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Effect of Reinforcing Steel Modeling in Seismic Collapse Assessment of Reinforced Concrete Buildings

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ABSTRACT

The effect of different reinforcing steel models used to characterize the behavior of reinforced concrete components is investigated in the context of developing collapse fragilities of a typical reinforced concrete moment frame building subjected to seismic loading. Incremental Dynamic Analyses are carried out using 20 site-specific ground motions to generate demand-intensity curves. The maximum inter-story drift ratio is selected as the critical seismic demand parameter and the spectral acceleration at the first mode period of the model is selected as the intensity measure. Two different approaches were used to specify the nonlinear behavior of the reinforcing steel: a uniaxial Giuffre-Menegotto-Pinto steel material with isotropic strain hardening and a trilinear model with post-peak softening. Additionally the structure was modeled using concentrated plasticity with moment-rotation springs whose multilinear hysteretic parameters were determined through pushover analysis of the elements. It is shown that the results can be sensitive to the choice of the constitutive model for reinforcing steel. Care should be taken to accurately model material and element behavior when developing collapse fragility curves for reinforced concrete structures.

1. INTRODUCTION

The development of collapse fragility curves is widely used for assessing seismic vulnerability. Haselton et al. (2011) examined the collapse safety of different buildings using this approach. Thirty different ductile RC moment frame buildings from 1 to 20 stories with different bay widths are studied. In addition, nonductile frames are examined for comparison (Liel et al. 2011). Besides, collapse fragility approach is a useful tool to examine uncertainties affecting building collapse. By comparing collapse fragility functions for short and long duration ground motions of different buildings, Raghunandan and Liel (2013) established the significance of ground motion duration in

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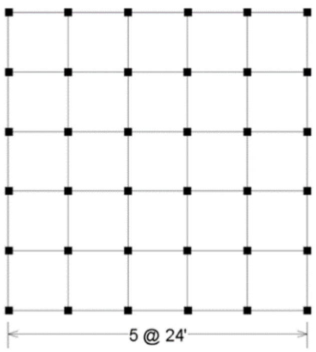
collapse analysis. Although collapse fragility approach is popular, the effect of different constitutive models to simulate the nonlinear behavior of reinforcing steel is rarely investigated. Concentrated spring models using nonlinear hinges with degrading strength and stiffness developed by Ibarra et al. (2005) was used by Haselton et al.(2011).

In this study, fiber-based models and concentrated spring models are used to model RC frame elements. Uniaxial Giuffre-Menegotto-Pinto steel material (Steel02 in OpenSees) with isotropic strain hardening and Hysteretic material model with post-peak softening are used to simulate reinforcing steel behavior for fiber-based frame elements. Moment-rotation with hysteretic behavior is used for the concentrated spring model. The effect of different reinforcing steel material models on the collapse probability of a typical 6-story reinforced concrete (RC) frame building is thus examined. To evaluate the difference in the response of the building to different types of reinforcing steel material models, the building model was subjected to a set of near-fault ground motions which contain strong coherent dynamic long period pulses and permanent ground displacements caused by rupture directivity effects.

2. BUILDING DETAIL AND GROUND MOTIONS

The building selected for the evaluation study was designed for a site in San Francisco in accordance with the requirements of ASCE/SEI 7-16 (2016) and ACI 318-14 (2014). The following spectral values were used to establish the design base shear: S_s = 1.715 g and S_1 = 0.792 g. The building is a typical 6-story RC frame building with a total height of 85 feet, with the first floor being 20 feet. The plan view of the building is shown in Fig.1. Additional design information, including section sizes and reinforcing details are also provided in the figure. The building is symmetric in plan, hence only a typical interior frame was considered in the analysis. An eigenvalue analysis of the building model resulted in the following modal periods: T1 = 1.09 sec, T2 = 0.37 sec.



	Beams				Columns		
Floor	Size, b x h (in x in)	Long. Reinf. Bott.	Long. Reinf. Top	Trans. Reinf.	Size, h	Long. Reinf.	Trans. Reinf.
1	26x30	8 #9	8 #10	#3 @ 6	30	14#12	#4 @ 5
2	22x30	6 #8	6 #9	#3 @4.8	30	14#12	#4 @ 5
3-5	22x28	6 #8	6 #9	#3 @4.8	28	11#12	#4 @ 5
6	20x24	3 #8	3 #8	#3 @4.8	24	8#12	#4 @ 5

Fig.1 Plan view of the 6-story RC frame building with section and reinforcement details

The building was subjected to ground motions with a velocity pulse consisting of 20 records extracted from the PEER Strong Motion database. Criteria used in the selection were: magnitude 5.0 – 8.0, fault distance 0 – 20 km (for pulse records) ad 0 –

30 km (non-pulse records), and soil sites with shear wave velocity 200 – 400 m/s. Fig.2 shows the spectra of the individual records. The design response spectrum and the median spectrum of the selected records are also superimposed in the same figure.

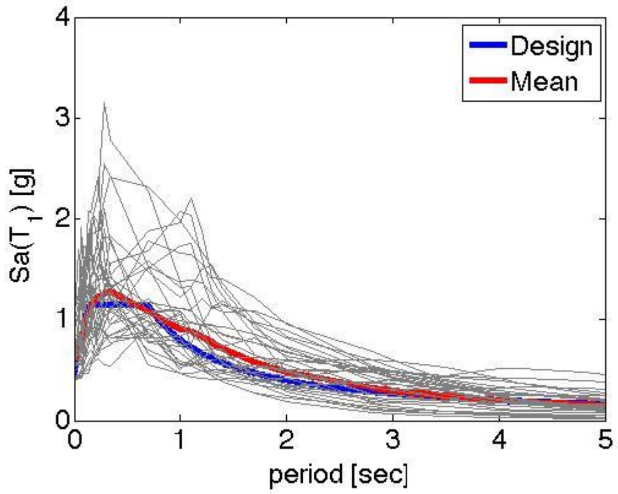


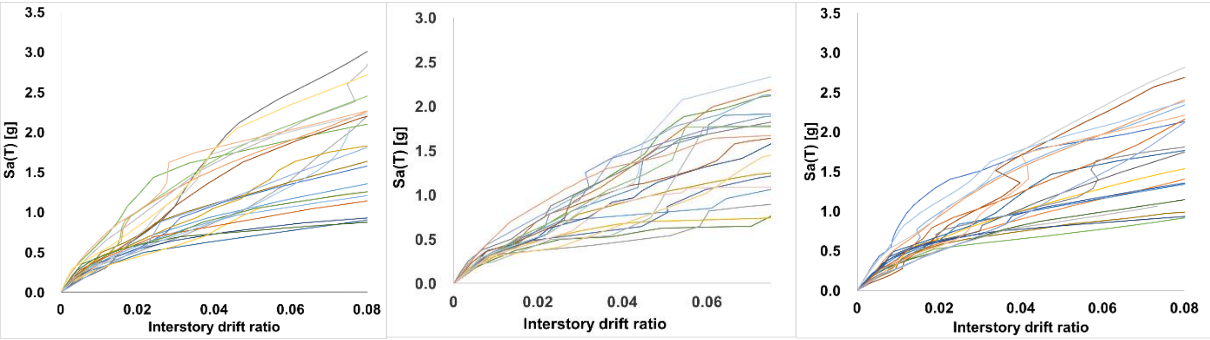
Fig. 2. Spectra of ground motions used in the simulations

3. SIMULATION RESULTS AND FINDINGS

Incremental Dynamic Analysis (IDA) was used to establish the collapse fragility curves for the building. Two-dimensional nonlinear response history analysis (NRHA) for generating the IDA curves was performed on the frame model using the OpenSees (2017) platform. Three different models are used to specify the nonlinear behavior of the reinforcing steel. In the first method (Model A), the steel reinforcing bars were modeled using the Steel02 model, which constructs a uniaxial Giuffre-Menegotto-Pinto steel material with isotropic strain hardening. For the second method (Model B), the Hysteretic model is used so that softening behavior was specified beyond the ultimate stress. The first and second methods use force-based nonlinear beam-column elements for all members, with four and five integration points along beam and column elements, respectively. A fiber section model is used at each integration point, which in turn is associated with uniaxial material models. The columns were assumed to be fixed at base floor. The material used to define the concrete is the “Concrete 02 Material” which utilizes the well- known Kent & Park model in compression and linear elastic behavior in tension up to tension cracking followed by linear softening. The third method (Model C) uses the concentrated plasticity concept with rotational springs. The multilinear hysteretic parameters of the moment-rotation springs were determined through pushover analysis of the elements. In this model, elements are modelled using elastic beam-column elements. Collapse is defined as the point of dynamic instability, where the lateral story drifts of the building increase without bounds. This typically occurs when the IDA curve becomes flat. In many cases, the so-called flat-lining of the IDA curve was not evident and these simulations were excluded from the study.

Ultimately, a peak inter-story drift of 6% was used to classify a collapse state. The IDA curves used to generate the collapse fragilities are shown in Fig.3. IDA curves highlight the variability of the required earthquake intensity to induce collapse. The obtained collapse fragilities for each model are displayed in Fig.4.

The following conclusions can be drawn from the study: the collapse probability for both Model A and Model C are approximately similar. When fiber-section discretization and uniaxial material models are used (model A and model B), the probability of collapse is higher for Hysteretic model than Steel02 model. The comparison of fiber-based model (model B) and concentrated spring model (model C) shows that the concentrated spring model is more conservative. Further studies examining other reinforcing steel material models is ongoing.



(a) (b) (c)

Fig.3. IDA curves for 3 models: (a) Model A; (b) Model B; (c) Model C

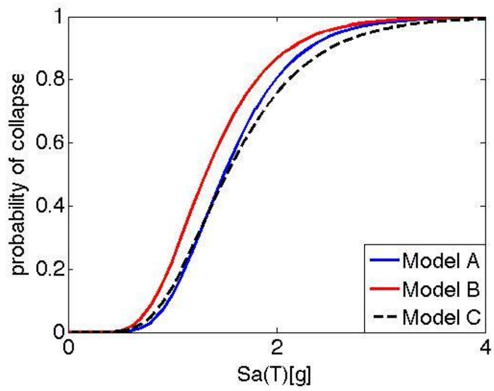


Figure 4. Collapse fragility

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