Seismic Retrofit of Old School Buildings Using Friction Dampers

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ABSTRACT

Many old RC reinforced concrete (RC) buildings exist in seismically active areas. Such buildings are generally known to have poor seismic reinforcement details which could lead to significant damage or even collapse during large earthquakes. To complement such buildings with satisfactory seismic performance, a friction damping system can be used. In this study, seismic performance of old RC building is assessed numerically. The considered model follows the vulnerable reinforcement details of old RC buildings. The numerical analysis results showed that the old RC buildings with friction dampers (Frame–R) had better seismic performance than the bare buildings (Frame–B) for 14% and 40% in static and dynamic analysis, respectively.

Keywords: Seismic retrofit, Friction damper, Old RC building

INTRODUCTION

Many reinforced concrete (RC) buildings with poor reinforcement details exist in populated areas. Most of these structures were designed considering only gravity load (Engindeniz et al., 2008). Therefore, they usually have poor reinforcement details: short lap splices of column longitudinal bars located just above the floor level, widely spaced column transverse bars. For this reason, majority of such buildings behaved poorly during large earthquakes, suffering significant damage and even collapsed (FEMA, 2006).

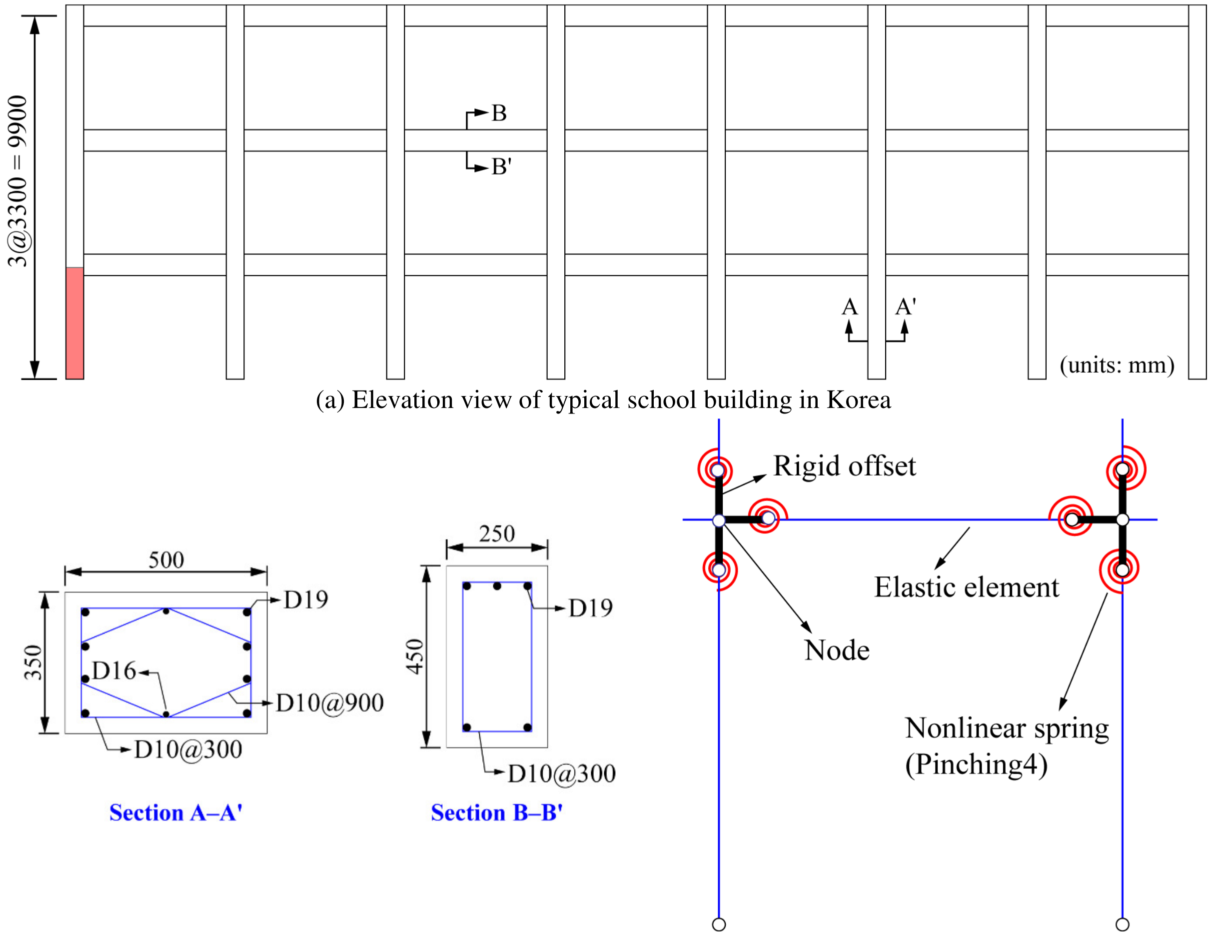
Various types of passive damping systems have been developed to improve the seismic performance of old RC building (Soong and Dargush, 1997). Friction dampers are one of the displacement dependent passive damping devices that can dissipate the seismic energy acting on a building. The amount of energy dissipation is primarily dependent on the displacement applied on the friction damping device (ASCE (2013)). The friction damping devices are also known for their low costs and low maintenance effort compared to other damping devices. For this reason, they have been widely used for the seismic retrofit of existing buildings (Pall and Pall, 1996, Benavent-Climent et al., 2015).

In the present study, old RC school building is retrofitted with friction dampers. The seismic performance of old RC school building with and without the friction damping devices are compared statically and dynamically. This study adopted a simple and accurate friction damper retrofit method proposed by Moon et al. (2017). This study considered a gravity-load designed three-story RC school building that was typically used in Korea as a case study building.

SUMMARY OF CASE STUDY BUILDING

The case study RC building shown in Figure 1a, is a standard design of Korean school buildings in 1980's. The information of member sections is also shown in Figure 1b. The clear cover of beams and columns is 40 mm. Columns and beams were modeled using an elastic element with two lumped nonlinear springs placed at both ends (Figure 1c). The nonlinear cyclic behavior of beams and columns were modeled with the Pinching4 model (Lowes and Altoontash, 2003). The joint regions are modeled with four rigid offset elements (Figure 1c). The base of the model is fixed to the ground. Although this school building had a slab width of 130 mm, effective beam width contributed by slab was not considered in the numerical model for simplicity. The adopted numerical analysis software is OpenSees (McKenna et al., 2010).

The gravity loads and masses were determined based on the load combination of 1.05DL+0.25LL, where DL and LL are the dead and live loads, respectively. The geometric nonlinearity associated with P–Δ effects was considered in analyses. Nonlinear static (pushover) and incremental dynamic analyses (IDA; (Vamvatsikos and Cornell, 2002)) were conducted in this study for the frame models. Two frame models are considered for seismic performance evaluation: i) bare frame model (Frame–B) and ii) retrofitted frame model using friction damping devices (Frame–R).



(a) Elevation view of typical school building in Korea

(b) Reinforcing details

(c) Analytical model representation

Figure 1. Description of the case study building

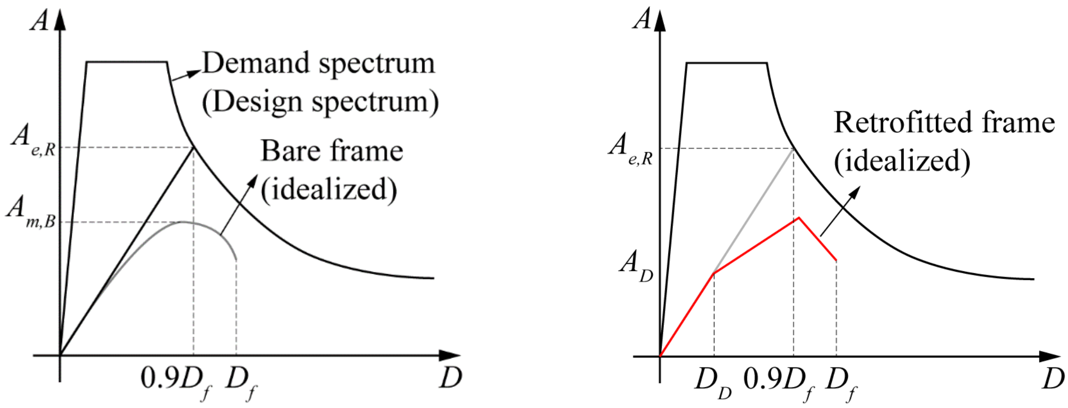
As it was stated in the previous section, seismic performance of the case study building was improved by friction dampers. This study followed the friction damper design process proposed by Moon et al. (2017). A brief illustration of retrofit process is shown in Figure 3. Demand spectrum can be constructed with a design response spectrum ASCE (2017). Idealized capacity curve of the bare frame can be obtained by converting pushover curve of the case study building to the corresponding equivalent SDF system. The spectral force (A) and displacement (D) is calculated with following equations:

$$A = \frac{V}{M_1^*} \tag{1}$$

$$D = \frac{d}{\Gamma_1 \phi_1} \tag{2}$$

where, V is the base shear force of the case study building, M_1^* is the effective modal mass, d is the roof displacement of the case study building, Γ_1 is the modal participation factor, and ϕ_1 is the value of the first modal vector.

In Figure 2a, D_f is defined as the corresponding spectral displacement at $0.8A_{m,B}$ force, and $A_{e,R}$ is the elastic demand acceleration of the equivalent SDF system (retrofitted building). In this study, elastic demand displacement of retrofitted building is assumed as $0.9D_f$. The inelastic demand spectral displacement of the retrofitted building under demand response spectrum should be equal or less than D_f. In this case, the inelastic displacement ratio (C_R) of the retrofitted building is 1.1 ($=D_f/(0.9D_f)$). Force required to activate the friction dampers (A_D in Figure 2b) can be calculated as $A_{e,R}/R$, where R (yield strength reduction factor) can be estimated by C_R (=1.1) and Miranda (2001)'s equation for inelastic displacement ratio (Moon et al., 2017).



(a) Capacity spectrum of bare frame (b) Capacity spectrum of retrofitted frame

Figure 2. Friction damper design process

SEISMIC PERFORMANCE OF CASE STUDY BUILDING

The static pushover analyses are conducted by distributing lateral force along the height of a frame by followed the first mode shape. Figure 3a shows the pushover curves of Frame–B and Frame–R, where V_{base} is the base shear, and $W_{building}$ is the seismic weight of the building. $V_{base}/W_{building}$ of Frame–R was 15% higher than that of Frame–B (0.15 for Frame–R and 0.13 for Frame–B), due to the strength contribution of friction damping system.

The collapse strength of Frame–B and Frame–R is also compared was quantified from IDA analyses (Figure 3b) To plot the IDA curves, the north-south component of ground motion recorded at Imperial Valley Irrigation District substation, El Centro, California was scaled until dynamic instability is observed during analysis. The collapse capacity (the onset of dynamic instability) of Frame–B and Frame–R was 0.43 and 0.60g, respectively. The collapse capacity of retrofitted frame (Frame–R) was 1.40 times larger than bare frame (Frame–B).

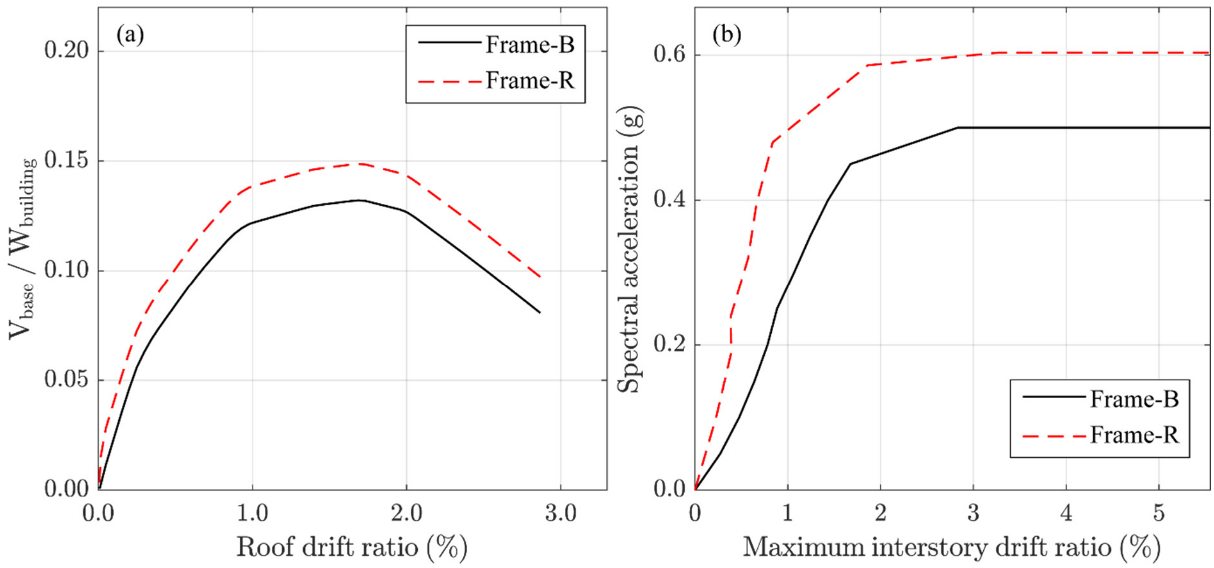


Figure 3. Analysis results: (a) Static pushover; (b) Incremental dynamic analysis

SUMMARY

This study adopted a simple and efficient retrofit method of old RC buildings and compared the seismic performance of old RC buildings. Nonlinear static and dynamic analysis was conducted for two frame models: bare frame model (Frame–B) and ii) retrofitted frame model using friction damping devices (Frame–R). Both models followed the standard design of old RC school buildings in Korea. It was found that Frame–R showed better seismic performance by 14% and 40% in static and dynamic analysis, respectively.

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