Los Angeles Inventory: Implications for Retrofit Policies for Nonductile Concrete Buildings

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SUMMARY:
Nonductile concrete buildings arguably represent the one of the greatest seismic life safety hazards in many urban centers world-wide because of their collapse potential. This paper discusses the preliminary results of an inventory to evaluate the risk from the approximately 1500 potentially nonductile concrete buildings in the City of Los Angeles. In an effort to identify typical building configurations, inventoried buildings have been categorized by age of construction, height, and use. Due to economic and development trends, the majority of buildings were built in the 1920s and 1960s. Although 1-3 story buildings predominate the inventory, approximately 40% of the square footage is in buildings 8 stories or taller. The HAZUS methodology is being used to estimate potential losses when the inventory is subjected to two likely earthquakes. The data are being utilized to inform ongoing physical and analytical simulations of performance of older concrete construction and to develop improved loss estimation tools and policy alternatives.

Keywords: Nonductile concrete, inventory collection, risk evaluation, policy development

1. INTRODUCTION

Nonductile concrete buildings were a prevalent construction type in highly seismic zones of the U.S. prior to enforcement of codes for ductile concrete in the mid-1970s. In California, nonductile concrete buildings were principally constructed between approximately 1890 (when elevators first enabled the construction of relatively tall buildings) and the mid 1970s (when improvements in building codes that reduce collapse risk were implemented). The Concrete Coalition estimates that in California, alone, 20,000 to 23,000 of these buildings exist, including residential, commercial, schools, and critical service facilities (Comartin et. al., 2011; Concrete Coalition, 2011). This type of construction is common internationally as well, and remains widespread in many developing countries. The poor seismic performance of nonductile concrete buildings has been documented in many earthquakes in both developed and underdeveloped countries, including in recent events such as New Zealand (2011) (Smyrou et al., 2011) and Haiti (2010) (O'Brien, et. al.,2011).

This inventory work is a component of a broader "Grand Challenge" project funded by the United States National Science Foundation (NSF) through the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) program. The objective of the broader project is to mitigate collapse risk of older nonductile concrete buildings subjected to earthquakes. It should be noted that while older tilt-up buildings were often constructed with deficient connections between the walls and roof diaphragm, posing a collapse hazard, they are not included in this study. The major components of the Grand Challenge project are to develop an inventory of older concrete buildings for a specified study area, to estimate collapse consequences with existing tools (e.g., HAZUS) using the inventory and the best available ground motion models, to improve risk assessment tools for nonductile concrete buildings through targeted large-scale testing and numerical simulation work, and to re-assess the collapse risk with the improved tools.

Prior experience (Otani, 1999; FEMA, 2000) suggests that existing risk assessment tools overstate the seismic risk associated with nonductile concrete construction, causing virtually all buildings with this typology in seismically active regions like Los Angeles to be identified as a collapse risk. While some structures certainly are at risk for collapse, this overly conservative approach causes the problem to appear so large that, paradoxically, effective public policy to mitigate the problem becomes untenable. Accordingly, the efforts of the Grand Challenge team are specifically directed towards developing procedures to identify the truly dangerous buildings from among the large building population, thereby scaling down an intractable problem to one that can be addressed with available resources.

2. CITY OF LOS ANGELES RESEARCH INVENTORY

Inventories of specific building types are a critical component of research and loss estimation that may serve to inform policy development. Many inventories have been compiled for building types with histories of poor seismic performance. Comerio (1992) evaluated the impact of the Los Angeles URM inventory and retrofit ordinance on housing costs and rents. The Disaster Resistant University program developed at University of California, Berkeley (Comerio, 2000a, 2000b, 2000c) used detailed university building inventories to estimate losses under different earthquake scenarios and to provide data for campus officials to establish retrofit priorities. The Grand Challenge research inventory developed for this project does not pretend to be as comprehensive an inventory as is used to enforce a city ordinance; instead it represents a best estimate of the number, type, square footage, value, occupancy, and geographic distribution of pre-1976 concrete buildings in the City of Los Angeles. As a research tool, the inventory provides a database for understanding the age and use of typical buildings and for loss estimates comparing retrofitted and non-retrofitted scenarios (Anagnos et al., 2008, 2010).

To estimate the number of older concrete buildings in the City of Los Angeles, researchers combined information from more than 15 sources. Baseline data on concrete buildings were purchased from the Los Angeles County assessor’s office and cross checked using a variety of public sources to confirm that all concrete buildings were represented in the database, without double counting, and that the data were consistent with local zoning patterns. A flowchart detailing the process was developed to ensure that all buildings were reviewed and assessed in a similar fashion, minimizing the potential bias from data collectors (Anagnos et al., 2008). Anagnos et al. (2012) discuss the process of collecting building inventories and challenges posed by the process.

Once verified against other databases and through validation exercises, the data were organized in a spatial database using Google Earth Pro™, which has overlay capabilities, and calculation tools. The software has the capability to store photos, drawings, and documents and allows for data retrieval in aggregate or as individual points. Equally important, the data were geo-coded and compatible with HAZUS risk analysis software.

2.1. Summary of general findings

The City of Los Angeles has approximately 1500 older concrete buildings comprising about 88 million square feet. For comparison purposes, the Concrete Coalition has estimated the number of older concrete buildings in San Francisco to be 3,000 (Comartin et al., 2011). Using default replacement costs per square foot specified in Table 3.6 of the HAZUS Technical Manual (FEMA, 2003) and using modifiers to reflect inflation and regional construction costs, the replacement value of the buildings (not including contents or inventory) was estimated to be $17 billion.

While the number of nonductile concrete buildings in Los Angeles may initially appear low, given the size of the city—470 square miles with a population greater than 4 million—it is important to consider what is not included in the inventory. First, the study is confined to the City of Los Angeles and not the greater Los Angeles metropolitan area, so buildings in Beverly Hills, Culver City, Santa Monica or other independent cities in the Los Angeles basin are not included. Second, the City of Los Angeles has had an aggressive retrofit or replacement program for public buildings, with 4.5 million square feet of city-owned buildings structurally upgraded or rebuilt (J. Steele, personal communication, October 27, 2009). Similarly, many state-owned buildings, such as universities, have also completed structural retrofits. Third, adaptive reuse incentive programs have transformed downtown warehouses into lofts and apartments, with structural improvements completed as part of the change of use. All together, these represent a significant number of buildings that are no longer catalogued on the nonductile concrete inventory. Finally, the researchers found that a number of vulnerable buildings that had been damaged in the 1994 Northridge earthquake had been demolished and the building replaced or the land was vacant.

Reflecting zoning and historical development of the city, older concrete buildings tended to be clustered in certain areas of the city such as Downtown and Hollywood, or along major commercial thoroughfares such as Wilshire Boulevard. Many Los Angeles neighborhoods are comprised of large tracts of single family woodframe houses or small two to three story woodframe apartment complexes. The majority of the buildings were built in the 1920s and the 1960s, and are mainly divided among industrial, commercial, schools, office buildings and residential uses with small numbers of other use-types. The majority of the buildings are one to three stories; however, the majority of the square footage is in buildings of four stories and taller (See Figures 1-4).

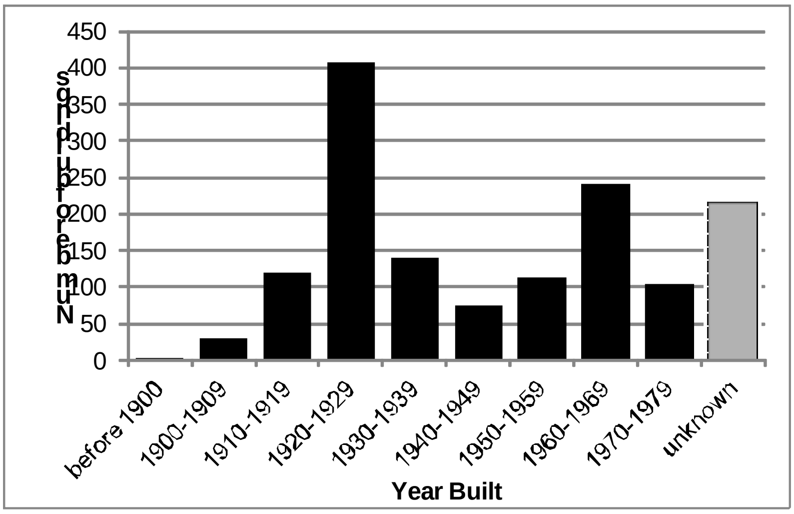

Figure 1. Number of older concrete buildings in the inventory of the City of Los Angeles by year built

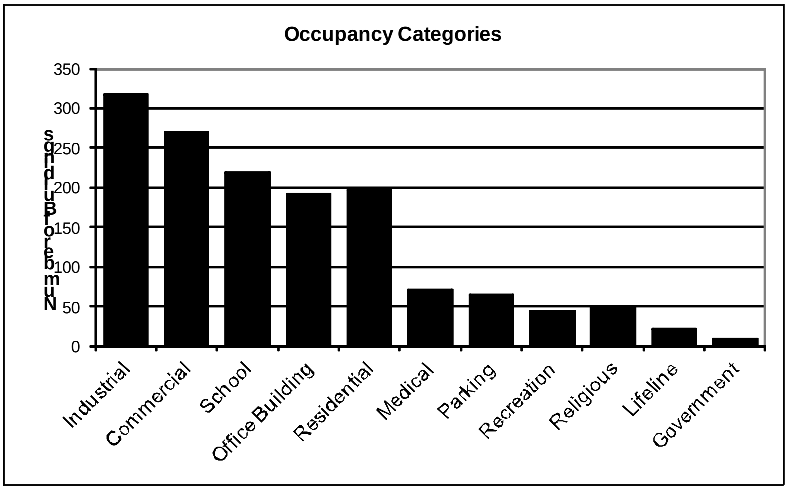

Figure 2. Number of Los Angeles Older Concrete Buildings by Use Type

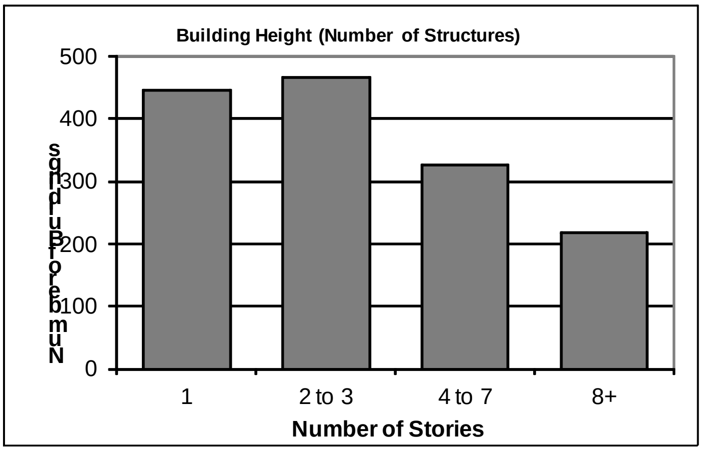

Figure 3. Number of Los Angeles Older Concrete Buildings by Story Height

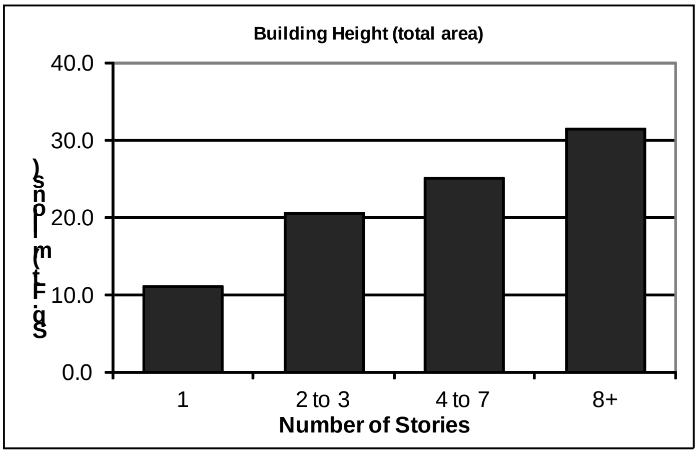

Figure 4. Square Footage of Los Angeles Older Concrete Buildings by Story Height

2.2. Breakdowns within building types

To better understand how the inventoried buildings might be grouped into categories that represent common construction typologies, the researchers analyzed sub-categories of data. The common construction typologies are used as a proxy for estimating structural performance. For example, the inventory contains many one story industrial buildings, which may possibly pose a lower risk because they typically have perimeter walls tied to relatively light wood roofs. In another example, there are fewer than 100 older pre-1929 industrial buildings 4 stories or taller, yet these buildings constitute close to two thirds of the industrial square footage (See Figures 5 and 6). These buildings likely pose a higher collapse risk than the one story buildings because many of them are frame structures or perforated walls with large windows.

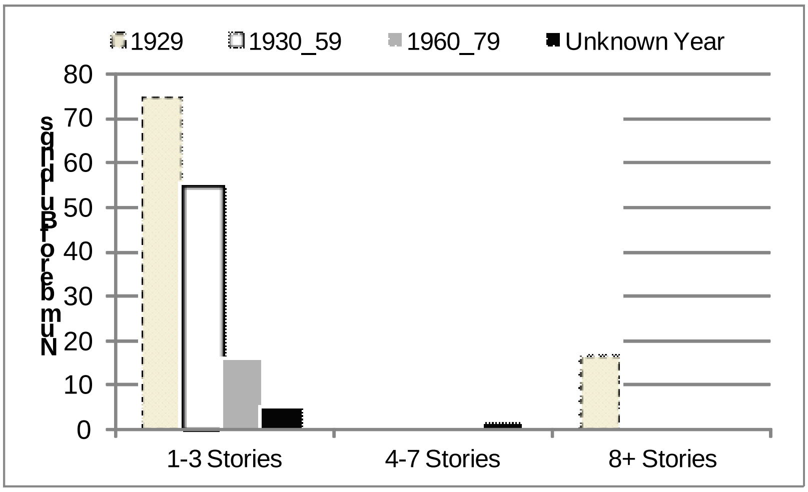

Figure 5. Number of Industrial Buildings by Story Height

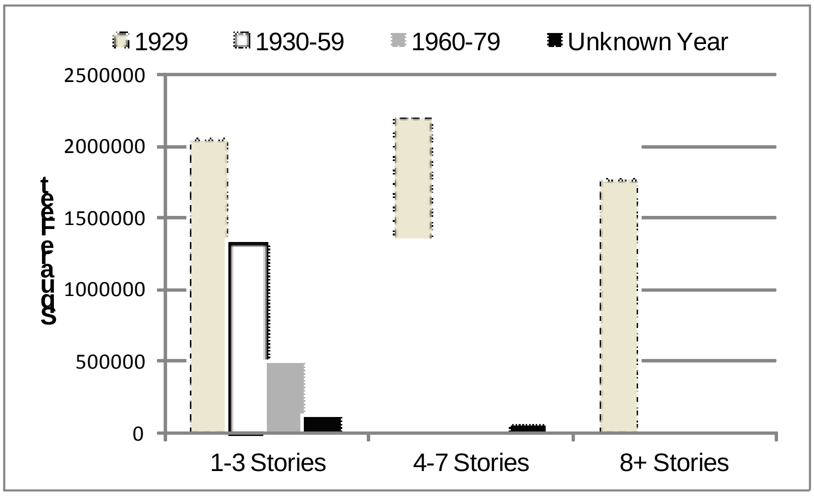

Figure 6. Square Footage of Industrial Buildings by Story Height

When a similar analysis is completed for each use category, and further reviewed by building age, patterns emerge that reflect the architectural characteristics of a period as well as the common construction methods used. The research team reviewed sixteen groupings of buildings with common characteristics with professional engineers, who ultimately reduced this to eight groupings:

1: lowrise (1-3 story), pre-1929, various occupancies.
2: 4+ story, pre-1929 warehouses.
3: 4+ story, pre-1959 apartments.
4: 8+ story apartments.
5: 8+ story hotels.
6: 4+ story, 1960-79 commercial/office.
7: 8+ story, pre 1929.
8: 8+ story, modern office.

The groupings suggest certain common architectural and engineering design conventions. For example, the lowrise pre-1929 buildings, of any occupancy, generally use walls for the vertical elements, which are not critical elements for collapse. On the other hand, many of the 4+ story, pre-1929 warehouse structures have perimeter walls and soft first stories, suggesting the need for structural modelling to better understand their collapse mechanism and potential. The 8+ story apartments are typified by frames with shear critical columns. Overall, the categories provide the research team with a way to specify parameters for preliminary modelling of building performance and rough estimates of the loss. In addition, categories with structural characteristics that typify buildings with a high potential for collapse were targeted for more in-depth analysis to better understand performance and the likely collapse mechanism. The research team used the “top ten deficiencies” in older concrete buildings (NEHRP Consultants Joint Venture, 2010) in developing representative analytic models. Of course, each building design is unique, and for policy implementation each building ultimately would need an engineering review before being classified as a nonductile concrete building with collapse potential, but the inventory provides researchers with a tool to understand the existing building stock and identify categories of buildings that may dominate damage and resulting economic losses and casualties.

4. USE OF INVENTORY IN LOSS MODELING

Researchers used the loss estimation methodology, HAZUS (FEMA, 2003), to study the potential losses when the inventory was subjected to two scenario earthquakes. The first, the 2008 Great Southern California ShakeOut scenario event (Graves et al., 2011), is an M7.8 earthquake along the southernmost San Andreas fault. The second earthquake, an M7.15 on the blind thrust Puente Hills fault (Graves & Somerville, 2006), would rupture right under the downtown area. The 1987 Whittier Narrows earthquake (M_w 5.9) occurred on a segment of the Puente Hills fault. Ground motions developed for both events took into consideration complex fault rupture processes, path effects, effects of sedimentary basins, and the effects of local shallow soil conditions. The San Andreas fault rupture is about 40 miles (64 km) from the downtown area, and as shown in Figure 7 the peak ground accelerations under downtown are in the range of .09g to .18g. On the other hand, while of smaller magnitude, because of its proximity to the city, the Puente Hills event produces peak ground accelerations in the range of 0.9 to 1.1 g (Figure 8) in the downtown area. For long spectral periods, the San Andreas event can produce stronger shaking, and occurs at shorter time intervals. Some corrections to the initial simulation methodology were made based on analyses by Star et al. (2011), which have been incorporated into the ShakeOut motions employed for this study (details in Stewart et al., 2011).

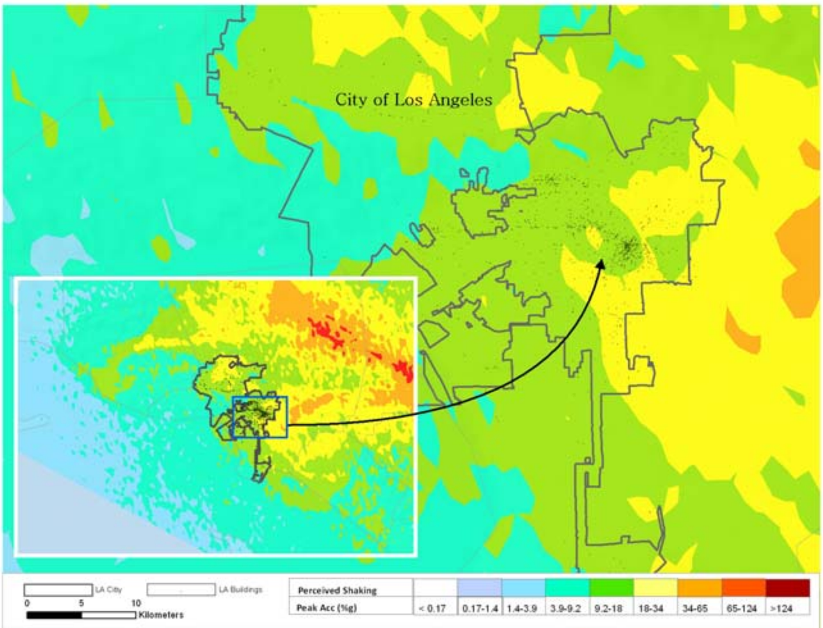

Figure 7. Peak ground accelerations for an M7.8 on the southern San Andreas fault. The gray outline represents the boundary for the City of Los Angeles and the dots are buildings in the inventory.

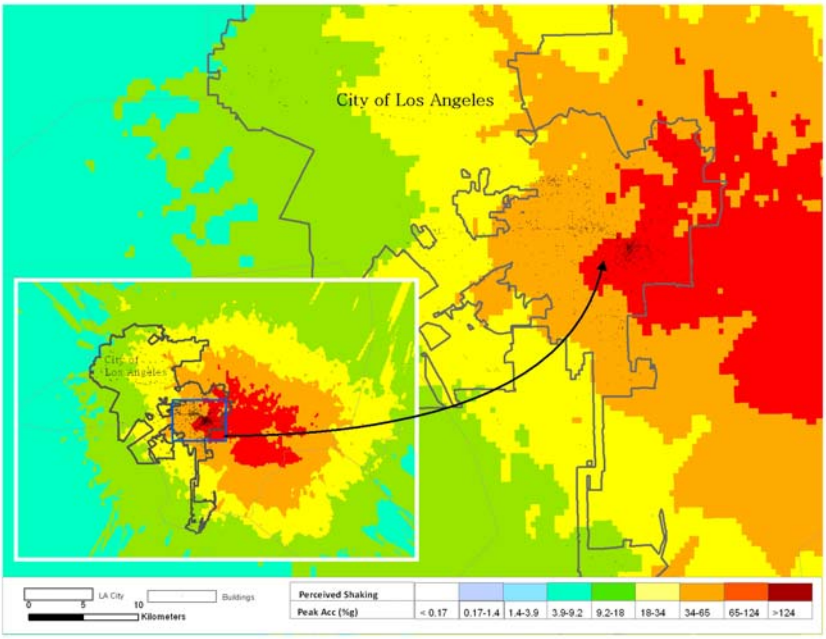

Figure 8. Peak ground accelerations for an M7.15 on the Puente Hills fault. The gray outline represents the boundary for the City of Los Angeles and the dots are buildings in the inventory.

While extensive research was done in developing and verifying the inventory of older concrete buildings in Los Angeles, considerable uncertainty remains about the exact structural system for each building. For example, based on the collected data it may not be clear whether a particular building is a frame, wall, or duel system. Therefore assumptions were made about structural system and performance based on building age, height, and occupancy. To gain certainty about all of the structural system information, a detailed engineering review would be required for each building. Parameters related to the performance of structures may be varied within the HAZUS software, allowing the user to test the sensitivity of various assumptions. For example Figures 9 and 10 show the default HAZUS capacity and fragility curves for two mid-rise (4 to 7 story) structures: a concrete frame and a concrete shear wall building of differing code levels. The capacity curves in Figure 9 indicate shear wall structures reach higher spectral displacements before they yield and thus perform better. Changing the mix of frame and shear wall structures provides bounds on the losses. By varying the capacity and fragility curves to reflect different code levels, the effect of retrofitting can be included in the model, allowing an analysis of the impact of potential mitigation policies.

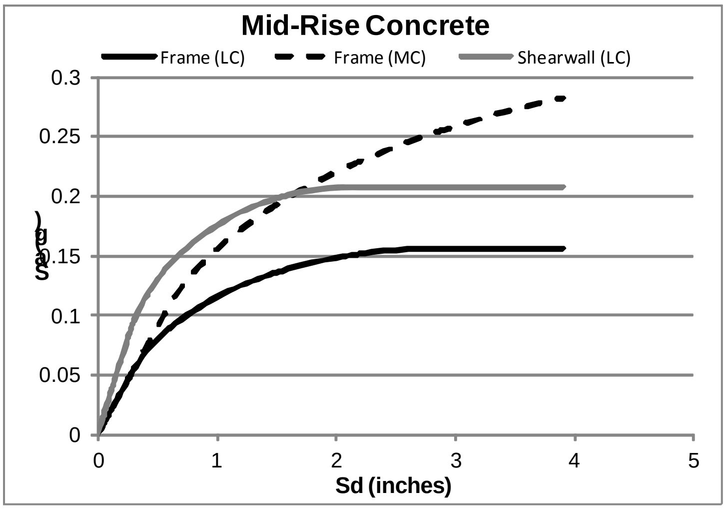

Figure 9. HAZUS (FEMA, 2003) capacity curves for concrete mid-rise low code (LC) and moderate code (MC) frames
and low code shear wall buildings.

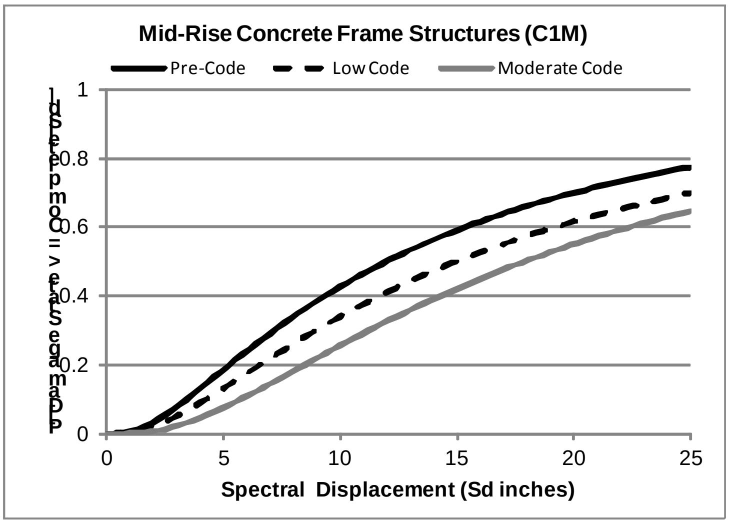

Figure 10. HAZUS (FEMA, 2003) fragility curves for pre, low and moderate code mid-rise concrete frames.

For modelling losses in the Los Angeles inventory, the approach is to create a range of simulations with differing assumptions on the structural systems of buildings, on the fragilities for different building types, as well as on a range of retrofit solutions for different building types. The results from multiple analyses will provide a range of loss estimates, and a range of potential benefits. Together these will create a base of information to inform policy.

5. CONCLUSIONS AND FURTHER RESEARCH

In general, the development of building inventories allows us to gain a detailed understanding of the characteristics of specific building types—in terms of age, height, size, use, and value. For the inventory of older concrete buildings in Los Angeles, the research team was able to develop eight preliminary categories of buildings with common architectural and engineering design components and construction methods, which could be used to further model structural performance. Although it is important to recognize that every building is unique, it is also important to find mechanisms by which we can generalize for research purposes.

The categorization of buildings in the inventory allows us to estimate the impacts of retrofits (in terms of loss-reduction) on a range of options such as particular building use-types or on high rise buildings of all types. It will also allow us to estimate a cost-benefit for certain retrofit approaches. For example, if retrofits for all 4+ stories buildings were needed this would affect 50% of the buildings and 75% of the square footage of older concrete buildings in Los Angeles. However, if the analysis demonstrates that the largest loss reductions are in retrofits of high rise (8+ story) buildings, regardless of use type, this would generate a specific policy recommendation affecting slightly less than one-quarter of the buildings (with about 46% of the total square-footage). It may be the case that certain use types (such as hotels and office buildings which typically have soft-first stories) may provide the greatest opportunities for loss reduction. As such, policy recommendations will be developed based on the results of the HAZUS results.

Ultimately, inventory data on particular building types in specific settings can help to refine hazard mitigation policies and help cities set priorities for retrofit of older vulnerable building stocks.

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