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LOS ANGELES INVENTORY OF NONDUCTILE CONCRETE BUILDINGS FOR ANALYSIS OF SEISMIC COLLAPSE RISK HAZARDS

T. Anagnos,[1] M. C. Comerio,[2] C. Goulet,[3] H. Na ,[4] J. Steele,[5] and J. P. Stewart[6]

[1] *Professor, Dept. of General Engineering, San José State University, San José, CA USA*
[2] *Professor, Dept. of Architecture, U.C. Berkeley, Berkeley, CA USA*
[3] *Research Associate,* [4] *Student,* [6] *Professor, Dept. of Civil & Environmental Engineering, U.C. Los Angeles, Los Angeles, CA USA*
[5] *Research Associate, U.C. Berkeley, Berkeley, CA USA*

Email: tanagnos@email.sjsu.edu, mcomerio@berkeley.edu, goulet@ucla.edu, steele.jj@gmail.com, jstewart@seas.ucla.edu

ABSTRACT :

Nonductile concrete buildings arguably represent the greatest seismic life safety hazard in many urban centers world-wide because of their collapse potential. This paper documents the development of an inventory to evaluate the risk from the approximately 1600 potentially nonductile concrete buildings in the City of Los Angeles. Using state-of-the-art spatial databases, publicly available online resources, and building inspections, we record the geographic distribution of these buildings as well as their general characteristics with respect to structural configurations and usage. We describe the diverse array of data sources used to develop the inventory, which provides information on building size, age, type, usage, and ownership type. We particularly emphasize the data collection methodologies developed and utilized for this project and the significant challenges associated with data collection of this type. This information is being utilized in ongoing collapse risk studies related to nonductile concrete construction in Los Angeles and to guide a testing/simulation program that will ultimately lead to more accurate loss estimation tools.

KEYWORDS: Nonductile concrete, inventory collection, risk evaluation

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 were implemented that reduce collapse risk). This type of construction is common internationally as well, and remains widespread in many developing countries. In California, alone, it is estimated there are 40,000 of these buildings, including residential, commercial, schools and critical service facilities (OES, 2004, p. 97). The poor seismic performance of nonductile concrete buildings was evident in recent earthquakes including Northridge (1994); Kobe, Japan (1995); Chi Chi, Taiwan (1999); Kocaeli, Turkey (1999); Sumatra (2005); Pakistan (2005); and Sichuan, China (2008).

In this paper, we describe the process by which an inventory of nonductile concrete buildings is being assembled for the City of Los Angeles. Inventories such as this are a first crucial step toward understanding the scale of the problem associated with this type of construction. The inventory remains a work in progress, so we are not presenting here a summative description. However, innovative use of online publicly available data has been effective in relation to data collection and synthesis. We expect such innovations will be useful for other regions facing similar problems, which is the motivation for presenting this information at the present time.

This inventory work is a component of a broader "Grand Challenge" project funded by the United States National Science Foundation (NSF). The objective of the broader project is to mitigate collapse risk of older nonductile concrete buildings during 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 the nonductile concrete building inventory, to estimate collapse risk using the inventory with existing tools (e.g., HAZUS) and the best available ground motion models, to improve risk assessment tools for nonductile concrete buildings through targeted testing and numerical simulation work, and to re-assess the collapse risk with the improved tools. The inventory is an essential component of each stage of the Grand Challenge project.

Prior experience (Otani, 1999; FEMA, 2000) suggests that existing risk assessment tools overstate the seismic risk in 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 certainly are at risk, this overly conservative approach causes the problem to appear so large that, paradoxically, effective public policy to address 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.

Following this introduction, we describe the diverse array of data sources utilized to develop the inventory, which provides information on building size, age, type, usage, and ownership type (e.g. government, private, utility, etc.). Particularly emphasized in this discussion are the data collection methodologies developed and utilized for this project and the significant challenges associated with data collection of this type.

2. SOURCE DATA

The inventory of nonductile concrete buildings in Los Angeles is being compiled using a variety of public data sets, Internet maps and streetscape technologies, sidewalk surveys and survey input from volunteer engineers through the EERI Concrete Coalition (Comartin et al., 2008).

For each of the approximately 1600 nonductile buildings in Los Angeles, the compiled data set includes: structure type, use, year built (and retrofit year, if applicable), number of stories, total size in square footage, building usage (residential, commercial, industrial, etc.), and data sources. For a subset of buildings, additional information will include design building code, configuration, details on the structural system, structural deficiencies, retrofit strategy, soil type, number of basement levels, and sample floor plans. For policy applications, the inventory needs to have information on ownership and uses of buildings in Los Angeles. Ownership data is broadly grouped according to public, private, for-profit and non-profit, and if available, owner-occupied or rented. Data will be sorted by use types (commercial, office, housing, schools, hospital, etc.) as well as age and physical characteristics to evaluate the inventory and better understand the severity of the collapse risk associated with these buildings.

Data is obtained from the following public resources, which are briefly discussed in the following paragraphs:

- LA County Assessor's Office
- Los Angeles Department of City Planning
    - Zoning Information and Map Access System (ZIMAS)
    - Land Use Planning and Management System (LUPAMS)
- Los Angeles City Housing Department
    - Property profiles and reports
- Los Angeles City Department of Building and Safety
    - Building permits and other information
- Sanborn Maps, Google Maps and Google Street View
- Aerial photos (maps.live.com and Google Earth)

- Sidewalk visits and building surveys
- Other publicly available databases compiled by government agencies such as the Los Angeles City Departments of General Services and Public Works, the Division of the State Architect, or the Chancellor's Office of the California State University System.
- Input from volunteer engineers in the Concrete Coalition

The public data sources are the backbone of the inventory. Any citizen can access data from the County Assessor's office online, but an address-by-address search can be slow and cumbersome. In this study, the research team purchased data from the County Assessor records through "Urban Research," which is a research unit within the Los Angeles County Chief Administrator's Office. Urban Research provided a file of concrete buildings in the City of Los Angeles with age, size, and use information.

It is important to note that the County Assessor's data are only kept for taxed properties and, therefore, a number of buildings are not captured in these public records. For example, the research team has used separate databases for hospitals, clinics, schools, universities, and government buildings to ensure a reasonably complete sample of building types. Even for taxable properties, the information is not always accurate or complete. The Assessor's data is organized by assessor parcel numbers (APNs) which represent a taxable entity and can show data for up to five buildings. Thus a property that has multiple structures may or may not have multiple entries each with a different construction date, building type, and square footage. This can be a challenge since a specific address is not linked to a single set of building data. The problem can be reversed in the case, for example, of condominium buildings. In that case, each condominium in a high rise building has a different owner, and thus its own APN. A building with 30 condominiums will have 30 entries in the assessor records, all with the same address but none that reflect the overall size and height of the building. Other challenges we found were multiple addresses on the same building or buildings for which the address changed over time. To verify the assessor records, our team used a variety of other public and Internet sources to check data on an address-by-address basis. This involved a systematic use of one or more of the above listed data sources as described further below.

Important sources of building data include various Internet sites and online-based tools. ZIMAS, a City of Los Angeles online zoning information database, is one such source. It was used extensively to validate and verify the assessor's data. For a particular address or APN one can view a map of the parcel as well as a detailed report containing zoning and permit information. Some building data such as square footage and year built can be checked. ZIMAS is particularly useful for condominiums, because it provides a report for all of the APNs in a building, thus square footage can be obtained for the whole building.

The Sanborn maps are used to identify property lines and to physically locate addresses relative to identifiable landmarks such as street crossings.[1] This was useful in reconciling conflicting information from multiple data sources or determining the exact location of an address for viewing in aerial photos, Google maps or Google Streetview.

Our team used Google Streetview and Live Search (maps.live.com) to look at aerial and street views of various buildings, and to check the accuracy of assessor data. For some buildings we were able to obtain only address and structural type; but, through the use of aerial photos and Google Earth, we could estimate the number of stories and the building area. In other cases, the Assessor's records identified one-story buildings with very large areas (200,000 to 1.8 million sq. ft.), which seemed inconsistent. Through Live Search, we were able to identify these as multi-story buildings or as large shopping centers with multiple buildings.

Sidewalk surveys of buildings are another critical component in verifying public data sets. Our team made a number of such surveys with the help of volunteer professional engineers to verify and review building data. In

[1] The Sanborn Map Company was founded in 1867 and was the primary American publisher of fire insurance maps. Although the company no longer updates their maps, sets from 1888 to 1955 are available online through the Los Angeles Public Library.

many cases, it is possible to enter the lobby and garage space of commercial buildings, allowing for a check on height, number of stories, structural system, and other building details.

Building permit data is another source of information. While recent permits are available online, older data must be reviewed in the City's Department of Building and Safety offices. The City does keep building permit data, but the material stored on microfiche is difficult to retrieve and sort, and plans for older buildings are available only if the owner agreed to pay for the documents to be stored. Property profiles from the City's Housing and/or City Planning Departments are often very detailed, but these require specialized access through department staff. Because of these difficulties, building permits and construction drawings are used only for a relatively small subset of structures.

The available databases have been compiled for different uses and therefore exhibit different levels of accuracy for building attributes and other identifying information. Certain categories of data may be more reliable or complete in one source than in another. For example the assessor's file may be unclear as to whether the property contains one or more structures. Using several sources to cross check information on this property provides a more accurate picture of the actual situation. When the online sources do not provide a consistent result, the team visits the property. As shown in Figure 1, data is verified by following a set of rules and flowcharts specific to the problem encountered. For example, if the data from ZIMAS does not match that from the assessor's database, then a corresponding check is done by first locating the address on the Sanborn maps and then looking at the building with Google Maps and Streetview. Discrepancies cannot always be resolved, in which case the address is saved for a site survey. Using Streetview as a first step, however, has proven to be a very efficient way to verify the data.

As a joint effort with this project, the Concrete Coalition has created a web-based inventory form to be completed by local engineers with expertise in existing building analysis and retrofit (Comartin et al., 2008). The form contains information about building size, configuration, functional use, lateral forces resisting system, soil and foundation information, etc. At this time the inventory is still being collected. When it is available, it will provide detailed information on specific properties and provide data to develop a set of rules that assign structural deficiencies to buildings in the inventory based on, for example, the year they were built, their size, and specific architectural features.

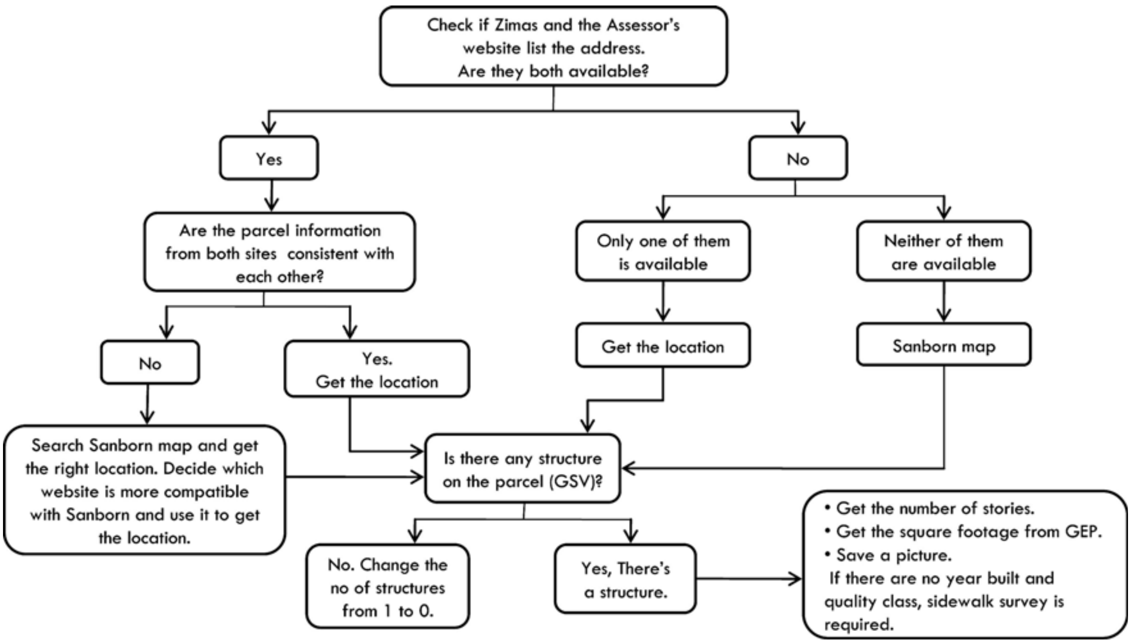

Figure 1 Flowchart of methodology for validating data

3. ATTRIBUTES OF DATABASE

The inventory is compiled in Google Earth, a powerful virtual globe program that allows for sorting and analyzing the database and mapping the entire database or elements of the database with specified characteristics. A free version of Google Earth is available online, but the GIS capabilities of the Google Earth Pro version were needed for this project. The project chose Google Earth because of its ease of use, requiring relatively little training. Google Earth Pro also comes with a set of tools for computing the square footage of arbitrary shapes and for converting street addresses to geocodes (latitude and longitude). In addition, the ability to overlay the inventory on satellite images and aerial photography that are included within Google Earth provides a tool for visual analysis of the inventory. Figure 2 shows a subset of the inventory overlaid on a satellite image of Los Angeles with major roads identified. Initially, visualizing the data this way showed that the nonductile concrete structures were clustered in regions of Los Angeles that were developed around the same time. The majority of the buildings are found Downtown, along the Wilshire Corridor, and in Hollywood. It also provided a check on the inventory to ensure that all data points were within the city limits.

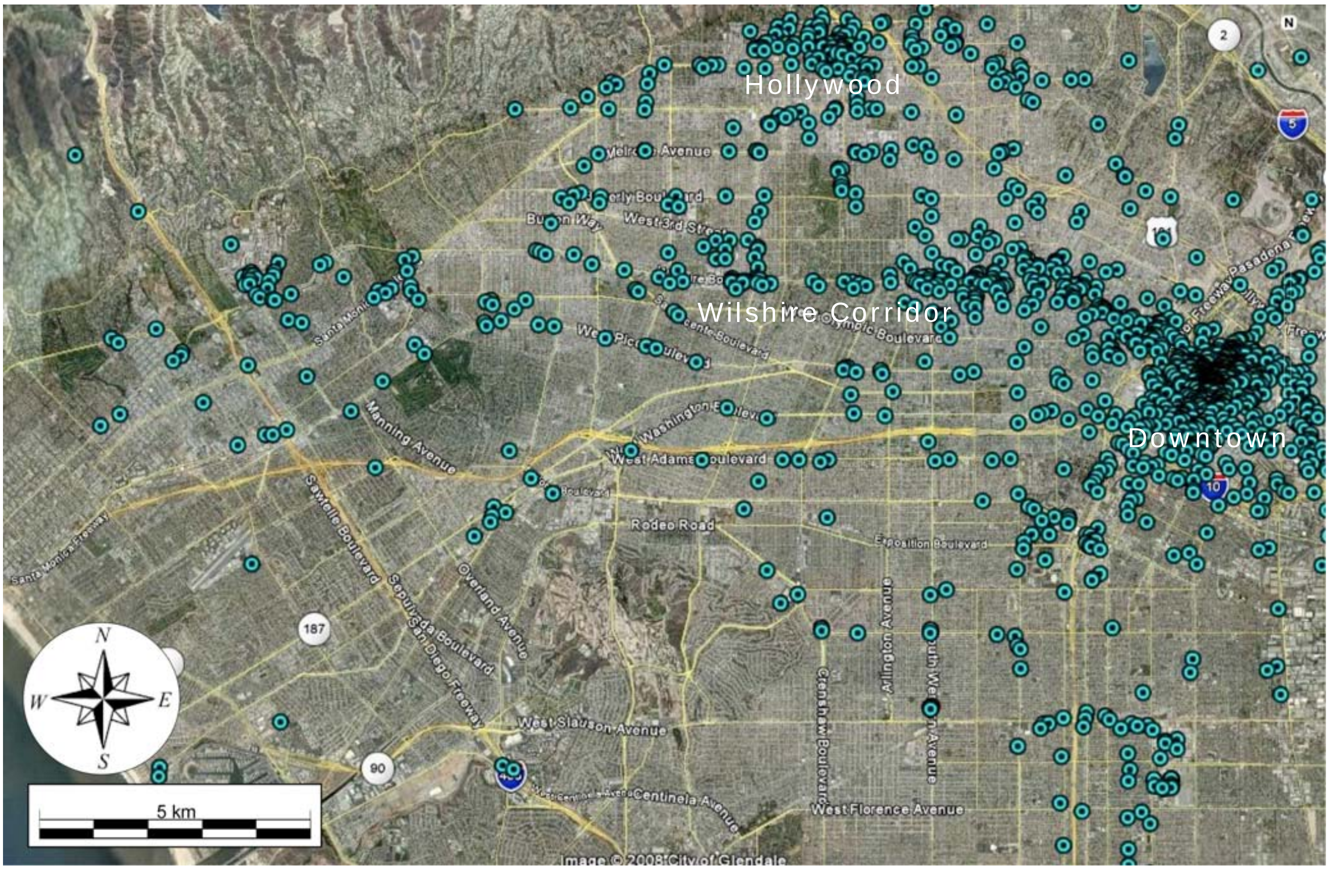

Figure 2. Subset of nonductile concrete inventory overlaid on image of Los Angeles.

The Google Earth program has the capability to store photos, drawings, and text files. The sidewalk survey form that was developed for this study is stored in Google Earth so that data from the surveys is easily retrieved. As with any GIS software, the user can click on a point and view the data associated with that point. Figure 3 shows an example of the data associated with a given data point from Figure 2.

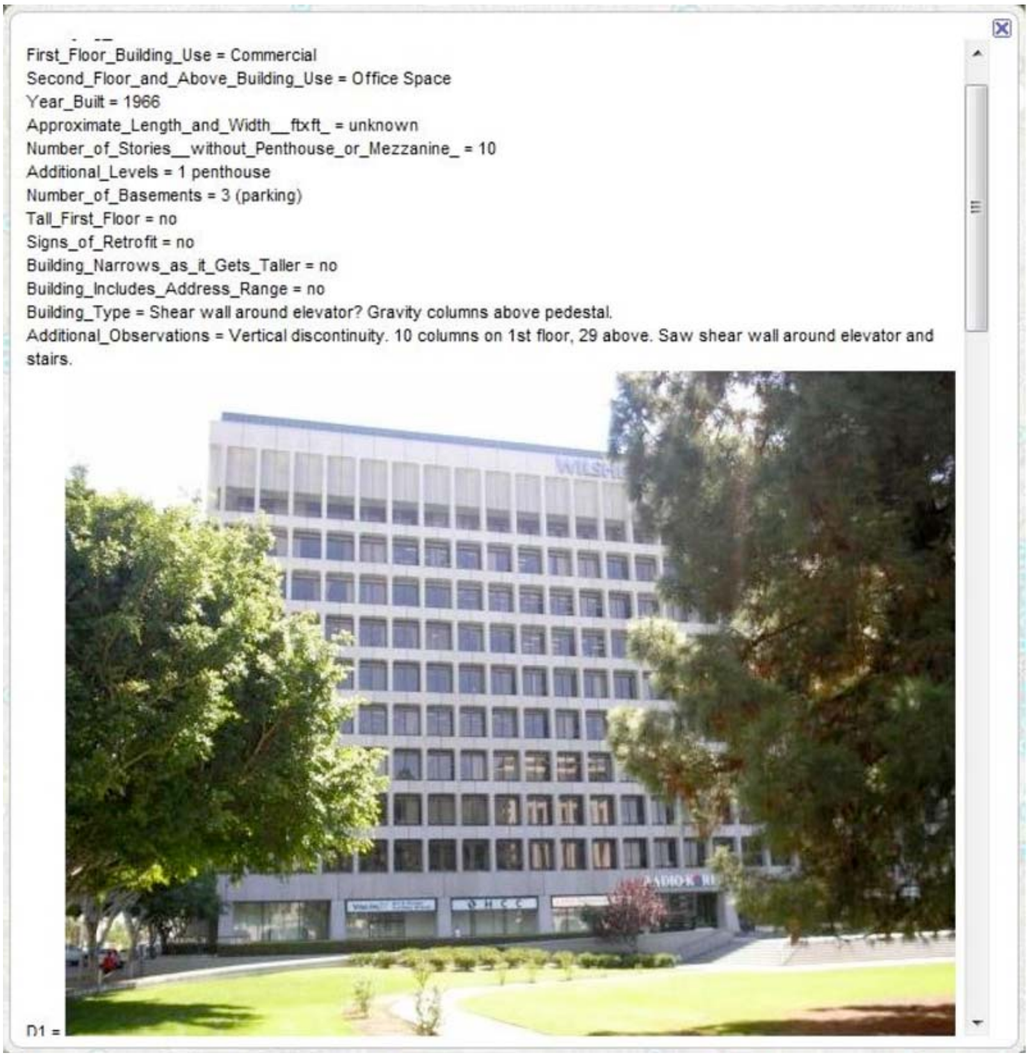

Figure 3. Photo and building attributes associated with a data point in the Google Earth database.

The database fields are defined to be compatible with the loss estimation software HAZUS, with the goal of importing the database into a Los Angeles study region. Additional fields are included in the database to facilitate tracking of properties, sidewalk surveys, and to accommodate detailed input from engineers. The database includes the following fields: address, latitude and longitude, building name, neighborhood (there are many distinct neighborhoods and commercial areas within the city of Los Angeles), assessor's parcel number (APN), use code from the assessor's files and an equivalent HAZUS occupancy class, year built, structural types based on assessor's data, number of stories, number of basement levels, square footage, number of units for residential buildings, and source of data.

4. PORTABILTY OF INVENTORY METHODS

California has been a leader in developing seismic risk mitigation policy, and Los Angeles is a leader within California. As a result, the project has been able to make use of databases that may not be available elsewhere. For example, AB 300, which passed in 1999, required the Department of General Services to collect an inventory of all California schools that are of tilt-up construction or that have non-wood walls that did not meet the requirements of the 1976 *Uniform Building Code* (DGS, 2002). Similarly the California Community Colleges, the California State University, and the University of California all have programs to identify and retrofit seismically hazardous buildings. These inventories are publicly available and were used to identify nonductile concrete educational buildings. These types of inventories may not be available in other states.

The City of Los Angeles has been proactive in addressing the risk from vulnerable buildings by enacting voluntary ordinances for the retrofit of tilt-ups (Division 91)[2], older concrete buildings and concrete frame buildings with infill (Division 95), wood frame buildings with weak cripple walls (Division 92), and hillside buildings (Division 94). This conscientiousness has spurred studies of government buildings such as police and fire stations, animal services facilities and libraries, followed by subsequent bond financing measures to retrofit or replace vulnerable structures. Therefore the City maintains inventories of nonductile concrete buildings for certain occupancies, and most of these structures have been repaired or replaced. A few municipalities in California have equally aggressive seismic risk mitigation programs, but many do not. Obtaining data on vulnerable government buildings in those communities may be more difficult.

Other online resources such as Google Street View and maps.live.com are available for many U.S. communities. In any community it is useful to meet with representatives from building departments, planning departments, school districts, and other local and state agencies to determine the types of data that are archived. Certainly, all communities can and should make use of local engineers in developing any inventory.

5. CONCLUSIONS

The database has several potential applications. By grouping and summarizing the data, we gain an understanding of the general characteristics of the nonductile concrete building stock. Where are they clustered? Are they high rise or low rise? What code was in effect when most were built? Are the buildings residential or commercial? This will be used to better understand the scope of the building collapse risk.

The data can be imported into HAZUS and included in a loss study for the City of Los Angeles providing an estimate of the magnitude of the losses (both dollar losses and casualties) from damage to nonductile concrete buildings. Later, once the project has developed improved structural performance models based on physical and numerical simulation work, those losses can be updated and will be more reliable. Moreover, because the NEESR-GC project is also testing the capacity of various retrofit strategies, the loss model can be run with a revised inventory that reflects the improved performance of retrofit buildings to provide a revised estimate of losses. This type of pre- and post-retrofit loss estimate is a valuable tool for decision makers in crafting appropriate policies and incentives to reduce the seismic risk in their communities.

When compiling a seismic risk building inventory for a community, no single data source is sufficient. The building stock of a community is complex and comprises many different owners and uses. Data sources are compiled by different users for different purposes. For example the tax assessor collects information to assess property value for the sole purpose of collecting taxes. The school district may maintain a list of structures for the purpose of scheduling and tracking maintenance. Often, unfortunately, the purpose for which a data source was designed overlaps only partially with the goals of a seismic risk inventory. The data source may use definitions for building attributes that require mapping from one classification scheme to another. For example the Los Angeles County tax assessor uses a numerical code that simultaneously identifies building use and number of stories. This code needed to be parsed and then mapped onto the building heights (low, medium, high) and occupancies required in HAZUS. Similarly, the data source may be missing key seismic attributes or certain fields may contain inaccurate information because the database was not designed to capture that information. To resolve this, one must check multiple databases to validate the accuracy of the inventory. In extreme cases, one may need to develop rules to populate the seismic risk inventory based on rather incomplete information.

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[2] A *Division* is an amendment to the Los Angeles Building Code and corresponds to a chapter. Division 91 is found in Chapter 91 of the Code.

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