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Verification of new seismic site characterization system in Korean Historical Areas

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ABSTRACT: New site characterization system using two parameters, depth to bedrock and Vs of soil above bedrock, was developed through site response analyses of 124 sites in Korea. Soil sites were divided into seven site classes and the corresponding site coefficients were proposed for each site category. In order to verify the effectiveness of the proposed site characterization system and assess the seismic risk for architectural heritages, site specific ground response analyses were performed at a historical city, Gyeongju. Using GIS based microzonation methodology, the seismic information such as bedrock depth, site period, peak ground acceleration, and site coefficients were spatially interpreted for the scenario earthquakes. Furthermore, to demonstrate the reliability and improvements of the proposed system, a comparison was conducted between the spatial distributions of site coefficients obtained from site-specific seismic response analyses for specific areas and the proposed site coefficients, as well as those specified in the currently used Korean seismic codes. Some verification works demonstrates the superiority of the proposed system over the current seismic codes.

1 INTRODUCTION

Korea is part of a region of low or moderate seismicity located inside the Eurasian plate with the bedrock located at depths less than 30m and with abrupt transitions from soil to much stiffer rock. Because the current site characterization system based on Vs30 in the 1996 NEHRP provision is not applicable at shallow bedrock, new site characterization system using two parameters, depth to bedrock and Vs of soil above bedrock, was developed through site response analyses of 124 sites in Korea. Soil sites were divided into seven site classes and the corresponding site coefficients were proposed for each site category.

In order to verify the effectiveness of the proposed site characterization system and assess the seismic risk for architectural heritages, site specific ground response analyses were performed at a historical city, Gyeongju. Thirty cultural heritage sites in Gyeongju were selected for the in-situ tests and the various pre-existing site investigation results in these areas were used. The sixty site characterization data in Gyeongju, such as boring, standard penetration test, seismic tests, and laboratory tests were collected for this study. Using GIS based microzonation methodology, the seismic information such as bedrock depth, site period, peak ground acceleration, and site coefficients were spatially interpreted for the scenario earthquakes. Furthermore, to demonstrate the reliability and improvements of the proposed system, a comparison was conducted between the spatial distributions of site coefficients obtained from site-specific seismic response analyses for specific areas and the proposed site coefficients, as well as those specified in the currently used Korean seismic codes.

2 TWO-PARAMETERS SITE CLASSIFICATION AND SITE COEFFICIENTS

Site response analyses were performed based on equivalent linear technique using the local geologic and dynamic site characteristics, which include the layer description and shear wave velocity (V_S) profiles for 125 sites collected in Korea peninsula.

The two-parameters site classification system divided the 125 sites into three site class categories: H_1, H_2, and H_3, based on H with boundaries of 10 and 20 m. H was determined as the depth from the surface to the depth where V_S values increase to more than 760 m/s in V_S profiles. $V_{S,Soil}$ was calculated using eq. (1) from V_S-profile.

$$V_{S,Soil} = (\sum D_i)/(\sum D_i/V_{Si}) \quad (1)$$

where, Di and Vsi are the thickness and the Vs of each soil layer above bedrock (H=∑Di).

Site classes are divided into a total seven groups. Table 1 lists the corresponding site coefficients, F_a and F_v, for the new site classes and regression curves. F_a and F_v values represent mean and mean+1σ values of site coefficients, respectively, based on the results of site response analyses.

For each site class based on the two-parameters site classification system, new standard design response spectra for the rock outcrop acceleration of 0.154g are shown in Fig. 1. Standard design response spectra were determined based on the Korean seismic design guide (MOCT, 1997) and the site coefficients listed in Table 1.

Table 1 Site coefficients in the two-parameters approach (0.154 g)

Site Class	H (m)	$V_{S,Soil}$ (m/s)	Short-period		Long-period	
			F_a	Regression	F_v	Regression
H1-1	<10m	< 300	1.37	$7.87(V_{S,Soil})^{-0.33}$	1.04	$1.27(V_{S,Soil})^{-0.038}$
H1-2		≥ 300	1.08		1.01	
H2-1	10~20	< 300	1.97	$79.42(V_{S,Soil})^{-0.67}$	1.20	$3.58(V_{S,Soil})^{-0.201}$
H2-2		≥ 300	1.43		1.06	
H3-1	≥20m	< 200	1.26	$-0.00003(V_{S,Soil})^{2}$ $+0.02(V_{S,Soil})^{-1.16}$	2.48	$109(V_{S,Soil})^{-0.75}$
H3-2		200~360	2.04		1.61	
H3-1		≥ 360	1.69		1.17	

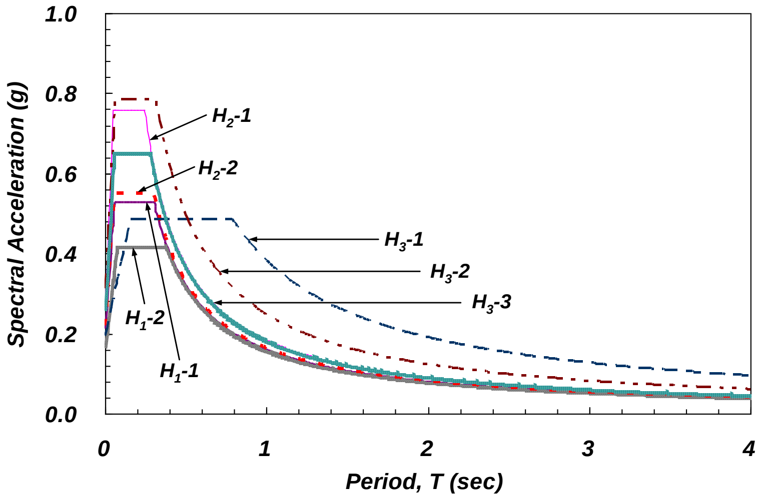


Figure 1. Standard design response spectrums for new site classes.

3 SITE-SPECIFIC GROUND RESPONSE ANALYSIS FOR GYEONGJU HISTORIC AREAS

Gyeongju, the capital of the ancient Silla Kingdom (B.C. 57~A.D. 935), is the one of the most glorious historic cities in Korea. The Gyeongju Historic Areas, UNESCO World Heritage inscribed in 2000, contain remarkable sites of Korean Buddhist art. The Gyeongju area also has frequent historical records of seismic damages and is located in a relatively higher earthquake prone region nearby the Yangsan fault line.

Thirty cultural heritage sites in Gyeongju were selected for the in-situ tests. The mountain and rock outcrop have relatively lower possibilities of local site amplification and seismic risk. Therefore, cultural properties in the mountain area were excluded from this study. In order to evaluate the GIS based seismic risk for the historic areas, the zone of 7 km by 7 km area were selected in Gyeongju. The various pre-existing site investigation results in this zone were used. The sixty site characterization data in Gyeongju, such as boring, standard penetration test, seismic tests, and laboratory tests were collected for this study.

Even though the earthquake resistant design guide for the cultural heritage sites was not yet proposed in Korea, considering the importance of a ripple effect on the collapse of the architectural heritage sites, the design rock outcropping accelerations were considered for the special structures and/or seismic classes I structures at collapse level of earthquake in this study. The design rock outcropping accelerations at Gyeongju were 0.20 g for the special structures (2400 year return period) and 0.14 g for seismic classes I (1000 year return period) structures at collapse level of earthquake based on the Korean seismic hazard map.

Figure 2 shows the typical summary of heritage information, in-situ test results and site-specific ground response analysis results for the Cheomseongdae Observatory site. Cheomseongdae, the astronomical observatory, was estimated to have been built in the period of Queen Seondeok (A.D. 632~647) in the Silla Era. It is highly valued as the oldest astronomical observatory in Asia. The representative shear wave velocity, the mean value of downhole and HWAW test results, was used for the site response analysis of the Cheomseongdae ground.

The cultural heritage information, in-situ test results and site-specific analysis results were summarized at cultural heritage sites following the same way shown in Fig. 2. The site information, the peak ground accelerations, and site periods were determined at heritage sites in Gyeongju

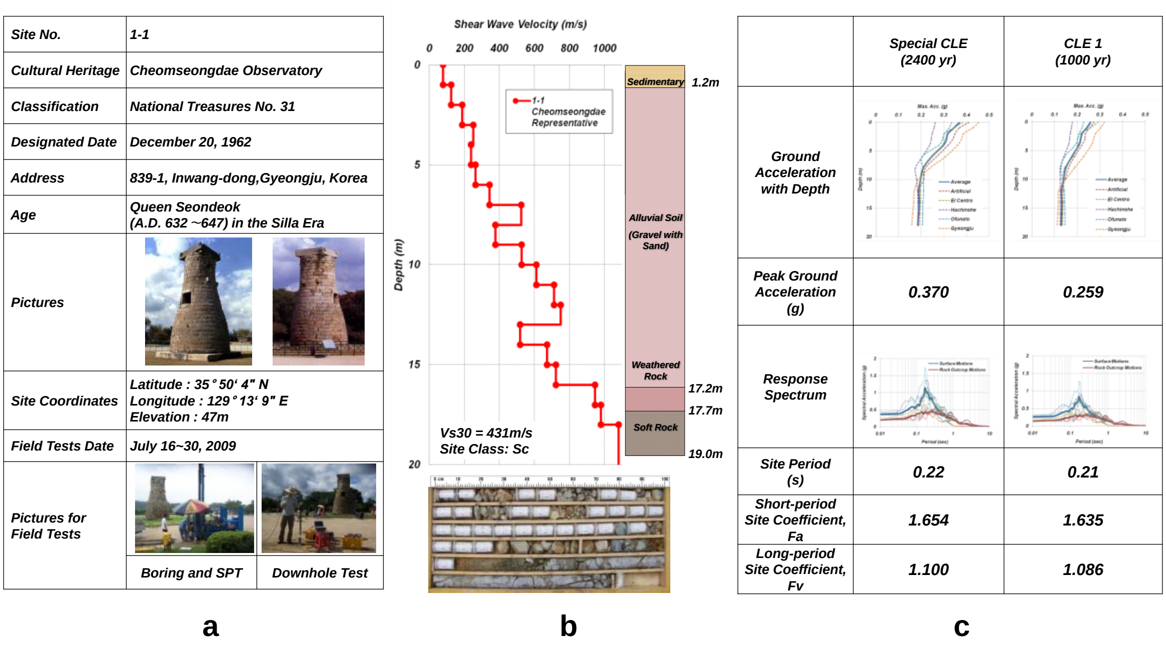


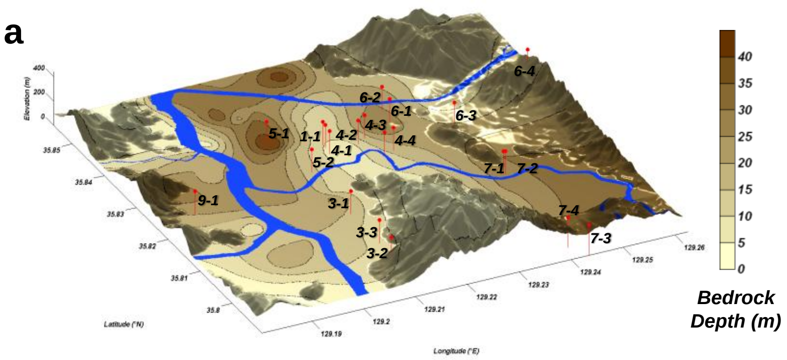
Figure 2. The cultural heritage information and site-specific analysis results:
(a) cultural heritage information and pictures, (b) in-situ test results, (c) ground response analysis results.

4 GIS BASED SESIMIC MICROZONATION

The seismic geotechnical information determined by site-specific ground response analysis was interpreted using GIS tool. In order to analyze the seismic sensitivity in geotechnical earthquake engineering, the spatial data were collected for assessing synthetically the earthquake.

Seismic microzonation, which is a city scale hazards distribution mapping based on the geotechnical information system, made a reliable estimation of spatial geotechnical data for the historic areas. This system incorporates a geostatistical kriging interpolation technique, which can be adopted for reliable prediction of geotechnical data values. The study areas of interest for the GIS based seismic microzonation are Gyeongju, which are centered around 7 km by 7 km.

Each geotechnical information system is shown in Fig. 3. The seismic information systems for the bedrock depth, natural site period, peak ground acceleration, and short-period site coefficients are interrelated and can be considered as reasonable results. The southeast area of Gyeongju has relatively deep bedrock, relatively high potential of site amplification and relatively large site period value.



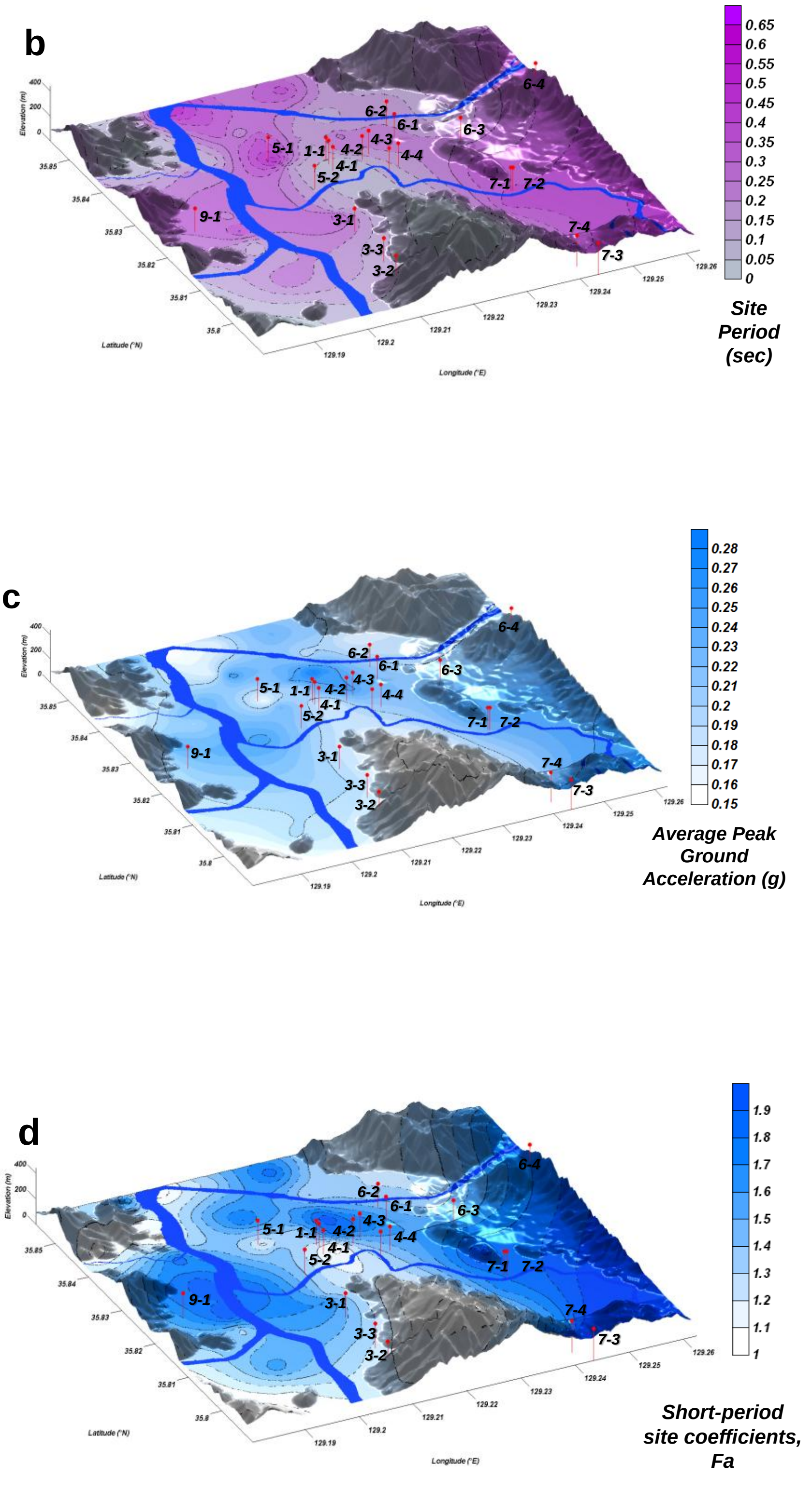


Figure 3. GIS based geotechnical information system for the earthquake level of 1000 year return period:
(a) the bedrock depth, (b) natural site period, (c) peak ground acceleration, (d) short-period site coefficients, Fa.

5 SPATIAL COMPARISON OF SITE COEFFICIENTS

The superiority of the proposed two-parameters site classification system for use in regions of shallow bedrock was demonstrated by comparing the spatial earthquake ground motions in Gyeongju from site response analyses with those determined by the proposed method and the current codes. Sun et al (2005) conducted various site investigations for 28 sites and gathered pre-existing boring data for 22 sites in a specific 10km×10km area of Gyeongju. Sun et al (2005) also conducted the site response analyses for all sites using equivalent linear (SHAKE 91) and nonlinear (NERA) analyses to estimate site-specific earthquake ground motion.

Short- and long-period site coefficients (F_a and F_v) based on the results of site response analyses were used as representative F_a and F_v values for each site and compared to those obtained using the proposed two-parameters site classification system, as well as those specified in the current Korean seismic code, using the following error values:

$$E_{a,i} = (F_{a,i} - F_{a,Analysis})^2 \quad (2)$$

$$E_{v,i} = (F_{v,i} - F_{v,Analysis})^2 \quad (3)$$

where $E_{a,i}$, and $E_{v,i}$ are the error values corresponding to the F_a and F_v values for each site, respectively (i=1: current Korean seismic code, i=2: two-parameters site classification system). $F_{a,Analysis}$ and $F_{v,Analysis}$ are the representative site coefficients from the site response analyses of each site.

To assess the spatial feasibility of site coefficients for each site classification system, kriging was used to interpolate the spatially distributed error values. Kriging is the optimal interpolation method for making spatial geological and geotechnical predictions (Sun et al, 2008). Figs. 4 and 5 show the spatial distributions of error values in the 10 km × 10 km area for F_a and F_v, respectively. The site coefficients from the current Korean seismic codes exhibited significantly high spatial error distribution as compared with those produced by the proposed two-parameters site classification system. The proposed site coefficients appear to yield a more reasonable interpretation of site-specific earthquake ground motions for the studied area, and furthermore, for the whole Korean peninsula. Therefore, the proposed system and the corresponding site coefficients are improved and superior as compared with the current system for regions of shallow bedrock including the Korean peninsula. Moreover, it is going on compiling continuously local geologic conditions in whole Korean peninsula, and the site coefficients will be further improved for predicting more reliable earthquake ground motions.

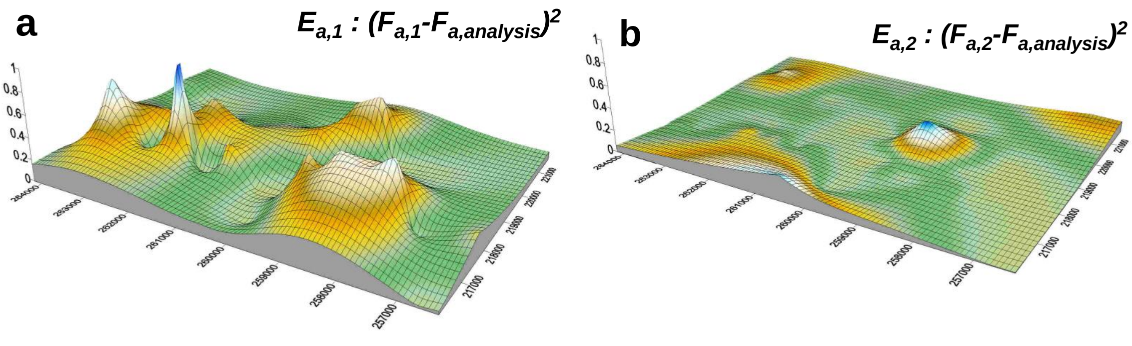


Figure 4. Spatial distribution of error values for the short-period site coefficient, F_a:
(a) Current Korean seismic code, (b) Two-parameters site classification

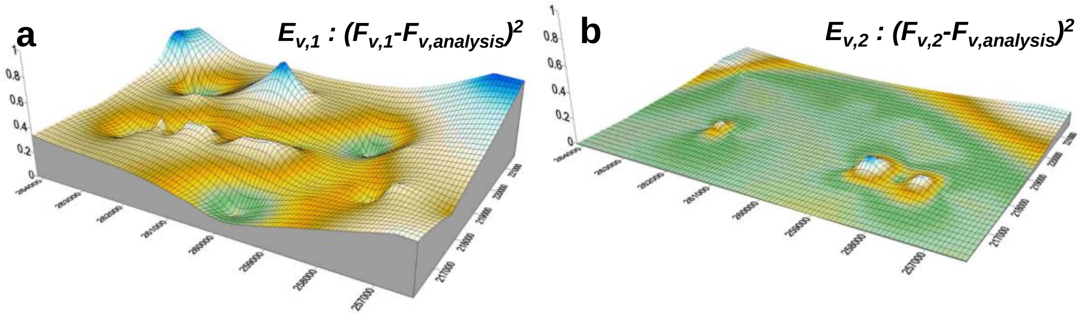


Figure 5. Spatial distribution of error values for the long-period site coefficient, F_v: (a) Current Korean seismic code, (b) Two-parameters site classification system.

6 CONCLUSIONS

New site characterization system using two parameters, depth to bedrock and Vs of soil above bedrock, was developed through site response analyses of 124 sites in Korea. Soil sites were divided into seven site classes and the corresponding site coefficients were proposed for each site category. In order to verify the effectiveness of the proposed site characterization system and assess the seismic risk for architectural heritages, site specific ground response analyses were performed at a historical city, Gyeongju. The developed site specific seismic responses of the cultural heritage sites and the GIS based seismic zonation can be utilized for the seismic risk assessment of cultural heritages in historic areas. Some verification works with comparisons of spatial distributions of site coefficients, demonstrates the superiority of the proposed system over the current seismic codes.

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