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SEISMIC LOSS ASSESSMENT OF EXISTING TALL STELL BUILDINGS IN LOS ANGELES

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Abstract: There is a renewed and growing interest on seismic performance of the existing tall-building stock in Los Angeles during a major seismic event. Of particular interest is the seismic performance of existing high-rise buildings constructed before the 1994 Northridge Earthquake. These buildings have been designed without the help of the state-of-the-art nonlinear analysis methodologies and recently published performance based seismic design guidelines (PEER, 2010; LATBSDC, 2014), and have been known to contain defects in the welded beam-to-column connections rendering them susceptible to large earthquakes

This study involves nonlinear modeling of a 24-story existing steel building in Los Angeles. The building has been analysed under 7 two-component horizontal ground motions and a retrofit scheme is proposed based on the observed deficiencies. Seismic performances of the existing and the retrofitted buildings are compared, and loss estimation analyses are conducted using FEMA P-58 methodology and the PACT (Performance Assessment Calculation Tool) (Naeim et. al., 2007) software. Results indicate that repair cost, downtime and probability of getting unsafe placard after an earthquake can substantially be reduced by the proposed retrofit scheme. Further analyses results and the accompanying seismic strengthening studies will provide a wider picture of the region-wide impact of the next major earthquake and aid in reinforcing city of Los Angeles's vision of increasing seismic resiliency in its disaster mitigation plans.

Introduction

Having many active faults such as San Andreas, Hayward, San Jacinto, etc., California is the most seismically active state in the United States. Earthquake history of California dates back to 1769, when the first strong shaking occurred in Los Angeles. Since then, many severe earthquakes have taken place, some of the major ones being the 1994 Northridge, 1989 Loma Prieta, 1971 San Fernando, 1952 Kern County and 1906 The Great San Francisco Earthquakes (Figure 1). The most recent and the most memorable one among these is the magnitude 6.7 Northridge Earthquake of January 17, 1994, which resulted in death of 57 and injury of around 10,000 people. Property damage costs due to the 1994 Northridge Earthquake was estimated to be more than $20 billion, and the observed structural damage varied from multi-story wood frame buildings to hospitals and highways.

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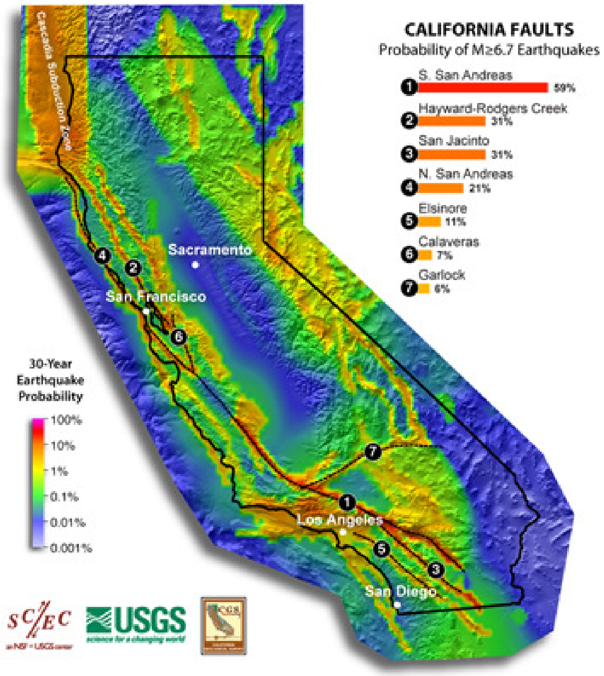
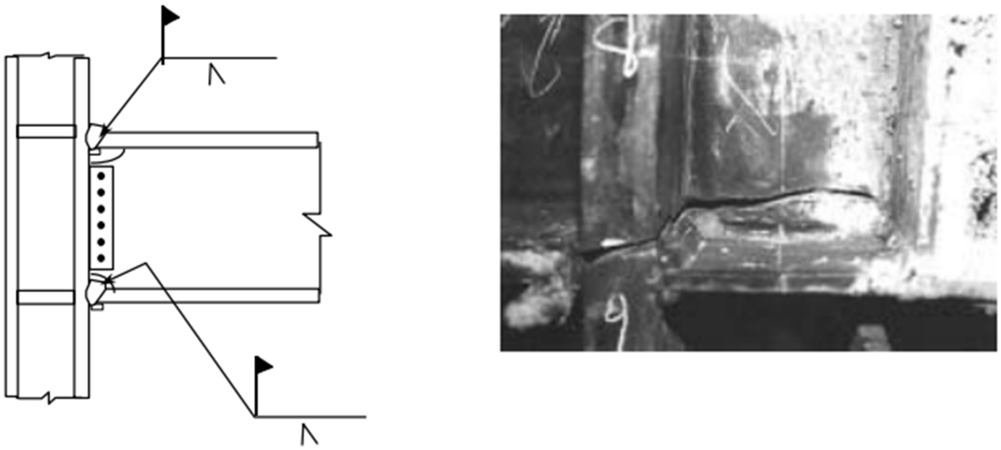


Figure 1. Major California faults

From 1960's to 1990's, moment-resisting frames were the most commonly used lateral load resisting system in California for medium to high-rise buildings. The performance of the concrete moment frame buildings of the era has been studied and has revealed significant deficiencies related to the non-ductile detailing practices of the time. Although there hasn't been a study of similar scope for steel moment-resisting frame buildings, their observed performance during the 1994 Northridge Earthquake has led the research and engineering community to expect similar deficiencies from these buildings (Gogus et. al., 2014).

The 1994 Northridge earthquake exposed the vulnerability of both older and newer steel moment frame structures to seismic-related damage. This damage was generally observed to be in the form of brittle failures at the interface of the beam and column members which progressed into column webs (Figure 2), and was found in buildings ranging from 10 to 30 stories in height (Gogus et. al., 2014).



(a) (b)

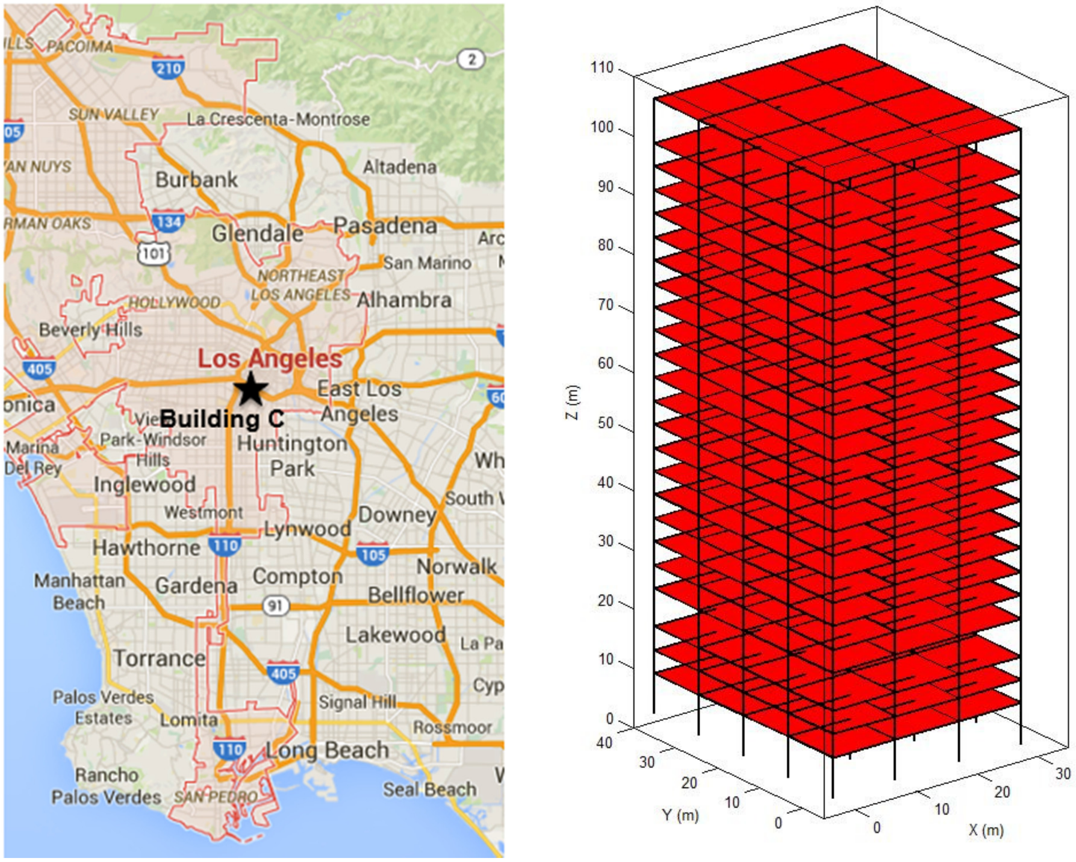
Figure 2. Pre-Northridge; (a) Typical welded moment-resisting connection (b) Fracture in column web (FEMA-355D, 2000)

The observations were mainly limited to the neighbourhoods that were affected by the Northridge Earthquake, and Downtown Los Angeles, where many of the medium to high-rise steel moment frame buildings were located, was outside of the mandatory inspection zone. After nearly two decades, the 2011 Christchurch Earthquake raised the concern on the expected seismic performance of the buildings in Downtown Los Angeles again. The performance of individual medium-rise buildings in downtown Christchurch had a big socio-economic impact on the whole surrounding area (Kam et al. (2011)) (Gogus et. al., 2014).

This paper focuses on one of the case study buildings (Building C) out of the four that were studied in the first phase. Building C is modeled using PERFORM-3D (Computers and Structures Inc., 2013) and analysed under seven two-component horizontal ground motion records. A retrofitted building is modeled based on the observed deficiencies of the existing building and loss estimation analyses using FEMA-P58 methodology are conducted. Results obtained from the existing and the retrofitted buildings are compared.

Site and Building Description

The case study building, Building C, is a 24-story pre-Northridge steel moment-frame structure which is located in downtown Los Angeles (Figure 3*)*. The building was built on a stiff to very dense soil site. Lateral load resisting system of the building consists solely of steel moment resisting frames. Gravity system consists of structural steel columns and beams supporting light-weight concrete on metal deck. Building parameters are summarized in Table 1.



(a) (b)

Figure 3. (a) Building location; and (b) Building model (Gogus et. al., 2014)

Table 1. Summary of the case study building

Building ID	Number of Stories	Typical Story Height (m)	Building Height (m)	Typical Grid Span (m)	Plan Dimensions (m x m)
C	24	4	105	10	30 x43

Seismic Hazard

Seven time history pairs which spectrally match to the Maximum Considered Earthquake (MCE) hazard level (2475 yr) for a site in Downtown Los Angeles were used to analyse the building (Melek et. al., 2014). The fault parallel direction was assumed to be parallel to the X axis of the building. Acceleration response spectra of the ground motions are provided in Figure 4. It is observed that for periods less than 4 seconds, the spectral accelerations of the records are closely matched, whereas a greater dispersion exists in the spectra for longer periods.

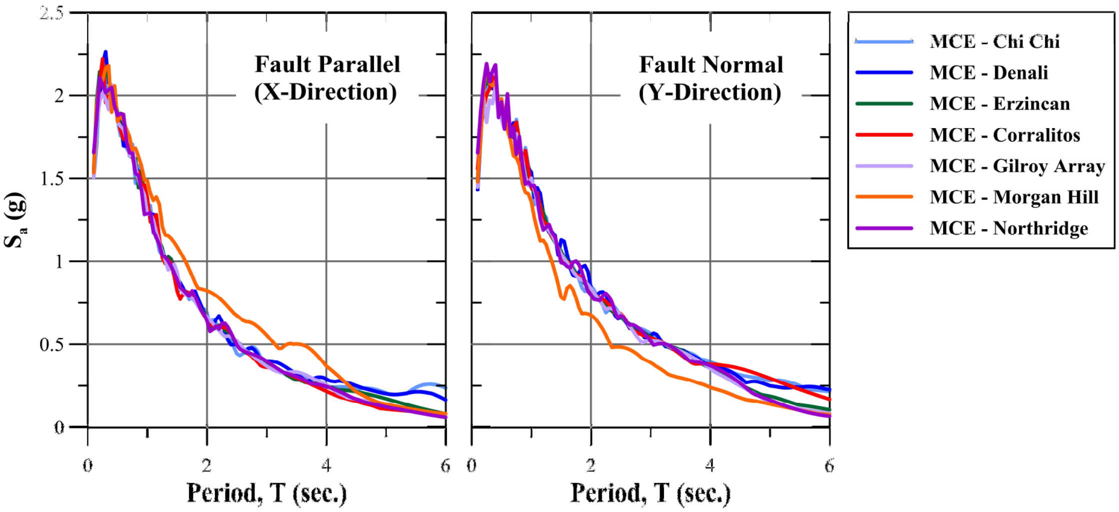


Figure 4. Acceleration response spectrum curves of Service Level and MCE scenario earthquake records for a site in Downtown Los Angeles (Melek et. al., 2014)

Nonlinear Modeling and Analysis

Nonlinear modelling and analysis of Building C was conducted using PERFORM-3D (CSI, 2013). Lumped plasticity model with modeling parameters based on ATC-72 (PEER/ATC, 2010) were used for the steel moment frame beams and columns. Panel zones were modelled using the connection panel zone type element with trilinear shear force and distortion behaviour (Figure 5) based on Gupta and Krawinkler (1999) and ATC-72 (PEER/ATC, 2010). An intrinsic damping of 2% has been assumed in the modeling of the structure.

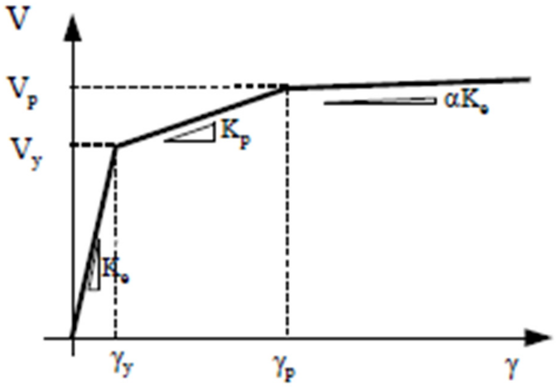


Figure 5. Panel zone behaviour (Gupta and Krawinkler, 1999)

Story shear demands of Building C are provided in Figure 6. Analysis results revealed that the building sustained some damage due to inter-story drifts as high as 10%. The observed high inter-story drift ratios were limited to the first three levels (Figure 7) and are associated with the development of soft story mechanisms. Accumulation of high rotation demands were observed on levels 14 to 19 in the X-direction, which is indicative of the rupture failure at beam connections. In addition, it was observed that a significant portion of the calculated plastic rotations at beam ends exceeded the plastic rotation capacities at the bottom eight levels. In order to improve the performance of Building C, a retrofit scheme has been studied.

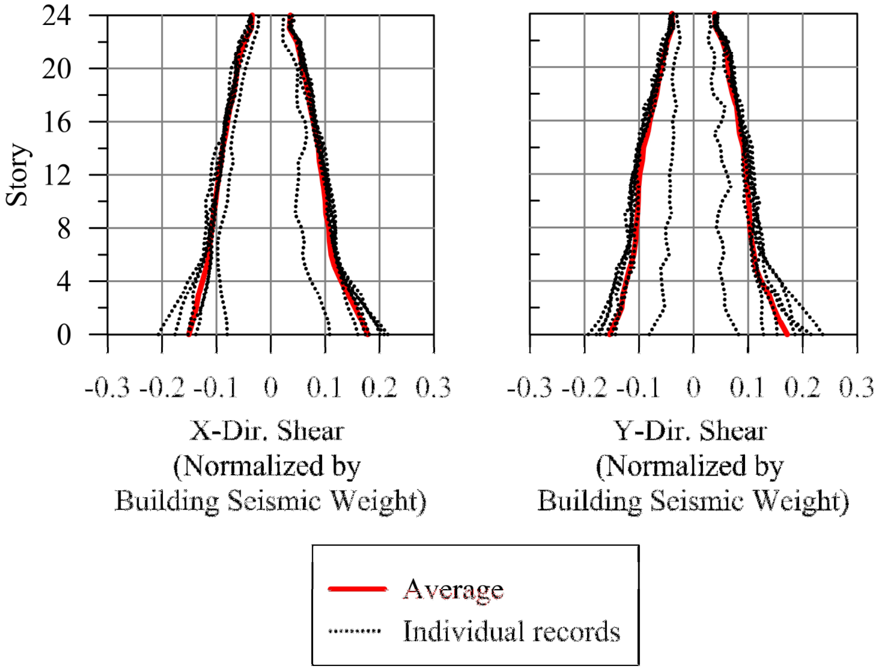


Figure 6. Story shears of Building C

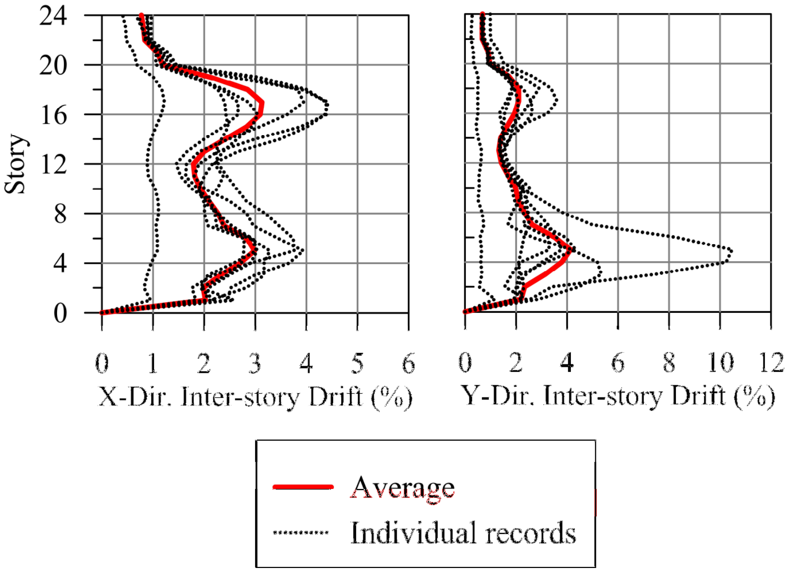


Figure 7. Inter-story drift demands on Building C

Retrofit Scheme

A retrofit scheme was implemented on Building C in which a total of 192 diagonally placed nonlinear viscous dampers (Figure 8) were used. The dampers were placed through the full height of the building along the perimeter as shown in Figure 9. Damper capacities varied from 2-MN to 6.5-MN. The non-linear characteristic that has been used to represent the damper is given as:

$$F = CV^{\alpha} \tag{1}$$

where; F is the restoring force, C is the damping constant, V is the end to end velocity across the element, and α is the velocity exponent constant, which typically ranges from 0 to 1. Nonlinear viscous dampers have α values less than 1, which is effective in minimizing high velocity shocks. The resulting force-deformation behaviour of the dampers is provided in Figure 10.

Figure 8. Viscous dampers

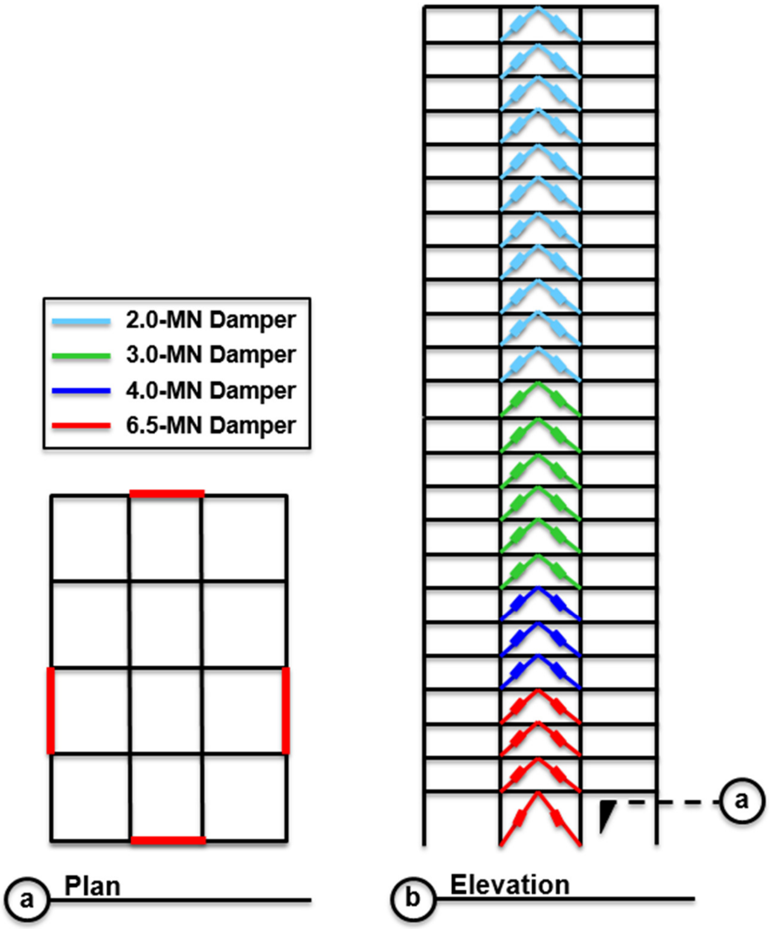


Figure 9. (a) Plan view; and (b) Elevation view of the viscous dampers

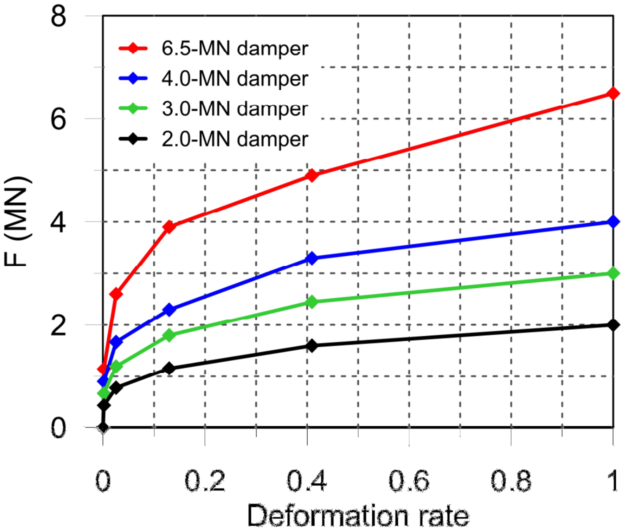


Figure 10. Force-deformation behaviour of the dampers

FEMA P-58 Evaluation

Loss estimation analyses using the FEMA P-58 methodology were conducted both for the existing and the retrofitted buildings in order to assess savings in repair cost, repair time, as well as the reduction in probability of getting unsafe placards.

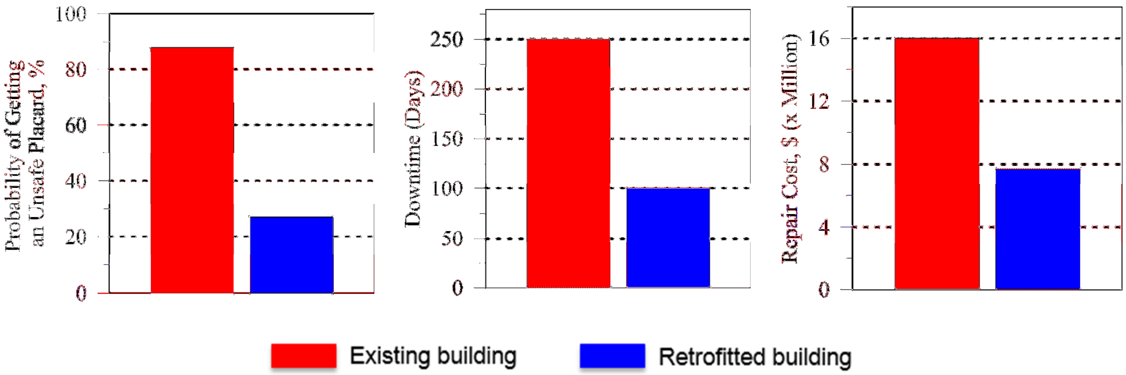


Figure 11. Comparison of FEMA P-58 assessment results of the existing and the retrofitted buildings

Figure 11 provides results of the FEMA P-58 evaluation. It is observed that the rehabilitation improves the building performance and the corresponding loss estimation results significantly. When the building is retrofitted, probability of getting unsafe placard after the MCE level seismic event decreases by 70%. Repair time of the building reduces from 250 days to 100 days, and around $8 million of savings is achieved in the repair cost as a result of the retrofit.

Conclusions

Expected seismic performance of a 24-story pre-Northridge steel moment resisting frame building located in Los Angeles has been studied by modeling and analysing the building in PERFORM-3D (CSI, 2013). Analysis results of the existing building show damage patterns similar to the ones observed after the 1994 Northridge earthquake. Brittle fracture failures at beam-column connections lead to a significant lateral strength and stiffness degradation at several floors yielding excessive story drifts and initiating an overall loss of stability which eventually would cause collapse.

Suggested retrofit scheme for the building, i.e., addition of dampers, improved the building performance and significantly reduced the repair cost, downtime and the probability of getting an unsafe placard after an MCE level seismic event.

Completion of similar building analyses would provide detailed information on the expected seismic performance of the existing medium to high-rise structural steel building stock in Los Angeles; thus a wider picture of the city-/region-wide impact of the imminent next major earthquake. Similar studies will help to reinforce City of Los Angeles's vision of increasing the seismic resiliency of the city in its disaster mitigation plans as well as be a motivation for other areas in the world which are susceptible to high seismic risks that would cause significant socio-economic impacts on the society.

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