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Energy-dissipation in Seismic Retrofit RC Building with Friction Dampers

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Abstract. Reinforced concrete (RC) buildings have suffered severe damage in the past due to inadequate lateral force resistance or energy dissipation capability. There is a need to improve the seismic performance of existing, vulnerable RC structures, particularly those that were either not initially intended for seismic effects or were planned to an obsolete seismic standard. Friction dampers are a revolutionary technique for improving lateral force resistance and energy dissipation capacity in the seismic retrofit of RC buildings. In this study, energy dissipation in seismically retrofitted RC buildings using friction dampers is investigated. An investigation of the nonlinear response history was performed after friction dampers were applied to the RC building. The analysis results indicate that the peak story drift ratios are reduced and constant throughout the height of the building, which may be a sign that the structure has not suffered soft story damage. In addition, the total friction damper's energy-dissipation is half of the total input energy.

1. Introduction

Numerous older reinforced concrete (RC) buildings have been destroyed in recent earthquakes as a result of their insufficient lateral force resisting systems [1-6]. Demolition of seismically unstable existing buildings and replacement with new construction is an option based on these criteria, but it is generally time-consuming and costly. Furthermore, when the number of schools or hospitals in a rural location is limited, rebuilding imposes additional costs because there may be few alternative facilities to undertake education or medical services. As a result, ancient RC buildings that were either not prepared for seismic effects or were created to an outdated seismic criterion must be retrofitted. The seismic retrofit typically refers to new seismic design guidelines to make sure the retrofitted RC building can resist future earthquakes.

Some of the most often used retrofit techniques for RC frames to increase the lateral force capacity include the construction of RC walls [7-8], the addition of conventional steel

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bracing [9–11], and the wrapping of the RC columns with carbon fiber reinforced polymers (CFRPs) [12-13]. The usual braced frame method has shown to be advantageous since the braces may be prefabricated and weigh less than the additional structural walls [11–13]. Installation of friction dampers and other energy dissipation devices [14-17] is a cutting-edge technique used recently to enhance the seismic performance of RC structures. However, an energy-dissipation in seismic retrofit RC buildings with friction dampers is lack investigation. Therefore, this study investigates the energy dissipation in seismically retrofitted RC buildings using friction dampers. The RC school building is used as an example building. Nonlinear response history was performed and used to compare the seismic performance of a bare RC frame to a retrofitted RC building with the friction damper.

2. Seismic retrofit design method

The constant drift method [14, 18–21] is selected in this study to design the requirement for friction dampers since it is effective in managing the peak story drift ratio and close to the specified target story drift ratio. The step-by-step retrofit design approach can be summed up as follows:

1. Conduct a nonlinear modal pushover analysis (based on the fundamental mode) and fit the roof displacement - base shear relationship to a trilinear backbone with elastic, cracked and yielding stages. Also obtain the story strengths of the existing RC frame ($Q_{fy,i}$).
2. Convert the RC frame into a simplified $SDOF_{RC}$ model, as shown in Fig 1 and determine the energy dissipation (E_f) of the current structure at the target drift (θ_{tar}).

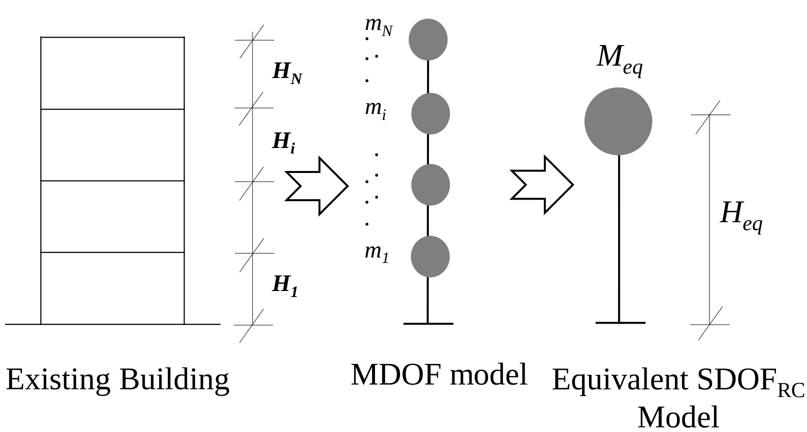

Fig. 1. Simplification of the RC building to $SDOF_{RC}$.

3. Determine the maximum story drift of the current RC frame using the $SDOF_{RC}$ (θ_{fu}), keeping in mind that the frame might not be proportioned to produce a consistent drift profile. The building needs a seismic retrofit if the maximum story drift is greater than the target story drift (θ_{tar}), but not if it is less than θ_{tar}. Then, distribute the story friction damper force ($F_{d,i}$) vertically along the height of the building, as indicated in Fig .2.

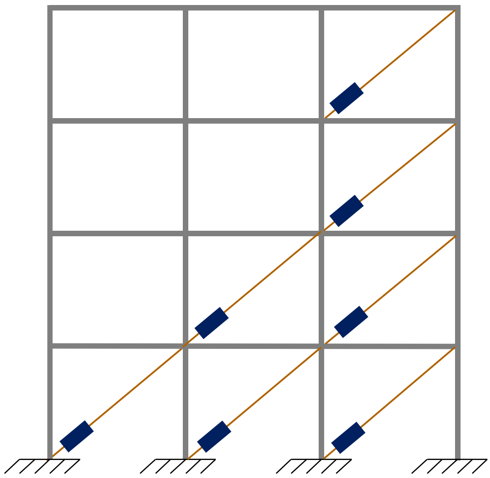

Fig. 2. Seismic retrofit distribution and configuration.

3. Seismic Region and Retrofit Design Results

Chiang Rai, Thailand's northernmost region has been selected to be the location because the location is one of the highest seismic regions in Thailand. Therefore, several buildings in this location should be seismically retrofit. A four-story local RC school building is used as an example for the seismic retrofit of this study. The frame measurements and member sizes, while the seismic mass was computed as 184 tons for the first to third levels and 171 tons for the fourth story, using the lowest stated strengths for the 24 MPa concrete and 300 MPa rebar. The same modeling assumptions as specified in the earlier BRB retrofit research when full information about the example building is provided [20] were used to create three-dimensional numerical models using ETABS [22]. The following is a synopsis of the suggested step-by-step retrofit design method:

1. The first three periods were determined by modal analysis to be 1.249 sec for longitudinal translation, 0.871 sec for torsional deformation, and 0.830 sec for transverse translation. Using a nonlinear modal pushover analysis (based on the fundamental mode), the roof displacement - base shear relationship was fitted to a tri-linear decaying backbone curve with elastic, cracked, and post-yielding phases.
2. It was determined what the SDOFRC properties were: H_{eq} = 10 m (73.5% of the building height), M_{eq} = 577 tons (80% of the overall mass), $K_{f,l}$ = 14.6 kN/mm (longitudinal lateral stiffness), and $K_{f,t}$ = 33.1 kN/mm (transverse lateral stiffness).
3. To prevent damage to drift-sensitive nonstructural components and increase the likelihood of an immediate occupancy seismic performance level under the design basis earthquake (DBE) level acceleration and displacement spectra as shown in Figs. 3 and 4, respectively, a target story drift ratio of 1/200 rad. (0.5% rad.) was chosen. The DBE displacement spectrum (Fig. 4) indicated $SDOF_{RC}$ displacements of $\delta_{d,l}$ = 76 mm in the longitudinal direction and $\delta_{d,t}$ = 48 mm in the transverse direction, with corresponding peak story drifts of $\delta_{d,l}$ / H_{eq} = 0.76% and $\delta_{d,t}$ / H_{eq} = 0.48%. The result indicated that peak story drifts of only the longitudinal direction exceeded the target story drift of 0.5% rad. Therefore, only in the longitudinal direction was a refit necessary. for the purpose of protecting drift-sensitive

nonstructural components and raising the chance that the seismic performance level will be reached immediately after occupancy.

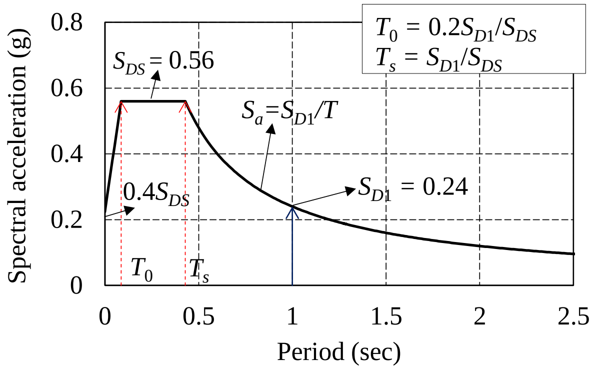

Fig. 3. Acceleration spectrum design for Chiang Rai, Thailand

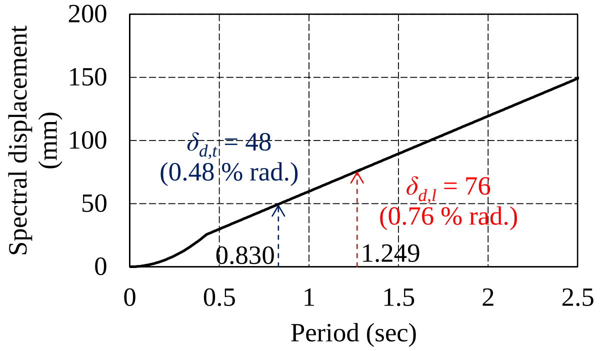

Fig. 4. Displacement spectrum for Chiang Rai, Thailand

4. The friction dampers are then designed, and the necessary friction damper strengths for seismic retrofit in the longitudinal direction are indicated in Table 1.

Table 1. Summary design results for the longitudinal direction

Story	Existing RC frame	Friction damper
	$Q_{fy,i}$ (kN)	$F_{d,i}$ (kN)
4th	1228	-
3rd	1127	155.02
2nd	1124	313.6
1st	1586	159

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4. Analysis Results

Nonlinear response history analysis (NLRHA) is performed on the bare RC frame and retrofitted RC building with friction dampers using five ground motions to investigate and compare the seismic response and the buildings' performance.

4.1 Analysis model

The sample building chosen is a four-story RC school. To examine the impact of the SF on the seismic performance of retrofitted RC structures with friction dampers, three-dimensional (3-D) models were developed. Each section of the bare RC frame was defined, as the fiber section. Fig. 5 depicts the retrofit using simply the friction damper model. The bare RC frame model and detailed information are presented in [20] and the friction damper was modeled with the Wen model [23]. The friction dampers are placed at the location to avoid the torsional effect.

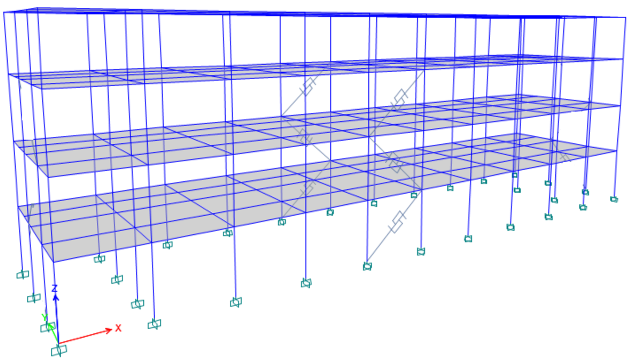


Fig. 5., Three-dimensional (3-D) model of retrofitted RC structures with friction dampers

4.2. Ground motions for NLRHA

A suite of five scaled single component records is selected from the PEER NGA2 ground motion database 2 [24]. The scaled DBE demand spectra are shown in Fig. 6. The scaling is conducted over a target period range from $0.2T_1$ to $1.5T_1$, which follows ASCE 7-16 requirements [25], where T_1 (1.249 sec) is the fundamental period of the bare RC frame, resulting in a target period range of 0.250 to 1.874 sec. The records are limited to strike-slip events with magnitudes of $6 \leq M_w \leq 7.5$ within 20 km fault distance and on soil class D ($180 \leq V_{s,30} \leq 360$ m/s). Selected data is consistent with the dominant seismic hazard risk in the Chiang Rai province, Thailand, which corresponds to the target building location and local site conditions. The scale factors of the ground motions vary between 0.68 and 1.69.

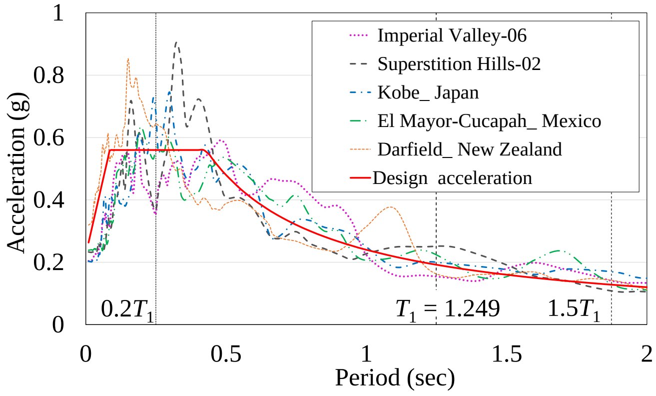
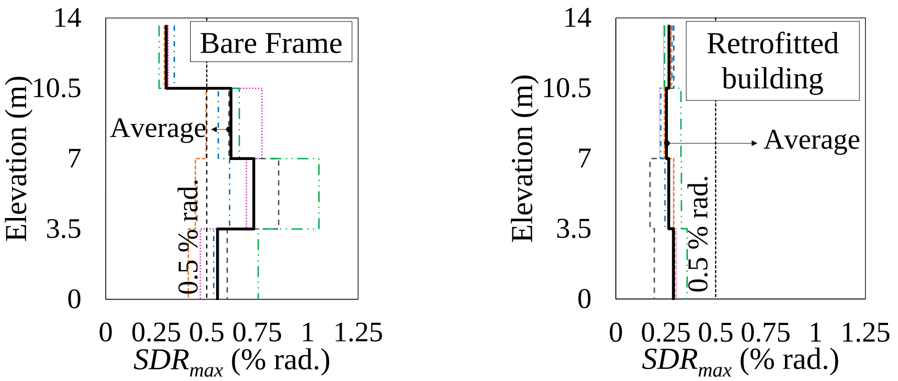


Fig. 6. DBE level spectrum and scaled ground motion elastic response spectra (5% damped)

4.3. Peak inter-story drift ratio

Fig. 7a and Fig. 7b show the peak inter-story drift ratio of bare RC frame and retrofitted building, respectively. The NLRHA results of the bare RC frame, as shown in Fig. 7a , indicate that all stories except the 4th story exceed the target story drift ratio of 0.5% rad., which corresponds to the design result that the 4th story does not require the friction damper.
The NLRHA results of the retrofitted building, as shown in Fig. 7b, indicate that the seismic retrofit with the friction damper may reduce the peak inter-story drift ratio significantly. In addition, the peak story drift ratios are uniform along the building height, which is the advantage of the selected constant drift method. This may imply that the building does not have the soft story damage after being retrofitted with the friction damper.



(a) Bare frame (b) Retrofit building

Fig. 7. Peak inter-story drift ratio

4.4 Energy-dissipation

Fig. 8 presents the ratio of energy dissipated by friction dampers to the total input energy. The energy dissipation ratio (R_E)

$$R_E = E_d / E_I \quad (1)$$

where E_d is the hysteretic energy dissipated by the friction dampers and E_I is the total input energy. The NLRHA results indicate that the total friction damper's energy-dissipation is about 50% of the total input energy.

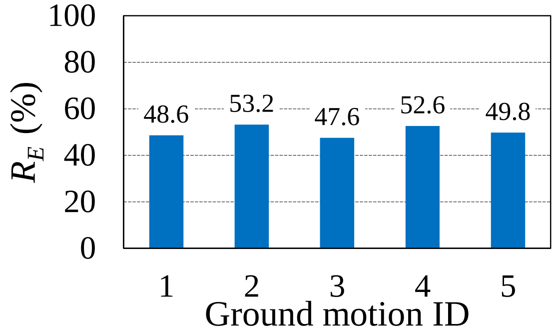


Fig. 8. Energy-dissipation by friction damper

5. Conclusion

This study investigates the energy-dissipation in seismic retrofit RC building with friction dampers. The NLRHA results indicated that the peak inter-story drift ratios were substantially improved after retrofitting the existing RC building with the friction damper, which may imply that the building does not have the soft story damage after retrofitting with the friction damper. Additionally, the total friction damper's energy-dissipation is half of the total input energy.

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