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Implementation of Geo-knowledge Based Geographic Information System for Estimating Earthquake Hazard Potential at a Metropolitan Area, Gwangju, in Korea

Chang-Guk Sun, and Jin-Soo Shin

***Abstract*—** In this study, an inland metropolitan area, Gwangju, in Korea was selected to assess the amplification potential of earthquake motion and provide the information for regional seismic countermeasure. A geographic information system-based expert system was implemented for reliably predicting the spatial geotechnical layers in the entire region of interesting by building a geo-knowledge database. Particularly, the database consists of the existing boring data gathered from the prior geotechnical projects and the surface geo-knowledge data acquired from the site visit. For practical application of the geo-knowledge database to estimate the earthquake hazard potential related to site amplification effects at the study area, seismic zoning maps on geotechnical parameters, such as the bedrock depth and the site period, were created within GIS framework. In addition, seismic zonation of site classification was also performed to determine the site amplification coefficients for seismic design at any site in the study area.

***Keywords*—**Earthquake hazard, geo-knowledge, geographic information system, seismic zonation, site period.

I. Introduction

OBSERVATIONS of recent destructive earthquakes have demonstrated that despite the same epicentral distances within an urban area, earthquake-induced hazard is often more severe over soft soils than over firm soils or rocks [1]. That is, the local geologic and soil conditions have a profound influence on the amplification of earthquake ground motions, which may result in the serious seismic hazards [2]. The difference of seismic amplification potential between the sites in a region would be estimated by spatially predicting the subsurface soil thickness and the corresponding seismic response behavior in the entire area of interesting. In the spatial prediction of the subsurface geotechnical conditions across the area of interesting, pre-existing borehole drilling data in and near the area can be efficiently used as the basic resources and geotechnical expert knowledge can be also applied for enhancing the prediction reliability [3].

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Geotechnical engineering data including borehole investigation data are distributed in the spatial domain [4]. In order to assess a geotechnical problem with regional scale, the geotechnical data referenced by the spatial geographic coordinate should be interpolated or extrapolated across the area of interesting based on the existing and/or obtained known geotechnical data. Advanced computer-based expert system is required for the management and estimation of geotechnical data in huge spatial domain such as urban and metropolitan area. As advances in the computer technology, geographic information system (GIS) in recent years has emerged to be a powerful computer-based technique that integrates spatial analysis, database management, and graphic visualization capabilities [2]. For geotechnical purposes, GIS-based expert systems have been developed and used to forecast and plan for natural hazards such as landslides or earthquakes [2], [3]. Especially, most of technologies for the applications of GIS in geotechnical earthquake engineering will be widely used in increasing number of seismic zonations for the prediction and mitigation of earthquake-induced hazards [2], [5]. In this study, a spatial GIS-based geotechnical engineering system is implemented for the reliable estimation of the geotechnical sub-layers and the corresponding earthquake-induced hazard potential over the selected inland metropolitan area, Gwangju, in Korea.

II. Earthquake Hazard Potential

Earthquake ground motion inducing a variety of hazards on and near the ground surface is influenced by several factors such as the seismic source, ray path, and local site effects. Among these factors, the geotechnical earthquake engineering has been mainly concentrated on the development of quantitative methods for evaluating the influence of local site conditions on the amplification of earthquake motion [6]. Particularly, it is commonly recognized in the discipline of earthquake engineering that the ground motion from earthquake base excitation can be significantly modified by the local site effects [1]. The site effects indicating site-specific seismic response is basically associated with the phenomenon of seismic waves traveling through soil layers. The phenomenon can be explained first by differences in the shear wave velocity (V_S) between the soil layers and the underlying rock, which represent an impedance contrast, and second by the thickness of soil layers or the depth to bedrock. The largest amplification of earthquake ground motion at a nearly level site occurs at approximately the fundamental lowest natural frequency [2]. The period of vibration corresponding to the fundamental frequency is called the site period (T_G) and for multi-layered soil can be computed as

$$T_G = 4\sum_{i=1}^{n}\frac{D_i}{V_{Si}} \quad (1)$$

where D_i is the thickness of each soil layer above the bedrock (i.e., the bedrock depth, $H=\Sigma D_i$), V_{Si} is the V_S of each soil layer, and n is the number of soil layers.

The site period is a useful indication of the period of vibration, at which the most significant amplification is expected. If the spatial variations in the thickness and V_S values of soil layers are known for an entire study area, the spatial variation of the T_G can be readily established and used for regional earthquake hazard estimations.

III. Framework of Geo-Knowledge Based GIS

The geo-knowledge based GIS for this study incorporates a geo-knowledge data and a geostatistical kriging interpolation technique, adopted for reliable spatial prediction of geotechnical data values. The geo-knowledge based GIS is implemented for an inland metropolitan area, Gwangju, in Korea. As presented in Fig. 1, the GIS implementation has four functional components: geo-knowledge database, spatial analysis, geotechnical analysis, and visualization components. Arrows in the figure indicate the direction of data flows, which occur between the database component and mutually geotechnical analysis component for assessing seismic hazards.

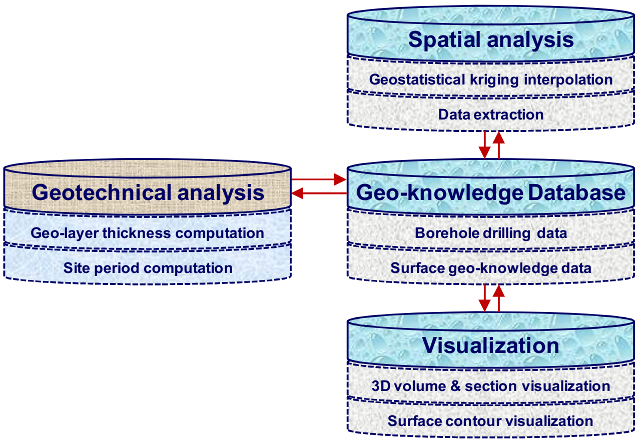

Fig. 1 Components for geo-knowledge based GIS

To build a database for the GIS [7], we first collected pre-existing borehole data drilling from surface to bedrock located in and near the area of interesting. In addition, for more reliably predicting the spatial geotechnical information in the area of interesting by building the geo-knowledge database [3], we applied new concept of the use of geo-knowledge to acquire additional surface geotechnical data. Geo-knowledge refers to information spanning the fields of geotechnical engineering, geology, and geomorphology and was acquired from topographic maps, remote sensing images, and surface geologies. We also conducted a walk-over survey to acquire data related to the ground surface mostly in areas where existing borehole data were lacking.

IV. Implementation of Geo-Knowledge Based GIS

The geo-knowledge based GIS was implemented for a typical inland area, Gwangju, in Korea, and applied to assess site characteristics, specially the thickness of geotechnical layers or bedrock depth. Gwangju is one the largest metropolitan areas in Korea located on the southwestern region of the Korean peninsula. In this study, subsurface geotechnical layers from the borehole data and surface geotechnical materials from the site visit were classified into five categories: fill, alluvial soil, weathered residual soil, weathered rock, and bedrock [3].

In order to manage and update the geotechnical data, database (DB) management system for the geo-knowledge data was developed for this study by using ESRI ArcGIS Engine 9.1 [8]. Fig. 2 shows the structure of the system composed of the MS SQL DB server supported by the FTP server and the DB management program for clients. The system allows the input and renewal of the data by communicating between server and client's program by TCP/IP network and the export for general-purposed application into the formats of text or spread sheet.

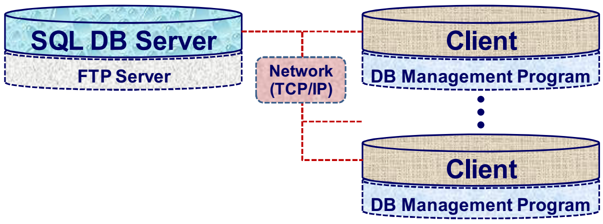

Fig. 2 Structure of DB management system for this study

The DB management program provides the interface as shown in Fig. 3, after accessing to the DB server. The left and right windows indicate the administrative units of South Korea and the data locations (indicated with points in the right window) in the study area (marked geographically on the left window) referenced by topographic features and administrative borders (thick lines in the right window), respectively. In the DB management program, the client can input new data according to the standardized format by opening other interface option. More than 2,000 data including about 1,900 borehole data and 300 surface geotechnical data were archived into the geo-knowledge database for Gwangju metropolitan area. The database in the program was exported for analyzing and displaying within the GIS framework.

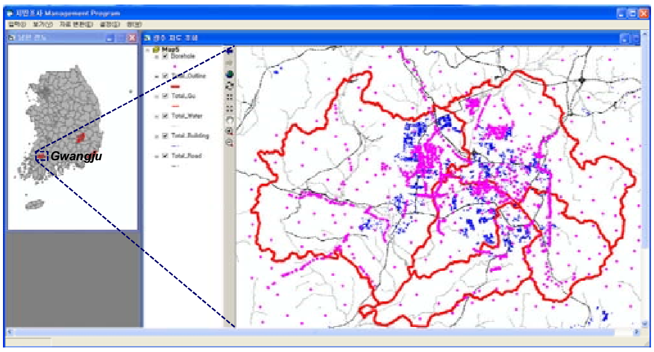

Fig. 3 An interface of client's DB management program

In geotechnical and earthquake engineering, a GIS can be used either alone or in conjunction with specified model-analysis techniques [9]. In this study, the geo-knowledge based GIS was developed based on several GIS tools, ESRI ArcGIS Desktop 9.1 [10], EVS-Pro [11], and AutoCAD LDDT [12], in combination with various specified expert techniques. Furthermore, for better spatial estimation of geotechnical information using an optimum variogram model for each sub-layer, a sophisticated kriging interpolation program based on Visual BASIC code was developed and adopted in the spatial analysis component, although GIS tools usually provide ordinary kriging estimation.

As interpolation is expected to produce more reliable in the prediction of unknown geotechnical data from known geotechnical data than extrapolation in the spatial domain, we introduced a concept of the extended area encompassing the study area [2], [3]. In order to estimate the spatial geotechnical layers for the Gwangju area in this study, we applied the kriging prediction method [13] to the extended area (37.8 km for WE × 26.6 km for NS) encompassing the study area (35.0 km × 23.8 km), which includes the whole administrative region of Gwangju. Then, the geotechnical layers information for the study area was extracted from that of the extended area using the GIS shape-cut function. Fig. 4 shows geotechnical layers for the study area, extracted from the extended area.

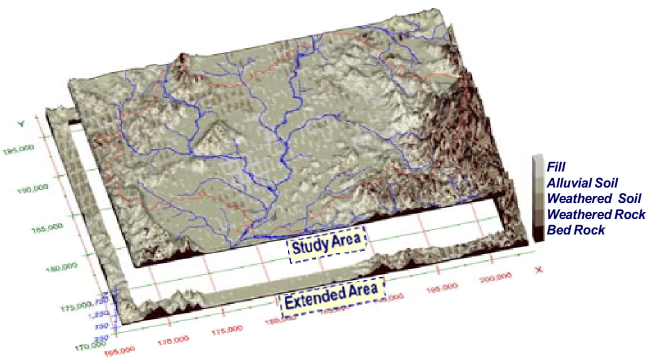

Fig. 4 Geotechnical layers predicted spatially within the GIS

In this paper, the vertical scales in three-dimensional figures were exaggerated five times and surface coverage data such as administrative borders, waterways, buildings, roads and main elevation contour lines were overlain on ground surface for better visual depiction of surface and subsurface features. The spatial information was built with the unit of meter on TM (Transverse Mercator) coordinate system, on which X and Y represent the directions from west to east and south to north, respectively, and Z means the elevation.

Spatial geotechnical data and their three-dimensional visualizations are generally quite informative. However, a solid three-dimensional ground volume cannot be directly applied in engineering projects because subsurface geological structures will not be clear to most users. Thus, visualizations within GIS usually present two-dimensional contour maps on the plane [14], [15], [16]. The thickness of geotechnical layers and the depth to bedrock are expressed as zoning contour maps and can be overlain with spatial topographic surfaces of the study area to better reflect reality [14]. Fig. 5 presents representatively a spatial zoning maps showing the distribution of the depth to bedrock in the study area, which were computed in the geotechnical analysis component of the geo-knowledge based GIS.

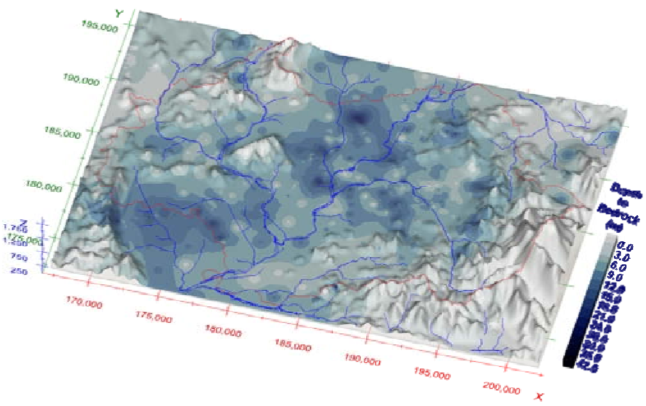
Fig. 5 Spatial distribution of the depth to bedrock

V. SPATIAL EARTHQUAKE HAZARD POTENTIAL

Seismic response characteristics represented as the site effects play an important role in earthquake hazards. Empirical relationships or simple site classification schemes have also been used to evaluate site-specific seismic responses at a regional scale because of their convenience and effectiveness [14], [17]. In this study, sole parameter of the site period (T_G) was used to estimate the site effects for the entire study area of Gwangju. The resulting site effects shown by the GIS are presented on zoning maps identifying locations or zones of varying seismic hazard potential.

The T_G is computed using both the thickness and V_S of soil layers over the bedrock. The thickness of soil layers were already estimated across the study area within the geo-knowledge based GIS. On the other hand, the V_S was not determined for the Gwangju area. Thus, the representative V_S values of geotechnical layers for Gwangju were determined by compiling the results of the previous in-situ seismic tests for obtaining V_S profiles in the Korean land areas [1], [3]. The V_S was determined representatively to be 350 m/s for fill, 330 m/s for alluvial soil, 450 m/s for weathered residual soil, 550 m/s for weathered rock, and 1,000 m/s for bedrock, from the prior seismic testing results in Korea.

For efficient zonation based on the T_G over the study area, the geotechnical thickness data interpolated in the spatial analysis of the GIS and the representative V_S values were imported into the geotechnical analysis component of the GIS. Then, the T_G was calculated at 50 m intervals based on (1). The calculated T_G's were spatially modeled, resulting in the seismic zoning map presented in Fig. 6. The T_G's for central northern and southwestern plains were generally longer than those for mountainous and hilly areas, ranging mainly between about 0.10 and 0.47 s in the Gwangju area. The spatial distribution of T_G is particularly consistent with the distribution of bedrock depth depicted in Fig. 5. In Fig. 6, the spatial main building coverage data are overlain on the T_G distribution to examine the seismic vulnerability of buildings. These rigorous zonations including building coverage can serve as a fundamental resource for predicting seismically induced structural damage. All objects or structures have their own natural periods. The natural period of a building is generally accepted to be 0.1 times its number of stories [18]. The buildings lower than five stories would therefore be vulnerable to seismic damage caused by earthquake resonance. Zoning information based on the T_G can contribute to earthquake-related strategies and also to rational land use and city planning or development in the study area.

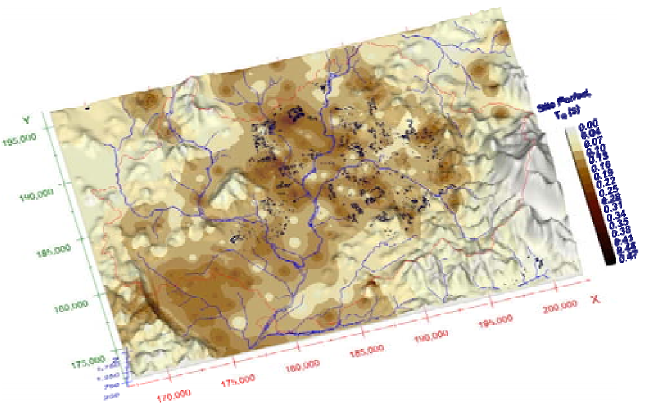

Fig. 6 Spatial seismic zonation on T_G for seismic hazard potential

Besides the prediction of earthquake-induced hazards, seismic design and seismic performance evaluation in the area of interesting can be carried out based on the seismic zoning map of the T_G, by adopting the site classification system according to the T_G. For seismic design in accordance with site conditions, correlations between mean V_S of the upper 30 m (V_S30) and site coefficients (or amplification factors) were established based on empirical and numerical studies [1], [6], [19]. Accordingly, in the current seismic codes, the site characterization for a site class is based only on the top 30 m of the ground. Recently, in order to use the T_G particularly for seismic design in Korea, Sun [3] proposed a new site classification system based on the T_G instead of the current classification criterion, V_S30. In most recent site classification scheme for seismic design, the local site effects are quantified by short-period (0.1 to 0.5 s) and mid-period (0.4 to 2.0 s) site coefficients, F_a and F_v, according to the site classes. Table I illustrates the site classification system according to the T_G especially for the inland region in Korea developed by Sun [3]. This site classification scheme (Table I) can be used by engineers to conduct the seismic design as well as the seismic performance evaluation at a site. In this study, the site classification scheme for the inland region in Korea (Table I) was adopted to demonstrate the spatial seismic zonation on site classification based on the T_G zoning map.

TABLE I
SITE CLASSES AND SITE COEFFICIENTS ACCORDING TO SITE PERIOD IN KOREA

Generic description	Site class		Criteria		Site coefficients	
			V_S30 (m/s)	T_G (s)	F_a	F_v
Rock	B		> 760	< 0.06	1.00	1.00
Weathered Rock and Very Stiff Soil	C	C1	> 620	< 0.10	1.20	1.03
		C2	> 520	< 0.14	1.40	1.07
Intermediate Stiff Soil		C3	> 440	< 0.19	1.60	1.12
		C4	> 360	< 0.27	1.80	1.17
Deep Stiff Soil	D	D1	> 320	< 0.34	2.00	1.22
		D2	> 280	< 0.43	2.20	1.27
		D3	> 240	< 0.55	2.40	1.32
		D4	> 180	< 0.68	2.60	1.37

The spatial zoning map on seismic site classification for Gwangju is shown in Fig. 7, which was created within the geo-knowledge based spatial GIS. The building coverage overlain on ground surface was also presented in Fig. 7. The short- and mid-period site coefficients (F_a and F_v) according to the T_G for the seismic design of structures, which are illustrated in the site classification system of Table I, are presented as the legend in Fig. 7. As shown in Fig. 7, the plain areas in Gwangju fall within site classes C (C1 to C4) and D (D1 and D2), which represent the site conditions amplifying earthquake ground motions, and match with the seismic vulnerable areas based on the T_G indicated in Fig. 6. On the other hand, most of mountainous and hilly areas in Gwangju fall into site class B having 1.0 in both F_a and F_v.

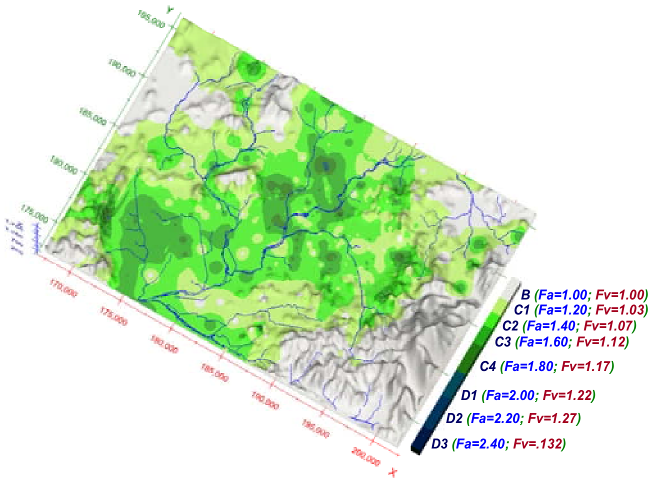

Fig. 7 Spatial distribution of site classes for seismic design

This spatial zonation map on site class provides the information for preliminary seismic design before practical seismic design of the structure or building at a site. Furthermore, the site classification map indicates that the buildings or structures located on the central northern and southwestern plains may need evaluating their seismic performances. As described from Fig. 7, the site class for seismic design and seismic performance evaluation can be determined solely and unambiguously by one parameter, T_G. Thus, if the spatial variations of T_G are known over the entire study area by predicting reliably the geotechnical information within the geo-knowledge based GIS, the site coefficients according to these site classes together with the earthquake-induced hazard potential can be readily determined for any site in the study area by spatial seismic zonation.

VI. Conclusion

This study presented the information on earthquake hazard potential for a highly urbanized city area, Gwangju, in Korea. In order to present the reliable information in the entire area of interesting, a concept of geo-knowledge was applied to acquiring data in the extended area including the study area. The data in this study were composed of the pre-existing borehole data and the surface geotechnical material data, which were archived into a database, called geo-knowledge database. For managing the database, the DB management system was developed and used in this study.

Based on the geo-knowledge database for the area of Gwangju, a spatial GIS was implemented for the geotechnical site characterization across the entire area of interesting in terms of the geotechnical layers. The spatial geotechnical layers were reliably predicted over the 35.0 km × 23.8 km area of Gwangju, using a geostatistical kriging interpolation method. Based on the spatially interpolated geotechnical layers, distribution map of the depth to bedrock was established. To apply to the prediction of earthquake-induced hazard potential associated with the site effects and preliminary seismic design in the entire study area, distribution of the T_G was efficiently created in the form of zonation maps within the geo-knowledge based GIS and V_S determined representatively from the prior researches. The T_G map suggests that buildings lower than five stories in Gwangju are vulnerable to seismic activity, particularly in central northern and southwestern plains. Based on the T_G in Gwnagju area, seismic zoning map for site classification was also created to determine the short- and mid-period site coefficients for preliminary seismic design according to the previous site classification system for the Korean inland region. This site classification map shows that the plains in the study area fall within site classes C and D amplifying earthquake ground motion and that the structures or buildings on the plains may need their seismic performance evaluation. This seismic zonation case study verifies the usefulness of the geo-knowledge based GIS as a regional seismic countermeasure.

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References

[1] C.-G. Sun, D.-S. Kim, and C.-K. Chung, "Geologic site conditions and site coefficients for estimating earthquake ground motions in the inland areas of Korea," *Engineering Geology*, vol. 81, no. 4, pp. 446-469, 2005.

[2] C.-G. Sun, S.-H. Chun, T.-G. Ha, C.-K. Chung, and D.-S. Kim, "Development and application of GIS-based tool for earthquake-induced hazard prediction," *Computers and Geotechnics*, vol. 35, no. 3, pp. 436-449, 2008.

[3] C.-G. Sun, "Geotechnical Information System and Site Amplification Characteristics for Earthquake Ground Motions at Inland of the Korean Peninsula," Ph.D. dissertation, Seoul National University, Seoul, Korea, 2004.

[4] A. S. Kiremidjian, "Spatial analysis in geotechnical earthquake engineering," in *Spatial Analysis in Soil Dynamics and Earthquake Engineering*, Geotechnical Special Publication no. 67, J. D. Frost, Ed. ASCE, 1997, pp. 1–14.

[5] C. Kolat, V. Doyuran, C. Ayday, and M. L. Süzen, "Preparation of a geotechnical microzonation model using geographical information systems based on multicriteria decision analysis," *Engineering Geology*, vol. 87, no. 3-4, pp. 241-255, 2006.

[6] R. Dobry, R. D. Borcherdt, C. B. Crouse, I. M. Idriss, W. B. Joyner, G. R. Martin, M. S. Power, E. E. Rinne, and R. B. Seed, "New site coefficients and site classification system used in recent building seismic code provisions," *Earthquake Spectra*, vol. 16, no. 1, pp. 41-67, 2000.

[7] T. D. Rockaway, "Spatial Assessment of Earthquake Induced Geotechnical Hazards," Ph.D. dissertation, Georgia Institute of Technology, Atlanta, GA,1997.

[8] ESRI, *ArcGIS 9: ArcGIS Engine Developer Kit 9.1 for Windows*, CD-ROM, 2006.

[9] S. Gangopadhyay, T. R. Gautam, and A. D. Gupta, "Subsurface characterization using artificial neural network and GIS," *Journal of Computing in Civil Engineering*, ASCE, vol. 13, no. 3, pp. 153-161, 1999.

[10] ESRI, *ArcGIS 9: Using ArcGIS Desktop*, 2006.

[11] CTech, *EVS/MVS manuals version 9.12: main helps and visualization fundamentals, module libraries, workbooks and sample applications*, CTech Development Corporation, 2001.

[12] Autodesk, *AutoCAD land development desktop 2i manuals and application books*, Autodesk, Inc., 2001.

[13] M. A. Oliver and R. Webster, "Kriging: a method of interpolation for geographical information systems," *International Journal of Geographic Information Systems*, vol. 4, no. 3, pp. 313-332, 1990.

[14] D.-S. Kim, C.-K. Chung, C.-G. Sun, and E.-S. Bang, "Site assessment and evaluation of spatial earthquake ground motion of Kyeongju," *Soil Dynamics and Earthquake Engineering*, vol. 22, no.5, pp. 371-387, 2002.

[15] C. Kolat, V. Doyuran, C. Ayday, and M. L. Süzen, "Preparation of a geotechnical microzonation model using geographical information systems based on multicriteria decision analysis," *Engineering Geology*, vol. 87, no. 3-4, pp. 241-255, 2006.

[16] P. Marinos, G. Bouckovalas, G. Tsiambaos, N. Sabatakakis, and A. Antoniou, "Ground zoning against seismic hazard in Athens, Greece," *Engineering Geology*, vol. 62, no. 4, pp. 343-356, 2001.

[17] C.-G. Sun, J.-S. Shin, and H.-C. Chi, "Systematic Prediction of earthquake-induced hazards for an urban area based on spatial GIS framework," in *Proc. 15th TIEMS Annual Conference*, Prague, Czech Republic, CD-ROM, 2008, Paper No. 7.

[18] S. L. Kramer, *Geotechnical Earthquake Engineering*, New Jersey: Prentice-Hall, 1996, pp. 309-323.

[19] R. D. Borcherdt, "Estimates of site-dependent response spectra for design (methodology and justification)," *Earthquake Spectra*, vol. 10, no. 4, pp. 617-654, 1994