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TIME-HISTORY ANALYSIS RESULTS OF RC FRAMES FOR DIFFERENT GROUND ACCELERATIONS

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Recent earthquake in Japan has increased the interest in seismic-resistance performance of building structures in Korea. Earthquake damages not only collapsed the buildings but also caused huge loss of both human lives and property. Therefore, the school buildings, which are often used as an emergency shelter during an earthquake, should be evaluated of their seismic-resistance performance. This study used a nonlinear dynamic analysis program, OpenSees, to perform nonlinear static and dynamic analyses for the seismic-resistance evaluation of school buildings, which were not designed for an earthquake load. Actual earthquake waves were normalized to make them similar to design acceleration spectrum as specified by current seismic design code KBC 2009. Three actual ground accelerations (i.e., El Centro 1940, Kobe 1995 and Northridge 1994) were used to carry out time-history analysis in order to evaluate the overall behavior of the structure and local nonlinear deformation at the element level. The analysis result shows that the old school building not designed for an earthquake may be damaged seriously by an earthquake load of the magnitude equivalent to current design spectrum standard.

Keywords: Seismic-resistance performance evaluation, Seismic-resistance design, School building, Non-linear time-history analysis, Ground acceleration.

1 INTRODUCTION

Catastrophic earthquakes have been increasing recently all over the world with more detrimental damage. In the past three years, Philippines, Japan, China, New Zealand, and Chile have suffered from earthquakes of Richter scale of 7.9, 7.3, 6.9, 7.2, and 8.0, respectively, and the economic damage and human life loss are very serious. Especially, Japan has suffered from breakdown of nuclear power plants due to recent earthquake impact accompanied by Tsunami attack, and its damage has been unprecedented in the history of the world. This is because the earthquake damage does not end in itself, but it is followed by the second and the third damage waves through the failure and collapse of structures. Because very strong earthquakes cause many after-shock earthquake waves to bring about additional damages, the securement of seismic safety of the structures is necessary.

2 ANALYSIS MODEL

2.1 Modeling of the building Brief

The shorter side, i.e., weak axis of the building, was modeled with two-dimensional elements using OpenSees v.2.2.2. All columns and beams were analyzed by applying 'Nonlinear Beam-Column' element, and 'Fiber section' was used for both columns and beams to consider P-M interaction (Mazzoni *et al*. 2007). Additionally, although there were in-filled masonry walls inside the building, the walls were not included in the modeling due to the irregular layout and lightweight panel in some cases. The mass for the structural modeling was determined by adding 25% of live load (L.L.=3kN/m^2) to the dead load (D.L.=3kN/m^2) on the tributary area subjected to loading.

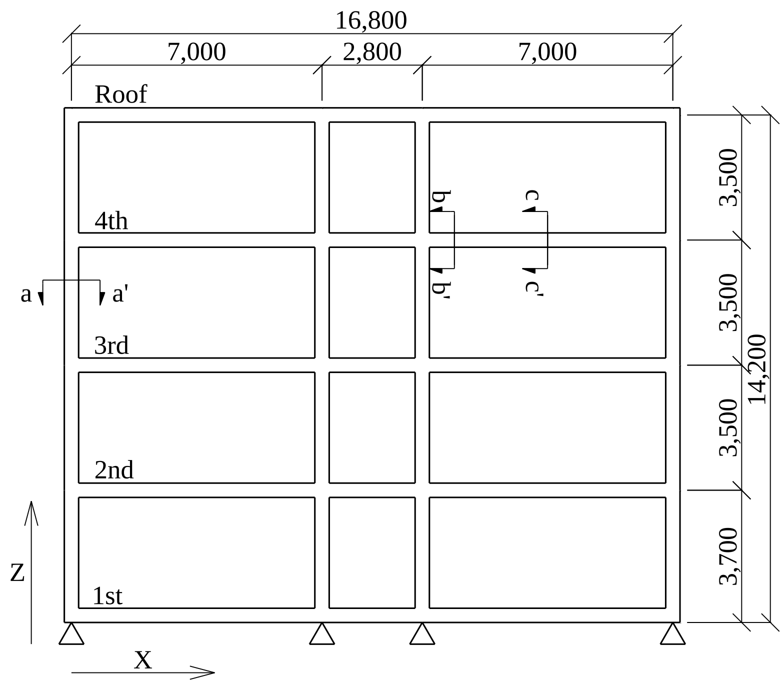

Figure 1. Analytical modeling of the building for OpenSees.

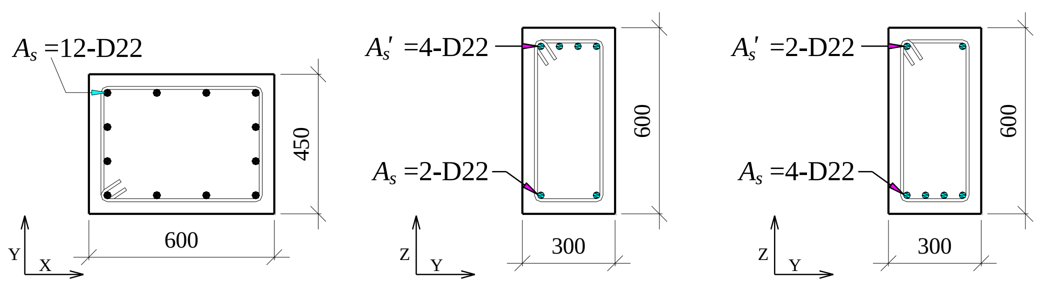

Figure 2. Details of (a) a-a' section; (b) b-b' section; and (c) c-c' section.

The materials were modeled with ‘Concrete02’ and ‘Steel02’. ‘Concrete02’ can withstand tensile strength of 1/8 of the compressive strength and strain-hardening up to strain of 0.02 after ultimate strain of 0.003. ‘Steel02’ shows nonlinear behavior of the structure at the yield strength of the reinforcing bar. Figure 2 shows the cross-section of column and beam, and the amount of steel reinforcement obtained from the old blue-print. The yield strength of the steel bar, fy, and the compressive strength of the concrete, fc' , were assumed to be 300MPa and 24MPa, respectively which were commonly used for the materials during the construction of the old buildings.

3 NORMALIZATION OF EARTHQUAKE WAVES

In this study, three earthquake waves, i.e., El Centro 1940, Kobe 1995 and Northridge 1994, were used as input ground accelerations. The specifications of the earthquake waves are summarized in Table 1. The response spectrum for the earthquake waves of Table 1 were compared with the acceleration of KBC 2009 design spectrum. The design spectrum specified the seismic zone (S=0.22) and the soil profile type as SB. The site coefficient mapped spectral response acceleration at short period, and 1 second period were assumed to be 1.0 (Han and Kim 2006). The earthquake waves were normalized by coinciding the acceleration at the period of 0.08~0.4, i.e., the peak of design spectrum (0.374g), to the average acceleration of the same period as the response spectrum of each earthquake wave. The normalized response spectrum of the earthquake waves and the design spectrum acceleration of KBC 2009 design spectrum were compared in Figure 3 (KBC 2009). The magnitude factors were 0.4921, 0.2318, and 0.1943 for El Centro, Kobe, and Northridge, respectively.

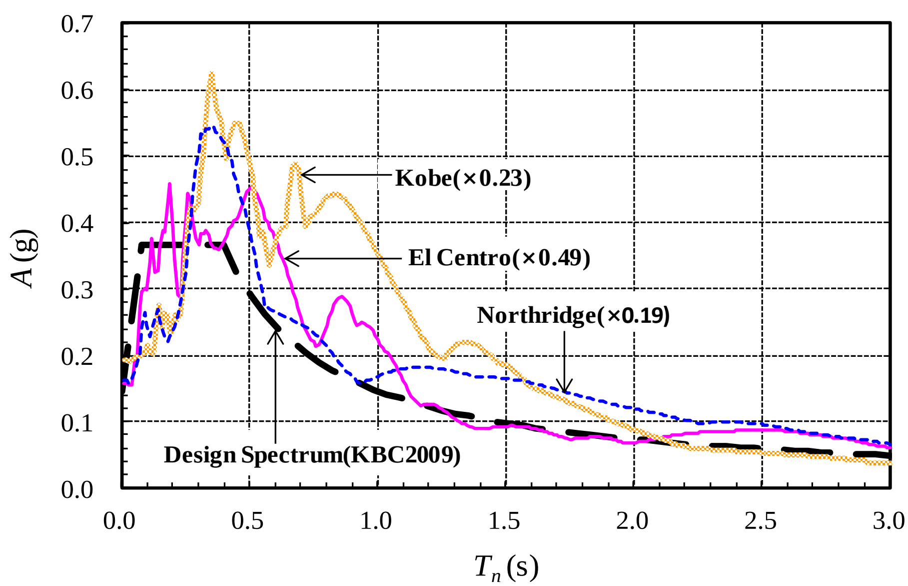

Figure 3. Comparison of design spectrum and response spectra of the earthquake waves.

4 NONLINEAR DYNAMIC ANALYSIS

4.1 Story Drift of the Frame

Nonlinear dynamic analysis was carried out by using the normalized earthquake waves. Time-drift graph at the top story for each earthquake wave are shown in Figure 4. The analysis results revealed that El Centro earthquake exhibited a wide range of drift response between −170mm(1.2%) and +98mm, and the Kobe and Northridge earthquakes showed drift responses of −61mm(0.43%) ~ +26mm and −47mm ~ +59mm(0.42%), respectively. The maximum peak drift of the top story was 170mm for El Centro earthquake wave.

The story drift ratio of each floor was investigated to find out the nonlinear deformation of the member. Table 1 shows the maximum story drift ratio for each earthquake wave, and the shaded area represents maximum story drift ratio of over 1.5%. The story drift ratio was over 1.5% at the first and second floors upon the exertion of El Centro earthquake wave, and the exertion of Northridge earthquake wave resulted in over 1.5% story drift ratio at the first floor. This finding points to the vulnerable condition of the research-subject building to the earthquake waves. Especially, the Northridge earthquake exceeded the limitation of FEMA450 for the story drift ratio of 2%, pointing to the serious damages of the old school building to the earthquakes (FEMA 2003). Kobe earthquake also manifested story drift ratio of 1.48%, attesting for the damages of the school building structure. Figure 5 shows maximum story drift ratio subjected to each earthquake wave (Sarno and Elnashai 2009). Most serious damage was expected in the lower story of the building. It can be seen that the deviation of story drift ratio in response to earthquake acceleration is high.

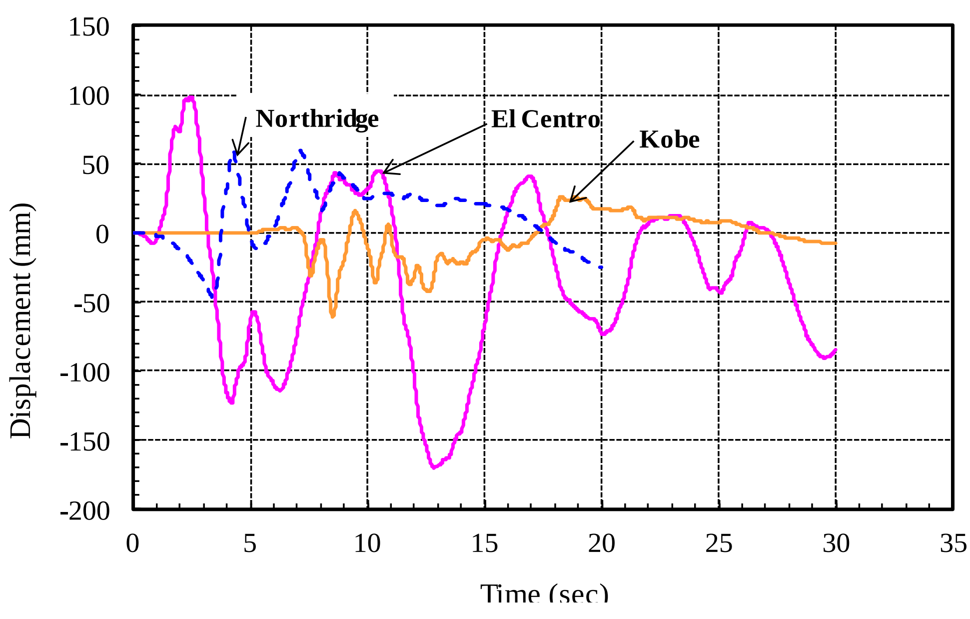

Figure 4. Top story drift response.

Table 1. Maximum drift ratio subjected to each earthquake wave.

Earthquake		El Centro	Kobe	Northridge
1st story	Time(sec)	5.66	8.52	4.24
	Drift ratio(%)	1.73	1.48	2.45
2nd story	Time(sec)	12.88	18.90	3.58
	Drift ratio(%)	1.65	0.37	0.49
3rd story	Time(sec)	13.04	13.62	4.28
	Drift ratio(%)	1.17	0.21	0.38
4th story	Time(sec)	12.24	14.18	4.92
	Drift ratio(%)	0.73	0.24	0.30

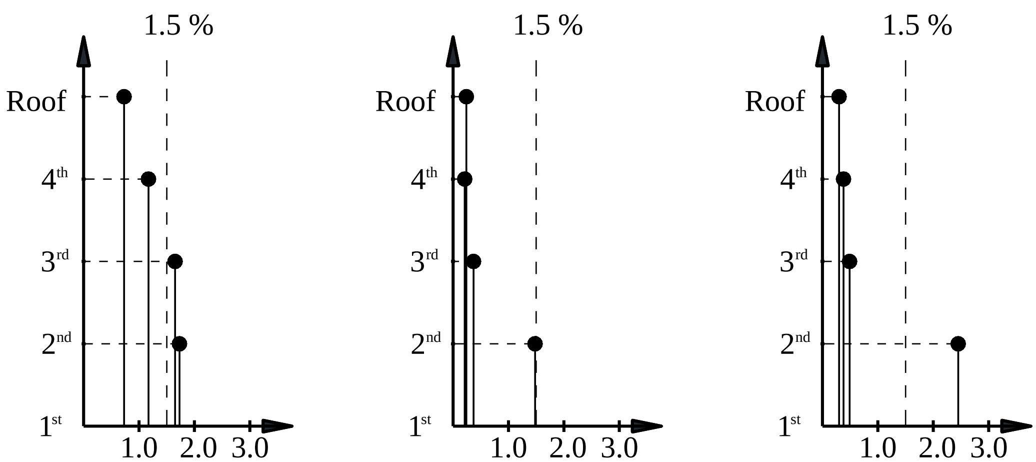

Figure 5. Maximum drift ratio subjected to (a) El Centro×0.49; (b) Kobe×0.23; and (c) Northridge×0.19.

5 CONCLUSIONS

An old school built in 1973, which was not designed for seismic standard, was modeled in two dimensions with consideration of only the shorter side. The normalized three ground accelerations with similar design response spectrum were applied to the frame model for the evaluation of the damage level. Roof story displacement, story drift ratio, and required plastic rotations were used to evaluate the damage level and the possibility of collapse.

- The result of pushover analysis up to 1.7% drift ratio of height building revealed that plastic hinges with large rotation at the right end of beam at the second, third, and fourth floors occurred and followed by plastic hinges at the upper and lower column of the first floor. The failure mechanism of the modeled frame started with beam collapse mechanism and then developed into combination failure mechanism finally.

- The maximum story displacement at roof was observed with El Centro earthquake, which comes from relatively even story drift ratio at each story, while the other two earthquakes resulted in less roof displacement with concentrated story drift at the first story.
- For normalized accelerations, El Centro earthquake generated story drift ratios of 1.73% and 1.65% in excess of the seismic standard of 1.5%, at the first and second floor, respectively. Kobe and Northridge earthquakes resulted in story drift ratio of 1.48% and 2.45%, respectively, at the first floor. This means the earthquakes of El Centro and Northridge will affect very detrimental and dangerous damage to the structure.

Acknowledgment

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