A Study on the Use of Friction Dampers for the Seismic Performance Upgrade of RC Structures

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ABSTRACT

A Performance Based Design procedure for retrofitting the RC frame with friction dampers is described. The Capacity Diagram Method procedure is used to estimate the inelastic response of the example model. The example models were retrofitted using SBC dampers and the retrofitted example models were computationally modeled. The results show that the performance of the retrofitted frame satisfies the target objective.

1. Introduction

Structural aid systems are required to avoid damage of components of buildings during earthquakes and have been advanced and are at various stages of development. One innovation is the friction damper. However, the proper design method, which can be used practically for design engineers, for the retrofitted structures with friction dampers has not been provided.

Through the review and comparison of several Performance Based Design (PBD) Guidelines, (including ATC-40 and FEMA 350), the performance objectives and criteria of FEMA 350 were selected for use in this study. The future effective use of PBD methodologies depends on the availability of reliable and convincing inelastic analysis procedures. The Capacity Diagram Method (CDM) procedure approach based on R-μ-T relationships is investigated. This procedure is applied to the RC frame (RCF) structures based on PBD concepts using IDARC program (Valles et al., 1999). Two levels of earthquake hazard, which are 10% and 2% exceedance in 50 years, are applied to the old and retrofitted RC frames.

2. CDM Procedure

The CDM procedure begins with plotting the elastic spectrum. The elastic spectrum format is a function of the spectral acceleration and the natural period. The elastic spectrum is a converted to ADRS (Acceleration-Displacement Response Spectra) format using:

$$D_e = \frac{T^2}{4\pi^2} A_e \tag{1}$$

where A_e and D_e are the spectral acceleration and displacement corresponding to elastic systems. From a bilinear representation, the yield strength can be defined:

$$f_y = \frac{A_e w}{R_y g} = \frac{A_y w}{g} \tag{2}$$

where w is the weight of the building, R_y is a reduction factor due to ductility ($R_y = A_e / A_y$), and A_y is the pseudo acceleration, which is related to corresponding ductility, the natural period, and the damping ratio of the elastic system. For inelastic spectra, S_a (inelastic spectral acceleration) and S_d (inelastic spectral displacement) are given by (Fajfar, 1999)

$$S_a = \frac{A_e}{R_y} \tag{3}$$

$$S_d = D_e \frac{\mu}{R_y} = \mu \frac{T^2}{4\pi^2} \frac{A_e}{R_y} \tag{4}$$

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Eq. 4 can be rewritten

$$S_d = \frac{\mu}{R_y}\frac{T^2}{4\pi^2}A_e = \mu\frac{T^2}{4\pi^2}S_a \tag{5}$$

The demand spectra can be plotted using Eq. 3 and 4 as shown in Figure 1. The peak displacement of the Multi-DOF can be obtained using the S_d of SDOF in Eq. 5 as follows:

$$D_i = \Gamma S_d = \frac{\sum_{i=1}^{N} m_i \Phi_i}{\sum_{i=1}^{N} m_i \Phi_i^2} S_d \tag{6}$$

where Γ is the modal participation factor, Φ is the normalized displacement shape of each floor, and m is the story mass.

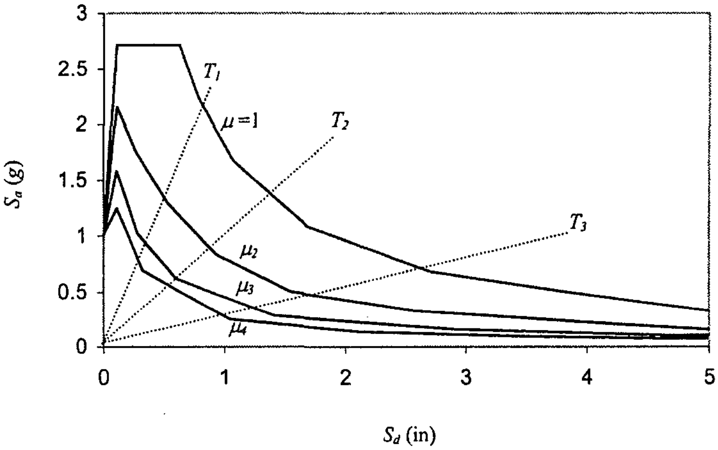
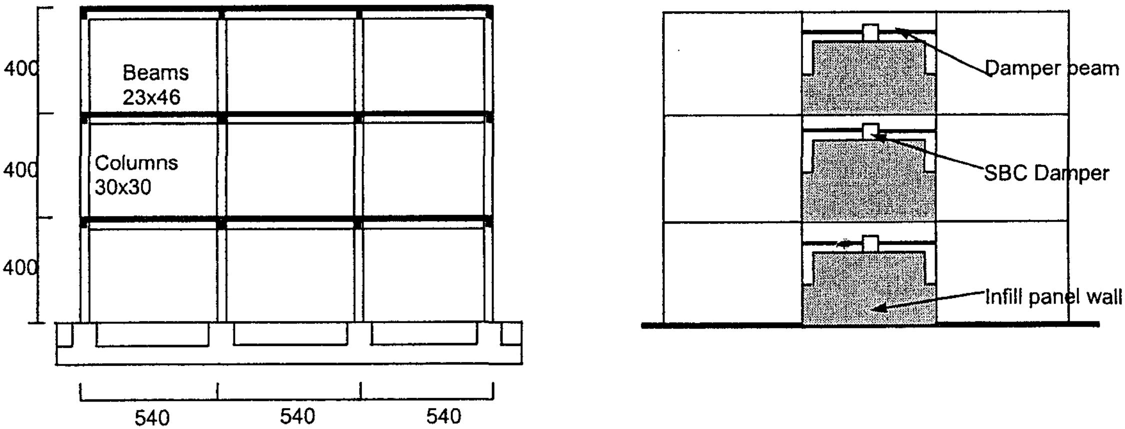


Figure 1 Schematic of Inelastic demand spectra

3. RC Frame Model



(a) existing RC frame (cm)

(b) retrofitted RC frame

Figure 2 Front elevation of the example RC frame

A one-third scale model of a low-rise RCF was investigated. As this typical RCF was designed with outdated detailing procedures, which did not consider the possibility of seismic loadings, the building would not effectively resist severe earthquake motions. Therefore, it is necessary to evaluate the performance of this type frame against specified earthquakes. Figure 2 (a) and (b) shows a schematic of the unretrofitted RCF and retrofitted RCF, respectively.

The computational modeling of the example RCF is performed using the IDARC 5.0 program. The bilinear hysteretic model is included for structural elements. Beams are modeled using flexural elements with shear deformations coupled. Columns are modeled considering flexural, shear and axial deformations. The boundary condition at the bases is modeled as fixed. The damping matrix is specified using Rayleigh damping coefficients. Table 1 shows dynamic properties of the RCF.

Table 1 Dynamic properties of the example RCF

	Weight (kN)	Height(m)	Period(s)	Mode Shape
Unretrofitted Frame	543	12	1.30 0.52 0.38	1.00 -0.74 -0.52 0.86 0.28 1.00 0.51 1.00 -0.69
Retrofitted Frame	801	12	1.2 0.55 0.41	1.00 -0.74 -0.64 0.92 0.50 1.00 0.67 1.00 -0.54

4. Earthquake Ground Motion

Two seismic hazard categories having exceedance probabilities of 2% in 50 years and 10% in 50 years earthquake ground motions have been selected for evaluating the performance of the example models. The time histories are scaled to match their spectral values with the USGS mapped values for the appropriate return period. Ground motions are time scaled by a factor of $1/\sqrt{3}$ so as to meet the similar requirements of the example models. Detailed information of these records is shown in Table 2.

Table 2 Earthquake ground motion

Level	Record Name	M_w	R_d(km)	Δt(sec)	PGA(g)
10% exceedance in 50 years	Imperial Valley, 1940, El Centro	6.9	10	0.02	0.46
	Northridge, 1994, Rinaldi RS	6.7	7.5	0.005	0.58
2% exceedance in 50 years	1989 Loma Prieta	7	3.5	0.01	0.47
	1994 Northridge	6.7	7.5	0.005	0.94

Note) M_w is Earthquake magnitude, R_d is Distance from earthquake source to station, Δt is measured time distance, and PGA is Peak Ground Acceleration

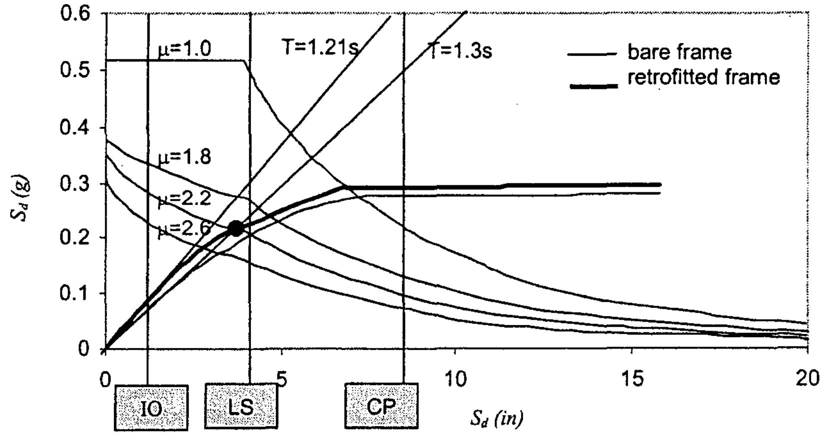


Figure 3 CDM plot for the example RCF under 10% / 50 yrs Northridge earthquake

5. Performance Evaluation for Retrofitted RCF

The capacity and demand curves for the bare frame and the retrofitted RCF are shown in Figures 3 for the 10% / 50 yrs Northridge earthquakes. After retrofitting the RCF, the capacity curves of the retrofitted frame show trilinear behavior. The curves indicate the period is reduced, the stiffness is increased, and the performance point is shifted to the target performance, compared to the bare frame. For Figure 3, the unretrofitted capacity curve indicates that the initial period is approximately 1.3 seconds and ultimate spectral acceleration is approximately 0.24g. After retrofitting the frame, the capacity curves show trilinear behavior and indicate that the initial elastic period of the retrofitted structure is 1.21 second. The performance points of the retrofitted structure shift to a spectral displacement which is less than 4.1 inches. Furthermore, the performance stage is the Life Safety (LS) stage, as shown in Figure 3. The performance point of the retrofitted structure is the LS stage under 10% / 50 yrs Northridge earthquake as shown in Figure3. Table 3 shows the performance points and objectives of the RCF. According to these results, the retrofitted RCF attains the selected Basic Safety Objective (BSO).

Table 3 Performance evaluation of the retrofitted RCF

	Bare Frame		Retrofitted Frame	
	P.P (S_d, S_a)	Stage	P.P (S_d, S_a)	Stage
El Centro (10% / 50 yrs)	(4.8, 0.24)	CP	(4.1, 0.21)	LS
Northridge (10% / 50 yrs)	(5.1, 0.25)	CP	(3.2, 0.22)	LS
Loma Prieta (2% / 50 yrs)	(10, 0.25)	Collapse	(8.3, 0.26)	CP
Northridge (2% / 50 yrs)	(10, 0.25)	Collapse	(8.7, 0.28)	CP

6. Conclusion

This study focuses on the application of PBD concepts to retrofitted structures with friction dampers using CDM. The example model was retrofitted using friction dampers and the retrofitted example model was computationally modeled. The CDM procedure was performed on the retrofitted example frame with PBD criteria. Due to the retrofitting of the example frame, the performance stage shifts from CP stage to LS stage under 10% / 50 years earthquake motions, and from Collapse stage to CP stage under 2% / 50 years earthquake motions. These performances of the retrofitted building satisfy the target objective. The results indicate that using friction dampers for retrofitting RC frames is effective.

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