Automation and Robotics in Construction XI
D.A. Chamberlain (Editor)

The Fujita Integrated Environment For Automation

Amr A. Oloufa[a] and Masaaki Ikeda[b]

[a] Penn State University, Department of Architectural Engineering, 104 Engineering Building "A", University Park, PA 16802, USA.

[b] Fujita Corporation, Technical Research Institute, 74 Ohdana-Cho, Kohoko-ku, Yokohama 223, Japan

Abstract

Due to the increased complexity of projects, an integrated information environment is needed. To demonstrate the capabilities of such a system, we choose an implementation in automated shield tunneling.

Automated shield tunneling applications have increased in popularity due to the increased flexibility and construction safety. These automated machines have proven to be cost effective in tunneling through congested areas, typical of large cities and metropolitan centers.

The productivity of tunneling machines is directly related to soil conditions in the site which impacts the total cost and schedule of the project. Therefore it is extremely advantageous to utilize an efficient method for the storage, retrieval and manipulation of soil information. The storage of borelogs should also contain information on the geographic locations of borelogs to allow the user to retrieve soil information related to all the borelogs in the vicinity of a construction project.

Geographic Information Systems (GIS) can relate descriptive project information to graphical displays showing their geographical locations on digital maps on the computer screen. Since GISs currently available concentrate on planar / surface applications, there is a need to extend their utility to show the soil variations as a function of depth (i.e. from a 2D to a 3D application).

This paper describes a system that integrates a database for the storage of descriptive soil data, a GIS to relate this data to a display of the corresponding locations of boreholes, and a module to interpolate between the soil borelogs to develop a three dimensional representation of the soil layers underlying the project site.

The outcome of this project is particularly useful for Design-Build organizations where the utilization of a single database for analysis, design and construction planning is an important step towards design-construction integration.

1. INTRODUCTION

Recently, large cities and metropolitan areas have witnessed an increased demand for the utilization of underground space. This space may be used for retail outlets, subway systems, other transportation systems, and for utilities and communications systems. Shield tunneling machines have been used successfully for a number of years. (Sato *et al 1989, 1993,* Mikami *et al* 1991, Hashiba 1992). These machines are generally cylindrical in shape, with cutting attachments connected to their faces. Construction starts with the excavation of a shaft, the shield tunneling machine is lowered until it reaches the shaft's bottom. The machine then advances under its own power by using the cutting heads on its cutting face. For the construction of vertical or horizontal curved tunnel sections, articulated shield tunneling machines are used.

Depending on the type of excavated soil, the shield tunneling machines advance with or without the use of a slurry mix. After the machine advances, the newly created tunnel length is lined with precast concrete or steel members, and the excavation continues. Excavated soil is transported to a container inside the machine which is moved to the surface using trucks or small trains and a crane.

A variety of complex control systems are needed for the control of tunneling construction operations. These systems are needed to adjust cutting force and pressure, spatial alignment, control of lining operations, and soil removal operations.

The investigation into the automation of tunneling construction has been prompted by the dangerous nature of these operations, and the decrease in the number of skilled workers coupled with a rise in their average age. Automated tunneling machines are currently available from several Japanese construction companies. Modern machines are capable of cutting tunnels up to 15m in diameter, including vertical or horizontal curved tunnel sections with a radius as small as 50m.

Due to the high cost and relative complexity of modern projects, the Fujita Corporation of Japan in a partnership with Penn State University of the United States have embarked on a research project to improve the reliability of construction planning, data retrieval and analysis for construction operations.

2. AN INTEGRATED ENVIRONMENT FOR SHIELD TUNNELLING AUTOMATION

The construction of shield tunnels requires detailed soils information. Soil information is used to select the required shield machine type, and to assess the various operating parameters of the machine. Soil type also dictates the type of liner used in the tunnel. Also, since automated shield tunneling is used mainly in congested areas, the tunnel route and its elevations must be selected carefully to avoid impacting any surface and subsurface structures or utilities.

An integrated information environment capable of serving such diverse requirements should therefore be capable of storing and retrieving soils information in a topologically-oriented structure. This structure is used to relate the tunnel route to surface and subsurface structures and utilities. Also, this computer integrated environment must retain the capability of developing three-dimensional representations of soil layers from borleogs. This allows for the development of soil sections showing the various soil types the tunneling machine will encounter while moving through its designated route.

For the reasons mentioned above, the authors developed the Fujita Integrated Environment For Automation. This environment is comprised of three modules, a geographic information system (GIS) module, a relational database module, and an elevation contouring and 3D soil layer development module.

Geographic Information Systems (GIS) are computer tools that store, manipulate, and display the descriptive aspect of spatial data about certain objects as well as the relative geographic locations of these objects. The geographic locations of objects are represented by the display of graphical objects on the computer screen. The definition of the location of the graphical objects in space is termed spatial data. The definition of the relative locations of graphical objects is termed topology. The descriptive data about the objects is termed non-spatial data. GISs are, therefore, database systems which deal with two types of data, the spatial and non-spatial data, thus allowing the analysis of data about the objects according to their topology or other criteria of descriptive data (Ooi, 1990).

Spatial objects can be classified into points, lines, and areas. A point is a zero dimensional object specifying a geodetic location in a set of coordinates. Points can be used to represent the location of certain objects, such as borelog locations. A line is a one-dimensional object linking two points. Lines can be used to represent water streams. An area, is a two-dimensional object defining an enclosure within a boundary (Antenucci *et al*, 1991).

Many applications use GIS in decision making (Oloufa *et al* 1991, 1994). For example, in geotechnical engineering, the display of the locations of boreholes on a digital map on the computer screen helps the geotechnical engineer in selecting boreholes according to their proximity to a new borelog probe. In environmental engineering, GIS programs can be used for the selection of a waste site which may be constrained by the locations of housing areas, the habitats of endangered species, production facilities, and highways (Star and Estes, 1990).

3. FIEA COMPUTER MODULES

The program starts with a screen allowing access to three modules. The database module allows the entry and modification of soil borelog data. The GIS module correlates the soils information of borelogs to the actual locations of borelogs. The third module (*Visualizer*), is used to interpolate data from three or more borelogs into a three dimensional representation of soil layers within the project area of interest. Below is a detailed description of these modules:

3.1. Database module

The Database module (see Figure 1) is a relational database. The Database has two modes of operation, read-only and full-editing. This design allows the database to be accessed by different groups of users where some users are only interested in viewing the data, whereas others may need to add, update or modify the data.

The data model contains three entities: borelog, layers and N-values. The borelog entity has a one-to-many association with layers and N-values. The primary key for a borelog is a unique number that identifies that borelog. This number is also used to connect to the layers and N-values records. Layers are stored with their initial and final elevations, i.e. no layer numbers need to be assigned by the user. The program includes overlap / gap checks to ensure that layers are entered correctly.

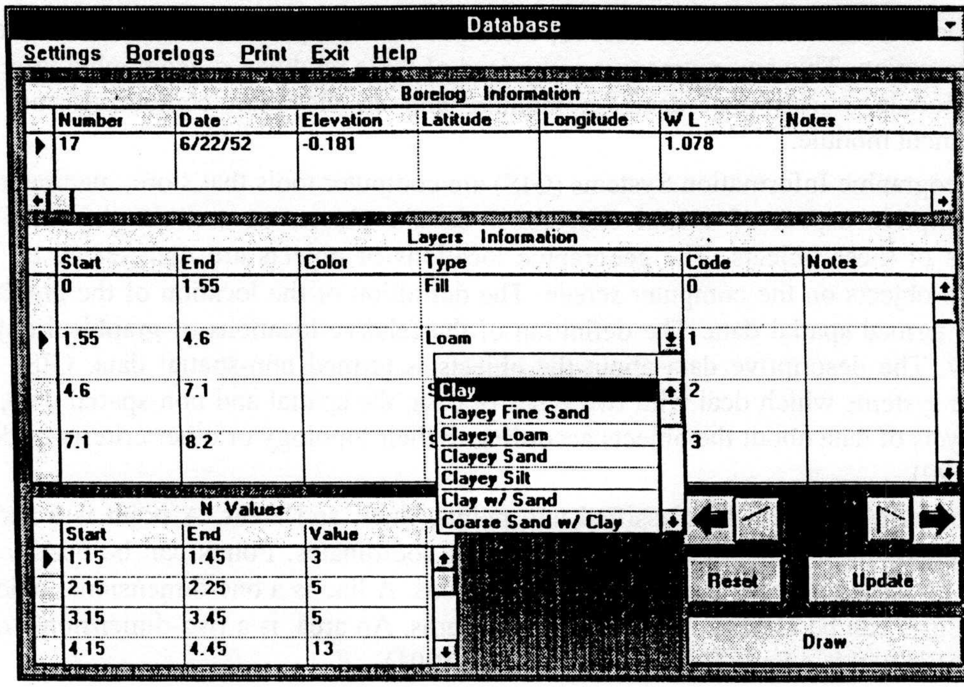

Figure 1

Currently, the database supports SQL searches on the borelog number. Users may search for one or more borelogs at a time, and "*Like*"-searches are also supported. The Database module uses a grid control with in-place editing, which greatly simplifies viewing and editing operations. Referential integrity capabilities have been added where the deletion of a borelog automatically deletes all related layers and N-values. The same applies for changing the borelog number.

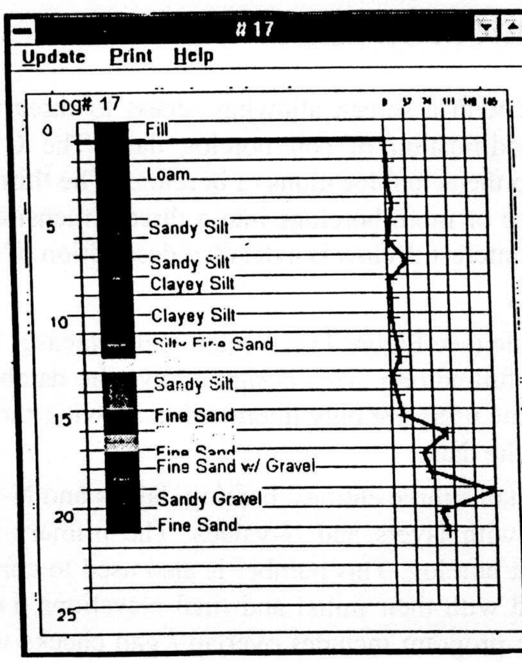

Figure 2

The Database module has full graphing and printing capabilities. The user may view the representation of one or multiple borelogs and has control on all aspects of graphing such as scale, font size, screen proportion, maximum allowable values etc. (see Figure 2).

3.2 GIS Module

The GIS module is comprised of MapInfo for Windows Version 2.1 and a read-only database module. Users can search for a specific borehole by its unique number or by its street address within a city. For the implementation of , the city of Tokyo was used to demonstrate the feasibility of this research.

MapInfo (GIS software) is used to display the map of Tokyo where the stored borelogs appear as symbols. Using MapBasic (MapInfo Customization Language) and Dynamic Data Exchange (DDE) under M.S. Windows, the user may click on any borelog symbol and the information related to that borelog is retrieved as shown in Figure 3. The user may also draw the borelog and multiple borelogs may be viewed simultaneously on the screen. If the user clicks on any layer within a borelog window, the database is updated with information related to the current borelog and an arrow points to the specific layer clicked on by the user.

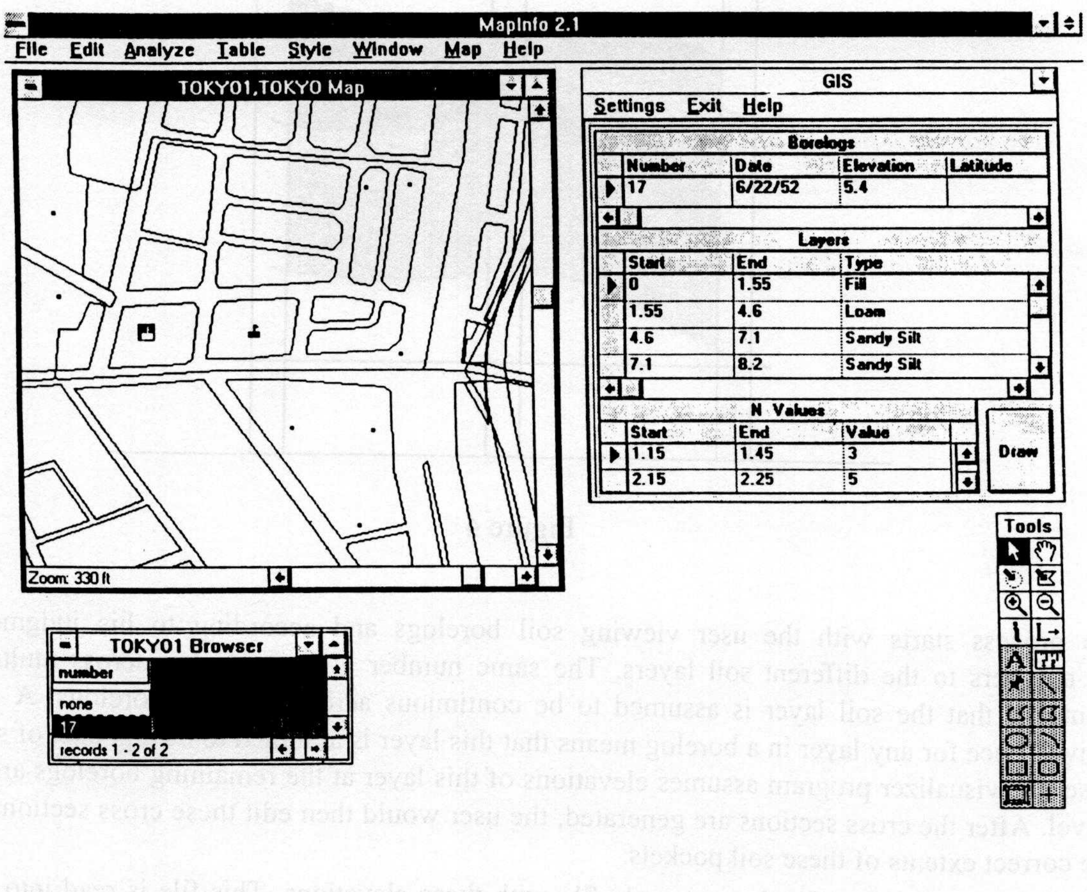

Figure 3

If the user wishes to edit a group of borelogs, the clipboard may be used to transfer the borelog numbers to the Database module where the information may be modified.

3.3 Visualizer Module

This module is used in conjunction with the Geographix Exploration System (GES) to interpolate between three or more borelogs to develop a three-dimensional representation of the soil layers surrounding and enclosing the chosen borelogs. The user may input the borelog numbers directly, or via the clipboard from the GIS, or database modules. The elevations are used by the Geographix Exploration System to contour the soil surface generated from these borelogs and their respective layers.

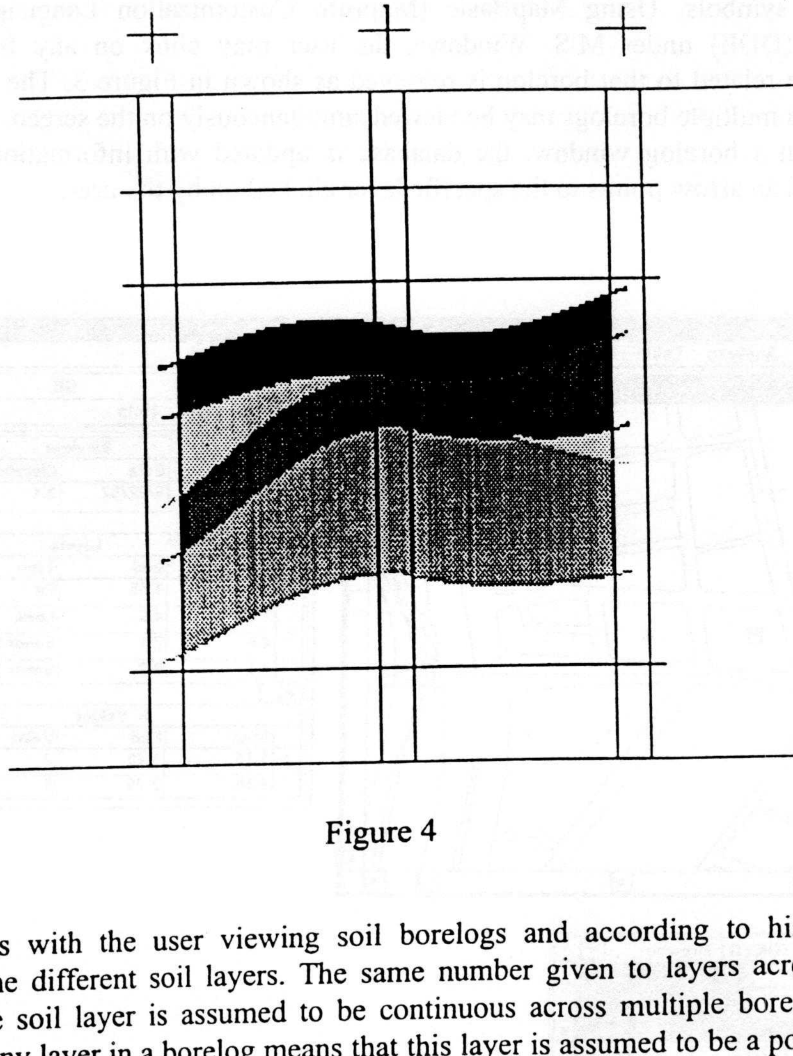

Figure 4

The process starts with the user viewing soil borelogs and according to his judgment, assigning numbers to the different soil layers. The same number given to layers across multiple borelogs means that the soil layer is assumed to be continuous across multiple borelogs. A soil number given once for any layer in a borelog means that this layer is assumed to be a pocket of soil. In this case, the visualizer program assumes elevations of this layer at the remaining borelogs are at ground level. After the cross sections are generated, the user would then edit these cross sections to reflect the correct extents of these soil pockets.

The visualizer program develops a single file with these elevations. This file is read into the GES environment which interpolates the results, thus allowing the user to view the three-dimensional soil layers. The user may input in the GES environment multiple 3D soil layers and generate cross sections at all required locations (see Figure 4).

4.0 HARDWARE AND SOFTWARE USED

80486DX PC, 16 Meg. Ram (4 Meg. minimum)

14 Meg. Hard Disk Space, Super VGA graphics (VGA minimum)

Microsoft Windows 3.1, FIEA modules, MapInfo and MapBasic Version 2.1

Geographix Exploration System (for visualizer module)

CONCLUSIONS

The research reported here has several important extensions. The FIEA modules may be implemented in a client / server architecture allowing access to the soil information from project sites. Real-Time comparisons of planned-versus-actual conditions may be done in an effort to improve the planning process both during, and after completion of the project.

Improvements in the database module will make possible the seamless integration with CAD programs. This will allow for better visualization of the design and construction processes. Also, discrete and continuous event simulations of design and construction will be possible where several design and construction scenarios may be evaluated.

The incorporation of some rules and AI techniques in the contouring and layer development module (*Visualizer*) is also an extremely useful and worthwhile extension of this work as it improves the quality and reliability of the developed cross sections.

ACKNOWLEDGEMENTS

The authors wish to thank the Fujita Corporation of Japan, and the Partnership for Achieving Construction Excellence (PACE) at Penn State University for supporting this research.

REFERENCES

Antenucci, J. C., K. Brown, P.L. Croswell, and M.J. Kevany. *Geographic Information Systems: A Guide to the Technology*. Van Nostrand Reinhold, New York, NY. 1991.

Geographix Exploration System (GES). Version 7.1, Geographix Inc., Denver, Colorado, November 1993.

Hashiba, S.: *Prospects for Applying Automation/Robotization of Shield Method Work*. The 9th International Symposium on Automation and Robotics In Construction, June 3-5, 1992, Tokyo, Japan.

MapInfo Corporation. *MapInfo, Desktop Mapping Software for Windows*. Troy, NY. 1993.

Mikami, T., Hanamori, Y., Ohnishi, T., and Kanno, M.: *An Automatic Direction Control System for Shield Tunneling*. The 8th International Symposium on Automation and Robotics In Construction, June 3-5, 1991, Stuttgart, Germany.

Oloufa, A. A., Papacostas, C. S., and Hamada, H. S. *Relating Structural Failures To Subsurface Conditions Using GIS*. Building and Environment Journal. March 1991

Oloufa, A. A., Eltahan A. A., and Papacostas, C. S. *An Integrated GIS for Construction Site Investigation*. Journal of Constructioon Engineering and Management, American Society of Civil Engineers (ASCE), March 1994.

Ooi, B.C. *Efficient Query Processing in Geographic Information Systems*. Springer- Verlag, New York, NY. 1990.

Sato, K.: *Shield Method Automation System*. The 6th International Symposium on Automation and Robotics In Construction, June 6-8, 1989, San Francisco, CA.

Sato, K., Sekiya, K., and Higaki, K.: *Hyper-Shield System Achieves Automated Excavation*. Automation and Robotics In Construction X, Watson and Tucker (Editors), Elsevier Sciience Publishers, 1993.

Star, J. and J. Estes. *Geographic Information Systems: An Introduction*. Prentice Hall, Englewood Cliffs, NJ. 1990.