough understanding of the state-of-the-art and insights into the limits of application of new technology.

## 3 TRAINING

### 3.1 *Training is not the same as education*

Before considering the issues associated with the training of geotechnical engineers in the private and public sectors it is relevant to clarify the difference between education and training. Education is the teaching of knowledge, and the passing on of a technical understanding relevant to geotechnical engineering, that occurs through school, college and university. This process is required to provide future geotechnical engineers with the necessary capability and understanding of mathematics, physics, chemistry, geology and communication skills, to enable the subsequent training process to succeed. These fundamental issues and current related challenges faced by academia and industry are documented in detail by Atkinson (2008).

The training of geotechnical engineers should be a career long process. This training builds on knowledge gained from earlier education in developing the necessary skills and experience so that practising geotechnical engineers can work effectively in producing the required results of safe, effective, economical, and durable geotechnical solutions.

On leaving university with a complete and hopefully rounded education, geotechnical engineers should possess sufficient understanding of engineering first principles, and the theoretical tools to apply them, to effectively commence on the training process that develops capability and experience.

There are many obvious similarities between the provision of geotechnical training in the private and public sectors and also some fundamental differences. Not too surprisingly the differences are closely related to the basic differences that exist between public and private practice.

### 3.2 *Training in the private sector*

The private sector geotechnical business, whether small or larger listed business, exists to make a financial return by the provision of a specialised technical service. These businesses operate within a range of activities including site investigation contracting, geotechnical consultancy and specialist geotechnical contracting, so the geotechnical products or services provided can vary enormously. However, in all cases the business activity is undertaken to produce a financial return. This requires that a pre-approved business case will be made for training to be undertaken to ensure that the costs of investment compare favourably to the benefit gained. This fundamental financial driver can result in a more short term focus on benefit and return and therefore can lead to less enthusiasm for support of longer term or less specific training activity.

### 3.3 *Training in the public sector*

In the public sector the enterprise exists primarily to provide a service to society. In relation to geotechnical engineering this would typically be teams of engineers working in governmental client bodies to ensure the safe, cost effective and efficient design, construction and maintenance of infrastructure such as roads, rail, water and energy facilities. The fundamental drivers in the public sector tend to better accommodate a longer term assessment of cost and benefit and so training includes activities such as cadetship, sponsorship and secondments. These training programs generally have a less immediate financial benefit, but can be supported in the public sector provided adequate funding support from government is maintained.

Geotechnical engineers working in the public sector will also need very specific specialised skills associated with communication with people such as the public and politicians, who are not in the geotechnical, engineering profession or associated industries.

### 3.4 *External and in-house training*

The provision, monitoring, reporting and budgeting for training, in both the public and private sectors, is frequently focussed on formal external training courses. This focus often occurs as external courses are very simple to note, record, measure and cost. In reality most truly effective training of geotechnical engineers is workplace training provided through professional guidance, working in a professional team and more formal mentoring from experienced engineers.

Training differs fundamentally from education in that it is undertaken to enable engineers to produce results utilising knowledge they have acquired through previous education. For this reason training is often most effectively delivered whilst working on real projects. Obviously the technical development of most engineers will also include external training that can range from a one day training session to a one or more year postgraduate course of study for an industry relevant Masters degree or similar.

It is a widely held view that gaining a Masters or PhD by research or mainly research is of limited immediate value to industry. Research does have a significant role to play in furthering scientific knowledge, generally in the field of science rather than engineering practice. In contrast postgraduate study by coursework, preferably completed after some years in industry, ensures that relevant practical applications are addressed.

### 3.5 *Training for geotechnical contractors*

Effective training needs to be focussed on supporting enhanced delivery of the job in hand. In a geotechnical contracting environment fundamental issues such as safe execution of work, adoption and development of efficient construction techniques, effective communication of technical requirements and good project management skills, encompassing productivity, quality, program, commercial and contractual aspects of geotechnical design and construction, are all essential. Adequate training to develop and enhance these skills will require a combination of site and office based training and is typically delivered on the job. In better organised companies this training program is structured and monitored, often along lines that are compatible with engineers achieving professional recognition with chartered engineer status, to ensure that the full required range of experience is gained in an acceptable time frame. Specialist training, for example in geotechnical analysis, project management or contract law, would typically be obtained from external training providers.

Successful contracting companies ensure that the training of their geotechnical staff covers a large range of processes, geological and geographical conditions. This broad based practical training is essential to ensure that adequate experience is gained such that future critical and urgent decisions, frequently implemented immediately on site, will produce the required results. Early in the engineers' career hands-on training from experienced operators and site foremen will often form an essential basis for the training process.

### 3.6 *Training for geotechnical consultants*

In a geotechnical consultancy business, training in the core business skills of geotechnical modelling, analysis, design and reporting is typically delivered to junior staff working in a team alongside senior and more experienced engineers.

Project management skills need to be developed to address both internal needs on behalf of the consultancy business and externally to ensure effective project delivery on behalf of the client. Typically external training in basic project management skills will be required followed up by in-house mentoring that is compatible with the particular needs, priorities and working methods adopted in that consultancy business.

Many established geotechnical consultancies develop in-house technical guidelines, design practice notes and concise case history reports that provide invaluable training material for the development of specific geotechnical modelling, analysis and design capability.

In all three sectors the most commonly used training tools will be largely based around industry guidelines, technical practice notes, codes of practice and reference to informative case history details.

External commercial training providers can provide valuable additions to internal training programs but it is generally the case that the best technical focus and capability, and certainly the best value for money, is provided by professional bodies such as the Institution of Civil Engineers (ICE) and British Geotechnical Association (BGA) in Britain and Engineers Australia (EA) and the Australian Geomechanics Society (AGS) in Australia. In particular these industry and professional bodies provide a mechanism for experienced practitioners to share their knowledge and experience with less experienced engineers in a non-competitive and non-commercial environment that can often lead to greater transparency and thereby increased effectiveness of the training provided. Two particularly notable and successful examples of training provision by professional societies are the Geology for Engineers and Engineering Geology courses in Australia that are both sponsored by the Australian Geomechanics Society (www.australiangeomechanics.org).

### 3.7 *Industry support of training and education*

Some major geotechnical companies have made formal steps towards the more structured and commercial provision of specialist training. Examples include the Coffey Institute (www.coffey.com) and the Golder Academy (www.golderassociates.com) which provide in-house and external specialist training as well as hands-on work based training in core geotechnical consulting skills.

These courses range from soil testing procedures and soil mechanics master classes to specialised pile design and finite element analysis. More generalised training in related issues such as safety, business practice and project management are also available. Since 2008 the Coffey Institute has operated on a commercial basis and offers geotechnical training to engineers not working for Coffey International Ltd.

In recent years grants and fee support funding for students, as well as research funds, have become increasingly difficult to obtain. Increased cooperation and liaison between industry and academic institutions has been developed to help address the problems these financial hurdles can cause for some students wishing to study geotechnical engineering. In both Australia and the UK these support and cooperation mechanisms have been implemented to help achieve a better outcome for all parties.

By providing funds and commitment to part time employment industry has access to a better pool of graduates, the university can attract larger numbers of better qualified students onto their courses and the students receive financial assistance during their studies as well as the opportunity to develop a relationship with industry that fosters effective professional training pre-graduation. These arrangements can take the form of industry-university foundations, bursary schemes and sponsored sandwich courses. In this way the transition from education into training is more progressive and all parties can gain significant benefit from the early association and connection between academic learning and professional training. Some recent successful examples of these schemes include the Futures Foundation at the University of Western Australia (www.uwa.edu.au/foundation) and bursary support at Surrey (www2.surrey.ac.uk) and Portsmouth (www.port.ac.uk/sees) Universities in the UK.

### 3.8 *Recent changes in training needs*

Recent access to low cost computing power has encouraged industry to move towards the use of increasingly complex analytical models and software. As a consequence, a commonly held concern, particularly amongst more experienced practitioners, is the prior need for effective training to enable engineers to carry out a 'sanity check' based on simple and robust calculations. This issue is often best addressed by ensuring engineers possess the skills associated with basic hand calculations from engineering first principles. Hand sketches and calculations should demonstrate and communicate a clear understanding of the geotechnical problem being addressed, all potential failure modes and the likely function and performance of any proposed solutions. Once these basic skills have been learnt, effective and safe use of the specialist software is more likely as gross errors will be spotted and addressed early in the process. Valuable insight into the training challenges associated with the use of complex finite element analysis methods is given by Potts (2003) and Barends (2009).

Since the geotechnical engineering profession operates in an increasingly litigious and financially constrained environment even small mistakes or delays cannot be accommodated. Very valuable experience can be gained by working through the process of identifying, assessing and correcting mistakes that have been made. If junior engineers are required to gain their professional training whilst working in an environment that cannot accommodate the time, costs or contractual risks associated with making and correcting even small errors, it is very difficult to develop the robust appreciation of risk management that is required to prevent large scale errors being identified and addressed effectively and in good time.

Geotechnical engineering tends to be carried out in the early stages of a project and so the profession and industry is frequently impacted by political and financial cycles. Following financial recessions in the early 80s and 90s career prospects in engineering in general and specialist forms of engineering such as geotechnical dropped significantly. This resulted in reduced applications to universities and a significant drop in the numbers of students completing specialist postgraduate courses. In developed nations there is a current shortage of geotechnical engineers with between 10 to 20 years postgraduate experience. The challenges these demographics pose to the profession, industry and academia are that as engineers aged 50 and over now retire or leave the work force, there are significantly reduced numbers of geotechnical engineers available to continue providing the required mentoring, training and professional development programs.

### 3.9 *The future for training in geotechnical engineering*

Data provided by the Higher Education Policy Institute in the UK (www.hepi.ac.uk) indicates that from 2009 – 2010 to 2020 – 2021 the number of 18 to 20 year olds in the UK is expected to drop from 2,050,000 to around 1,800,000. This nominal 10% reduction will make the attraction and retention of suitable students into geotechnical engineering education and the profession increasingly difficult and so increased focus, collaboration and support between academia, industry and our professional bodies will become essential. In particular, it is likely that closer connections between industry and academia will be essential to ensure increased benefit from sandwich courses, industry placements and postgraduate training programs.

Graduate development programmes based on structured professional development to cover the necessary balance of technical, construction and commercial capabilities, closely aligned to professional institutions and the prescribed route to chartered engineer status will need to be adopted and supported by more geotechnical businesses and public sector entities.

Niche training providers such as the Coffey Institute, Golder Academy and more geologically focused organisation such as First Steps in London (www.firststeps.eu.com) will need to further develop their capability to meet the needs of industry that are not adequately provided in academic courses.

Universities and industry will need to further support and encourage bursary schemes, industry-academia foundations and other mechanisms to help improve the practical relevance of the undergraduate courses and facilitate enhanced industry involvement in teaching and course content. The profession must ensure the success of increased opportunity for more taught postgraduate geotechnical study and the long term viability of the current courses.

It is likely that international bodies such as ISSMGE will have a crucial role in facilitating effective and continuing contact and communication between industry, academia and engineering professional bodies to ensure the necessary education and training outcomes are achieved.

## 4 FUTURE OF GEOTECHNICAL ENGINEERING EDUCATION

Predictions about the future are always fraught with danger. A myriad of examples exist in history and in the literature where attempts to predict the future have failed, sometimes dismally. It is sobering to reflect on the words of the famous Danish physicist Niels Bohr who is quoted as having said "*Prediction is very difficult, especially if it's about the future.*" Vest (2007) suggests that "*we always underestimate the rate of technological change and overestimate the rate of social change.*" Hence, it is with this background that we attempt to predict the future of geotechnical engineering education. Please forgive us if our attempt fails the test of time.

As we begin, it is worthwhile to place this treatment in its historical context. Burland (1987) undertook the first systematic examination of geotechnical engineering education and he concluded that "*it is high time that the International Society [ISSMGE] took up… the matter of education and training in soil mechanics.*" The Society duly acted on Burland's challenge, and in 1990, established a Task Force on Education and subsequently, in 1994, an International Technical Committee TC31 on Education in Geotechnics. Poulos (1994) reported on the progress of the Task Force. Since that time, TC31 has continued its activities, and, in 2005, the three sister societies – the ISSMGE, ISRM and IAEG – recognising the collective importance and synergy of education to their respective disciplines, established a Joint Technical Committee JTC3 on Education and Training. The catalyst for this union, as well as the recently established Federation of International Geo-engineering Societies (FedIGS), was the *GeoEng 2000* conference where, for the first time, the three sister societies came together with a single purpose in a single symposium to share 'common ground.' Steenfelt (2000) presented state of practice of geo-engineering education at this conference, as well as an historical perspective.

Two important international conferences on geotechnical engineering education have since followed; both being held in Romania, and both under the leadership of Prof. Iacint Manoliu. The *First International Conference on Geotechnical Engineering Education and Training* was held in Sinaia in June, 2000 (Manoliu et al. 2000) and the second followed the direction of JTC3 by involving each of the three sister societies. The latter, entitled the *First International Conference on Education and Training in Geo-Engineering Sciences: Soil Mechanics and Geotechnical Engineering, Engineering Geology, Rock Mechanics*, was held in Constantza in June, 2008 (Manoliu & Rădulescu 2008). A great wealth of information is provided within these two proceedings, including status reports on geo-engineering education from most of the societies' member countries. All geotechnical engineering educators are strongly encouraged to refer to these proceedings and to read the papers by Burland (1987), Poulos (1994) and Steenfelt (2000).

Geotechnical engineering education, as it has in the past, will in the future continue to be heavily influenced and informed by developments in geotechnical engineering practice, improvements in geotechnical theory and the understanding of soil behaviour, and advancements in education research and technology. This will be ongoing in a higher education sector which continues to evolve and respond to significant challenges and demands. Our foretelling of the future begins with crystal-ball-gazing of the world that might exist in 2050 and which is likely to influence geotechnical engineering education. We then turn our attention to the changing nature of higher education and where it might proceed in the future, followed by an examination of expected developments in engineering education. The predicted future of geotechnical engineering will then be investigated, followed by discussion of the technological and pedagogical developments which will likely impact on geotechnical engineering education in the future.

### 4.1 *The world in 2050*

A recent report by the Population Division of the United Nations' Department of Economic and Social Affairs (United Nations. 2009) predicts that, by 2050, "*world population is expected to reach 9.1 billion and to be increasing by about 33 million persons annually at that time.*" In addition, United Nations (2009) predicts:

> "*The population of the least developed countries is projected to double, passing from 0.84 billion in 2009 to 1.7 billion in 2050. Growth in the rest of the developing world is also projected to be robust, though less rapid, with its population rising from 4.8 billion to 6.2 billion between 2009 and 2050… Population growth remains concentrated in the populous countries. During 2010-2050, nine countries are expected to account for half of the world's projected population increase: India, Pakistan, Nigeria, Ethiopia, the United States of America, the Democratic Republic of Congo, the United Republic of Tanzania, China and Bangladesh.*"

In contrast, the following countries will see the population decline by 10% by 2050: Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Cuba, Georgia, Germany, Hungary, Japan, Latvia, Lithuania, Moldova, Poland, the Republic of Korea, Romania, the Russian Federation and Ukraine. In terms of migration:

> "*The major net receivers of international migrants during 2010-2050 are projected to be the United States (1.1 million annually), Canada (214,000), the United Kingdom (174,000), Spain (170,000), Italy (159,000), Germany (110,000), Australia (100,000) and France (100,000). The major countries of net emigration are projected to be Mexico (-334,000), China (-309,000 annually), India (-253,000), the Philippines (-175,000), Pakistan (-161,000), Indonesia (-156,000) and Bangladesh (-148,000)*" (United Nations. 2009).

The world's population is also expected to age, with the median age projected to increase from 29 to 38 years between 2009 and 2050. Today, Europe has the oldest population, with a median age of nearly 40 years, which is expected to reach 47 years in 2050 (United Nations. 2009).

In addition, Katehi (2007) suggests that, by 2050, the biggest social problem occupying the world will be poverty, and its primary impact will be on the female population. Furthermore, she contends that "*in 20 to 30 years, the primary economic growth in nations around the world will depend on females working in all professions, from farming to high-tech industry.*"

With regards to energy, the European Commission (2006) expects that the world's total energy consumption will, by 2050, more than double from the current 10 Gtoe (gigatons of oil equivalent) per annum to 22 Gtoe p.a. Fossil fuels are expected to provide 70% of this total (coal and oil 26% each, natural gas 18%) and non-fossil sources 30% (divided almost equally between renewable and nuclear energy). By 2050, the production of energy is more efficient, with the size of the world economy in 2050 predicted to be four times as large as now, but world energy consumption only increases by a factor of 2.2. As one might expect, oil and gas prices are forecast to increase, mostly as a result of increasing resource scarcity. Coal is anticipated to return as an important source of electricity and is increasingly converted using new advanced technologies. Renewable sources and nuclear energy increases rapidly after 2020 and is massive after 2030, with "*rapid deployment of new energy technologies, from large offshore wind farms to 'Generation 4' nuclear power plants.*"

With regards to the global climate, it is expected that the mean temperature of the Earth will continue to rise, primarily as a result of emissions from fossil fuels and deforestation (Holdren 2007). In fact, "*global climate change is increasingly recognized as both the most dangerous and the most intractable of all of energy's environmental impacts – indeed, the most dangerous and intractable of all of civilization's environmental impacts, period*" (Holdren 2006). As a result, it is anticipated that much greater attention and resources will be devoted to reducing the impact of greenhouse gas emissions.

### 4.2 *The changing nature of higher education*

Worldwide, the higher education sector is undergoing rapid evolution and the nature of universities may well be very different in two to three decades time to the current system which has largely been in existence since the very beginning of tertiary education. A number of countries have recently reported on the future directions of their tertiary sectors, such as the USA (U.S. Department of Education. 2006), UK (Brown et al. 2008, Ramsden & Brown 2008) and Australia (Bradley et al. 2008), as well as the global sector in general (OECD 2008). As a consequence, continued change is inevitable. Furthermore, over the last three decades or so, higher education has changed dramatically. During this period the following major trends have occurred:

- <u>Domestic student numbers have risen markedly.</u> Since about 1960, the sector has moved from elite to mass education (Trow 1973, Bradley et al. 2008, OECD. 2008) with an explosion in student numbers. Furthermore, the student population continues to grow and is expected to do so in the future (Brown et at. 2008, OECD. 2008). For example, in the UK, in the period between 1989/90 and 2006/7, the number of students enrolled in higher education has roughly doubled, from approximately 1 million students in 1989/90 (Ramsden 2001) to 1.6 million in 1994/5 and 2.4 million in 2006/7 (Universities UK. 2008). In terms of a proportion, in 1979 just over one in ten young people entered higher education and by 1997 this had risen to almost one in three (Warwick 1999) and by 2010 the UK Government seeks to increase this proportion to one in two (Grocock 2002). In Australia, the statistics show a similar trend. Nearly fifty years ago in 1963, there were just over 69,000 enrolled students in Australian universities (Boumelha 2008) and by 1996 the numbers had grown by an order of magnitude to 640,000. In 2006, just over 1 million students are enrolled in Australian universities (Bradley et al. 2008). In the USA, since 1998, the student population has grown by almost 32% (OECD 2009). Similar growth patterns are observed in most other countries (Trow 1973, OECD 2009). The top five countries which have experienced the greatest growth in higher education student numbers since 1998 are: (1) Iceland (94%, 16,000 total students), (2) Poland (80%, 2.1 million students), (3) Greece (75%, 650,000 students), (4) Hungary (72%, 440,000 students) and (5) Turkey (66%, 2.3 million students) (OECD 2009). Of the 30 member countries listed by OECD (2009), only Canada, with just over 1 million students in 2006, appears to have contracted, although student numbers have risen by as much as 6.4% in four of the eight years since 1998. A recent OECD report, however, suggests that the higher education sectors in Japan and Korea "*have started to decrease and… this trend is very likely to continue*" (OECD. 2008).

- International student numbers have also grown rapidly. In many of the established higher education sectors, the proportion of international students has increased significantly, For example, in the UK, in 2001, 12% of the student population was from abroad (Ramsden 2001). By 2006/7 this had risen to 15%, with 5% from other European Union countries and 10% from non-EU countries in 2006 (Universities UK. 2008). Australia, which had the highest proportion of international students in its universities of any OECD country in 2006, shows a similar trend, with 8.5% in 1996 increasing to 26.5% in 2007 (Bradley et al. 2008). Furthermore, many of these countries rely heavily on income generated from international students. In Australia, education services are the country's third-largest export industry, with the higher education sector accounting for 60% of all education export revenue in 2007 (Bradley et al. 2008). Many are concerned that the heavy reliance on international student income presents a significant threat for the sector in the near to medium-term future (Bradley et al. 2008). In the UK, some reports suggest that increased competition from the developing nations of Brazil, Russia, India and China, are likely to diminish the international student population, particularly with regards to engineering students (Royal Academy of Engineering. 2007). Despite this, a recent UK report projects that the international student market will grow by 4.7% by 2019/20 (Brown et at. 2008).
- Increasing globalisation of tertiary education. The Bologna Declaration (1999) initiated the establishment of a series of reforms, known as the *Bologna process* (Bologna Secretariat. 2009), which seeks to create a European Higher Education Area by 2010 and to make "*European Higher Education more compatible and comparable, more competitive and more attractive for Europeans and for students and scholars from other continents*" (European Commission 2007). This major European reform, aims to provide students with the choice of a wide range of high quality courses and to benefit from smooth articulation procedures. The three priorities of the Bologna process are the: Introduction of the three cycle system (bachelor/master/doctorate), quality assurance and recognition of qualifications and periods of study (European Commission 2007). The Bologna process has major ramifications for higher education in Europe, but also across the globe, with several countries outside Europe participating in the process (Bologna Secretariat. 2009), and several of their institutions have either already adopted the model, or have established one similar to it (Manoliu 2000, Jaksa et al. 2008). Whilst the Bologna process will facilitate increased globalisation of higher education, a more global student market is inevitable and institutions will increasingly be subject to global influences (Bradley et al. 2008, Brown et al. 2008, OECD. 2008).
- The amount of public funding has diminished. The growth in student demand, both domestic and international, as described above, has largely occurred in an environment with diminished government funding, even though many public universities derive significant proportions of their income from non-government sources, particularly those in the United States, Canada, Hungary and Korea (Warwick 1999, U.S. Department of Education. 2006, Bradley et al. 2008, OECD. 2008). In 2004, it was largely the Scandinavian countries who invested more than any other OECD countries in higher education, with Denmark providing 1.8 as a proportion of GDP, followed by Finland (1.7), Switzerland (1.7), Sweden (1.6), Norway (1.6), Belgium and France (1.2). The United States ratio was 1.0, and the UK and Australia, 0.8. The OECD average was 1.0. To exacerbate diminished funding for learning and teaching, there is evidence of substantial cross-subsidy to research from funds for teaching domestic and international students (Bradley et al. 2008). A number of countries, however, are planning to increase higher education funding in the near future, such as Germany (eGov Monitor. 2008).
- Student staff ratios have increased significantly. With diminished public funding in many countries, the number of staff teaching the increased student population has fallen. In the UK in 1975/6 the student staff ratio (SSR) was 9:1 and, by 2003/4 it had more than doubled to 19:1 (University and College Union 2006). A similar picture is seen in Australia where, in 1990 the SSR was 13:1 and in 2006 it had climbed to 20.5:1 (Bradley et al. 2008). With this increase has brought "*clear signs that the quality of the educational experience is declining*" and that the SSR is "*unacceptably high*" (Bradley et al. 2008). Projections for the future show, for the majority of countries, increasing SSRs (OECD 2008).
- Increased student diversity. With the movement from elite to mass education has come much greater diversity in the student body (Bradley et al. 2008). The proportion of women, international, mature-age and part-time students has grown rapidly and it is expected that these trends will continue into the future (Warwick 1999, OECD. 2008).
- Changing student expectations, demands and acquired knowledge. There is clear evidence that the current group of students, known as *Generation Y*, *Millenials* or the *Net Generation*, have often significantly different expectations to previous student cohorts. They expect value for money and that higher education providers will accommodate pressures outside of study, such as paid employment and meeting family responsibilities, through the flexible delivery of teaching, services and advice (Bradley et al. 2008). Furthermore, several commentators suggest that they learn by doing rather than reading and listening to lectures, are adept with new technology, multi-task, expect more immediacy, have shorter attention spans and diminishing literacy skills (McNeely 2005, Roberts 2005, Windham 2005, Rogers 2007).
- Increased use of technology in teaching and learning. The last two decades or so has seen a rapid expansion in the use of e-learning or online education. This has facilitated different pedagogies, broadened access to higher education (OECD. 2008) and enhanced student-centred learning. Nowadays there are numerous courses available online, some of which are free (e.g. Carnegie Mellon. 2009, MIT. 2009, Open University. 2009, University of California, Berkeley. 2009) or very low cost (e.g. Virtual University. 2009), and many resources that are available to students and teachers. Those that are relevant to geotechnical engineering are described later in the paper. Several educators (e.g. Rossman 1992, van Horn 1996, Starr 1998) predict that the nature of universities may be vastly different in the future and may be entirely online and offered remotely. Whilst acknowledging that web-based learning "*will have* [a] *dizzying impact on every aspect of education in the next century*", Bridges (2000) recognises its "*profoundly disruptive potential*."
- High quality academic staff are difficult to attract and retain and the academic workforce is ageing. It is a worldwide phenomenon that the academic workforce is ageing and will continue to do so in the future (Willekens 2008). It is not that the average age of 45 is particularly old, it is more a function of the employment system with tenure or 'job security', combined with a change of size in the system at a constant SSR (OECD. 2008). Academics in their 20s and 30s (*Generation X*), in particular, are significantly underrepresented (Bradley et al. 2008). To compound this, it is increasingly difficult to attract and retain high quality academic staff (Bradley et al. 2008).
- Greater pressures on academic staff. Increased student numbers and SSRs, the demands of new technologies and student expectations, increased course offerings, as well as

an increased focus on research outcomes and quality, has added greatly to the pressures placed on academic staff. In addition, in a number of countries, tenure is coupled with academic performance – both in research and in teaching and learning. It is unlikely that these pressures will abate in the near to medium future.

It is within this context that engineering education has evolved. Let us now turn our attention to how engineering education may progress in the future.

### 4.3 *Future of engineering education*

Just as many countries have re-examined the nature of their higher education sectors, several, such as the USA (National Academy of Engineering. 2005, American Society of Civil Engineers. 2007), the UK (Royal Academy of Engineering. 2007), Ireland (Engineers Ireland. 2007) and Australia (King 2008), have also recently reported on the future of their engineering education systems and practices. The following is a list of trends which are predicted to influence engineering education in the future.

- Engineering in the future will be increasingly more multi-disciplinary and globalised. The Royal Academy of Engineering (2007) review noted that "*today, business environments increasingly require engineers who can design and deliver to customers not merely isolated products but complete solutions involving complex integrated systems* [and] *…they also demand the ability to work in globally dispersed teams across different time zones and cultures.*" These sentiments are echoed by American Society of Civil Engineers (2007) and King (2008). Katehi (2007), in her prediction of the U.S. engineer in 2020, argues that engineers of the future:

  "*must become global engineers. …They will have to know how to replenish their knowledge by self-motivated, self-initiated learning. They will have to be aware of socio-economic changes and appreciate the impact of these changes on the social and economic landscape in the United States and elsewhere. The engineer of 2020 and beyond will need skills to be globally competitive over the length of her or his career.*"

  Translating this into engineering education, she advocates a quantum-level change in engineering education:

  "*Engineering schools… must prepare engineers for solving unknown problems and not for addressing assumed scenarios. Therefore, the emphasis should be on teaching to learn rather than providing more knowledge. Teaching engineers to think analytically will be more important than helping them memorize algebra theorems. Teaching them to cope with rapid progress will be more critical than teaching them all of the technology breakthroughs.*"

  The engineering review reports also stress that:

  "*In addition to producing engineers who have been taught the advances in core knowledge and are capable of defining and solving problems in the short term, institutions must teach students how to be lifelong learners…* [and] *engineering educators should introduce interdisciplinary learning in the undergraduate curriculum and explore the use of case studies of engineering successes and failures as a learning tool*" (National Academy of Engineering. 2005).
- The 4-year undergraduate engineering degree is increasingly seen as being too short. In many parts of the world (e.g. Australia, Canada, Hong Kong, Ireland, Japan, Korea, NZ, South Africa, UK, USA), a 4-year engineering baccalaureate degree is the established and accredited entry point to the practice of engineering, as agreed by the Washington Accord of 1989 (International Engineering Alliance. undated). Several recent reports (e.g. National Academy of Engineering. 2005, Engineers Ireland. 2007, King 2008), have identified that an undergraduate degree of 4-years duration may be unable to prepare students appropriately for an engineering career in the future. As a result, the 5-year, 2-cycle Bologna model, with an exit point at Masters level, is becoming increasingly more popular as the preferred engineering educational model. Several signatories of the Washington Accord have committed to extending the duration of their professional engineering programs (King 2008).
- Engineering education needs greater engagement with industry. The National Academy of Engineering. (2005) report stated that "*at the application end of engineering practice, there is a growing disconnect with engineering education that begs for enlightened industrial engineering leaders and a new generation of faculty able to bridge the gap more effectively. For their part, if engineering faculty, as a group, are to adequately prepare students for practice, then some population within that group must have credible experience in the world of non-academic practice.*" The Royal Academy of Engineering (2007) similarly recommended that "*universities and industry need to find more effective ways of ensuring that course content reflects the real requirements of industry and enabling students to gain practical experience of industry as part of their education*", and King (2008): "*engineering educators and industry practitioners must engage more intensively to strengthen the authenticity of engineering students' education.*"
- Engineering education needs greater resources. The Royal Academy of Engineering (2007) noted that engineering schools in the UK are seriously under-funded and King (2008) reported that Australian engineering deans explicitly identified lack of resources as the most critical issue they face in providing high quality engineering programs. This is note surprising given the reduced funding to the higher education sector discussed above. As a consequence, student staff ratios have risen, laboratory equipment has become more obsolete and library resources have diminished (King 2008).
- Engineering education needs to implement best-practice in learning and teaching. King (2008) recommended that "*engineering schools must develop best-practice engineering education, promote student learning and deliver intended graduate outcomes. Curriculum* [should] *be based on sound pedagogy, embrace concepts of inclusivity and be adaptable to new technologies and inter-disciplinary areas*. Aligned with this, engineering schools need to recognise and reward good teaching, along with research performance (Royal Academy of Engineering 2007, King 2008).
- Proficiency with mathematics and sciences of school leavers is diminishing. A growing concern in a number of regions is the decreasing level of knowledge of the fundamentals of mathematics and sciences, as students enter the tertiary sector (Springer et al. 1999, Pollock 2002, National Academy of Engineering. 2005, Dobson 2007, Rogers 2007, Broadbridge & Henderson 2008, King 2008). There is also an acknowledged shortage of quality teachers in mathematics and physics (Royal Academy of Engineering. 2007, King 2008).

Let us now explore how geotechnical engineering may evolve in the future.

4.4 *Future of geotechnical engineering*

In celebration of the 60th anniversary of the establishment of the international geotechnical engineering journal *Géotechnique*, Simpson & Tatsuoka (2008) boldly and skilfully predicted the state of the profession 60 years hence. Their vision foreshadowed the following areas where developments will be made or greater attention will be needed:

- Environmentally-related issues: In the future, climate change is likely to have a more profound influence on civil design and construction practices than at present. More emphasis is likely to be placed on the use of carbon-neutral technologies, both in construction and for the generation of energy. Geotechnical engineers will need to adopt more environmentally-friendly construction methods which minimise the total construction energy used and carbon dioxide emissions. In addition, more restrictive environmental legislation is likely to be enacted in the future leading to the development of innovative soil and groundwater remediation solutions, possibly using transferable skills and techniques from physics, biology medicine and biochemistry.

  Geotechnical engineers will also need to have a better appreciation of the thermal behaviour of the ground, both in terms of its capacity to transmit and store heat, and the effects of temperature change on other geotechnical properties such as strength, stiffness and solubility of solid components in groundwater. The reuse of foundations is also likely to be much more prevalent than at present, especially as brownfield sites are redeveloped.

  Geotechnical engineers and geologists have been critically involved in the generation of energy, particularly in the extraction of coal, oil and gas from both land and sea, as well as their associated infrastructure. It is anticipated that this will continue in the future, perhaps with greater emphasis on coal, as oil and gas reservoirs diminish. The use of alternative sources of energy, such as wind, tidal and nuclear, is also likely to increase in the future, with geo-engineers playing an important role in their development. Methane gas hydrates (or methane clathrates) present another potential and important source of energy. They are crystalline, water-based solids physically resembling ice, in which methane is trapped inside cages of hydrogen bonded water molecules. It is predicted that the global inventory of methane hydrate may exceed $10^{13}$ tonnes of carbon, which is comparable to the potentially recoverable reserves of coal, oil and natural gas (Buffett & Archer 2004). It is estimated that $5 \times 10^{12}$ tonnes of methane is sequestered in marine sediments below the ocean floor (Buffett & Archer 2004). Simpson & Tatsuoka (2008) predict that gas hydrates will become increasingly important in the future because of their potential: as a significant energy source; for global warming; and as a geotechnical hazard, as evidenced by the Storegga Slide (Ashi 1999). Simpson & Tatsuoka (2008) suggest that geo-engineers will play a key role in these developments.

  Finally, the development of cost-effective solutions for the prevention and mitigation of natural hazards, such as landslides, soil erosion, flooding and earthquakes, will also need greater attention from geo-engineers.

  These predictions align well with those made by American Society of Civil Engineers (2007) who forecast "*an ever-increasing global population…* [and] *demands for energy, drinking water, clean air, safe waste disposal, and transportation will drive environmental protection and infrastructure development. Society will face increased threats from natural events, accidents, and perhaps other causes such as terrorism.*"
- Tunnelling and ground improvement: Increased pressure for habitable space will inevitably lead to greater utilisation of the underground. Hence, the design of tunnels and large excavations will become increasingly necessary and important as cities continue to grow globally. In addition, increased use of reclaimed land and marginal ground will require greater levels of reinforcement such as geosynthetics and/or ground improvement by physical or chemical means, or a combination of both.
- Soil modelling: It is anticipated that improvements will be made, mainly by academics, to capture more accurately the stress-strain behaviour of soil which will yield more realistic models. In particular, Simpson & Tatsuoka (2008) predict that a more detailed understanding of the stress-strain and hydraulic behaviour of soil will be obtained in the future, which will movement towards: complex non-linear and elasto-viscoplastic analysis; inclusion of cyclic loading and the effects of ageing, temperature and soil chemistry and their coupled effects; and further development in unsaturated soil mechanics. In addition, Simpson & Tatsuoka (2008) suggest that advancements will be made in the development of general unified models which cover a wide range of geomaterials such as bound and unbound, saturated and unsaturated and from soft clays, sands and gravels to rock. The authors also forecast that there will be further moves towards, and developments made in, modelling the particulate nature of soil using the discrete element method. Analyses to date have been limited to $10^5$ particles, although Cundall (2001) predicted that within 20 years analyses will incorporate as many as $10^{11}$ particles. However, Simpson & Tatsuoka (2008) noted that a soil volume of 1 $m^3$ is equivalent to $10^9$ $mm^3$. Hence, even $10^{11}$ particles struggles to adequately represent even 1 $m^3$ of soil.

  Finally, with respect to soil modelling, the authors suggest that the gap is widening between the models used in academe and those used in practice. They speculate that the development of simpler and more robust models, which replicate features confined to a limited, but clearly defined, range of situations, will remain important.
- Design and analysis: It is expected that the basic process of geotechnical analysis and design will not change in the future, but improvements will be made in the tools used. With regards to numerical modelling, Simpson & Tatsuoka (2008) expect the use of finite element modelling to continue for both the analysis of failure mechanisms and serviceability. More sophisticated features, such as three dimensions, time-dependence, anisotropy and progressive and post-peak behaviour, are also likely to be utilised in the future.

  Coupled with ever-more powerful computers, the use of data mining tools, such as artificial neural networks (ANNs), is likely to become more prolific, particularly in practice. One of the main criticisms levelled at ANNs is their lack of transparency (Jaksa et al. 2008). However, as noted by Jaksa et al. (2008), this is being addressed by researchers and it is likely that, in the very near future, ANNs will be more transparent and robust. Of great promise, particularly in this regard, is an alternative approach, which utilises genetic programming (GP) techniques (Rezania & Javadi 2007). Rather than resulting often in convoluted algorithms, GP often yield extremely tractable models, which can be readily adopted by practitioners.

  Simpson & Tatsuoka (2008) also predict that client demand will result in greater use of statistical methods in order to assess geotechnical risks. With greater computational power, better and more universal geotechnical databases, and more logical algorithms, geotechnical risk analysis is likely to be more rational and accurate in the future. Fenton & Griffiths (2008) also note that, in recent years, there has been a remarkable increase in activity and interest in the use of probabilistic methodologies applied to traditional areas of geotechnical engineering, both by academics and practitioners. Jaksa (2006) noted that the development and availability of sophisticated probabilistic tools, such as the random finite element method (RFEM)

(Paice et al. 1996, Fenton & Griffiths 2008) which incorporates the spatial variability of soil properties in a realistic manner, provides great benefits with regards to risk assessment, reliability based design and the effectiveness of geotechnical investigations.

In relation to codes of practice, Simpson & Tatsuoka (2008) believe that, with future developments in computing, information databases and artificial intelligence, design procedures are likely to become more automated. They also predict that concepts about the application of safety factors and margins will continue to converge. As this occurs, significant collaboration will be needed between the research community and practice, with undergraduate teaching reinforcing the principles and magnitudes of design safety margins.

- Geotechnical investigations: Again, as technology improves, geotechnical investigations will become more accurate and cost-effective. New test methods are likely to be developed. In respect to in situ testing, Simpson & Tatsuoka (2008) suggest that the use of traditional methods such as the SPT, cone penetrometers, pressuremeters and dilatometers will continue but with improved correlations between their outputs and the required geotechnical parameters. Direct evaluation of soil properties will become more reliable and cost effective, with remote sensing techniques able to capture the properties of greater volumes of soil and rock. Field loading tests will become faster and the results available in real-time. Investigations in very remote regions, such as deep offshore, and perhaps on other planets, will also become more cost-effective and reliable.

  With respect to sampling, Simpson & Tatsuoka (2008) expect that few, if any, significant developments to be made. In regards to laboratory testing, it is predicted that more automation in operation and data acquisition will occur, more flexibility will be available in the control of stress and strain paths, control and measurement of stresses and strains will be more accurate, and such testing will be more cost-effective and, therefore, more readily available. Further developments are expected, too, with centrifuge testing and better modelling of construction sequences, geotechnical processes, and inclusions, such as piles and geosynthetics.

  With growth in computing power and the internet, databases will increase the amount data they contain and become more publicly accessible. Highly developed computational processes will be required to locate relevant data for a particular application, categorise their quality and to interpret them.

  Tools such as Google Earth and Google Maps will inevitably develop further with higher resolution images becoming more readily available. This will add greatly to desktop studies, particularly if historical images are also available.

- Field monitoring and reconnaissance: Finally, Simpson & Tatsuoka (2008) predict that more cost-effective, accurate, reliable and robust field monitoring and measuring systems will be available in the future to record, not only conventional geotechnical parameters, but ones that may become increasingly relevant, such as biological, chemical and nuclear. 'Smart' technologies, which monitor structures during construction and throughout their serviceable life, will also become more useful, cost-effective and hence more prolific.

  In terms of field reconnaissance, it is expected that 3D tomography will be used for site investigations to identify stratification, boulder and voids. This may be aided, too, by developments in satellite and internet technologies. For example, with regards to Google Earth mentioned above, it is not beyond the realms of possibility that real-time, high resolution images of the entire Earth may be available to geo-engineers in the future, thereby improving field reconnaissance and monitoring.

  Lastly, Simpson & Tatsuoka (2008) imagine the availability of geotechnical robots and intelligent probes:

  > "*Developments in electronics and communications are likely to be very rapid, and future applications of these could be imagined. For example, a geological robot might be developed, delivered to site on a lorry, submarine or spaceship. It would be able to assemble and propel itself, take samples and carry out field tests such as geophysical and penetration tests, provide detailed photographs and micrographs, analyse rock jointing in exposures (perhaps by sending a flying probe up the rock face), and so on. All this might be controlled interactively from an office at great distance, making top-quality human expertise readily available anywhere in the world at acceptable cost.*"

Having glimpsed the possible future of the geotechnical engineering profession, we now investigate technological and pedagogical developments which may well influence geotechnical engineering education in the future.

### 4.5 *Developments in teaching and learning with relevance to geotechnical engineering*

Educational research over the past decade or so has challenged educators to rethink the efficacy of current teaching practices and their consequent influence on student learning. It has been demonstrated above that rapid developments in technology, particularly in relation to the World Wide Web and the internet, as well as the changing expectations and skill base of the current and immediate future student population, suggest that such a rethink is particularly relevant at this time.

Bowden & Marton (1998) argue that the traditional lecture approach has evolved more by social and economic rather than pedagogical factors, largely as a result of diminished funding. Furthermore, it is implicit in this educational paradigm "*that students will be helped to learn if an expert sets out in detail the content to be learned*" (Bowden & Marton 1998). The authors also attest that effective learning occurs when "*the teaching method or a learning environment is constructed in ways that… both stem from judgements about what is needed to support appropriate learning and also allow for dynamic change through professional judgement by teachers interacting with their students.*"

It is becoming increasingly apparent that, as we move forward in time, engineering educators, including those in geotechnical engineering, are more engaged in and contributing to fundamental research in learning and teaching. In the future, the linkage and dialogue between geotechnical engineering teachers and educational researchers will continue to grow, and this will lead to an improved student experience and enhanced student learning. In recent years, appraisal of teaching has been considered much more in terms of student learning outcomes, than ever before (Bowden & Marton 1998). Teaching portfolios are usually needed "*to provide documentary evidence of the activities of an academic in addressing curriculum, planning of learning environments and assessment and evaluation aspects of their teaching role, including the degree of success with each over time*" (Bowden & Marton 1998).

In the treatment that follows, attention is given to innovations and developments in learning and teaching, which in the authors' opinion, show promise or are particularly relevant to the field of geotechnical engineering education.

#### 4.5.1 *Student learning*

Over the last few decades, a great deal of attention and research has been directed towards understanding how people learn. Such an understanding greatly informs educational practices and pedagogies. It is universally acknowledged by educational researchers that students learn in a variety of ways. Kolb

(1984), for example, suggested that individuals learn in 4 different ways, that is, as:

- Convergers who are characterised by abstract conceptualisation and active experimentation. They are strong in the practical application of ideas and they can focus on hypo-deductive reasoning on specific problems. They are unemotional and have narrow interests.
- Divergers tend toward concrete experience and reflective observation. They have strong in imaginative ability and are good at generating ideas and seeing things from different perspectives. They are interested in people and have broad cultural interests.
- Assimilators are characterised by abstract conceptualisation and reflective observation. They are strong in creating theoretical models and excel in inductive reasoning. They are concerned with abstract concepts rather than people.
- Accommodators use concrete experience and active experimentation. Their greatest strength is in doing things. They are risk takers and perform well when required to react to immediate circumstances. They solve problems intuitively.

Felder & Silverman (1988) proposed an alternative set of learners, which was subsequently updated (Felder 2002), as those who are active and reflective, sensing and intuitive, visual and verbal, and sequential and global. A number of other learning models also exist.

#### 4.5.2 *E-learning*

With the explosion in affordable, accessible and powerful personal computers since the mid-1980s, has emerged a new form of learning termed electronic learning, or e-learning. E-learning refers to the "*use of information and communications technology (ICT) to enhance and/or support learning in tertiary education… and refers to both wholly online provision and campus-based or other distance-based provision supplemented with ICT in some way. [E-learning] encompasses activities ranging from the most basic use of ICT (e.g. use of PCs for word processing of assignments) through to more advanced adoption (e.g. specialist disciplinary software, handheld devices, learning management systems, adaptive hypermedia, artificial intelligence devices, simulations, etc.)*" (OECD. 2005).

In their major report on e-learning, the OECD (2005) acknowledged that "*e-learning has the potential to improve and even revolutionise teaching and learning*." The authors found that the "*overwhelming view of respondents of the OECD/CERI survey was that e-learning had a broadly positive pedagogic impact.*" However, on a less positive note, they OECD (2005) also concluded that "*failures of e-learning operations have, at least, temporarily, overshadowed the prospects of widened and flexible access to tertiary education pedagogic innovation, decreased cost, etc.*"

Bowden & Marton (1998) sound a salutary warning for the use of ICT in higher education. They state that "*one of the difficulties that the advent of information technology has produced is the tendency to want to use ICT for all aspects of the education process, the idea of the virtual campus. …For many students in most areas of education, there is a need for 'hands-on' activity, personal interaction with academic teachers and face-to-face discission with other students. …[W]e should be wary of being seduced by the glamour of technology and the status of being fashionably up-to-date or providing slickly prepared materials.*"

The treatment that follows focuses on some of the more promising e-learning resources and approaches. In particular, computer assisted learning (CAL), learning objects, web based learning (WBL), just in time teaching (JiTT) and e-assessment will be examined.

*Computer assisted learning (CAL) and learning objects*

Over the last two decades or so, computer assisted learning (CAL) has provided additional learning resources to those traditional methods of instruction such as lectures, tutorials, text books, practical sessions and videos. CAL offers many advantages over traditional forms of learning. These include (Jaksa et al. 2000): (1) the ability to run simulations of laboratory experiments and design scenarios that allow the student to observe the effect on some behaviour by modifying various parameter(s); (2) the subject matter can be delivered in an exciting and challenging manner; (3) students are able to learn at their own pace, rather than adhering to a schedule established by the course timetable; (4) student progress and areas of difficulty can be automatically monitored; (5) scarce teacher, technician and equipment resources can be diverted to other areas, such as research.

Whilst CAL has a number of benefits, it also suffers from a number of limitations. These include: (1) students do not handle soil or rock nor operate real test apparatus, hence, they are unable to benefit from these important tactile experiences; (2) students may not appreciate experimental errors nor the often significant time needed to carry out some geotechnical tests; (3) if the CAL resources are poorly designed, the student may be more concerned with navigating or 'playing' the software than with learning; (4) hardware limitations may cause the software to crash or the web-navigator to be unbearably slow, hence, detracting from the learning experience. As a consequence, CAL should not be seen as a replacement for traditional instructional methods. Rather, CAL offers an additional powerful and engaging instructional tool which enhances the students' learning experience and learning outcomes.

Among the early developments of CAL specifically for geotechnical engineering, were the significant UK *GeotechniCAL* suite of programs (Davison 1996) (environment.uwe.ac.uk/geocal/old/geocal.htm), Geotechnical Courseware (Budhu 2006), *CATIGE* (Jaksa et al. 1996), and the TU Delft Software and Resources (Verruijt 2006, Delft University of Technology 2009). Jaksa et al. (2000) provided a relatively extensive overview of the geotechnical engineering CAL resources available at that time and the interested reader is referred to this paper for details on each of the above, as well as resources in the wider geo-engineering context. Since then, however, very few new CAL resources have been developed and many of the ones listed above have failed to keep pace with changes in PC operating systems. This is a serious issue for CAL, as new operating systems and technology often render obsolete the significant efforts devoted to developing such CAL resources.

However, as a more positive development in recent years, several geo-engineering software companies provide student versions of their programs at no cost (e.g. Centre for Geotechnical Research, 2009, Geo-slope Int. 2009, Oasys, 2009, SoilVision Systems, 2009). Each of these software packages contains several powerful geotechnical analysis and design programs, which have been limited for student use. Despite this, and while they have been developed primarily to facilitate analysis and design and not necessarily to assist students in learning, the programs are nonetheless extremely valuable tools for use in geotechnical engineering education.

Recently, the first author's *CATIGE* suite of 10 programs (which include Consolidation Processes, Direct Shear Test in Sand, Mohr's Circle, Permeability Test, Phase Relationships, Proctor Compaction, Sheet Pile Retaining Wall Analysis, Soil Classification and Triaxial Test and Vertical Effective Stress Calculation) have been updated to incorporate several improvements, most notably, inclusion of a facility for educators to translate the programs' text into their native language and the ability to enter user-specific soil properties, as well as student-centred learning exercises. This software is available free-of-charge from the first author's home page (www.ecms.adelaide.edu.au/civeng/staff/mjaksa01.html).

The first author uses various CAL modules in lectures as a demonstration aid to reinforce key concepts and makes these available to students for use in their private study.

Yuen et al. (2005) have recently developed the *Excavate* CAL module which consists of a DVD incorporating a 21 minute narrated video of the construction of a 6-storey basement car park in central Melbourne, Australia, as well as a CD containing background material to assist further in understanding the issues associated with the project. The multimedia resource is available free-of-charge from Dr. Samuel Yuen from the University of Melbourne (http://www.civenv.unimelb.edu.au/about/webpage.php3?login=syu).

A more recent CAL resource developed by Yuen & Kodikara (2008) is the *Direct Shear Strength Test* DVD, which includes narrated videos of the theory associated with direct shear, the direct shear test itself, and analysis of the test results. The *Direct Shear Strength* module is discussed again later in the paper and is due to be published in the near future.

Ledesma & Prat (2008) discuss the development of a computer-based virtual soils laboratory, *Virtual Lab*, which is able to simulate drained and undrained triaxial tests, as well as oedometer tests.

An issue which has presented a continual frustration for developers of CAL is that of providing ease-of-access of software to students. Access to and maintenance of student computer facilities and networks is an ongoing challenge. Educators can often spend inordinate amounts of time with computing managers installing software, ensuring that students can readily access it and that it runs appropriately on the network. However, application virtualisation is emerging as a promising technology which appears to address this problem. Application virtualisation is a software technology which improves portability and mobile computing, manageability and compatibility of applications by encapsulating them from the underlying operating system on which they are executed. These technologies allow users to access and run software – in this context, for example, geotechnical engineering analysis software – remotely without the need to install them on their own computer. Software might, for example, be streamed wirelessly from a host server located on campus. Such technologies are currently available, with Microsoft *Application Virtualization* (www.microsoft.com/systemcenter/appv/default.mspx or *SoftGrid* as it was formerly known), *InstallFree* (www.installfree.com/) and VMware *ThinApp* (www.vmware.com/products/thinapp/) being three such examples.

Recently, such CAL resources have been termed *learning objects* which "*can be described as an electronic tool/resource that can be used, re-used and redesigned in different contexts, for different purposes and by different academics*" (OECD. 2005).

*Web based learning (WBL)*

With great improvements in the speed and availability of the internet, over the last 10 years or so, the use of the World Wide Web has grown astronomically, with a recent report stating that the number of users worldwide has topped one billion (The Economic Times. 2009). As a result of these improvements, as well as the 'needs' of Generation Y, as discussed above, web based learning (WBL), or online learning, has also grown rapidly in recent years. The development and uptake of enterprise-level learning management software, such as the commercial Blackboard™ (www.blackboard.com) and Web-CT™ (www.blackboard.com) packages and the open source Moodle (moodle.org), has also facilitated the explosion in WBL. To further enhance access to learning and teaching resources, the developers of Blackboard have created a platform whereby Blackboard courses and organisations are readily accessible via the Apple® iPhone™ or iPod touch® mobile digital devices (Blackboard 2009).

Geotechnical engineering education has also moved with these developments in WBL, with a number of educators adopting the technology and incorporating WBL into their curricula (e.g. Budhu 2000, Sharma 2000, Davison et al. 2002). Perhaps most commonplace is the use of the online environment by educators to facilitate the distribution of and ease-of-access to lecture notes and assignments. To a lesser extent, keen adopters of online technology are making use of discussion boards to enhance learning.

More recently, because of the limitations imposed by platform-dependent CAL, as discussed above, online, Java-based applets have become increasingly prevalent in WBL environments as learning objects (Crisp 2007). The benefit of such applets is that they run within the user's internet browser and can either be downloaded or executed from a web page.

In recent times, Java applets are also being developed to facilitate geotechnical engineering simulations. For example, TAGA Engineering Software Ltd. (2009) provides a relatively simple Java applet for the solution of an infinite slope. Jaksa & Kuo (2009) have recently made 8 of the *CATIGE* suite of programs (Consolidation Processes, Direct Shear Test in Sand [Fig. 10], Mohr's Circle, Permeability Test, Proctor Compaction, Sheet Pile Retaining Wall Analysis [Fig. 11], Triaxial Test and Vertical Effective Stress Calculation), discussed above, in the form of Java applets. These applets are again available free-of-charge from the first author's home page, as provided above.

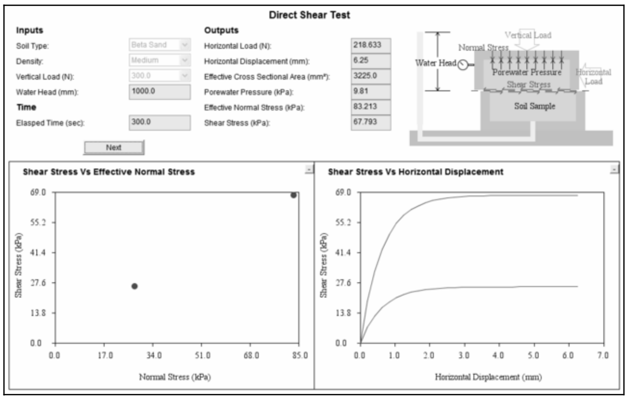


Figure 10. Direct shear test Java applet (Jaksa & Kuo 2009).

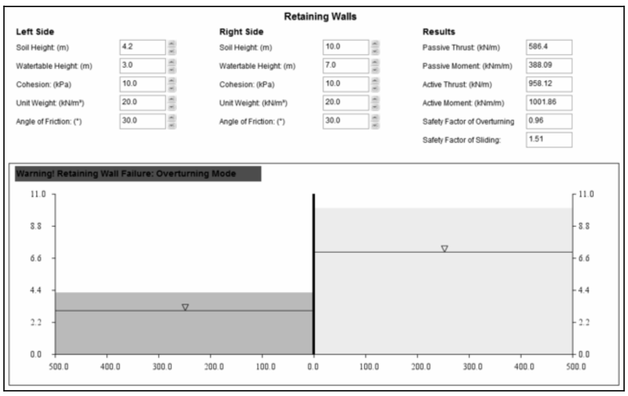


Figure 11. Sheet pile retaining wall Java applet (Jaksa & Kuo 2009).

Prof. Muniram Budhu has been instrumental in the development of a library of resources known as GROW (Geotechnical, Rock and Water Resources Library, www.grow.arizona.edu) which includes a wide range of interactive, multimedia and text resources (Budhu 2003). The site encourages external contributions and includes an extensive list of Budhu's online virtual soil laboratory tests (e.g.

consolidation, triaxial test, permeability, sieve analysis, soil water content) and two other interactive resources (e.g. shallow foundation design and mudslides).

Further geotechnical engineering e-learning resources are currently under development by Profs. Sunil Sharma from the University of Idaho, USA and Muniram Budhu from the University of Arizona, USA and will be made available in the near future (Budhu 2009, Sharma 2009).

Recently available software, such as *Articulate Presenter* (www.articulate.com/products/presenter.php), Adobe *Captivate* (www.adobe.com/ap/products/captivate/?sdid=EIKDK) and *Raptivity* (www.raptivity.com/raptivity-software.html), enables subject matter experts rapidly to generate e-learning objects from standard Microsoft *PowerPoint* files on their desktop and it allows for audio and video narrated content to be packaged with interactive and feedback mechanisms, such as Adobe *Flash* (www.adobe.com/products/flashplayer/) interactions and quizzes (Carrington & Green 2007). This is particularly desirable given the universal nature of Flash files, and provides a quick and efficient means of creating, delivering and managing educational material. Maier (2008b) argues that the use of such multimedia Flash presentations "*can increase student engagement and improve student experience by providing an appropriate learning context and an active learning environment.*" The issue of student engagement is discussed in greater detail later in the paper.

An example of a WBL environment incorporating Flash learning objects developed using Articulate Presenter is shown in Figure 12 (Maier 2008a). Such learning objects allow students to navigate the content freely and learn the topics in their own time. This is particularly relevant to international students, whose language skills may influence their learning ability in a traditional lecture format.

Such Flash learning objects have recently been incorporated into the Just-in-Time-Teaching (JiTT) approach to improve learning outcomes and enhance student engagement.


Figure 12. An example of a Flash learning object (Maier 2008a).

*Just in time teaching (JiTT)*

A relatively recent constructivist pedagogical approach, which has yet to be widely adopted, is that of Just-in-Time-Teaching (JiTT) (Novak et al. 1999, Marrs & Novak 2004, Linneman & Plake 2006). Novak & Patterson (2000) describe JiTT as a "*pedagogical strategy that combines the best features of traditional in-class instruction with the exciting new communication channels provided by the World Wide Web technologies*" and appears to show great promise for teaching and learning in the higher education sector, because of its student-centred approach and that it more effectively blends face-to-face and online activities than other pedagogies. Novak & Patterson (2000), who developed the methodology from a sciences background, point to dramatic improvements in retention rates, as well as significant increased cognition. JiTT is particularly useful in courses with large numbers of students, for part-time or commuting students, and for time-challenged students, such as those with employment and personal responsibilities (Novak et. al 1999).

The JiTT approach seeks to address three main objectives (Novak & Patterson 2000):

1. To maximize the efficacy of the classroom session, where human instructors are present;
2. To structure the out-of-class time for maximum learning benefit; and
3. To create and sustain team spirit, where students and instructors work as a team to maximise learning outcomes.

In essence, JiTT makes use of online material and subsequent assessment (usually formative, but in some cases diagnostic is also used) to inform the learning process in an 'interactive' fashion (Novak et al. 1999, Carrington & Green 2007). Rather than in the traditional face-to-face lecture format, introductory material relating to a particular topic is presented to the student body in an online environment, for example in the form of a learning object (Maier 2008a,b), as presented above. Students are then required to submit responses electronically to a series of small questions, usually 12 to 24 hours before a face-to-face class. The assessment task is designed to improve their learning, as well as a diagnostic tool for the instructor to assess the students' level of knowledge in regards to the topic. Informed by the results of this assessment, the face-to-face session is then designed to respond to both the needs and strengths of the students. An important additional aspect of the assessment is that it is explicitly discussed in the lecture to further improve learning outcomes. Finally, Novak et al. (1999) recommended that the lecture should also include periods designated for collaborative group learning, where small groups of two to four students work together to solve problems, aided by the instructor as required.

With respect to the online nature of the instruction process, Novak & Patterson (2000) stress that, although JiTT makes heavy use of the web, it is not to be confused with either distance learning or with computer assisted learning. Virtually all JiTT instruction occurs in a classroom with human instructors. The web materials, added as a pedagogical resource, act primarily as a communication tool and secondarily as content provider and organizer. Novak & Patterson (2000) suggested that JiTT web pages fall into three major categories:

1. Student assignments which are used in preparation for a classroom activity;
2. Enrichment pages, which are short essays on the practical and everyday applications of the topics and which include many web links to interesting material; and
3. Stand alone instructional material, such as simulation programs and spreadsheet exercises.

Carrington & Green (2007) proposed a slight variant to the JiTT theme, where they repackaged an 8-10 minute portion of a standard Law lecture in the form of a rapid e-learning presentation, using a Flash delivery tool (Articulate Presenter) from a narrated PowerPoint source file. After completing this short online module, the students then completed a multiple-choice quiz and the responses were returned to the lecturer in the form of tabulated figures. Of the 22% of students who responded to the survey, there was 66% broad agreement (students either agreed or strongly agreed) that: the preparatory lecture material was stimulating; it was useful to hear what others students thought about the issues; viewing content prior to attending the lecture improved my engagement with the issues discussed; and they would like to attend similar style lectures in the future. Carrington & Green (2007) also reported that the lecturer of the course commented that the process had identified a significant misconception, where 30% of the students misunderstood a point of law that was crucial to the development of the topic under discussion, and that she was able to adjust her teaching plan in order to address it. The lecturer also stated that obtaining the results from the assessment energized her presentation.

In the context of Water Engineering, Maier (2008a) proposed a hybrid Just-in-Time-Teaching / Project-Based Learning (JiTT/PBL) approach with elements similar to those of Carrington & Green (2007). Maier (2008a) suggested that the JiTT/PBL approach provides an active student learning environment which enables them to achieve higher-order learning outcomes, while offering a support structure that presents essential course content in an engaging and efficient manner.

At the centre of Maier's approach is a project- or problem-based learning (PBL) activity, with structured learning support provided by the Just-in-Time-Teaching (JiTT) framework, as summarised conceptually in Figure 13. In this context, Maier (2008a) implemented JiTT by utilising web-based, diagnostic feedback on the degree to which students understand key concepts and learning objectives, which is used to inform the structure, content and emphasis of the subsequent lecture. This feedback is generally obtained by the use of online quizzes, which students submit a few hours prior to the lecture. The lecture can then be altered 'just-in-time' in response to the quiz results, enabling greater emphasis to be given to topics students have difficulty with. This enables best use to be made of the precious face-to-face interaction between students and teachers.

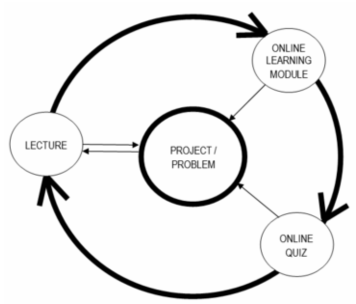


Figure 13. Conceptual framework for proposed hybrid JiTT / PBL approach (Maier 2008a).

In Maier's Water Engineering II course (compulsory introductory water engineering course delivered at second year to Civil and Environmental Engineering students), the learning support structure consisted of 9 JiTT cycles. The online modules were developed as multimedia Flash presentations using Articulate Presenter, as discussed earlier and shown in Figure 12. This enabled the incorporation of multimedia background and motivational material (e.g. video clips of recent news reports of major floods in different parts of the world), as well as the presentation of technical material, in an interactive and engaging manner. The presentations are audio-narrated and allow for easy navigation by clicking on links and tabs (Figure 12). It also enables students to access the relevant background material repeatedly and in their own time, on an as-needs basis (e.g. the online modules can be re-visited once students are working on related material for the design project).

Similar to the results of Carrington & Green (2007), the students involved in Maier's course overwhelmingly supported the JiTT/PBL approach with 85% broad agreement (BA) that the method of delivery adopted in this course was more conducive to learning than the more traditional lecture-tutorial format; 90% BA that the information in the face-to-face lectures was easier to understand as a result of having undertaken the online modules and quizzes beforehand; and 81% BA that the method of delivery adopted was more enjoyable than a more traditional lecture-tutorial format (Maier 2008a).

In moving forward, Carrington & Green (2007) stated that, for JiTT to be more widely adopted, two challenges need to be addressed: "*a capacity to readily and flexibly generate teaching and learning material, and an ability to conduct reliable and readily interpretable online assessments.*"

*e-simulations and situational learning*

Another emerging and promising e-learning paradigm is that of e-simulations, which is essentially a sub-set of situational learning. Situational learning incorporates a number of methodologies including simulations, case studies, scenario based learning and online role plays. These approaches immerse learners (working individually or in groups) into a situation where they face a series of authentic problems. In order to solve these problems, the learner must make decisions and deal with the consequences as they endeavour to achieve a satisfactory outcome. Material or learning aids are provided as needed, and the online learning environment is particularly appropriate to e-simulations, as images, video, audio and access to email or mobile technologies, can be used to enhance engagement and provide an authentic learning space. Discussion boards and face-to-face or online sessions are often incorporated in courses involving e-simulations to encourage students to reflect on the learning process. The use of e-simulations has been found to engage students, be efficient, represent an authentic learning environment and allow learners to use what they know and focus their time and energy on what they need to know.

Perhaps the earliest example of this in geotechnical engineering is the GeotechniCAL *Site Investigation* simulation of Moran et al. (1997). The e-simulation, which appears now to be no longer available, enabled students to encounter, through images, animation, video and audio, the challenges of authentic site investigations.

The authors are unaware of any existing geotechnical engineering e-simulations, but several exist in other areas of civil engineering. For example, Barends (2009) discusses an e-simulation known as *Levee Patroller*, which is used to train personnel in identifying, diagnosing, remediating, reporting on and mitigating levee risks and failures. Maier & Baron (2005) present the educational merits of the *Mekong e-sim* (www.adelaide.edu.au/situationallearning/mekong/), which is an online roleplay simulation set in the Mekong region of South-East Asia and which seeks to inform participants of the issues faced in the Mekong region and involve them in the hypothetical management of some of these conflicts.

Another recent development, and one which seeks to further engage Generation Y learners, is the use of the free online virtual world *Second Life* (secondlife.com/) as a learning and teaching tool. According to the owners and developers of Second Life, Linden Labs:

> "*Hundreds of leading universities and school systems around the world use Second Life as a vibrant part of their educational programs. Linden Lab works enthusiastically with education organizations to familiarize them with the benefits of virtual worlds, connect them with educational peers active in Second Life, and showcase their inworld projects and communities. …The Open University, Harvard, Texas State, and Stanford are just a few of the many universities that have set up virtual campuses* [Fig. 14] *where students can meet, attend classes, and create content together*" (Linden Research Inc. 2009).

Conklin (2007) presents 101 uses for Second Life in university learning and teaching, with her particular focus being associated with her course on Imaging Technology. Despite this, and as noted above, many universities are actively engaged in developing educational resources in Second Life. How this proceeds in the future is anyone's guess.

*e-assessment*

An essential aspect of education in general is that of assessment. This area, too, continues to be influenced by technological developments. Crisp (2007) presents an excellent overview of


Figure 14. A virtual university campus in Second Life (Linden Research Inc. 2009).

the e-resources that are currently available with respect to assessment in the higher education sector. Remote audience response systems, or 'clickers', have recently emerged as useful tools in obtaining 'instant' learner feedback in the classroom. Clickers, as shown in Figure 15, are remote devices similar in nature to television remotes controls. They use infrared or radio frequency technology to transmit and record student responses to questions posed by educators (EDUCAUSE 2005). A small, portable receiver is placed at the front of the classroom to collect and record student responses. Clickers are available for a nominal charge at campus book stores and are increasingly a required item, along with text books and calculators. More elaborate clickers are also available when more complex responses are required. Clickers are quite simple to adopt and educators are now using extensively to evaluate student mastery of content and to identify concepts that are proving difficult for students to grasp. They are also used in lectures to improve student engagement (EDUCAUSE 2005). On the negative side, although the simple units are relatively inexpensive, clickers are either purchased by the students or the institution. If the latter, they need to be distributed and collected at the beginning and end of the class, adding a further burden to the educator. The receivers and associated infrastructure can also be a mitigating factor, as these are generally expensive. Clickers can also detract from the learning experience, if poor questions are asked (EDUCAUSE 2005).


Figure 15. Two examples of a clicker.

*VotApedia* (www.votapedia.com/index.php?title=Main_Page) is an audience response system which overcomes several of the limitations associated with clickers listed above. The resource was developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia and makes use of mobile phones as the surrogate clicker, although a web-based interface is also available. The resource is available free-of-charge, does not require the issuing of clickers or need specialist infrastructure. It does, however, assume that the students have access to personal mobile phones, which, by the standards of today, as a realistic assumption. Prior to the lesson, the educator creates on the VotApedia website, either a 'simple survey', i.e. with a single question, or a 'questionnaire' with more than one question. Students are then asked to dial the phone number (or SMS the relevant text) associated with the their selected multiple choice answer. After allowing a small amount of time for the students to vote, the survey results can then be accessed via the internet and summarised in real-time in the classroom. Mobile learning technologies of this type are likely to continue to evolve in the future and be incorporated in mainstream teaching.

Before leaving the topic of assessment, it is worth emphasising the essential learning ingredient of feedback. There exists a great body of educational research which demonstrates that providing students with prompt and constructive feedback on their assignments and assessments can play an important role in helping them to achieve high-quality learning outcomes (e.g. Hounsell et al. 2006). As class sizes grow and educational resources diminish, e-assessment tools are needed to make the task of providing individual and relevant feedback more efficient. *Wimba Voice* (www.wimba.com/solutions/higher-education/wimba_voice_for_higher_education/) is an example of such a resource which allows educators to record audio feedback, as well as enabling voice discussion boards, embedded voice within course pages and voice-enabled e-mail.

*Challenges for the future of e-learning*

While e-learning technologies promise and deliver many benefits and efficiencies to higher educational learning, a number of challenges remain to be overcome in the future. For example, a key barrier for some institutions and in some countries, is infrastructure and funding, while another is engaging academics and students to use innovatively and effectively existing technological functionalities (OECD. 2005). Resistance to engaging many academics in e-learning can be explained "*by a lack of time (or motivation) to carry out what is foremost an additional task, by insufficient ICT literacy, or insufficient pedagogical literacy related to e-learning*" (OECD. 2005).

An important ingredient for e-learning success identified by OECD (2005) was the development of faculty-led initiatives. However, the scaling up of successful initiatives and mainstreaming of good practices, remain as real challenges.

Finally, OECD (2005) noted that, during the dot-com boom, one of the most frequently cited benefits of e-learning was the promise of lower program development and delivery. However, it is now recognised that e-learning generally incurs significant ongoing infrastructure costs. A geotechnical engineering example of this is related to the development and maintenance of many of the geotechnical CAL resources mentioned above and by Jaksa et al. (2000). Several consumed significant resources in their development, but many are now obsolete or now longer available, as they have failed to keep pace with changes in computer operating systems. The UK *GeotechniCAL* suite of PC programs (Davison 1996) for example, attracted significant government funding and much of the suite is now unfortunately obsolete or no longer available.

4.5.3 *Project-based learning*

Several geotechnical engineering educators (e.g. Seidel et al. 1994, Wesley 2000, McDowell 2001, Airey & Hull 2002, Wartman 2006, Airey 2008, Ledesma & Prat 2008, Phillips & McCabe 2008) have advocated the benefits of the project-based learning (PBL) approach. PBL "*refers to the theory and practice of utilizing real-world work assignments on time-limited projects to achieve mandated performance objectives and to facilitate individual and collective learning. [This form of learning] assumes that people learn most effectively when working on real-time problems that occur in their own work setting*" DeFillippi (2001). According to Airey (2008), PBL is "*one of a variety of inductive methods that also include problem-based learning, case-based teaching, discovery learning and just-in-time learning.*" The benefits of inductive approaches include: "*they enhance motivation to learn; they are more likely to lead to transfer of skills and knowledge to the workplace; they promote deeper approaches to learning and promote intellectual growth; they are consistent with the constructivist model of learning; and they are consistent with many learning cycle instructional models*" (Prince & Felder 2006, as cited by Airey 2008). PBL is widely used in engineering education, particularly for laboratory courses, final year projects and as part of introductory courses (Schachterle & Vinther 1996, Esche 2002, Mills & Treagust 2003, Airey 2008).

Airey (2008) stated that, in contrast to the great number of text books which have been written to support traditional, lecture-based engineering instruction, little guidance is available for the educator to implement new teaching practices such as PBL. His paper, on the other hand, succeeds in providing useful information for geotechnical engineering educators to implement PBL in their courses.

Summarising the results of student surveys of learning and teaching experience, Airey (2008) stated that PBL "*led to greater understanding than conventional lecture and tutorial courses.*" However, he also acknowledged that "*although the students unanimously reported that they had developed a greater understanding, their performance in examinations showed little evidence that they could generalise and apply this knowledge to other problems any better.*"

In their assessment of the pedagocial efficacy of PBL, Mills & Treagust (2003) concluded that "*the use of project-based learning as a key component of engineering programs should be promulgated as widely as possible, because it is certainly clear that any improvement to the existing lecture-centric programs that dominate engineering would be welcomed by students, industry and accreditors alike.*"

4.5.4 *Student engagement*

Student engagement, which has been defined as "*students' involvement with activities and conditions likely to generate high-quality learning*", is becoming increasingly understood to be essential for quality higher education (National Survey of Student Engagement 2008, Australian Council for Educational Research 2008, Little et al. 2009) and improving learning outcomes (Bowen, 2005; Carini et al., 2006; Bryson & Hand, 2007). Shulman (2002) stated "*learning begins with student engagement, which in turn leads to knowledge and understanding.*"

As has been observed above, the students of today have, as part of their pre-tertiary education, generally been exposed to a much richer variety of pedagogical methodologies and media than is currently employed in the vast majority of university engineering instruction. It is as a consequence of this that Jaksa (2008) believes that it is now a much greater challenge to engage and excite such students in what might be argued as the rather staid topics associated with soils and rock. Student engagement is also particularly challenging as class sizes continue to grow along with the increasing demands on academics' time.

With a particular focus on geotechnical engineering, Jaksa (2008) argued for a multi-faceted, or *blended*, approach to enhancing student engagement. Blended learning is a process which seeks to combine a variety of physical and virtual resources in order to facilitate improved learning and which incorporates many different learning styles. Jaksa (2008) advocated the continued use of the traditional forms of engineering instruction, such as formal lectures, tutorials, experimental practical classes and design sessions, but augmenting these with the use of demonstration models, e-learning, treatment of engineering case studies and failures and documentaries. Apart from e-learning, which has been treated above, the others are examined briefly below.

*Demonstration models*

Physical models have been used for decades to demonstrate various geotechnical engineering phenomena and have been shown to assist greatly with the understanding of fundamental geo-engineering principles (Burland 1987, 2008, Steenfelt 2000, Jaksa 2008). In fact, several academics have proposed a wide variety of physical demonstration models in relation to geotechnical engineering and extolled their virtues (e.g. Burland 1987, 2000, 2008, Barton & Grabe 1991, Poulos 1994, Kodikara 2000, Elton 2001, Atkinson 2007, Herle & Gesellmann 2008, Jaksa 2008). A brief treatment of a selection of useful physical demonstration aids follows.

Burland (1987, 2008) discussed the use and flexibility of the *Base Friction Model* (Fig. 16), which reinforces the particulate nature of soils. The 'soil particles' are represented by short lengths of copper tubing of three different diameters which are contained in a thin box having wooden sides that are hinged at the base (Fig. 17). The device is placed onto an overhead projector and it consists of a Perspex base, across which a standard acetate strip is drawn by means of a small, variable-speed, battery-powered, electric motor (Fig. 16). If the instructor wishes to trace movements and rotations of the individual 'particles', Burland (1987) suggested that a disc of transparent acetate sheet could be glued to one end of each tube, on which lines may be drawn with a felt-tip pen. Burland (1987, 2000, 2008) proposed that the base friction model can be employed to teach the following geotechnical engineering concepts: deposition, bearing capacity, simple shear, dilatancy and active and passive earth pressures.

Burland (2008) also proposed the use of a plastic cup (or beaker) to reinforce effective stress and demonstrate its influence on slope stability. The demonstration involves placing a plastic cup, which has been pre-filled with water to a certain level, on a damp slope made from a smooth timber or plastic board. The cup is stable and does not move. Next, a second cup is placed adjacent to the first and then filled with water to the same level as the first, whereupon it slides quickly down the slope. It is then explained to the class that the only difference between the cups is that the second has a small pin-hole in its base. Burland (2008) then asks the class for an explanation for the behaviour of the two cups. Later, he sets the class an exercise with a parallel-sided cup incorporating a small pin-hole, where he asks them to evaluate the limiting inclination of the slope.

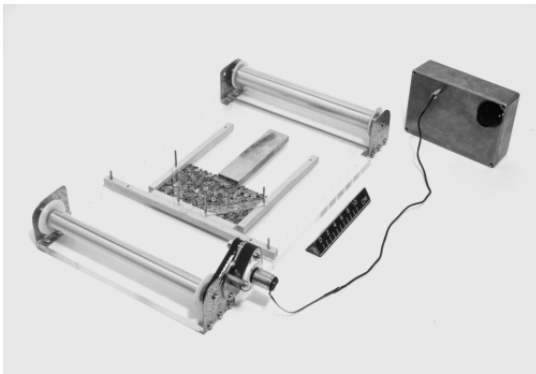

Figure 16. Base friction model. (Burland 1987, 2008).

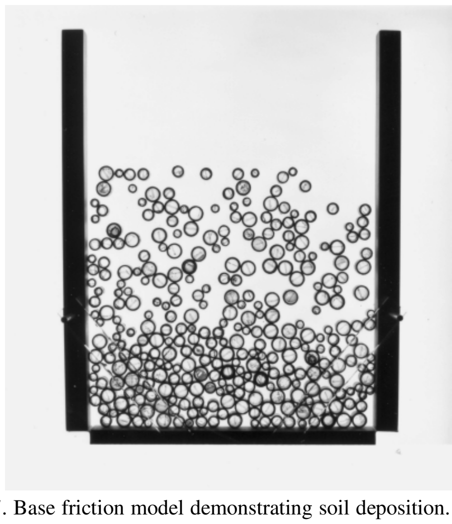

Figure 17. Base friction model demonstrating soil deposition. (Burland 1987, 2008).

Jaksa (2008) highlighted the efficacy of three demonstration models: the *Liquefaction Sand Column* (Fig. 18), *Vacuum-sealed Coffee Brick* (Fig. 19), and the *Consolidation Model* (Fig. 20), as being particularly valuable in engaging students but, more importantly, in reinforcing relevant geotechnical principles. The liquefaction sand column is a particularly useful teaching aid to facilitate a deeper understanding of pore water pressure, effective stress, the influence of flow direction on these, soil heave and liquefaction, whereas the vacuum-sealed coffee brick is an excellent physical example of the concept of effective stress, particularly when coupled with a brief discussion of vacuum mattresses (Fig. 21). The consolidation model is a physical representation of the conceptual model of the consolidation process proposed by Terzaghi. The demonstration is especially helpful in enabling the students to understand better the consolidation process, excess pore water pressure and consolidation settlement. Details of the demonstration models, how they are utilised in teaching, and specifications for their construction are provided by Jaksa (2009).

A survey conducted by the first author in late 2008, involving 66 third-year geotechnical engineering students, concluded that 91% of the students found these demonstrations to improve their learning and understanding of the topics, 89% found them to be engaging and relevant, and 92% believed that they understood the concepts presented in the course.

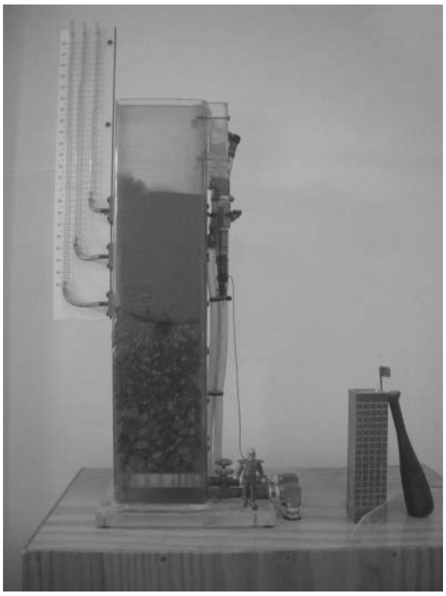

Figure 18. Liquefaction sand column. (Jaksa 2008).


Figure 19. Vacuum-sealed coffee brick. (Jaksa 2008).

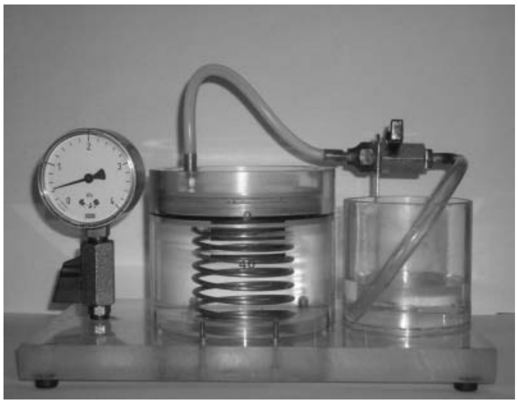

Figure 20. Consolidation model. (Jaksa 2008).

Figure 21. Vacuum mattress with hand pump. (Jaksa 2008).

In his booklet "*Soils Magic*", Elton (2001) catalogues a wide array of demonstrations to engage and educate students. The CD included with the booklet contains small video files showing each demonstration in a somewhat light-hearted fashion, where Elton assumes the role of 'Soil Magician.' Elton et al. (2006) states that the Soils Magic program has been effective at demonstrating the principles of soil mechanics to undergraduate engineering students, but has also been used effectively for elementary, middle and high school students as a means of outreach. This particular issue will be discussed again later in the paper.

Whilst not a demonstration as such, Wartman (2006) proposed a strategic approach to the use of physical modelling in geotechnical engineering education based on the learning styles of Kolb (1984). He applied his approach to the example of learning bearing capacity theory using the centrifuge. Whilst not readily available in many engineering schools, Wartman suggests that video archives of the experiment can be presented and reviewed in class.

Space does not permit discussion of the relative merits of all models, but the interested reader is directed to the following for additional examples of physical demonstration models: Barton & Grabe (1991), Poulos (1994), Andrei & Manea (2000), Bucher (2000), Kodikara (2000), Wesley (2000), Atkinson (2007), and Herle & Gesellmann (2008).

*Engineering case studies and failures*

In their recent review of civil engineering education, American Society of Civil Engineers (2007) recommended that "*engineering educators should explore the development of case studies of engineering successes and failures and the appropriate use of a case-studies approach in undergraduate and graduate curricula.*" Case studies (or case histories) are also closely aligned with project-based learning, which was discussed above in §4.5.3. Poulos (1994) also acknowledged the value of incorporating geotechnical case studies into the undergraduate and postgraduate curricula, although not before third year. He stated that the case studies "*should be directed towards giving the student an appreciation of the challenges involved in applying theory and analysis to real problems.*" In addition, he suggested that students should include treatment of: "*(1) an appreciation of the significant features and mechanisms* *of the problem; (2) the idealisation and simplification of the problem; (3) the assessment of the relevant geotechnical parameters; and (4) the fact that, almost invariably, there is insufficient data available on which to base this assessment.*" Many other geotechnical engineering educators have extolled the virtues of incorporating case studies in their instruction (e.g. Schlosser et al. 2000, Semprich 2000, Phillips & McCabe 2008, Popa et al. 2008).

Finally, with respect to case studies, Poulos (1994) urged the ISSMGE to develop a catalogue of suitably documented case histories for use by academics who may not have access to suitable design projects. To this end Pantazidou et al. (2008) proposed a template for the development of such case studies by means of a collaboration between industry and academia.

Intimately associated with the process of sound engineering design practice is learning from failure. In fact, Petroski (1985) argued that engineering is a human endeavour and it is therefore subject to error and that we learn from an early age about engineering success and failure. They are integrally linked with our childhood through growing (e.g. learning to walk) and nursery rhymes, such as *Rock-a-Bye Baby*, *London Bridge*, *The Three Bears*, and *The Three Little Pigs*. Petroski (1985) stated that "*success may be grand, but disappointment can often teach us more*." The recent special issue of the Proceedings of the Institution of Civil Engineers in November 2008, entitled *Learning from Failures*, further underlines the importance of incorporating treatment of failures in the education of geotechnical engineers.

Jaksa (2008) advocated incorporating treatment of relevant geotechnical failures into the curriculum for the dual purpose of increasing student engagement and enhancing learning. In his paper, Jaksa (2008) made reference to the following engaging and relevant geotechnical failures: *Dam Failures:* Malpasset 1959, South Fork 1889, Stava 1985, St. Francis 1928, Teton 1976, Vajont (also Vaiont) 1963; *Landslides and Sinkholes:* Aberfan 1966, Frank Slide 1903, Rissa 1978, Saint-Jean-Vianney 1971, Thredbo 1997, Waihi Sinkhole 2001; *Bearing Capacity Failures:* Transcona Grain Elevator 1913, Fargo Grain Elevator 1955; *Other Failures:* Bulbul Drive landfill 1997, Loscoe landfill gas explosion 1986, Niigata earthquake 1964, Port Broughton house collapse 2000, and Schoharie Creek 1987. Treatment of the iconic Leaning Tower of Pisa, and it subsequent rehabilitation is particularly relevant and engaging.

The survey reported earlier, involving 66 third-year geotechnical engineering students, concluded that 94% of the students found treatment of geotechnical engineering failures to be engaging and relevant.

Popescu & Popescu (2000) include two of the above geotechnical failures in their courses, as well as six others, in order to build student research skills.

*Documentaries*

Recently, as highlighted by Jaksa (2008), the production of high-quality, engineering-related documentaries has increased greatly over the last 5 to 10 years. These are often broadcast on cable (pay-TV) channels, such as the Discovery and the National Geographic Channels and, to a lesser extent the History Channel. These documentaries, which are typically 60 minutes in duration, are highly engaging, for engineers and engineering students, as well as the public at large. Notable series, which generally consist of several different episodes, include: Building Big (2000), Building the Biggest (Discovery Channel 2009b), Extreme Engineering (Discovery Channel 2009a), Frontlines of Construction (DigiGuide 2009), Megastructures (Wikipedia 2009a), Modern Marvels (Wikipedia 2009b) and Seven Wonders of the Industrial World (BBC 2003). A more extensive list of geo-engineering-related documentaries is shown in Table 1. A number of these documentaries are available for purchase on DVD, however, many are not. With the advent of relatively cheap and available

Table 1. List of geo-engineering-related documentaries.

| **Series** (references) and Episodes |
|---|
| **Building Big** (Building Big 2000): Dams; Tunnels |
| **Building the Biggest**[D] (Discovery Channel 2009b): Diamond Hunters; Underground Singapore |
| **Decoding Disaster**: Mudslides |
| **Disasters of the Century**[H] (Partners in Motion 2004): All Fall Down (Malpasset Dam failure, France 1959); Black Week (Senghenydd mine collapse, Wales 1913); Deadly Elements (Rapid City dam failure, South Dakota 1972); Death and Profits (Springhill mine collapse, Nova Scotia 1958); Death in a Small Town (St Jean Vianney sinkhole, Québec 1971); In an Instant (Vajont Dam failure, Italy 1963); Living on the Edge (Frank Slide, Alberta 1903; Hillcrest Mine disaster, Alberta 1914); When the Earth Moves (Great Kantō earthquake, Japan 1923; Managua earthquake, Nicaragua 1972) |
| **Extreme Engineering**[D] (Discovery Channel 2009a): Boston's Big Dig; Building Hong Kong's Airport; Malaysia Smart Tunnel; Subways in America; Three Gorges – The Biggest Dam in the World; Transatlantic Tunnel; Tunneling Under the Alps; Widening the Panama Canal |
| **Frontlines of Construction**[NG] (DigiGuide 2009): Blasting; Danger; Defying Gravity; Disaster; Dubai's Palm Island; Hammer This!; Mega Machines; Oasis; Offshore; Risk Top Ten |
| **Frontiers of Construction**: A Giant Out of Water (Chek Lap Kok Airport); The Big Dig; Dubai – City of Dreams; The Eurotunnel; Heavy Traffic; The Oresund Link |
| **Kings of Construction**[D]: Hallandsas Tunnel; Hoover Dam Bridge; South Ferry Subway Terminal |
| **Man Made Marvels**[D] Taiwan's Hsuehshan Tunnel |
| **Mega Builders**[D] (Barna-Alper undated): Madrid's Big Dig; Moving Mountains; Palm Islands; Quake Proofing an Icon; Saving New Orleans |
| **Megastructures**[NG] (Wikipedia 2009a): Boston's Big Dig; Channel Tunnel; Deep Sea Drillers; Diamond Diggers; Garbage Mountain; Hoover Dam; Itaipu Dam; Kansai Airport; Megabridges – China; Megabridges – Denmark to Sweden; Megabridges – Greece Rion-Antirion Bridge; Rock Breakers of Iceland; Millau Bridge; North Sea Wall; Panama Canal Unlocked; Petronas Towers; Port of Rotterdam; Ultimate Oil Rigs; World Island Wonder |
| **Modern Marvels**[H] (Wikipedia 2009b): Aswan Dam; The Basement; Building a Skyscraper– The Skeleton; China's Great Dam; The Chunnel; Coal Mines; Dams; Diamond Mines; Dredging; Drilling; Earthmovers – The Power to Move Mountains; Earth Movers II; Engineering Disasters of the 70s; The Erie Canal; Engineering Disasters (1–21); Gold Mines; Grand Coulee Dam; Hoover Dam; Levees; London Underground; More Earthmovers; The New York City Subway; Offshore Oil Drilling; Panama Canal; Paving America; Quarries; Runways; Shovels; Suez Canal; Superhighways; Tunnels; World's Biggest Machines |
| **Seconds From Disaster** [NG] (National Geographic 2009): Flood at Stava Dam; Killer Quake (Kobe Earthquake); Mount St. Helens Eruption |
| **Seismic Seconds**[NG] (Wikipedia 2009c): The Eruption of Mount Saint Helens; Sarno Slides; Teziutlan Slides |
| **Various**: Catastrophe: San Francisco Earthquake[D]; China's Mega Dam – The Three Gorges Dam[D]; Extreme Earth – Saving Our Crumbling Coastlines[D]; Landslides – Gravity Kills; Legacy: St. Francis Dam Disaster with Frank Rock; On the Inside: The Leaning Tower of Pisa[D]; The Rissa Landslide: Quick Clay in Norway; Seven Wonders of the Industrial World[B]; Stress Test – Collapse[D]; Tunnels – Digging in[D]; Ultimate Earthquake Disaster[NG]; When Nature Strikes Back – Landslides[D]; Wild Weather – Landslides |

B: BBC; D: Discovery Channel; H: History Channel; NG: National Geographic Channel.

video editing software, it is possible for geotechnical engineering educators to record, download and edit these documentaries and show some, or parts of them, in class to highlight various aspects of geotechnical theory.

As part of his teaching, the first author makes regular use of the following documentaries: *Rissa Landslide: Quick Clay in Norway* (Norwegian Geotechnical Institute 1981), *The Leaning Tower of Pisa* (BBC, NG, Discovery Documentary Video 2008); the *Building Big* series (Building Big 2000); *Extreme Engineering: Building Hong Kong's Airport* (Discovery Channel 2009a); *Disasters of the Century: All Fall Down (Malpasset Dam failure, France 1959), Death in a Small Town (St Jean Vianney sinkhole, Québec 1971), and In an Instant (Vajont Dam failure, Italy 1963)* (Partners in Motion. 2009). It is the first author's experience that inclusion of such documentary footage in lectures greatly enhances student engagement, which in turn, leads to improved student learning outcomes. This is supported by the results of the student survey discussed above, where 94% of the students found the documentaries to be engaging and improved their learning.

#### 4.5.5 *Teacher engagement in student learning and qualities of a good teacher*

Learning and teaching research also clearly demonstrates that for learning to be effective, teachers must be committed to and actively engaged in the learning process. Brain (1998) identifies the four 'core' qualities of a good teacher as being:

- Knowledge: He found that, of the surveys that he performed on tertiary students, where he asked them to list the qualities of a good teacher, every one listed, as a primary prerequisite, 'knowledge of the subject.' In addition, the subject matter must be relevant.
- Communication: A good teacher can effectively communicate with the students and can convey often complex concepts in a manner which enables students to learn effectively. Brain (1998) states that "*a good teacher can take a subject and help make it crystal clear to the students*" and "*a good teacher is willing to expend the effort needed to find innovative and creative ways to make complicated ideas understandable to their students*."
- Interest: Good teachers exude a passion for their subject matter, and this enthusiasm is increases student engagement and improves learning. "*The best teachers… are interested in the material being taught, they make the class interesting and relevant to the students*" Brain (1998).
- Respect: Finally, Brain (1998) argues that good teachers "*have a deep-seated concern and respect for the students in the classroom*." This includes providing or facilitating student pastoral care and effecting a nurturing learning environment. Novak & Patterson (2000) noted that consistent and friendly support often means the difference between a successful course experience and a fruitless effort, and often the difference between graduating and dropping out.

Another important ingredient of a good teacher is that of humour. De Bono (1996) stated that "*humour is by far the most significant behaviour of the human brain…* [and] *is the essence of creativity*." In addition, as Edwards et al. (1997) indicate, humour "*gives a fresh view*", "*helps build teams*", "*enriches lives*" and "*makes people feel good*." Powell & Andresen (1985) found, through empirical studies of the connections between humour and learning, that the use of humour "*provided it is not used to excess, can increase attention and interest and help to illustrate and reinforce what is being taught. It is suggested that the presentation of humorous material involves skills which can be learnt through practice and that staff development programmes should provide opportunities for academics to acquire such skills.*" In addition, Powell & Andresen (1985) state that "*it is well-known that students appreciate an element of humour in their teachers and that humour is an aid to effective communication.*"

### 4.6 *Future challenges for geotechnical engineering education*

A number of challenges remain to be addressed in geotechnical engineering education in the future. These include:

- Training versus education: As outlined in §3, the nature of education and training is very different. It has been observed that pressure remains, and is likely to increase in the future, for engineering courses to include more 'soft skills', such as those related to communication, management, personal development, and social, environmental and ethical awareness. Atkinson (2002, 2008) strongly argues that development of soft skills is the responsibility of training carried out in the work place, post-tertiary education, not universities. The latter, Atkinson (2002, 2008) suggests is where the future engineer acquires their essential knowledge of fundamental geotechnical engineering principles. Atkinson (2008) lists 6 basic formulae which geotechnical engineers should be able to derive from first principles. In this context, Atkinson defines a geotechnical engineer as being a Masters-level graduate. If soft skills training is included in undergraduate education, within a finite 4- or 5-year program, the amount of time devoted to learning the basics of soil mechanics diminishes and will, as a direct consequence, affect the competency of future geotechnical engineers. Phillips and McCabe (2008), however, proposed a framework whereby soft skills could be acquired without adversely affecting the geotechnical engineering academic rigour.
- Codes of practice and standards: Lively debate continues about the importance and place of Codes of Practice in undergraduate education. Atkinson (2002) suggests that many codes and standards are flawed, based on unsound theories and out-of-date practices, and their range of application is limited to the situations that they cover. As a consequence, Atkinson (2002, 2008) argues that teaching codes of practice and standards is training and should be carried out at work. In the other camp, Orr (2008) advocates the holistic nature of standards and codes of practice and argues that Eurocode 7 should be taught at university.
- Cohesion: Perusing most past and present geotechnical engineering text books demonstrates that most are inadequate when it comes to the distinction between fine- and coarse-grained soils, and the description of cohesion. Atkinson (2002, 2007, 2008), as well as Santamarina (1997) and Schofield (1998), strongly advocates that soils should be differentiated only by their grain size and terms such as 'cohesive' and 'cohesionless' are incorrect and should be avoided. Viana da Fonseca & Coutinho (2008) suggest that cohesion occurs as the result of 6 different, possible sources: (i) cementation; (ii) suction; (iii) van der Waals attraction; (iv) 'clay bonding', which is adhesion of clay particles around some larger silt or sand particles; (v) contact cementation that develops with time and pressure; and (vi) the interaction of organic matter, mostly fibres, with particles. Nevertheless, in uncemented soils, cohesion is essentially the manifestation of soil suction. Atkinson (2008) states that "*soils should be described as coarse-grained or fine-grained as grain size (strictly pore size) controls suction and drainage.*" It is essential that geotechnical engineering educators heed such advice.
- Who teaches the teacher: Atkinson (2008) raises another fundamental aspect of geotechnical engineering education; that is, the quality of the instructors. He states:

> "*Many university teachers teach what they themselves were taught, and so teach another generation the same thing in the same way. (This is entirely understandable since university staff will further their careers more by excellence in research than excellence in teaching.) Several standard and well-used textbooks were first written several decades ago*

*and, although they have been revised they remain much the same as the original. As a result the basic principles of geotechnical engineering are often badly taught and there is little progress and innovation in geotechnical engineering practice*."

Opportunities for early career academics to further their understanding of basic geotechnical engineering are limited, as coursework Masters-level programs disappear in many institutions around the world.

- Practical classes: As student numbers continue to grow, limited laboratory and technical staff resources, as well as academic workload pressures, have caused several engineering schools to consider deleting practical classes (i.e. laboratory or experimental classes) from their courses. This is an undesirable outcome, as competent geotechnical engineers require skills in identifying and classifying soils, as well as the time and care needed to undertake reliable soils testing and appreciating the errors inherent in it. Burland (1987) question the educational value of requiring undergraduate students undertake routine laboratory testing, such as the triaxial, direct shear and oedometer tests. He stated that students are far from inspired by these. Burland argued that these are best demonstrated in class by means of video recordings, using modern equipment and up-to-date procedures.

  The same view is held by Poulos (1994) who stated that "*with the advent of modern technology, it would seem desirable that, in the laboratory component of the basic courses, less emphasis be placed on the testing procedures themselves, and more emphasis be placed on demonstration experiments and tests which enable comparisons to be made with theoretical analyses*." Prof. Muir Wood is quoted by Orr (1992) as having stated "*…there is no sympathy for the view that the manual recording and processing of data is good for students. Time needs to be spent productively and experiments which merely confirm well understood facts should be removed. Routine tests should be demonstrated using modern equipment such as video and up-to-date procedures… The role of geotechnical teachers is not to train laboratory technicians but to impart understanding*."

  Despite these statements, some more than 20 years ago, the geotechnical engineering education literature is largely silent on this issue. With the modern technology, currently available today, particularly in relation to digital audio-visual resources, one would expect that such teaching resources would be readily available. This is far from the case. Isolated examples do exist, or are under development (e.g. Budhu 2000, Yuen & Kodikara 2008, Sharma 2009), but geotechnical engineering education is in great need of such resources.

### 4.7 *The way forward*

So what can one make of the trends and developments articulated above with respect to geotechnical engineering education in the future? It is clear that the world's population will continue to grow and hence demand for infrastructure and geotechnical engineers will increase as a direct consequence. Demand will be particularly strong in the developing world, and somewhat less so in the developed world. Demand for energy is expected to double by 2050, with fossil fuels accounting for 70% of this. Energy production will be more efficient and despite this, the mean global temperature is anticipated to continue to rise. In relation to the tertiary sector, increasing demand for infrastructure and energy will translate into greater student numbers in geotechnical engineering undergraduate programs. Unless the political will changes dramatically, it is also likely that student staff ratios will continue to grow in a climate of diminished public funding. With the maturation of the Bologna process, as well as more developed and available mobile and learning and teaching technologies, education will become increasingly globalised. If current trends continue, the mean age of academic staff will continue to grow, as younger staff become more difficult to attract into academe.

In relation to engineering education, it appears that engineers will need to be more multi-disciplinary in nature and the requirement for even greater 'soft skills' upon graduation seems likely to increase. Aligned with this, as well as the Bologna process, it is conceivable that the signatories of the Washington Accord may extend undergraduate engineering degree programs from 4 to 5 years in duration.

The crystal-ball gazing of Simpson & Tatsuoka (2008) showed us a glimpse of the future of geotechnical engineering in 60 years time. Associated with the trends mentioned above, it is expected that environmental issues, particularly in relation to satisfying the world's energy needs, as well as arresting global warming, will be increasingly prominent. The need for more underground space will grow and technological developments will improve the accuracy and complexity of geotechnical investigations, monitoring, modelling, analysis and design.

Technological developments will also continue to influence learning and teaching, perhaps more so in the near future than in the past. Advancements in mobile technology will greatly affect how students learn. Geotechnical engineering teachers will increasingly engage with researchers in the mainstream of education and the result will be more informed and evidence-based instruction and learning than is currently the case.

With the future geotechnical engineering emphases predicted by Simpson & Tatsuoka (2008) it is likely that future courses will include treatment, to varying degrees, of the topics listed in Table 2.

Table 2. Likely additional future topics in geotechnical engineering courses.

| |
|---|
| Environmental geotechnics |
| Sustainable geotechnical engineering |
| Designing underground spaces and tunnels |
| Thermal behaviour of the ground |
| Unsaturated soil mechanics |
| Reuse of urban foundations |
| Development and implementation of geotechnical databases |
| Artificial neural networks |
| Risk analysis in geotechnical engineering |

The addition of these new topics, as well as the predicted direction for greater treatment of soft skills and topics which provide academic breadth, is likely to exacerbate the current pressure on the geotechnical engineering curriculum, as articulated above. Hence, the tension between education of the geotechnical engineering fundamentals versus on-the-job-training, as argued by Atkinson (2002, 2008), will be even more relevant and acute than at present.

There is a role for the ISSMGE to play in the future of geotechnical engineering education. It is recommended that the ISSMGE, probably through JTC3, consider driving the following initiatives:

- Shared educational resources: Geotechnical engineering teachers across the globe develop and need educational resources, such as lecture notes, PowerPoint presentations, tutorial and examination questions and answers, photographs, videos, CAL resources, and details of laboratory experiments and design projects. Given the current pressures on academics, there is never enough time nor funding to facilitate the development of these. The GROW resource developed by Budhu (2003), as discussed earlier, is a web-based facility for sharing such resources. Details of demonstration models, CAL resources and Java applets could also be disseminated through such a vehicle.

  As mentioned above, there is an urgent need for the development of high-quality educational resources which educate students in the often mundane aspects of laboratory experiments, such as the triaxial, direct shear and oedometer tests. The development of innovative and pedagogically effective practical experiments is also in great need.

- Develop a bibliography of useful geotechnical engineering education references: Geotechnical engineering teachers need ready access to important and useful papers relating to geotechnical engineering education. Compiling a list of these, as well as making them available through a web-based library, as discussed above, would be extremely desirable and helpful.
- Promote increased recognition of the importance of quality education: As mentioned earlier in the paper, academics are increasingly under pressure to perform as measured by a variety of key performance indicators. In almost all but a few isolated instances, academics are measured much more on the quantum and quality of their research output than on the quality of their teaching. The ISSMGE could make a strong statement to redress this situation to some extent by establishing an award, or series of awards, which recognise excellence in geotechnical engineering learning and teaching.
- Contribute to the debate on soft skills: Again, as discussed previously, professional engineering bodies, who often accredit engineering undergraduate programs, generally mandate that greater amounts of soft skills training be included as part of an engineer's tertiary education. As Atkinson (2002, 2008) argued, this is often to the detriment of education in the fundamentals of geotechnical engineering. The ISSMGE has the opportunity to be a strong voice which reins back such professional society demands.

## 5 RAISING AWARENESS OF IMPORTANCE OF GEOTECHNICAL ENGINEERING

The recent reviews of engineering education discussed earlier, all highlight the critical importance of engaging the community to raise the public perception of engineering "*by increasing the visibility of the innovative and creative nature of engineering and the range of engineering occupations that contribute to [the nation's] prosperity, security, health and environment*" King (2008). In addition, these reviews also recognised that much greater effort is needed to engage with school children so that they perceive that engineering is an exciting and rewarding profession worth pursuing (Royal Academy of Engineering 2007). The aim of the ISSMGE is "*the promotion of international co-operation amongst engineers and scientists for the advancement and dissemination of knowledge in the field of geotechnics, and its engineering and environmental applications*" (ISSMGE 2009) and this includes raising the awareness of the importance of geotechnical engineering. This section examines this objective and proposes a number of vehicles and strategies for improving awareness of the public, the engineer and the owner.

### 5.1 *Engaging the general public and school children*

Burland (2006) begins his treatment of changing the public perception of civil engineering with the well-known British telephone directory entry: "*Civil Engineering… see Boring*" and suggests that this is, all too often, the general public perception of civil engineering. Perhaps more relevant in one sense, the entry should say: "*Geotechnical engineering… see Boring*." However, we in the geotechnical profession know that our field is exciting and essential to the fabric of society. A significant challenge for the geotechnical profession, on many levels, is that the ground is generally hidden from view, as are the vast majority of the structures that we create. Hence, the general public is mostly ignorant of much of what we do. This is also true for civil engineers, to a certain extent, but skyscrapers, bridges, tunnels and dams are examples of iconic human creations which underscore the vital importance of civil engineering in enhancing civilisation. In fact, one could argue that it is civil engineers who put the 'civil' in 'civilisation' (Walker 2008). However, the foundations which support them and the inner details of tunnels and dams which allow them to serve their intended purpose, are almost exclusively hidden from view. Illustrations such as those created by Keller (1998) (Fig. 22) and Macaulay (1976, 2000) (Fig. 23) assist in this regard, but much remains to be done.

Figure 22. View from underground (Keller 1998).

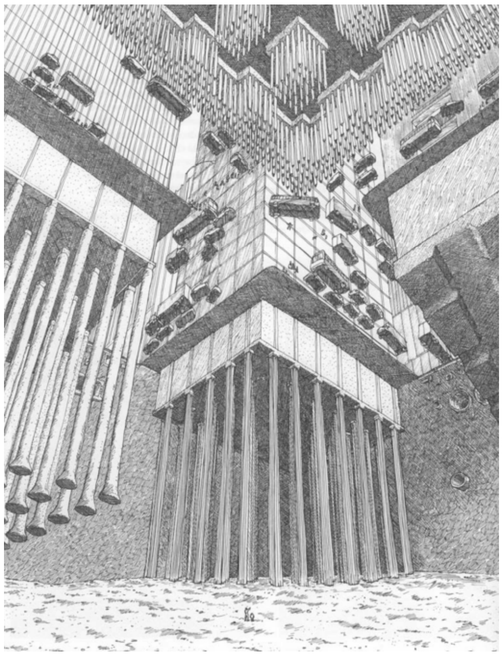

Figure 23. View from *Underground* (Macauley 1976).

Whilst also being valuable for the education of engineering students, these documentaries are powerful vehicles for educating the general public in the value of geotechnical engineering to society. In order to enhance this, it would be useful for the geotechnical engineering profession, including the ISSMGE, to be pro-active with the producers of such documentary series to facilitate the development of more high-quality and engaging geo-engineering-related documentaries, which would improve public awareness of the importance of geotechnical engineering.

As attested by Petroski (1985), that failure can often teach us more than success, the public are captivated by stories of engineering failures. The shear number of documentaries dealing with failures and tragedies attests to this. However, positive stories dealing with geotechnical engineering's successes must also be highlighted to further inform the public about the importance of geotechnical engineering. An excellent example is the 2001 Discovery Channel documentary on the successful application of geotechnical engineering to the

Leaning Tower of Pisa (BBC, NG, Discovery Documentary Video 2008). Another is the 1978 Rissa landslide (Norwegian Geotechnical Institute 1981) and how the sudden quick clay failure identified unacceptable risks which were mitigated through successful geotechnical engineering investigation and remediation.

The general public are also informed and educated about geotechnical engineering through the use of demonstrations (Elton 2001, Jaksa 2008). The first author's experience that a demonstration of quicksand using the liquefaction sand column (Jaksa 2008) facilitates public engagement and also provides an opportunity for discussing how geotechnical engineers might design solutions to mitigate the risk of liquefaction, thereby providing education regarding the importance of geotechnical engineering. Elton's *Soil Magic* demonstrations provide further examples of means by which the general public, and engineering students, can be further engaged (Elton 2001).

### 5.2 *Engaging the owner and non-geotechnical engineer*

An education matter of critical importance for the owner and the non-geotechnical engineer is that of characterising the ground appropriately. The construction and ultimate performance of some piece of infrastructure, such as a road, building, tunnel or dam, lies in successfully characterising the ground, so that appropriate geotechnical elements can be designed. If inadequate site investigations are undertaken, greater uncertainties are associated with the ground characterisation and resulting geotechnical design parameters which, in turn, may lead to unforeseen construction problems, construction delays and cost over-runs and geotechnical elements which are overdesigned. Several international studies have demonstrated that, in the vast majority of cases, too few resources are committed to the geotechnical investigation (National Research Council 1984, Institution of Civil Engineers 1991, Littlejohn et al. 1994, Whyte 1995, Jaksa 2000). Expenditure on geotechnical site investigations varies considerably, sometimes as low as between 0.025% (Jaksa 2000) and 0.3% (National Research Council 1984) of the total project cost. As a result, the Institution of Civil Engineers (1991) concluded that: "*You pay for a site investigation whether you have one or not*." This is a message of vital importance which must be communicated to owners, developers, project managers and non-geotechnical engineers, who often set budgets for site investigations and decide the successful site investigation tenderer, which dictate the scope of the ground investigation undertaken for a particular development.

Atkinson (2002) noted the unsatisfactory position that much of the ground engineering work in the United Kingdom is done by non-geotechnical professionals. This is probably also true in many other places. The value and importance of timely input by suitable geotechnical and engineering geological experts, from the planning stage through investigation, design, construction to the maintenance stage, are often not fully appreciated by civil engineers and project managers.

Educating owners, developers, project managers and non-geotechnical engineers about the importance of appropriate site investigations and geotechnical input may be enhanced by the ISSMGE promoting the establishment of a database which compiles costs and details associated with projects which resulted in problems associated with inadequate site investigations and geotechnical input. This would enable risks and probabilities of failure to be quantified, thereby better informing the public and engineering profession about the risks inherent with limited site investigations and inadequate geotechnical input by suitably qualified and experienced personnel.

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