3-D simulation analysis for visualizing geotechnical site investigation

Analyse de la simulation 3-D pour visualiser la recherche géotechnique de site

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ABSTRACT: With improving computer performance and advancing simulation techniques, a growing number of soft wares are being developed for visualization of investigation results in geotechnical problems. It is a very important subject for geological site investigation to understand or predict if there would be any hazardous geological condition that might cause any increase of construction costs or long extension of construction period. A 3-D visualization technique may be one of the powerful tools to overcome an uncertainty problem of geological site investigation. In addition, this tool is very useful for civil engineers to make a plan of tunnel construction at the design stage and also during construction with the advantage of improving the economy and safety of tunnels. The paper gives an overview of a newly developed geotechnical interpretation system that is an integrated and automatic computer-aided tool for requirements of tunneling in geological site investigation.

RÉSUMÉ: Avec améliorer des performances d'ordinateur et avancer des techniques de simulation, un nombre de plus en plus important de logiciel sont augmentés pour la visualisation des résultats de recherche géotechniques. Prevoir, comprendre sur les plusieurs conditions geologique qui pourrait causer l'augmentation des coûts de construction ou l'extension de la période de construction, est un des des objectifs très important de recherche de site. Une technique de la visualisation 3-D peut être un des outils puissants pour surmonter un problème d'incertitude de recherche géologique de site. En outre cet outil est très utile pour que les ingénieurs fassent un plan de la construction de tunnel à l'étape de conception et également pendant la construction avec l'avantage d'améliorer l'économie et la sûreté des tunnels. Le papier donne une vue d'ensemble d'un système géotechnique nouvellement développé de traduction qui est un outil assisté par ordinateur intégré et automatique pour des conditions du perçage d'un tunnel dans des problèmes géologiques de recherche de site.

1 INTRODUCTION

Site characterization is an essential process of understanding the geological structure and geotechnical properties of a site. The process generally provides engineers and geologists with the necessary information to carry out the design and the construction. During the process one collects an enormous amount of geologic and geotechnical data. Geologic information is generally difficult to quantify because observation data are often imprecise and incomplete. And incomplete data collection results from the difficulty to measure the spatial variability of earth materials that is due to the inherent properties and the geological history. For using the data to make decisions during design and construction, they must be assembled and analyzed by geologists and engineers. A significant part of such interpretations is valid to understand geotechnical or geologic character. The adequate analysis with attention to geologic conditions prevents construction delay and additional cost. Furthermore, it leads to minimize geologic and geotechnical uncertainties. The result of data analysis and the interpretation of site investigation are generally summarized graphically such as 2-D images of several types of conceptual cross-section, contour map and 3-D images of conceptual model of a site. They are useful to determine the geological and geotechnical characteristics of a site.

In the last few years a demand for visualization technology have grown in the civil and the geotechnical industry. An intense research and development effort is under way to develop an advanced geotechnical interpretation system that is used to perform site characterization. However, such systems are difficult to use for the most computer-illiterate engineer or scientist because three-dimensional computer-aided modeling needs an expensive hardware system and even more complicated software. Recently, with rapid advance of more powerful personal computers and development of more simple software, such advanced geotechnical interpretation systems could be available for the geologists and engineers. During the past two years Underground Structure Research Group in Korea Institute of Construction Technology (KICT) has developed an advanced geotechnical interpretation system that is the first stage Intelligent Tunneling Information System, or ITIS (I). It supports an integrated geological data management, discontinuity analysis, and visualization. ITIS (I) is one of many modules included in ITIS system that supports the integrated management of tunnel design and construction including tunnel design database, prediction of unexcavated area, evaluation of the effects of adjacent structures, visualization of construction data and selection of a support system, etc. In this paper, the authors introduce the overview of ITIS (I) such as the features and the functionality for analyzing and interpreting data collected. Recently, the approach of artificial neural networks (Najjar & Basheer 1996, Kumar et al. 2000) is proved as efficient in determining the spatial distribution of geotechnical properties using that the variation of any of the geological properties follows a specific pattern. Artificial neural network technique has been adopted for creating subsurface profiles within ITIS (I). And the further extension of ITIS will be discussed.

2 BASIC CHARACTERISTICS OF ITIS (I)

A preliminary site investigation is carried out at initial stage of civil engineering project especially in tunneling, where the available pre-existing technical information, including pre-existing data contained in project reports, regional geotechnical maps, geotechnical databases, etc., are reviewed. They contain many types of geological and geotechnical information available to plan a construction program. Using the existing data and new subsurface information from borehole advanced

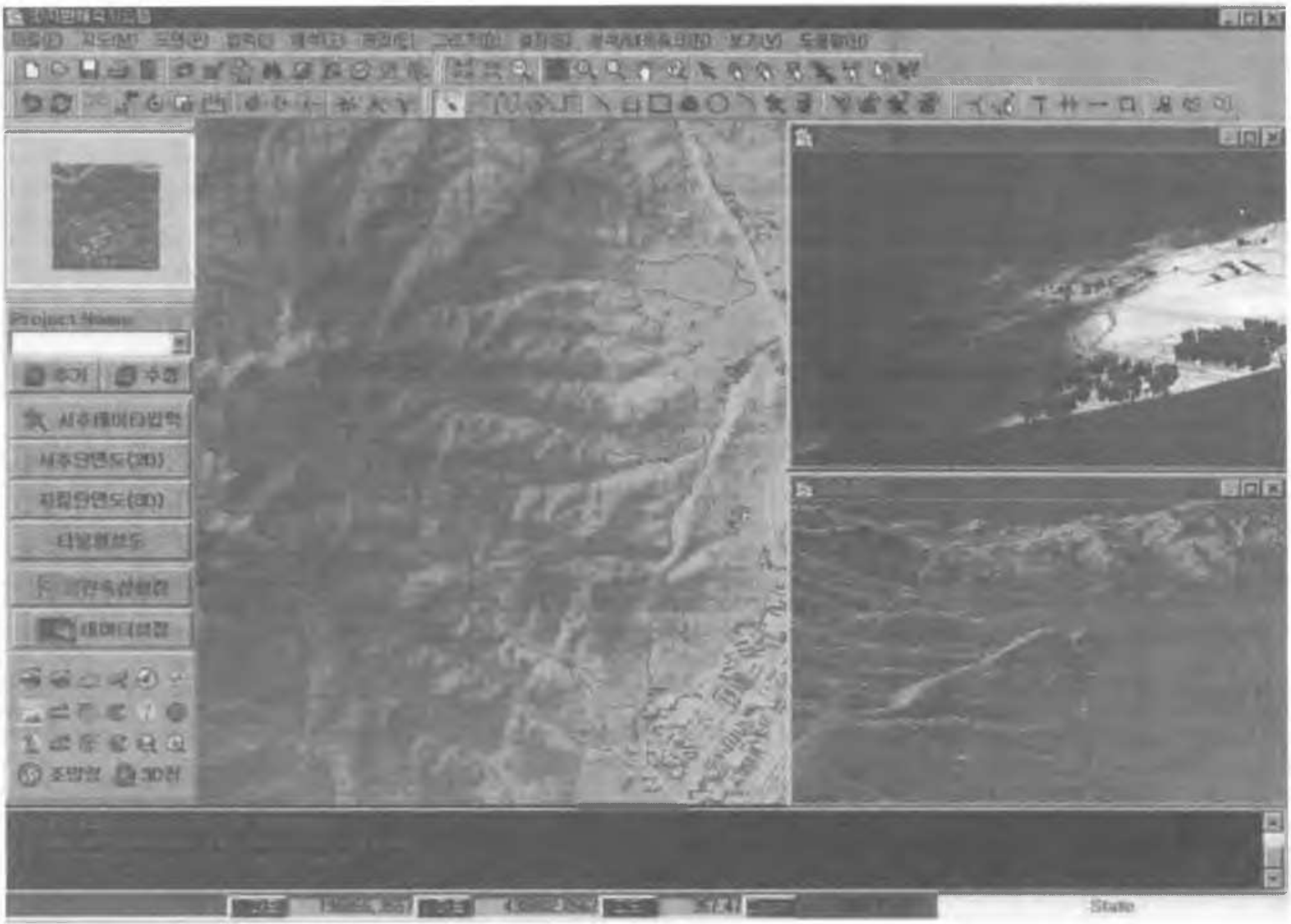

Figure 1. ITIS (I) graphical user interface with 3-D windows.

to depths up to several ten meters over the project area of concern, several geologic and geotechnical profiles are created. These cross-sections are usually made by hand and revised with several repetitions. It is very annoying procedure to make a three-dimensional model of the site with using 2-D cross-sections drawn in different directions. The use of geotechnical data for planning purposes has required a three-dimensional or four-dimensional viewpoint with time related component. In this reason, a computer-aided geotechnical modeler is needed for engineers to create 3-D or 2-D subsurface model easily.

ITIS (I) is an integrated geological and geotechnical data management, analysis and visualization system for geotechnical projects especially in tunneling. It provides graphic display, manipulation, output for reports, and diagrams generated by sub-modules. The system is also used for applications in the environmental, petroleum, and mining projects. It includes sub-modules for point and contour mapping, stratigraphic block modeling, strip logs, cross-section, fence diagram, volumetric calculations, statistic analysis of discontinuities, geomorphologic analysis, coordinate conversions, data-conversions, etc. The three-dimensional visualization and presentation function is one of the characteristic functions in ITIS (I). It is a powerful tool to visualize and present many geologic data and experimental data in geotechnical field. It transforms base maps and many kinds of data into 3-D images of the site and creates presentation-quality images quickly. Site investigation brings many types of data objects. The user is able to handle them simultaneously. In general, visualization systems were expensive and difficult to operate for the most computer-illiterate engineer or scientist. In developing ITIS (I) for geotechnical site investigation, the important considerations are easy-operating environment and PC-Windows-based for civil engineers who have antiquated computing capabilities. ITIS (I) was developed using C language with OpenGL and runs on Pentium PC operating under Windows 98/NT operating system.

3 THE ITIS (I) GRAPHICAL USER INTERFACE

ITIS (I) was developed as an interactive computer program that allows engineers or scientists to input, edit and manage data easily. Once logged on to the system the user meets the Graphical User Interface (GUI). Figure 1 is an example of GUI of ITIS (I). It is conjunct with a mouse that the user can access and display functions. This interface is simple and easy to understand because it is made on the familiar Microsoft Windows format. The GUI comprises two units. One enables the user to use all the functions such as file management, digital map editing, data input and analysis, drawing, setting of options, and help. The other is used for creating 2-D and 3-D models with selecting projects. The same selections can be made on window using the mouse and right control button. It is possible to zoom, measure scaled distances, drag, select layers, and copy/paste directly to other compatible programs.

3.1 *Input and management of data*

ITIS (I) treats most of the data observed and measured in site investigation.

- Three-dimensional geomorphologic data (x, y coordinates and elevation)
- Borehole location and depths of samples and stratigraphic samples taken in borings
- Physical property and other attribute data measured at outcrops
- In Situ and laboratory test results

Table 1. Typical data contents for borehole classes.

Class	Data content
Project	ID and name, input-date, type, start and endpoint, period, description
Company	ID and name, address, president, field
Borehole (general)	ID and name, input-data, location, coordinates, elevation, groundwater level, depth, direction, angle, driller, inspector, boring and machine type, etc.
Borehole (technical)	Sample number, method, depth, type, result of SPT, TCR/RQD, type and spacing of discontinuity, descriptions, etc.

- Tunnel initialization information, including start and endpoints

These are divided into several types of data. A point type data is used to represent outcrops, geological and geotechnical samples, and survey points of mechanical parameter. These data are showed in the form of a table including identifier, coordinates and a set of fields containing the observed or measured values. Borehole data consists of general information about boreholes such as name, date, location, total depth, etc. It is also input in the form of a table. Geomorphologic and geologic structures such as discontinuities and boundaries are included in a curve type data. One can uses and makes both lines and polygons. Grid type data describes a surface such as 2-D cross-sections and 3-D models. This is obtained by interpolation of the three types of data described previously.

ITIS (I) manages collectively all the data that the user wants to include in the project by using Object- oriented database system (OODB).

3.2 *Managing of borehole information*

Details of boreholes collected and observed are entered into a borehole database. It consists of project, company and borehole classes. Typical data contents are described in Table 1. With using the boring log function, borehole log (Figure 2) is created from data and is automatically updated when the data is modified. A standard heading and contents of columns could be selected to form a suitable log format. The user is also able to use prepared palettes of patterns and symbols for data. Furthermore, the log is exported as a windows file.

4 CREATION OF CROSS-SECTION AND 3-D MODEL

One of the main purposes for a site investigation in geotechnical project is to settle geologic and geotechnical boundaries. These are unregulated by the effect of original geology, geological structure, deposition sequence and degree of weathering in the complex geologic history. Geology formations are traditionally inferred using data from topographic analysis, surface survey and borehole. However, the data is usually insufficient to interpret or interpolate subsurface distribution of geology. Because of the reason, we studied the problem of geology and geotechnical interpolation in the cross-borehole and developed a computer interpolation method using artificial neural network with the back-propagation algorithm based on the generalized delta rule by Rumelhart et al. (1986). The method is the most popular learning procedure for multi-layer neural networks among more than 50 neural network models (Kim et al., 2000). The basic strategy for developing a neural network-based model of spatial distribution of geologic boundary is introduced by Hong et al. (2001). In ITIS (I), two- and three-dimensional model are build using real data from site investigation and calculated data together.

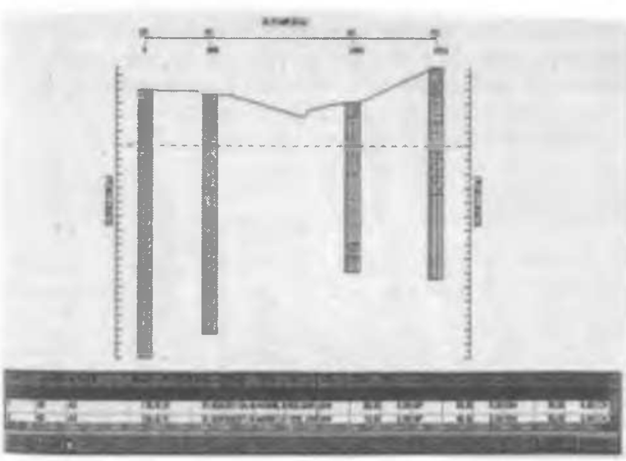

Figure 2. Vertical views of several boreholes.

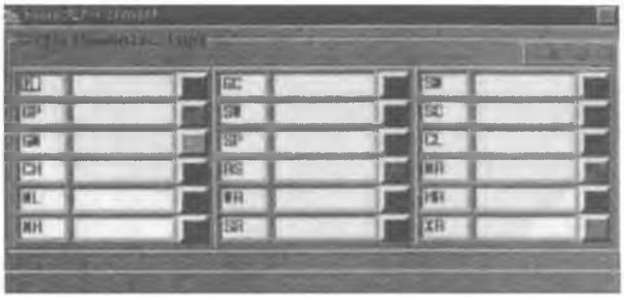

Figure 3. The prepared palettes of patterns and symbols for data .

Using observed borehole and outcrop information, measured mechanical test data, geophysical exploration results, and inferred data, ITIS (I) allows the user to visualize two-dimensional surfaces, fence diagrams and three-dimensional solid models. In 2-D surface the user creates surface models and contours for geology, rock mass classification, mechanical properties of rocks, etc. Furthermore, the features can be adjusted as contours, colors and labels using symbolic log functions shown in Figure 3. Fence diagrams are generated with using several stratigraphic 2-D surface models. They also support the same features as 2-D surface models. An example of two-dimensional geotechnical model for tunnel construction is shown in Figure 4. All of the created cross sections are easily compared with each other. This function is useful to discuss or verify complex geologic site conditions and to solve a problem of disagreement between staffs concerned with construction projects. Figure 5 shows the fence diagram produced from borehole data of Figure 2.

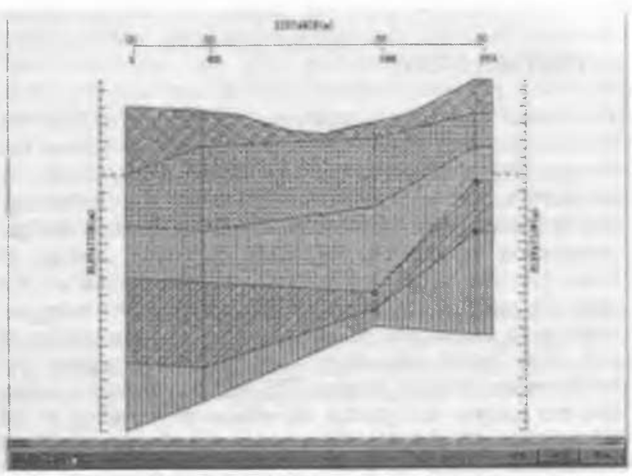

Figure 4. An example of two-dimensional geotechnical cross section for tunnel construction; view after interpolation using borehole and calculated data.

Figure 5. Fence diagram produced from borehole data.

For creating 3-D model borehole and 2-D surface information are used and analyzed with adapting mathematical and scientific algorithms in a lump. The process of generating 3-D model from the relative data is quick and simple. A set of data elements is selected from data that is used to create 2-D surface model, and then is executed a function on that set. This data set consists of all of the same type or of differing type such as geologic and geotechnical stratigraphic information, mechanical properties and experimental results. The user can take and create the cross sections in any directions from 3-D solid model. ITIS (I) interpolates the set of the selected data elements and creates a 3-D model. In ITIS (I), one can observe the project site from arbitrary direction and get any different perspectives of the three-dimensional representation using rotation function. Spatial data structure in ITIS (I) is a set of points (**x**, y, z coordinates and **r**). **r** contains information about bore hole data, laboratory test data or any other type of data related to geological and geotechnical information.

5 OTHER FUNCTIONS

Using the report functionality, the user can get most of the requested information. The extensive prepared report formats are available. Furthermore, the query options can be used to generate lists of data that exist within the database. These can be exported as a pre-prepared files. ITIS (I) also includes Geodips module that is a discontinuity analysis tool using a stereonet projection. The user can use a data file of ITIS (I) with the import option in the file menu of Geodips and also create a new data file in Geodips. It is a program for the graphical and statistical analysis of structural geological data using spherical projection techniques.

6 FURTHER STUDY

The authors have a plan to add several extensions to ITIS as a National Research Laboratory (NRL) Project in Korea. The ultimate objective of the project is the establishment of advanced tunnel information design/construction technology and the development of future tunnel-information design/construction system. The extensions include a database of tunnel face observation data and measurement data that are just used as a usage of once, an applicable expert system using the database to predict the subsurface structure and condition of rock mass before excavation of tunnel, and a support and reinforcement decision system. ITIS will also include a system that can analyze and predict the effects of tunneling to the adjacent ground and structures around tunnel using Artificial Intelligence method as a way of prevention against the civil resentment for the ground settlement and environment problems due to the tunneling. Finally, the system is developed as an integrated expert system including visualization, evaluation and prediction technology of tunnel survey, design, construction and reinforcement system.

7 CONCLUSIONS

With the development of more powerful and cheaper personal computers, applications of visualization technology in geotechnical engineering are quickly moving to engineers and scientists. ITIS (I) is a powerful computer-aided subsurface visualization system. The use of the system enables geologists and civil engineers to utilize precisely the available geotechnical data at an early stage of a site investigation and characterize the subsurface geological structure and geotechnical state of a project site. The main applications in ITIS (I) are geomorphologic analysis, discontinuity analysis, three dimensional modeling, drawing arbitrary cross-section and data export to other applications. The system uses the artificial neural network method including the back-propagation algorithm for creating ground profiles taking into account both observed and measured data. With using the two- and three-dimensional model created in the study, the spatial distribution of geological and geotechnical information can be easily visualized in the site investigation.

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