A Retrofitting Framework for Pre-Northridge Steel Moment-Frame Buildings

Arnar Bjornsson[1)](arnar@caltech.edu), Swaminathan Krishnan[2)] (krishnan@caltech.edu)

1) PhD Candidate in Civil Engineering, California Institute of Technology, USA

2) Assistant Professor of Structural Engineering and Geophysics, California Institute of Technology, USA

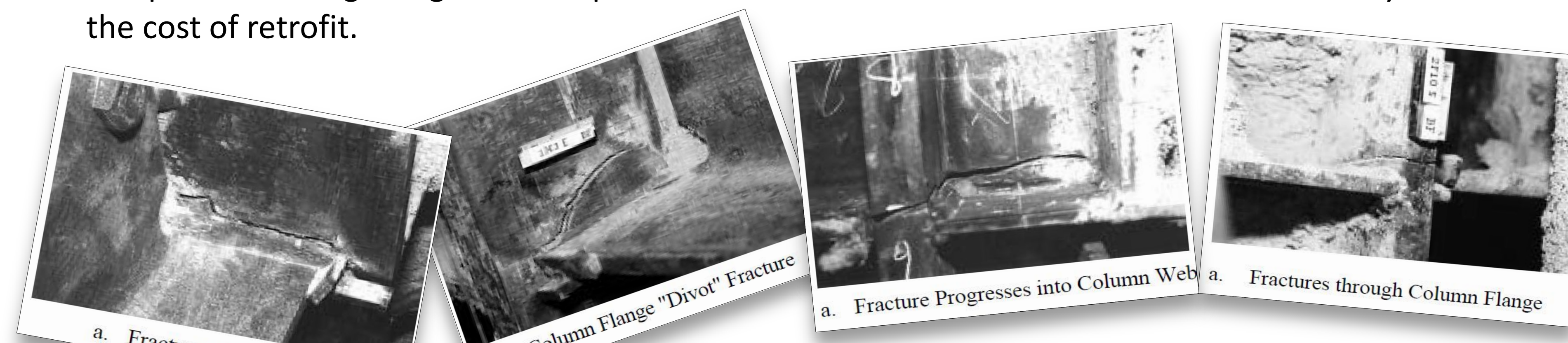
peer.berkeley.edu

1 Introduction

In the M_w 6.7 Northridge earthquake many beam-to-column connections in steel moment-frame buildings experienced brittle fractures, even at low levels of shaking. Prior to this event, the connections were believed to be very ductile and were widely utilized in the construction of tall buildings. There is a great deal of uncertainty regarding the number and extent of this localized failure mode in existing buildings in southern California and majority of these buildings have been left unaltered. They may be susceptible to collapse in the event of a major earthquake. Retrofitting measures that realize a lower probability of collapse for the structures at a given intensity of ground shaking when compared to the existing versions must be taken. These measures also need to be economically feasible and, to the extent possible, must preserve the architectural integrity and functionality of the building.

Rupture-to-rafters simulations offer a convenient platform for exploring possible benefits of a range of retrofit schemes that could be adopted for a given building. By generating multiple plausible realizations of large ruptures on the most threatening fault systems in the proximity of the building, computing the response of a range of retrofit schemes to the resulting ground motions and performing a cost-benefit analysis on the suite of retrofit schemes, we can identify the optimal scheme with the greatest reduction in collapse potential for the least cost.

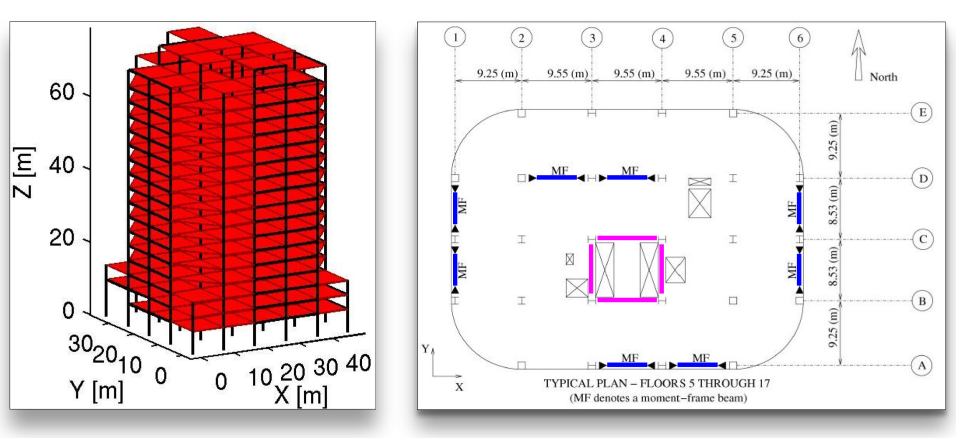
In order to systematically develop a framework for retrofitting existing pre-Northridge steel moment-frame buildings, we start with a case study of an existing 18-story office building. We develop 13 retrofit schemes which involve progressively increasing degrees of intervention (in this study we investigate potential benefits of chevron brace frame systems only). FRAME3D models of the existing building and the 13 retrofit schemes are analyzed under synthetic ground motions from the magnitude 7.8 ShakeOut scenario and a magnitude 7.9 1857-like San Andreas fault earthquakes and a magnitude 7.2 earthquake on the Puente Hills fault, underneath downtown Los Angeles. We compute the margins against collapse of each model for each record and simultaneously estimate the cost of retrofit.



Observed fractures from the Northridge earthquake (FEMA 2000)

2 The Existing Building

- The focal point of this study is an existing 18-story pre-Northridge steel moment-frame building, located within 5 miles of the epicenter of the Northridge earthquake. Many moment-frame beam-column connections in the building fractured during that event.
- The lateral force-resisting system consists of two-bay welded steel moment-frames (MF), two apiece in either principal direction of the structure as shown in the floor plan.



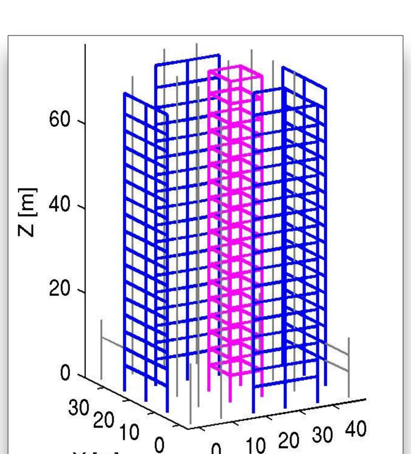
a) b)

a) Isometric view of a FRAME3D model of the existing building. b) Plan view of a typical floor plan in the existing building. The location of the MF bays and the elevator shafts are highlighted.

- Fundamental periods, computed assuming 100% dead load and 30% live load contribution to the mass, are 4.52s (X-translation), 4.26s (Y-translation) and 2.69s (torsion).

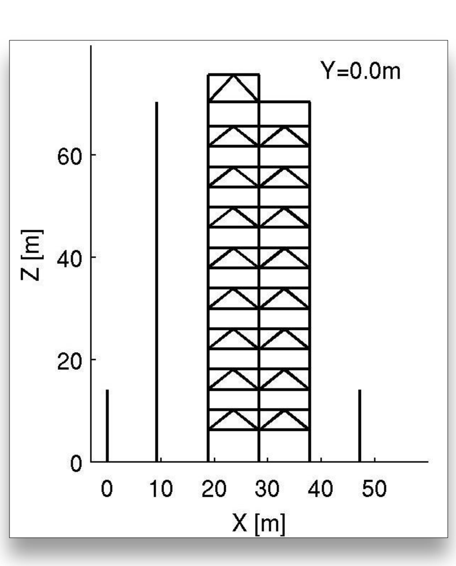
3 Retrofitting Strategy

i) Two locations within the floor plan of the existing building stand out as potential targets for introducing retrofit elements: **a) In the existing moment-frame bays** and **b) surrounding the elevator shafts.**



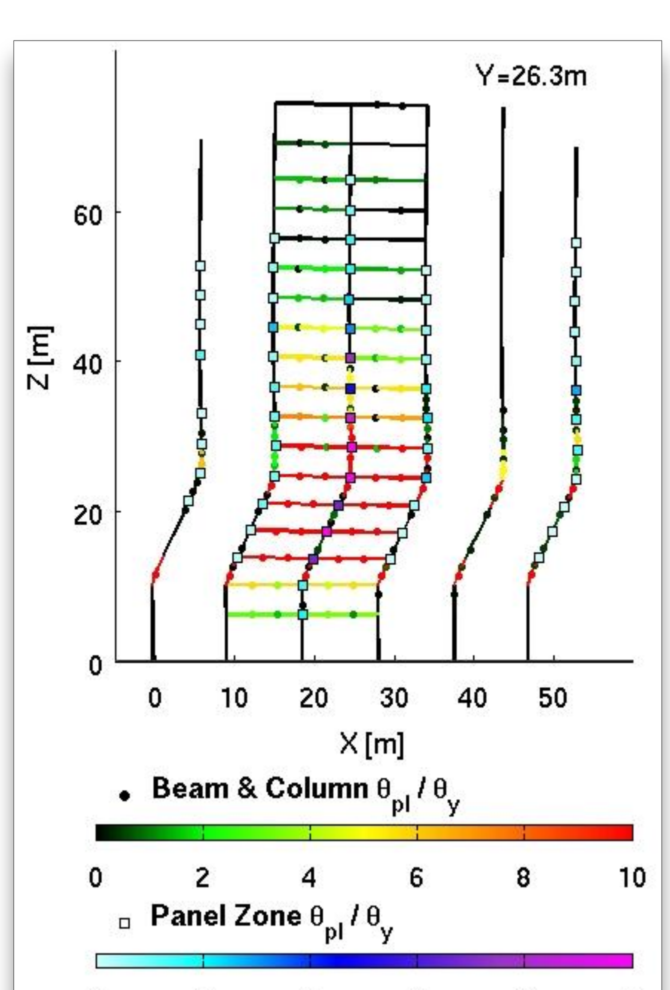
Isometric view of the MF bays and gravity columns in existing building, highlighting the two target locations for introducing retrofit elements. In the figure gravity beams are precluded except surrounding the elevator shafts.

ii) Introducing retrofit elements to every story vs. every alternate story. Introducing brace elements to the existing structural system renders it being more stiff and thus it attracts greater stiffness forces. Introducing retrofit elements to every alternate story only may reduce the P-Δ effects when compared to the existing building but at the same time will attract less stiffness forces compared to retrofitting every story.



Elevation view along the south MF bays showing a retrofit scheme that involves introducing brace elements to every alternate story only.

iii) Introducing retrofit elements to the lower half of the building alone vs. over the full height. Krishnan and Muto (2011) identified a side-sway mechanism located in the lower half of the existing building as being the preferred collapse mechanisms of the building. As a result, we investigate introducing brace elements to the lower half of the building alone as well as over the full height.



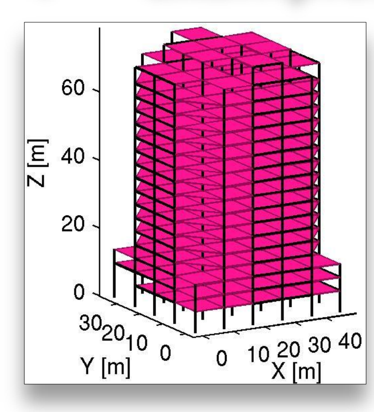
An elevation of the existing building being subjected to ShakeOut ground motion wave-forms at a site near downtown Los Angeles at the instance of simulated collapse. A side-sway collapse mechanism has formed in stories 3 through 6. Yielding in beams, columns and panel zones are shown with shapes and colors.

Notes:

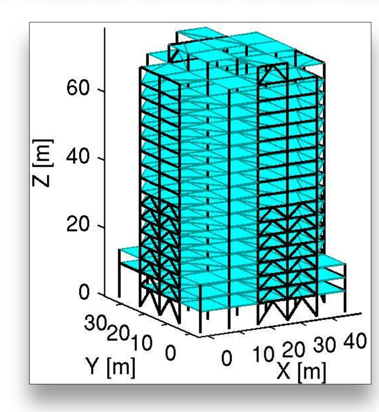
a) Using permutations and combinations of these retrofit measures we developed 13 retrofit schemes.

b) A nonlinear dynamic procedure is used to ensure that the retrofit schemes satisfy the Basic Safety Objective (BSO) as defined in ASCE-41-06, Seismic Rehabilitation of Existing Buildings. The short period and long period design spectral acceleration parameters (S_{XS} and S_{X1}, respectively) are taken as 2.09g and 1.07g, respectively, which is a conservative seismic loading for the greater Los Angeles region.

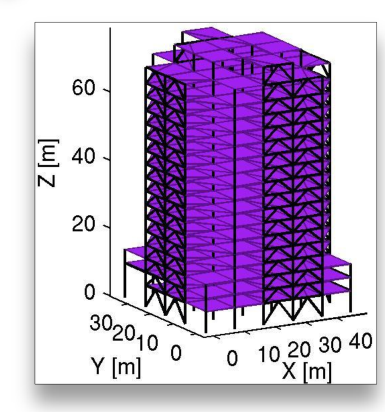
4 Examples of Retrofit Schemes



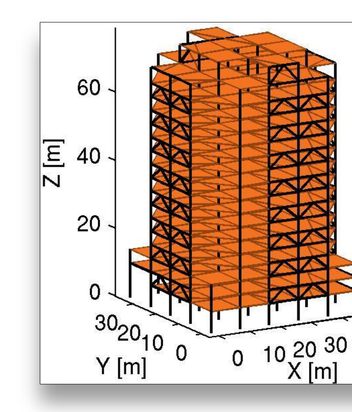
Retrofit Scheme (i): Boosted beam-column MF connections. ***T_1=4.40s, T_2=4.15s, T_3=2.59s***



Retrofit Scheme (ii): Chevron Bracing in every story in the MF bays in the lower half. ***T_1=3.07s, T_2=3.06s, T_3=1.85s***



Retrofit Scheme (iii): Chevron Bracing in every story in the MF bays over the full height. ***T_1= 2.09s, T_2= 2.03s, T_3=1.25s***



Retrofit Scheme (ix): Chevron Bracing in every alternate story in the MF bays over the full height. ***Natural periods are not available at this point.***

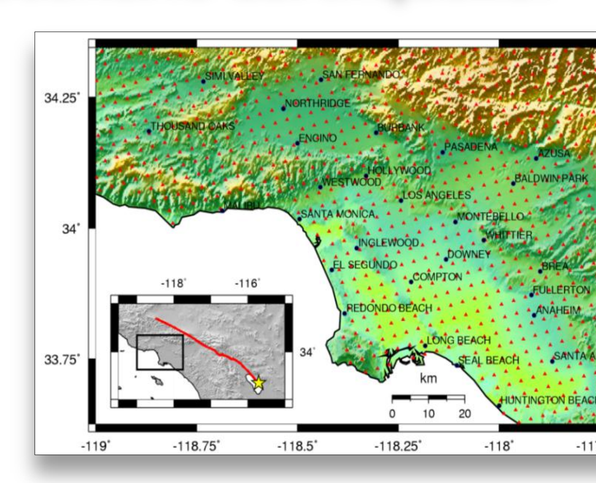
5 Performance in the M_w 7.8 ShakeOut Scenario Earthquake:

- **FRAME3D** models of existing building and retrofit schemes (i) through (iii) are subjected to 3-component synthetic ground motion waveforms from the ShakeOut scenario earthquake at 784 sites in the Los Angeles region.
- To evaluate building performance simulated peak inter-story drift ratio (IDR) at each site is compared against transient IDR limits set forth in ASCE-41-06. The IDR exceedance limits for the Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) performance levels for moment-frame (MF) and braced-frame (BF) systems are given as:

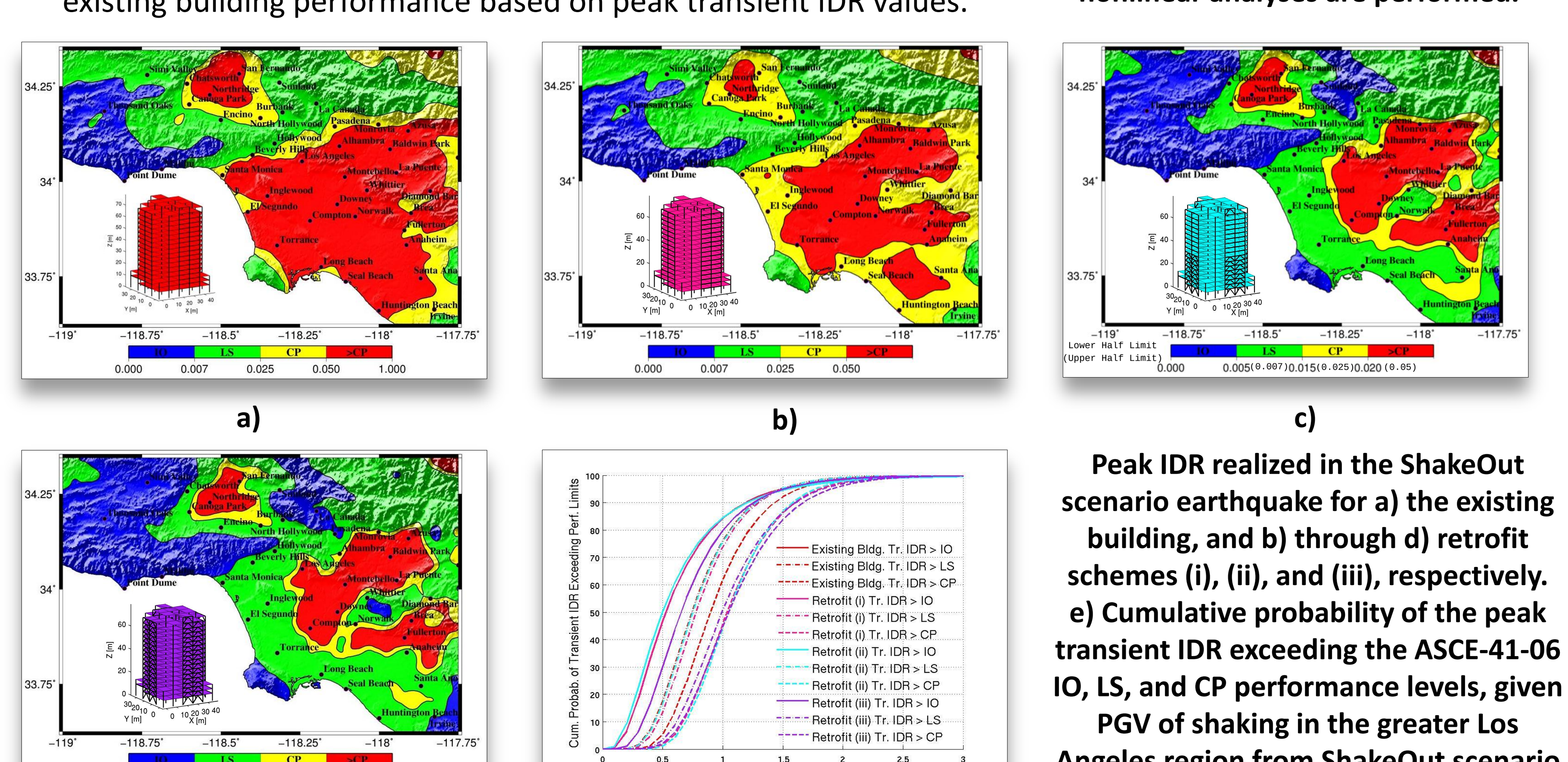
ASCE-41-06 transient IDR limits:

	IO	LS	CP
MF	0.007	0.025	0.05
BF	0.005	0.015	0.02

- The retrofit schemes show substantial improvement in structural performance at most locations when compared against the existing building performance based on peak transient IDR values.



Schematic view of the M_w7.8 ShakeOut scenario earthquake on the San Andreas fault. The rupture initiates in Bombay Beach, propagates northwest and terminates in Lake Hughes (Graves et al. 2011). The small triangles show the locations of the sites where the nonlinear analyses are performed.



a) b) c) d) e)

Peak IDR realized in the ShakeOut scenario earthquake for a) the existing building, and b) through d) retrofit schemes (i), (ii), and (iii), respectively. e) Cumulative probability of the peak transient IDR exceeding the ASCE-41-06 IO, LS, and CP performance levels, given PGV of shaking in the greater Los Angeles region from ShakeOut scenario earthquake

6 Conclusions and Future Work

- We present the initial steps of a more extensive body of work currently being undertaken. The ultimate goal of this work is to establish a retrofitting framework for pre-Northridge steel MF buildings.
- Through three retrofit schemes we achieve significant reduction in collapse potential for an existing 18-story office building, but to different degrees.
- Performing this kind of analyses on several index buildings would reveal what degree and cost of retrofitting would be required to gain a marginal reduction in collapse potential for this class of buildings.

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