4th International Conference on
Earthquake Geotechnical Engineering
June 25-28, 2007
Paper No. 1338

VERSATILE APPLICATIONS OF A GEOTECHNICAL INFORMATION SYSTEM FOR ESTIMATING SITE EFFECTS AT GYEONGJU IN KOREA

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ABSTRACT

Amplification of earthquake ground motion due to the local site effects is strongly related to the subsurface soil conditions as well as the geological structure. To reliably predict geotechnical information and make a correspondingly accurate estimate of the site effects at a study area, Gyeongju in Korea, a geotechnical information system (GTIS) was constructed within a spatial GIS framework. The system was built based on both the performed and collected site investigation data in addition to acquired geo-knowledge data. Seismic microzoning maps were constructed using the site period (T_G) and mean shear wave velocity to a depth of 30 m (V_S30), and these maps were presented as a regional strategy to mitigate earthquake-induced hazards for the study area. In particular, the T_G distribution map indicated the susceptibility of ground motion resonance in periods ranging from 0.2 to 0.5 s and a corresponding seismic vulnerability of buildings with two to five stories. In addition, we investigated the site effects according to subsurface and surface ground irregularity at Gyeongju using seismic response analyses in time domains based on both two- and three-dimensional finite element (FE) models, which were generated based on spatial interface coordinates between geological subsurface layers predicted by the GTIS. In this practical study, it was verified that the GTIS built to reliably predict spatial geotechnical information has versatile applications when estimating the site effects.

Keywords: Geotechnical information system, GIS, site effects, site period, seismic response

INTRODUCTION

The local geologic and soil conditions at a site profoundly influence the characteristics of earthquake ground motion. Site effects related to geologic conditions have been observed as amplified ground motion from a number of recent earthquake events (Sun et al., 2005). Moreover, surface topography and basin geometry cause the site effects on ground motion under seismic loading (Bakir et al., 2002). Severe seismic damages caused mostly by the site effects have been observed in large city areas located on the alluvial basins, which show geomorphological and geological irregularities. In particular, the subsurface geological structure and soil condition and surface topographical features control the irregular distribution of seismic intensity and damage over relatively short distances in urban areas, where residences and facilities are built close together. This illustrates how an accurate evaluation of site effects over an entire urban area depends on the reliable prediction of spatial geotechnical information, represented as subsurface soil geometry (Anastasiadis et al., 2001).

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During the last several decades, many empirical and numerical studies have attempted to evaluate the site effects, mainly in regions of strong seismicity (Dobry et al., 2000; Nordenson and Bell, 2000), and a systematic approach adopting geographic information system (GIS) technology was recently developed to synthetically evaluate the site effects in urban areas. To synthetically evaluate the site effects in the city of Gyeongju, Korea, we developed a geotechnical information system (GTIS), which was constructed within a three-dimensional GIS framework and was accomplished preferentially to construct a reliable detailed model of subsurface geological structure. The data set included a variety of previously collected and observed geotechnical data in the Gyeongju area, in addition to the geo-knowledge data required to implement the GTIS. Within the GTIS framework, microzonations were performed in terms of the site period (T_G) and the mean shear wave velocity to a depth of 30 m (V_S30) as regional mitigations against the seismic hazards related to the site effects. In addition, based on spatial geotechnical information predicted across the study area within the three-dimensional GTIS, seismic response analyses using a finite element method (FEM) were conducted by generating two- and three-dimensional models, enabling a more realistic evaluation of the local site effects.

GEOTECHNICAL INFORMATION SYSTEM WITHIN A GIS FRAMEWORK

In recent years, the geographic information system (GIS) has emerged as a powerful tool. It integrates the capabilities of spatial analysis, database management, and graphic visualization, and has been widely adopted in the construction of geotechnical expert systems. GIS-based geotechnical expert systems have been developed to forecast and reduce natural hazards. For instance, a landslide can be predicted as a result of rainfall or earthquake. Several research studies based on GIS have been published, especially in the field of geotechnical earthquake engineering. More recently, GIS has been recognized as potentially useful in earthquake engineering practices; its applications in geotechnical earthquake engineering include seismic zonation and seismic modeling (Kiremidjian, 1997; Miles and Ho, 1999; Cid et al., 2001). The former can predict and mitigate earthquake-induced hazards, and the latter can analyze earthquake-induced geotechnical phenomena such as site effects. Because accuracy is vital to any prediction of spatial geotechnical information, such as soil or rock layers and geotechnical properties, GIS applications are developed and then applied for geotechnical and earthquake engineering problems.

In this study, a geotechnical information system (GTIS) was developed based on GIS technology to enable reliable prediction and application of spatial geotechnical information in the evaluation of earthquake ground motion with subsurface geologic structure. A geostatistical kriging prediction method was incorporated into the GTIS design, allowing more reliable prediction of geotechnical information. This method is known as the best linear unbiased estimate method that can be used in spatial geological and geotechnical predictions (Oliver and Webster, 1990). In the fields of geotechnical and earthquake engineering, a GIS is used either alone or in conjunction with specified model analysis techniques (Gangopadhyay et al., 1999). For the practical research described in this paper, the GTIS was developed based on GIS tools, EVS-Pro from CTech and AutoCAD LDDT from Autodesk, in combination with various specified expert techniques (Sun, 2004). The EVS-Pro was utilized mainly for advanced spatial visualization, and the AutoCAD LDDT was used to manipulate digital topographic maps. In addition, although ordinary kriging estimation can be provided within the EVS-Pro tool, we developed and applied a sophisticated kriging interpolation program using FORTRAN code to enable more reliable spatial estimation of geotechnical information.

The GTIS over the entire study area was judiciously constructed by developing a procedure utilizing two new elements: the extended area surrounding the study area and geo-knowledge for acquiring additional surface geotechnical data. As data are fundamental to an information system (Rockaway, 1997), we adopted a geo-knowledge element to obtain sufficient data to predict spatial geotechnical information reliably across the entire study area. Geo-knowledge information about the extended area were acquired by using topographical maps and remote sensing images to analyze landscapes. A preliminary analysis of geologies was conducted using surface geological maps, and then a site visit was conducted at the extended area to acquire geotechnical materials data about the ground surface, referenced by spatial coordinates using global positioning system (GPS). Because thes interpolation results were expected to be more reliable than the extrapolation, the kriging technique was applied to the extended area containing the study area. Finally, geotechnical information about the study area was extracted from information about the extended area predicted within the GIS tool. This allowed versatile application of the information when seismic microzonation and geotechnical modeling were used to evaluate the site effects in the study area. As shown in Figure 1, the GIS-based GTIS developed in this study is composed of five primary functional components: database, spatial analysis, seismic response analysis, geotechnical analysis, and visualization. The arrow in the figure represents the data flow between the database in the general GIS frame and two additional components for assessing the site effects, allowing geotechnical analysis and seismic response analysis to be mutually complementary.

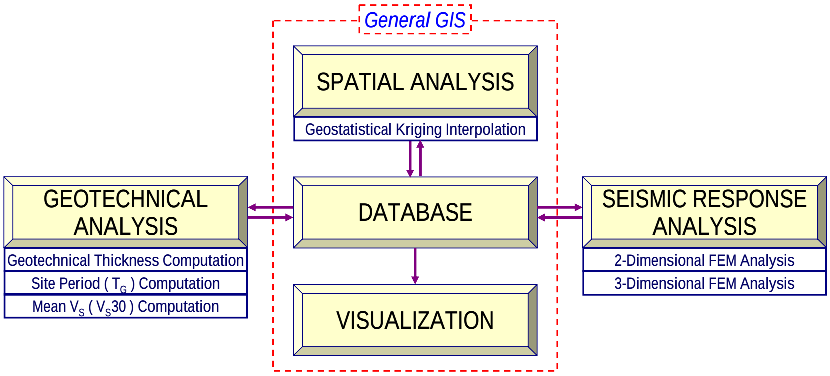

Figure 1. Functional components in architecture of the GTIS based on a GIS

GEOTECHNICAL EARTHQUAKE CHARACTERISTICS OF THE STUDY AREA

The Korean Peninsula is in a region of moderate seismicity and thus only a small amount of instrument-collected strong earthquake data has been recorded on and near the peninsula. Nevertheless, abundant historical seismic activities, including a few strong events, have been recorded at Gyeongju, which was the old capital of the Silla dynasty for a thousand years. Gyeongju is located in the southeastern part of the Korean Peninsula, near capable faults such as the Yangsan fault (Sun et al., 2005). For these reasons, it was selected as a case study for estimation of how site effects affect ground motion. To evaluate the site effects and corresponding ground motion at Gyeongju using seismic microzonations and numerical methods, topographic and geologic informative data were compiled and extensive geotechnical site investigations were conducted as part of this study.

Topographic and geologic features

Gyeongju (35.84°N, 129.21°E) is a typical inland city area located at the lower end of the Taebaek Mountains, the great backbone of the Korean Peninsula. The topography of Gyeongju is a basin of plains containing the urban area and farms surrounded by mountains. The Hyeongsan River flows northward across the area, and several creeks from valleys join the river. Waterways within the basin are now restricted to narrow area for flood control, but in ancient times, the river and creeks across the basin frequently flooded. Most of the basin was in a flood zone, so the subsurface soils are mainly composed of relatively thick alluvium over bedrock influenced by rivers and creeks.

Gyeongju lies within the Gyeongsang Basin at the southeastern part of the Korean Peninsula. This area is mostly composed of sedimentary rocks formed during the Cretaceous period (Sun et al., 2005). Nevertheless, as shown in Figure 2, the geology of Gyeongju is mainly covered by intrusive granite and is partially covered by sedimentary rocks such as sandstone and shale. Figure 2 illustrates geology with topography at Gyeongju (6 km × 6 km area), established by overlaying the surface geologic map and layers for buildings, waterways, and roads on the topographic surface within the GTIS. The central plain is widely distributed with Quaternary alluvial formation, composed mainly of gravel, boulder, and sand, and underlain by Bulguksa granite. Granitic rocks are classified as granodiorite, biotite granite, and hornblende granite.

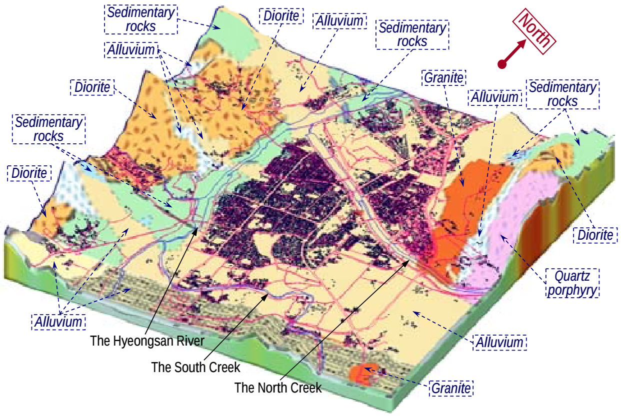

Figure 2. Surface geology with topographic variation at Gyeongju (6 km × 6 km area; the vertical scale is exaggerated by three times.)

Site investigations for geotechnical earthquake characterization

To determine the earthquake geotechnical characteristics at Gyeongju, including geologic profiles and shear wave velocity (V_S) as representative dynamic property, various site investigations were performed over the entire extended area at 23 sites in total; tests included 13 boring investigations and in-situ seismic tests including 4 crosshole tests, 9 downhole tests, and 21 SASW tests. Previously gathered data from 144 boring investigations around the study area were also included. Figure 3 shows the spatial locations of the previously collected and performed geotechnical investigation data in the extended area together with the coverage information of the iso-elevation contour lines for surface terrain, waterways, and roads for the study area. The spheres in Figure 3 represent bedrock outcrop data, one of example of the additional geo-knowledge data acquired during site visits across the extended area.

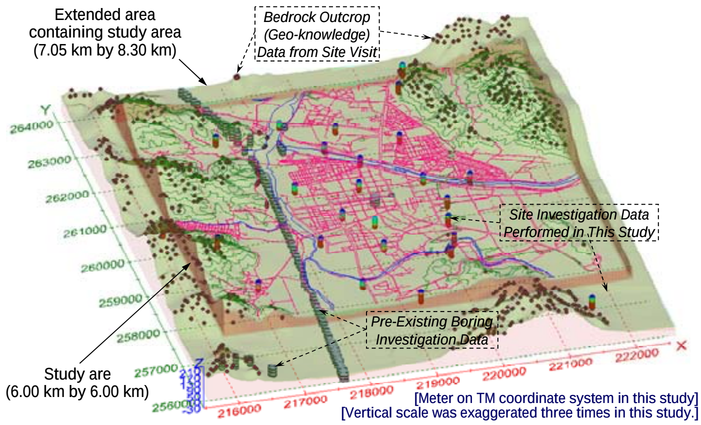

Figure 3. The spatial distribution of performed and collected site investigation data and bedrock outcrop geo-knowledge data for the extended area

Surface and subsurface geologic layers, determined from site investigations and site visits, were classified into five categories of geotechnical layers: fill, alluvial soil, weathered residual soil, weathered rock, and bedrock. Geotechnical investigations revealed that in most areas of Gyeongju, with the exception of mountain zones, subsurface soils are composed of 10 to 40 m thick alluvial sands and gravels over weathered residual soils. Alluvial soils were particularly thick, 30 to 40 m, in plain zones adjacent to the river or creeks. These soil formation characteristics represent a general topographic basin area where soils could have developed mainly from fluvial actions during frequent flooding near rivers and creeks surrounding the mountains, and especially indicate the geologic basin shape in the Gyeongju area.

Building the geotechnical information system (GTIS)

A GIS-based GTIS was constructed for Gyeongju using a procedure to allow more reliable prediction of spatial geotechnical information such as surface and subsurface geologic layers and V_S values. To build the GTIS, many geologic, geomorphic, and geotechnical resources were gathered from across the extended area, and analyzed. Then, various site investigations were conducted to obtain data about subsurface characteristics, considering geologic and geomorphic features and geotechnical data locations. Because data are fundamental to information systems (Rockaway, 1997), site visits were conducted for the extended area to acquire geotechnical material data from the ground surface for geo-knowledge. These data were classified into one of five geotechnical layer categories. Site visits to acquire surface geotechnical data for geo-knowledge were especially concentrated in some areas where previously collected and investigated geotechnical data were deficient. A GTIS illustrating spatial variation in geotechnical layers was first constructed for the extended area based on a database of collected boring data, geotechnical investigation data, and geo-knowledge data obtained during site visits. Then spatial geotechnical layers in the study area were extracted from those in the extended area using the shape-cut methodology within the GTIS, which applies only interpolation (making it more reliable than results from extrapolation) to predict geotechnical information about the study area.

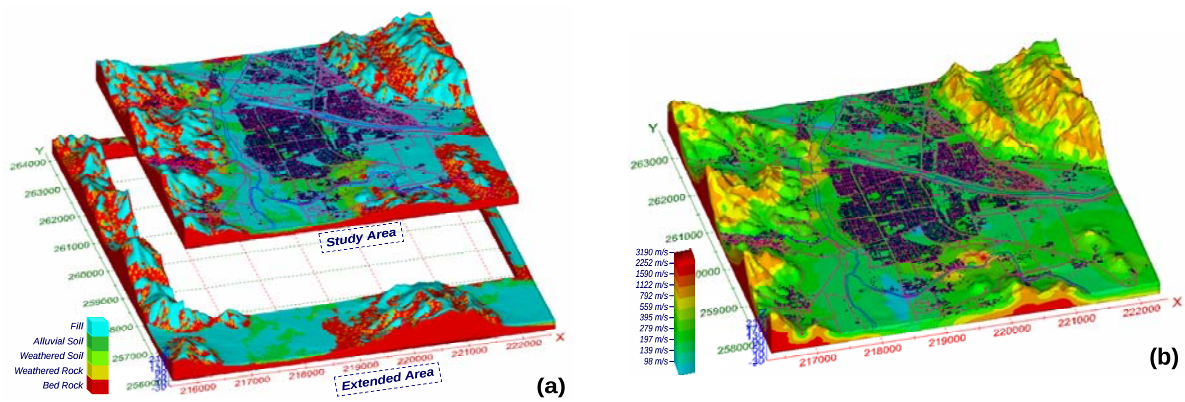

Figure 4. Building the GTIS for (a) spatial geotechnical layers and (b) spatial V_S at Gyeongju

Figure 4 was generated using the GTIS and shows the variation of geotechnical layers particularly expressing the simulated process of extracting the study area's geotechnical layers from the extended area (Figure 4(a)), and the spatial variation of V_S values in the study area (Figure 4(b)). The constructed GTIS for the geotechnical layers presented in Figure 4(a) also identities soil basin shape of Gyeongju. The variation in spatial V_S values shown in Figure 4(b) can be helpful when used as a fundamental parameter for estimating characteristic site period (T_G) and mean V_S to the 30 m depth (V_S30) in this study. This GIS-based GTIS enables users to examine geotechnical data referenced by spatial coordinates using a vertical and/or horizontal slice function and three-dimensional cut of ground volume, and to export these data in the form of ASCII or DXF, which can be easily imported into other numerical tools.

MICROZONATION WITHIN THE GTIS

Although a GIS-based GTIS for assessing the local site effects can be constructed based on instrumented or analyzed ground motions, we applied empirical relationships or simple site classification schemes to evaluate seismic responses related to the site effects on a regional scale due to their convenience and effectiveness (Kiremidjian, 1997). Among various quantified parameters for seismic responses, this study predicted two parameters within the GIS-based GTIS over the entire study area: site period (T_G) and mean V_S to 30 m (V_S30), from which the site effects can be assessed without any numerical analysis. GTIS outcomes for site effects have mainly been presented using micro-scaled zoning maps identifying locations or zones with differing levels of potential for seismic hazards.

Microzonation of site period (T_G) for estimating site effects at Gyeongju

The site effects are basically associated with the phenomenon of seismic waves traveling into soil layers. This is explained by the differences in V_S between soil layers and underlying bedrock and by the thickness of soil layers or the depth to bedrock. Specifically, the largest amplification of earthquake ground motion at a nearly level site occurs approximately at the fundamental frequency. The period of vibration corresponding to this fundamental frequency is called the characteristic site period (T_G), and in the case of the multi-layered soil, T_G (i.e., the unit is second) 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 bedrock (i.e., bedrock depth, $H = \sum D_i$), V_{Si} is the shear wave velocity of each soil layer, and n is the number of soil layers. Site period provides an extremely useful indicator of the period of vibration, at which the most significant amplification is expected. Thus, if spatial variations in thickness and V_S values are known for soil layers over the entire study area, spatial variations in the site period can be readily established and utilized for regional earthquake hazard reduction programs.

In order to accomplish the efficient microzonation based on the site period over the study area, interpolated spatial data for each soil layer and V_S values were imported into the geotechnical analysis component of the GTIS, and imported spatial V_S data were assigned to each layer with reference coordinates. Average values of layer thickness and V_S were calculated for each layer at each grid point with 10 m intervals, and then site periods at each grid point were computed based on equation (1). Calculated site periods were modeled into a spatial form of seismic microzonation in the GTIS. Figure 5 presents the resultant constructed zoning maps over the entire study area of Gyeongju; Figure 5(a) shows the depth to bedrock, and Figure 5(b) shows the site period. The depth to bedrock is one of the most important geotechnical and earthquake engineering parameters (Olsen, 2000), and was computed using the thickness of geotechnical layers in the geotechnical analysis component.

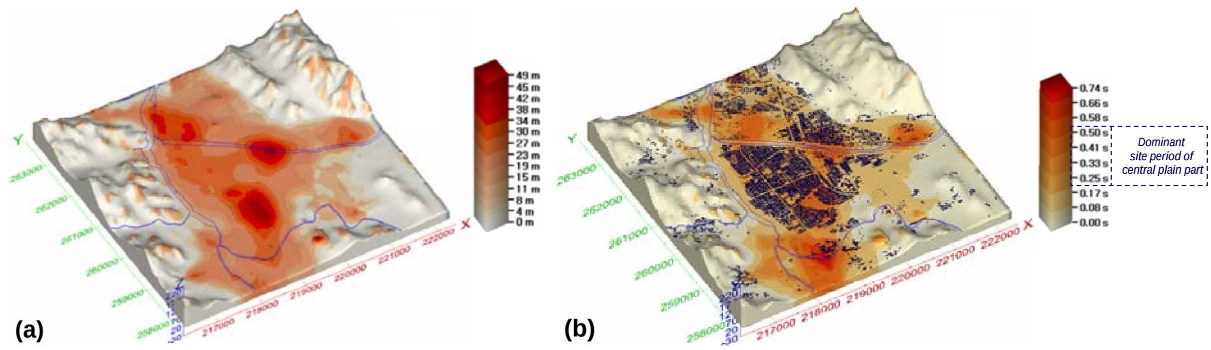

Figure 5. Spatial distribution of (a) the depth to bedrock and (b) the site period at Gyeongju

At Gyeongju, site periods in central plain areas tended to be longer than in mountains or hilly areas, generally ranging from 0.2 s and 0.5 s. As indicated in Figure 5(b), the spatial distribution of site periods was particularly consistent with the depth to bedrock. Figure 5(b) presents spatial building coverage data overlain on the site period distribution, indicating the seismic vulnerability of buildings. These rigorous zonations with building coverage data can be directly utilized as a fundamental source for mitigating and reducing seismically induced structural damage. All objects or structures have their own natural periods. Normally, multi-storied buildings with long natural periods will react in totally different ways from shorter buildings with shorter natural periods. In general, a building's natural period is considered to be 0.1 times its stories. Thus, any two- to five-storied buildings in the city of Gyeongju may be susceptible to resonance during earthquakes. Most of the downtown buildings actually have two to five stories, and would therefore be vulnerable to earthquake. Spatial microzoning information of the site period over the entire study area could be utilized as a regional counterplan against earthquake-induced hazards; it could also be very useful for determining rational land use and city planning or development.

Microzonation of mean V_S to a depth of 30 m (V_S30) for estimating site effects at Gyeongju

Since the geology and V_S profile to a shallow depth at a site can have a relatively great influence on the site-specific seismic response (Wills et al., 2000), it is important to investigate the geological and geotechnical properties of the shallow subsurface for reasonably evaluating the site amplification. Seismic design according to site conditions requires establishing correlations between mean V_S to a depth of 30 m (V_S30) and site amplification coefficients (F_a and F_v) in specific earthquakes based on empirical and numerical researches (Borcherdt, 1994; Dobry et al., 2000). Accordingly, in current seismic code, the site characterization for site class is based only on the depth of 30 m from the ground surface. The site class is determined solely and unambiguously by one parameter, V_S30. Specifically, for a profile consisting of n soil and/or rock layers, V_S30 (i.e., the unit is m/s) can be given by

$$V_S 30 = 30 / \sum_{i=1}^{n} \frac{d_i}{V_{Si}} \tag{2}$$

where d_i is the thickness of each soil and/or rock layer to a depth of 30 m (30 m = $\sum d_i$). Site conditions can be characterized as one of five categories (denoted by A to E or S_A to S_E) in accordance with the V_S30 as suggested in current codes, such as the Korean seismic design guide, Uniform Building Code (UBC) and National Earthquake Hazard Reduction Program (NEHRP) provisions (Sun et al., 2005). In the current seismic design guides, site coefficients, F_a (for short-period range) and F_v (for mid- or long-period range) are used to quantify the amplification caused by the local site effects, and they are dependent upon both the site categories and the intensity of rock motions. Both F_a and F_v are unity (1.0) for rock (site class B) and increase as the soil becomes softer with a decreasing V_S30, or the site class evolves through C, D, and E. Thus, if the spatial distribution of V_S to a depth to 30 m or more is known over an entire study area, spatial distributions of V_S30 and site classes for seismic design can be readily determined within the GTIS framework.

Site-specific seismic responses associated with the site effects can be quantified by both F_a and F_v according to site classes in current seismic design guides. Site class is determined solely by one parameter, V_S30, which can be easily calculated from spatial V_S values with depth. To effectively build spatial V_S30 seismic zoning maps for site categories, kriging interpolated spatial V_S data over the study area were imported into the geotechnical analysis component of GTIS, and V_S30 were computed at each grid point using equation (2). Then the computed V_S30 were modeled as a form of spatial distribution map within the GTIS. Figure 6 illustrates the spatial V_S30 developed for site classification in the Gyeongju area. In the figure, contour lines for the same site categories were overlain on the V_S30 distribution to identify site classes. In the study region, plain areas tended to have lower V_S30 distributions than mountainous or hilly areas. Spatial variation among the V_S30 presented in Figure 6 allows all locations in the study area to be easily classified preliminarily based on the site classification system before additional site investigations. In the study area, most locations (with the exception of mountainous areas) fell into site classes B, C, or D according to their V_S30 values. Furthermore, most plain zones were designated as site classes C and D, for which the site coefficients quantifying the site effects were larger than unity. Consequently, these spatial seismic microzoning maps for the V_S30 can be used to directly create a preliminary earthquake-resistant design for every location in the study area.

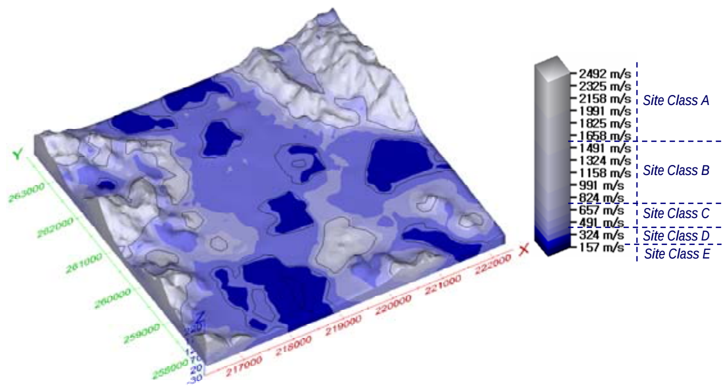

Figure 6. Spatial distribution of mean V_S to a depth of 30 m at Gyeongju

SEISMIC RESPONSE ANALYSES BASED ON THE GTIS

To evaluate the site effects at Gyeongju, which has a geologic basin shape, two-dimensional seismic response analyses were performed using a general-purpose finite element method (FEM) program, ABAQUS (Hibbitt et al., 1998). In addition, three-dimensional FEM seismic response analyses were conducted for a preliminary evaluation of the site effects over the entire study area. An explicit solver was applied during these FEM analyses in the time domain for computational efficiency. In this study, spatial coordinates of interfaces between the geotechnical layers predicted within the GTIS were imported to generate an accurate finite element (FE) models, reflecting the actual basin geometry at Gyeongju. This generation was distinct from previous general two- and three-dimensional models used to evaluate site effects.

Two-dimensional seismic responses at Gyeongju

Two sections (N-S and W-E sections) were selected for two-dimensional FEM seismic response analyses, as illustrated in Figure 7. The dimensions of the selected cross sections for FE modelings consist of 4,152 m in length and 124 m in height for the N-S section and 3,763 m in length and 116 m in height for the W-E section. The subsurface soil structures revealed very shallow and wide (flat) shapes with a width of about 3,650 m and a maximum depth of 48 m for the N-S basin and a width of 3,020 m and a maximum depth of 51 m for the W-E basin.

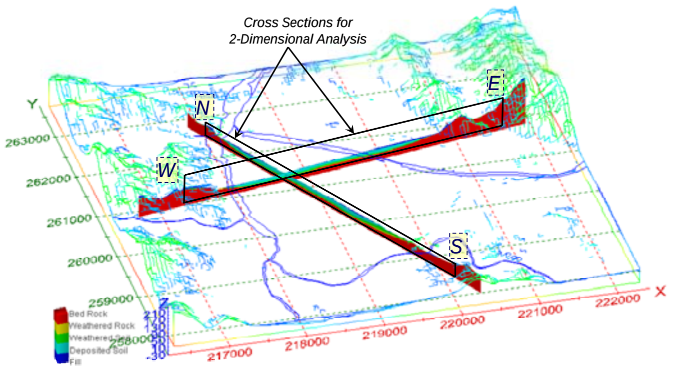

Figure 7. Cross sections selected for two-dimensional FEM seismic response analyses at Gyeongju

As discussed above, the FE meshes for the two-dimensional analyses were generated based on the spatial coordinates of subsurface structures exported from the GTIS. The input properties of V_S and density were set at 330 m/s and 1,835 kg/m^3 for alluvial soil with fill, 550 m/s and 1,989 kg/m^3 for weathered layer, and 1,000 m/s and 2,244 kg/m^3 for bedrock, based on a synthetic compilation of overall in-situ seismic and geotechnical testing results. The Poisson's ratio (ν) was assumed to be 0.3 for soil layers and 0.2 for bedrock. A material damping of geotechnical layers was adopted in the order of 5 % for the Rayleigh type (Psarropoulos et al., 2001). Material nonlinearity was considered by adopting an elasto-plastic model reflecting material plasticity using the von Mises yield surface (Desai and Siriwardance, 1984). Nonlinearities of soil materials were determined based on the results of laboratory resonant column tests. For the FE analyses, two artificial input motions with respective total duration times of 16 s (AS 16) and 25 s (AS 25) were synthesized with a peak acceleration of 0.10g in bedrock underlying soil layers. The input motions impinged horizontally from the bottom of the bedrock, since from a geotechnical engineering perspective, the earthquake source could be assumed to be far from the study area.

Engineering applications normally adopt a single parameter when estimating severity of an earthquake at a particular location or along a specific area. Peak acceleration on ground surface is perhaps the most common parameter (Xu et al., 2003). This study used results from the two-dimensional seismic response analyses of Gyeongju with a peak input bedrock acceleration level of 0.10g. First, horizontal peak ground accelerations (PGA) were examined using a lateral distance from the left side boundary of each model to assess seismic responses according to basin geometry. Figure 8 presents the distribution of peak ground accelerations in the N-S and W-E sections of the basin. The shapes of the basin sections are also illustrated in the lower subset of each figure. Overall, interior basin parts adjacent to the edges exhibited greater accelerations than the central parts, primarily because of the shear wave reflection and the corresponding generation of surface waves at the basin edges. Generally, accelerations in the N-S basin were greater than those in the W-E basin, caused by differences in the geometry of subsurface geotechnical layers and in the thicknesses of modeled bedrock. This indicates the importance of correct geotechnical modeling based on reliable prediction of subsurface structures, particularly within the GIS-based system.

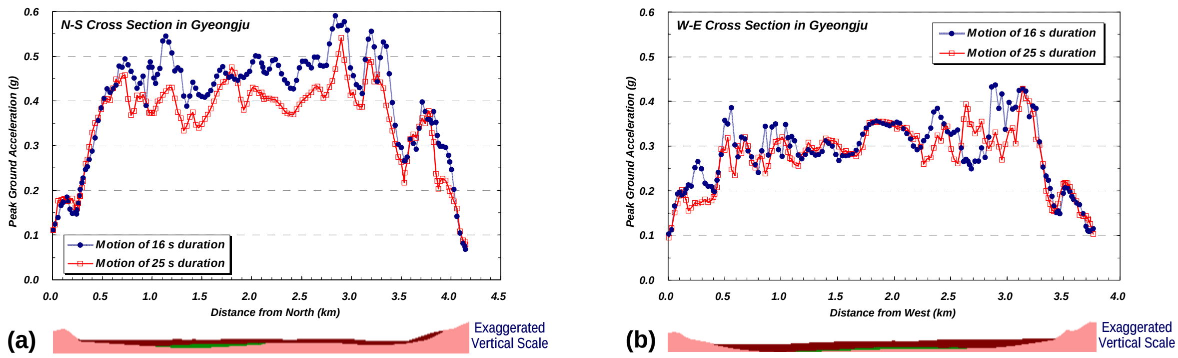

Figure 8. Peak ground acceleration (PGA) distribution in (a) the N-S basin and (b) the W-E basin from two-dimensional analyses

With regard to the time responses of the basins, the acceleration time-histories across both basin sections were examined based on those on the output nodal points from the two-dimensional analyses. Figure 9 shows the typical results of acceleration time responses for the N-S and W-E sections of the Gyeongju basin. These results were built by interpolating the time-histories at surface output nodes. Figure 9(a) is a bird's eye view indicating both positive and negative fluctuations in acceleration levels. Figure 9(b) is a plane view using shading to indicate duration. As indicated with the solid elliptical lines in Figure 9, the duration of motions was considerably prolonged at the interior locations adjacent to the basin edges. This phenomenon is mainly interpreted as the trapping of shear waves and the generation of surface Rayleigh waves. The complexity of seismic responses was clearly observed at the basin edges as marked with the dashed elliptical lines in Figure 9(a) and the dashed rectangular lines in Figure 9(b), because the waves were reflected at the inclined bedrock. At the central part of the basins, the motion of low frequency was dominant as indicated by the dotted rectangular line in Figure 9(b), because the incident waves were mainly propagated vertically without any wave reflection and the high frequency components of motions were filtered through soil layers like the typical one-dimensional seismic response. Generally, the seismic responses were greatly influenced by the subsurface geotechnical structures modeled into alluvial soil and weathered layer overlying bedrock in this study. Also, the acceleration responses on ground surfaces over the boundary of the weathered layer differed from those on their outskirts as illustrated with solid rectangular lines in Figure 9(b).

Therefore, the exact modeling of the subsurface structure composed of multiple geotechnical layers has been very important in reliably predicting the surface seismic response.

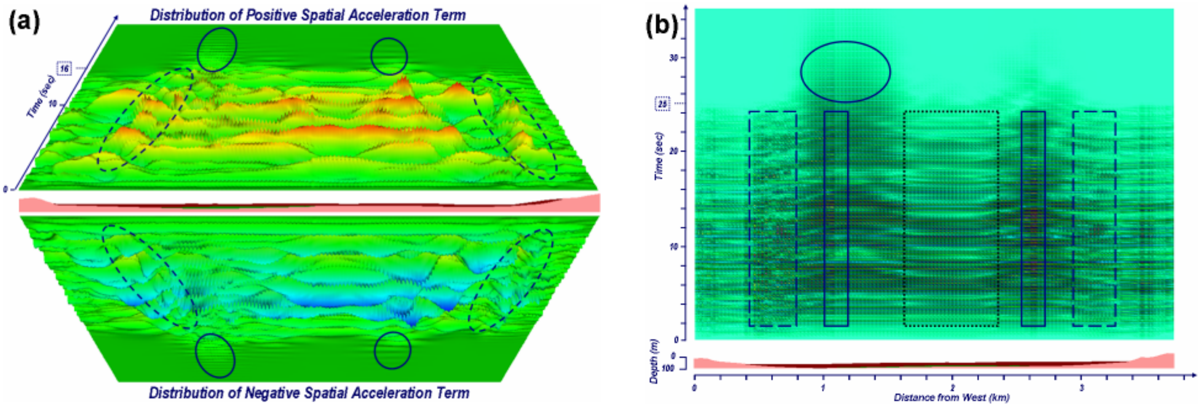

Figure 9. Acceleration time-responses on basin surface from two-dimensional analyses in (a) the N-S basin for AS 16 motion and (b) the W-E basin for AS 25 motion

Three-dimensional seismic responses at Gyeongju

Advances in computer technologies and the desire to clarify the spatial and temporal distributions of earthquake ground motion have enabled geotechnical earthquake engineers to conduct three-dimensional seismic simulations using realistic models (Olsen, 2000), which can be efficiently embodied using the spatial coordinates of the interfaces between soil and bedrock predicted within the GTIS. The 6 km × 6 km study area at Gyeongju was selected for three-dimensional FEM seismic response analyses, in which the FE meshes were also generated based on geotechnical information from the GTIS. Figure 10 presents the three-dimensional FE meshes modeled into two geotechnical layers of soil and bedrock and the element types and boundary. Input properties and analysis conditions were based on those used for the two-dimensional FEM analysis. In particular, the excitation of a synthetic input motion (only AS 16 motion for this three-dimensional analysis) with two-way components (x and y) with a peak input bedrock acceleration of 0.10g was applied to the interface plane between the bedrock and infinite bedrock.

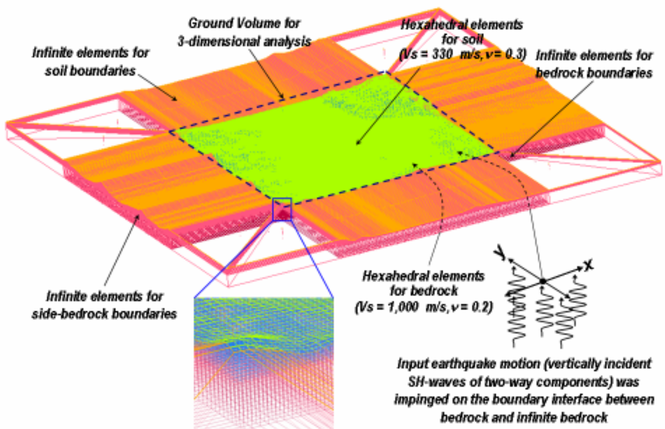

Figure 10. Three-dimensional finite element discretization for the 6 km × 6 km area at Gyeongju

The three-dimensional FEM seismic response analysis produced a preliminary estimate of the site effects at Gyeongju. To evaluate the exact site effects for this large-scale ground volume, a methodology partitioning the area into several sub-domains could be adopted using multi-processors in parallel computers (Olsen, 2000; Xu et al., 2003). However, this study investigated acceleration responses with time at Gyeongju using the three-dimensional analysis. Figure 11 shows representative results of acceleration time responses at 7 s (during strong shaking) and 22 s (after motion excitation) with respect to the y-direction component. As shown in Figure 11(a), at 7 s, greater accelerations were observed in areas of the plain nearer the basin edge, rather than inside the basin or at several ridges. In addition, prolonged shaking caused by trapped surface waves was exhibited in areas of the plain near the basin edge at 22 s, as shown in Figure 11(b). These results were similar to those from two-dimensional analyses. Although the three-dimensional analysis provided a preliminary estimate of the site effects, the three-dimensional FEM analysis also yielded a rough investigation of three-dimensional site effects at Gyeongju using modeling based on the GTIS.

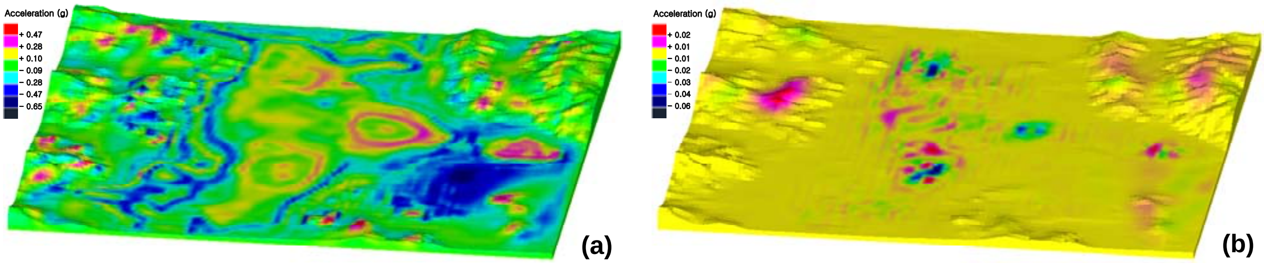

Figure 11. Acceleration responses from three-dimensional analysis at (a) 7 s and (b) 22 s

CONCLUSIONS

To accurately estimate the site effects at Gyeongju, Korea, which is located near several capable faults, a GTIS within a GIS framework for reliably predicting of spatial geotechnical information was built. The GTIS was based on both extensive data from site investigations and geo-knowledge data obtained from site visits. The subsurface soil structure at Gyeongju showed very shallow and wide basin shape. Using the GTIS constructed for a 6 km × 6 km area at Gyeongju, microzonations were conducted for both the site period and the V_S30 to estimate the site effects and also for use in a seismic counterplan for the study area. The seismic microzoning maps were efficiently built based on the spatial geotechnical layers and V_S values within the GTIS. The spatial site period map indicated that two- to five-storied buildings in the Gyeongju area were vulnerable to seismic activity. The spatial V_S30 maps identified site classes for seismic design in the study area, indicating that most plain zones could be categorized into site classes C and D. Furthermore, two- and three-dimensional seismic response analyses were conducted for the study area by generating FE models based on the spatial coordinates of the geotechnical layers interpolated within the GTIS. The acceleration responses with times computed from seismic response analyses indicated prolonged durations in the interior areas near basin edges, primarily because of the surface waves generated by the reflection of shear waves and their trapping. These case studies on the seismic zonation and the two- and three-dimensional seismic response analyses based on the GTIS within a GIS framework verified the utility of the GTIS in resolving geotechnical earthquake engineering problems, particularly when estimating the site effects.

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