

## Looking ahead - geotechnique goes high tech

Za-Chieh Moh, Chung-Tien Chin and Richard N. Hwang - *Moh and Associates., Taipei, Taiwan*

**ABSTRACT:** This paper discusses how geotechnical engineers shall adapt to the rapid advancement in technology and what can be expected in the years to come. It covers automation, database management, geographic information system, remote sensing, and global positioning system, etc., leading to final goal of Internet-engineering. Emphasis is on the use of Internet and web technology to facilitate information sharing with the aim of improving the quality of works and productivity.

### INTRODUCTION

In 1773, Charles Augustin de Coulomb addressed the Academy of Science and presented the "essay on the application of the rules of maxima and minima to certain static problems relevant to architecture". This essay, printed three years later by the Academy, is believed to be the earliest published soil mechanics theory starting the active and passive pressure concepts. In the past two centuries since then, geotechnical engineering has progressed rapidly in the same pace as other fields of engineering. New field tools were invented for characterizing soils with better precision and new laboratory techniques were made available to determine soil response to complex loading conditions. Geo-processes, such as high-pressure grouting, ground freezing, dynamic compaction, etc., gained the wide acceptance of the profession for improving ground conditions. Numerical algorithms, together with non-linear material models, enabled complicated soil-structure interaction problems to be solved.

The rapid advancement of computer technology since the mid-80's, however, appears to have left civil engineering, and geotechnical engineering as well, behind in comparison with other fields in science and engineering, not to mention the financial and business sectors. The so-called e-mailing, e-commerce, e-business, e-service, e-book, e-card, e-banking and e-library, so on and so forth, have become a trend of future. While computers have dramatically changed the way other fields operate, the use of computers by civil engineers, as a whole, is still pretty much limited to administrative and analytical works.

### INTERNET AND WEB TECHNOLOGY

The most significant advancement in technology in recent years must be the invention of internet which practically links computers all over the world into a gigantic network, the so-called world-wide-web (www). Nearly all the firms, even ones with a handful of staff, nowadays have local-area-networks (LAN) to connect computers and peripheral devices in the offices for their staff to share information and resources. Furthermore, information is kept in databases and made accessible to a large number of users at the same time. These databases are well organized and managed in a systematic manner to form an "intranet". Many large firms already have connected the LAN at various offices to form a wide-area-network (WAN) and expanded the intranets to form an "extranet" to enable their staff at various locations to communicate with each other. With the technology of the so-called virtual private networks (VPN), which tunnel through the

networks, one may gain access to databases, which are stored anywhere in the world via internet. This is particularly important for companies with a large number of branch offices and/or international companies with branch offices in many countries.

The use of internet is not limited to internal applications and internet has essentially become a common backbone for communication among individuals, institutes, governmental agencies, and practically anyone who desires to have the connection, and digital information is free to flow in a web-like network. Since internet is an open system and is intentionally designed to be easy to use by everyone, the security of information is a concern. Information is protected by a combination of firewall server management, the use of digital certification, user authentication and encryption of messages.

Neither is the use of internet limited to sending and receiving messages. As illustrated in Fig. 1, practically all types of digital information, being text, photo images, audio messages, animation, and video records, can be transmitted via internet. Bandwidth of the transmission lines, however, limits the amount of data, which can be transmitted effectively. A few years ago, dial-up modems were mostly of 9.6-Kbps (bits-per-second) type and nowadays 56-Kbps modems are prevailing. Recently, the DSL (Digital Subscriber Line) technology has matured and allows transmission speed up to several Mbps. The way it goes, as far as engineering applications are concerned, bandwidth will no longer be a limiting factor in a few years to come.

Internet and web technology are making geography vanish and removing barriers between disciplines. The concept of the so-called "virtual office" is fast spreading. It goes far beyond sharing of data. It allows works to be distributed to parties over different places and integrated on a website, i.e., a centralized data center. One can get hold any piece of information on the internet at his/her fingertips and distance is no longer measured in miles, but in seconds. This is to drastically change the mode of operation in every field and how successful a company is adapting to this mode of operation will be a primary factor determining its growth.

### INFORMATION SYSTEM

Figure 2 shows the technical and non-technical information involved in, for example typical transportation projects. The items

shown are indicative and are by no means exhaustive. Many large projects require information far more than what are shown. Rapid transit systems, hydro-electrical power plants, etc., for instances, involve hydrology, mechanical, electrical, trackwork, etc. All these data, whatever they are, can easily be shared by, as depicted in Fig. 3, project owner, designer, construction manager, site supervising staff, contractor, subcontractor, specialist contractor, etc. by using internet as long as they are digital and stored systematically. This drastically reduces interface problems among various parties and shortens the response times.

Powerful software packages, however, are required to transfer the digital data in the databases to a type of information understandable to users. As illustrated in Fig. 4, non-technical information systems usually are referred to as management information systems (MIS) which handle administrative and financial information required for book-keeping, reporting and decision making. Most of the technical information can be manipulated by the so-called geographical information systems (GIS). In its original context, GIS manages only information involving geographic features. Nowadays, the definition of GIS has been expanded to include all the software systems developed with the specific aim of organizing databases in an orderly manner to facilitate easy retrieval and picturesque display. Although this definition is still being challenged by some people for its looseness, it is gaining recognition worldwide. With this definition, GIS is moving beyond its traditional role as a standalone system and has emerged as a core data management technology.

Modern GIS software has combined internet technology to become Internet-GIS. The so-called client-server configuration allows a large number of users to use the same database in a server at the same time no matter where they are. It is a world-wide trend for all the large organizations to centralize information on servers at their headquarters and made it accessible, with proper security control, to users all over the world. This makes the maintenance of the databases much easier.

#### Internet-GIS GEOTECHNICAL ENGINEERS

As far as geotechnical engineering is concerned, refer to Fig. 5, information such as soil data, geological data, and instrument readings, etc., can be transmitted on internet to the various parties shown in Fig. 3. These data can be displayed together with topographic and geological data so ground conditions can be interpreted with better accuracy. This is particularly important when difficulties are encountered during underground works and geo-data are urgently needed for judging whether the situation is serious.

There are already many Internet-GIS software packages which are either specifically developed for geotechnical engineering or can be applied by geotechnical engineers for routine works. It has been popular for major cities to establish databases on geological data in a standardized format so engineers and property developers can gain the access to these databases to have an overall appreciation of the ground conditions at sites to be developed. These databases are particularly useful for area-wide projects such as rapid transit systems and major highway networks. Although this does not eliminate the necessity of performing additional investigations, it does save some guesswork right from the beginning.

Instrumentation is critical to the safety of underground works, such as deep excavations and/or tunneling, in difficult ground. It will provide early warnings as soon as risks develop. In major constructions, the number of instruments installed could be of an order of thousands and the quantity of data could be of an order of millions.

It is not possible to manipulate such an enormous amount of data manually and a computerized system is necessary for efficiency. More importantly, any irregularity in ground response to construction activities can be identified timely. Warnings can now be transmitted to parties of concern, refer to Fig. 6, by using local-area-network or internet. They can be sent together with maps, instrument readings, and other associated information such as progress of construction, conditions of structures being affected, etc. In fact, since all the information already exists in the database, all the people involved may acquire the access to the database via internet and obtain necessary information in seconds. This much shortens the response time, which is extremely critical during an emergency. A software package of this nature had been developed by the Moh and Associates Geotechnical Information Center (MAGIC) and adopted in the construction of the Taipei Rapid Transit Systems (Moh and Associates, 2000). There are more than 15 million sets of instrument readings in the database which proved to be useful in dealing with emergency situations during the construction and is now being extensively used in back analyses of ground response to construction activities.

Many countries have established national GIS standards for all types of digital information. In Taiwan, for example, an ambitious National GIS program was launched in 1990 and was jointly responsible by Ministry of Interior, Ministry of Economic Affairs, Ministry of Transportation and Communications, Environmental Protection Administration, Taipei Municipal Government, and Kaohsiung Municipal Government. The program calls for collection and compilation of data, digitization and establishment of databases, which are to be made accessible via internet. Geology is referred to in two of the 9 divisions in the program. In Division 1, entitled "Basic Information", geological maps for the entire island will be included with emphasis on regional geology, engineering characterization of soils, seismicity and groundwater. In Division 3, entitled "Environmental", natural disasters such as landslides, debris flows, etc., will be documented.

Geological maps can be used together with other types of maps for many purposes, for example, hazard prevention, urban development, traffic corridor study, identification of dumping sites, etc. With digitization, maps of various types can easily be overlaid with each other for correlating various features of interest as long as the same coordinate is used. In fact, information relevant to these features are stored in the databases as attributes, enabling each analysis to be performed with ease.

#### LOOKING AHEAD

The modern technology has improved the accuracy of the results obtained by GPS to centimeters in all three directions. The system is particularly useful in establishing bench marks in remote and/or mountainous areas. It also allows continuous monitoring of, for example, ground settlements, landslides, fault boundaries and movements of important/sensitive structures. GPS equipped with wireless signal-sending devices powered by solar energy can be used to monitor structures which are sensitive to movements, for example, foundation of high speed rails, foundation of power transmission lines, and radar towers, etc., in very remote area.

Global positioning system has been used in a research project for assessing the ground settlement in a coastal area of approximately 30 square kilometers in Taiwan (Moh and Chin, 1994) using the "Rapid-static" survey method. The accuracy of the GPS survey is comparable to the conventional level survey in this pilot study, while the efforts and costs of the GPS survey were many times lower. With increasing accuracy of the GPS technology, monitoring landslide patterns by

using GPS survey becomes feasible and practical. The boundary and the movement vectors of landslide area can be rapidly depicted.

Most modern GPS receivers also support the concept of waypoints and routes. A waypoint is a specific point (longitude and latitude) stored in memory. A route is a series of waypoints connected together to form a path from one point to another. This technology has been widely adopted in vehicle tracking and routing. The results can be shown together with maps for better appreciation of the history of movements. This is particularly useful for tracing geotechnical engineers working in remote areas and for contour map to be prepared.

Another area which is receiving growing interest is remote sensing. A study (Moh and Chin, 1994) has been carried out to identify the fishing ponds in the southern part of Taiwan, where deep-well pumping for fish farming is a major source that causes serious ground subsidence, by using SPOT satellite image. With the help of advanced image processing techniques, changes made in the fish-farming areas can be reasonably identified rather rapidly. Another example of the use of remote sensing technique is to trace and to identify debris flows after typhoons (Moh and Associates, 1997). Damages in large areas made can be identified and assessed in days. After the devastating Chi Chi Earthquake of 21 September, 1999, the value of remote sensing has been recognized and efforts are being made to include remote sensing as an essential element in the national hazard prevention program.

The information obtained by remote sensing is often not used alone but is always integrated with other useful information into geographical information systems. In an on-going project carried out by Moh and Associates, engineers and geologists have heavily relied on the results of satellite image to evaluate the potential geological hazards of slopelands in Taiwan (Moh and Associates, 1999). Information such as landslides, debris flows, erosions, and all other geological hazards interpreted from satellite images is integrated into a common database. Environmental geological maps of all the slopelands in Taiwan can be produced with ease and will be made available on Internet.

Computer technology has progressed at a rate far beyond anybody's expectation and is likely to remain so for the years to come. Notwithstanding the fact that civil engineering is rather slow in adapting the modern computer technology, personal computers have indeed become a tool for daily works for nearly all the engineers. Furthermore, civil engineers are inherently keen on computer technology. This does pave the way to the extended applications of information technology.

While centralization of information will drastically reduce the demand for engineers in quantity, the demand in quality will increase with time. With the convenience of data sharing, companies tend to reduce in-house personnel and distribute works to their affiliates. The concept of "virtual office" will soon become a reality. As telecommunication with the internet via cellular phones and satellite becomes feasible, engineering goes wireless and mobile. Notebook-size computers and palm-size computers will soon be standard equipment for field works. The data collected at sites, no matter how remote they are, can be transmitted to the headquarters in seconds. The whereabouts of the field staff can be tracked by GPS and displayed on screens at the headquarters. With the full access to databases, field staff can work at sites as if they were at the headquarters.

In the years ahead, the demand for Internet-GIS databases is expected to be fast growing and GIS, GPS and remote sensing

technologies are expected to be better integrated. It is even envisaged that all the databases involved in the construction industry will be merged into a complete construction information system. This will streamline the booking and decision-making process. More importantly, it will maintain the consistency of data and the timeliness of changes.

Full automation of instrumentation and real-time monitoring of performance of structures and ground response to construction activities will soon be seen. It is anticipated that CCTV (close-circuit television) will be widely adopted as a primary tool in site supervision. More advanced geophysical devices, such as ground penetrating radar, will also come into play. Artificial intelligence and expert systems will eventually be realized. With all these, we are looking forward to a much better quality of life.

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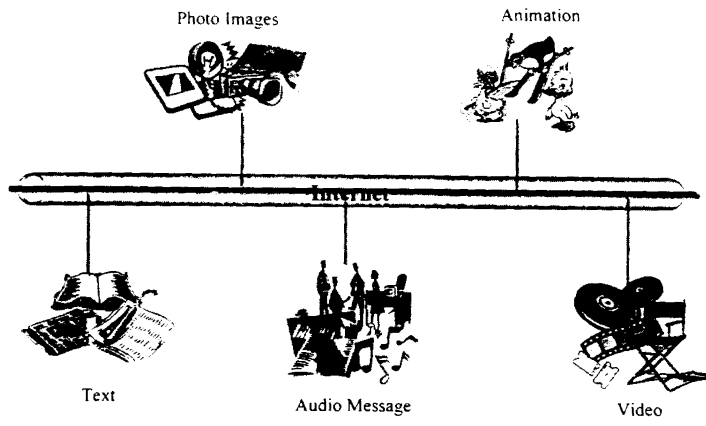


Figure 1 Type of Information Transmittable on Internet

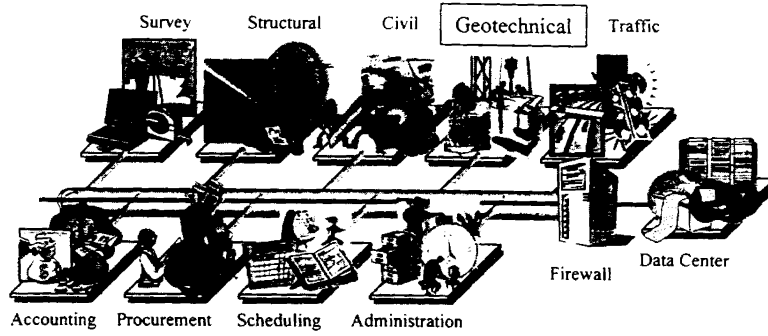


Figure 2 Information Involved in Transportation Projects

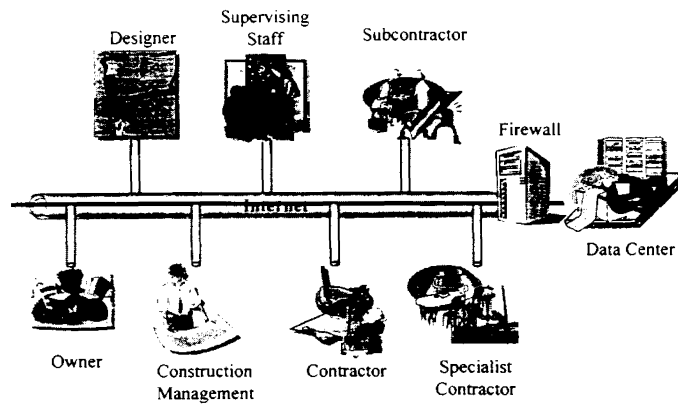


Figure 3 Parties Involved in Constructions

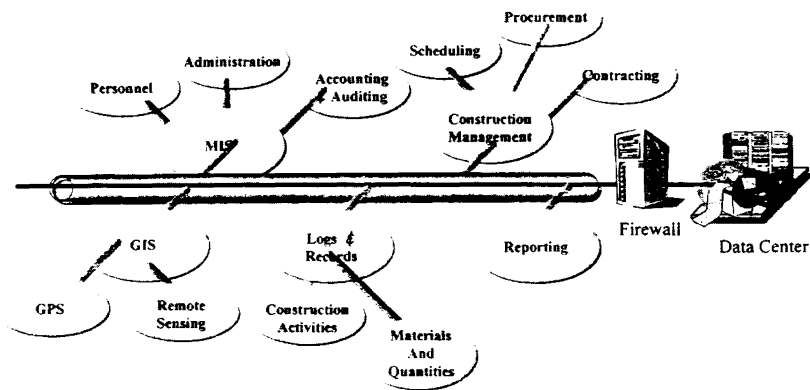


Figure 4 Information Systems for Construction Industry

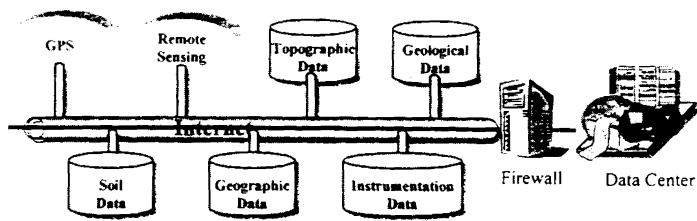


Figure 5 Internet – GIS for Geotechnical Engineering

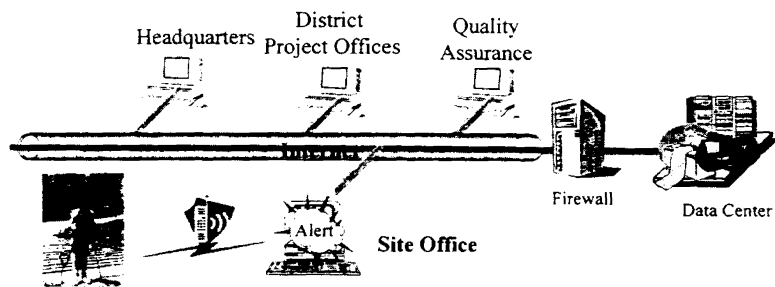


Figure 6 Internet Instrumentation - and - Alert System