ESTIMATION OF SEISMIC CAPACITY OF KOREAN TYPICAL SCHOOL BUINDINGS UNDER DESIGN RESPONSE SPECTRUM

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ABSTRACT

In the current seismic design provisions of Korea, school buildings are specified as evacuation shelter after an earthquake and are constantly requested the seismic design. However, there are no investigations on whether existing school buildings can play a role as evacuation shelter against future earthquakes.

In this study, the seismic capacity and the damage class of existing typical school buildings in Korea are therefore analytically estimated. For this purpose, a 4-story frame including unreinforced concrete block walls based on the standard design of Korean school buildings in the 1980s is selected as a model structure, and 6 artificial ground motions corresponding to Korean design response spectrum level are used to estimate the seismic capacity of the model structure.

All of the analysis results of first story for 6 artificial ground motions exceed the maximum strength and reach in the state of damage class III through V. This result means that existing typical school buildings in Korea do not escape at least moderate damage and then may not be able to play a role as evacuation shelter against the earthquakes of Korean design acceleration level.

1. INTRODUCTION

In Korea, countermeasures against earthquake disasters such as the seismic capacity evaluation and/or retrofit schemes of buildings have not been fully performed since Korea had not experienced many destructive earthquakes in the past. However, due to more than eight hundred earthquakes with slight/medium intensity in the off coastal and inland of Korea during the past 30 years as shown in Figures 1 and 2, and due to the recent great earthquake disasters in neighboring countries, such as the 1995 Hyogoken-

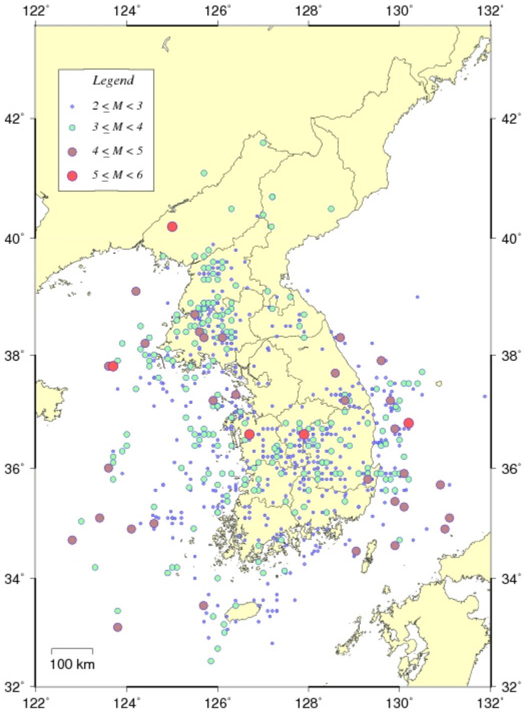


Figure 1: State of earthquake occurrence in Korea after 1978

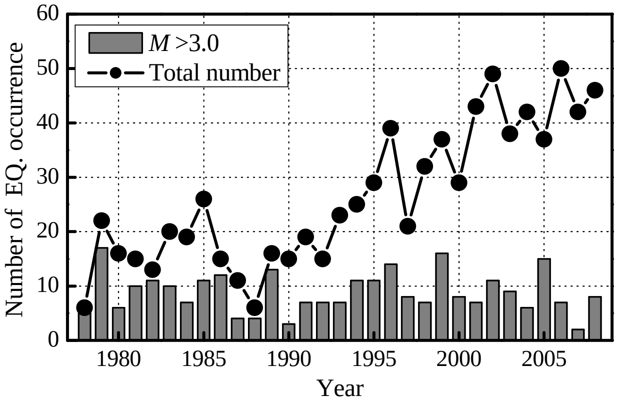


Figure 2: Frequency rate of earthquake occurrence

Nanbu Earthquake with more than 6,500 fatalities in Japan and the 1999 Chi-Chi Earthquake with more than 2,500 fatalities in Taiwan, the importance of the future earthquake preparedness measures in Korea is highly recognized.

Seismic design provisions for building structures in Korea first were introduced in 1988 and were revised in 2000 and 2005. Since the seismic design, however, was requested for the buildings more than 6 stories before 2005, school buildings which are mainly less than 5 stories have been excluded from the seismic design. In the current seismic design provisions of Korea, school buildings are specified for the first time as evacuation shelter after an earthquake and are constantly requested seismic design regardless of the number of stories. However, there are no investigations on whether existing school buildings can play a role as evacuation shelter against future earthquakes.

In this study, the seismic capacity and the damage class of existing typical school buildings in Korea are therefore analytically estimated under Korean design response spectrum level. For this purpose, a 4-story frame including unreinforced concrete block (CB) walls based on the standard design of Korean school buildings in the 1980s is selected as a model structure, and 6 artificial ground motions corresponding to Korean design response spectrum level are used to estimate the seismic capacity of the model structure.

2. OUTLINE OF MODEL STRUCTURE

Figure 3 shows a standard design of Korean school buildings in the 1980s (The Ministry of Construction and Transportation, 2002). In this study, the 4-story RC frame including CB walls as shown in this figure is analytically investigated as a model structure. Since seismic design provisions for building structures in Korea first were introduced in 1988 as mentioned above, the model structure studied herein is not designed to seismic loads. Therefore, they have (1) large spacing of hoops (300*mm*) and (2) 90 degree hook at both ends of hoops. The design strength of concrete is $21N/mm^2$, and the deformed bar SD40 (nominal yield strength: $395N/mm^2$) is used for longitudinal and shear reinforcement. The size of a CB unit is 390×190×190*mm*. It has three hollows inside and a half-sized hollow on both ends.

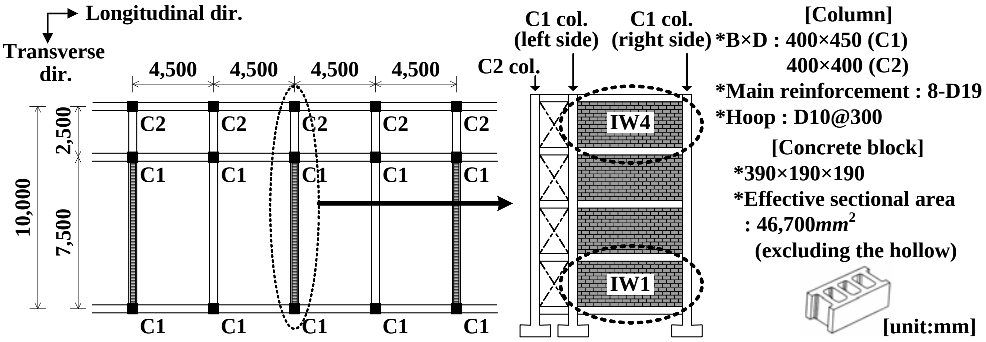


Figure 3: Standard design of Korean school buildings in the 1980s and model structure

3. SEISMIC CAPCITY AND DAMAGE CLASS OF EXISTING TYPICAL SCHOOL BUILDING IN KOREA

3.1 Hysteretic characteristics of model structure

In this section, shear strengths of each column and CB wall are calculated based on the test results previously performed, and the load-deformation curves of each story are determined with a simplified model.

3.1.1 *Outline of experiment*

In order to calculate the shear strengths of each column and CB wall of the model structure, the test results previously performed by authors are referred (Nakano and Choi, 2005). In the tests, 2 specimens representing a first or fourth story of 4-story RC school buildings are investigated as shown in Figure 3. They are an infilled wall type (IW1) assuming the first story and an infilled wall type 2 (IW4) assuming the fourth story. Material properties of C1 and C2 columns (see Figure 3) obtained the test results are shown in Table 1. Although the design strengths of concrete and reinforcement specified in the standard design of Korean school buildings in the 1980s are $21N/mm^2$ and $395N/mm^2$, respectively, as mentioned in the previous chapter, those strengths exceed the design values. Figure 4 shows the relation between the lateral load and the drift angle of specimens IW1 and IW4. Assuming the discrepancy between the observed peak load of overall frame and the calculated shear strength of both columns is carried by the CB wall, the average shear stresses τ_B of CB wall to sectional area A including hollow (A=390×190mm) for both specimens are identically $0.4N/mm^2$ as plotted in Figure 4.

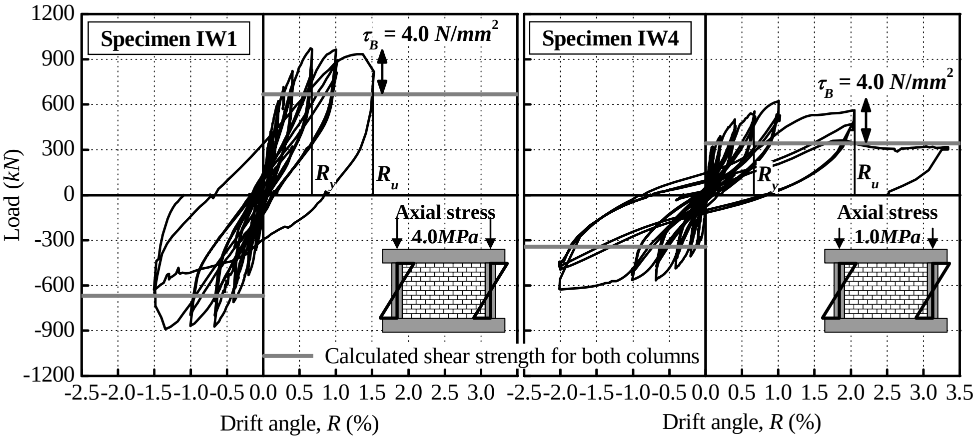


Figure 4: Load vs. drift angle of specimens IW1 and IW4

Table 1: Material properties of C1 and C2 columns

Col.	**Column width b (mm)**	**Column depth D (mm)**	**Column height h_0 (mm)**	**Compressive strength of concrete F_c (N/mm^2)**	**Yield strength of longitudinal reinforcement σ_y (N/mm^2)**	**Yield strength of transverse shear reinforcement σ_{wy} (N/mm^2)**
C1	400	450	2,800	26.2	432	404
C2	400	400				

3.1.2 *Determination of hysteretic characteristics*

To simulate the inelastic behaviors of the model structure, the load-deformation curve is represented by a simplified hysteretic model with assumptions (1) through (3) described below.

(1) The Takeda model is employed for the basic hysteretic rule assuming (a) no hardening in post-yielding stiffness and (b) stiffness degradation factor α of 0.7 derived from the test results during unloading.

(2) Table 2 shows the shear strengths of each column and CB wall calculated using each value of Figure 4 and Table 1. The yield load Q_y is simply calculated as the sum of shear strengths of three columns and

one CB wall, and the average shear stress τ_B of the CB walls for each story are identically assumed $0.4N/mm^2$ from test results. The yield drift angle R_y for each story is equally assumed 0.67%, and the load Q_{cr} and drift angel R_{cr} at cracking point are assumed $Q_y/3$ and $R_y/15$, respectively, based on test results.

(3) The ultimate ductility factors μ of specimens IW1 and IW4 defined by R_u/R_y, where the ultimate drift angle R_u is defined as the drift angle when the lateral load carrying capacity decreases to 80% of the peak load, are approximately 2.0 and 3.0 (see Figure 4). According to this result, the factors μ of first story through forth story are assumed 2.0, 2.5, 2.5 and 3.5, respectively.

Figures 5(a) through 5(d) shows the load-deformation relation of each story determined by assumptions above together with damage class determined by definition for RC members in the Guidelines for Post-Earthquake Damage Evaluation and Rehabilitation of RC Buildings in Japan (2001) shown in Figure 6.

3.2 Korean design response spectrum and artificial ground motion

In this section, design response spectrum provided Korean seismic design provisions is discussed, and artificial ground motions corresponding to design response spectrum are determined.

In the current seismic design provisions of Korea, general response spectrum with 5% of critical damping can be obtained by the design short-period spectral response acceleration parameter of S_{DS} and the design spectral response acceleration parameter at one second of S_{D1} as shown in equation (1) (Architectural Institute of Korea, 2005). Figure 7 shows spectral response acceleration determined by equation (1). The parameters S_{DS} and S_{D1} are determined respectively from Tables 3 and 4, based on the site class and the seismic zone as shown in Tables 5 and 6, respectively. In this study, site class, S_C, at seismic zone 1 is selected since the soil type of Korea mainly consists of soft rock.

$$\begin{aligned} S_a &= 0.6\frac{S_{DS}}{T_0}T + 0.4S_{DS} && \text{for } 0 \le T < T_0 \\ S_a &= S_{DS} && \text{for } T_0 \le 0 \le T_S \\ S_a &= \frac{S_{D1}}{T} && \text{for } T > T_S \end{aligned} \tag{1}$$

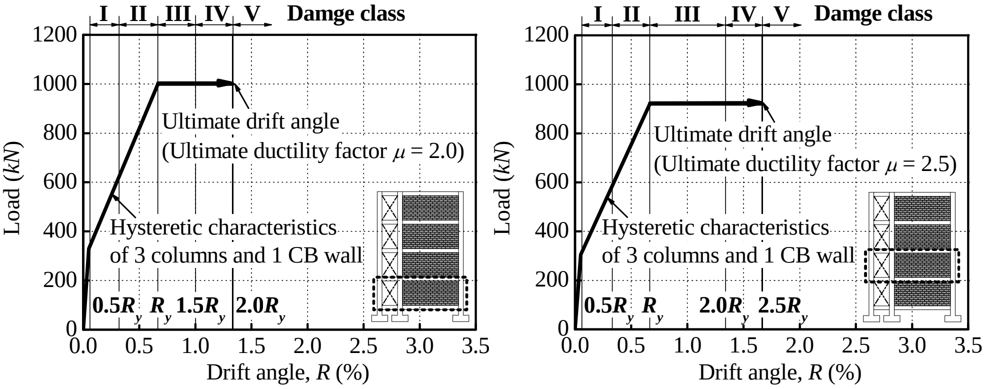
where, T_0 and T_S are given by the equations (2) and (3).

$$T_0 = 0.2\frac{S_{D1}}{S_{DS}} \tag{2}$$

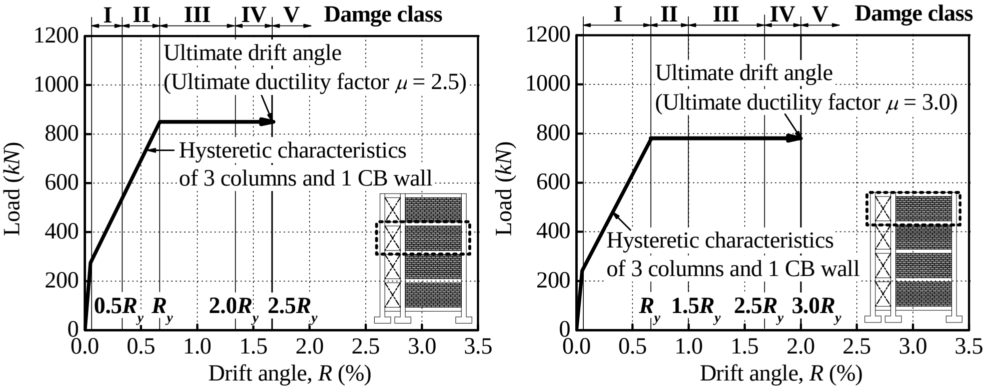
$$T_S = \frac{S_{D1}}{S_{DS}} \tag{3}$$

Table 2: Shear strengths of each column and CB wall

Story	C1 column (right side)		C1 column (left side)		C2 column		CB wall
	Axial force N (kN)	**Shear strength Q_c (kN)**	**Axial force N (kN)**	**Shear strength Q_c (kN)**	**Axial force N (kN)**	**Shear strength Q_c (kN)**	**Shear strength Q_B (kN)**
4	165	109	221	116	55	84	521
3	331	131	441	144	110	91	
2	496	150	662	168	165	97	
1	662	168	882	190	221	103	



(a) First story *(b) Second story*



(c) Third story *(d) Fourth story*

Figure 5: Load-deformation relation of each story

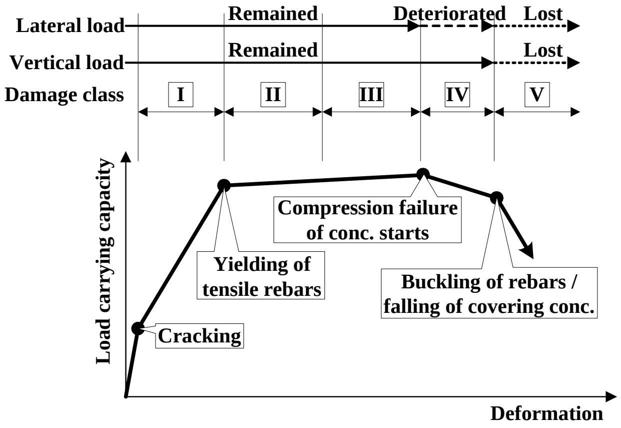


Figure 6: Schematic illustration of damage class (Ductile member)

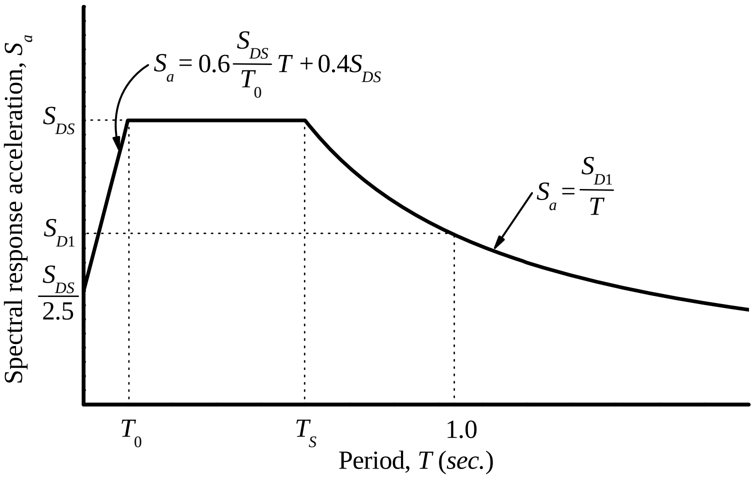


Figure 7: General response spectrum

Table3: Short-period spectral response acceleration parameter, S_{DS}

Site class	Seismic zone, A	
	1	2
S_A	$2.0M^{*1}A^{*2}$	$1.8MA$
S_B	$2.5MA$	$2.5MA$
S_C	$3.0MA$	$3.0MA$
S_D	$3.6MA$	$4.0MA$
S_E	$5.0MA$	$6.0MA$

Table4: Spectral response acceleration parameter at one second, S_{D1}

Site class	Seismic zone, A	
	1	2
S_A	$0.8MA$	$0.7MA$
S_B	$1.0MA$	$1.0MA$
S_C	$1.6MA$	$1.6MA$
S_D	$2.3MA$	$2.3MA$
S_E	$3.4MA$	$3.4MA$

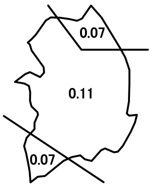
*1 M =1.33 (M is a response acceleration parameter at 2%/50 year probability of exceedance (2,400 years of mean return period))

*2 A : Seismic zone factor (see Table 6)

Table 5: Site classes in Korea

Site class	Soil class	Shear wave velocity V_s (m/s)	Standard penetration test blow count N (/300mm)	Undrained shear strength S_u ($\times 10^{-3} N/mm^2$)
S_A	Hard rock	>1,500	-	-
S_B	Rock	760 - 1,500	-	-
S_C	Very dense soil, Soft rock	360 - 760	>50	>100
S_D	Stiff soil	180 - 360	15 - 50	50 - 100
S_E	Soft clay	<360	<15	<50

Table 6: Seismic zone factor corresponding to each zone

Seismic zone	Zone	Seismic zone factor A	Remarks
1	All of zone Except seismic zone 2	0.11	
2	North Gangwon-do, South Jeolla-namdo, Jeju-do	0.07	

Since the earthquakes of maximum acceleration level specified in the current seismic design provisions of Korea have not been occurred, 6 artificial ground motions herein are used to estimate the seismic capacity of the model structure. The following 6 records are used to determine phase angles of ground motions: the NS component of El Centro 1940 record (ELC), NS component of Kobe 1995 record (KOB), EW component of Hachinohe 1968 record (HAC), NS component of Tohoku University 1978 record (TOH), NS component of Uljin 2004 record (ULJ) which has the highest maximum acceleration among the earthquake data measured by Korean meteorological office, and random excitation (RAN). Figure 8 shows 5 earthquake record data except random excitation, and Figure 9 shows the elastic acceleration response spectra of artificial ground motions with 5% of critical damping corresponding to the design response spectrum at seismic zone 1 and site class, S_C.

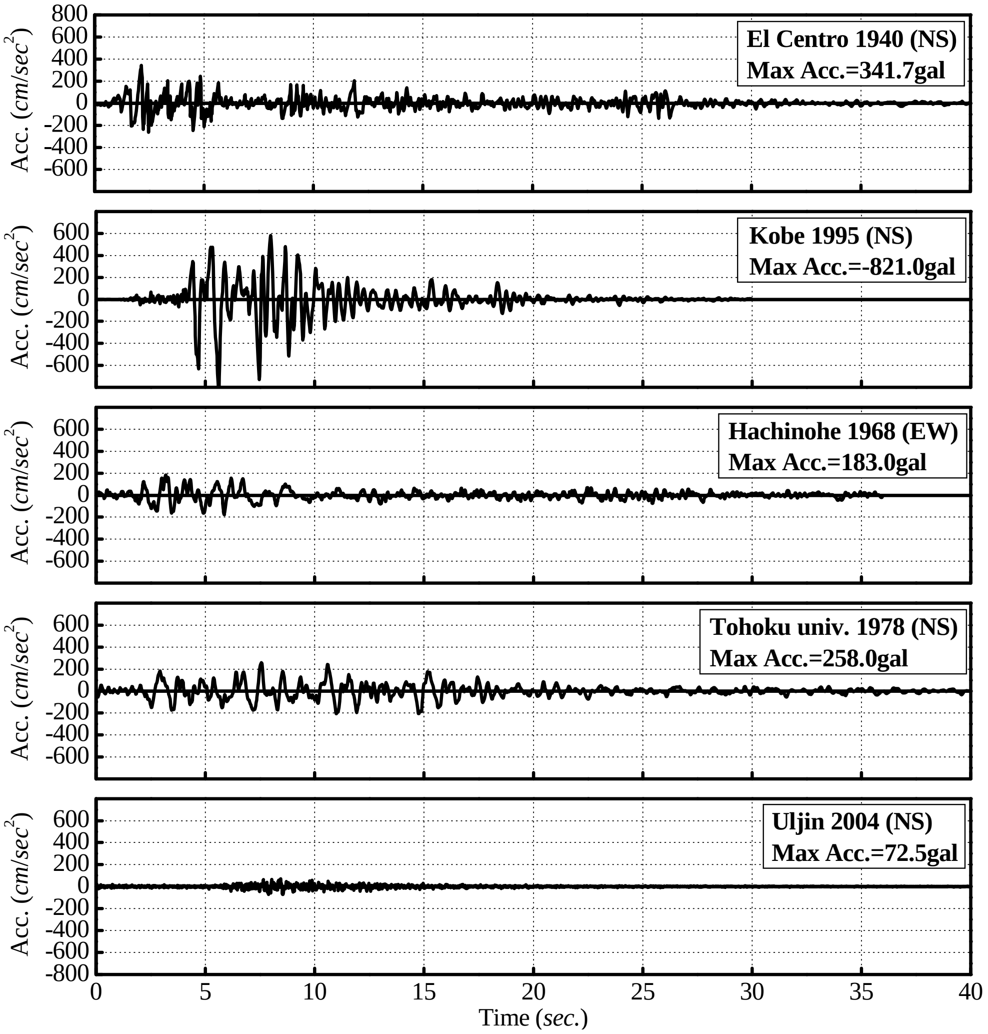


Figure 8: Earthquake record data

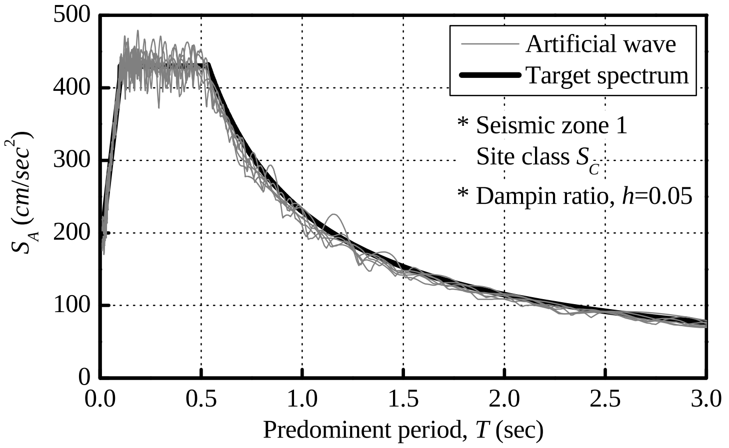


Figure 9: Elastic acceleration spectra of artificial ground motions

3.3 Seismic capacity and damage class of existing typical school building in Korea

In this section, the seismic capacity and the damage class of existing typical school buildings in Korea, which should be properly functional as evacuation shelter as well as structurally safe after an earthquake, are analytically investigated using the hysteretic characteristics and 6 artificial ground motions mentioned in previous sections.

Figure 10 shows the inelastic behaviors of first story, where the most serious damage is found, for 6 artificial ground motions together with the damage class. As shown in this figure, the behaviors and damage classes are slightly different due to phase angles of each ground motion. However, all of analysis results exceed the maximum strength and reach in the state of damage class III. The results due to KOB, HAC and RAN particularly exceed the ultimate drift angle of 1.35% and reach in the state of damage class V (i.e., collapse). For the RC frame without CB wall, more serious damages are expected since the lateral load carrying capacity is relatively small than that with CB wall. This result means that existing typical school buildings in Korea do not escape at least moderate damage and then may not be able to play a role as evacuation shelter against the earthquakes of Korean design acceleration level.

4. CONCLUSIONS

The seismic capacity and the damage class of Korean school buildings, which should play a role as refuge facilities after an earthquake, are analytically estimated under Korean design response spectrum level based on the test results. All of the analysis results of first story for 6 artificial ground motions exceed the maximum strength and reach in the state of damage class III through V. It is revealed that existing typical school buildings in Korea do not escape at least moderate damage and then may not be able to play a role as evacuation shelter against the earthquakes of Korean design acceleration level.

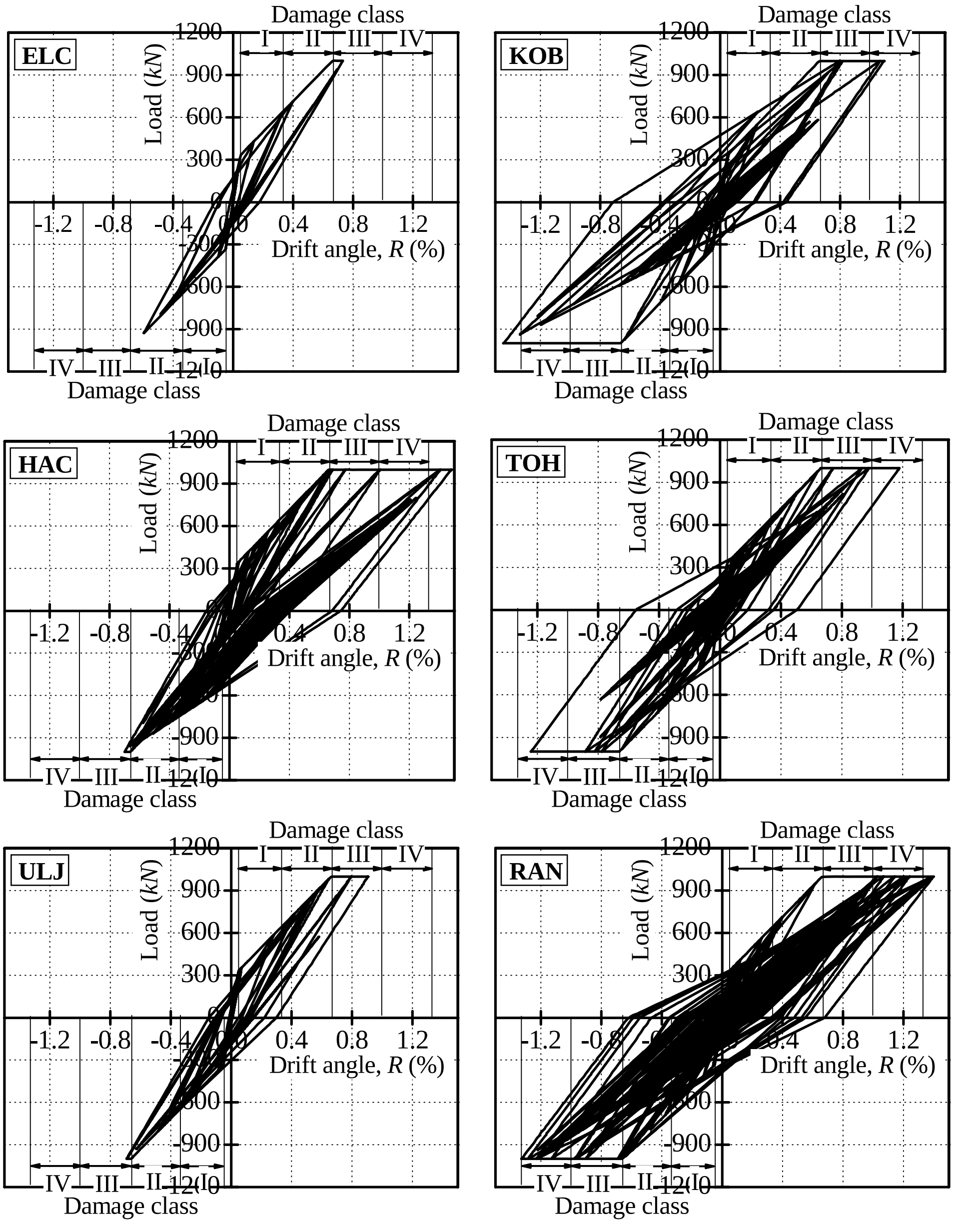


Figure 10: Inelastic behaviors and damage class of first story

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