Workshop for Young Researchers
Feb. 13, 2020 Tokyo Tech

Seismic Retrofit of RC Buildings using Elasto-Plastic Dampers with Elastic Steel Frame in Moderate Seismic Region

Panumas Saingam[1], Fatih Sutcu[2], Yuki Terazawa[3], Pao-Chun Lin[4], Toru Takeuchi[5]

[1]*Ph.D. Student, Department of Architecture and Building Engineering, Tokyo Institute of Technology, Tokyo, Japan, saingam.p.aa@titech.ac.jp*
[2] *Assist. Prof., Earthquake Engineering and Disaster Management Institute, Istanbul Technical University, Turkey fatih.sutcu@itu.edu.tr*
[3]*Assist. Prof., Department of Architecture and Building Engineering, Tokyo Institute of Technology, Tokyo, Japan, terazawa.y.aa@m.titech.ac.jp*
[4]*Postdoctoral Research Fellow. Department of Architecture and Building Engineering, Tokyo Institute of Technology, Tokyo, Japan, lin.p.ab@titech.ac.jp*
[5]*Professor, Department of Architecture and Building Engineering, Tokyo Institute of Technology, Tokyo, Japan, takeuchi.t.ab@m.titech.ac.jp*

Abstract—**Seismic retrofit of reinforced concrete (RC) building using dampers is proven to increase an energy dissipation capacity and seismic performance for the building. This study proposes a seismic retrofit design method using elasto-plastic damper (EPD) implementing an elastic steel frame (SF). The SF not only supports construction for applying the damper to the RC frame but also prevents damage concentration to limited stories and secures self-centering function. The proposed equations to evaluate the optimal stiffness ratio of the EPD to RC frame based on the equivalent linearization approach is introduced. A four-story RC school building in Thailand is used as a benchmark model, and nonlinear response history analysis is performed to verify the effectiveness of the proposed retrofit method. The results suggest that the proposed retrofit method is considered to be effective in the example building. The maximum story drift ratio (SDR_{max}) of retrofitted using EPD with SF is reduced significantly when compared to the bare RC building without retrofit, and SDR_{max} of the retrofitted building is close to the design target story drift ratio.**

I. Introduction

Seismic retrofit using EPD with SF based on the equivalent linearization is applied to the RC buildings. The RC building is simplified to a single-degree-of-freedom model ($SDOF_{RC}$). Then, the hysteretic response of EPD is considered and parallel to the $SDOF_{RC}$. The optimal equation to evaluate the stiffness ratio of the EPD (K_d) to the $SDOF_{RC}$ (K_f) is proposed. A four-story RC school building, which is located in Chiang Rai province Thailand, is used as a benchmark model, and nonlinear response history analysis (NLRHA) is performed to verify the proposed method.

II. Seismic Region and Target Building

A. Seismic Region

Fig. 1 presents the design acceleration, corresponding to a damping ratio of 5% in Thailand (Chiang Rai province) [1]. In addition, Fig. 1 shows a suite of scaled single component records, which is selected from the PEER NGA2 ground motion database 2 [2] to perform NLRHA. The scaling is conducted over a target period range of $0.2T_1$ and $1.5T_1$, which follows requirements in [3].

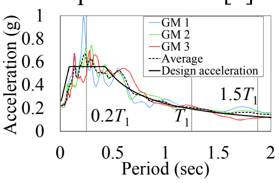


Fig. 1 –5% damped response spectra of the design acceleration spectrum and scaled ground motions.

B. Target Building

A typical four-story RC school building, which is located in Chiang Rai province, Thailand, is chosen to represent as a target building for this study. Fig. 2a, Fig. 2b, Fig. 2c show the elevation, details of cross-sectional the RC members, and structural plan, respectively.

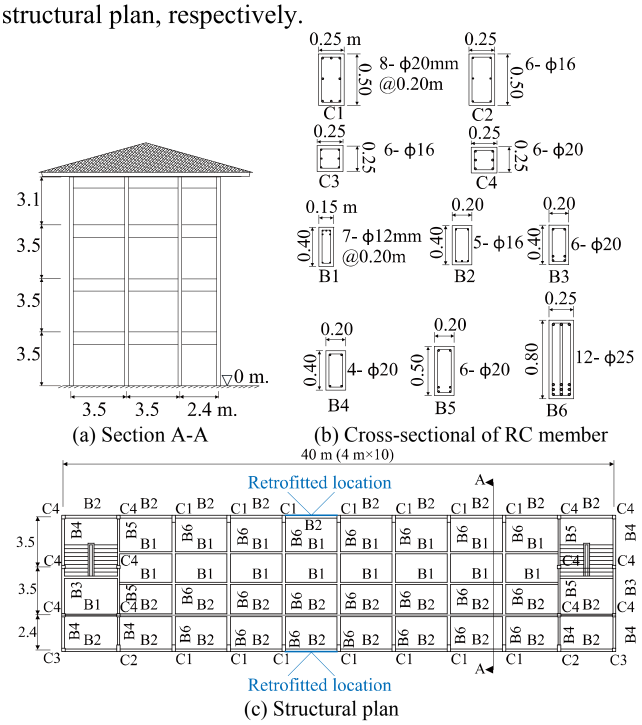


Fig. 2 –Details of the four-story RC building

III. Retrofit Design Method

Fig 3. shows the retrofitted concept of the RC frame using EPD with SF. The optimal equation to evaluate the stiffness ratio of K_d/K_f is proposed based on following assumptions:

(a) The hysteretic energy of the EPD (E_d) is given in Eq. (1), where K_d is EPD stiffness, δ_{dy} is lateral yield deformation , and μ_d is damper ductility.

(b) The average equivalent hysteretic damping ratio (h_{eq}), given in Eq. (2), is assumed constant at all displacement amplitudes, where E_f is hysteretic energy, E_{fe} is strain energy of the SDOF$_{RC}$ [4], inherent damping of SDOF$_{RC}$ (h_{f0}) is 3%, damping reduction factor (R) is 0.6 [4], and E_d is the hysteretic energy of the EPD. To evaluate the equivalent damping of SDOF$_{RC}$ ($h_{f\mu}$), the E_d is substituted by zero.

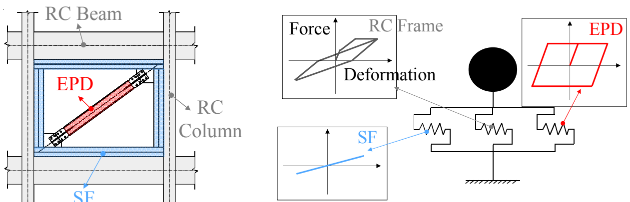
(c) The damping response reduction factor was proposed in [5]. In this study, a=25 is used for the real earthquake ground motion.

(d) The target story drift at each story i^{th} ($\theta_{tar,i}$) is constant ($\theta_{tar,\,i} = \theta_{tar}$). Therefore, the optimal ratio of the damper to frame stiffness (K_d/K_f) can be obtained by Eq. (3), where $\theta_{f\mu}$ is story drift of SDOF$_{RC}$, θ_{tar} is target story drift, γ_s is stiffness ratio of SF to EPD (this study assumes γ_s = 0.05), and p is the stiffness reduction coefficient [4] of SDOF$_{RC}$.

$$E_d = 4K_d(\mu_d - 1)\left(\delta_{dy}\right)^2 \qquad ;(1<\mu_d) \tag{1}$$

$$h_{eq} = h_{f0} + R\left(\frac{E_f + E_d}{4\pi E_{fe}}\right) \tag{2}$$

$$\frac{K_d}{K_f} = \frac{p\left(\frac{\theta_{f\mu}}{\theta_{tar}}\right)^2\left(\frac{1+ah_{f\mu}}{1+ah_{eq}}\right)^2 - p}{\gamma_s + \frac{1}{\mu_d}} \tag{3}$$



Retrofit model (SF+RC frame+EPD)

(a) Retrofit configuration (b) Retrofit model

Fig. 3 –Retrofit concept.

IV. Validation of the Proposed Retrofit Method

Retrofit design examples of the four-story RC buildings using EPD with SF is presented, and NLRHA is performed in order to validate the proposed retrofit method.

A. Retrofit design example

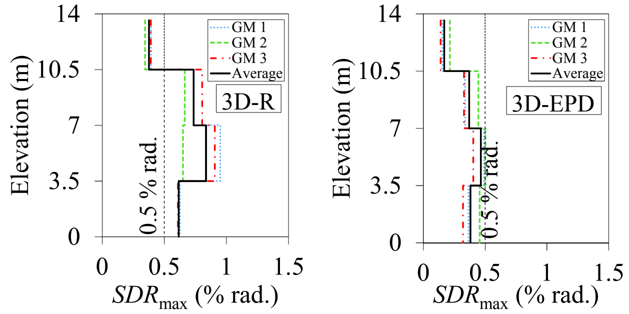
Table 1 shows the retrofit design result of the example building using EPD with SF. The elastic stiffness of bare RC building on i^{th} story (K_{fi}) is obtained by pushover analysis. The EPD to frame stiffness ratio (K_d/K_f) of 0.90 is obtained by the step from Eq. (1) to Eq. (3). Then, the required stiffness of EPD (K_{di}) for i^{th} story (K_{di}) is obtained from multiply K_d/K_f by K_{fi}.

TABLE I EPD distribution

Story	K_{fi} (kN/mm)	K_d/K_f	K_{di} (kN)
4	39.6	0.90	35.64
3	32.2		28.98
2	32.1		28.89
1	45.3		40.77

B. NLRHA result

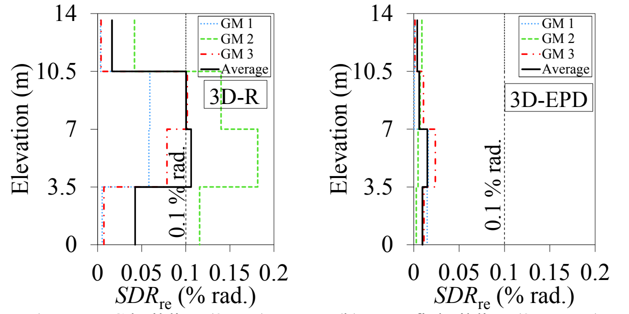
The maximum story drift ratio (SDR_{max}) responses of each ground motion for the bare RC building (3D-R) and retrofit building (3D-EPD) models are shown in Figs 4(a) and 4(b), respectively. The NLRHA analysis results indicate that the proposed retrofit method using EPD with SF can efficiently limit the SDR_{max} in every story within SDR_{tar} of 0.5% rad.



(a) Bare RC building (3D-R) (b) Retrofit building (3D-EPD)

Fig. 4 –Maximum story drift ratio

The residual drift ratio (SDR_{re}) responses of each ground motion for the 3D-R and 3D-EPD models are shown in Figs 5(a) and 5(b), respectively. The analysis results indicate that the SDR_{re} is controlled within 0.1% after retrofit RC building. It implies that both structural and non-structural damage can be mitigated for the retrofitted buildings.



a) Bare RC building (3D-R) (b) Retrofit building (3D-EPD)

Fig. 5 –Residual story drift ratio.

V. Conclusions

The seismic retrofit method of RC building using EPD with SF was introduced. The proposed method was validated by NLRHA on the four-story RC school building in Thailand. The conclusions can be drawn as follows:

1) Assigning the EPD to the RC building improved the seismic performance of the building. The SDR_{max} of the retrofitted building can be reduced significantly.

2) Based on the example retrofit design, the proposed retrofit method can result in SDR_{max} close to the design SDR_{tar}.

3) The SDR_{re} was controlled within 0.1%, which implied that both structural and non-structural damage can be mitigated.

References

[1] Department of Public Works and Town & Country Planning (DPT) (2009): Thailand Seismic Design Code.

[2] Pacific Earthquake Engineering Research Center (PEER). PEER NGA Ground motion database, < http://ngawest2.berkeley.edu/site >

[3] American Society of Civil Engineers (ASCE) (2016): Minimum Design Loads for Buildings and Other Structures 2016 (ASCE/SEI 7-16).

[4] Sutcu F, Takeuchi T, Matsui R. Seismic retrofitting design method of existing RC buildings with buckling restrained braces, Journal of Constructional Steel Research, 101 (2014), 304–313.

[5] Kasai K, Fu Y, Watanabe A. Passive control systems for seismic damage mitigation. Journal of Structural Engineering, 124 (1998), 501-512.