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Development of a web-based Geographic Information System for the management of borehole and geological data

Yoon-Seop Chang, Hyeong-Dong Park*

School of Civil, Urban and Geosystem Engineering, Seoul National University, Shillim-dong, Kwanak-gu, Seoul 151-744, South Korea

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Abstract

The main objective of this study is to develop a prototype model of Web-based Geographic Information System (GIS) application for efficient management of borehole and geological data. More than 10,000 boreholes and other geological data were archived into the database and Web-based GIS system was implemented for a local urban area of Seoul in Korea. A standard form of borehole data was suggested and the database was developed in the system. The system provides client users with geological information search function, on-line geological information function, statistical summaries, and administrative functions. As a result, the system makes the efficient management of geological data possible by adopting database and Web-based system. It is also expected that the system can be connected with other existing GIS applications for further applications.

Keywords: Web-based GIS; Borehole data; Data standard; Geological functions; 3D visualization

1. Introduction

Geological data, especially borehole data, can provide useful information about both surface and underground conditions of the earth. Thus, they have been frequently used in a number of fields such as civil construction, natural resource exploration, environmental problem, transportation and so on. Geological data are composed of various types of data: borehole data, topographical data, rock and soil data, geophysical data and hydrology and so on. The vast amount and diversity of these geological data (see Fig. 1) cannot be easily handled without using database and Information System (IS). Geographic Information System (GIS) can be one of the solutions for the management of geological data because most of geological data are referenced to locations of the earth and such spatial complexity can be well accommodated in GIS (Table 1).

Recently, most of GIS applications have been modified from desktop GIS to Web-based GIS (Kraak and Brown, 2001; Plewe, 1997; Richard, 2000; Tang and Selwood, 2003). Such change was initiated by the advantages of Web-based GIS compared to an earlier desktop GIS. Desktop GIS has some drawback; the limit of accessible users and centralization of most of all resources and system on the local machine. Due to the limits of resources and performance in desktop GIS, many related problems occur. One such problem is the limited sharing of data and information due to the absence of suitable dissemination on the network (Kingston et al., 2000; Plewe, 1997; Zhu et al., 2001). On the other side, Web-based GIS can support unlimited users and can be accessible from anywhere and at anytime through the Web. These advantages

*Corresponding author. Tel.: +82-2-880-8808; fax: +82-2-871-8938.

E-mail address: hpark@snu.ac.kr (H.-D. Park).

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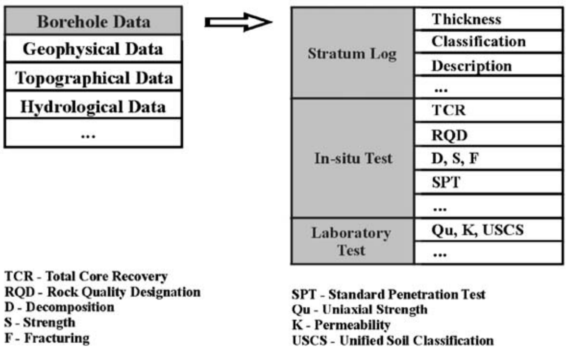


Fig. 1. Example to show amount and diversity of geological data.

Table 1
Example of borehole data to show spatial complexity of geological data

Data item	Constraints				
	x^a	y^a	z^a	Δz^a	Time
TCR	✓	✓		✓	
RQD	✓	✓	✓	✓	✓
GWL[b]	✓	✓	✓	✓	
D	✓	✓	✓	✓	
S	✓	✓	✓		
F	✓	✓			
SPT	✓	✓			
Lab. test results	✓	✓			

[a] x, y, z—coordinates in 3D space.
[b] GWL—ground water level.

come from the fact that Web-based system efficiently distributes the required resources and system of application on the network which can solve the problems of performance and reliability of GIS applications. Thus it maximizes the sharing of useful data and information through the Web.

This trend also has been introduced in the field of geological or geotechnical information (Huang and Worboys, 2001; Lin et al., 1999; Markstrom et al., 2002; Sokolov and Wulff, 1999; Sugamaran et al., 2000; Su et al., 2000). Geological data and its applications have been shown on the Web in recent years as forms of simple downloading, Web database, Web maps and functions, etc. (Plewe, 1997).

However, there yet remain many important problems to be solved for advanced Web-based GIS applications. One problem comes from the requirement of suitable standards for geological data and good design of geological database. For example, there exist very different methods of description of borehole data according to different project scheme and organizations (Park and Yu, 1998). Another problem is the implementation of more advanced geological functions and analyses on the Web. Those functions and analyses in previous Web-based GIS applications are limited to the simple viewing of geological information using geological data layers on the map. The other problem is the support and implementation of visualization and analysis functions in 3D. Although there have been several challenges for 3D functions (Guillen et al., 2001; Huang et al., 2001; Huang and Lin, 1999, 2002; Lin et al., 1999), most of the results have not been completely successful.

Geological data from many construction projects should be standardized, structured, archived and properly used through suitable system and applications for efficient management especially in urban area because of limits from continuing urbanization. Applications using Web-based GIS are very essential to maximize the sharing of geological information and to solve problems related to geotechnical engineering. This paper describes the details of a project for Web-based GIS application into geotechnical information in the urban area of Seoul, South Korea.

Thus it is focused on the development of Web-based GIS application for the management of geological data; (1) suggestion of standards of borehole data description and database, (2) application to the developed system, (3) design of several advanced geological functions for geological data, (4) implementation in the system.

2. Review of previous studies

Each geological data has its own type, description, characteristic and source necessary to use database and GIS for management. Recently,management and sharing of geological information using Web-based GIS technologies has been rapidly increased for more efficient management and sharing of geological information.

An example is GeoLibrary, one component of the Idaho Geospatial Data Center (IGDC) and is a map browser for an Internet-based GIS data repository (Jankowski et al., 2001). Although GIS data in the IGDC are rather far from the full geological usage, they cover Digital Line Graph, Digital Raster Graphics, USGS Digital Elevation Model (DEM) and Tiger boundary files, etc. GeoLibrary was developed as a form of stand alone and TCP/IP-based application using Microsoft Visual Basic 6.0 and ESRI MapObject. It provides users with metadata such as size, type, projection, scale, name of server, access path and so on for GIS data files. It also enables users to connect and retrieve useful data using FTP protocols from servers. The most remarkable feature is that limited network resources are intensively utilized by the use of client browser application, local database on client, metadata application on server and FTP-based downloading.

Another good example, GeoFrance 3D is a framework research program which aims at developing an archive and providing the storage, access and 3D visualization of geological and geophysical data of France (Guillen et al., 2001). Spatial data in the GeoFrance 3D are geospatial metadata, vector-type geological map, regular-grids seismic data and raw data. Standardization of the geological and geophysical information was necessary to be accessed by different users, applications and systems from remote locations. ESRI SDE software was adopted and customizing was done using Java to manage the spatial queries from client users. Gravity point data, aeromagnetic data, structural data and others are provided as raw data. System architecture was implemented by Java technology, database, Internet connection and a browser. Java technology enables client users to access information with existing Internet browsers only and to provide many advantages such as interoperability, security and memory management, etc. Implemented system provides three interfaces to client users: META interfaces providing the visualization of the results from metadata queries, DGIS (Distributed GIS) interface providing the formulation of spatial queries on geological data and the results, and geophysical interface realizing thematic queries on the geophysical data. Visualization tools provide various mapping functions such as Paint, FitAll, Zoom, Pan and Convert, etc. With GeoFrance 3D, it is possible to have graphical visualization environment using pure Java technology, geological and geophysical data storage and usage in other server, and processing of spatial information by SDE. A wide range of geological and geophysical data and 3D visualization of underground geological structures are the most noticeable features of this project.

An example, GeoVR is a toolkit designed for interactive building up of virtual environments from existing GIS data (Huang and Lin, 1999, 2002; Huang et al., 2001). Virtual reality (VR) allows users to interact with and to explore 3D geological data. GeoVR is designed to generate 3D VRML models from 2D GIS data and to provide user interface for interaction with GIS data on the Internet. It provides 3D visualization, 3D analysis and VRML interaction. GeoVR was implemented by extending ArcView IMS (Internet Mapping Server) with Java and Avenue language to the client and server side, respectively. It is composed of Java client, Web server and visualization server. Java client applet can communicate with applications on both client and server side. ArcView IMS can run user-defined applications coded by Avenue. It adopts a hybrid system of client-side and server-side methods for its improved performance. In GeoVR, it is possible to build 3D model from existing 2D GIS data possible. 2D GIS data such as shapefile, coverage, image and other ArcView-compatible files can be explored and are used to create 3D VR model on the Web.

Recent work by Korea Institute of Construction Technology (KICT) is a typical example of web-based GIS system. The KICT is the government-sponsored institute to conduct researches and developments on the national infrastructures such as civil engineering, architecture, water resource environment, etc.[1]

KICT developed a Web-based GIS system based on the site investigation data from constructions of road, railway and highway in South Korea. Recently, standardization of borehole data was carried out and Web-based system was implemented by KICT. Borehole data includes borehole logging and properties from experimental tests. Borehole logging, in detail, includes the information of the borehole and project, strata information, sampling and in situ test results.

The most noticeable function of the Web-based system of KICT is the cross-section view of borehole data. The system supports multiple boreholes selection and visualization with user's access to more detail information about underground. The cross-section view of boreholes provides the visualization of in situ test results with graph plot and fence diagram. The result from test of samples can be queried through symbols on the cross-section view. The table and logging sheet also can be acquired for each individual borehole. Due to its borehole data standard and its management application using the Web, many companies can access useful information more easily and can manage their projects more efficiently.

Comparison (Table 2) was made based on the following: (1) data managed in their applications, (2) suggestion of data standard, and supports for (3) metadata search, (4) 3D visualization, and (5) VRML.

Considering data management problem, there has been no fully reliable data standard in preceding projects and it is necessary to suggest more suitable data standards for each geological data. More supports for the implementation of metadata search, 3D visualization and VRML on the Internet are required to improve the performance of existing applications and to attain the full maturity of future applications.

3. Borehole data standard and database design for web-based geotechnical information in Seoul

In highly urbanized city like Seoul, the capital of Korea, there are many site investigation reports from different types of construction such as roads, subways,

[1]KICT General Information, http://www.kict.re.kr/front/eng.

Table 2
Comparison among projects in case studies

Project	Geological data	Geophysical data	Data standard	Metadata search	3D visualization	VRML	References
GeoLibrary	✓			✓			Jankowski et al. (2001)
GeoFrance3D	✓	✓	✓	✓	✓		Guillen et al. (2001)
GeoVR	✓				✓	✓	Huang and Lin (1999); Huang and Lin (2002); Huang et al. (2001)
KICT	✓		✓		✓		Footnote-1

Table 3
History of subway construction in Seoul area

Subway line	Length (km)	Year
Line 1	7.8	1971–1974
Line 2	54.2	1978–1984
	3	1986–1996
Line 3	27.7	1980–1990
	8	1989–1993
Line 4	28.3	1980–1985
	1	1989–1993
	3	1989–1994
Line 5	52	1990–1996
Line 6	31	1993–2000
Line 7	42	1990–2000
Line 8	20	1990–1999
Line 9	38	2002
Total length	316	

railways, tunnels, airports and ports (Table 3). Because these construction works and site investigations are managed by many different governmental and non-governmental organizations, there is no single standard type or format. For this reason, many different types of site investigation reports and borehole logs should be examined against possible problems such as discrepancy and redundancy in data items before the design of the standard and database of geological data. For Web-based GIS project of the Seoul city, enormous amount of site investigation reports, borehole logs and related data were collected and used for the design of a data standard and database of geological data. More than 10,000 boreholes were acquired and used for the project.

A number of site investigation reports and borehole logs were analyzed to reveal principal components among various borehole data from different construction works of road, railway, and buildings. An example of borehole data standard by KICT was also critically reviewed whether it is suitable for the standard in this study.

3.1. Structure and characteristics of borehole data

According to the comparison among various types of borehole data, borehole information can be classified into three categories: (1) general information about individual borehole, (2) stratum information and (3) tests and engineering properties. General information about individual boreholes includes project description (project name and company), drilling (drilling method, equipment, date, purpose and name of drilling engineer), borehole location (coordinates and elevation) and geometry (drilling depth, ground water table, casing depth and hole diameter). Stratum information is divided into rock and soil information. It includes the detail of stratum shape (thickness, depth and symbolic log), engineering properties (color, N value from standard penetration test (SPT), total core recovery (TCR), rock quality designation (RQD), weathering, strength, density, fracturing, cracks and joints) and sampling information (sample type and core shape). Engineering properties from various tests are recorded in site investigation reports. Typical examples are as follow: water content, density, saturation, void ratio, permeability, Poisson's ratio, Young's modulus, direct shear test, uniaxial test and seismic test.

3.2. A previous example of borehole data standard

Before designing a new data standard from the result of borehole data characterization, it was necessary to review the previous standard of other organization. In South Korea, KICT suggested a standard by using borehole data from site investigation reports for construction works of road, railway and highway.

The standard suggested by KICT is mainly composed of borehole logs and test results. Borehole logs are largely divided into rock and soil types. Borehole log includes general information, stratum information, sampling method, in situ test, and legend (Tables 4–6).

Table 4
Details of general information about boreholes: an example of standard suggested by KICT

Soil type	Rock type
Sheet number	Sheet number
Project name	Project name
Client	Client
Hole number	Hole number
Location	Location
Coordinates	Coordinates
Elevation	Elevation
Date	Date
Hole depth	Hole depth
Ground water level	Ground water level
Drilling machine	Drilling machine
Drilling method	Drilling method
Drilling engineer	Drilling engineer
Inspector	Inspector
Casing depth	Drilling direction
	Drilling angle

Table 5
Details of stratum information of boreholes: an example of standard suggested by KICT

Soil type	Rock type
Depth	Depth
Elevation	Elevation
Thickness	Thickness
Casing	Casing
Symbolic log	Symbolic log
Soil and rock type	Soil and rock type
Color	Color

Table 6
Details of sampling method and in situ tests of boreholes: an example of standard suggested by KICT

Soil type	Rock type
SPT[a]	SPT[a]
TCR[b]/RQD[c]	TCR[b]/RQD[c]
Sample number	Sample number
Sampling method	Sampling method
Depth	Depth
Sample type	Sample type
Fracture log	Joints (weathering, strength, fractures)
Permeability	Drilling condition (velocity, rotations, leakage)

[a]SPT—standard penetration test.
[b]TCR—total core recovery.
[c]RQD—rock quality designation.

3.3. *A new standardization of borehole data*

A new standardization of borehole data in this study was by modifying and improving the previous KICT standard with particular consideration on compatibility and efficient management. Information on borehole data was classified into categories such as project information, borehole information, stratum information, SPT which is most widely used in Korea, in situ tests and laboratory tests information (Tables 7–12).

- Project information
  All boreholes can be queried and accessed through codes assigned for each project. This category

Table 7
Project information in newly suggested borehole data standard in this study

Field	Details (* with codes)
Project type*	Road (01), subway (02), railway (03) and building site (04) etc.
Project code	Serial numbers to manage projects
Project name	Name of the project
Client organization	Name of client organization
Company name	Company executing the site investigation
Project start date	Start date of corresponding project
Project end date	End date of corresponding project
Starting point	Referred to administrative division
Terminal point	Referred to administrative division
Number of boreholes	The number of whole boreholes in the project
Remarks	Remarks

Table 8
Borehole information in a new suggested borehole data standard in this study

Field	Details
Project code	Serial number referred to corresponding project
Borehole code	Serial number to manage boreholes
Borehole name	String name of borehole
Purpose	Basic design, working design and etc.
Elevation	Elevation of drilling point
Depth	Total drilling depth
Ground water level	Depth to the ground water level
Drilling start date	yyyy/mm/dd
Drilling end date	yyyy/mm/dd
Driller	Driller and/or inspector
Drilling method	Rotary drilling or high pressure drilling
Hole diameter	BX and NX, etc.
Coordinate (x)	TM (transverse mercator) coordinate
Coordinate (y)	TM (transverse mercator) coordinate
Administration division	Administrative division name
Address	Address to locate borehole
Station number	Station number for construction

Table 9
Stratum information in a new suggested borehole data standard in this study

Field	Details
Borehole code	Serial number referred to corresponding borehole
From	Depth to the top of stratum
To	Depth to the bottom of stratum
Thickness	To–from
Engineering classification	Fills, alluvium, completely weathered, highly weathered, moderately weathered, slightly weathered, fresh
Scientific classification	USCS or geological name
Color	Color of stratum
Description	Description of stratum

Table 10
Details of SPT (standard penetration test) in a new borehole data standard in this study

Field	Details
Borehole code	Serial number referred to corresponding borehole
Test depth	SPT test starting depth
Blows	Number of blows (*N* value)
Penetration depth	The amount of penetration

Table 11
Details of in situ rock test results in a new borehole data standard in this study

Field	Details
Borehole code	Serial number referred to corresponding borehole
From	Depth to the top of stratum
To	Depth to the bottom of stratum
TCR	Total core recovery
RQD	Rock quality designation
D	Decomposition
S	Strength
F	Fracturing

includes information about project name, project period, number of boreholes, administrative area and company names.

- Borehole information
  Drilling method, date, location, and drilling engineer are included in this category. Project code and borehole code enable boreholes to be combined with corresponding project, stratum and test information.

Table 12
Details of laboratory test results in a new borehole data standard in this study

Field	Details
Borehole code	Serial number referred to corresponding borehole
From	Start of borehole
To	Finish of borehole
Qu	Uniaxial compression test—strength
C	Direct shear test—cohesion
Phi	Direct shear test—frictional angle
Cuu	Triaxial compression UU test—cohesion
Ccu	Triaxial compression CU test—cohesion
Phi	Triaxial compression test—frictional angle
Pc	Consolidation test—preconsolidation stress
Cc	Consolidation test—compression index
K (static)	Permeability test—static permeability coefficient
K (dynamic)	Permeability test—dynamic permeability coefficient
Lu	Hydraulic test—Lugeon
Ep	Extensometer—modulus of deformation
Em	Extensometer—modulus of elasticity
USCS	Unified soil classification

- Stratum information
  Each stratum can be discriminated by both practical stratum name for geotechnical engineers and geological name. Color description is created considering compatibility with that of KICT standard. All other descriptions are subdivided for efficient input, update and query.
- Standard penetration test (SPT)
  From the reason that SPT result is a preliminary data of borehole logging and is almost available for many applications in Korea, it is managed independently as an additional category.
- In situ tests
  Properties such as TCR and RQD are essential data from in situ tests. It can provide important information about joints and rock strength, etc.
- Laboratory tests
  Various laboratory tests are usually carried out using samples from boreholes in order to acquire important engineering properties for the site.

4. Web-based system architecture and interfaces

4.1. Preliminary design of web-based system

To launch a test bed for Web-based GIS system, a preliminary study on the implementation of Web-based system was carried out. A Web-based application was implemented for local-scale area for construction work. Data, map and analysis services were successfully provided for the site using boreholes and geophysical data from site investigation by the authors (Chang et al., 2002; Yu and Park, 2002). The target site was the local area for construction of national road with a total length of 6255 m with nine bridges and one tunnel.

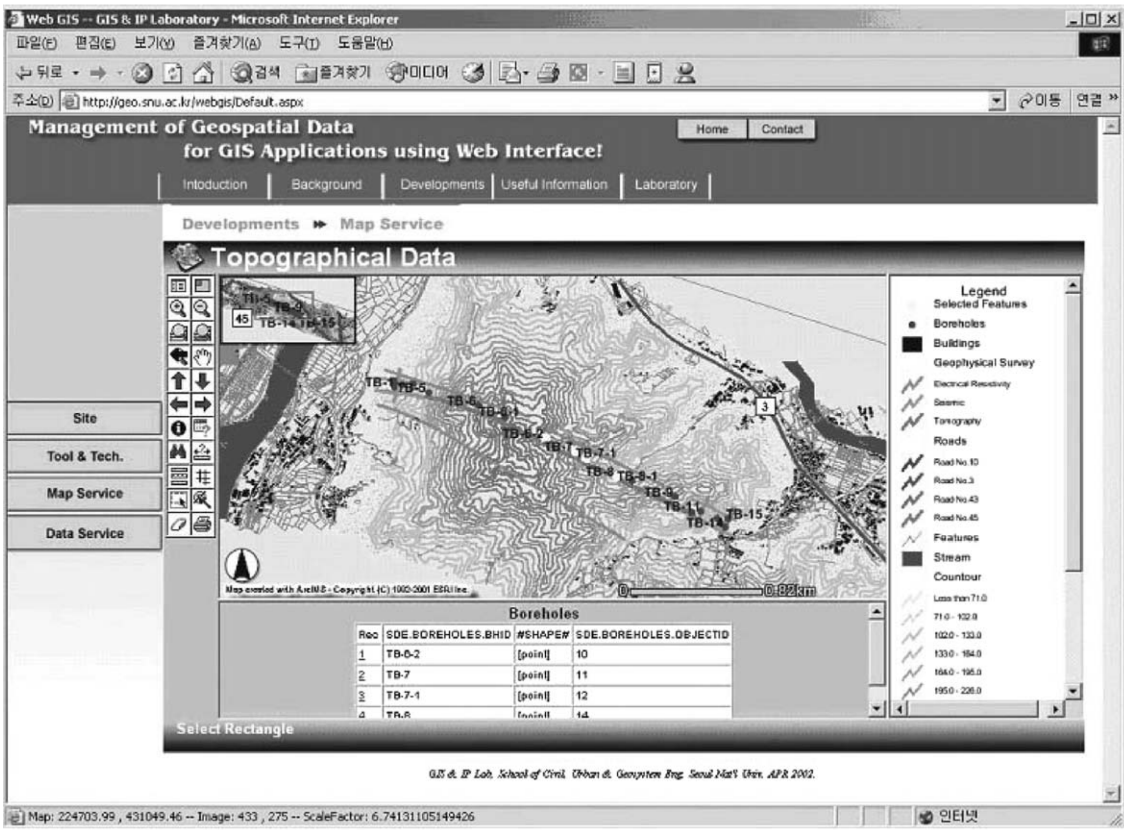
The system was implemented by using ESRI ArcIMS (version 3.1) and ArcSDE (version 8.1) for map and data services on the Web. Geological data were archived into the database of Oracle DBMS (version 8.1.6). ArcSDE played a role as a gateway to the DBMS. For user interfaces, Web pages were created by using ASP.NET technology.

The implemented system provides map, data and analysis services for the target site. Fig. 2 shows an example of the map service. Two map services were provided: one was for topographical information and the other was for geological information. Data service was implemented to show boreholes with strata information and results of in situ and laboratory tests. 3D VRML view of the site and cross-section view with multiple boreholes were implemented as analysis services.

4.2. System configuration and architecture

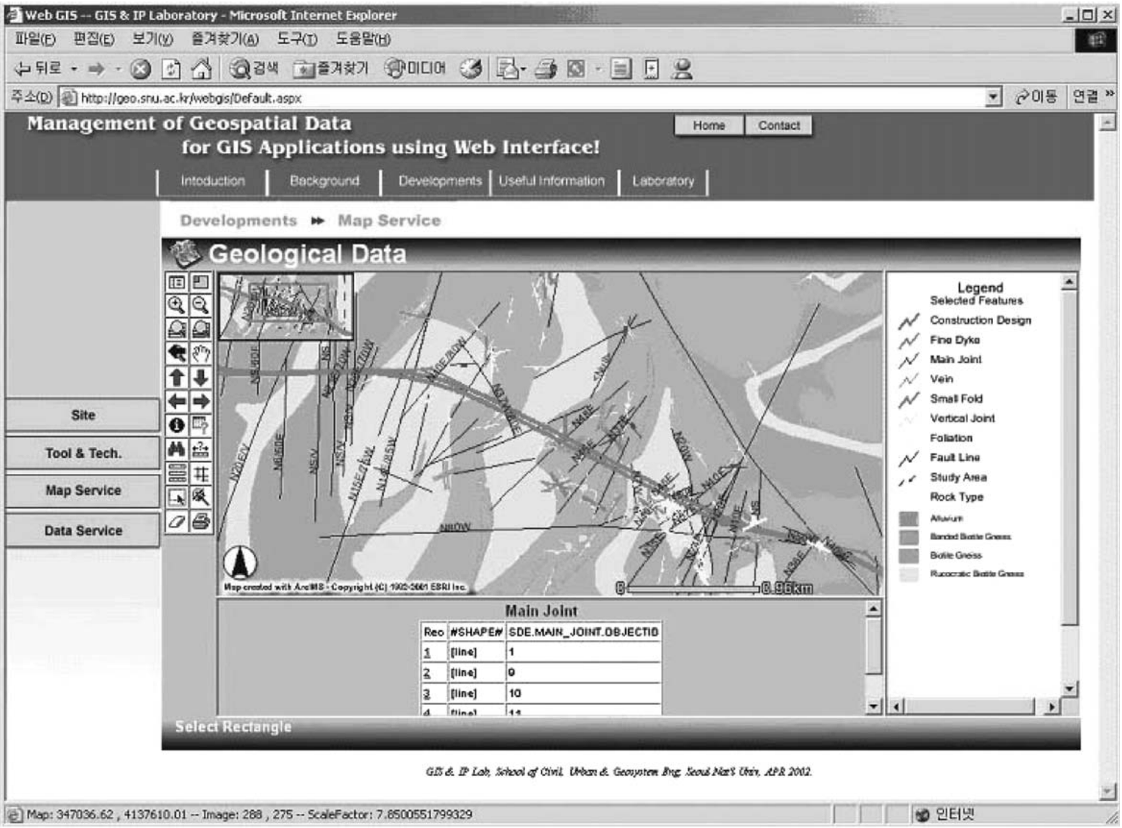
The structure and main functions of the Web-based system are shown in Fig. 3. The system allows the improvement of the reliability and efficiency during the input of subsequent geological data into the database. It also allows to bring real-time and users' easier access to the system, data and functions. Finally, the practical usage of geological information can be extended when the system is combined with other existing GIS applications. Hardware platform configuration and software architecture of the system can be described as follows:

(1) Hardware platform configuration
Web server machine used for the system is Compaq Proliant ML570 and it has the specification like the following
- CPU: Dual Pentium III Xeon 700 MHz, 1 MB cache memory,



(a)

Fig. 2. Test bed of Web-based system implements two kinds of map services for a local-scale area. (a) One map service provides topological information and (b) other map service provides geological information.



(b)

Fig. 2. (*Continued*)

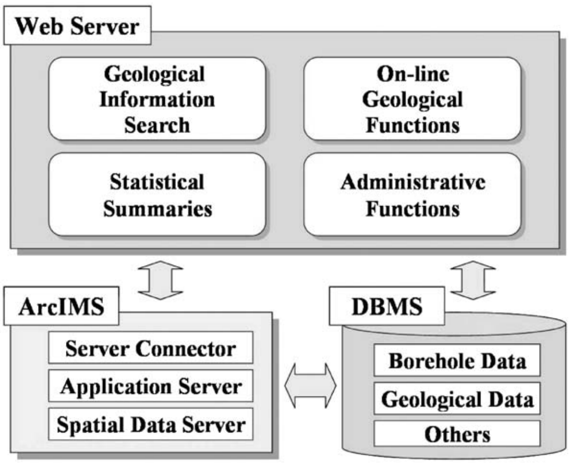


Fig. 3. Structure and main functions of implemented Web-based system in this study.

- Main memory: 1024 MB (512 MB × 2),
- HDD: 72 GB (36 GB × 2),
- OS: Windows 2000 Server,
- Web server: Internet Information Server (IIS) 5.0,
- DBMS: Oracle 8.1.6.

(2) Software architecture of the system
Software architecture for Web-based GIS application in this study consists of three components such as ESRI ArcIMS package, Web server software and DBMS (Fig. 4).

- ArcIMS software
ArcIMS package has three-tier architecture which consists of client-side, middleware and data provider component. ArcIMS package consists of client viewer, application server connector, application server and spatial server
  a. Client viewer: There are HTML viewer and Java viewer. Client viewer provides users with map functions and spatial query support.
  b. Application server connector: This component connects ArcIMS application server to Web server such as IIS or Appache.
  c. Application server: This component generates and provides map images or map functions from spatial data in the server.
  d. Spatial server: ArcIMS spatial server plays a role as a gateway between application server and DBMS. It builds spatial data by query on DBMS and provides those data to other GIS software.

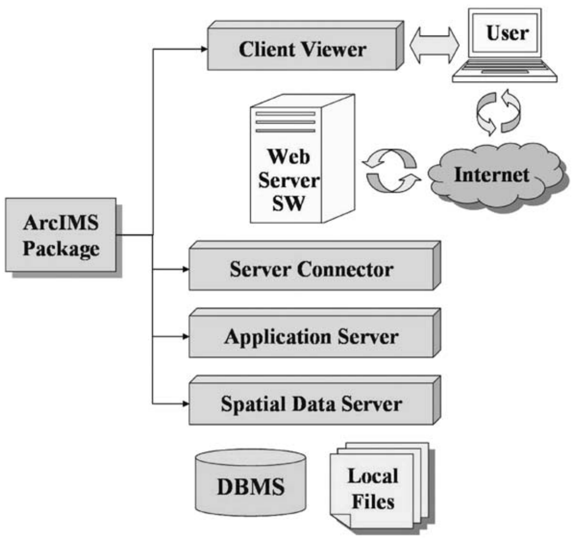


Fig. 4. Software architecture of Web-based system in this study.

- Web server software
  In this study, Microsoft IIS which is built-in software of Windows 2000 was used as Web server software. Web server software provides user interfaces with forms of Web pages. This component can be connected to ArcIMS application server by application server connector.
- DBMS
  Oracle 8.1.6 was adopted as a DBMS in this study. DBMS manages geological data including more than 10,000 borehole data and other additional data such as administrative divisions, users, geological terminology and help information, etc.

4.3. Implemented system interfaces and functions

Implemented system interfaces and functions can be classified into four categories with respect to their purposes. Four categories are geological information search, on-line geological functions, statistical summaries, administrative functions and others.

(1) Geological information search
Geological information in the system can be searched and accessed by three kinds of criteria through the Web: project, user-defined and map-based query.
- Search based on their projects
  Search by this criterion can be carried out based on project type and subsubjects. Project type can be such as road, subway, railway, building site, tunnel and bridge. Subsearch subjects are like project name, ordering organization, company name, start year, administration number and Geo-Seoul code.
- User-defined search
  Users can search and access geological information by executing user-defined queries. This search can be done for project type, administrative division, year and ground water level. Information can be searched for the years from 1990 to 2003 and for ground water level from 0 to 100 m which are normal ranges in Seoul area.
- Map-based search
  Map-based search can be more intuitive than any other searches. In this search, geological information can be searched and accessed directly by selecting boreholes on the base map.

(2) On-line geological functions
On-line geological functions of the system provide the visualization of borehole log, borehole cross-section, strata cross-section, geological map and contour of underground strata.
- Borehole log
  Users can access borehole log by selecting boreholes using mouse. All borehole logs are created dynamically by users' queries on the web.
- Borehole cross-section view
  Cross-section view of multiple boreholes can be visualized on the Web. Several option buttons for SPT graph, strata connection, ground water level and surface line enable users to easily access each result.
- Strata cross-section view
  Users can see strata cross-section view by drawing arbitrary straight line on the base map. Strata cross-section views are shown with reference map and borehole data table.
- Geological map
  For the specific region on the base map, geological map can be overlaid by user queries. Because this geological map is shown transparently, users can recognize both geological and other information
- Contour of strata relief
  Contour lines for specific underground stratum can be shown on the Web for each stratum. With this visualization, users can understand the relief of specific stratum. Several visualization options enable users to see these contour lines more easily.

(3) Statistical summaries of boreholes
Statistical summaries of borehole data are provided through the Web. Summaries can be created by several criteria: project, administrative division, year, ground water level and user-defined query. Each summary is presented with numerical values

and graphs: (i) The whole summary shows the entire borehole of Seoul on one map. (ii) Different summaries for several kinds of project types such as road, subway, railway, building site, tunnel and bridge. (iii) Summaries also can be shown for each administrative division. The number of projects and boreholes are summarized with numeric values and graphs. (iv) Boreholes in Seoul are summarized with location map, values and graphs. Borehole data from 1990 to 2003 are arranged for each year. (v) With respect to ground water level, borehole data summaries can be shown for each 10 m interval up to 100 m.

(4) Administrative functions and others
The system provides the administrative functions to administrate users. The input and update of borehole data also can be managed by the administrative functions. Administrator can manage projects, borehole data and others through Web.

Other accompanying functions such as announcement, Q&A, guideline, help and so on are also provided through Web.

4.4. Discussion

One important advantage of the system developed in this study is that it implements systemic interfaces and functions in one system to provide the convenience of public officials, geotechnical experts, system administrators and public users. Four important modules in one system, i.e., geological information search, on-line geological functions, administrative functions and statistical summaries are provided each for public officials, geotechnical experts, system administrators and public users. The other important advantage is that a borehole data standard and corresponding database were suggested and utilized in the system developed in this study. Because this borehole data standard can be conformed to and also improves the existing government standard such as that of KICT, the system in this study can be efficiently used without paying much costs for many governmental and non-governmental projects.

One problem which can be improved with further study is the implementation of 3D visualization functions on the Web. The system provides 3D visualization function as the form of cross-section view at this time, but it can be improved by adopting VRML technologies in which it is more convenient to visualize 3D object on the Web. Another problem is the implementation of interoperability, this became a very important issue since various hardware, software and Internet technologies have emerged. The implementation of interoperability in this field will be possible by adopting OpenGIS concept and its specifications together with Web service and Component-based development technologies, etc. The other potential problem is that caused by continuing data input. Solution like data clustering may be necessary for maintaining the performance of the system.

Many additional applications will be available when the system in this study is combined with other existing GIS applications of Seoul such as each GIS application for transportation, buildings and underground facilities and so on.

5. Conclusions

In this study, an example of Web-based GIS applications has been developed for efficient management of borehole geological data on the Web. GIS application development adopting Internet technology was essential because the efficiency of data usage is very important in the case of fast developing and growing country such as Korea in which there are vast amount of geological data due to new construction works. A prototype for Web-based GIS application was successfully designed by using ESRI ArcIMS software package, Microsoft IIS Web server software, Oracle DBMS and Web programming language with more than 10,000 borehole data to provide systemic interfaces and functions such as geological information search, on-line geological functions, statistical summaries and administrative functions. For efficient management of borehole data, an example of borehole data standard has been suggested based on the previous example of data standard of KICT. The above combination of software, data and data standard in this study is efficient enough to bring the following remarkable advantages of the developed system: (1) Many different users including small companies can be data providers and they can share their geological data more easily through this system on the Internet. (2) Engineers can input and update geological data instantly on the construction site and this real-time data management can bring the reduction of time and cost for construction work. (3) Companies can access useful geological data on the target site and can make preliminary plan before the start of their construction works, e.g., selection of site for detail investigation. (4) The system developed in this study can be an infrastructure as a data provider for other related applications such as environmental project, urban planning, transportation design where similar type of geological and geotechnical data are used. The system was designed to be upgraded by further improvements such as 3D VRML visualization, interoperability implementation and data clustering. Additional GIS application is also expected when the system is combined with other existing GIS application of Seoul.

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