

## Evaluation of the Seismic Load Level in Korea based on Global Earthquake Records

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**ABSTRACT:** This paper briefly introduces the design seismic loads in Korea (KBC 2009). Then, over 10,000 recorded earthquake ground accelerograms, with the moment magnitude ( $M_w$ ) ranging from 4.0 to 8.0 and the hypocentral distance ( $R$ ) ranging from 0 to 200km, were used to examine the level of seismic load defined in Korea known as a low-to-moderate seismicity region. The following conclusions are drawn based on the results: (1) The effective peak ground accelerations (EPA) of recorded earthquake accelerograms under  $M_w \leq 6.0$  and  $R \geq 15\text{km}$  appear to be less than that of MCE in Korea for all site conditions defined in KBC 2009. (2) The design spectrum (two-thirds of the intensity of MCE) in KBC 2009 is comparable to those of earthquake records in the magnitude 6 - 7 and the hypocentral distance less than 50km. Therefore, (3) the current design level of earthquake in Korea seems to be comparable to those of strong-seismicity regions, though the Korea peninsula is generally conceived to be a low seismicity region.

### 1 INTRODUCTION OF SEISMIC CODES AND DESIGN PRACTICE IN KOREA

Seismic design requirements in the building design code was introduced for the first time in 1988 by the Architectural Institute of Korea (AIK) since the damages and loss of lives by 1985 Mexico City earthquake exceeded the level tolerable to any government such as the Korean government that was then preparing for the 1988 Summer Olympic Game in Seoul. The change in the equations for the design base shear of building structures is shown in Table 1.

Design peak ground acceleration (PGA) defined as zone factor was 0.12g or 0.08g in 1988 version. In 1997 Earthquake Engineering Society of Korea (EESK) set forth the equation of design base shear for all type of facilities as shown in Equation (2) with the modification of zone factor to 0.11g or 0.07g. This formula is actually the same as the corresponding equation in UBC 97 (Uniform Building Code 1997). In the same report, EESK also defined seismic hazard factors representing the relative intensity of design earthquakes (DE). According to modification of zone factor by EESK 1997, AIK changed the corresponding factor, from 0.12g and 0.08g to 0.11g and 0.07g in the earthquake load equation in 2000 (AIK 2000). Architectural Institute of Korea substantially revised AIK 2000 to Korea Building Code (KBC) in 2005. KBC 2005 (AIK 2005) follows the framework of International Building Code (IBC) in 2000. The maximum considered earthquake (MCE) having the return period of 2500 year, was defined with effective  $\text{PGA} = 0.22\text{g}$  or  $0.14\text{g}$  (zone factor,  $S$ ). The design earthquake in KBC 2005 has been changed from the earthquake with the return period of 500 years to two third of the intensity of the MCE. With a calibration of the values of  $S_{DS}$  and  $S_{D1}$  for this level of PGA's for several soil conditions, the values are defined as the design values for the Equation (4) in Table 1. As shown in Figure 1, which compares the elastic design spectra of AIK 2000 and KBC 2005, the design base shear in KBC 2005 has increased remarkably due to the considerations of high amplification of soft soil and the change in the definition of design earthquake. KBC 2009 has maintained the frame work of KBC 2005, but expanded the classification of structures and modified some factors.

The case of soil condition  $S_B$  are compared between Seoul in Korea and Melbourne in Australia in Figure 2, where the design intensity in Seoul appears much higher than that in Melbourne. Also, design spectrum in KBC 2009 is compared with the response spectrum of El Centro (1949) and Taft (1952) earthquake recorded accelerograms, where soil condition of El Centro corresponds to  $S_D$  with that of Taft to  $S_C$  in Figure 3. It can be seen that the design spectrum in KBC 2009 is comparable those of magnitude 6.9 and 7.3 earthquake ground motions, which means that the intensity of Korean design earthquake may be **too high** since Korean peninsula is generally known to be a low-to-moderate seismicity zone.

Table 1. History of base shear in seismic building design codes in Korea

Design code	Base shear
AIK 1988 (allowable stress design: ASD)	$V = \frac{AIS}{1.2\sqrt{TR}}W \leq \frac{1.75AI}{R}W \text{ or } V = \frac{1.5AIS}{R}W \quad (1)$ <p><math>A</math> = zone factor (0.12, 0.08); <math>I</math> = importance factor; <math>S</math> = soil factor (3 groups); <math>R</math> = response modification factor; <math>T</math> = fundamental period; Design earthquake (EQ) = EQ with return period of 500 years.</p>
EESK 97* (strength design)	$V = \frac{C_v I}{RT}W \leq \frac{2.5C_a I}{R}W \quad (2)$ <p><math>C_a, C_v</math> = seismic coefficient (0.11, 0.07); <math>I</math> = importance factor; <math>R</math> = response modification factor; <math>T</math> = fundamental period; Soil factor = 6 groups (<math>S_A, S_B, S_C, S_D, S_E, S_F</math>); Design earthquake (EQ) = EQ with return period of 500 years.</p>
AIK 2000 (allowable stress design: ASD)	$V = \frac{AIS}{1.2\sqrt{TR}}W \leq \frac{1.75AI}{R}W \quad (3)$ <p><math>A</math> = zone factor (0.11, 0.07); <math>I</math> = importance factor; <math>S</math> = soil factor (4 groups); <math>R</math> = response modification factor; <math>T</math> = fundamental period; Design earthquake (EQ) = EQ with return period of 500 years.</p>
KBC 2005 (strength design)	$V = \frac{S_{D1}}{(R/I_E)T}W \leq \frac{S_{DS}}{R/I_E}W \quad (4)$ <p><math>S_{D1}, S_{DS}</math> = spectral accelerations at period 1sec and 0.2sec, respectively; <math>I</math> = importance factor; <math>R</math> = response modification factor; <math>T</math> = fundamental period; Soil factor = 5 groups (<math>S_A, S_B, S_C, S_D, S_E</math>); Design earthquake = (2/3)×MCE (return period of 2500 years)</p>

\* EESK 97 is a research report which was not implemented into the design code.

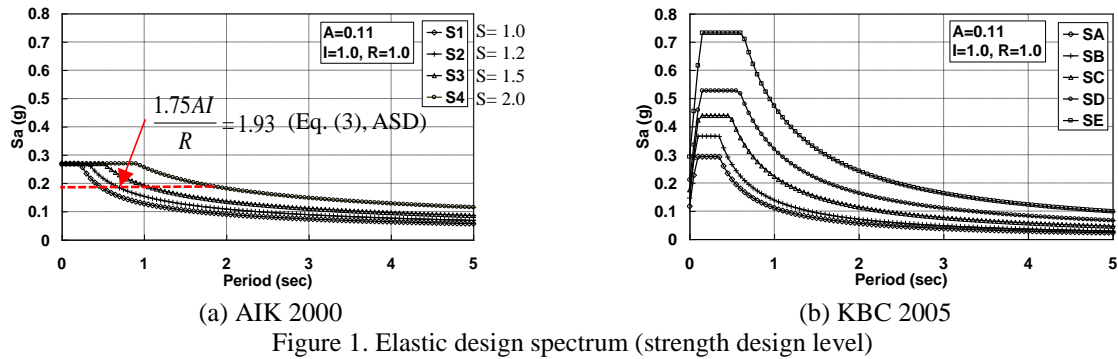


Figure 1. Elastic design spectrum (strength design level)

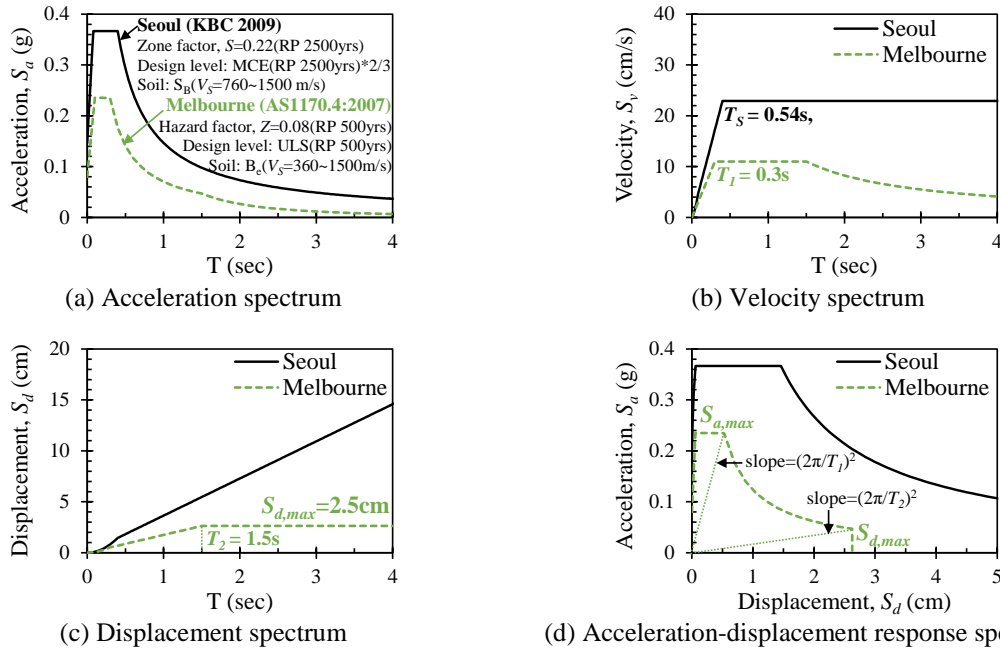


Figure 2. Design spectra for Seoul (KBC 2009) and Melbourne (AS 1170.4:2007): low-to-moderate seismicity regions (RP: Return Period, ULS: Ultimate Limit States,  $V_S$ : shear wave velocity)

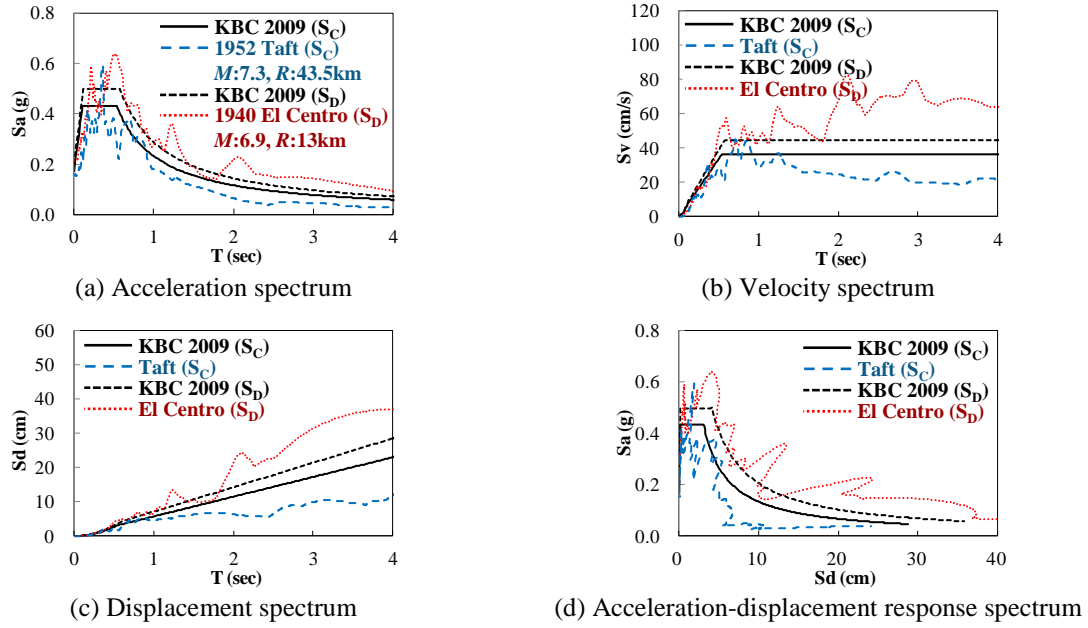


Figure 3. Comparison among KBC2009, 1940 El Centro, and 1952 Taft Spectra

The seismic design categories of KBC 2009 are classified by the level of effective peak ground acceleration (EPA) under the MCE and by the importance of facilities as given in Table 2 (Fardis 2014). The value of EPA for the seismic zone 1 in Korea on the rock ( $S_B$ ) is 0.22g, and the corresponding seismic design category is determined as “D” regardless of the importance of facilities. In spite of a low-to-moderate seismicity zone, special detailing is required as shown in Figure 4, where the congestion of reinforcement due to this requirement cause difficulty in construction.

In this study, over 10,000 recorded earthquake ground accelerograms provided in PEER ground motion database (2013), with the magnitude ranging from 4.0 to 8.0 and the hypocentral (site-source) distance ranging from 0 to 200km, were used to examine the level of seismic load defined in Korea known as a low-to-moderate seismicity region.

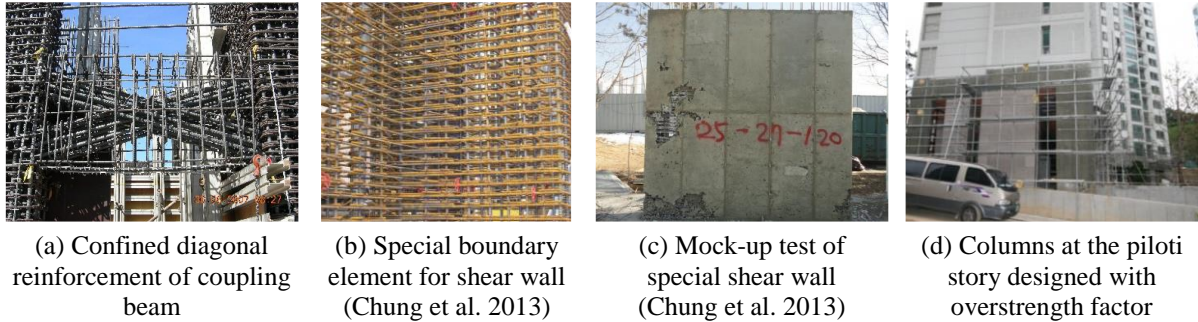


Figure 4. Problems of current seismic design in KBC 2009

Table 2. Classification of facilities to “seismic design categories” in KBC2009 (Fardis 2014)

EPA on rock under MCE	Special facilities*	High consequences**	Ordinary facilities	Temporary, not for people
$0.045g < EPA < 0.05g$	B	A	A	A
$0.05g < EPA < 0.06g$	B	B	A	A
$0.06g < EPA < 0.075g$	B	B	B	A
$0.075g < EPA < 0.085g$	B	B	B	B
$0.085g < EPA < 0.1g$	D	B	B	B
$0.1g < EPA < 0.12g$	D	D	B	B
$0.12g < EPA < 0.15g$	D	D	D	B
$0.15g < EPA$	D	D	D	D

\* Special facilities: essential in post-disaster emergency, or with hazardous contents.

\*\* High consequences: large occupancy, congregation areas, etc.

## 2 SEISMIC LOAD LEVEL IN KOREA BASED ON GLOBAL EARTHQUAKE RECORDS

### 2.1 Comparison of effective peak ground acceleration (PGA) of global earthquake records

Earthquake ground records in Korea are very limited. To overcome the shortage of recorded accelerograms in Korea, 10,642 recorded earthquake ground accelerograms in PEER ground motion database (2013) with the moment magnitude ( $M_w$ ) ranging from 4.0 to 8.0 and the hypocentral (site-source) distance ( $R$ ) ranging from 0 to 200km were used, and their EPA's are compared in Figure 5. The EPA is calculated from the spectral acceleration value (5% damping) in the region 0.1 to 0.5 s, by dividing the average ordinate by amplification factor, 2.5.

Figure 5 shows that the EPA's of some earthquake accelerograms on the rock ( $S_B$ ) for  $M_w \geq 6.5$  and  $R \leq 50$ km exceed  $S = 0.22g$ , which is the zone factor (EPA) for the rock representing the MCE in Korea in KBC 2009. Almost all of the EPA's on the very dense soil and soft rock ( $S_C$ ) and the stiff soil ( $S_D$ ) for  $5.0 \leq M_w \leq 6.5$  and  $R \leq 15$  km are larger than  $F_a S = 0.26g$  ( $S_C$ ) and  $0.30g$  ( $S_D$ ), respectively, corresponding to MCE in Korea, whereas most of the EPA's for  $R \geq 50$ km are within the limit value,  $F_a S$  ( $F_a$ : short-period site coefficient at 0.2s-period). The nearer the fault, the larger EPA's for  $M_w \geq 5.0$  regardless of the magnitude. Generally, the magnitude of MCE ground motion for the moderate seismicity region is considered within 6.0 to 6.5, but it can be seen in Figure 5 that it is inappropriate to determine the intensity of the earthquake by the parameter of magnitude only.

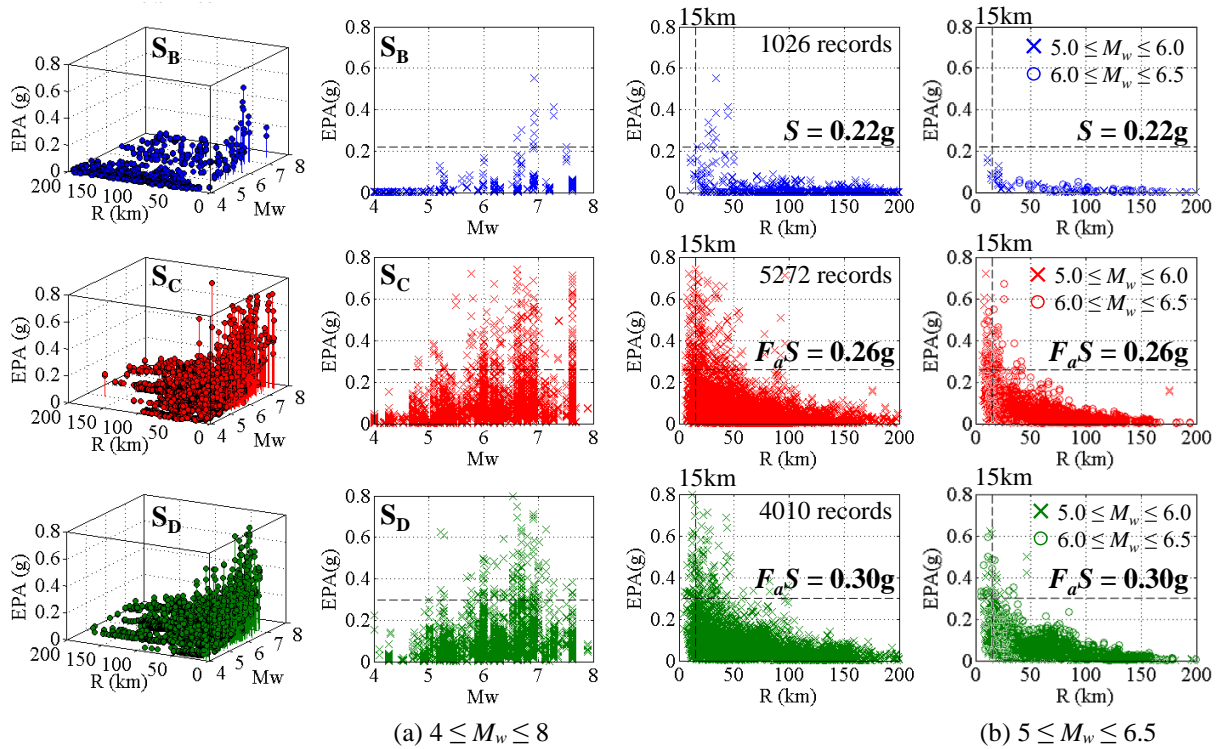


Figure 5. Effective PGA

To estimate the combination of  $M$ - $R$  considering the intensity of EPA, the earthquake scenarios (Table 3) for a low seismicity region for the return period of 2500 years based on the response spectral relationships derived from the component attenuation model (Lam et al. (2000) and Looi et al. (2013)) are used. The EPA for the rock under the MCE in Korea defined in KBC 2009 is 0.22g, so, in this study, the MCE scenario for Korea is assumed as  $M = 6$  and  $R = 15$ km.

Table 3. Earthquake scenario on rock for low seismicity region (Lam et al. (2000) and Looi et al. (2013))

Bound	Scenario		Peak Displacement Demand (PDD)	Effective Peak Ground Acceleration (EPA)
	Magnitude ( $M$ )	Rupture Distance ( $R$ )		
Lower	6	30 km	20 mm	0.09 g
Mid	6	20 km	35 mm	0.16 g
Upper	6	15 km	50 mm	0.22 g

## 2.2 Comparison of design spectra in KBC 2009 with spectra from recorded EQ accelerograms

In Figures 6(a) to (f), the response spectra obtained from recorded ground accelerograms are classified with respect to the soil condition ( $S_B$ ,  $S_C$ , and  $S_D$ ), the magnitude ( $M_w \leq 6$  and  $6 \leq M_w \leq 6.5$ ), and the rupture distance ( $R \leq 15\text{km}$  and  $R \geq 15\text{km}$ ). Generally, the near-fault ground motions are defined to the ground motions of site within a distance of about 20km from the rupture fault (Yang and Wang 2012). In this paper, however, the recorded ground motions in Figure 6 are classified as near-fault (red dotted line) and far-fault (blue solid line) ground motions within and beyond a distance of 15km from the rupture fault, respectively, to compare the assumed MCE scenario for Korea,  $M = 6$  and  $R = 15\text{km}$  in the former section.

For the soil condition  $S_B$  (Figs. 6(a) and (b)), most of the spectra obtained from recorded ground accelerograms are well within the MCE spectra, and the spectral velocity and displacement in the velocity- and displacement-sensitive regions are significantly smaller than the DE spectral values in KBC 2009. In particular, the spectral displacement from the recorded accelerograms remains nearly constant beyond the period,  $T = 1.0$  s, while that of the DE spectrum in KBC 2009 is linearly increasing.

Figure 6(c) shows the response spectra from recorded accelerograms under  $M_w \leq 6$  on the soil condition  $S_C$ . The recorded spectral accelerations exceed the design values in KBC 2009 in the acceleration-sensitive region regardless of the fault distance. In Figure 5(b), however, the value of their EPA's under  $5 \leq M_w \leq 6.5$  and  $R \geq 15\text{km}$  is less than that of the MCE in Korea for corresponding site conditions, 0.26g. The spectral velocities and displacements of the far-fault ground motions have nearly constant values in the velocity- and displacement-sensitive regions remaining within the MCE spectra in KBC 2009 except for a few cases. In Figure 6(d), the response spectra from the recorded accelerograms under  $6 \leq M_w \leq 6.5$  are comparable to the MCE spectra, but the spectral displacement obtained from some far-fault motions increases as the  $T$  increases above  $T = 1.0$  s.

In Figures 6(e) and (f), the response spectra obtained from the recorded ground accelerograms on the soil condition  $S_D$  are similar to those on the soil condition  $S_C$ . Comparing the spectra obtained from the far-fault ground motions under  $M_w \leq 6$  in Figures. 6(a), (c), and (e), most spectral displacements remain nearly constant value at periods above  $T = 1.0$  s regardless of the soil condition, which indicates that the maximum spectral displacement of the low and moderate ground motions can be represented with a constant displacement value.

Figures 6(g), (h), and (i) compares the response spectra and EPA's of accelerograms recorded from the 1994 Northridge ( $M_w = 6.7$ ), the 2009 L'Aquila ( $M_w = 6.3$ ), and the 2011 Christchurch ( $M_w = 6.2$ ) earthquakes with the DE and MCE spectra in KBC 2009. While the three earthquakes occurred at the high-seismicity regions which have caused significant damage, the magnitudes are within the range of 6 to 7.

The recorded ground motions on the  $S_D$  in the 1994 Northridge earthquake including the aftershocks are shown in Figure 6(g). As the moment magnitude of the main earthquake,  $M_w = 6.7$ , is larger than 6.5, the EPA's of the far-fault ground motions exceed that the corresponding soil condition,  $F_a S = 0.3g$ . However, most of the spectral velocity and displacement of the far-fault ground motions in the velocity- and displacement-sensitive regions are within those of the MCE spectra in KBC 2009.

In case of the 2009 L'Aquila earthquake including aftershocks, the ground accelerograms recorded on the  $S_C$  are used in Figure 6(h). The ground motions recorded from the 2011 Christchurch earthquake in Figure 6(i) are obtained on the  $S_D$ . The value of EPA's from the recorded accelerograms from these two earthquakes, except for a few near-fault ground motions within a distance of 15km from the fault, is smaller than that of the MCE in Korea,  $F_a S$ . The acceleration, velocity, and displacement spectra obtained from the far-fault ground motions are within those of the DE in Korea. The spectral velocities and displacements obtained from the 2009 L'Aquila and 2011 Christchurch earthquakes appear to be generally very small compared with the design spectra particularly for the far-fault ground motions, but comparable to those of MCE for the near-fault ground motions.

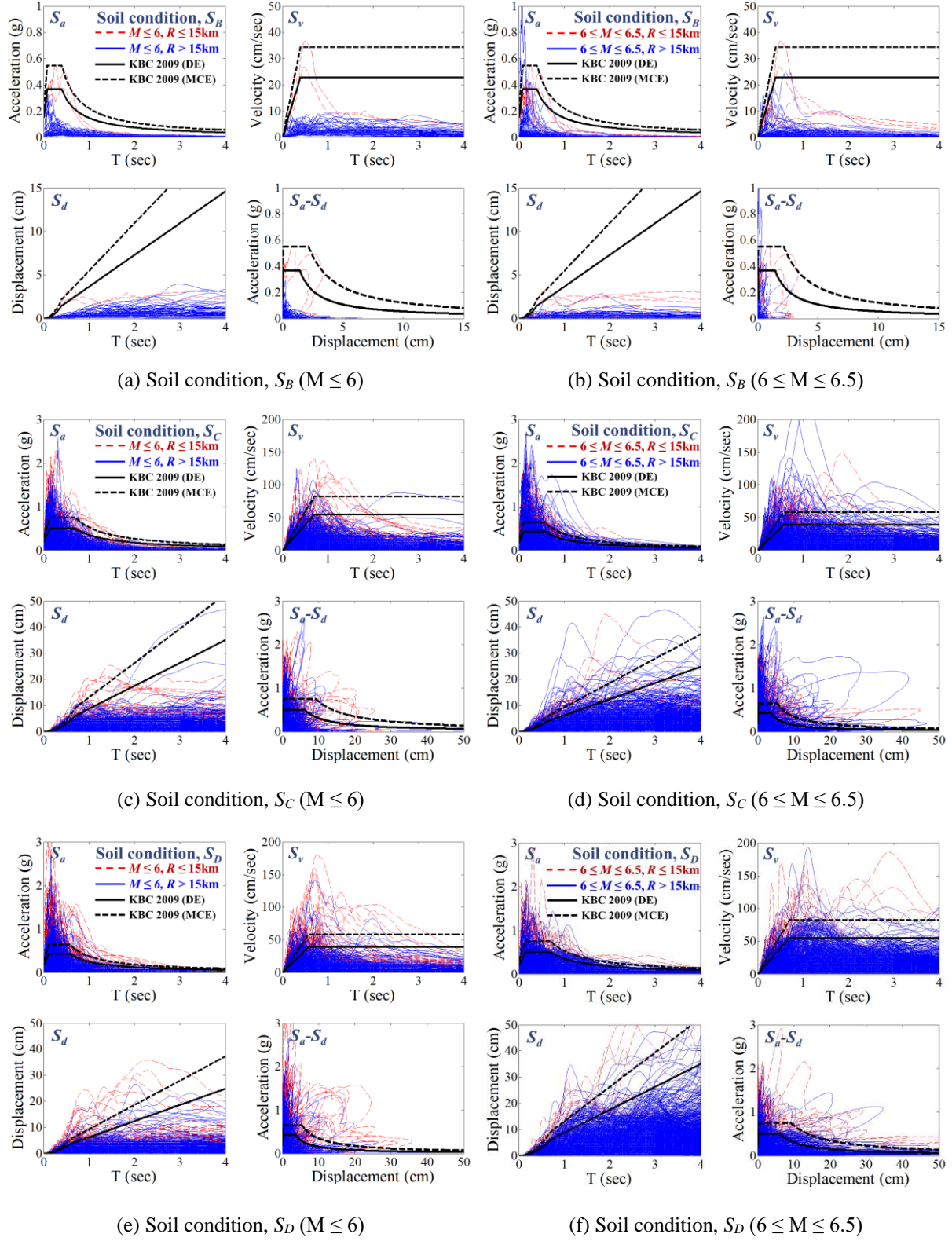
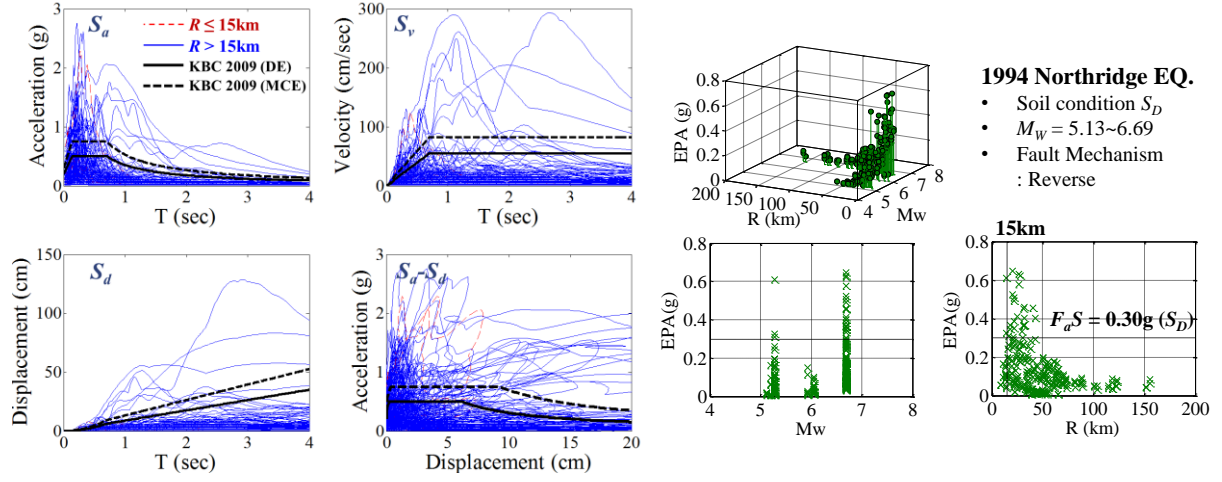
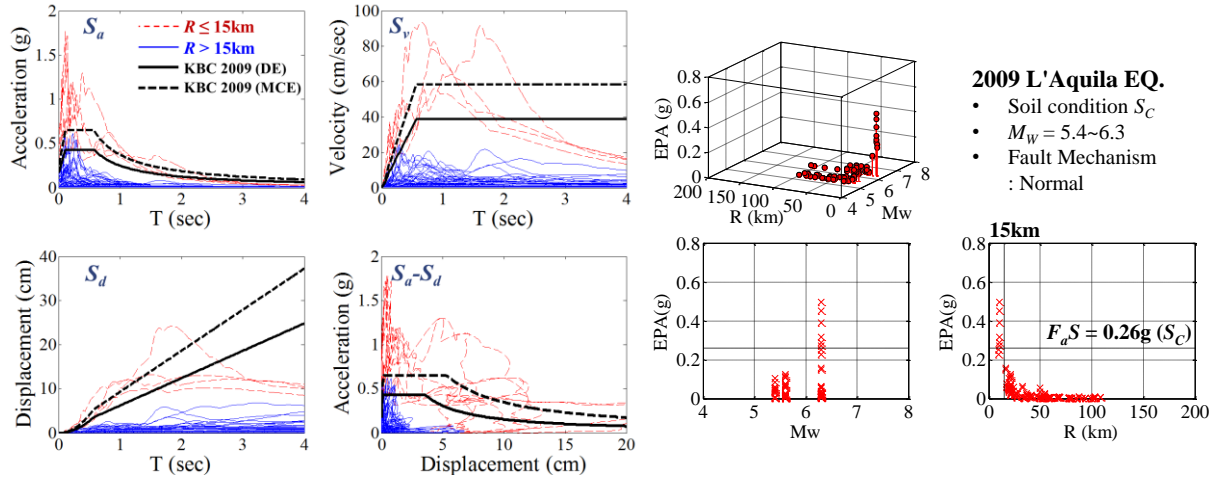


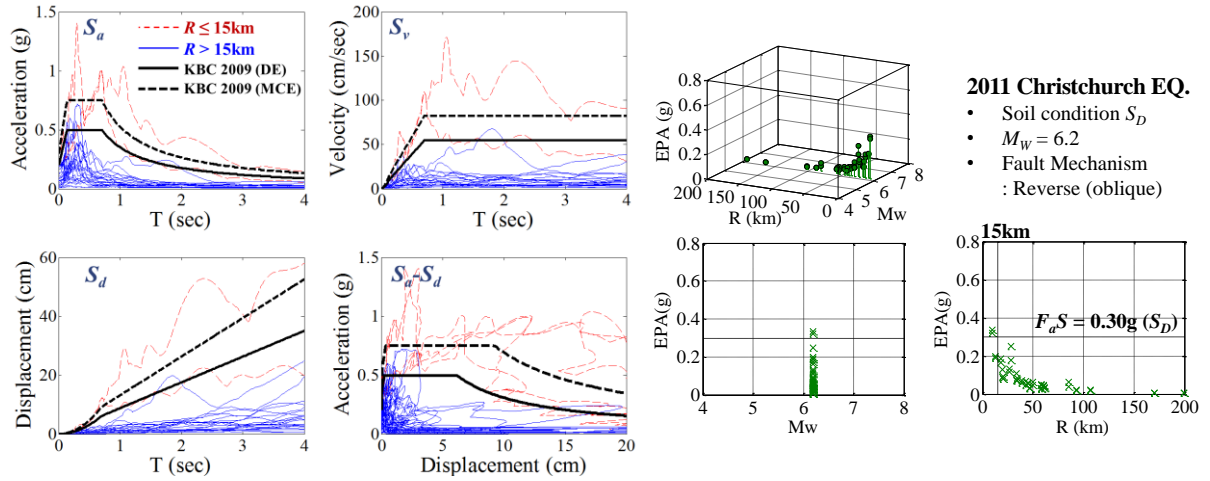
Figure 6. Comparison of design spectra with those obtained from earthquake records



(g) 1994 Northridge EQ. ( $S_D$ ),  $M_w = 5.13 \sim 6.7$



(h) 2009 L'Aquila EQ. ( $S_C$ ),  $M_w = 5.4 \sim 6.3$



(i) 2011 Christchurch EQ. ( $S_D$ ),  $M_w = 6.2$

Figure 6. Comparison of design spectra with those obtained from earthquake records (continued)

### 3 CONCLUSIONS

To evaluate the level of seismic load defined in Korea known as a low-to-moderate seismicity region, 10,642 recorded earthquake ground accelerograms provided in PEER ground motion database (2013), with the moment magnitude ( $M_w$ ) ranging from 4.0 to 8.0 and the hypocentral (site-source) distance ( $R$ ) ranging from 0 to 200km, were used to compare the intensity of the maximum considered earthquake (MCE) in Korea defined in KBC 2009. The conclusions of this study are as follows:

- (1) The comparison of the effective peak ground acceleration (EPA) obtained from global earthquake records with that of MCE in Korea shows that the nearer the fault, the higher intensity of EPA's under  $M_w \geq 5.0$  regardless of the magnitude. Although the magnitude of MCE ground motion for a moderate seismicity region is generally considered within 6.0 to 6.5, it can be seen that it is inappropriate to determine the intensity of the earthquake by the parameter of magnitude only. The EPA's of recorded earthquake accelerograms under  $M_w \leq 6.0$  and  $R \geq 15\text{km}$  appear to be less than that of MCE in Korea for all site conditions defined in KBC 2009.
- (2) The design spectrum (two-thirds of the intensity of MCE) in KBC 2009 is comparable to those of earthquake records in the magnitude from 6.0 to 6.5 and the hypocentral (site-source) distance from 15km to 50km. the current design level of earthquake in Korea seems to be comparable to those of strong-seismicity regions, though the Korea peninsula is generally conceived to be a low seismicity region.
- (3) Most of the spectral velocities and displacements obtained from global earthquake records under  $M_w \leq 6.0$  and  $R \geq 15\text{km}$  remain constant when periods become larger than 1.0s. Since the displacement response spectrum defined in KBC 2009 has a linear relationship with increasing natural period, the spectral displacement in the high period range are significantly overestimated. The bi-linear displacement response spectrum is more appropriate for a low-to-moderate seismicity region.

### ACKNOWLEDGMENTS:

The research presented herein was supported by Architecture & Urban Development Research Program funded by Ministry of Land, Infrastructure and Transport of Korean government (13AUDP-B066083-01). The writers are grateful for this support.

### REFERENCES:

- AIK. 2001. *AIK 2000*, Architectural Institute of Korea, Seoul, Korea. (Korean)
- AIK. 2005. *Korean Building Code, KBC 2005*, Architectural Institute of Korea, Seoul, Korea. (Korean)
- AIK. 2009. *Korean Building Code, KBC 2009*, Architectural Institute of Korea, Seoul, Korea. (Korean)
- AS 1170.4. 2007. *Structural Design Actions Part 4: Earthquake Actions in Australia*, Standards Australia, Australia.
- Chung, K.R., Chung, H.J., Kang, M.S., Kim, S.H., & Park, K.M. 2013 Eliminating special seismic boundary of special shear wall system using NLTHA, *Korea Concrete Institute Conference 2013 Fall*: 1-2. (Korean)
- Fardis, M.N. 2014. Comments on the seismic design provisions of the Korean Building Code 2009, *Opinion paper*.
- ICC. 2000. *International Building Code, IBC 2000*, International Code Council, Country Club Hills, IL.
- International Conference of Building Officials. 1997. *Uniform Building Code, UBC 97*, Whittier, CA.
- Lam, N., Wilson, J., Chandler, A., & Hutchinson, G. 2000. Response spectral relationships for rock sites derived from the component attenuation model, *Earthquake engineering & structural dynamics*, 29(10): 1457-1489.
- Looi, D.T.W., Hee, M.C., Tsang, H.H., & Lam, N.T.K. 2013. Earthquake loading model in the proposed National Annex to Eurocode 8 for peninsular Malaysia, *IStructE Conference 2013*, Beijing and Shanghai.
- PEER Ground Motion Database. Available from <http://ngawest2.berkeley.edu/site> (last accessed 28 February 2015), 2013.
- Yang, D. & Wang, W. 2012. Nonlocal period parameters of frequency content characterization for near-fault ground motions, *Earthquake Engineering & Structural Dynamics*, 41(13), 1793-1811.