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DEVELOPMENT OF A CONCRETE BUILDING INVENTORY: LOS ANGELES CASE STUDY FOR THE ANALYSIS OF COLLAPSE RISK

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ABSTRACT

We describe the development of an inventory of approximately 1,500 nonductile concrete buildings in the City of Los Angeles. Nonductile concrete buildings represent a significant life safety hazard in many urban centers world-wide because of their collapse potential when subjected to earthquake ground motion. The inventory is being used to identify prototypical deficiencies, to guide a testing/ simulation program, and to develop loss models and policy proposals. The inventory uses state-of-the-art spatial databases, publicly available online resources, sidewalk building inspections, and input from local engineers to record the geographic distribution of these buildings, their general characteristics, structural configurations and usage. The data show that nonductile concrete buildings are clustered in certain neighborhoods, that more than half were built in the 1920s and 1960s, and about 13% are taller than 8 stories. Los Angeles has been proactive in developing required and voluntary retrofit programs, suggesting that this dataset may not be reflective of other cities in California or the U.S.

Introduction

Nonductile concrete buildings were a prevalent construction type in highly seismic zones of the U.S. prior to development of codes for ductile reinforced 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. Nonductile concrete buildings have a history of poor seismic performance, and many have collapsed in past earthquakes including Northridge (1994); Kobe, Japan (1995); Chi Chi, Taiwan (1999); Kocaeli, Turkey (1999); Sumatra (2005); Pakistan (2005); Sichuan, China (2008), and L'Aquila, Italy (2009). In 2004, the State of California Multi-Hazard Mitigation Plan estimated the presence of 40,000 of these buildings in California, with 14,000 in

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Los Angeles County. The estimate was based on selected local inventories and included residential buildings, commercial buildings, schools and critical service facilities (OES, 2004, p. 97). This study, and other inventory studies by the Concrete Coalition (Comartin et al., 2009), suggest that estimate of 40,000 nonductile concrete buildings in California may be too high.

Inventories, such as this inventory of nonductile concrete buildings assembled for the City of Los Angeles. are a crucial first step toward understanding the scale of the problem associated with potentially dangerous buildings. 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 due to earthquakes. It should be noted that while older tilt-up buildings were often constructed with deficient wall/roof connections 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.

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 briefly describe the diverse array of data sources and the data collection methodologies used to develop the inventory. We then describe attributes of nonductile concrete buildings in Los Angeles revealed by the inventory, including building size, age, type, usage, and ownership type (e.g. government, private, utility, etc.). We discuss processes used to validate the inventory and describe its anticipated future use in identifying prototypical deficiencies, loss modeling and policy development.

The Study Region

The City of Los Angeles covers about 470 square miles of the Los Angeles Basin and is one of 88 cities located within Los Angeles County ("Los Angeles," 2009). Although settled by the Native Americans thousands of years ago, and then by the Spanish in the 1500s, the little pueblo only started to grow after its incorporation as a city in 1850. The first census, taken in that year, indicated a population of 1,610. By 1900 the population had grown to 102,000, more than doubling every ten years until the 1930s. The population in 1930 was 1.2 million and growth remained between 20% and 30% every decade for the rest of the century. According to the California State Department of Finance, the city has grown to 4.1 million in 2009. Construction growth in the city followed a similar pattern.

Los Angeles City has been proactive in implementing voluntary and required programs to reduce seismic risk. To bring its own properties up to current code standards, the City has aggressively pursued a facilities retrofit, replacement and new construction program using a variety of public funding strategies, including bond financing, which totaled more than $3.7 billion since 1989 (City of Los Angeles Department of Public Works, 2009). As a result, 155 of the City's most critical properties, totaling more than 4.2 million square feet, now meet current seismic codes, including most administrative buildings (City Hall, City Hall East, the Central Library, Personnel Department, and the Valley Municipal Building), all City libraries, all Animal Services facilities, most police stations, about 18 percent of fire stations, and many of the Parks and Recreation and Zoo properties. All City-owned unreinforced masonry structures have been either demolished or retrofitted (Alesch & Petak, 1986).

In 1981 the City of Los Angeles adopted Division 68 (later Division 88) requiring evaluation and upgrading of unreinforced masonry buildings (URMs) regardless of ownership. At the time the ordinance was passed, 8,242 URMs had been identified. As of 2003, 1,939 had been demolished and 6140 retrofitted under Division 88 (SSC, 2003). After the Northridge earthquake, in 1994 the City passed Division 91 requiring the mandatory retrofit of 2,618 pre-1976 tilt-up buildings (OES, 2004). Other ordinances have addressed wood cripple walls, wood buildings with soft stories, hillside homes, and concrete buildings with or without masonry infill (voluntary). Another program that has effectively mitigated seismic risk of older buildings is the Adaptive Reuse Ordinance, passed in 1999. This program, designed to encourage conversion of existing buildings into residences (apartments, condominiums, and hotels) in designated areas of the city, requires converted buildings to be analyzed for 75% of the Design Basis ground motion as specified in the current California Building Code and not less than the original Design Basis ground motion (City of Los Angeles, 2006). As of 2007, more than 150 buildings had been analyzed through the program with more than 50 of the buildings complete and occupied (Linares, 2007). The current study has been able to identify more than 6 million square feet of retrofitted nonductile concrete buildings in the city. Millions of additional square feet of older unreinforced masonry and steel buildings have also been retrofitted through this program.

Source Data

The Los Angeles nonductile concrete building inventory has been 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 1,500 nonductile buildings identified 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 building usage. Ownership data is broadly grouped according to public, private, for-profit and non-profit, and if available, owner-occupied or rented. Data has been sorted by use types (commercial, office, housing, schools, hospital, etc.) as well as age and physical characteristics.

Data was obtained from public resources, which are briefly discussed in the following paragraphs and in more detail by Anagnos et al. (2008):

- 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 Maps)
- 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 local engineers through cooperation with the Concrete Coalition

The public data sources are the backbone of the inventory. Los Angeles County Assessor's data are publicly available online, but an address-by-address search is 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. In addition, many buildings have multiple entries in the assessors' data, which occurs when there are multiple owners (e.g., condominiums). To correct for these issues and verify the assessor records, our team used a variety of other public and Internet sources to check data on an address-by-address basis. The checking/verification process followed strict protocols that are described by Anagnos et al. (2008). Several of the additional data sources we utilized are described below.

ZIMAS, a City of Los Angeles online zoning information database, is one such source. It was used extensively to validate and verify assessor's data. For a particular address or parcel number, 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.

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 the address and structural type; but, through the use of aerial photos and Google Maps, we could estimate the number of stories and the building area. These tools were also useful to clarify discrepancies in the data (very large square footage associated with 1-story building for example).

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 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 can be challenging. While recent permits are available online, they rarely contain the information useful to our study. Permit documents indicate whether or not remodeling was completed, but do not indicate seismic retrofit or the level of retrofit. Older data must be reviewed in the City's Department of Building and Safety offices, which is a very time consuming process because the materials are stored on microfiche that are difficult to retrieve and sort. Moreover, plans for older buildings are only sporadically available, because they are only archived if paid for by the owner. 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 were used only for a relatively small subset of structures.

As a joint effort with this project, the Concrete Coalition, a network of engineers with expertise in existing building analysis and retrofit, is collecting detailed inventory data on a small set of buildings (Comartin et al., 2008). Each building is described by size, configuration, functional use, lateral forces resisting system, soil and foundation information, etc. As this inventory is developed, it will provide detailed information on engineering attributes useful to identify and classify structural deficiencies. We hope to merge that relatively small inventory with our broader inventory, with the goal of potentially correlating engineering deficiencies to broadly documented attributes such as year built, area, and specific architectural features.

Attributes of the Database

The inventory is compiled in Google Earth, which is GIS software that allows for sorting and analyzing the database and visualization of spatial patterns through mapping. For example, the data show that nonductile concrete structures are clustered in regions of Los Angeles developed in similar eras. The majority of the buildings are found Downtown, along the Wilshire Corridor, and in Hollywood. Mapping also provides a check on the inventory to ensure that all data points are within the city limits.

The Google Earth program has the capability to store photos, drawings, and text files. A sidewalk survey form developed for this study is stored in Google Earth so that data from the surveys is easily retrieved. The database fields are defined to be compatible with the loss estimation software HAZUS. Additional fields are included in the database to facilitate tracking of properties, sidewalk surveys, and to accommodate detailed input from engineers. Key database fields for analysis and tracking are address, latitude and longitude, building name, 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 data source.

Workflow for Completing the Inventory

The *Source Data* section above describes the public information sources used to create the inventory. Here we describe the workflow required to complete and validate the inventory, which are ongoing tasks. This includes 1) adding a layer of zoning and planning maps to the Google Earth database (Figure 1) and evaluating whether or not the data appear consistent with zoning classifications, 2) reviewing data attributes with professional engineers who have experience in the Los Angeles area to provide a general “reality check”, 3) verifying information in the database for the sample areas identified in (1) using sidewalk surveys by professional engineers in coordination with the project team, and 4) hosting a workshop to evaluate prototypical buildings (by age and occupancy type) with professional engineers to develop a list of common deficiencies.

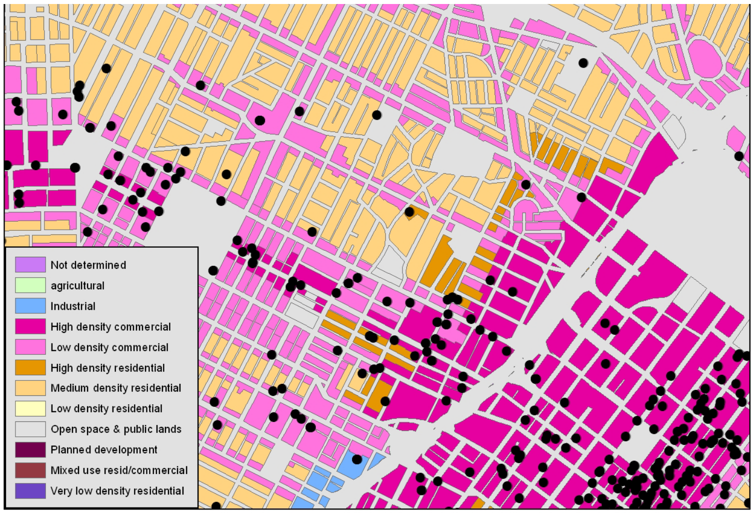

Figure 1: Subset of nonductile concrete inventory overlaid on zoning map for Los Angeles.

One of the major concerns in developing the inventory is the possibility of overlooking a large number of nonductile concrete buildings in some region of the city. As a first step, the database was overlaid on zoning maps for the City of Los Angeles and potential anomalies were identified. Figure 1 shows an area with dense clusters of data adjacent to areas where no nonductile concrete buildings were identified. However, the planning maps show that the data are clustered in the bright pink areas (corresponding to high density commercial) whereas the blank areas generally correspond to medium density residential (light yellow). A second check using Google Streetview shows the medium density residential area to consist of older two or three story wood frame apartment buildings with a few more modern (post 1970s) five-story wood frame over concrete garage apartments interspersed in between. The lack of data in the bright pink area at the right in Figure 1 also raises questions. However, satellite images reveal that much of this area is covered with parking lots, two story braced steel parking garages, and redeveloped zones that includes new office buildings, museums, and theaters.

Figure 2 shows a neighborhood of high density residential development (dark yellow) with just a few data points, which raises suspicions. High density residential construction frequently consists of 6 to 10 story concrete buildings, which if built before 1976 would likely be nonductile concrete. A review of the neighborhood using satellite images and Google Streetview, shows that this neighborhood is a mix of older and newer construction with mid-rise apartments, 1 to 3 story residences, a school, and a commercial area with mostly one story older buildings. Because of the mix of construction types and ages, this area has been identified as one that engineers should review in detail using sidewalk surveys.

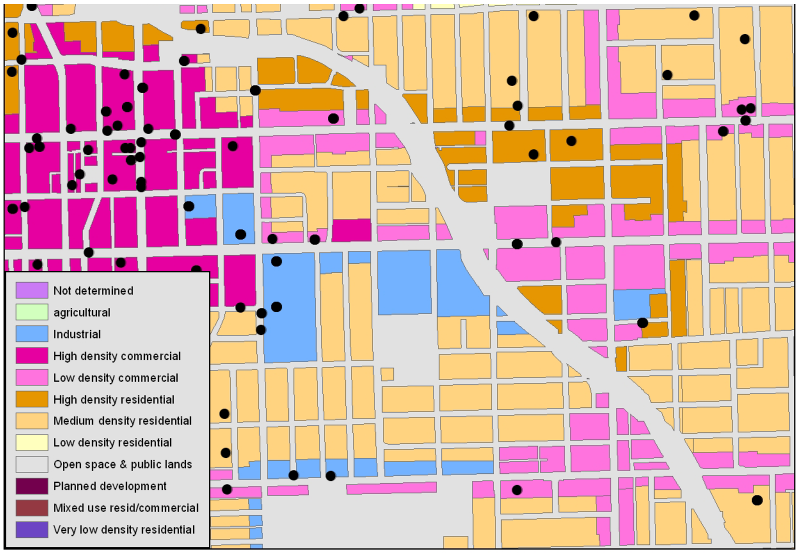

Figure 2: Neighborhood of high density residential with few data.

The research team is identifying sections of the city with different characteristics and organizing groups of engineers to walk several city blocks and validate that the database is correct for those areas. Using the planning maps, validation study areas have been identified in areas that are primarily residential, commercial, and industrial, respectively. Each set of engineers will be provided with a map of the study area showing lot lines. As engineers walk the block they will mark on the map if they identify (or suspect) a building is nonductile concrete. So as not to bias the outcome, engineers will not be told in advance where the research team has identified buildings. The validation will involve comparing the results of this mapping exercise with the existing database.

Finally, a workshop is in development to provide expert input into how to best classify these buildings with respect to seismic deficiencies. These buildings are clustered in specific areas of the city because of both zoning restrictions and historical development trends. Common construction practices in certain periods for particular types of occupancies result in similar deficiencies. A preliminary discussion with practitioners revealed that certain buildings in the database can be considered “typical.” Identifying the deficiencies in these typical buildings will provide a basis for a risk classification scheme.

Preliminary Database Analysis

The database currently contains about 1,500 buildings. Schools and hospitals are severely under-represented because of difficulties obtaining data. Publicly-owned buildings included in the inventory are primarily those owned by the City of Los Angeles. Very little data was accessible regarding other publicly-owned buildings located in the City, so the inventory includes few County, State, or Federal properties. In the case of the City, the inventory also does not include data regarding structures in the Port of Los Angeles which includes the Harbor Department and Airport Department (LAX, Ontario and Van Nuys airports). While the number of City-owned structures fluctuates slightly as the City builds, sells or otherwise transfers title on its many properties, the City’s total inventory approaches 900 buildings (personal communication, LA Dept. General Services). Of these, many were built post-1976, were not concrete, or were retrofitted. For example, all City-owned unreinforced masonry structures were either demolished or retrofitted, and only two or three nonductile concrete structures have yet to be addressed.

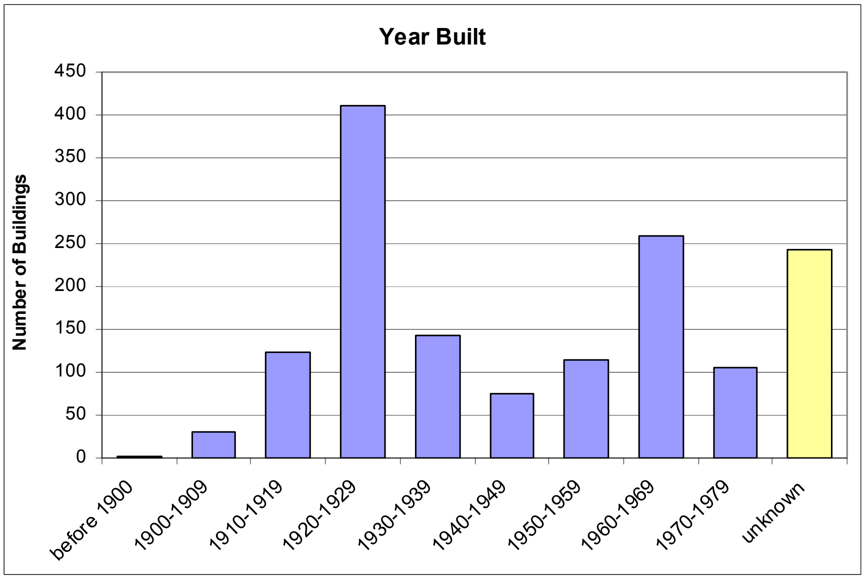

Figure 3: Breakdown of database by year of construction. Almost all of the unknown buildings are schools, which were likely built in the 1950s and 1960s when the Los Angeles Unified School District expanded extensively.

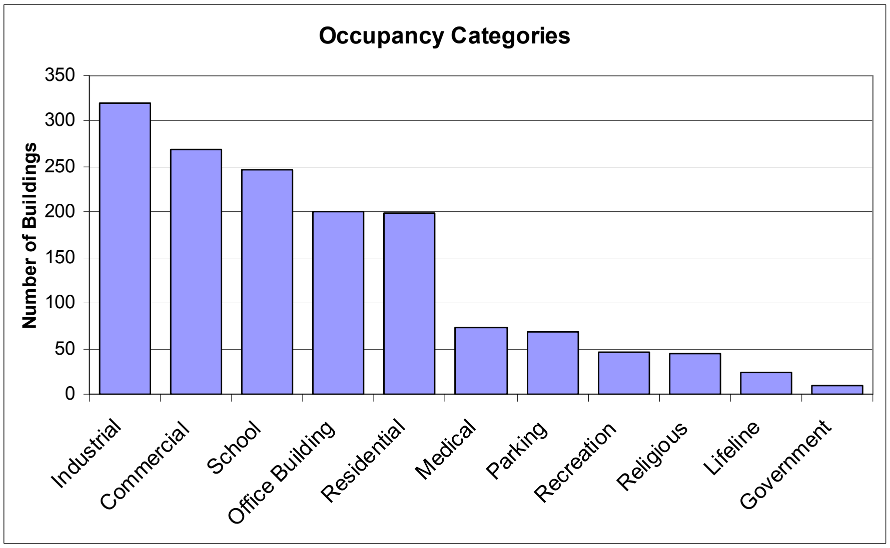

Figure 4: Breakdown of database by primary occupancy. Mixed used buildings are classified according to the occupancy that consumes the majority of square footage.

To gain a deeper understanding of the characteristics of the nonductile concrete buildings in Los Angeles, statistical analyses of the data are underway. Figures 3 and 4 show that the majority of the buildings in the database were built in the 1920s and the 1960s, and these are typically industrial (manufacturing/warehousing), commercial, office, high rise residential and school buildings. Close to 2/3 of the buildings are 1 to 3 stories and slightly more than 200 are taller than 8 stories. However, the 8+ story buildings constitute close to 40% of the total known square footage in the database. Accordingly, addressing those 200 taller buildings could significantly reduce the overall risk.

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.

As a next step, the data will 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 Grand Challenge 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. The 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. Often, the purpose for which a data source was designed overlaps only partially with the goals of a seismic risk inventory. Each data source may use different definitions for building attributes, which requires mapping to a common classification scheme. Similarly, the data source may be missing key attributes relevant to seismic risk assessment or certain fields may contain inaccurate information. This necessitates drawing upon multiple data sources and developing protocols to assemble data from these multiple sources and reconcile conflicting information. Other online resources such as Google Street View and maps.live.com can be very helpful in this process. In addition, input from local engineers and public officials from building departments, planning departments, school districts, and other agencies is invaluable to ensure appropriate data sources are accessed and to validate the inventory.

The City of Los Angeles has been at the forefront of addressing its seismic risk through both voluntary and required programs. Consequently, many of the potentially dangerous buildings in the city have been removed or retrofitted. Thus, the inventory in Los Angeles may not reflect the situation in other cities in California or in the country.

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