

# Evaluation of Current Code Criteria Selecting Ground Motions for Dynamic Analysis

## Assessment of structural responses

Seongjin HA

Architectural Engineering  
Hanyang University  
Seoul, Republic of Korea  
e-mail: hasz2233@gmail.com

Taeo KIM

Architectural Engineering  
Hanyang University  
Seoul, Republic of Korea  
e-mail: tokim27@gmail.com

Sangwhan HAN

Architectural Engineering  
Hanyang University  
Seoul, Republic of Korea  
e-mail: swan@hanyang.ac.kr

**Abstract**—Current seismic design provisions such as ASCE 7-10 provide criteria for selecting ground motions for conducting response history analysis. This study is the sequel of a companion paper (I – An accurate algorithm for selecting ground motions) for assessment of the ASCE 7-10 criteria. The results show that the target seismic demands for SDF can be predicted using the mean seismic demands over seven and ten ground motions selected according to the proposed method within an error of 30% and 20%, respectively.

**Keywords**—seismic design provision; criteria; seismic demand; ground motion; selection

### I. INTRODUCTION

For evaluating seismic demand of the building, linear or nonlinear response history analysis (RHA) are often conducted to calculating accurate estimations of seismic response under earthquakes. Particularly, for the structures with structural irregularity, high SDC and height, RHA should be used rather than equivalent lateral force analysis.

According to the ASCE 7-10 [1], minimum three of ground motions which have magnitudes, fault distance, and source mechanisms that are consistent with those that control the maximum considered earthquake at a site should be used as the earthquake loads of a structure for RHA. If fewer than seven ground motions are used in the analyses, design response demands shall be taken as the maximum values of response demands over all ground motions. If at least seven ground motions are used, the design response demands are permitted to be taken as the average value of response demands over all ground motions.

There are several researches to assess the seismic design provision criteria for selecting input ground motions. Kalkan and Çelebi [2] evaluated the accuracy of the ASCE 7-10 [1] ground motion selection procedure and criteria with a fifty-two story building located in Los Angeles. They reported

that the ASCE 7-10 [1] criteria and procedure does not insure a unique scaling factor for each ground motion.

Reyes and Kalkan [3] conducted nonlinear RHA for various single degree of freedom (SDF) systems with ground motions selected and scaled according to the ASCE 7-10 [1] procedure and criteria. It was shown that significant overestimation arose in the analysis results of the structures when using ground motions that were selected and scaled according to the ASCE 7-10 [1] criteria.

Araújo et al. [4] assessed the ground motion selection procedures and criteria provided in various seismic provisions such as Eurocode 8, NZS1170.5 and ASCE 41-13. They reported that the use of seven recorded ground motions in RHA, as proposed by codes for determining mean seismic demands, was adequate if additional control of the spectrum mismatch was adopted.

In the companion paper (I – An accurate algorithm for selecting ground motions), the accurate and computationally efficient algorithm for selecting ground motion is developed. With this algorithm, the purpose of this study is to assess the ASCE 7-10 [1] ground motions selection criteria. For verification of the accuracy of the criteria, nonlinear response history analyses conducted with various SDF systems.

### II. TARGET RESPONSE SPECTRUM AND LIBRARY

In order to construct a target response spectrum and displacements of the structure, 184 ground motions are collected from the PEER NGA database using the following criteria.

- Magnitude:  $M = 6.5 - 6.9$
- Joyner-Boore distance:  $R_{JB} = 20 - 30$  km
- Source mechanism: Reverse fault
- NEHRP soil type: C or D ( $V_{S30} = 180 - 360$  m/s)

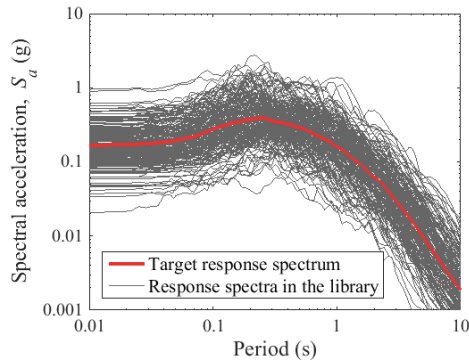


Figure 1. Target response spectrum

In this study, ground motions library is constructed with 184 ground motions and the median response spectrum of these is defined as a target response spectrum. Fig. 1 shows the response spectra in the library and target response spectrum.

According to section 16.1.4 of ASCE 7-10 [1], if fewer than seven ground motions are used in analyses, seismic design responses shall be taken as the maximum values of response demands over all ground motions. This study considers various numbers ( $n_g < 7$ ) of ground motions selected by the ASCE 7-10 [1] criteria with the proposed selection algorithm.

### III. MODEL STRUCTURE AND TARGET DISPLACEMENT

In this study, various SDF systems are considered as model structures, which have four different fundamental periods ( $= 0.5s, 1.0s, 2.5s, 4.0s$ ) of the SDF systems and different yield strengths ( $f_y$ ). The level of yield strength is defined using the normalized yield strength ( $\bar{f}_y$ ), which is defined as the ratio of the yield strength ( $f_y$ ) of a system to its elastic strength demand ( $f_o$ ). The reciprocal of  $\bar{f}_y$  is the yield strength ratio ( $R_y$ ).

In this study, three different normalized yield strength ratios ( $= 0.25, 0.125$ ) are considered. Thus, a total of eight SDF systems ( $= 4 \times 2$ ) are considered in this study for conducting RHA. The elastic strength demand ( $f_o$ ) of a system is determined by multiplying its mass by a 5% damped target spectral acceleration at  $T_n$ , and its yield strength ( $f_y$ ) is a product of  $f_o$  and  $\bar{f}_y$ . The elastic-perfectly plastic force-deformation relation is used for representing the inelastic behavior of the systems.

In order to estimate target displacements ( $u_{target}$ ) of SDF systems, nonlinear RHA are conducted with the 184 unscaled ground motions, collected in the previous section. For each of 184 ground motions, the peak inelastic displacement of a system is estimated. The median value of peak displacements over 184 ground motions is considered as the target displacement of a system.

Since ground motion and response spectrum models are constructed using a lognormal distribution, the use of median

structural responses is more appropriate for target responses than the use of mean structural response [3]. The target displacements of model eight SDF systems according to the fundamental periods and yield strengths are summarized in Table I.

TABLE I. TARGET DISPLACEMENTS OF SDFs

$T_n$ (s)	$u_{target}$ (mm)	
	$\bar{f}_y (R_y)$	
	0.25 (4)	0.125 (8)
0.5	25	31
1.0	43	49
2.5	61	59
4.0	57	54

### IV. ASSESMENT OF ASCE 7-10 CRITERIA

#### A. Ground Motions

For conducting RHA of the SDFs, input ground motions are selected from form the library using proposed algorithm.

According to the number of ground motions, there are two different procedures for selecting ground motions in the companion paper. For fewer than 7 ground motions, a desired number of ground motions are sequentially selected from scaled ground motions in a library that best match a target spectrum. If at least seven ground motions are used in analyses, ground motions are sequentially selected from scaled ground motions which make the mean response spectrum of selected ground motions that best match for the target response spectrum. Fig. 2 and 3 show the results of selected ground motions for SDFs with  $T_n=1s$  for  $n_g=3$  and 7, respectively. Similarly, this study selected several ground motions sets according to the different structural period (0.5s – 4.0s) of the SDFs and  $n_g$  (3 – 10).

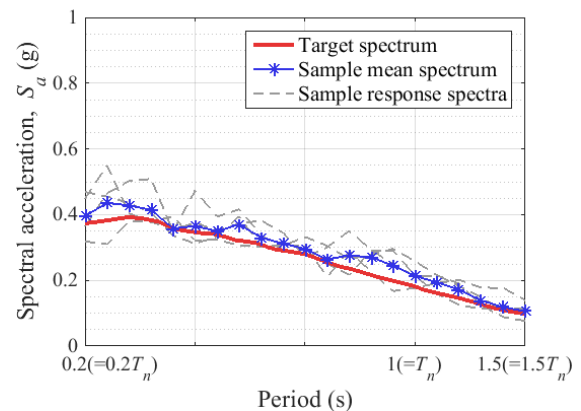


Figure 2. Target response spectrum and selected ground motions for  $n_g=3$

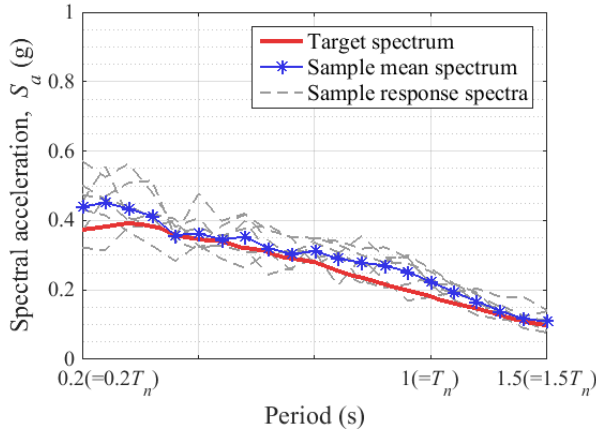


Figure 3. Target response spectrum and selected ground motions for  $n_g=7$

### B. Responses for Fewer than Seven Ground Motions

According to section 16.1.4 of ASCE 7-10 [1], if fewer than seven ground motions are used in analyses, seismic design responses shall be taken as the maximum values of response demands over all ground motions. This study considers various numbers ( $n_g < 7$ ) of ground motions selected by the ASCE 7-10 [1] criteria with the proposed selection algorithm. Nonlinear RHA are conducted for eight SDF systems with four different periods ( $T_n = 0.5s, 1.0s, 2.5s$ , and  $4.0s$ ) and three different levels of normalized yield strengths ( $\bar{f}_y = 0.25, 0.125$ ). Peak displacements of a system are computed for each of the selected ground motions. Then, the maximum value ( $u_{max}$ ) of peak displacements over all ground motions is determined. The errors of  $u_{max}$  in predicting  $u_{target}$  is calculated with (1).

$$\text{Error} = \left| \frac{u_{max} - u_{target}}{u_{target}} \right| \times 100 [\%] \quad (1)$$

Fig. 4 shows  $u_{target}$  and  $u_{max}$  of 8 SDF systems obtained for fewer than 7 selected ground motions ( $n_g < 7$ ). Errors calculated using (1) are also plotted in this figure. It is observed that  $u_{max}$  for  $n_g < 7$  is always larger than  $u_{target}$ . In other words, the ASCE 7-10 [1] criteria with the proposed selection procedure for  $n_g < 7$  always overestimate target drifts.

This figure also shows that the error of  $u_{max}$  is always larger than 20% except for systems with  $T_n=4s$  and  $R_y=8$  [Fig. 4(l)]. When increasing the degree of yielding (larger  $R_y$ ), the error of  $u_{max}$  generally increases. For example, the errors of  $u_{max}$  for a system ( $T_n=0.5s$ ) with  $R_y=4$ , and 8 are 89% and 120%, respectively [Fig. 4(a) and (b)].

It is also observed that the error of  $u_{max}$  does not decrease with an increase in the number ( $n_g$ ) of selected ground motions used in analyses. For example, the error of  $u_{max}$  for  $n_g=6$  is often larger than that for  $n_g=3$ . Particularly, for systems ( $T_n=4s$ ) with  $R_y=4$  and 8 [Fig. 4(g) and (h)] under three ground motions ( $n_g=3$ ), the errors of  $u_{max}$  are 26% and

3%, respectively, but the errors of the same systems for  $n_g=6$  are 79% and 83%, respectively.

Intuitively, this trend is expected because  $u_{max}$  deviates more from  $u_{target}$  with an increase in the number of ground motions. This expectation is confirmed by  $u_{max}$  for  $n_g=1$ . Errors for a single ground motion are generally smaller than that for multiple number ( $n_g=3-6$ ) of ground motions. In particular, for a system ( $T_n=4s, R_y=4$ ), the error of  $u_{max}$  for a single ground motion is only 2%, whereas the error for  $n_g>1$  ranges from 26% to 80%. It is, however, noted that for systems with  $T_n=2.5s$  and  $R_y=8$ , and  $T_n=4.0s$  and  $R_y=8$ ,  $u_{max}$  for  $n_g=1$  is 22% and 15% less than  $u_{target}$ , respectively.

### C. Responses for at Least Seven Ground Motions

As specified in section 16.1.4 of ASCE 7-10 [1], if RHA are conducted using at least seven ground motions, seismic design responses are taken as the mean of response demands over all ground motions. For evaluating the accuracy of ASCE 7-10 [1] selection criteria, different numbers ( $n_g=7, 8, 9, 10$ ) of ground motions are selected from a library with 184 ground motions using the proposed algorithm.

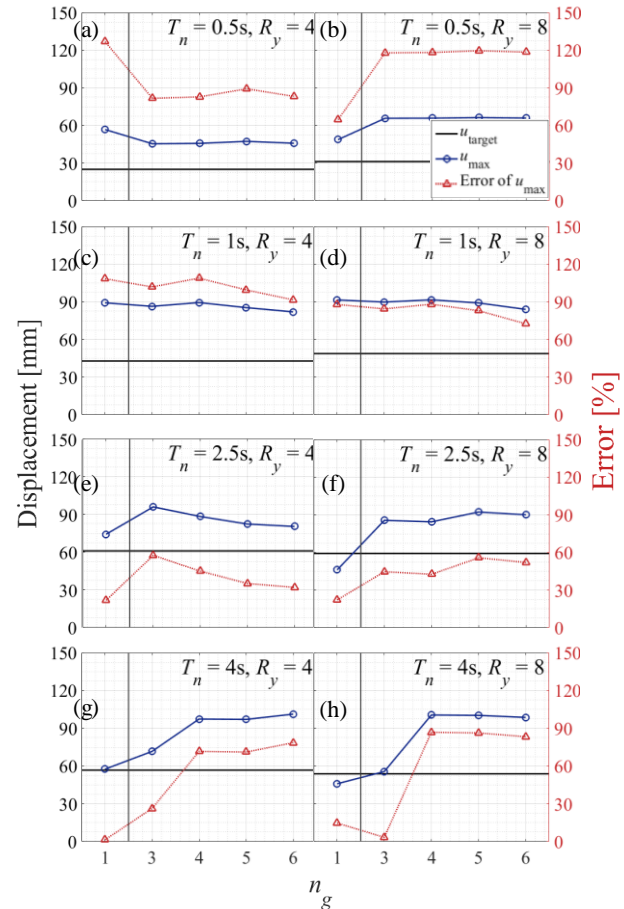


Figure 4. Target and maximum displacements of SDFs and corresponding errors according to different ground motions

Eight SDF systems with four different periods and three different levels of normalized yield strengths are considered, which were used in the previous section.

For each of the selected ground motions, the peak displacement of a system is determined from the results of the RHA. Then, the mean of peak displacements over all ground motions is calculated, which is termed the mean displacement ( $\bar{u}$ ). The errors of  $\bar{u}$  in predicting  $u_{\text{target}}$  are calculated using (1) after replacing  $u_{\text{max}}$  by  $\bar{u}$  in (1).

Fig. 5 shows  $\bar{u}$  of eight SDF systems and corresponding errors of  $\bar{u}$  according to  $n_g$  ( $\geq 7$ ). The errors of  $\bar{u}$  for all systems for  $n_g = 7, 8, 9$ , and  $10$  are within 25%, 25%, 23%, and 16%, respectively. Therefore, the errors of  $\bar{u}$  for  $n_g \geq 7$  (Fig. 5) are much smaller than those of  $u_{\text{max}}$  for  $n_g < 7$  (Fig. 4). This indicates that the use of  $\bar{u}$  for  $n_g \geq 7$  predicts a target displacement more accurately than the use of  $n_g < 7$ . The largest error of  $\bar{u}$  is 25%, which occurs for a system with  $T_n = 0.5\text{s}$  and  $R_y = 8$  under seven ground motions [Fig.5(b)]. For this system, the errors of  $\bar{u}$  for  $n_g = 9$  and  $10$  are 23% and 16%, respectively.

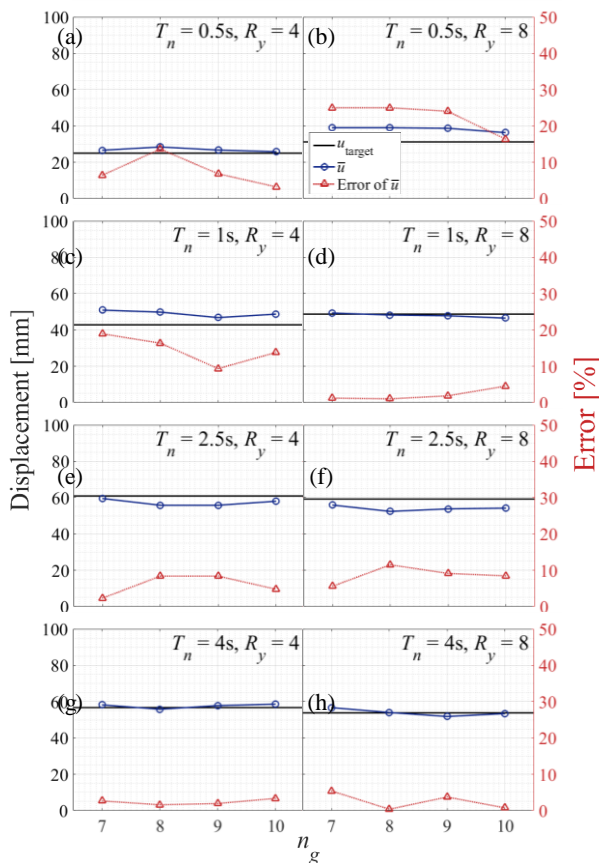


Figure 5. Target and mean displacements of SDFs and corresponding errors according to different ground motions

Except for this system ( $T_n = 0.5\text{s}$ ,  $R_y = 8$ ), the errors of  $\bar{u}$  are within 20% irrespective of  $n_g$ . It is, however, noted that the use of  $\bar{u}$  for  $n_g \geq 7$  does not always overestimate  $u_{\text{target}}$ . For a system with  $T_n = 2.5\text{s}$ ,  $\bar{u}$  is smaller than  $u_{\text{target}}$ , but the errors of  $\bar{u}$  s for this system are within 10% [Fig. 5(e) and (f)]. It is also observed that with increasing  $R_y$ , the error generally increases. The errors for a system ( $T_n = 0.5\text{s}$ ) with  $R_y = 4$  and  $8$  are 14%, and 25%, respectively [Fig.5(g) and (h)].

## V. CONCLUSION

In this study, the accuracy of the ASCE 7-10 [1] ground motion selection criteria was evaluated with the proposed selection algorithm and nonlinear RHA for 8 SDFs. The conclusions are as follows:

(1) For  $3 \leq n_g < 7$ , the use of  $u_{\text{max}}$  for eight SDF systems overestimates  $u_{\text{target}}$ . For  $n_g = 3$ , the error of  $u_{\text{max}}$  in predicting  $u_{\text{target}}$  ranged from 3% to 120%. The error of  $u_{\text{max}}$  tended to increase with increasing  $n_g$ .

(2) For  $n_g = 7, 8, 9$ , and  $10$ , the errors of  $\bar{u}$  for SDF systems were within 25%, 25%, 23%, and 16%, respectively. Therefore, seismic demands were more accurately predicted using mean structural responses with 7 or more ground motions than using maximum responses with fewer than 7 ground motions.

## ACKNOWLEDGMENT

Authors would like to acknowledge the financial supports provided by the National Research Foundation of Korea (No. 2014R1A2A1A11049488).

## REFERENCES

- [1] ASCE, "Minimum design loads for buildings and other structures," American Society of Civil Engineers, Reston, VA, 2010.
- [2] E. Kalkan and M. Çelebi, "Assessment of ASCE-7 ground motion scaling method using computer model of instrumented high-rise building," Improving the Seismic Performance of Existing Buildings and Other Structures. San Francisco, CA, USA.
- [3] J. J. Reyes and E. Kalkan, "How many records should be used in an ASCE/SEI-7 ground motion scaling procedure?," Earthq Spectra, vol 28, no. 3, pp. 1223–1242, August 2012.
- [4] M. Araújo, L. Macedo, M. Marques and J. M. Castro, "Code-based record selection methods for seismic performance assessment of buildings," Earthq. Eng.Struct. D, vol. 45, no. 1, pp.129–148. January 2016