

# DEVELOPMENT OF A WEB-BASED GEO-SPATIAL INFORMATION SYSTEM FOR THE ANALYSIS AND EVALUATION OF SOIL DATA

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**ABSTRACT:** The Ministry of Construction and Transportation (MOCT) has been constructing a nationwide soil information DB since 2000, as basic data for the construction of ‘underground geographical information,’ a project under the 2nd National Geo-spatial Information System (NGIS) master plan. The inputted soil information includes not only underground conditions such as the layer depth, type, color, and groundwater level, but also engineering information that can be applied to construction work design, such as on the standard penetration test and the compression test. It is difficult to use this information in soil analysis and design, however, because only the test results are currently available. A web-based geo-spatial information system was developed in this study to facilitate the effective application of the soil information database (DB). First, the space information, layer information, and engineering test information were loaded from the soil information DB in real time, and the earth volume, bearing capacity, and settlement were calculated to develop a web client that will evaluate the ground softness and liquefaction. It seems that the soil information DB can be actively applied to the planning and design of construction works using this system.

*Keywords: soil information analysis/evaluation, underground cross-section model, soil information DB, web-based geo-spatial system*

## 1. INTRODUCTION

The soil information DB contains basic data on ‘underground geographical information,’ which is a project of the 2nd National Geo-spatial Information System (NGIS) master plan. Korea’s Ministry of Construction Technology (MOCT) has been constructing a nationwide soil survey database (DB) since 2000, and the DB has more than 60,000 boreholes to date (MOCT, 2006). The inputted soil information covers fields such as on the underground layering structure, groundwater level, and physical and chemical characteristics of soil and rocks, in the form of an electronic report on the Internet.

The constructed soil information DB has boring data generated during construction, and contains not only general soil information such as on the layer depth, type, color, and groundwater level, but also engineering test information such as on the standard penetration test, shearing test, triaxial compression test, etc. Therefore, the DB is expected to be very useful in analyzing adjacent soils and designing underground structures.

In this study, a web-based geo-spatial information system was developed that calculates the soil parameters used in the engineering evaluation and detailed design of the subject soil using the constructed DB. First, an

underground cross-section model was created by interpolating the digital elevation model (DEM) extracted from the geographical map of the soil information DB and the layer depth collected from the borehole. Then the earth volume, soil bearing capacity, and soil settlement were calculated based on the constructed model, and a function that evaluates the ground softness and probability of liquefaction was formulated.

### 1.1 Relevant Studies

As a large quantity of soil engineering data are generated according to the development of methods of analyzing soil surveys, etc., the management of existing documents has reached its limit, and the soil survey data are now required to be stored and shared through computerization. Accordingly, in 1992, the Association of Geo-technical and Geo-environmental Specialists (AGS) announced its Electronic Transfer of Geo-technical and Geo-environmental Data Project, which has become the standard for computerized transfer of soil survey data. Petroleum development enterprises that conduct numerous boring surveys also developed and are using the Public Petroleum Data Model (PPDM).

As examples of soil information, which are classified as underground geo-spatial information, Hawke (1991)

developed an initial form of soil information DB and its applications, and Iwasakie et al. (1999) offered a soil information DB in the Kansai region that also contained geography, disaster, and accident information. Adams et al. (1993), Toll et al. (1995), and Davey-Wilson et al. (1998) developed many DBs, which have been applied to the storage, processing, and application of soil survey data.

Later, with the introduction of the GIS concept, geo-spatial information has been integrated in and applied to various sectors. Okimura et al. (2000) used GIS and soil information in city development and disaster management, and Nishie et al. (2000) developed a GIS-based integrated soil information management system to visualize the internal geological structure and use it in slope management.

In Japan, the applications of soil information such as the standardization of soil and geological survey information and the preparation of a simplified soil diagnosis tool and a geological map based on three-dimensional (3D) geological model construction are actively done at the Construction Center, the Regional Soil Environment Institute, the Osaka Soil Test Laboratory, etc. The U.S. is promoting ease of use by individual of GIS-based soil search, mapping, and analysis, through the development of the GeoLibrary system. In Australia, the use of soil information is maximized through the development of a soil analysis support system, 3D analysis, and data sharing based on distributed computing technology (Korea Institute of Construction Technology, 2004). Figure 1 shows the housing soil information system (GEODAS) based on web-GIS. This system provides soil survey results, a reinforcement method, and a simplified soil diagnosis tool on the Internet.



Figure 1. Housing soil information system in Japan

In Korea, after the results of the soil information construction study of the Korea Institute of Construction Technology (1994) were released, MOCT (since 1999), Seoul Special City (1997, 2003), Incheon International Airport Corporation (1998), Suwon City (2006), and Daegu City (2006) constructed DBs with soil survey data.

With the active construction of soil information DBs by central authorities and local autonomous entities, the GIS DB was introduced to encourage its use. It is constructed for basic 'underground geographical information' under the 2nd NGIS master plan. Unlike in overseas studies, however, the soil information DB in Korea is not applied to analyses in combination with GIS space information, although it has engineering information for use in soil

analysis and evaluation.

## 1.2 Introduction to the Soil Information DB

Since 2000, MOCT has been managing the National Soil Information DB Construction Project, which is the subject of this study. The project was initiated to cut costs by preventing the waste or loss of paper documents that contained soil survey data. That is, the project was meant to introduce a computerized system for soil survey documents. It was not limited to simple document computerization, however, but was extended to the construction of nationwide underground map information, according to the introduction of GIS linked with the location of boreholes. By sharing information with soil surveyors, foundation designers, builders, building clients, facility users, and researchers, the project yields various outputs such as planning and preliminary design support, and inspection and design cost savings through soil analysis.

More than 60,000 boreholes and relevant geo-spatial information have been constructed nationwide as a result of DB construction between 2000 and 2006. Until 2006, paper documents from completed soil survey data were computerized, but in 2007, a system was developed for the soil surveyor or builder to enter the newly created soil survey data in the fields and to construct the DB automatically. To support this institutionally, MOCT formulated the "Guidelines on the Computerization and Use of Soil Survey Results (March 23, 2007)."

The soil information DB is being constructed with the boring survey results and the test results of construction works and resource development works so that data can be efficiently distributed through a web-based GIS, by constructing the space information using information on the drilling log location and the terrain of construction works (<http://www.geoinfo.or.kr>).

## 2. SOIL INFORMATION ANALYSIS AND EVALUATION SYSTEM DESIGN

### 2.1 Research Method

To analyze and evaluate the soil in a specific area using the constructed soil information DB, the soil parameters for work analysis and construction works were determined. Then for the analysis, a model in the form of a cross-sectional view was created with the information from the soil information DB. Based on the model, an analysis/evaluation system that evaluates the earth volume, bearing capacity, settlement, liquefaction, and softness of the ground according to the additional data entries was designed and realized. Figure 2 shows the research process.

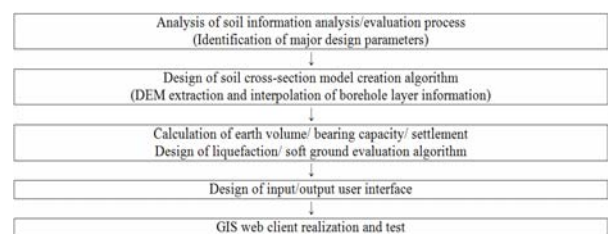


Figure 2. Research process

**2.2 Analysis of Subjects to Be Evaluated and Requirements**

Construction work is classified into civil engineering work, which involves cutting and filling, and building work, which involves building structures, according to the work items.

First, the cutting/filling volume by layer, which is directly covered by the project cost, and the bearing capacity and settlement volume, which are inevitable in the structure design, were chosen as the design parameters. In addition, the ground softness and liquefaction were chosen for the evaluation process because of the increasing demand for the evaluation of ground softness according to new town developments, etc., and for the evaluation of liquefaction according to the dynamic load generated from reconstructions in populated districts or from earthquakes. The major subjects to be analyzed in the system are shown in Table 1.

**Table 1.** Major Subjects of Analysis/Evaluation

Classification	Details
Calculation of the earth volume	-Generation of drawings for the cutting/filling and planning sections -Calculation of the cutting/filling volume by layer
Calculation of the bearing capacity and the settlement	-Calculation of soil parameters according to the test data -Selection of the basic bearing layer and calculation of the bearing capacity by basic type -Calculation of the settlement according to the structure
Evaluation of the ground softness and liquefaction	-Calculation of the ground softness according to the layer/test data -Determination of the settlement in the soft ground and the liquefiable ground

This study employed the formulas and standards shown in Tables 2-6, according to the structure foundation design standard of MOCT (2002). The development system provided standard and detailed descriptions for each function via GUI to allow the user to choose parameters according to his/her purpose.

To calculate the earth volume, the user enters the planning section and the planned elevation in the map and determines the cutting/filling section, from which the earth volume conversion coefficient is calculated via layer classification and the earth volume is calculated by layer. The major processes and the use case diagram selected to calculate the earth volume are shown in Table 2 and Figure 3.

**Table 2.** Major Processes for the Calculation of the Earth Volume

Function	Linked Data	Details
Route longitudinal section	Digital map	Spatial DB
	Drilling log	Attribute DB
Soil model creation	Route longitudinal section	Soil model view
	Drilling log	

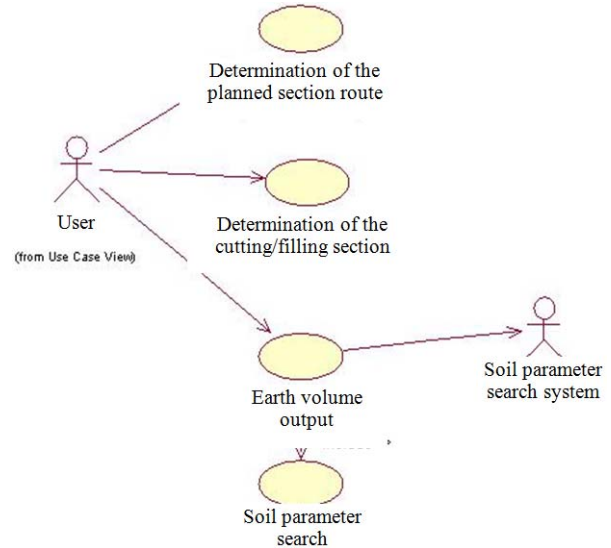
Determination of the cutting/filling section	Soil model	Soil model view
Soil change ratio (Soil conversion factor)	Drilling log	Calculation of the soil conversion factor according to the soil character
	Indoor test data	
Calculation of the cutting/filling volume	Soil model	Calculation of the earth volume
	Soil conversion factor	

Formula:

$$\text{Earth volume} = \text{Cutting/Filling volume} \times \text{Earth conversion factor (C, L)}$$

$$C = \text{Natural density} / \text{Rammed density}$$

$$L = \text{Natural density} / \text{Scattered density}$$



**Figure 3.** Use case diagram for calculating the earth volume

To calculate the bearing capacity as a major soil parameter in the structure design, the user enters the information on the type, location, and weight of the foundation along with the structure’s section information.

This study used a bridge as a representative structure in road construction, and calculated its bearing capacity on the soil at its lower foundation using USCS and the soil consistency through the entered section information and by searching in the soil information DB. Then the relevant empirical formula is applied according to the type of layer (weathered rock or soft rock layer) and foundation (direct/pile). The major processes and the use case diagram selected to calculate the bearing capacity are shown in Table 3 and Figure 4.

**Table 3.** Major Processes for the Calculation of the Bearing Capacity

Function	Linked Data	Details
Selection of the foundation type		Direct/Deep foundation selection
Entry of the foundation weight	Foundation type	User entry
Bearing capacity calculation	Soil model	Soil/Rock classification
	Strength parameter	Cohesion, internal friction
	Deformation modulus	Elastic modulus, Poisson’s ratio
	RMR	Bieniaski’s RMR

Bearing capacity output	Bearing capacity calculation	Empirical formula by soil/rock (Terzahi, Hoek-Brown, etc.)
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Formula:  
 1) Direct foundation: Terzaghi formula applied (weathered rock)  

$$q_u = \alpha c N_c + q N_q + \beta \gamma_1 B N_\gamma$$
 qu: Ultimate bearing capacity of soil (tf/m<sup>2</sup>)  
 c: Cohesion (tf/m<sup>2</sup>)  
 q: Surface load of foundation (tf/m<sup>2</sup>)  
 γ: Unit weight (tf/m<sup>2</sup>)  
 α, β: Shape factor of the foundation  
 Nc, Nq, N: Bearing capacity coefficient  
 : Bell formula applied (soft rock)  
 2) Pile foundation: Bearing capacity formula by static mechanics applied

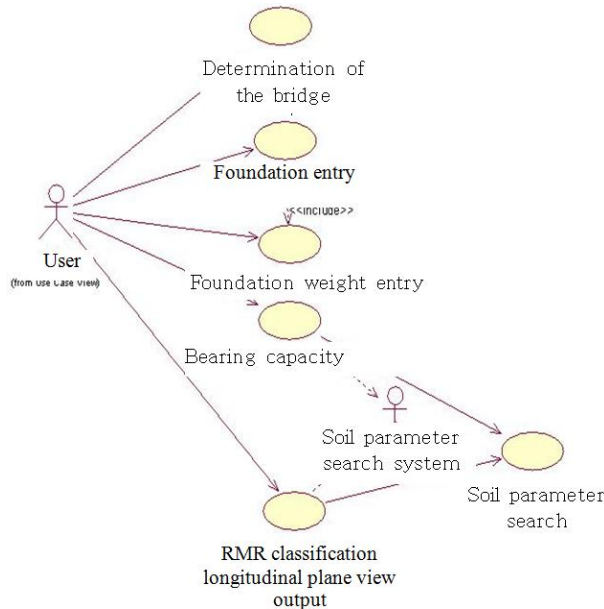


Figure 4. Use case diagram for the calculation of the Bearing Capacity

The soil settlement is calculated after the user has determined the subject section and structure. The settlement at the lower foundation of the structure generated according to time is estimated and provided in graph form. The first consolidation settlement, the settlement time, and the final settlement are substituted into each empirical formula. The major processes and the use case diagram selected to calculate the soil settlement are shown in Table 4 and Figure 5.

Table 4. Major Processes for the Calculation of the Soil Settlement

Function	Linked Data	Details
Soil classification	Soil information DB	Normal-consolidation clay, overconsolidated clay
Consolidation settlement	Soil classification	
	Consolidation test data	Using the soil DB
Long-term settlement	Consolidation settlement	Total settlement according to the time lapse
Settlement time	Consolidation settlement, long-term settlement	

Formula:  
 One dimension consolidation settlement for normal-

consolidation clay	$S_c = \frac{C_c}{1 + e_0} \cdot H \cdot \log \frac{\sigma'_0 + \Delta\sigma}{\sigma'_0}$
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Sc: One-dimension consolidation settlement  
 Cc: Compression index  
 e<sub>0</sub>: Initial void ratio  
 H: Clay layer thickness  
 σ'<sub>0</sub>: Valid surface load of the original soil  
 Δσ: Increase in the valid stress

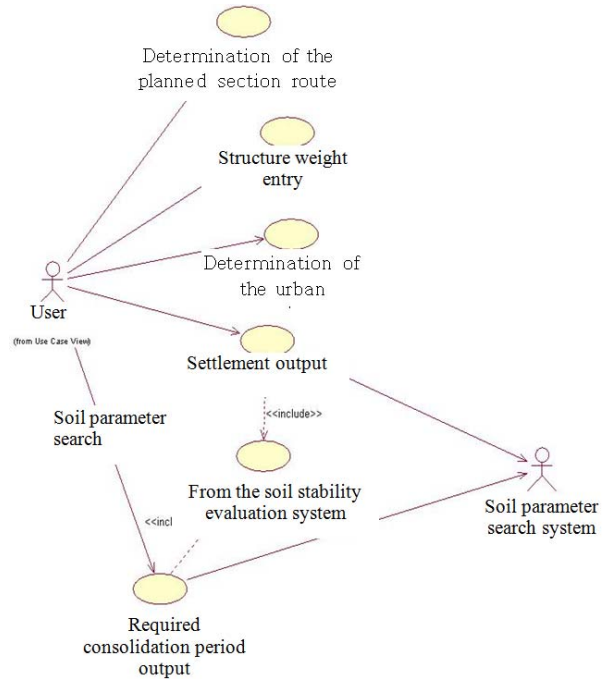


Figure 5. Use case diagram for the calculation of the soil settlement

To evaluate the ground softness, the user chooses an area in the map, defines the unconfined compression strength (qu) using the N value of the standard penetration test in the soil information DB, and outputs the distribution of the soft ground on the plane view. Physical properties such as the soil characteristics, unit weight, and void ratio, and mechanical properties such as the compressive strength and cohesion are outputted by borehole. The major processes and the use case diagram selected to evaluate the ground softness are shown in Table 5 and Figure 6.

Table 5. Major Processes for the Evaluation of the Ground Softness

Function	Linked Data	Details
Soft ground condition	Drilling log	Examination of the N value condition
	Unconfined compression test	Examination of the qu condition
Soft ground output		On the plane view

Applied Standards:  
 1) Layer thickness: ≥ 10m clay  
 2) N value: clay ≤ 6, sandy soil ≤ 10  
 3) Unconfined compression strength: clay ≤ 1.0 kgf/cm<sup>2</sup>  
 4) Ultimate bearing capacity: clay ≤ 12 kgf/cm<sup>2</sup>, sandy soil ≤ 20 kgf/cm<sup>2</sup>

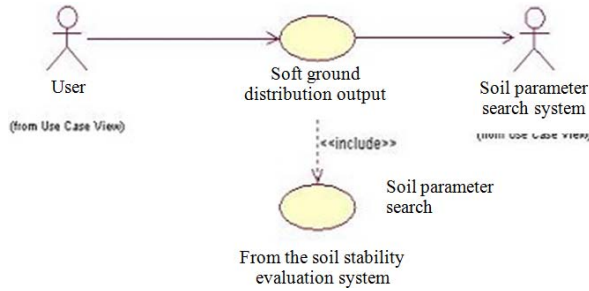


Figure 6. Use case diagram for the evaluation of soft ground

The evaluation of the liquefaction is conducted by calculating the soil parameters using the soil information DB according to the section determined by the user. The soil parameters are determined using grading, the N value, etc. The distribution map is outputted by substituting parameters into the liquefaction condition. The major processes and the use case diagram are shown in Table 6 and Figure 7.

Table 6. Major Processes for the Evaluation of Liquefaction

Function	Linked Data	Details
Liquefaction condition	Drilling log	N value
	Consolidation test	Uniformity coefficient, average particle diameter ( $D_{50}$ )
	Grading test	Grading distribution, degree of saturation
Liquefaction forecast		Using the standards
Liquefaction area output		On the plane view

Applied Standards:

- 1) Degree of saturation: 100%
- 2) Uniformity coefficient ( $C_u$ ):  $C_u < 10$
- 3) Average particle diameter ( $D_{50}$ ):  $0.075 \text{ mm} < D_{50} < 2.0 \text{ mm}$
- 4) Grading distribution: Particle size of the silt and clay  $\leq 10\%$
- 5) N value: The N value of saturated soil is smaller.

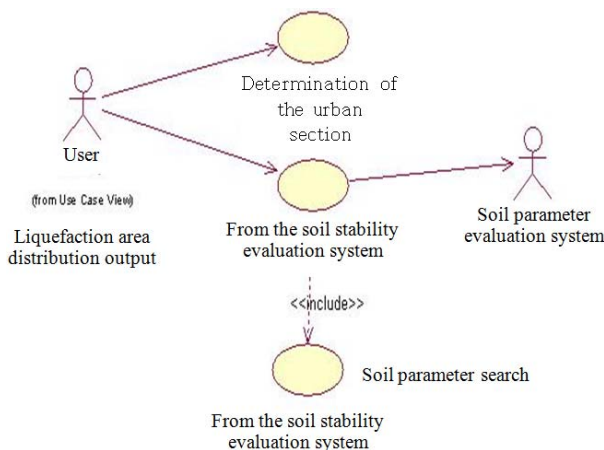


Figure 7. Use case diagram for the evaluation of liquefaction

### 2.3 Analysis and Evaluation System Design

The analysis/evaluation system was constructed based on the soil model that comprised GIS map modules, DEM, layer information, and various attributes so that the user

could choose a specific area in which to conduct the analysis and evaluation. Figure 8 shows the structure of the module in this system.

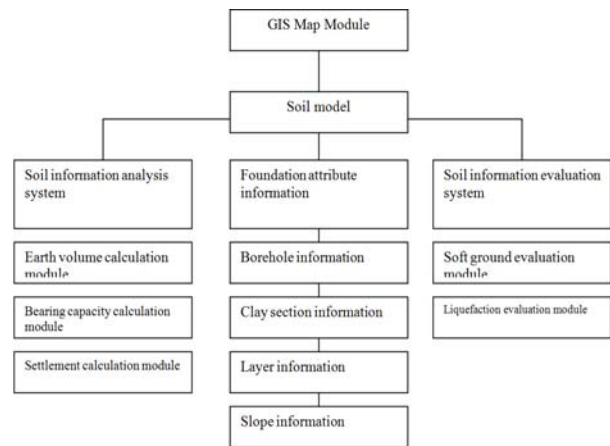


Figure 8. Analysis/Evaluation system structure

The RUP (Rational Unified Process) methodology, an object-oriented development methodology, was applied to the design of the system. Using the Unified Modeling Language (UML), specific scenarios for the modules were prepared according to the use case diagram in the previous section, based on which the sequence/activity/class diagrams were prepared for the design.

Figure 9 shows a sequence diagram for the evaluation of soft ground that shows the message sequence of each object in the form of time flow.

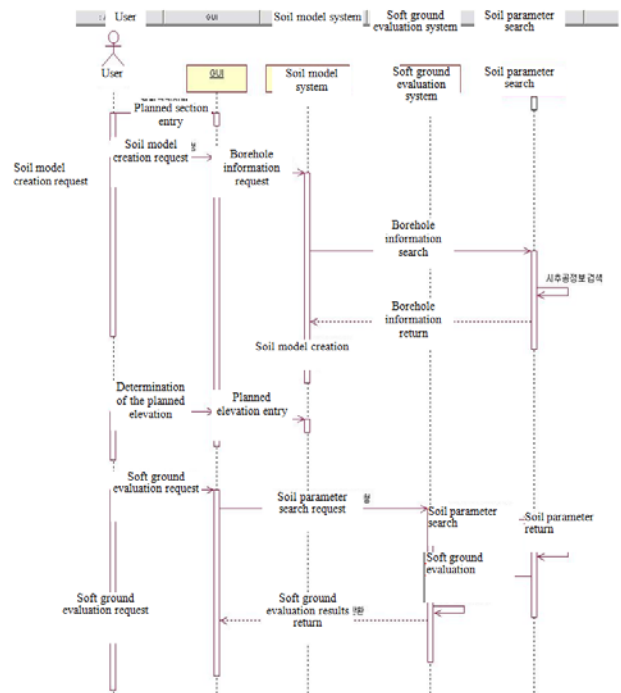


Figure 9. Sequence diagram for the evaluation of soft ground

Figure 10 shows an activity diagram for the calculation of the soil settlement, which shows the activities occurring according to the activities of the object.

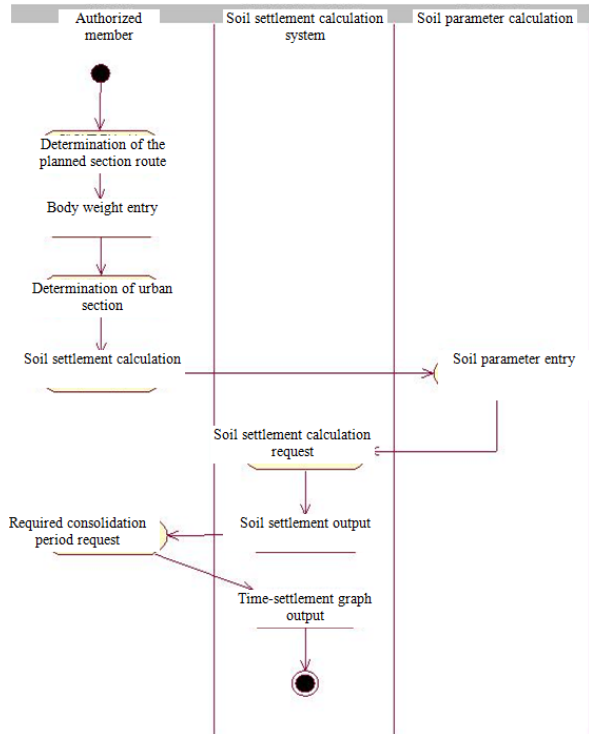


Figure 10. Activity diagram for the calculation of the soil settlement

The web client receives the soil parameters pertaining to the layers (Layer\_Data) and tests (Sample\_Data, Spt\_Data), and creates a soil cross-section model that facilitates its control such as via expression (SichudanDraw, etc.). Figure 11 shows the data structure for the creation of the soil cross-section model by dividing it into attributes and activities in the form of a class diagram.

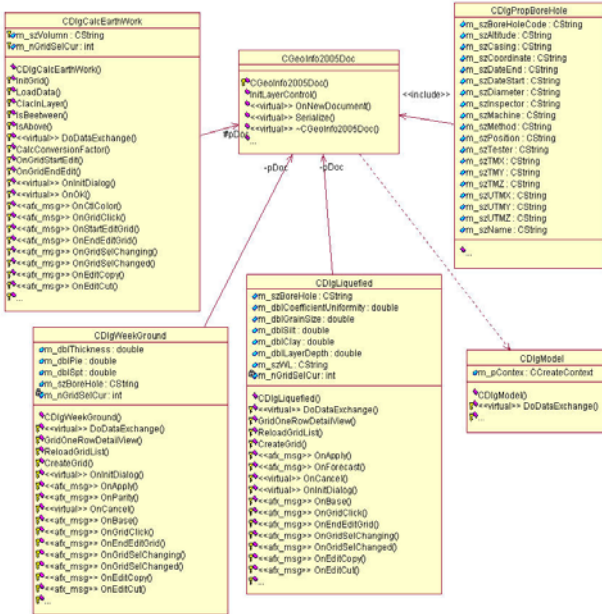


Figure 11. Class diagram of the soil model

### 3. CREATION OF A SOIL CROSS-SECTION MODEL AND AN ANALYSIS/EVALUATION SYSTEM

The web GIS client made for the creation of the soil model and the analysis/evaluation system retrieves the space information and attribute (soil parameter) information in real time from the soil information DB. A middleware that is exclusively for communication with the client was developed in the DB server to retrieve the required information via HTTP at the request of the client. Visual C++ was used as the development tool, and the IntraMap2D/X engine of Korea Geo-spatial Information & Communication Co., Ltd. was used as the GIS map engine. This system was developed as part of the 2006 National Soil Information DB Construction Project of MOCT.

#### 3.1 Soil Model Creation

When the user enters the planning section of the client, it retrieves the DEM, boreholes, and test information of the section via the DB and middleware, and creates the soil model by merging the coordinates of the objects. Figure 12 shows the function flow of the soil model.

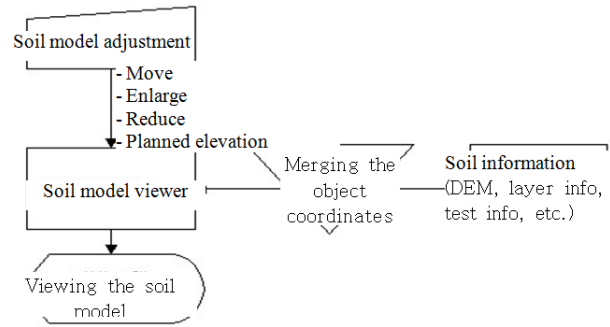


Figure 12. Function flow of the soil model

Figure 13 shows a client window that created a soil model, in the form of a layer cross-section in the lower part, for the section specified by the user. The created model is an independent object that can be enlarged and reduced. The layer color change and the planned elevation entry are also available. The analysis/evaluation is conducted based on this soil model.

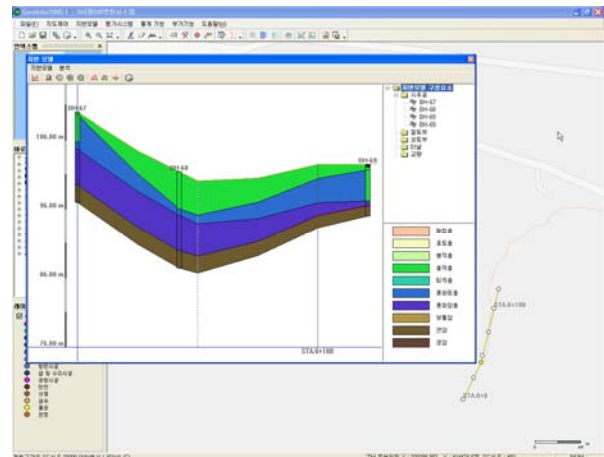


Figure 13. Soil model creation window (GIS client)

#### 3.2 Soil Information Analysis and Evaluation System Realization

The planned elevation was entered in the section using the created soil model, and the cutting/filling section was

thereby selected to calculate the earth volume by layer, as shown in Figure 14.

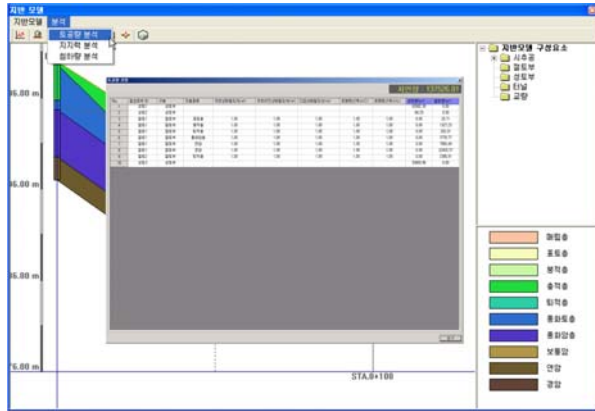


Figure 14. Earth volume calculation window (GIS client)

The user entered the structure type and the foundation type in the section, and calculated the settlement by time according to the formula suggested in Table 4. The results are shown in Figure 15 in the form of a graph.

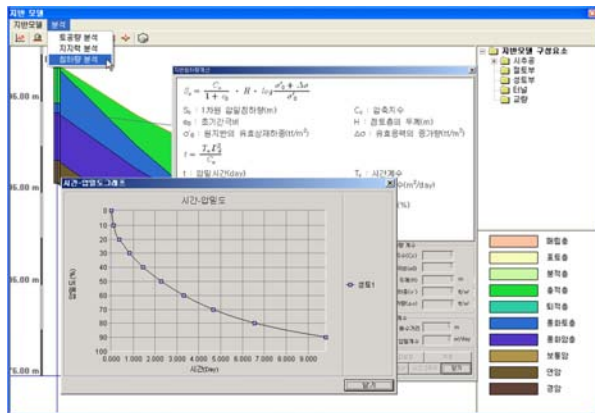


Figure 15. Settlement calculation window (GIS client)

The evaluation of soft ground and liquefaction for the section is also conducted with the soil parameters received from the soil information DB according to the standards shown in Table 6. The evaluation results are expressed by color in the specified section. Figure 16 shows a window that expresses the liquefaction evaluation results on the map.

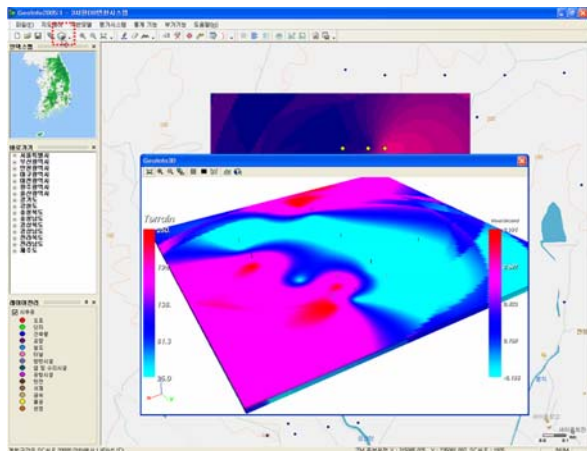


Figure 16. Liquefaction evaluation results window (GIS client)

#### 4. APPLICATION

The soil information analysis and evaluation system allows for the analysis/evaluation of an area on the web, unlike the existing system that constructs the soil information DB and only provides information in the form of electronic documents. If this function is extended, this system will be able to function as a GIS-based OLAP (OnLine Analytical Process) that provides a tool for web-based processing of construction planning and design. Table 7 shows the expected applications of this system.

Table 7. Expected application of this system

Sector	Description
Policy making/ feasibility study	- Feasibility study and policy making related to large construction projects - Estimation of the construction cost and potential problems
Construction method selection/ cost estimation	- Selection of the construction method by evaluating the bearing capacity, ground softness/liquefaction, and subsequent estimation of the foundation's construction cost
Design	- Basic design, including the proper selection of the foundation construction method via soil analysis
Design change	- Preliminary review of potential design changes via accurate initial soil analysis
Underground facility maintenance	- Selection of the optimal location for underground facilities and maintenance - For an area with a high groundwater level, prevention of pipe corrosion and estimation of the excavation cost

#### 5. CONCLUSIONS

In this study, a soil analysis/evaluation system was developed to make full use of the more than 60,000 boreholes of Korea's nationwide soil information DB in the construction sector. First, the design constants and evaluation factors for soil analysis and detailed design were determined, and algorithms of each element were defined to use the engineering data in the soil information DB. The web-based GIS client was employed for the user to easily use the defined algorithm.

The web-based GIS client retrieves space information and boring and engineering test information from the soil information DB in real time, and calculates the earth volume, bearing capacity, and settlement and evaluates the ground softness and liquefaction according to the defined algorithms.

It was difficult for this system to reflect all the soil engineering tasks in 3D space, however, due to the limitations of 2D GIS. This is because the existing soil model is simply based on the layer cross-section created by the soil information extracted from the boreholes. It is suggested that future developments create a 3D layer model by extending the dimensions of the interpolation, by which real-time analysis and evaluation can be conducted.

The system developed in this study provides a web-based support tool to solve problems concerning soil, which is inevitably required in construction work. This will effectively cover policy making and feasibility studies for SOC construction, construction method selection, and construction cost estimation, as well as

design support, review of design changes, underground facility maintenance, etc. In addition, it is expected that the demand for the soil information DB will reach practical tasks such as construction planning and design.

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