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Developing Regional Building Inventories: Lessons from the Field

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Between 2008 and 2011 members of the Concrete Coalition completed numerous building inventories of California cities to assemble a database of California pre-1980 concrete buildings. Inventory collectors used a variety of data sources ranging from county assessors files to Sanborn maps and satellite images. Sidewalk surveys were used to corroborate data collected from multiple sources, and a regression model was developed to extrapolate data to cities where detailed inventory collection was not possible. Lessons drawn from inventories of three cities – Alameda, Los Angeles, and San Francisco – indicate that no single approach can be recommended, but instead the approach depends on many things including city size, building stock, available budget, available data, and availability and experience of human resources. Regardless of approach, inventory data is a valuable resource for developing loss estimates and policy recommendations.

Introduction

Developing an inventory of the built environment is an important first step in estimating the risk to a region from natural hazards such as earthquakes, floods, or hurricanes. The insurance industry, federal agencies such as the United States Geological Survey (USGS) and the Federal Emergency Management Agency (FEMA), state and local governments, universities, utilities, the military, and many others have been grappling with the challenges associated with developing inventories since the 1970s. FEMA-249 (1994) provides a detailed assessment of the inventory methodologies through the early 1990s. The seminal publication ATC-13 (1985) introduced a classification system and inventory collection methodologies that serve as the foundation of most of the work today.

Often inventories are estimated using a combination of existing databases, land use data, statistical sampling, and inference rules based on expert opinion (ATC, 1985; Rojahn et al., 1997; Jaiswal & Wald, 2008). A number of attempts have been made to use rapid screening techniques for identifying hazardous buildings (FEMA, 2002; Wang and Goettel, 2007; Inel et al., 2008). As recently as February 2009, Utah introduced a state bill (which did not pass) to use rapid visual screening (RVS) to inventory school buildings for the purpose of

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estimating relative seismic vulnerability, at a cost of $300 to $600 per building. A FEMA funded $69,000 pilot study carried out by the Utah Seismic Safety Commission and the Structural Engineers Association of Utah completed RVS for 128 buildings, and efforts are currently underway to pass legislation to allocate $500,000 to inventory all Utah school buildings (Siegel, 2011). Other simplified approaches rely on limited data sources. In response to AB 300 passed in 1999, the California Department of General Services (DGS) completed an inventory of approximately 16,000 school buildings of tilt-up construction or non-wood frame walls that did not meet the minimum requirements of the 1976 *Uniform Building Code*. To minimize cost, DGS developed a process to review design documents rather than perform field surveys (DGS, 2002).

Depending on the purpose of the inventory, its scope, and the size of the region, building-by-building data collection may or may not be possible. Sidewalk surveys or windshield surveys using generic instruments and procedures such as FEMA-154 (2002) take only 15 to 30 minutes per building in the field but still require an army of surveyors and months of planning, data collection, and analysis for a large region. Advances in information technology, including geographic information systems, online databases, satellite imagery and street level photos available through online services such as Google Earth and Bing Maps have revolutionized inventory collection strategies. Traditional resources such as zoning maps, Sanborn Maps, and expert opinion remain important elements of the inventory collection process; however, electronic resources and extrapolation of data through numerical models are useful in refining inventories. While these new approaches do have limitations, they provide a significant improvement over previous methods. For example, as recently as 2004 the State of California estimated the size of the state's nonductile concrete building inventory by extrapolating from a single data point, based on a summary of a Los Angeles assessor's file (OES 2004).

This paper offers practical insights into the development of building inventories for the purpose of seismic hazard mitigation. The authors first provide an overview of the purpose of regional inventories, discuss the different types of data to be collected, and present a set of data sources and data gathering approaches that can be used. This is followed by a succinct summary of the approaches taken for several case studies: Alameda, primarily a residential city with a population of about 75,000 people, and the cities of San Francisco and Los Angeles, both large urban areas. Surveys in all three of these cities were focused on identifying older concrete buildings. Finally, the authors present an approach for estimating the size of an inventory for the entire State of California by extrapolating data collected from a subset of California cities. It is important to note that while all the examples are California based, the methods could be used in any locale.

Purpose of regional inventory

The most familiar inventories may be those associated with the planning, development, and enforcement of a retrofit ordinance. Often in planning for the ordinance and developing legislation, jurisdictions want to understand the size of the problem and the potential economic impact on building owners. The inventory component for this purpose needs only to include a reliable estimate of the number and types of buildings requiring retrofit. To enforce an ordinance, the jurisdiction needs a more detailed list of which buildings are covered by the ordinance. In 1986, the California state legislature passed Senate Bill 547, which required jurisdictions in the most seismically active areas (seismic zone 4 according to the 1985 UBC) to create inventories of their unreinforced masonry (URM) buildings and to

develop plans to address the hazard (CSSC, 2003). Typically, building departments conducted sidewalk surveys and consulted department records to create a public list of targeted buildings. If a building appeared on the inventory list in error, the building owner had to prove the case to the building department before the address would be removed (Comerio, 1992; CSSC, 2003).

Another common use of inventories is for emergency planning. Cities and aid organizations may develop inventories of shelter sites for emergency housing, or lists of regional medical facilities including ambulances, blood banks, and pharmaceutical suppliers as part of emergency response planning. Cities may also develop an inventory of vulnerable building types, such as soft-story wood frame housing, in order to develop mitigation policies or to estimate the costs and benefits of mitigation. City building inspectors, architects and engineers, university students, and others interested in public safety may also develop such inventories for research purposes or to provide public information. The Association of Bay Area Governments (ABAG) has compiled soft-story apartment building data on their web site (ABAG, 2011) that includes estimates of the number of soft-story buildings and associated housing units in Bay Area cities and counties, as well as links to various ordinances, policies, planning documents, cost estimates for retrofits and technical recommendations. The data serve not only Bay Area cities but other communities interested in how such policies and programs are developed.

Many inventories have been compiled for building types with histories of poor performance in previous earthquakes. Inventories of specific building types are a critical component of research and loss estimation that may serve to inform policy development. Comerio (1992) evaluated the impact of the Los Angeles URM 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. Currently, one of the Grand Challenge projects funded through the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) program is focused on the mitigation of collapse risk for vulnerable concrete buildings. Components of the five-year project include a case study inventory, testing of concrete components in laboratories, loss estimation studies, and development of public policy recommendations. The research inventory 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, and geographic distribution of older 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). The Grand Challenge research team coordinated with the Concrete Coalition (a primarily volunteer organization) to aggregate estimates of the number of older concrete buildings in California and to develop strategies for improving their performance (Concrete Coalition, 2011; Comartin et al., 2008).

Inventory Attributes

The type and level of detail needed for an inventory depends on its ultimate use. An in-depth regional loss study that would estimate repair and replacement costs, casualties, short-term and long-term shelter needs, and business interruption losses requires the documentation (or estimation) of many building attributes. Typically data about building type are used to evaluate structural performance and data related to building use are used to evaluate social

and economic losses, which are related to both occupancy and structure type. For example, the standardized loss estimation methodology HAZUS (FEMA, 2010) requires building location, structural system, seismic design level, occupancy (residential, school, commercial, etc.), number of stories, square footage, number of occupants at different times of day, and cost for repair or replacement. Table 1 summarizes typical inventory attributes and how they related to hazard and loss estimates.

Table 1: Relationship of Building Attributes to Various Uses Qualitative Uses

Attribute	**Hazard Related**	**Damage Related**	**Loss Related**
Location	x		
Site conditions	x		
Structural System		x	
Height		x	
Square Footage			x
Age		x	
Seismic Design		x	
Hazardous Elements (e.g. unbraced parapets)		x	
Structural Irregularities		x	
Use			x
No. of Occupants –Day/Night			x
Contents			x
Special Equipment			x
Costs for Repairs			x
Costs for Replacement			x

Determining this many attributes for every single building in a region is a daunting task, so proxies are used to simplify the data collection. For example, year built is often used as a proxy for the seismic design code, and square footage along with occupancy type can be used to estimate the total number of occupants. Square footage, which can be combined with regional averages of repair or replacement costs per square foot to estimate economic exposure, is an important measure of risk and may be more meaningful than the number of buildings. For example, in Los Angeles, about 60% of residential concrete buildings are one to seven stories, but the exposure (measured in square footage) is dominated by 8+ story buildings that constitute about 40% of the total number of residential buildings (See Fig 1).

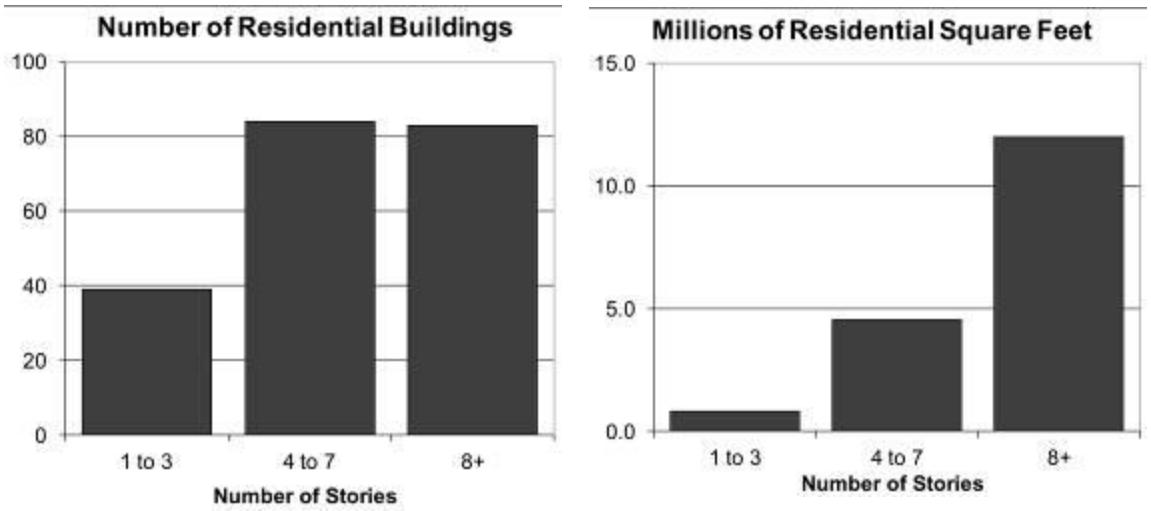

Figure 1. A comparison of the number of residential nonductile concrete buildings with the total square footage reveals that the majority of exposure is in 8+ story buildings.

An inventory for an emergency response planning exercise might need such information as the number of beds in each hospital or the number of fire trucks at each fire station. On the other hand, inventory to support a hazard mitigation ordinance might need identification of only a few specific building attributes, such as unbraced parapets or indications of soft first stories. Nevertheless, when mitigation options are reviewed in light of the completed inventory, one routinely finds that more data would help guide decisions; the initial question – how many buildings – is replaced by sub-questions: How many in each neighborhood, in each size range, serving which occupancies? The inventory challenge is to anticipate the most meaningful questions, make the trade-offs between effort and completeness, and deploy the available resources most effectively.

The inventory collection challenge can be reduced with consideration of zoning and regional construction patterns. For example, if virtually all of the structures of interest are found in commercial areas, there is little value in a close study of residential areas. Or if construction practices changed after a certain date, buildings after that date may be excluded from investigation.

The level of detail in an inventory will vary depending on the size of the study area, the resources available to do the inventory, and the intended use. In a small city, one individual may be able to estimate the number of concrete buildings in a few days by walking or riding a bicycle to survey the buildings. However, in a large city, or in a situation where research or local government funding is not available to support the inventory, volunteers might benefit from a variety of strategies to estimate the number of particular building types. The use of a large number of volunteers creates other challenges such as ensuring that the collected data are consistent. The following section summarizes a few key data sources and presents example strategies used for development of concrete building inventories for a small city (Alameda, CA) and two large urban areas (San Francisco and Los Angeles).

Initial Sources for Collecting Data

Independent of the purpose of the inventory and the number of attributes to be recorded, collecting an inventory will be a challenge. Typically, no single source contains the necessary information so multiple sources must be consulted, often with different or even conflicting systems for classifying attributes. In a recent study to estimate the number of

older concrete buildings in the City of Los Angeles (Anagnos et al., 2010), researchers combined information from more than 15 sources. Occupancy categories vary among sources so that, for example, hotels are classified as residential in one system and as commercial in another. Another challenge is that many data sources are proprietary and owners are not willing or legally permitted to share them. For example, engineering firms might not be permitted to share design documents and school districts might not be willing to share detailed data about their school buildings.

The choice of data sources should relate to the size and characteristics of the survey area, and the availability of data, as well as the skill sets and knowledge base of the volunteers. Table 2 shows, for a few selected cities, the data sources that were used by members of the Concrete Coalition to attempt to assess the size and scope of the potential risk due to older concrete buildings for the whole state of California. The complete table is available in the Concrete Coalition final report (Comartin et al., 2011). Note that Burlingame and Calabasas did not use Sanborn Maps, possibly because they were not readily available. Only the city of Berkeley used assessor's files, partially because the Berkeley volunteer was a building official who had ready access to assessor's files. Some volunteers may not have used assessor's files because running a query on data from the assessor's office usually costs money. In Daly City the surveyors were able to make use of data compiled by the History Guild. In four of the cities shown, volunteers relied on the expertise of building officials to understand building patterns and construction practices.

Table 2: Data Sources for Selected Cities Surveyed by the Concrete Coalition

(Comartin et al., 2011)

City	Sanborn Maps	Zoning Maps	Google Earth	Street Surveying	Building Officials	Tax Assessor's Data	Internet	Library Research	Engineer Firm Archives	Other Online Database	Other
Alameda	X	X	X	X	X			X			
Albany	X		X	X	X						
Berkeley	X			X	X	X				X	
Burlingame			X	X			X				
Calabasas				X							X(familiarity with city)
Daly City	X		X	X			X				X (US Census city; City-Data.com; Daly City History Guild)
El Cerrito	X		X	X	X						
Emeryville	X			X							

In order to be most effective, the format of the collected data (e.g. the database) should reflect the intended or expected use and will usually involve a compromise between simplicity, ease of use, cost, and cross-referencing capabilities. The simplest database would consist of a spreadsheet in which the various columns can be sorted, but a relational database could also be used for more flexibility, although it requires more planning and more effort to populate. Although many online sources are now available to access satellite or street view images of buildings, access can be cumbersome requiring zooming and orienting images to see specific characteristics. Therefore, it is usually also a good idea to collect pictures of the buildings along with the descriptive data. Because inventory information is spatially distributed, the authors found that using maps and overlays to plot the different types of data

was extremely useful at the planning and gathering stages as well as for data interpretation. Commercial geographic information system (GIS) software such as ArcGIS® or Google Earth Pro™ allows overlays, geocoding and importation of data from spreadsheets.

Often, it is effective to use a primary data source to generate the core of a database while using other sources to verify the collected information or to populate additional fields using cross-references such as parcel numbers or addresses. A few of the main sources of data to be explored in inventory collection are reviewed in the following sections.

COUNTY ASSESSOR FILES

Assessor files are a common starting place for inventory collection, partly because these are publically available records. Accessibility of assessor's files varies by jurisdiction. Many counties across the country provide records online, but an address-by-address search can be slow and cumbersome. In other counties the data are still stored on microfiche, requiring a visit to the assessor's office. Typically the assessor will sell the complete database or property data can be purchased from commercial enterprises such as First American CoreLogic® or DataQuick® that support the real estate sector. The commercially available data are derived from assessor's records. A major disadvantage of both sources is that the tax assessor's data are kept for property tax purposes and, therefore, the information for a number of building occupancies are likely missing. For example, information for most hospitals, clinics, schools, universities, churches, and government buildings is typically missing from the files.

Even for taxable properties, the information is not always accurate or complete. First, since structural performance is not the assessor's primary interest, "construction" data in assessor's files frequently does not use standard engineering or building code terminology and is therefore often unreliable or unusable when studying engineering questions. Second, assessor's data are organized by assessor parcel numbers (APNs) which represent a taxable entity and thus can include data for multiple buildings. A property with multiple structures may or may not list 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 unit in a building has a different owner, and thus its own APN. A building with 30 condominiums may have up to 30 entries in the assessor records, all with the same address but none that reflect the overall height or square footage of the building. Other challenges are that a single building may have multiple addresses or the building address or occupancy changes over time. In Los Angeles many structures have been changed from factories or office buildings to condominiums through the Adaptive Reuse Program, yet the assessor's record may or may not reflect this occupancy change.

In San Francisco, the Concrete Coalition used assessor's data to make an initial estimate of the total number of buildings in San Francisco. This figure was compared with estimates made by other researchers; it was never more than rough first order count, and not a database or a thorough inventory (Kadysiewski, 2010).

COUNTY/CITY ZONING MAPS

Zoning maps are most useful in the planning phase of the inventory collection. Combined with an understanding of the study area's evolution, past building practices, and history, they can help to focus the data gathering where the desired structures are concentrated. In California for example, potentially hazardous URMs are expected in industrial or commercial

areas developed before the 1950's but not in residential areas consisting mostly of single-story wood frames. Zoning Maps were used in the Alameda concrete building study to identify the residential areas of the city where the likelihood of finding concrete buildings would be small. By using the zoning maps in the planning phase, detailed collection efforts can be focused on areas of higher concentrations of targeted structures, while a less detailed scan through the low concentration areas can be achieved by a driving survey or by using Google Street View™.

In San Francisco, historic zoning maps were used only to assist a quick first estimate of the concrete building count. A walking survey of two neighborhoods established a rough frequency of building types in an old industrial area and along a neighborhood shopping street. The zoning maps were then used to extrapolate the survey findings to similarly zoned areas in other parts of the city, providing a very rough estimate.

Zoning maps also can be a useful data validation tool. In the Los Angeles study, electronic zoning maps were overlaid on the area base-map along with plots of the inventory of older concrete buildings. Researchers used this technique to confirm that low concentrations of concrete buildings correlated with low and medium density residential areas, and high concentrations of concrete buildings correlated with commercial and industrial areas. Figure 2 shows a zoning map overlaid on inventory data for a region of Los Angeles. As expected, the concrete buildings are clustered in the high and low density commercial zones with very few structures in the medium density residential areas. Medium density residential zones consist of 2 to 4 story apartment buildings, which in California are typically constructed of wood, especially for pre-1980 construction.

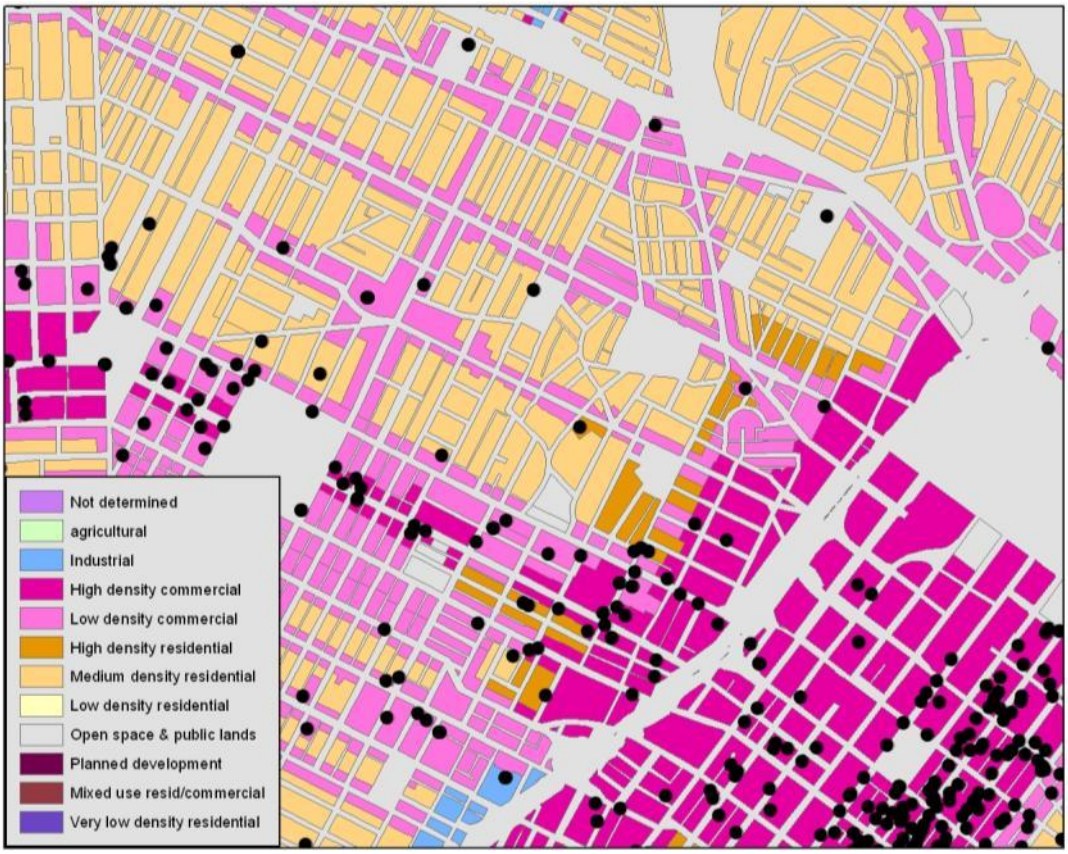

Figure 2. Los Angeles area base map overlaid with zoning map and inventory data serves as one technique for validating inventory data.

SANBORN MAPS

Sanborn maps were originally developed as an assessment tool for the fire insurance industry. These maps were produced for over 12,000 cities and towns in the U.S. from the mid 1860's to 1970. Oswald (1997) compiled a detailed history of these maps and their uses. The maps were drawn at a scale of 50 feet to one inch and show the footprint of structures and other information such as use, number of stories, and building materials (Figure 3). The maps used colors to indicate the building's exterior material, for example pink for brick and blue for stone or concrete. They were modified every year or two to reflect urban growth and building modification or construction. Because the maps typically were maintained over a large part of a city's history (keeping in mind that they typically do not include data after 1970), they can help reconcile issues encountered in drawing from multiple databases (e.g. streets re-named or address numbers amended over time).

Figure 3. Sanborn maps are published in volumes of 30 to 100 sheets each covering 4 to 6 city blocks. The City of New York comprises 39 volumes (Oswald, 1997). Maps provide detailed information about each city block.

Perhaps their most effective use, described in the case studies, is in combination with a visual sidewalk confirmation. Because the Sanborn maps were maintained and used repeatedly by industry, the data they record is generally reliable, as long as the mapped building still exists. Meanwhile, a sidewalk survey can confirm the existence of a building and note major alterations, but often cannot discern properties such as age or structure type. In combination, if the mapped building is confirmed visually, then the Sanborn map can be relied on for many (but not all) details, leading to a reliable address-specific inventory.

On the other hand caution must be taken with the data. The creators of the Sanborn maps were concerned with fire insurance issues, and their classifications may not conform to those used by structural engineers. For example, because concrete-encased steel columns and concrete cladding panels historically were used as fire protection, in some cases buildings

denoted as concrete may in fact be steel moment frames with concrete-encased columns, or with concrete cladding panels. Of course, many of the buildings denoted as “concrete frame” in the maps are indeed concrete moment frames. However, in San Francisco, surveyors found some errors on the maps. Buildings were classified as concrete frames but were known to be steel frames. Sanborn maps can usually be consulted at city offices or libraries, but some cities have made the maps available online, which makes them a very convenient tool. A disadvantage of the online maps is that they are typically black and white. The omission of the colors on the maps makes them more challenging to use.

The San Francisco study focused on identifying concrete buildings that were built before 1980, a date before which codes and construction practices did not include ductile detailing. Volunteers reviewed all 1,200 pages in the 11 volumes of Sanborn maps for the city and recorded the number of suspected pre-1980 concrete buildings on each one. This summary was used to focus later volunteer efforts on the neighborhoods with the highest concentrations of concrete buildings. Since the San Francisco maps had last been updated in 1985 (many jurisdictions around the U.S. stopped updating in 1970), the next step involved a more detailed analysis of high concentration areas to eliminate from the inventory those buildings that had been demolished or incorrectly identified. In Oakland, volunteers attempted to use Google Earth's historic imagery database to investigate changes in existing buildings over time. Unfortunately, the gap between satellite images for the city of Oakland was too large to be of much assistance. However, this may be an appropriate strategy for other cities.

The Alameda study used the Sanborn maps to verify data previously collected from sidewalk surveys. The Alameda Sanborn maps have a major limitation. The decommissioned Alameda Naval Air Station (NAS) occupies 6.1 km^2 on the west end of the city and the buildings on this property are not included on maps. Based on a comparison of lists of potential pre-1980 concrete building from the initial sidewalk survey and Sanborn maps (excluding the Alameda NAS), the lists agreed for 85% of the entries and 15% needed further review and verification. An attempt was made to improve the data through library research of historical references. While this confirmed a few more buildings (another 1% to 2 %), the amount of effort was extensive.

SIDEWALK SURVEYS

Sidewalk surveys are enormously valuable for verifying public data, but, with the exception of certain vernacular building types, they do not confirm or reveal much in the way of structural details or earthquake vulnerability. For this reason they are perhaps most appropriate for estimating the potential scope of a risk, not for quantifying likely or specific losses. Recent efforts have effectively used large groups of volunteers to confirm or update data compiled in advance from public agency records or from Sanborn maps. For example, in addition to the survey of concrete buildings described later in this section, in February 2007, San Francisco's Department of Building Inspection, together with volunteers from the Structural Engineers Association of Northern California (SEAONC) and EERI's Northern California (EERI-NC) chapter, conducted a sidewalk survey of about 3000 multi-unit residential buildings. Addresses were compiled in advance from the city's Housing Department data. The purpose of the survey was to confirm the Housing data and to supplement it with estimates of perimeter "openness" as an indicator of soft or weak first stories (ATC, 2009). In the fall of 2008, ABAG, together with SEAONC and EERI-NC volunteers, conducted a similar sidewalk survey of about 3000 multi-unit residential buildings in Oakland, with addresses identified in advance from county assessor's files

(ABAG, 2009). Some efforts (for example, for the Alameda concrete survey described here) have approached the inventory from the opposite end, using the sidewalk survey to first canvass a district, identify candidate buildings by eye, and record addresses for confirmation later using other references.

Sidewalk surveys are different from faster "windshield surveys" that have time only to note broad patterns and addresses for further investigation. Sidewalk surveys allow the time to collect information on number of stories or structural system visible from the street, building lobby, or public garage and, most effectively, to confirm data from other more detailed sources. As described in the next section, the growing availability of online satellite imagery makes it increasingly possible to simulate a traditional sidewalk survey from one's desk. Not only is the work faster, but such a virtual sidewalk survey can offer the additional advantage of overhead views that show a structure's massing, roof construction, plan irregularities, and building adjacencies. Online views, however, do not provide on-site information such as building condition, the number of units listed on a building registry, or the history of a building recorded on a cornerstone or plaque. Also, as Concrete Coalition volunteers found in a virtual sidewalk survey of Berkeley, California, online street views are limited or obscured surprisingly often by traffic, trees, reflections, or just an unhelpful camera angle.

Sidewalk surveys are an excellent tool for collecting and verifying data, but they require a lot of work in pre-planning including pre-field data management, travel time, time on the street (about 20-30 minutes per building), , plus the time to merge the collected information in the database. An important first step is to clearly define what to count. In the case of older concrete buildings, specifying 1980 as the cut-off year was the first important decision. Another example is the need to specify what occupancies should be counted. When the Concrete Coalition survey organizers assumed that databases for public K-12 schools, hospitals, state buildings, federal buildings, county courthouses, and public universities would be available, they told volunteers they did not need to collect data on these structures. Ultimately however, some of the databases did not materialize and the decision to let volunteers opt out of collecting data on these structures resulted in some incomplete inventories.

Concrete Coalition Sidewalk Survey Example

The Concrete Coalition's sidewalk survey of pre-1980 concrete buildings in San Francisco was actually the fourth phase of a broader inventory effort (Comartin et al., 2011). In Phase 1, volunteers met at the San Francisco public library and counted every concrete building on each of the 1200 Sanborn maps available for the city. The Phase 1 estimate from the maps was 3,851 buildings (confirming an even earlier estimate of 1000 to 4000 buildings based on assessor's data, a zoning map and a count of two neighborhoods). Phase 2 involved a field verification of a random sample from the maps, and led to Phase 3, an adjustment of the initial count to eliminate demolished structures, structures constructed after 1980, non-concrete buildings, etc. After Phase 3, the estimate stood at roughly 3,200 buildings (Kadysiewski, 2010).

The Phase 1-3 work suggested that it might be possible, with enough volunteers, to generate a detailed building-by-building inventory for a large jurisdiction. Building-specific data would enhance the basic count of San Francisco's pre-1980 concrete buildings with information about their ages, current occupancies, size, and structure type. Importantly, as Phases 2 and 3 showed, field work would also confirm and correct the data compiled initially from Sanborn maps.

Thus, Phase 4, a sidewalk survey of about 850 pre-identified addresses in nine neighborhoods, was organized by the EERI- NC chapter, EERI staff, and SEAONC. Ninety-three volunteers, including 44 students from five local universities, participated. From previous building inventory efforts, and from the recognition that concrete buildings are not as easily identified from the street as other structure types, the organizers knew that volunteers would need to work from lists of specific addresses.

For the field survey itself, teams of two to four students and engineers (with at least one practicing engineer per team) were each assigned an area of about four city blocks (one Sanborn map page). Practicing engineers were essential to the survey teams. In San Francisco, data from students and young engineers were about 80% as accurate as those completed by more experienced engineers, particularly in historic districts where finishes have been added, buildings are immediately adjacent to each other, and modifications have been made. Each team was issued a photo of the relevant Sanborn map and survey sheets pre-printed with the addresses of interest. Teams were asked to record selected building characteristics and take at least one photo of each building.

Preparation and detailed instructions were key to the survey's success. Two participants went to the San Francisco public library and took high resolution digital photographs of each Sanborn map in the downtown area. Four photographs were taken (top left, top right, bottom left, bottom right) for each of 41 maps for the target survey area. The photographs were then printed out as color maps to be handed out as part of the package to volunteers on the Saturday walk-around day. In addition, a group of students from UC Berkeley's EERI student chapter as well as several professional volunteers reviewed all the maps and prepared preliminary lists of addresses of suspected concrete buildings for each team to use on its walk-around day. Before going into the field, all surveyors participated in a half-hour training session. Topics included how to read the Sanborn maps, how to identify a concrete building, how to complete the data forms, tips for taking useful photos, and what to do if a building owner or tenant asks you not to survey his building. Surveyors were given several copies of a one page FAQ document (found in the Appendix) to hand to building owners, tenants, or members of the public curious about the inventory collection.

As shown in Figure 4, the data collection forms were created especially for this survey and were generated from the spreadsheet of Sanborn map addresses compiled in advance. While this avoided certain technology hiccups and allowed the project to focus on directly relevant data fields, it did involve some tedious data entry after the fact. Student volunteers spent two days entering data from the survey forms into a master spreadsheet. A machine-readable bubble form might have been more efficient, but it would have meant collecting less data on a single sheet. A sidewalk survey of certain residential woodframe buildings in Oakland had successfully used that method (ABAG, 2009). The organizers considered using the ROVER software developed to work with FEMA 154 (Porter, 2010; FEMA, 2011), but its generic nature, while valuable when dealing with a wide variety of structure types, would have required difficult customization (as well as volunteer training) to suit the Coalition's goals. A lesson here is that advance thinking about the data fields of interest and about the logistics of collecting it can rule out certain technological options or provide the impetus for making them more adaptable. While this can necessitate more preparation and customization up front, it can also lead ultimately to a smoother and more fruitful survey.

Sidewalk Survey Data, Feb 27, 2010 Survey Team: Bonowitz, McCormick, Greene

#			Construction				Age			Use		Size				Deficiency			
		Y/N/M	See list	Y/N/DK	Y/N	C/W/DK	Year/DK	Y/N/DK	Y/N/DK	See list	See list	#	[ft]	[ft]	[sf] Opt'l	Y/DK	Y/N/DK	Y/N/DK	See Instructions
Sanborn page	Address	Matches Sanborn?	SFRS(s)	Vert combination?	Obvious retrofit?	Floor/Roof const'n	Year built	Pre-1950?	Post-1980?	Ground floor Use(s)	Upper floor Use(s)	Stories above grade	Street dimension [ft]	Side dimension [ft]	Total floor area [sf]	Discont. shrwls?	Short columns?	Torsion likely?	Photo notes
188	351-361 9th St	Y	C1 C2	N	N	DK	DK	Y	N	M: Furniture store	B: Office	2	~80'	~80'	13,000	N	N	N	1. "351" 2. Front 3 Rear

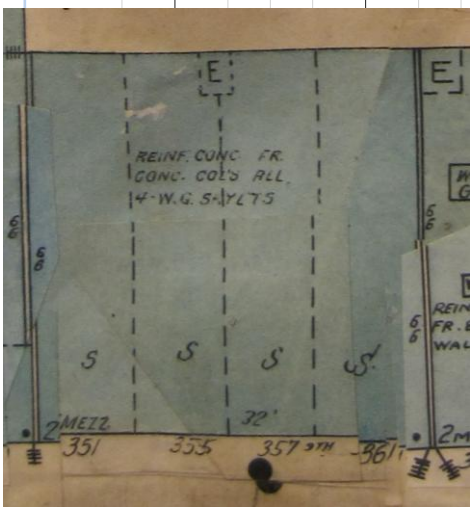

Figure 4. Each team was issued a data collection form pre-printed with addresses of the properties of interest. Pre-survey training on how to complete the forms was provided. The figure shows a sample from the training materials.

Once the sidewalk survey was completed, approximately ten students who participated in the survey worked for two days entering the information from each field sheet into a master spreadsheet. The students entered all the information from the worksheets prepared by volunteers into a master spreadsheet. The students indicated corrections made in the field by the volunteer teams, particularly changes in addresses. Summarizing the data for a large survey like this can be a major effort.

A major outcome from San Francisco sidewalk survey is that it confirmed that the estimates generated by the team that counted buildings on every one of the 1200 Sanborn maps, plus their verification process and the adjustments, were very accurate. This suggests that, for those jurisdictions where Sanborn maps are available, it would be possible to conduct a concrete inventory using the counting and verification process. This might be particularly useful for older, larger jurisdictions where it is not possible to make a field visit to every block that might have such buildings.

ONLINE MAPS, AERIAL PHOTOS AND GOOGLE STREET VIEW

Google Maps™ and Street View™ (maps.google.com) and other services such as Live Search™ (maps.live.com) provide aerial and street views of various buildings that facilitate a cost-effective collection and verification of data. These tools are especially useful to verify the accuracy of data collected through the purchase of an assessor's database. The on-line tools can verify whether a candidate property has been demolished or replaced. In addition, aerial photos and Google Street View™, can be used to estimate the square footage and the

number of stories, or to verify that the architectural style corresponds to the year built. Online tools are also useful to clarify discrepancies in the data that may be due to input or typographic error (very large square footage associated with 1-story building for example). In many instances, these tools can replace sidewalk surveys by resolving discrepancies by virtual visual inspection, leaving only difficult cases for in-person visits. Such tools were extensively used for the Los Angeles inventory work.

ADDITIONAL SOURCES OF DATA

Other city- or county-specific sources of data can also be exploited when populating an inventory database and official websites should be consulted early on in the inventory development. The City of Los Angeles, for example, has an online service called ZIMAS (Zoning Information and Map Access System) that includes most of the Assessor data, a parcel and APN locator, parcel maps, and recent building permits information. City Planning services often have Historic and Cultural Heritage programs or commissions that may have collected detailed information on older structures. Historic societies may also be a good source of information, along with published material on architecture and historic landmarks (including for example the "Images of America" collection from Arcadia Publishing). A search of the library in Alameda uncovered a number of studies and reports used to qualify buildings in Alameda for the National Historic Building Register. These reports identified the construction types of many relevant buildings.

Departments of Building and Safety usually keep records of improvement and remodeling permits, but they rarely contain information about seismic retrofits. While recent permits are available online, older data must be reviewed in the City's Department of Building and Safety offices, which is a very time consuming process. In Los Angeles, 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 can only be used for a subset of structures and only at relatively great expense. Other public sources of data may include: city housing departments, departments of general services and public works, Division of the State Architect, chancellor's office of local or state universities, school districts, hospital regulatory agencies, etc.

Finally, local structural engineers can be extremely useful in providing insight on the specifics of existing building stock based on their historical knowledge of local practices. They can often highlight typical deficiencies encountered while designing retrofits and may be able to share structure-specific details.

Refining A Database: the Los Angeles Example

For the City of Los Angeles nonductile concrete building inventory, a total of 15 sources of data were used to cross-check and further populate the original data purchased from the County Assessor. While Assessor data can be obtained free in some jurisdictions, Los Angeles County sells tabulated data through the Urban Research Unit. The research team purchased data on pre-1976 concrete buildings in the City of Los Angeles for $2000, however, assessor's data is notoriously incomplete, and the data needed validation to ensure that they represented current conditions. The researchers wanted 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 (Figure 5) was developed to ensure that all buildings were reviewed and assessed in a similar fashion, minimizing the potential bias from data collectors.

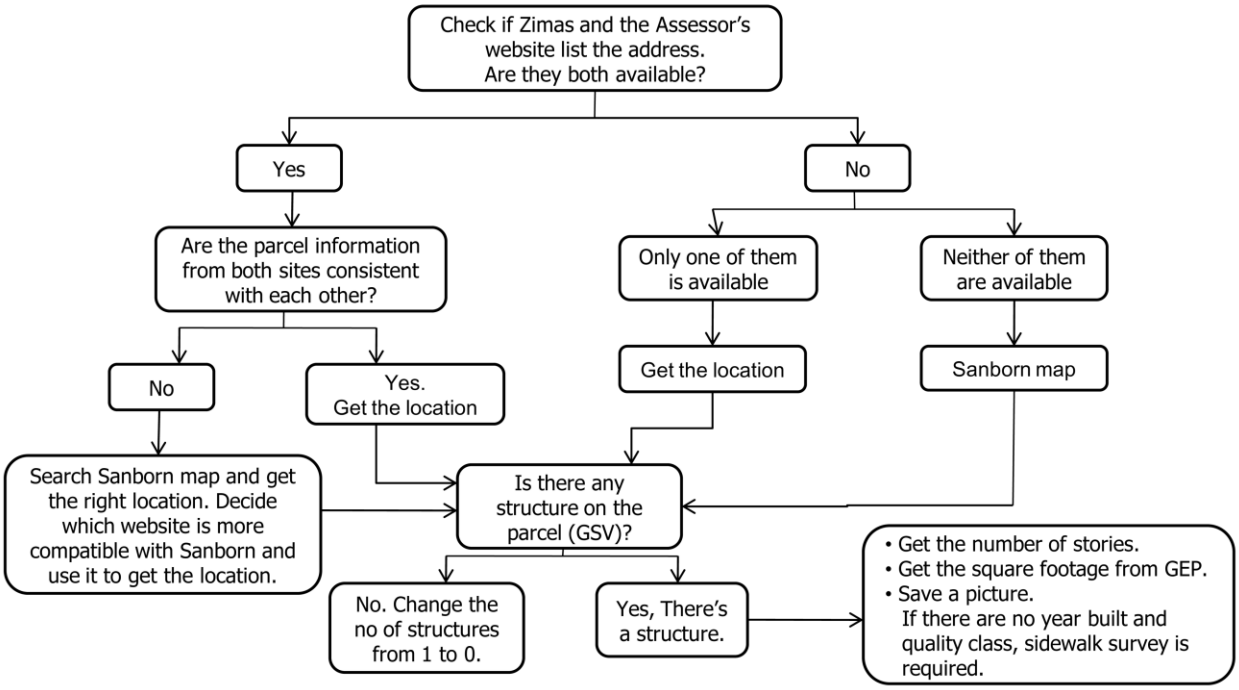

Figure 5 Flowchart of methodology for validating data. Note: GSV means Google Street View, GEP means Google Earth Professional (Anagnos et al., 2008).

Data were verified by following a set of rules and flowcharts specific to the problem encountered. For example, data from ZIMAS were compared with assessor's data. If the data did not match, then an additional check consisted of first locating the address on Sanborn maps and then looking at the building with Google Maps™ and Google Street View™ (GSV). Typical inconsistencies included address (e.g. more than one address for a property), square footage, number of stories, or even the existence of a building on a parcel. Discrepancies could not always be resolved, in which case the address was saved for a site survey. Using GSV as a first step, however, proved to be a very efficient way to verify much of the data.

Another step in the validation process was to gather a group of structural engineers experienced with Los Angeles design and construction practices. This group of practicing engineers interacted with the researchers throughout the process. In one instance, the group was shown photographs of 64 buildings from the database. The goal of the meeting was to confirm that the buildings in the database were representative of older concrete construction in Los Angeles, to ensure that a subset of the buildings had not been overlooked, and to better categorize the structural systems. Engineers were shown buildings about which there were questions regarding construction type, and buildings that were suspected to be steel.

The final step in the validation process involved a "blind" street survey that used some of the data collection techniques developed for the San Francisco sidewalk survey. A map was made of all data in the inventory and overlaid with planning maps to identify nine areas of

the city for validation. Two types of areas were selected: 1) areas densely populated with data that were zoned commercial or industrial suggesting there should be older concrete buildings, and 2) areas with few data points that were zoned low to medium density residential suggesting woodframe construction. Twenty-five volunteers were divided into eight teams to survey the buildings in each of the selected areas. Each team was given a parcel map and asked to walk the area and identify older concrete buildings and locate them on the parcel map. They were not given any information about any of the buildings in their study zone. Data collected by the survey teams were compared with the database to check their agreement. Typically the data from the field and the database agreed about 70% of the time. Reasons the databases did not agree included surveyors identifying buildings that were concrete but had been retrofitted, designating buildings as concrete that were in fact steel, and not identifying buildings that were in fact concrete. A lesson reaffirmed in this "blind" sidewalk survey is that sidewalk surveys are important tools but not completely accurate.

EXTRAPOLATION FROM EXISTING DATA

A goal of the Concrete Coalition (Comartin et al., 2008, 2011) was to develop an estimate of the number of pre-1980 concrete buildings among California's 350 cities and towns within areas subject to moderate-to-high seismic hazard. According to the 2000 Census, these jurisdictions range in population from less than 100 (Vernon) to more than 4 million (Los Angeles). It was not possible to collect field data for all 350 cities, thus a unique method of extrapolation was developed. While the case study described here is for California and has a number of limitations, the technique could be replicated for any region.

Normally an extrapolation can be made on the basis of obtaining information for a sample of jurisdictions and then generalizing from this sample. This procedure could be used in principle for the field-collected inventory data for various cities. Two factors made this infeasible. First, since inventories were only available where volunteers were willing to collect them, the selected building inventories were based on opportunistic rather than statistical samples of jurisdictions. Given that the opportunistic sample was non-random, the traditional statistical extrapolation from samples to broader populations—as with an opinion poll—was not possible. Even if the cities for which inventories were collected approximated a random sample, insufficient numbers of cities with population greater than 500,000 were included to permit generalizing for larger cities.

Given this limitation, other information was used to inform the desired extrapolation. In particular, the mix of building stock in a jurisdiction is related to various factors that affect population growth and development. Researchers developed a prediction model that was based on these relationships. The first step was to estimate, for the cities in which field-based inventories were completed, simple statistical models of the relationships among the number of pre-1980 concrete buildings and various data about each city's population, housing stock, land area, and development history. These data, obtained from the 2000 U.S. Census of Housing and 2000 Census of Population, are compiled in Appendix F of Comartin et al. (2011). To predict the number of pre-1980 concrete buildings for non-inventory cities, relevant Census data for those jurisdictions were substituted into the statistical prediction model.

The selection of the appropriate statistical model entailed balancing statistical assumptions, predictive accuracy, and meaningful relationships. Two resultant regression models are shown in Table 3. These differ in the number of cities that are included in the model estimation. Different sets of cities were excluded from each model based on visual

inspections of the prediction plots showing outliers that distorted the regression estimates. The "final model" was used to make predictions for non-inventory cities. The latter is preferred because it has a lower standard error of prediction while meeting other desired statistical criteria.

Table 3. Inventory Regression Prediction Models for California (Comartin et al., 2011)

	Regression Coefficients [a]	
Variable	**Initial Model** [b]	**Final Model** [c]
ln(Number of housing units)	.780*** (.098)	.809*** (.097)
ln(Percent built before 1939)	.756*** (.125)	.675*** (.132)
ln(Percent in structures with 20 or more units)	.706*** (.242)	.706*** (.241)
Constant	-7.663*** (1.057)	-7.711*** (1.033)
Model Statistics		
Number of observations	29	27
Adjusted R^2	.84	.85
F-value for overall model	49.181***	50.154***
Standard Error of Prediction	.691	.675

*** $p < .01$

[a] Values are the unstandardized coefficients for predicting the natural log of the number of pre-1980 concrete buildings in inventory cities. Standard errors are in parentheses.

[b] Excluding four outliers that distort model estimates: Pasadena, Piedmont, Riverside, and San Bernardino

[c] Excluding six outliers that distort model estimates: Freemont, Pasadena, Piedmont, Richmond, Riverside, and San Bernardino.

A variety of choices were made in developing these models. Because the inventory and Census data are highly skewed (long right tail in the distributions), the data had to be transformed using natural log transformations to meet Ordinary Least Squares regression assumptions of linear relationships. A variety of models were estimated that involved different demographic and housing data. The models shown in Table 3 provide the best statistical fit and substantive interpretation of the estimated relationships. It makes sense that the number of pre-1980 concrete buildings is positively associated with increased population, greater numbers of number of housing units in structures with 20 or more units, and greater number of pre-1939 buildings. The number housing units is a proxy for population. The number of pre-1939 buildings is a measure of the age of the building stock while the percentage of units in structures with 20 or more units is a measure of the type of buildings. Efforts to incorporate measures of density, employment ratios of various kinds, and other indicators of the housing stock did not result in prediction models with as good a fit as these. Identification of outliers from the fit of the data and visual inspection of estimated residuals in the initial modeling led to re-estimates without the outliers as reflected in these two statistical models.

Predictions of the number of pre-1980 concrete buildings for non-inventory cities (NDCP) were made by substituting relevant values for each city into the final model then exponentiating the predicted value according to Eq. 1.

$$NDCP = \exp(-7.711 + .809 * \ln(\text{housing units}) + .675 * \ln(\text{pct built before 1939}) + .706 * \ln(\text{pct units in structures with 20 or more units})) \quad (1)$$

Using this formula to estimate the number of pre-1980 concrete buildings for the 350 cities in the 23 high seismicity/high population counties and 2 additional cities where data were collected produces an estimate of 13,726. When actual values from available field observations were combined with predicated values for those cities for which there were no field observations the resulting estimate was 13,718. Given that the prediction errors are quite broad—more than quadruple the estimates themselves—these estimates provide a false sense of precision even if a rounded value of 14,000 is used. As a consequence, it is best to consider the estimate as an order of magnitude estimate rather than a precise point estimate.

Table 4 presents the results of the model extrapolation for 28 cities with 2000 populations greater than 150,000. These are presented because they are more likely to have substantial numbers of pre-1980 concrete buildings. (The results of the extrapolation for all jurisdictions are reported in Comartin et al., 2011, Appendix F.) The City Inventory column contains the inventory values reported by inventory methods discussed in this article; the Predicted Value column contains the values estimated using the final regression model of Table 3. Where available, actual inventory values are compared with predictions. Among these larger cities, there are an estimated 8,000 pre-1980 reinforced concrete buildings. Again, these are best considered order of magnitude estimates.

The results for cities with populations over 150,000 illustrate some of the limitations of the modeling. One is the difficulty of predicting values for the largest cities. The estimate for Los Angeles is twice what the field-inventory process provided while that for San Francisco is only 60 percent of what the field inventory showed. City policies, such as proactive retrofit ordinances or limits on demolition clearly impact the estimates. In addition, the definitions of "what to count" was inconsistent between cities. Prediction errors also reflect the limited number of larger cities for which data could be used to refine the prediction model

The differences in the model-predicted and field-estimated inventory values may be a useful diagnostic for assessing the quality of the field estimates. The statistical prediction and field estimates each constitutes an estimate with different bases. Divergence in the field estimates when compared with the predicted estimates suggest values that differ from the norm. Identification of these should lead to assessments of why such differences exist. In most cases the difference can likely be explained by unique circumstances for the jurisdiction in terms of growth and development patterns, aggressive retrofit policies, or in lack of consistency in which buildings should be counted.

Table 4. Inventory Predictions for California Cities with Population Greater Than 150,000 (Comartin et al., 2011)

City	2000 Population	Pre-1980 Non-Ductile Concrete Buildings	
		City Inventory[(a)]	Predicted Value[(b)]
Los Angeles	4,018,080	1,500	3,088
San Diego	1,255,540		509
San Jose	912,332	363	205
San Francisco	739,426	3,000	1,855
Long Beach	492,912		396
Fresno	461,116		101
Sacramento	456,441		202
Oakland	395,274	1,300	683
Santa Ana	340,368		100
Anaheim	331,804		77
Bakersfield	295,536		51
Riverside	290,086	5	130
Chula Vista	210,497		33
Glendale	207,157	160	243
San Bernardino	205,010	5	81
Fremont	200,468		36
Huntington Beach	194,457		27
Irvine	186,852		4
Oxnard	183,628		20
Fontana	181,640		14
Moreno Valley	178,367		4
Santa Clarita	177,158		12
Ontario	172,701		22
Rancho Cucamonga	172,331		9
Oceanside	166,108		27
Garden Grove	166,075		25
Pomona	162,140		48
Santa Rosa	154,212	55	58
Total Predicted - All cities			**8,060**
Totals (w/actual substituted for predicted)			**8,105**

a) City Inventory contains inventory values reported by inventory methods discussed in this article

b) Predicted Value contains values estimated using the regression model

The predicted estimate of lower tens of thousands of pre-1980 concrete buildings provides a sounder basis for such estimates than prior guesstimates based on rules of thumb. Yet, this experience in extrapolating field-based inventories underscores the difficulty of establishing regional estimates of specialized categories of buildings such as nonductile concrete buildings. The validity of such predictions is based on development of valid predictive models and accurate data. In this case, the predictive model is limited by the non-random sample of cities for the field-based inventories and data limitations for modeling relationships between the nonductile concrete building data stock and development patterns.

Important Lessons

Inventory collection is resource intensive and there is no single standardized process. It requires extensive planning, flexibility, and creativity to combine disparate data sources that typically are not designed for the purpose of hazard mitigation. A few strategies can help make the process smoother:

- Define the goal of the inventory from the start so as to best understand which attributes are most important. As part of goal setting, decide how accurate the inventory needs to be. For many applications an exact count is not needed. Perhaps only an order of magnitude is needed.
- During the planning stage, talk with local experts to identify the best sources of data and potential problem areas.
- Use local experts to define characteristics to look for in buildings of interest.
- Use planning maps to narrow the detailed collection to those areas that have a high density of relevant data.
- Data sources will be incomplete and inaccurate. Plan to use a variety of data sources and methods to confirm the data and to assess its quality.
- Whenever possible, try to use a single data-entry person or provide thorough training and strict procedures for all workers so that all buildings are assessed and documented uniformly.
- If using volunteers, training and detailed guidance on what to count and how to identify relevant buildings is needed. Information meetings as well descriptions of pilot applications of the inventory collection process are essential in the training of volunteers.
- If extrapolating beyond the collected data to estimate a complete inventory, good data are needed to model relationships between different categories of building stock and population and development patterns.
- Sidewalk surveys have limitations. While attributes such as number of floors, dimensions, occupancy, corner buildings, and vertical irregularities are usually straightforward to capture, the specifics of lateral force resisting system often are not obvious. A reliable judgment regarding which of the old buildings are truly hazardous would need building access and a lot more time for detailed examination.
- Based on the experience of the Concrete Coalition, an order of magnitude concrete inventory using Sanborn maps and the counting and verification process is possible.

This might be particularly useful for older, larger jurisdictions where it is not possible to make a field visit to every block that might have such buildings.

Conclusion

The development of building inventories has been greatly aided by digital technology; however, the use of public records and databases from a variety of sources, as well as volunteer surveys are critical to creating reasonably accurate and useful inventories. For small cities, the combination of Sanborn maps and volunteer sidewalk surveys may be sufficient. For large urban areas, purchased data and digital technologies will provide a base data set which can be improved with a variety of spot-checking techniques.

Development of inventories needs thoughtful planning including consideration of methods of collecting and archiving data, careful definition of what is to be counted, pilot testing of methodologies on a small scale before tackling a large region, and development of case studies to provide guidance for the inventory team or volunteers. Where resources are not available to compile an inventory, alternative techniques such as the statistical extrapolation developed for this study can provide an order of magnitude estimate. However, ultimately a more detailed inventory based on systematic evaluation of the existing building stock is needed to effectively inform mitigation decisions. A major challenge is finding the resources to collect the inventory.

Inventories are a first step in estimating risk on a local or regional level and they provide a mechanism for the technical and policy communities to raise awareness of a particular building type and hazard (or risk). Further, inventories are critical to providing an understanding of the scale of a particular seismic hazard relative to other issues threatening the built environment. Engineers can use inventories to inform models and simulations of building components and systems that can lead to better targeting of deficiencies in existing buildings and better, more cost effective methods for retrofits. With respect to public policy, inventories provide an understanding of the location of hazardous buildings, such as concentrations by neighborhood, as well as the uses and occupancies. Policies will be different for different conditions. For example, a hazard such as a soft first story in wood construction where the problem is predominantly in residential buildings would elicit a different policy approach than nonductile concrete buildings where the concentrations in office, commercial, residential or industrial buildings will vary in different cities. Ultimately, good data about any seismic hazard will improve mitigation policy alternatives.

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APPENDIX – FAQ Document for SF

San Francisco Concrete Building Survey, February 27, 2010

What are we doing?
We are collecting data related to certain concrete buildings. A survey of this type is one of the first steps toward understanding and reducing risks to the public and to the city's ability to respond effectively after an earthquake. We are *not* making engineering judgments about the safety or legality of any building.

Who are we?
We are volunteers interested in earthquakes and public safety; mostly building design professionals, earthquake scientists, or university students in those fields; mostly from two organizations: SEAONC and EERI-NC. As volunteers, we are not working for the city or for any business venture.

What are we looking for?
Our survey concerns concrete structures designed and built before building codes were significantly revised around 1980. We already know roughly how many of these buildings there are in San Francisco. The purpose of our survey is to enhance that data with information about building size, use, and approximate age.

What will happen to the data we collect?
The data will be used by researchers, engineers, and planners to help estimate the city's earthquake risk. We will make the data available to the San Francisco Department of Building Inspection for its use in planning and earthquake preparedness.

Is my building safe?
We are not making that judgment with this survey. If you are concerned about the safety of your building, the best thing to do is to call an engineer or the Department of Building Inspection.

Will I have to retrofit my building?
We are not making that judgment with this survey. Mandatory safety improvements generally require legislation. For more information, the best thing to do is to call your Supervisor, your state Assembly member, or the Department of Building Inspection.

Where can I learn more?
This section contained links to a number of resources including the Department of Building Inspection, the Concrete Coalition, the Structural Engineers Association, the US Geological Survey, EERI, and the Seismic Safety Commission.