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# New site classification system and design response spectra in Korean seismic code

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**Abstract.** A new site classification system and site coefficients based on local site conditions in Korea were developed and implemented as a part of minimum design load requirements for general seismic design. The new site classification system adopted bedrock depth and average shear wave velocity of soil above the bedrock as parameters for site classification. These code provisions were passed through a public hearing process before it was enacted. The public hearing process recommended to modify the naming of site classes and adjust the amplification factors so that the level of short-period amplification is suitable for economical seismic design. In this paper, the new code provisions were assessed using dynamic centrifuge tests and by comparing the design response spectra (DRS) with records from 2016 Gyeongju earthquake, the largest earthquake in history of instrumental seismic observation in Korea. The dynamic centrifuge tests were performed to simulate the representative Korean site conditions, such as shallow depth to bedrock and short-period amplification characteristics, and the results corroborated with the new DRS. The Gyeongju earthquake records also showed good agreement with the DRS. In summary, the new code provisions are reliable for representing the site amplification characteristic of shallow bedrock condition in Korea.

**Keywords:** site classification system; design response spectrum; dynamic centrifuge test; 2016 Gyeongju earthquake

## 1. Introduction

Even in the adjacent site, the earthquake motion transmitted to the surface free-field changes according to the local site condition (Adanur *et al*. 2016). The effect of local soil condition on earthquake motions is generally taken into account in seismic codes by using site amplification factors for different site categories based on soil conditions (Beneldjouzi *et al*. 2017). The current Korean seismic code (MOCT 1997) uses a site classification system and site coefficients that are similar to the 1997 NEHRP provisions (BSSC 1997). Recent studies have shown that the site coefficients obtained from site response analyses of inland areas of the Korean peninsula are significantly different from those provided in the current Korean seismic code (Sun *et al*. 2005, Kim and Yoon 2006, Lee *et al*. 2012, Manandhar *et al*. 2017). The main reason for this discrepancy is that the site coefficients in NEHRP provisions are based on geological conditions in the western United States, and hence cannot represent the ground motions expected in Korea for which the site and seismicity conditions are very different. Therefore, suitable site coefficients based on local site conditions in the Korean peninsula are required to produce reliable estimates of earthquake ground motions.

The soil parameter $V_{S,30}$, which indicates the mean shear wave velocity for the top 30 m of soil, as a criterion for site classification (BSSC 1997, MOCT 1997, CEN 2004, ICC 2015) is adopted in many countries. This kind of site classification system is acceptable for regions with relatively deep bedrock and soil sites with a gradual transition from soil to hard rock, both of which are common geologic conditions in the western US. However, the scheme may not be acceptable for regions with bedrock located at depths less than 30 m from the ground level and with abrupt transitions from soil to much stiffer rock, both of which are common in Korea. In regions of shallow bedrock, site investigations are often performed down to the bedrock, so the depth to bedrock is clearly defined, and $V_S$ values can generally be determined for the soil layers and bedrock for site response analysis. Hence, site classification using depth to bedrock ($H$) and time-averaged shear wave velocity of soil layers above bedrock ($V_{S,Soil}$) can be considered appropriate for Korea as proposed in a recent study by Manandhar *et al*. (2017). Moreover, the seismic provisions in Australia (AS1170.4 2007) and New-Zealand (NZS1170.5 2004) have also been using non-$V_{S,30}$ based site classification system.

In this study, a brief description of site classification system and the site coefficients suggested in Manandhar *et*

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*al*. (2017) is presented. Next, the proposed site classification system and site coefficients are modified based on a public hearing process so that it meets the 'minimum seismic design load requirements' criteria in Korea. Preliminary notice of amendment using these new code provisions was announced in July 2017 by the Ministry of Public Safety and Security (MPSS 2017) with modifications to address concerns raised during the public hearing process. Finally, the newly enacted stipulations are assessed by dynamic centrifuge tests and also by comparing the design response spectra (DRS) with the 2016 Gyeongju earthquake records, which was the biggest-ever earthquake experienced in Korea since 1978. Because of the schedule of the public hearing process, to date, no verification of these code provisions have been undertaken using the records from the 2016 Gyeongju Earthquake.

## 2. Development of new seismic code provisions

In this section, development of new site classification system and site coefficients, which were proposed by Manandhar *et al*. (2017), is briefly described. In their study, site response analyses were performed using the SHAKE 91 program (Idriss and Sun 1992) for estimating design ground motions at 300 soil sites collected from all over the Korean peninsula. Of the 300 sites, 100 sites each were classified under site classes $S_C$, $S_D$, and $S_E$ based on $V_{S,30}$, according to the current code. As there is lack of strong ground motions in Korea, eight input earthquake motions recorded at different regions around the world were used in the analysis, such that the average input motion is compatible with the design response spectrum (DRS) for the reference site class $S_B$. Design rock outcrop accelerations were 0.11 g, 0.154 g, 0.22 g and 0.286 g corresponding to earthquake return periods of 500 years, 1000 years, 2400 years and 4800 years, respectively, according to the Korean seismic hazard map. The soil non-linear deformation characteristics expressed in terms of normalized modulus reduction curves ($G/G_{\max}$–log$\gamma$) and damping ratio curves ($D$-log$\gamma$) were used for representative soil types in Korea (Kim and Choo 2001, Sun *et al*. 2005).

$$F_{a\ or\ v} = \frac{1}{\beta - \alpha}\int_{\alpha}^{\beta} \frac{RS_{soil}(T)}{RS_{rock}(T)}\,dT \tag{1}$$

The site classification parameters, bedrock depth ($H$) and $V_S$ of soil ($V_{S,Soil}$), were used for classifying shallow bedrock sites, as they are directly related to soil amplification (Rodriquez-Marek *et al*. 2001, Tsang *et al*. 2012, 2017a). Site coefficients were calculated from each SHAKE output from a total of 9600 SHAKE runs (300 sites, 4 rock outcrop accelerations, and 8 input motions) and were divided into short- ($F_a$) and mid-period ($F_v$) site coefficients. These coefficients were calculated from the ratio of response spectra (RRS) for the soil surface and corresponding rock surface (Borcherdt 1996, Dobry *et al*. 1999) using Eq. (1).

Where $\alpha$ and $\beta$ are periods to define the amplification band of interest. The $F_a$ values were calculated using Eq. (1) with an integration interval of 0.1-0.5 s, whereas the $F_v$ values were calculated using Eq. (1) with an integration interval of 0.4-1.5 s. The integration interval for $F_v$ value was adjusted to improve the DRS at mid-period range considering shallow-bedrock-condition in Korea.

Table 1 New seismic site classification system (MPSS 2017)

| Site class | Site description | Parameters for classification | |
|---|---|---|---|
| | | Bedrock* depth, $H$ (m) | $V_{S,Soil}$ (m/s) |
| $S_1$ | Rock | $H$<1 | - |
| $S_2$ | Shallow and stiff soil | 1≤$H$≤20 | ≥260 m/s |
| $S_3$ | Shallow and soft soil | | <260 m/s |
| $S_4$ | Deep and stiff soil | $H$>20 | ≥180 m/s |
| $S_5$ | Deep and soft soil | | <180 m/s |
| $S_6$ | Special soil requiring site-specific evaluation | | |

*Stratum showing a shear wave velocity higher than 760 m/s

-Soil sites with $V_{S,Soil}$≤120 m/s are included in $S_5$ site class regardless of bedrock depth

In order to group the sites having similar amplification characteristics for site classification, the trend and dispersion of site coefficients were examined. Initially, the $H$ equal to 20 m was used to divide the sites into two groups ($H$≤20 m and $H$>20 m) based on the trend in variation of $F_a$ and $F_v$ values with site period. The first site class contains mostly shallow and stiff soils, while most sites in second site class are relatively deep and soft. Next, the site classes were subdivided using $V_{S,Soil}$ with boundaries corresponding to 260 m/s and 180 m/s. These boundaries were based on average $V_{S,Soil}$ of the first and the second site classes. Consequently, four new site classes ($S_2$, $S_3$, $S_4$ and $S_5$) were created for soil sites while the rock site is specified as $S_1$ site classes. It is worth mentioning that the rock site definition in this study as the site with depth of stratum having $V_S$ is greater than 760 m/s is less than 1 m corresponds with the studies in which the natural period ($T_G$) of the rock site is recommended to be less than 0.15 s or 0.2 s (Tsang *et al*. 2017b, Pitilakis *et al*. 2013). Detailed information regarding the development of site classification system and site coefficients can be found in Manandhar *et al*. (2017).

The new site classification system is presented in Table 1. This is a modified version of the site classification system initially proposed in Manandhar *et al*. (2017). In this system, all sites in $S_6$ site class should perform site-specific evaluation of seismic response. Additionally, soil sites with $V_{S,Soil}$≤120 m/s are included in $S_5$ site class regardless of bedrock depth, as these sites are too soft to be included in the $S_3$ class. Likewise, very deep sites ($H$>50 m) are included in the $S_6$ site class as these sites are rare in Korea (Lee *et al*. 2012, Sun *et al*. 2012). Preliminary notice of revision using this system and corresponding site coefficients was announced in July 2017 as a part of new minimum seismic design load requirements for general seismic design in Korea after the public hearing process by the Ministry of Public Safety and Security (MPSS 2017); these provisions are to be implemented from January 2019.


Fig. 1 Public hearing held on 18th January 2017 in Seoul

## 3. Modification of the provisions by public hearing process

### *3.1 Holding the public hearing*

The site classification system and DRS, which is constructed using site coefficients of each site class, proposed in Manandhar *et al*. (2017) were discussed in a public hearing process for ascertaining if it meets the 'minimum seismic design load requirements' for seismic design in Korea. The public hearing process was held on 18$^{th}$ January, 2017 in Seoul, Korea. The 'minimum seismic design load requirements' is a common standard applied to general seismic design for maintaining consistency in determination of earthquake design load for the facilities managed by every department. The 'minimum seismic design load requirements' criterion is included in seismic design codes for 31 specified facilities under 11 ministries in Korea. The public hearing process was attended by more than 300 people (Fig. 1) from various fields such as the national government, local governments, research institutes, and person-in-charge of company facilities, thereby reflecting the interest of related industries in the minimum requirements.

### *3.2 Change in nomenclature of site classes*

The site classes were named as *R*, *H*1-1, *H*1-2, *H*2-1, *H*2-2, and *SP*, for the rock, soil sites and special site class, respectively in Manandhar *et al*. (2017). Additionally, site classes *A*~*E* were also proposed as a possible alternative. However, the public hearing process suggested to use different names for the site classes; starting from $S_1$ for the rock site class, $S_2$~$S_5$ for the four soil site classes, and $S_6$ for the special soil class. The adoption of this naming system clears the confusion of relating the sites with those in other codes, and also it is convenient to remember the name of the site classes. Further, the consecutive naming system is consistent with site classification from hard rock to soft soil.

### *3.3 Adjustment of amplification factors*

For each site class, the $F_a$ and $F_v$ values were obtained from the mean RRS curves and mean +1$\sigma$ RRS curves, respectively, of all the sites within a site class using Eq. (1). The amplification factors obtained were then adjusted after the public hearing process to ensure that it meets the 'minimum seismic design load requirement' criteria. The analyses results are expressed as empty circles shown in Fig. 2. Dark solid lines represent the final $F_a$ and $F_v$ values. The $F_a$ values for site classes $S_3$ and $S_4$ were adjusted to a level similar to those proposed in Eurocode-8 (CEN 2004) and the Korean Building Code (KBC) (AIK 2016) for equivalent site classes (see Table 2) after the public hearing process for ensuring economic efficiency. The initial and final amplification factors ($F_a$ and $F_v$) are plotted with respect to rock shaking intensity for the new site classes to consider the effect of soil non-linearity on the site coefficients as presented in Fig. 2.

Table 2 New site classes with equivalent site classes from two other codes

| New site class | Code | Equivalent site class |
|---|---|---|
| $S_2$ | Eurocode 8 | *E* (5 m<*H*<20 m) |
| | KBC 2016 | $S_C$ (*H*<20 m) |
| $S_3$ | Eurocode 8 | *E* (5 m<*H*<20 m) |
| | KBC 2016 | $S_D$ (*H*<20 m) |
| $S_4$ | Eurocode 8 | *C* |
| | KBC 2016 | $S_D$ (*H*>20 m) |
| $S_5$ | Eurocode 8 | *D* |
| | KBC 2016 | $S_E$ |

Table 3 New site coefficients* of each site class with rock outcrop acceleration levels

| Site class | Short-period site coefficient, $F_a$ | | | Mid-period site coefficient, $F_v$ | | |
|---|---|---|---|---|---|---|
| | *S***(*g*)≤0.1 | *S*=0.2 | *S*=0.3 | *S*≤0.1 | *S*=0.2 | *S*=0.3 |
| $S_2$ | 1.4 | 1.4 | 1.3 | 1.5 | 1.4 | 1.3 |
| $S_3$ | 1.7 | 1.5 | 1.3 | 1.7 | 1.6 | 1.5 |
| $S_4$ | 1.6 | 1.4 | 1.2 | 2.2 | 2.0 | 1.8 |
| $S_5$ | 1.8 | 1.3 | 1.3 | 3.0 | 2.7 | 2.4 |

*Use straight-line interpolation for intermediate values of S
**Effective peak ground acceleration (rock shaking intensity)

The KBC is a building design code which has been continuously updated based on the International Building Code (IBC); an updated version was last issued in 2016. The KBC provides site classes from $S_A$ to $S_E$, similar to IBC 2015 (ICC 2015), and it uses $V_{S,Soil}$ together with $V_{S,30}$ for site classification, depending on the bedrock depth (*H*). If the *H*<5 m or *H*>30 m, the code uses $V_{S,30}$, otherwise it employs $V_{S,Soil}$. Additionally, if the evaluated site is classified as $S_C$ or $S_D$ based on $V_{S,Soil}$, then *H* of 20 m is used to divide the site class into two groups. The $F_a$ and $F_v$ values are represented by dotted lines for KBC in Fig. 2. Eurocode-8 (CEN 2004) suggests an amplification factor (S) for each site class to construct the DRS. The $F_a$ and $F_v$ values were derived for each site class based on the DRS constructing method proposed in NEHRP provisions in order to express the S value as two corresponding amplification values (i.e., $F_a$ and $F_v$). Furthermore, two $F_a$ and $F_v$ (for Type-1 and Type-2 spectra) were considered for each site class based on peak ground acceleration (PGA) of 0.2 g given that the Eurocode-8 suggests different *S* values depending on whether the earthquake magnitude is above or

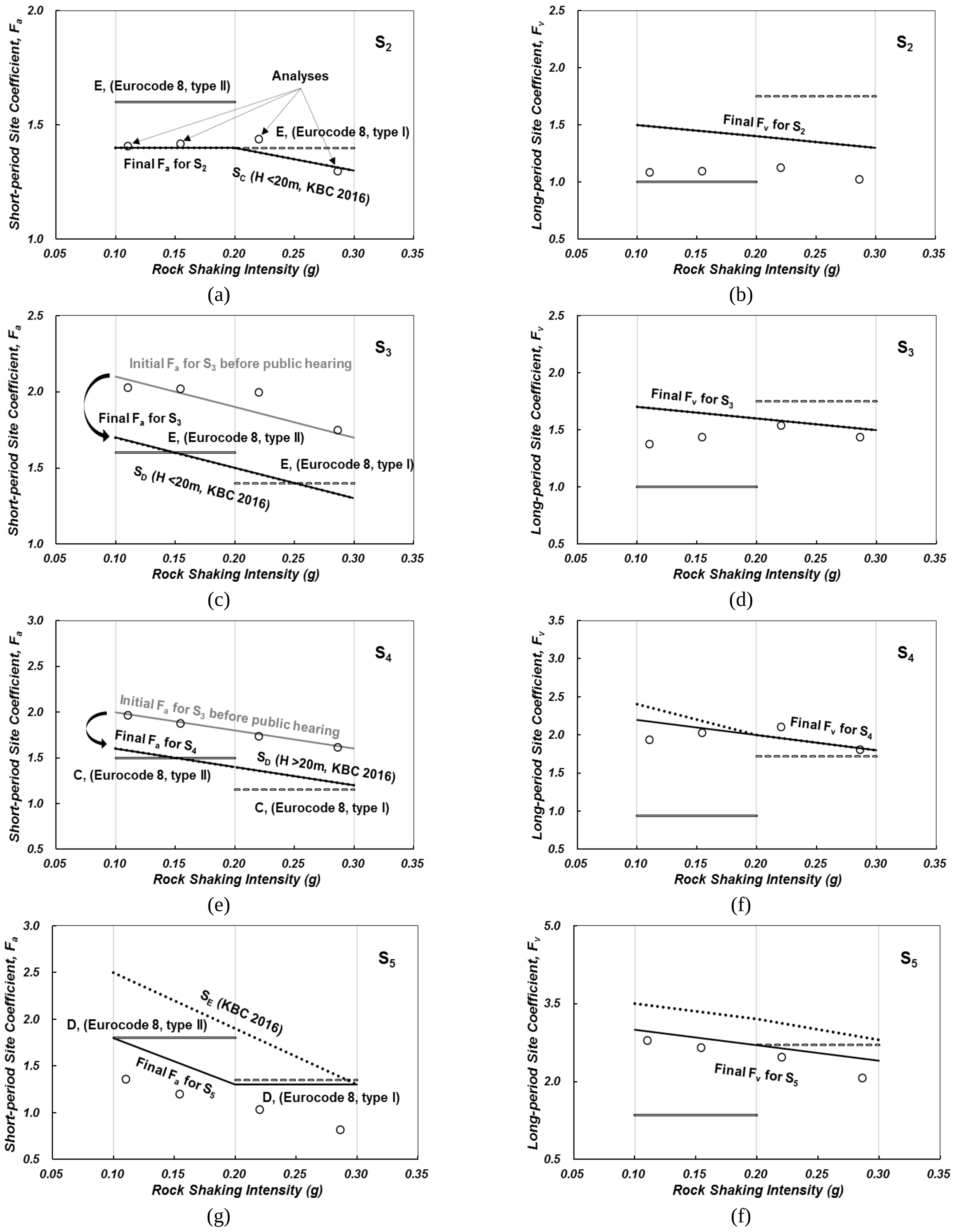



Fig. 2 Adjustment and determination of site amplification factors after the public hearing process: (a) $F_a$ for site class $S_2$; (b) $F_v$ for site class $S_2$; (c) $F_a$ for site class $S_3$; (d) $F_v$ for site class $S_3$; (e) $F_a$ for site class $S_4$; (f) $F_v$ for site class $S_4$; (g) $F_a$ for site class $S_5$; (h) $F_v$ for site class $S_5$

below 5.5, which corresponds to PGA of about 0.2 g (Pitilakis *et al.* 2012, 2013). Two horizontal lines discontinuous at 0.2 g represent Eurocode-8 in Fig. 2. The final DRS of all the site classes are expressed in Fig. 3 for an earthquake return period of 2400 years. The DRS for different levels of seismic intensity can be determined by the amplification factors according to the effective peak ground acceleration (*S*, which is different from the

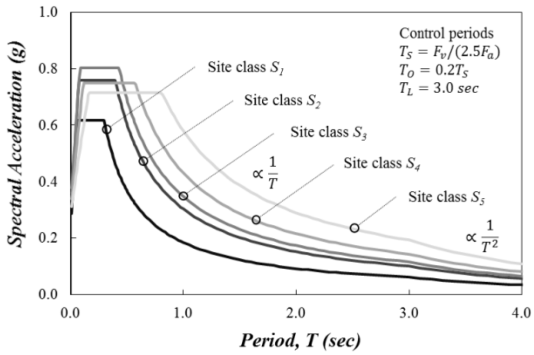



Fig. 3 Final design response spectra (DRS) of all the new site classes for an earthquake return period of 2400 years (rock shaking intensity=0.220 g)

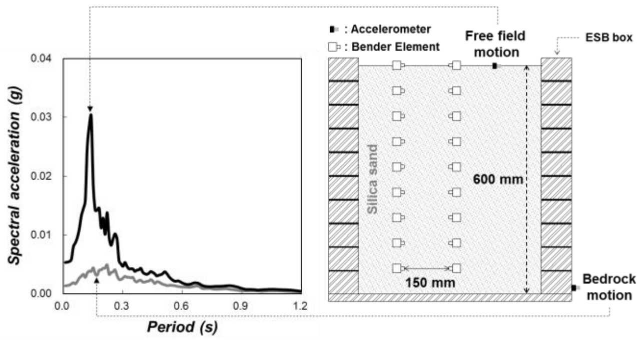



Fig. 4 Evaluation of seismic response of centrifuge model ground

amplification factor $S$ in Eurocode 8) as listed in Table 3.

## 4. Assessment of the new provisions by dynamic centrifuge tests and 2016 Gyeongju earthquake records

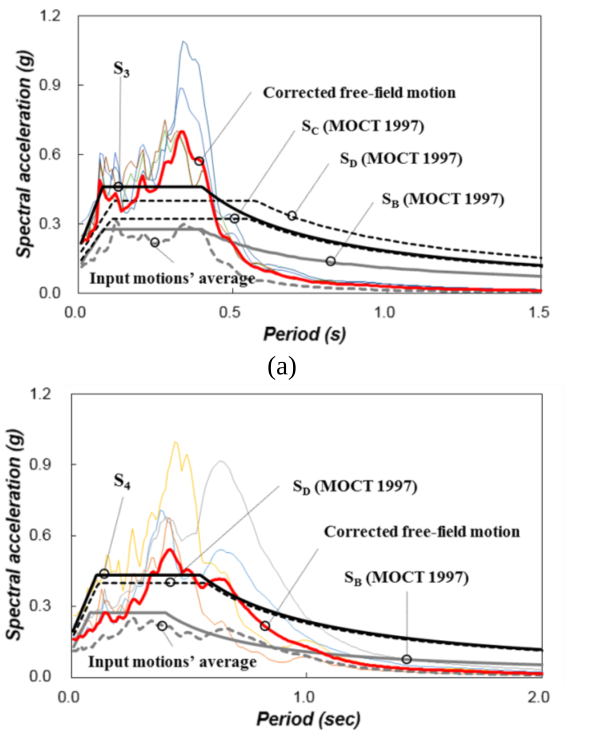
### 4.1 Dynamic centrifuge tests

Dynamic free-field centrifuge test can be considered as one of the novel way to circumvent the problem with lack of strong ground motions for direct evaluation of the seismic response during scenario earthquake events. In this section, dynamic free-field seismic tests were performed in a centrifuge to study soil amplification of various types of soil (Lee *et al*. 2013). The free-field seismic response of centrifuge models were compared with the DRS in the new provisions for similar soil conditions.

Typical shallow bedrock condition in Korea was simulated in the dynamic centrifuge tests. Fig. 4 shows configuration of the centrifuge model: a uniform sand model with sensors embedded at various depths. The height of the model was 60 cm at the model scale, and the centrifugal accelerations of 20 g and 40 g level were applied to the model. The model depth simulated prototype depths of 12 m and 24 m at 20 g and 40 g, respectively, according to the centrifuge scaling law. A series of two different tests were performed at different relative densities of 44% and 81%. The models were prepared using dry silica sand by air pluviation method. The centrifuge models were excited by the earthquake motions at 20 g, and then the tests were proceeded to the 40 g centrifugal acceleration. Four input earthquake motions: Morgan hill, Kobe, San Francisco and Northridge earthquakes were used for evaluating the seismic responses at each centrifugal acceleration level.

Table 4 Information of dynamic centrifuge models

| # | Model thickness (cm) | Relative density (%) | Target *g*-level (*g*) | Simulated (prototype) site conditions: Height (m) | $V_{S,Soil}$ (m/s) | $V_{S,30}$ (m/s) | Site class: MOCT 1997 | Proposed |
|---|---|---|---|---|---|---|---|---|
| 1-1 | 60 | 81 | 20 | 12 | 194 | 423 | $S_C$ | $S_3$ |
| 1-2 | | | 40 | 24 | 234 | 284 | $S_D$ | $S_4$ |
| 2-1 | | 44 | 20 | 12 | 157 | 352 | $S_D$ | $S_3$ |
| 2-2 | | | 40 | 24 | 204 | 249 | $S_D$ | $S_4$ |




(b)

Fig. 5 Comparison of response spectra from centrifuge tests with DRS (0.110 g): (a) site class $S_3$; (b) site class $S_4$

Table 4 shows the test information about soil depth ($H$), $V_{S,30}$, and $V_{S,Soil}$ of the soil models at different centrifugal acceleration levels. The $V_S$ of the soil models was determined using bender element array during the centrifuge tests (Kim and Kim 2010) as shown in Fig. 4. For determination of $V_{S,30}$ of the centrifuge model ground, the bedrock stiffness of 2,000 m/s was assumed considering the stiffness of aluminium as the material of the model container. Based on the information in Table 4, the soil models were classified according to the site classification system in the current seismic code (MOCT 1997) and the new site classification system.

The response spectra obtained from the centrifuge tests were compared with the DRS from each seismic code as shown in Fig. 5. The free-field response spectrum of the earthquake motions at input acceleration level of 0.110 g (500 year earthquake return period) in prototype scale was used for comparison. Because both uniform sand models having different relative densities were classified into $S_3$ site class at 20 g and $S_4$ site class at 40 g level in the new site classification system, the response spectra from each test were averaged for each site class. The average response spectra at the surface and the bedrock (base motion) for all the input earthquake motions were calculated and compared with the DRS. The average base motions are also compared with the reference site class $S_B$ as defined in the current Korean seismic code. Except the average base motion above 0.5 s period range for the model at 20 g, the average base motions match well with the DRS of $S_B$ site class.

In order to consider the unavoidable effect of the high impedance contrast at the soil-container interface on the free-field response, the average free-field response spectra were reduced quantitatively by a certain factor obtained using one-dimensional numerical simulation of similar soil profiles as used in the centrifuge tests. The equivalent linear analysis method using the SHAKE 91 program (Idriss and Sun 1992) was used to perform the one-dimensional numerical analysis of the soil model retained in the model container. The input soil parameters such as thickness, $V_S$-profile, and unit weight of soil for the SHAKE analysis were adopted from the centrifuge test data. The non-linear modulus reduction and damping curves were determined using resonant column (RC) test for silica sand at various confining pressures. The input earthquake motions used in the analysis were recorded motions at the base of the container using accelerometer attached on the ESB box. For elastic base condition, a bedrock $V_S$ of 760 m/s was used as this represents the reference ground condition in the current seismic code. For rigid base condition, the bedrock $V_S$ of 2,000 m/s was adopted to represent the stiffness of the aluminum base plate of the ESB box.

The difference in the maximum-average spectral accelerations obtained from the SHAKE analysis for elastic and rigid base conditions was 17.8% in case of Model 2-2 at 20 g-level. Likewise, other centrifuge tests were simulated using numerical analysis, and the results were compared for finding the difference in maximum-average spectral accelerations between elastic and rigid base conditions. These differences were then used to scale down the corresponding average free-field response spectra obtained from the centrifuge tests. The same amount of decrease in spectral acceleration was made for all the periods based on the calculated difference.

The subsequent modified free-field response spectra are well covered by the new DRS, but the DRS fails to cover the short-period response for the model simulated as $S_3$ site class. This can be attributed to the result of reduction in $F_a$ values through public hearing process. Meanwhile, the current code underestimates the level of spectral acceleration and is limited in covering the spectral accelerations at short-periods when compared with the new DRS curves. Hence, the newly proposed DRS curves are comparatively better than those in the current seismic code based on the results of the centrifuge tests.

### *4.2 2016 Gyeongju earthquake records*

On September 12, 2016, Korea experienced the biggest-ever earthquake since 1978, when the government started monitoring seismic activity. A series of earthquakes having maximum ML of 5.8 occurred in the south-eastern Korean peninsula, Gyeongju (Kim *et al*. 2016). These earthquakes have shown that Korea is no longer safe from earthquakes. Despite considerable damages, the Gyeongju earthquakes provided a meaningful record for earthquake related research in Korea. This allows for development and verification of DRS considering Korean geotechnical condition and earthquake amplification characteristics. In this section, earthquake records obtained from two seismic stations for the main Gyeongju earthquake were used to assess the performance of the new DRS curves. The epicenter of the main Gyeongju earthquake and the locations of target seismic stations are shown in Fig. 6.

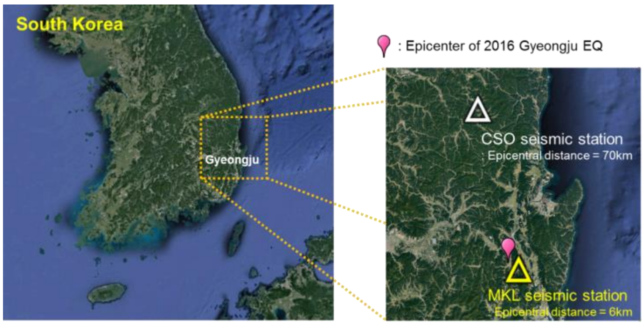


Fig. 6 Epicenter of 2016 Gyeongju earthquake and adjacent seismic stations


Fig. 7 Field seismic testing for CSO seismic station

Response spectra were computed using the records from the nearest seismic station installed on the rock site around the epicenter (MKL seismic station) and from a seismic station installed on the soil site (CSO seismic station) where site amplification occurred. As seismic stations, which are operated under the KMA (Korea Meteorological Administration), were installed without considering subsurface conditions, sub-surficial site conditions of the CSO seismic station (i.e., operated by KMA) was obtained by field seismic test such as the SASW (Spectral analysis of surface waves) (Stokoe *et al.* 1994) and the HWAW (Harmonic wavelet analysis of waves) (Park and Kim 2001) as shown in Fig. 7. On the other hand, all 43 KIGAM stations including the MKL seismic station are installed on rock outcrops. The site condition of the CSO seismic station is represented by the $V_S$- profile (see Fig. 8) and is classified into site class $S_C$ or $S_3$ according to the current and new seismic provisions, respectively. In the case of MKL

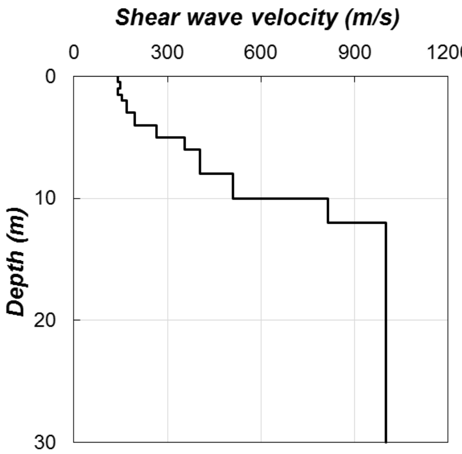
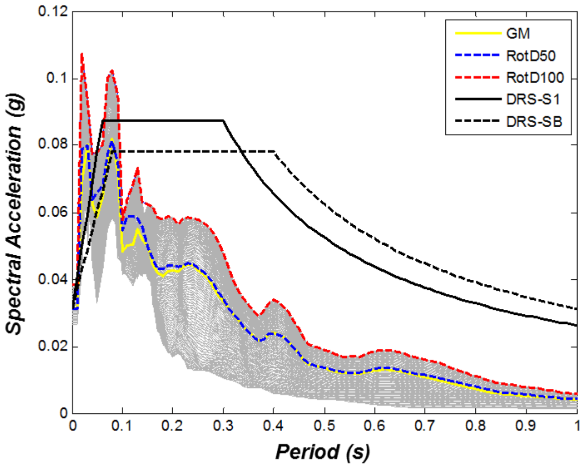
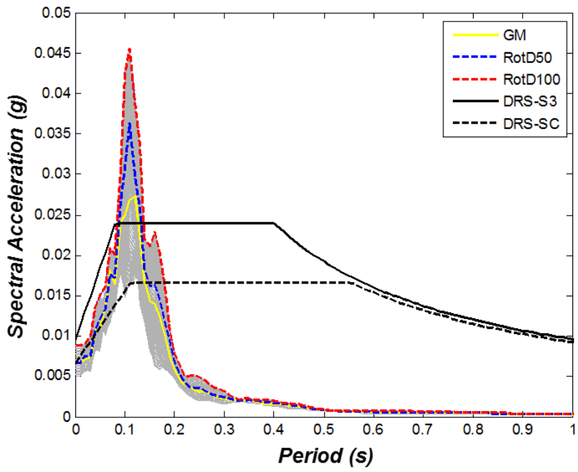



Fig. 8 $V_S$-profile of CSO seismic station




(a)




(b)

Fig. 9 Comparisons of DRS with 2016 Gyeongju earthquake records: (a) MKL seismic station; (b) CSO seismic station

seismic station, the site was categorized into class $S_B$ or $S_1$.

The acceleration time series obtained for both the EW and NS directions were firstly integrated to make RotDpp records (Boore 2010) to remove the effect of directionality, and the records were used to compute spectral accelerations corresponding to RotD100 and RotD50 at each period as presented in Fig. 9. Geometrical mean (GM) response spectra were also compared. Then, the response spectra were compared with the corresponding DRS curves considering the site condition of each seismic station. The response spectra from the MKL seismic station were compared with DRS curves of site class $S_B$ from the current seismic code (MOCT 1997) and the site class $S_1$ from the new site classification system. The response spectra from the CSO seismic station were also similarly compared. It can be seen that spectral accelerations of the MKL and CSO seismic stations were better covered by the new DRS curves as compared with the previous DRS curves. This can be considered as an evidence that the new site classification system and DRS curves reflect short-period amplification characteristics of shallow bedrock sites in Korea. Additional site investigations will be required for the correct identification of site condition of all the Korean seismic stations and then further verification of the new DRS curves can be performed. Nevertheless, it is possible to conclude that the new DRS curves adequately covers the entire seismic response, expect the amplification response at periods less than 0.1 s and 0.15 s for MKL and CSO seismic stations, respectively.

## 5. Conclusions

In this paper, new seismic code provisions, which was adopted on a preliminary basis as a part of ‘new minimum seismic design load requirements’ for general seismic design in Korea were described and assessed. The site classification system and site coefficients based on Manandhar *et al.* (2017) were discussed in a public hearing process for the new provisions and recommendations were made to modify the naming of site classes and adjust the site amplification factors to meet the ‘new minimum seismic design load requirements’ criteria for economical seismic design in Korea.

To assess the final version of the provisions after the public hearing process, dynamic centrifuge tests were carried out using soil models, which represented shallow-bedrock characteristics of Korean sites. Dynamic responses of simplified soil models were evaluated using the dynamic centrifuge tests for various simulated input earthquake motions. The seismic responses of the soil models were compared with the new DRS for the corresponding site classes. Even though there were higher average spectral accelerations from the centrifuge models than the new DRS at periods close to the site period of the soil model, the DRS curves showed better coverage of the average spectral acceleration than those defined in current seismic code.

In addition, earthquake records from the 2016 Gyeongju earthquake, which was the largest earthquake in the history of instrumental seismic observation in Korea, were used to assess the new provisions. The seismic responses from the 2016 Gyeongju earthquake records were compared with the new DRS constructed using the adjusted site coefficients. The comparison showed that the new DRS curves are more reliable and superior to those in the current seismic code.

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