

Regional Estimation of Site-specific Seismic Response by Spatial Zoning at an Inland Urban Area, Daegu, in Korea

CHANG-GUK SUN¹, JIN-SOO SHIN² and HEON-CHEOL CHI³

Earthquake Research Center

Korea Institute of Geoscience and Mineral Resources (KIGAM)

92 Gwahangno, Yuseong-gu, Daejeon 305-350

KOREA

¹pungsun@kigam.re.kr; ²jinsoo@kigam.re.kr; ³chi@kigam.re.kr

Abstract: - Most of earthquake-induced geotechnical hazards have been caused by the site effects relating to the amplification of ground motion, which are strongly influenced by the local geologic conditions such as soil thickness or bedrock depth and soil stiffness. In this study, an integrated GIS-based information system for geotechnical data, called geotechnical information system (GTIS), was constructed to establish a regional counterplan against earthquake-induced hazards at an urban area, Daegu, in Korea. To build the GTIS for the area of interesting, pre-existing geotechnical data collections were performed across the extended area including the study area and a walk-over site survey was additionally carried out to acquire surface geoknowledge data. For practical application of the GTIS used to estimate the site-specific seismic response across the area of interesting, seismic microzoning map of the characteristic site period was created and presented as regional synthetic strategy for earthquake-induced hazards prediction. In addition, seismic zonation of site classification according to the spatial distribution of the site period was also performed to determine the site amplification coefficients for seismic design and seismic performance evaluation at any site in the study area.

Key-Words: - Seismic zonation, Site effects, Seismic hazard, GIS, Site period

1 Introduction

The local geologic and soil conditions have a profound influence on the amplification of earthquake ground motions. The amplification capabilities depending on the local geologies at sites have been incorporated into current seismic design code provisions, because of their importance in earthquake-induced hazard mitigation [7]. Moreover, the local site effects related with geologic conditions have been frequently observed in recent earthquake events such as the 1967 Caracas, 1985 Mexico City, 1989 Loma Prieta, 1994 Northridge, 1995 Kobe, and 1999 Chi-Chi earthquake [23]. These earthquake events revealed that seismic damages were concentrated at areas which were composed of sediments rather than firm rock [13, 17, 20]. These findings indicate that site effects are directly associated with the spatial distribution and dynamic properties of the soils overlying a rock bed [24].

Geographic information system (GIS) in recent years has emerged to be a powerful computer-based technique [27]. For geotechnical purposes, the GIS-based information systems have been developed and utilized to forecast and reduce natural hazards [9, 13, 21, 28]. In geotechnical earthquake engineering, there have been several researches on GIS

technology [1, 5, 21]. And this technology will be widely used in increasing number of seismic zonations for the prediction and mitigation of earthquake-induced hazards [12, 13, 26]. In this study, for the presentation and reliable estimation of the geotechnical sub-layers and dynamic properties information over the selected Daegu area in Korea, Geotechnical Information System (GTIS) was built within three-dimensional GIS framework. The constructed GTIS was applied to geotechnical earthquake engineering problems related to those dealing with site-specific seismic response.

2 Site-specific Seismic Response

Observations of destructive earthquakes have demonstrated that despite the same epicentral distances, damage is often more severe over soft soils than over firm soils or rocks [21, 22]. Since a number of sites on recent alluvial deposits are prime locations for the development of urban areas, local seismic amplification is a major concern not only in earthquake-prone regions but also in weak or moderate seismicity regions like the Korean peninsula. The site effects that induce seismic

amplification are mainly associated with geological site conditions.

2.1 Site period

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 [23]. 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, $H = \sum D_i$), 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.

2.2 Site classes and site coefficients

For seismic design in accordance with site conditions in most of design guides, the local site effects are quantified by short- and mid-period site coefficients (or amplification factors), F_a and F_v , according to the mean V_S to a depth of 30 m (V_{S30}) and the corresponding site classes [7, 23]. Accordingly, in the current seismic codes, the site characterization for a site class is based only on the top 30 m of the ground. The site class is determined solely and unambiguously by one parameter, V_{S30} . For a profile consisting of n soil and/or rock layers, V_{S30} (in units of m/s) can be given by:

$$V_{S30} = 30 / \sum_{i=1}^n \frac{d_i}{V_{Si}} \quad (2)$$

where d_i is the thickness of each soil and/or rock layer to a depth of 30 m ($30 \text{ m} = \sum d_i$).

In order to quantify the site effects, correlations between the V_{S30} and the site coefficients were established based on empirical and numerical studies [3, 23]. F_a and F_v are calculated by the average ratio of response spectra (RRS) or ratio of Fourier spectra (RFS) between a soil and a nearby firm to hard rock site, computed in period bands from 0.1 to 0.5 s and from 0.4 to 2.0 s, respectively. The period between 0.1 and 0.5 s indicates the short-period band, while the period between 0.4 and 2.0 s represents not only the mid- or intermediate-period band but also the long-period band [23]. In this study, the site coefficients, F_a and F_v , were based on the RRS and calculated by:

$$F_a(\text{RRS}) = \frac{R_{\text{soil}}}{R_{\text{rock}}} \frac{1}{0.4} \int_{0.1}^{0.5} \frac{RS_{\text{soil}}(T)}{RS_{\text{rock}}(T)} dT \quad (3)$$

$$F_v(\text{RRS}) = \frac{R_{\text{soil}}}{R_{\text{rock}}} \frac{1}{1.6} \int_{0.4}^{2.0} \frac{RS_{\text{soil}}(T)}{RS_{\text{rock}}(T)} dT \quad (4)$$

where RS_{soil} and RS_{rock} are the acceleration response spectra for a ground surface of soil and for rock-outcrop sites, respectively, in a given period (T), and R_{soil} and R_{rock} represent the hypocentral distances of the soil and rock sites.

Table 1. Current site classification with the mean V_S to a depth of 30 m (V_{S30}) for seismic design

Site Class (Soil Profile Type)	Generic Description	V_{S30} (m/s)
A (S _A)	Hard Rock	$1500 < V_{S30}$
B (S _B)	Rock	$760 < V_{S30} \leq 1500$
C (S _C)	Very Dense Soil and Soft Rock	$360 < V_{S30} \leq 760$
D (S _D)	Stiff Soil	$180 < V_{S30} \leq 360$
E (S _E)	Soft Soil	$V_{S30} \leq 180$
F (S _F)	Requires site-specific evaluation	

As illustrated in Table 1, the site conditions can be classified into five categories (denoted by A to E or S_A to S_E) according to the V_{S30} values, as suggested in current seismic codes, including Korean seismic design guides, the Uniform Building Code (UBC), and National Earthquake Hazard Reduction Program (NEHRP) provisions [7, 21, 23]. A sixth site category F (or S_F) is defined as requiring site-specific evaluation. In the current seismic design guides, site coefficients (F_a and F_v),

quantifying the seismic amplification, are used to estimate the design response spectra dependent on both the site categories and the intensity of rock motions. Both F_a and F_v are unity for rock (site class B) and become greater as the soil becomes softer with decreasing V_{S30} or as the site class evolves through C, D, and E. In addition, the site coefficients are generally higher for small rock motions than for large rock motions because of geo-material nonlinearity [20, 23].

In spite of common use of the V_{S30} as sole criterion considering the representative geotechnical property in the current seismic design codes, the depth to bedrock is disregarded in the current site classification system [20]. Recently, in order to use the T_G taking account of both the bedrock depth and the geotechnical property particularly for seismic design in Korea, Sun [20] proposed a new site classification system based on the T_G instead of the current classification criterion, V_{S30} . In the proposed site classification scheme for seismic design, the local site effects are also quantified by F_a and F_v according to the site classes but the site classes C and D are subdivided into four sub-classes, respectively. Table 2 illustrates the site classification system according to the T_G especially for the inland region in Korea developed by Sun [20]. This site classification scheme (Table 1) can be used by engineers to conduct the seismic design as well as the seismic performance evaluation at a site.

Table 2. Site classes and site coefficients based on site period for the inland region of Korea [20]

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	C	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

3 Geotechnical Information System

The geotechnical information system (GTIS) described here incorporates a geostatistical kriging interpolation technique, adopted for reliable spatial prediction of geotechnical data values [21, 22]. Geostatistical kriging can be regarded as the best linear unbiased estimate and optimal interpolation method for geological and geotechnical predictions in space, because it is a linear combination of weighted sample values having minimum variance [18]. The basic premise of kriging interpolation is that every unknown point can be estimated by the weighted sum of the known points. The estimated value, $Z^*(x_i, y_j)$, at coordinates (x_i, y_j) , can be calculated by:

$$Z^*(x_i, y_j) = \sum_{\alpha=1}^n w_{ij\alpha} \times Z_{\alpha} \tag{5}$$

where n is the number of the known values, Z_{α} . A set of weights, $w_{ij\alpha}$, is calculated for every point. These weights are computed to place greater emphasis on the known points close to the unknown points and less emphasis on known points far from unknown points. This process is performed by calculating a variogram that characterizes the spatial continuity or roughness of a point data set with the distance between each pair of points.

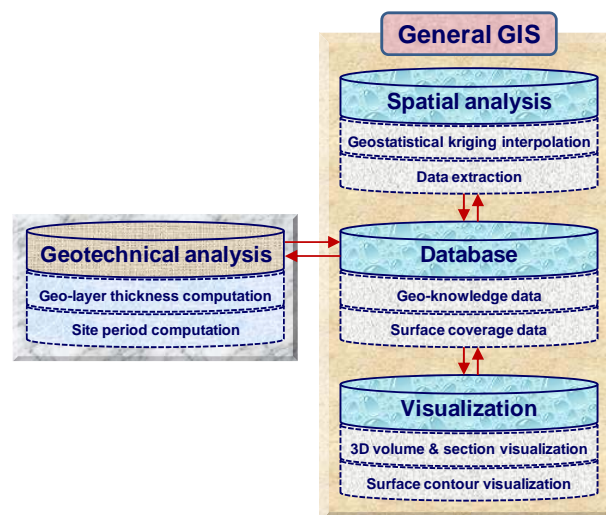


Fig. 1. Architecture of the GIS-based GTIS.

In this study, a procedure for building a GTIS is proposed and then a GTIS is constructed for an urban area, Daegu, in Korea. As presented in Fig. 1, the developed GTIS has four functional components: 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 complementary component (geotechnical analysis component) for assessing seismic hazards [14, 25].

The database component contains information on the geotechnical layers, as well as the spatial coverage of waterways, buildings, and roads. Data from the database component are provided to the spatial analysis component, in which the point data are interpolated or extrapolated over the area of interest by the geostatistical kriging method. To evaluate additional geotechnical and earthquake engineering information based on estimated data from the spatial analysis component, geotechnical analysis was performed. The geotechnical analysis component contains computation modules on the thickness of geotechnical layers, depth to bedrock (H), and site period (T_G). In general, these values can be used to assess the seismic sensitivity of the ground without any numerical analysis procedure. The computed geotechnical data were then interpolated over the study area within the spatial analysis components. Finally, the interpolated data were displayed in three dimensions or two dimensions, together with the spatial coverage data, within the visualization component.

In geotechnical and earthquake engineering, a GIS can be used either alone or in conjunction with specified model-analysis techniques [9]. In this study, GTIS was developed based on GIS tools, ArcGIS from ESRI [8], EVS-Pro from CTech [6], and AutoCAD LDDT from Autodesk [2], in combination with various specified expert techniques. ArcGIS was used for spatially assigning and analyzing the characteristic geotechnical values including T_G in the area of interesting. EVS-Pro was used mainly for the advanced spatial visualization, and AutoCAD LDDT was applied to manipulate the digital topographic maps. Moreover, for better spatial estimation of geotechnical information using an optimum variogram model for each geotechnical sub-layer, a sophisticated kriging interpolation program based on Visual BASIC code was developed and adopted in the spatial analysis component, although ArcGIS and EVS-Pro provides ordinary kriging estimation.

For more reliably predicting the spatial geotechnical information in the entire area of interest within the GTIS [9, 20, 21], we applied new concepts, such as the use of an extended area encompassing the main study area and the use of geo-knowledge to acquire additional surface geotechnical data [4, 21]. Table 3 shows the procedure developed to build the GTIS. 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 field observation study to acquire data related to the ground surface. Because interpolation was expected to produce more reliable spatial predictions than extrapolation [21, 22], we applied the kriging technique to the extended area (36.8 km for west to east \times 27.2 km for north to south) encompassing the study area (34.8 km \times 25.2 km), which includes the major central region of Daegu. Geotechnical information for the study area was then extracted from that of the extended area using a GIS tool.

Table 3. Procedure for reliably estimating spatial geotechnical information within GTIS

<i>Step</i>	<i>Working Details at Each Step</i>
<i>1st</i>	Select the extended area including the study area
<i>2nd</i>	Compile all available documentary information for geo-knowledge in the extended area
<i>3rd</i>	Determine local landform characteristics based on terrain analysis
<i>4th</i>	Zone the extended area with the geologic and geomorphic characteristics
<i>5th</i>	Collect the existing site investigation data including borehole data for the extended area
<i>6th</i>	Visit the extended area to collect additional nearby surface geo-knowledge data in field
<i>7th</i>	Build a database based on site investigations data and surface geo-knowledge data
<i>8th</i>	Interpolate geotechnical information for the extended area
<i>9th</i>	Extract geotechnical spatial information for the study area from the extended area

4 Building GTIS for Daegu in Korea

The GTIS was implemented for an inland model area in the Korean peninsula by adopting the developed procedure, and applied to assess site characteristics, specifically the thicknesses of geotechnical layers or depth to bedrock.

4.1 Selection of target area for building GTIS

To demonstrate the GTIS in this study, we selected the Daegu area, as a case study area, which is characterized as a topographical inland basin area. Daegu is one of the largest metropolitan areas in Korea and thus may be extensively damaged during

earthquake. To build a GTIS, we collected existing borehole data and additionally acquired surface geo-knowledge data from a walk-over site visit across the extended area including the study area.

Subsurface geotechnical layers from the borehole data and surface geotechnical materials from the site visits were classified into five categories: fill, alluvial soil, weathered residual soil, weathered rock, and bedrock [20]. Fig. 2 shows the geographic information of Daegu and corresponding selected areas (extended area and study area). The spatial information for the areas is the unit of meter on TM (Transverse Mercator) coordinate system on the basis of local origin. The administrative border of Daegu is also presented together with waterways and roads on DEM (digital elevation model) map in the left subset of Fig. 2.

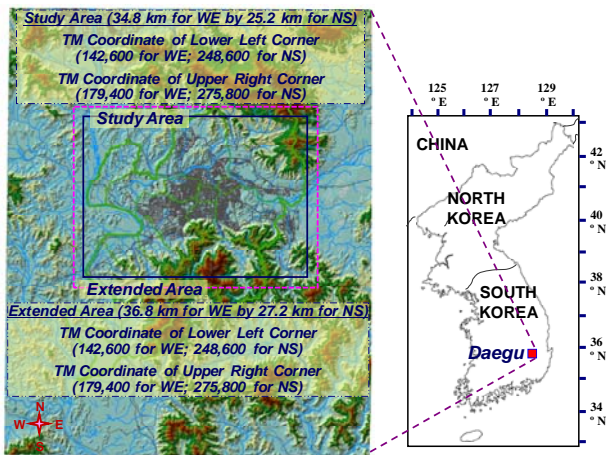


Fig. 2. Geographic information of selected areas for building the GTIS at Daegu.

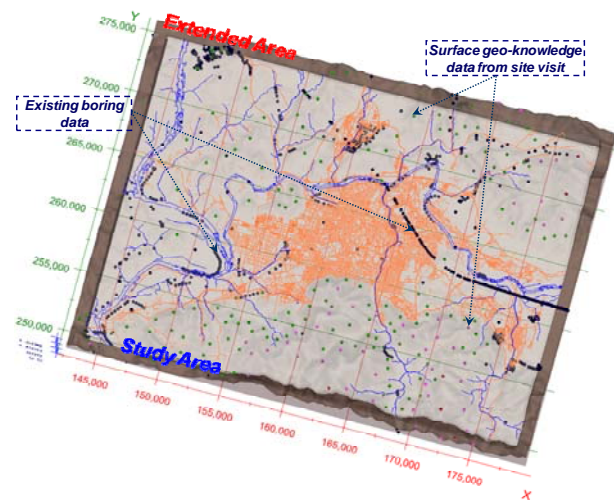


Fig. 3. Distribution of existing borehole data and surface geo-knowledge data in the extended area.

The utilization of only existing borehole data is inadequate to cover the study area because of the

biased distribution of the data. Accordingly, for acquiring of additional surface geotechnical layers data as geo-knowledge data, the site visits are conducted mostly in areas where borehole data were lacking. To estimate the spatial geotechnical layers across the extended area, we used both of 1,297 existing borehole data and 211 surface geo-knowledge data. Based on these results, the spatial information for the smaller study area was extracted using the GIS shape-cut technique. Fig. 3 shows the spatial distribution of existing borehole data and surface geo-knowledge data in the extended area of Daegu created within the spatial GIS-based GTIS. In Fig. 3, it can be examined that most of surface geo-knowledge data acquired from the site visit are located the areas lacking the existing borehole data. In this paper, the vertical scales in three-dimensional figures were exaggerated five times and surface coverage data such as waterways and roads 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 the local TM coordinate system.

4.2 Site characterization at Daegu within GTIS

As resultant geotechnical information for the site characterization, Fig. 4 shows the geotechnical layers predicted based on the borehole and surface geo-knowledge data by adopting the geostatistical kriging estimation [18, 21]. Particularly, Fig. 4 indicates geotechnical layers for the study area, extracted from the extended area. This step for extracting the geotechnical information of the study area from the extended area increases the reliability of the spatial prediction, because the geotechnical layers on the outer boundary for study area are estimated by the interpolation more reliable than the extrapolation [20, 21].

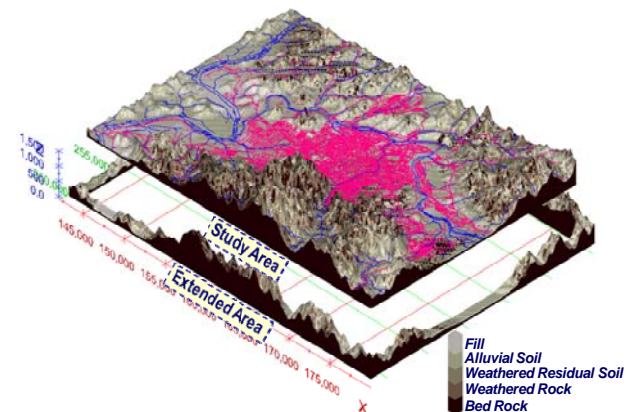


Fig. 4. Extraction of geotechnical layers of the study area from the extended area within the GTIS.

The variation of geotechnical information at any section in the area of interest can be examined by using the expert GIS tools, which were adopted in this study. Fig. 5 shows the sections of predicted spatial geotechnical layers for a couple of slices of the study area together with the topographic variation illustrated by superposing the remote sensing image. In the GTIS procedure, the spatial distribution of geotechnical layers across the study area was predicted based on both vertical borehole data and surface geo-knowledge data of the ground surface. Particularly, the area along the river flowing and several creeks has thick soil deposits while thin soil deposits were observed at hilly and mountainous areas, as shown in Fig. 5. Thus, the deep soil deposits in Daegu have been mainly developed the fluvial actions during frequent floods along the rivers and creeks. This formation of the river basin on the subsurface geological structure is correspondent with the topographic feature of Daegu.

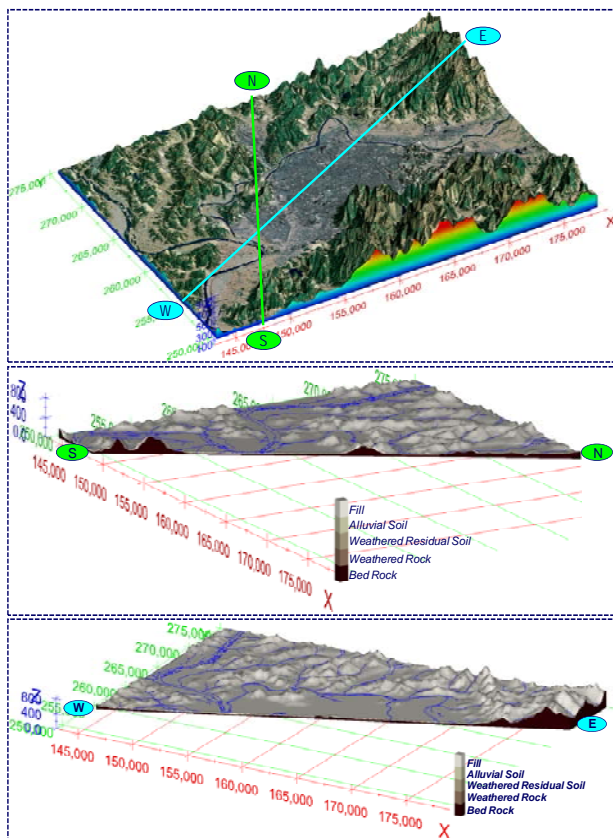


Fig. 5. Sections examined for subsurface geological structures with topographic feature in Daegu.

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 [11, 13, 17]. 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 [11]. Fig. 6 presents representatively spatial zoning maps showing the distribution of the thickness of alluvial soil (Fig. 6(a)) and the depth to bedrock (Fig. 6(b)) in the study area, which were computed in the geotechnical analysis component of the GTIS.

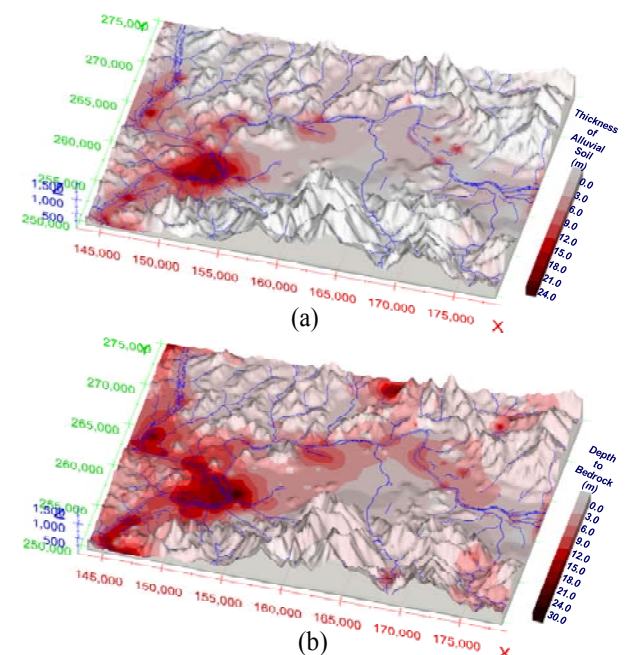


Fig. 6. Distribution of (a) the thickness of alluvial soil and (b) the depth to bedrock on the ground surface in Daegu.

From Fig. 6(a), it is observed that the thick alluvial soils of 10 to 25 m thickness are distributed in western plain zones adjacent to a river or creek. These characteristics in soil formation represent the general inland topographical basin area. They resulted from the fluvial actions during the historical frequent floodings along the rivers and creeks surrounding mountains. The depth to bedrock is one of the most important geotechnical parameters for various geotechnical problems. The rocks beneath or harder than weathered rock are commonly designated as bedrock; the V_s values ($V_s > 750$ m/s) of these rocks in the study area fall within the category of engineering rock [21, 23]. In the evaluation of the seismic ground amplification and corresponding seismic hazards, the depth to bedrock is particularly important [20, 23]. As shown in Fig. 6(b), the depth to bedrock on plain zones including

rivers and creeks is deeper than that in surrounding mountain areas. Such zones of deep bedrock depth are susceptible to ground motion amplification due to site effects during earthquakes.

5 Seismic Zonation on the Site-specific Seismic Response for Daegu

Site-specific seismic response characteristics represented as the site effects play an important role in seismic damage to structures. Although the evaluation of site-specific seismic response based on the seismic scenario has been applied by assuming the size and location of a hypothetical earthquake, empirical relationships or simple site classification schemes [19, 29] have also been used to evaluate site-specific seismic responses at a regional scale because of their convenience and effectiveness [21, 24]. The site effects at Daegu area selected for this study were evaluated by adopting the site classification scheme. In this study, sole parameter of the site period (T_G) was used to estimate the site effects for the entire study area. The resulting site effects shown by the GTIS are presented on zoning maps identifying locations or zones of varying seismic hazard potential. The scale of seismic zonation for Daegu area in this study is the micro scale, which is the most detailed among three scale levels: general, macro and micro scale [10].

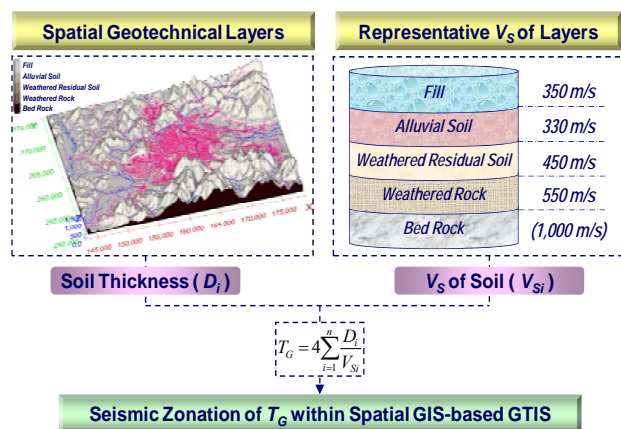


Fig. 7. Conceptual flow for seismic zonation on T_G .

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 spatial GTIS. On the other hand, the V_S was not determined for the Daegu area. Thus, the representative V_S values of geotechnical layers for Daegu were determined by compiling the results of the previous in-situ seismic tests for obtaining V_S profiles in the Korean land areas [20, 23]. Fig. 7 describes the conceptual flow for building the

seismic microzoning map on the T_G within the GTIS. As indicated in Fig. 7, 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 microzonation based on the T_G over the study area, the geotechnical thickness data interpolated in the spatial analysis of the GTIS and the representative V_S values were imported into the geotechnical analysis component of the GTIS. Then, the T_G was calculated at 50 m intervals based on Equation (1). The calculated T_G 's were spatially modeled, resulting in the seismic microzoning map presented in Fig. 8. The T_G 's for central and western plains were generally longer than those for mountainous and hilly areas, ranging mainly between about 0.10 and 0.35 s in the Daegu area. The spatial distribution of T_G is particularly consistent with the distribution of bedrock depth depicted in Fig. 6(b). In Fig. 8, 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 [15]. The buildings lower than three or four stories would therefore be vulnerable to seismic damage caused by earthquake resonance. Microzoning 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 entire study area.

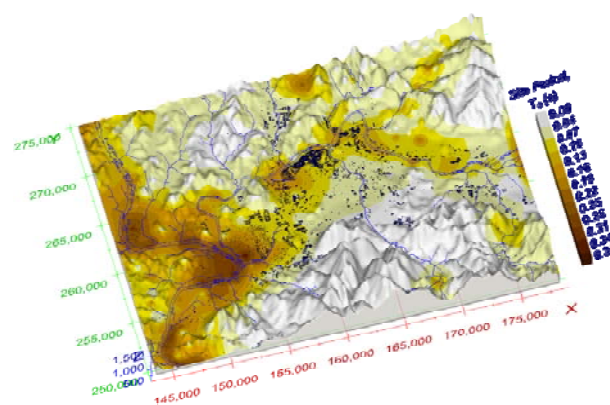


Fig. 8. Spatial seismic zonation on T_G in Daegu.

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 microzoning map of the T_G , by adopting the site classification system according to the T_G . In this study, the site classification scheme for the inland region in Korea developed by Sun [20] (Table 2) was adopted to demonstrate the spatial seismic microzoning on site classification based on the T_G zoning map. Fig. 9 is the spatial microzoning map on seismic site classification in the study area, Daegu, built within the GTIS. The building coverage overlain on ground surface was also presented in Fig. 9. 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 2, are presented as the legend in Fig. 9. As shown in Fig. 9, the plain areas in Daegu 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. 8. On the other hand, most of mountainous and hilly areas in Daegu fall into site class B having 1.0 in both F_a and F_v . This spatial microzoning 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 and western plains may need evaluating their seismic performances. As described from Fig. 9, 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, the site coefficients according to these site classes can be readily determined for any site in the study area by spatial seismic zonation.

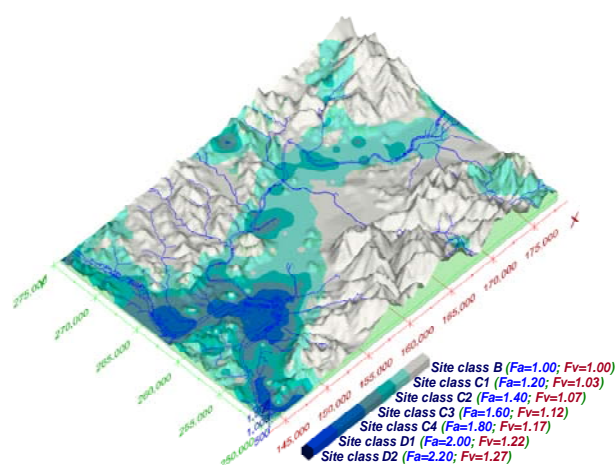


Fig. 9. Spatial distribution of site classes and corresponding site coefficients in Daegu.

The spatial seismic microzoning maps on T_G produced by the GTIS can be used to predict earthquake hazards. Also, the spatial site classification map based on the T_G can be applied in both preliminary seismic design and seismic performance evaluation of structure at any site in the entire study area. The GTIS developed in this study successfully revealed the seismic microzoning for estimating systematically the local site effects in an inland urban area of Korea. The fundamental seismic information provided should prove useful to earthquake engineers, regional agencies, and insurance companies [16, 21]. The microzoning map with site classes, which provide short- and mid-period site coefficients referenced by spatial coordinates across the entire study area, can also be used to develop earthquake preparedness plans and strategies for the Daegu area.

6 Conclusion

In this paper, a methodology was proposed and used in GTIS to manage a variety of geotechnical data and to reliably estimate spatial geotechnical information based on both existing borehole drilling data and additionally acquired surface geoknowledge data. The developed GTIS was applied in the geotechnical site characterization to assess local site effects and corresponding earthquake-induced hazards for the Daegu area in Korea.

A GIS-based tool, the GTIS, was developed based on new concepts of an extended area and geoknowledge and combined with established procedure. The spatial geotechnical layers were reliably predicted over the 34.8 km in WE \times 25.2 km in NS area, Daegu study area, using a geostatistical interpolation technique. To apply to the seismic hazard prediction associated with the site effects and preliminary seismic design in the entire study area, distribution of the site period (T_G) was efficiently created in the form of microzoning maps based on the spatial geotechnical layers estimated within the GTIS and shear wave velocity (V_s) determined representatively from the prior researches. The T_G map suggests that the buildings lower than three or four stories in Daegu are vulnerable to seismic activity. Based on the T_G in Daegu area, seismic microzoning 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 central and western plains in Daegu 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 spatial seismic zonation case study using GIS technology verifies the usefulness of the GTIS as a regional systematic tool for use in seismic hazards planning.

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