WILL THE LOS ANGLES SOFT STORY ORDINANCE ENHANCE THE SEISMIC RESILIENCE OF THE CITY’S RESIDENTIAL COMMUNITIES?

H. V. Burton\(^1\)

H. Kang\(^2\)

**ABSTRACT**

The effect of the ordinance-mandated retrofit of woodframe soft-story apartment buildings in Los Angeles on the seismic resilience of a set of test-bed communities is assessed. Seismic resilience is quantified by the immediate loss of permanent housing occupancy as well as the time to recover some fraction of the pre-earthquake housing capacity. The study region comprised approximately 8000 residential buildings located in the neighborhoods of Koreatown, Westlake, Pico Union, Lomita and East Hollywood. The damage assessment was performed using HAZUS fragilities. The baseline fragilities were scaled to account for the difference in the vulnerability of the existing soft-story, existing non-soft-story and retrofitted soft-story buildings. These differences were established from the results of nonlinear response history analyses performed on structural models developed for a set of index buildings. The spatial distribution of damage was assessed using shaking intensities from the Northridge earthquake scenario and a stochastic process model was used to simulate the post-earthquake recovery. The effect of the retrofit on building damage increased with the severity of the damage, which is consistent with the primary focus on life safety performance. The ordinance retrofit reduced the immediate loss in housing for the soft-story buildings by about 20% and the time to restore 95% of the pre-event capacity was reduced by a factor of about four.

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\(^1\) Assistant Professor, University of California Los Angeles, CA 90095 (email: hvburton@ucla.edu)

\(^2\) PhD Candidate, University of California Los Angeles, CA 90095 (email: kanghua@ucla.edu)

Will the Los Angeles Soft Story Ordinance Enhance the Seismic Resilience of the City’s Residential Communities?

Henry V. Burton¹ and Hua Kang²

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The effect of the ordinance-mandated retrofit of woodframe soft-story apartment buildings in Los Angeles on the seismic resilience of a set of test-bed communities is assessed. Seismic resilience is quantified by the immediate loss of permanent housing occupancy as well as the time to recover some fraction of the pre-earthquake housing capacity. The study region comprised approximately 8000 residential buildings located in the neighborhoods of Koreatown, Westlake, Pico Union, Lomita and East Hollywood. The damage assessment was performed using HAZUS fragilities. The baseline fragilities were scaled to account for the difference in the vulnerability of the existing soft-story, existing non-soft-story and retrofitted soft-story buildings. These differences were established from the results of nonlinear response history analyses performed on structural models developed for a set of index buildings. The spatial distribution of damage was assessed using shaking intensities from the Northridge earthquake scenario and a stochastic process model was used to simulate the post-earthquake recovery. The effect of the retrofit on building damage increased with the severity of the damage, which is consistent with the primary focus on life safety performance. The ordinance retrofit reduced the immediate loss in housing for the soft-story buildings by about 20% and the time to restore 95% of the pre-event capacity was reduced by a factor of about four.

Introduction

In December 2014, the City of Los Angeles established the Resilience by Design initiative with the goal of enhancing the city’s resilience by strengthening its social and economic functions. As part of the initiative, the Mayor’s Office worked with various experts to develop tools and strategies to adapt to and recover from major disruptive events including storms, earthquakes and economic recessions. One of those initiatives, which was signed into law on October 9, 2015, mandated the seismic retrofit of existing soft, weak and open front (SWOF) woodframe buildings whose permit application for new construction was submitted prior to January 1, 1978. Residential buildings containing three dwelling units or less were exempted. The Los Angeles Department of Building and Safety (LADBS) estimates that there are 13,500 SWOF buildings through the city. The stated goal of the Ordinance is to “promote public welfare and safety by reducing the risk of death or injury that may result from the collapse of wood-frame buildings with soft or weak stories”.

The main objective of this study is to investigate the post-earthquake recovery-related benefits to the city of Los Angeles’ residential communities that is derived from implementing the ordinance-mandated SWOF retrofits. The study region comprised approximately 8000 residential buildings located in the neighborhoods of Koreatown, Westlake, Pico Union, Lomita and East Hollywood. Data on the number of stories, plan geometry and soft-story wall layout for the inventory was acquired using Google Street View. The data was used to develop a set of 40 index buildings that
capture the variation in the key structural characteristics of the inventory. In addition to geometric properties, variations in the type of panel was also considered. The existing index buildings were then retrofitted per the Ordinance requirements and nonlinear structural models (existing and retrofitted) constructed and analyzed in OpenSees assess the differences in vulnerability of the existing soft-story, existing non-soft-story and retrofitted soft-story buildings. The spatial distribution of damage was assessed using the Northridge earthquake shaking intensities and post-earthquake recovery was simulated using a stochastic process model. The goal is to compare the recovery trajectories for livable housing existing and SWOF-retrofitted inventories. The results of this study will provide useful insights into the extent to which a policy that was primarily targeted towards public safety, enhances community resilience.

**Inventory and Damage Assessment**

Figure 1 shows a map of the distribution of soft story buildings in the five neighborhoods considered in the study. Green points indicate the building has no soft story. Red points specify partial or full soft story buildings. The location, number of stories and the wall layout in the 1st/soft story were obtained from Google Maps and Google Street View. Information on the year of construction for individual buildings was obtained from Zillow (http://www.zillow.com/). This information was used to compute the shaking intensity and select the appropriate HAZUS [1] fragility function. Forty index buildings (32 soft-story and 8 non-soft-story) were developed for the study based on the following structural considerations: wall layout in 1st (soft story), plan aspect ratio, the type of interior panel, and the number of stories. The four 1st story layouts shown in Figure 2 were considered in the development of the index buildings. A fifth non-story story layout was also considered. Plan aspect ratios of 2:1 and 3:1 are incorporated. 2- and 3-story height variations are considered, which represents over 95% of the soft-story buildings in the five neighborhoods. Exterior panels are assumed to be stucco and gypsum and plaster on lath interior panel variations are included. An additional set of 32 index buildings were developed, representing the soft-story buildings retrofitted in accordance with the
requirements of the ordinance.

The basic HAZUS fragility functions were used for the non-soft story buildings in the neighborhood inventories. Structural models of the 72 index buildings (32 existing soft-story, 32 retrofitted soft-story and 8 existing non-soft-story). The structural models were analyzed using incremental dynamic analyses and the engineering demand parameters were used to develop fragility functions corresponding to the HAZUS damage states (none, slight, moderate, extensive and complete). The fragility functions for the existing soft-story buildings in the inventory were obtained by scaling the basic HAZUS fragilities based on the ratio of the median values of the existing soft-story and non-soft-story fragilities generated using nonlinear response history analyses. The fragility functions for the retrofitted soft-story buildings were obtained by scaling the existing soft-story fragilities by the ratio of the median values of the existing and retrofitted soft-story buildings.

The building fragilities were coupled with the spatially interpolated spectral accelerations corresponding to the Northridge earthquake scenario to generate multiple realizations of building level damage within the target region. Given the spectral acceleration associated with the building, a discrete probability distribution is obtained for the five limit states. Monte Carlo simulation is used to generate 1000 realizations of damage for each building. Figure 3a shows that the ordinance retrofit has reduced the overall level of damage. It can also be observed that the impact of the ordinance retrofit is higher for the more severe damage states. For example, the fraction of buildings in the moderate damage state is reduced by 11% when the ordinance retrofit is applied. In contrast, the retrofit reduces the fraction of buildings with extensive and complete damage by factors of 1.73 and 2.87 respectively.

The methodology developed by Burton et al [2] was used to map fragility functions from the HAZUS loss-based to recovery-based (e.g. building closure, demolition and collapse) building damage states. Figure 3b shows the distribution for recovery-based limit states.

![Figure 3. Damage distribution of (a) loss-based and (b) recovery-based limit states for light wood frame buildings in the target distinct.](image-url)
Stochastic Process Post-Earthquake Housing Recovery Model

A stochastic process model [2] was used to simulate post-earthquake recovery, which uses building damage and median time of each recovery activity from HAZUS and REDi to evaluate. Four functioning states associated with the following activities are used: (1) post-earthquake inspection, (2) acquisition of financing for repairs, (3) engineering assessments (where needed) and mobilization for construction (e.g. permit acquisitions) and (4) repair and reconstruction. Figure 4 shows recovery curves for only the soft-story buildings under existing and retrofitting condition. The ordinance retrofit reduces the loss immediately after the earthquake by about 20% and the time to recover 95% of the pre-event housing capacity decreases about 200 days to 50 days.

Conclusion

The City of Los Angeles enacted an ordinance to mandate the retrofit of soft-weak and open front wall woodframe buildings. In this study, the effect of the ordinance-mandated retrofit on the seismic resilience of a set of test-bed communities is assessed. The results showed that the degree to which the retrofit reduced building damage increased with the severity of the damage. This observation is consistent with the intended life safety performance objective for the retrofit. The immediate loss in housing capacity was reduced by about 20% when the ordinance-mandated retrofit was applied and there was approximately a four-fold reduction in the time to restore 95% of the pre-event capacity.

References