Evaluation of the Seismic Performance of a Typical Reinforced Concrete School Building Built in Korea during the 1980s.

Sung-Ho Kim, Hae-Jun Yang, Su-Won Kang
Chungnam National University, South Korea

Hyun-Do Yun
Chungnam National University, South Korea, Professor (wiseroad@cnu.ac.kr)

SUMMARY:
Korea introduced and enforced the earthquake resistant design code in 1988, and buildings have been constructed complying with the seismic design code only thereafter. Thus, it has become necessary to evaluate the seismic performance of reinforced concrete school buildings constructed before the introduction of the code. This study presents evaluation of the seismic performance of a reinforced concrete school building built in compliance with the 1980 Standard Drawing for School Buildings by comparing the performance before and after seismic retrofitting of the building. The reinforcement materials are infill walls and steel braces which are widely used for seismic retrofit. Nonlinear static analysis (pushover) is used to compute and compare the performance points and the occurrence of plastic hinge at the performance points before and after seismic retrofitting. Results of the comparisons show that performance points of the object school building occur at plastic zones and that the building is vulnerable to earthquakes with the base shear forces and displacements below the demand spectrum. Therefore, it is required that a seismic performance evaluation is conducted for existing school buildings built before 1988 and a seismic retrofit is carried out for those schools whose seismic performance falls short of the current seismic design code of buildings to ensure their resistance to seismic activities.

Keywords: Nonlinear static analysis, Seismic performance, R/C school building, Steel brace, Infill shear wall

1. INTRODUCTION

1.1. Background and Objectives

The frequent occurrence of major earthquakes over the last few years and its damage has led to a heightened interest in the seismic design of new buildings and in the development of seismic retrofitting technology for the existing buildings. School buildings are in particular need of seismic design as they have proved more vulnerable to earthquakes with heavier casualties and a larger property loss as seen in numerous earthquake cases. In this regard, school buildings in Korea require seismic performance evaluation and, when necessary, seismic retrofitting as a majority of the school building structures were designed and built before 1988 when the seismic design code was not yet enforced and thus without considering the influence of earthquakes.
Therefore, this study aims to evaluate the seismic performance of a school building built in compliance with the 1980 Standard Drawing for School Buildings by comparing before and after seismic retrofitting of the building using a nonlinear static pushover analysis.

1.2. Case Study Building and Methodology

This study focuses on a school building constructed on the stiff soil profile(S_D) according to the 1980 Standard Drawing for School Buildings provided by the Ministry of Education. A nonlinear static analysis is carried out, which is a relatively simple seismic performance evaluation procedure as depicted in FEMA 356.

2. CASE STUDY BUILDING

The plan, exterior, and summary of the case study building are shown in Figure 1, Figure 2 and Table 2.1 respectively. Sectional properties of columns and beams are presented in Table 2.2 and Table 2.3. The subject building is a reinforced concrete rahmen structure built before the introduction of earthquake-resistant design code and, thus, its principal structural parts such as columns and beams have non-seismic details. It is a one-side corridor type plane structure with the standard compressive design strength of concrete at 21MPa, the strength of reinforcing bar 240MPa, the floor height 3.3m and the slab thickness 150mm. The school building is composed of two parts connected by an expansion joint and an individual seismic performance evaluation was carried out for each of the two parts.

Figure 1. The external appearance of case study building

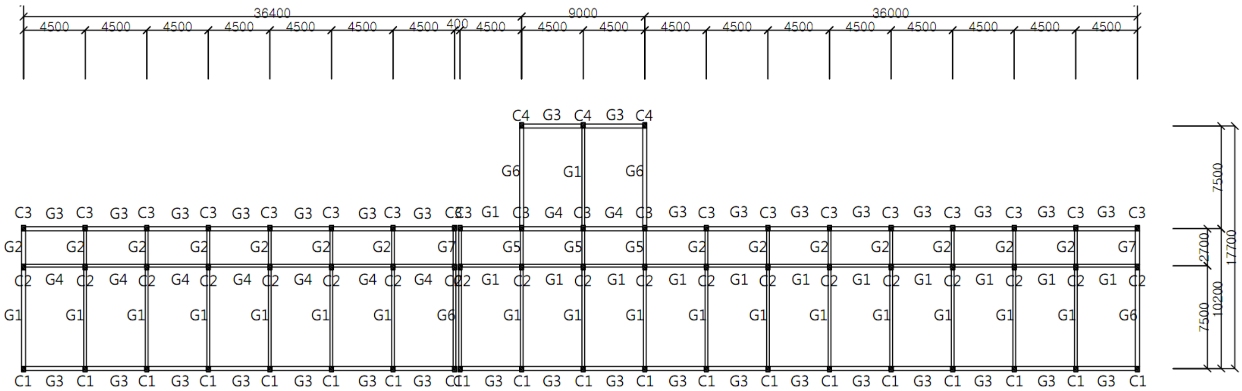


Figure 2. Plan of case study building (unit : mm)

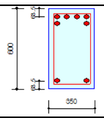
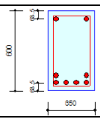
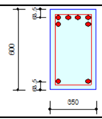
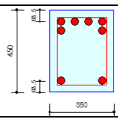
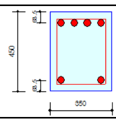
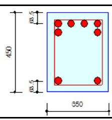
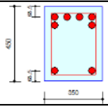
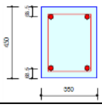
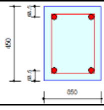
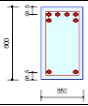
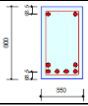
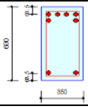
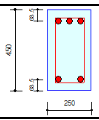
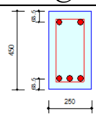
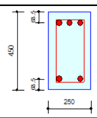
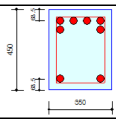
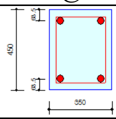
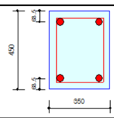
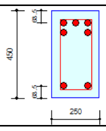
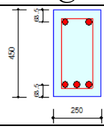
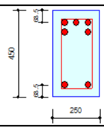
Table 2.1. Description of object building

Building use type	Completion year	Structure type	Total square	Height	Size
Educational facilities	1980	Reinforced concrete	3,740m^2	3.3m	3 stories high

Table 2.2. Column sections of object building

Column	$B_C \times H_C$ (mm)	Covering thickness (mm)	Main bars		Stirrup
			Numbers	Rows	
C1	350×500	5	10-D19	3	2-D10@300
C2	350×400	5	14-D19	5	2-D10@300
C3	350×400	5	8- D16	3	2-D10@300
C3A	350×500	5	14- D19	5	2-D10@300
C4	350×500	5	8- D19	3	2-D10@300

Table 2.3. **Girder sections of object building**

Beam		END-I	MID	END-J	Beam		END-I	MID	END-J
G1	Section				G5	Section			
	Top	6-D22	2-D19	6-D22		Top	6-D22	4-D22	6-D22
	Bottom	2-D19	6-D22	2-D19		Bottom	2-D22	2-D22	2-D22
	Stirrups	2-D10@300				Stirrups	2-D10@300		
G2	Section				G6	Section			
	Top	6-D22	2- D19	2- D19		Top	6-D22	2-D19	6-D22
	Bottom	2-D19	2-D19	2- D19		Bottom	2-D19	6-D22	2-D19
	Stirrups	2-D10@300				Stirrups	2-D10@300		
G3	Section				G7	Section			
	Top	3-D19	2-D19	3- D19		Top	6-D22	2-D19	6-D22
	Bottom	2-D19	3-D19	2- D19		Bottom	2-D19	6-D22	2-D19
	Stirrups	2-D10@300				Stirrups	2-D10@300		
G4	Section								
	Top	5-D19	2-D19	5- D19					
	Bottom	2-D19	3-D19	2- D19					
	Stirrups	2-D10@300							

3. METHODS FOR SEISMIC RETROFIT OF EXISTING SCHOOL BUILDING

In general, seismic rehabilitation techniques aim to improve either the strength of the structure or deformation capacity or both. This study applies a technique using infill walls and steel braces effective in improving strength against seismic loads.

3.1. Infill wall

Infill walls are being recognized to be highly effective in enhancing lateral strength. Reinforcement of only a small portion of the wall can have a significant retrofit effect. The concrete compressive strength(fc') and the strength of the reinforcing bar in the infill walls used in this study are 24MPa and 400MPa respectively. The reinforcement vertical rebars D19 as well as horizontal rebars D16 are arranged 150mm apart.

3.2. Steel Brace

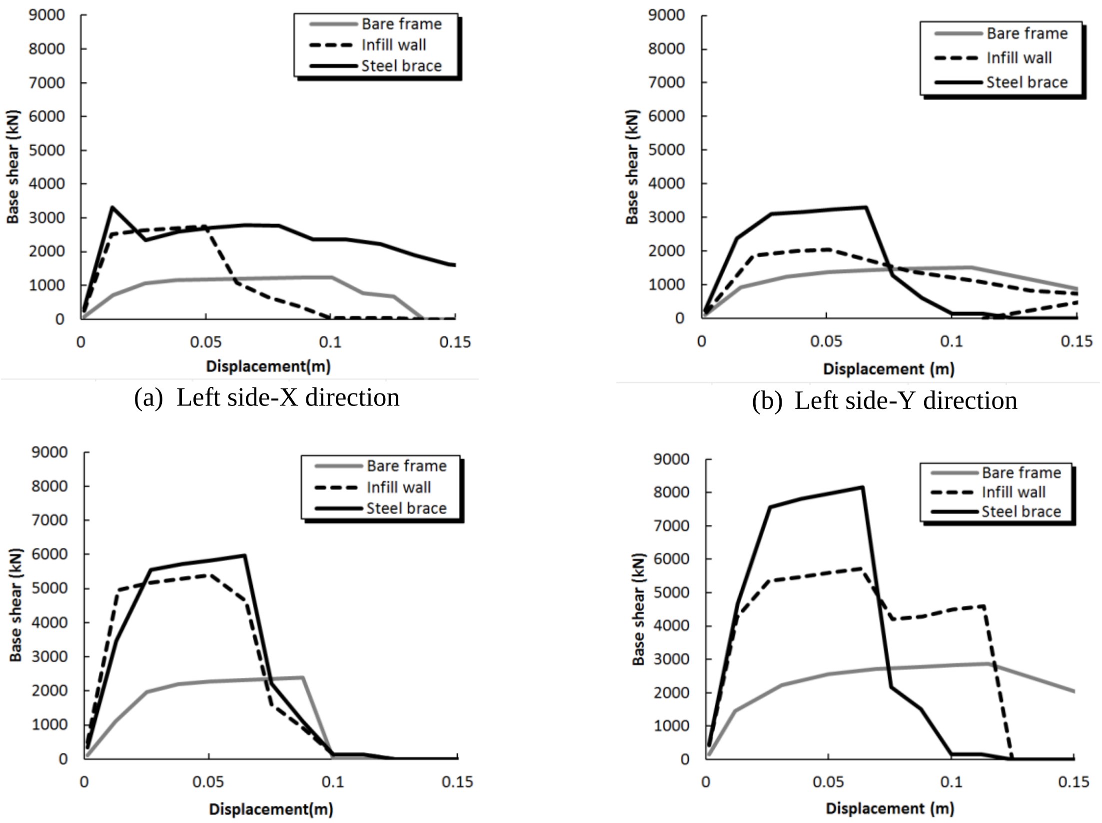
Steel braces are used to improve seismic performance by means of increasing buildings' strength and ductility. This study plans to fill the SS400 steel brace of Φ165.2 with 21MPa non-shrinkage mortar.

4. PUSHOVER ANALYSIS

The nonlinear static analysis is a relatively simple seismic performance evaluation technique which analyzes the inelastic behavior of a building taking into consideration the toughness of the material and structural redundancy. This study uses MIDAS/GEN to perform the pushover analysis and idealized the object school building as a three-dimensional structure ignoring the effects of masonry walls and slabs. The design and analysis develop the response spectrum based on KBC 2009.

4.1. Comparison of Strength and Limit State

Comparison of the base shear force–displacement relation before and after seismic retrofitting on each of the two parts of the object school building is presented in Figure 3. The figure shows that a seismic retrofit using infill walls and steel braces tends to enhance the base shear force of the existing structure by 35 to 185 %.



(a) Left side-X direction

(b) Left side-Y direction

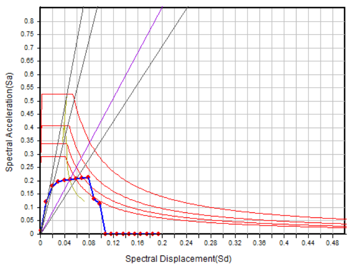
(c) Right side-X direction

(d) Right side-Y direction

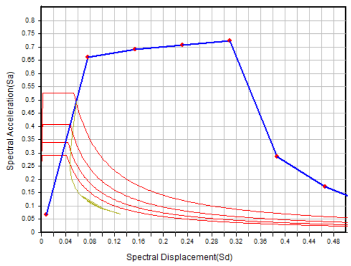
Figure 3. Base shear-displacement curve

4.2. Capacity Spectrum Analysis

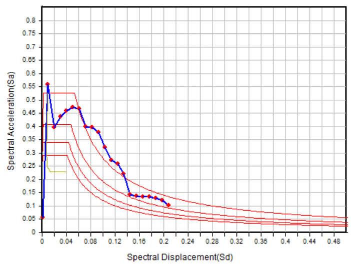
Capacity spectrum method is used to evaluate the performance level of a building by converting the base shears and roof displacements from a non-linear pushover to equivalent accelerations and displacements in a capacity spectrum, and identifying the performance points at the intersections of the demand spectrum and the capacity spectrum. This study uses ATC-40 Procedure-B to compute performance points and applies the seismic design spectrum in KBC2009 to the demand spectrum. As presented in Figure 4. and Table 4.1., the result of the capacity spectrum analysis shows that seismic performance of the object building before the seismic retrofit is not sufficient with performance points occurring at plastic zones on the bare frame but the seismic retrofit increases the stiffness and thus the overall elastic response of the structure to the same demand spectrum. When retrofitted with steel braces, the structure is found to have a significantly bigger base shear force than that of the bare frame and a brittle fracture tendency.



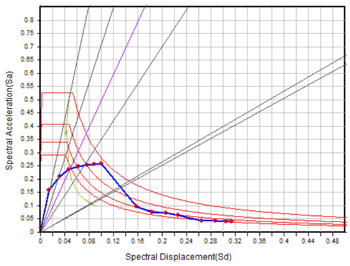
(a) Left side-X direction
(Bare frame)



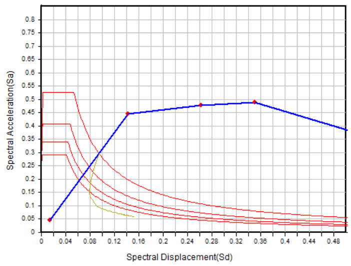
(b) Left side-X direction
(Infill wall)



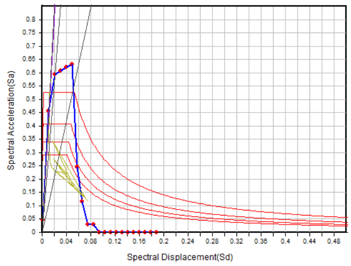
(c) Left side-X direction
(Steel brace)



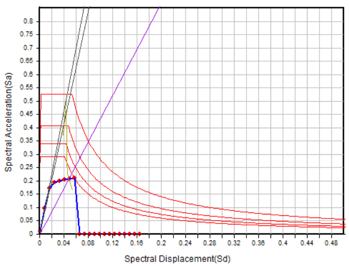
(d) Left side-Y direction
(Bare frame)



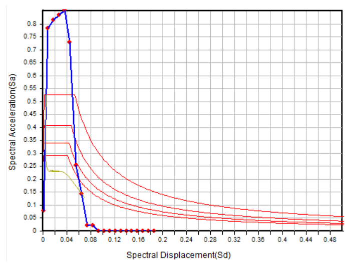
(e) Left side-Y direction
(Infill wall)



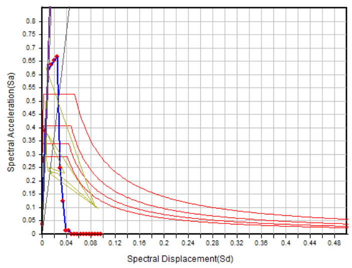
(f) Left side-Y direction
(Steel brace)



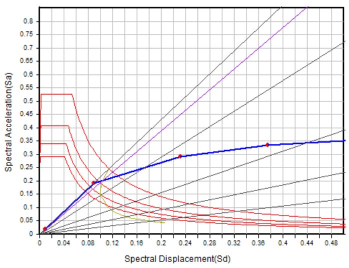
(g) Right side-X direction
(Bare frame)



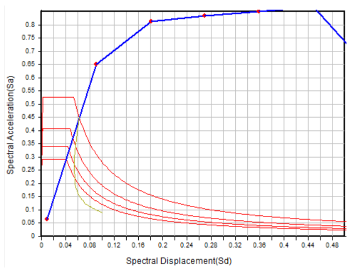
(h) Right side-X direction
(Infill wall)



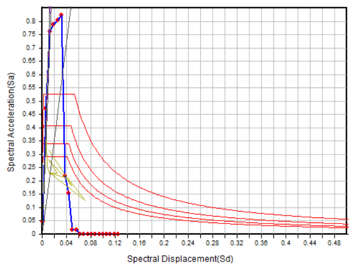
(i) Right side-X direction
(Steel brace)



(j) Right side-Y direction
(Bare frame)



(k) Right side-Y direction
(Infill wall)



(l) Right side-Y direction
(Steel brace)

Figure 4. Capacity spectrum curve

Table 4.1. Capacity spectrum analysis result

			V (kN)	D (m)	Sa (g)	Sd (m)	Teff (sec)	Deff (%)
Left side	Bare Frame	X direction	1204	0.0618	0.205	0.0480	0.9711	25.88
		Y direction	1382	0.0518	0.2375	0.0479	0.901	21.65
	Infill wall	X direction	Elastic	Elastic	Elastic	Elastic	0.0714	5
		Y direction	Elastic	Elastic	Elastic	Elastic	0.0632	5
	Steel brace	X direction	Elastic	Elastic	Elastic	Elastic	0.2408	5
		Y direction	2246	0.0152	0.468	0.0114	0.3136	7.039
Right side	Bare Frame	X direction	2345	0.0724	0.2069	0.0477	0.9637	25.78
		Y direction	1543	-0.013	0.2021	0.1041	1.44	8.654
	Infill wall	X direction	Elastic	Elastic	Elastic	Elastic	0.1404	5
		Y direction	Elastic	Elastic	Elastic	Elastic	0.0724	5
	Steel brace	X direction	4009	0.0166	0.4477	0.0064	0.2405	7.968
		Y direction	4921	0.0141	0.4959	0.0070	0.2389	6.136

5. PLASTIC HINGE

Comparison of the occurrence of plastic hinges at performance points from Capacity Spectrum Method before and after seismic retrofitting shows, as presented in Table 5.1., that the seismic retrofit using infill walls and steel braces reduces the occurrence of plastic hinges by 65-88% in the left part of the school building and by 48-96% in the right, indicating a remarkable improvement in the earth-resistant performance of both parts of the school building.

Table 5.1. Plastic hinge occurrence result at performance point

			Plastic hinge occurrence spot	Plastic hinge decreasing rate (%)
Left side	Bare Frame	X direction	144	-
		Y direction	111	-
	Infill wall	X direction	50	65.28
		Y direction	59	46.85
	Steel brace	X direction	17	88.19
		Y direction	26	76.58
Right side	Bare Frame	X direction	245	-
		Y direction	144	-
	Infill wall	X direction	8	96.73
		Y direction	31	78.47
	Steel brace	X direction	23	90.61
		Y direction	74	48.61

6. CONCLUSION

This study conducted the nonlinear static (pushover) analysis in order to evaluate the seismic performance of a reinforced concrete school building constructed in compliance with the Korean government-published 1980 Standard Drawing for School Buildings by comparing the building's performance before and after seismic retrofitting. Results obtained are as follows:

1) Korea's school buildings constructed in the 1980s in the absence of seismic requirements are deemed vulnerable to earthquake loads and, as a result of the capacity spectrum analysis that this study conducted, it was found that they tend to have a lower seismic performance than required to withstand earthquake loads. However, seismic retrofitting with infill walls and steel braces decreased spectral

accelerations and displacements at performance points, meeting the performance criteria;

2) Comparison of the number of plastic hinges occurred before and after seismic retrofit showed that a seismic retrofit using infill walls and steel braces reduced the occurrence of plastic hinges in the bare frame by 46-96% from previous over 100 hinges, ensuring the building's earthquake-resistant performance; and

3) Therefore, this study concludes that the school buildings designed and constructed in the 1980s require evaluation of the adequacy of their seismic performance and, if necessary, a seismic retrofit for reliable seismic performance.

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