

ALTERNATIVE METHODS FOR HAZARD REDUCTION  
IN UNREINFORCED MASONRY BUILDINGS

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SUMMARY

In the United States, engineers have long identified unreinforced masonry buildings as particularly hazardous in earthquakes. However, traditional methods of addressing this problem have proven too costly and too difficult to implement. This report summarizes the characteristics of unreinforced masonry building types in the U.S. Southwest. It then identifies major damage patterns from past U.S. earthquakes, and isolates factors such as configuration, use, location and construction affecting the seismic performance of different subcategories of this building type. From this data, we derived preliminary alternative hazard reduction strategies for these buildings.

INTRODUCTION

Experience in past U.S. earthquakes has shown that, as a class, unreinforced masonry buildings (masonry buildings constructed prior to 1933) have performed poorly compared to other building types (1)(2)(3). Since numerous such buildings still exist today in most U.S. communities, engineers believe them to seriously threaten lives and property. It is their opinion that these buildings should either be structurally upgraded or demolished.

As a result, policy makers have instituted hazardous building ordinances and code enforcement, which, however, affect only a small percentage of the existing U.S. unreinforced masonry buildings in seismically active areas. These ordinances are controversial because of their potential socio-economic impact, because they may well prove unenforceable, and because they affect buildings which seem to vary in seismic performance.

By virtue of their age and location, unreinforced masonry buildings in most urban areas in the West house marginal businesses and socially and economically disadvantaged residents. In addition, this building type comprises the bulk of the central business district of most small towns. In many cases, the cost of seismically upgrading these buildings can not be economically justified. Moreover, demolition would displace low income renters and businesses from their only affordable shelter. Finally, current regulatory approaches to the problem look only at engineering solutions, and attempt to impose a common standard of renovation on a group of buildings whose construction, architecture, occupancy and organization

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types in fact incorporate wide variation. Some unreinforced masonry buildings, because of their architectural configuration, may be much safer than others; some, because of their occupancy, may represent much less hazard to life.

As we will clearly continue to have with us, for the foreseeable future, a huge inventory of these pre 1933 buildings, we have begun to investigate other approaches to this problem. These alternative approaches are based on planning, architectural, functional, non structural, and operational aspects of earthquake hazard reduction in existing buildings. By categorizing the great volume of these buildings to reflect their significant characteristics, we can determine the real hazards presented. Since building owners and occupants have limited resources for earthquake hazard reduction, an approach based on a combination of these techniques, tailored to specific building sub-classes, should be more acceptable, whether through voluntary action or by regulation.

#### RESEARCH OBJECTIVES

This on-going research program aims at developing a methodology, for assessing an unreinforced masonry building, which includes a mix of techniques. This study was conceived as an initial fact finding investigation necessary for designing this loss reduction methodology. Although numerous decision-making heuristics were readily available, they lacked the necessary data. Our main task thus became discovering the relevant empirical data that already exists, or could be found, to provide preliminary answers to the following questions:

- 1) What are the types and locations of unreinforced masonry buildings in the U.S. Southwest?
- 2) What are the patterns of earthquake damage common to different types of unreinforced masonry buildings?
- 3) What are the threats to life safety posed by these damage patterns?
- 4) What are the alternative methods of hazard reduction?

#### KEY CHARACTERISTICS AND LOCATION OF UNREINFORCED MASONRY BUILDINGS IN THE SOUTHWEST

##### Method

In order to study the location of unreinforced masonry buildings, four sites in Southern California were selected for analysis. Since we were interested in investigating a range of urban contexts, we chose the following types of settings: a small town which once served an agricultural region but which had been surrounded by suburban development; an industrial area serving a major city; part of the downtown of a major Southern California city. We then analyzed Sanborne maps and other planning data for each of these locations. The Sanborne maps, originally

constructed for fire rating purposes and covering the period of the late eighteen hundreds to the mid-nineteen fifties, provided periodic cross-sectional records of location, use and structural features of all unreinforced masonry buildings in each site. In addition, other documentation provided accounts of key architectural and structural features of these buildings.

### Findings

- 1) Despite extensive demolition, unreinforced masonry buildings remain prevalent in larger western cities.
- 2) In smaller communities, the number of unreinforced masonry buildings has remained relatively constant over the years.
- 3) In small cities, unreinforced masonry buildings frequently comprise the bulk of the central business district. As such, these buildings constitute an important component of the building inventory and play a vital role in the economic life of the community.
- 4) Unreinforced masonry buildings have traditionally experienced use downgrading which lessened their potential as an earthquake hazard. However, this trend may be changing in light of rising construction costs and increasing interest in preservation.
- 5) Due to distinct functional and structural characteristics, unreinforced masonry buildings lend themselves to classification and study along lines relevant to developing earthquake hazard reduction strategies.

### Discussion

#### Architectural and Planning Features

Architectural features have important implications for developing earthquake hazard reduction strategies. For instance, commercial buildings have ground floors dedicated to stores, lobbies, banks, restaurants and other commercial establishments. Offices or residential rooms occupy the upper levels. Unreinforced masonry apartment buildings, on the other hand, tend to be subdivided into small spaces on all levels. Buildings designed for manufacturing, warehousing and retail sale of larger items (e.g. automobiles) usually require large open areas on all levels.

The exterior configuration of most individual commercial buildings is rectangular in plan with a narrow exposure to street front and alleys as dictated by local subdivision ordinances. Industrial facilities tend to be more square in plan. However, the plan configuration of multiples of these buildings is linear in nature with blocks of unreinforced masonry buildings butted up against each other and separated by party walls. In small towns, the commercial strip configuration consists of one and two structures. In large cities, such as downtown Los Angeles, block after block of four story buildings can be found. Such planning features have

important implications for seismic performance.

Practically all unreinforced masonry buildings have some form of exterior architectural ornamentation including cornices, molding and statues. A key architectural element is the parapet or firewall.

The interior configuration of unreinforced masonry commercial buildings consists mainly of a large open area adjacent to the street entrance with smaller spaces for offices and storage toward the alley. On the floors above, the spatial organization usually consists of small spaces along a double loaded corridor. Vertical spatial elements include stairways, fire stairs and elevators. Lath and plaster is frequently used as a finish material for walls and ceilings; however, the use of hollow masonry tiles is also quite common. Industrial structures differ considerably from commercial in their lack of small interior spaces. However, most manufacturing and warehousing buildings have some smaller interior spaces which are offices, storage areas and restrooms.

#### Engineering

The typical unreinforced masonry building has load bearing walls composed of three wythes of brick. The floors and roof are essentially of wood frame construction with wooden joists or light wood trusses commonly used in residential and commercial buildings. In industrial buildings, where longer spans were required, deep wooden trusses supported by pillars were often utilized. Many interior walls, which are non-load bearing, are of wood frame construction

### DAMAGE TO UNREINFORCED MASONRY BUILDINGS

#### Method

In order to study patterns of damage to specific types of unreinforced masonry buildings, available damage and loss data from several past U.S. earthquakes were reviewed. This analysis included data from San Francisco (1906), Santa Barbara (1925), Long Beach (1933), Imperial Valley (1940), Bakersfield (1952), San Fernando (1971), El Centro (1979) and Coalinga (1983).

#### Findings

- 1) There have been relatively few instances of the complete collapse of unreinforced masonry buildings in past U.S. earthquakes. However, the failure of parapets, ornamentation and the partial collapse of walls is very common.
- 2) Unreinforced masonry buildings have exhibited high variability in earthquake resistance. Factors such as site characteristics, mortar strength, proper wall anchors and quality of workmanship appear to influence seismic performance.
- 3) There is some evidence to suggest that specific types of unreinforced masonry buildings experience less damage than others. Tentative factors appear to be structure, configuration and the relationship of buildings to each other.

## Discussion

### Extent of Damage

The relatively small number of unreinforced masonry buildings suffering complete collapse or serious damage has been documented by J.R. Freeman (2) and the Long Beach Coroner's Inquest Commission (6). For example, only about twelve cases of complete collapse in the 1906 San Francisco earthquake have been confirmed (11). Of 1623 unreinforced masonry buildings surveyed by the Long Beach Building Department, only about 5% were considered damaged to the extent that repairs were impractical (5).

Although at a gross level the relative risk of severe damage to any one unreinforced masonry building in a given earthquake appears low, even moderate damage can pose risks to life and property. Therefore, the damage data was further analyzed to document both general and specific contributing factors.

### General Contributing Factors

Workmanship and materials ensures the safety of any building, but is especially important to unreinforced masonry buildings. Freeman observes, "Well-built structures of wood or brick or of squared stone laid up in strong mortar, have generally withstood earthquake shock." (2). W.H. Homes reported from the scene of the 1940 Imperial Valley Earthquake that "well constructed buildings were undamaged" (15). The Long Beach Coroner's Jury stated that "damage was mostly confined to those (masonry buildings) built with poor quality of lime mortar, inadequate bonding and anchoring, or of inferior workmanship, and built to designs that took no account of horizontal forces" (5). After studying earthquake damage in San Francisco, Himmelwright stated that "in all cases where a good quality of lime mortar or Portland cement was used, and where the workmanship was fairly good, much less damage was noted" (1). Site characteristics and strength of foundations are also important factors in earthquake resistance.

### Specific Contributing Factors

Building-specific factors such as type, configuration, and aggregate relationship affect vulnerability.

Several surveys of damage to buildings in the cities of Long Beach and Compton after the 1933 earthquake offer tentative conclusions that unreinforced masonry residential buildings were not damaged as extensively as commercial buildings and that both building types performed better than industrial buildings (7)(16).

Observation made after the recent Coalinga earthquake confirms that the combination of wood trusses, wood frame floors and wood frame interior walls often prevented collapse by providing structural redundancy. In buildings with long span wood truss roofs, complete collapse was prevented by interior walls, columns, and large pieces of equipment supporting sections of the roof trusses.

Key Aspects of building configuration such as building height (buildings of two and three stories) and plan configuration (L shaped

configuration) have been identified by previous observers (2)(12) and by our review as showing increased vulnerability. However, aggregates of buildings, or buildings configured together, can help to stabilize individual buildings; Abel, after reviewing 1971 earthquake damage, noted that "in some cases, it was apparent that an adjacent building shared the load and reduced the damage" (18).

#### Damage Patterns

The damage that did result, short of complete collapse, fell into certain patterns. Collapsed parapets were frequent examples of partial building failure. Improperly attached ornamentation often became dislodged. Unbraced non-structural elements often collapsed and fell through roofs. Exterior walls were frequent casualties, as evidenced by extensive cracking in or partial collapse (usually outward) of one or more of three brick wythes. The interior of buildings suffered cracked and fallen plaster from ceilings and walls, broken glass, and overturned building contents. Hollow tile walls have performed very poorly.

### THREATS TO LIFE SAFETY POSED BY DAMAGE PATTERNS

#### Method

This part of the study involved a review of coroner's reports, expert testimony, articles, news stories, interviews with victims, and other accounts of injury in and around unreinforced masonry buildings in past California earthquakes.

#### Finding

Because the majority of casualties in past U.S. earthquakes have occurred outside rather than inside unreinforced masonry buildings, we need to know more about the specific role that occupant behavior plays in the susceptibility to earthquake injury.

#### Discussion

Fortunately, the U.S. so far has been spared the high mortality from earthquakes of other countries, primarily because of significant differences in construction and because of fortuitous timing. However, unreinforced masonry buildings still pose threats to life safety. Indeed, the Coroner's Inquest following the 1933 Long Beach Earthquake concluded that the failure of masonry buildings occasioned the principal loss of life(5). Walls fracturing and falling outward, on the people outside, poses perhaps the greatest threat. The Joint Technical Committee stated in June of 1933 that "no precise estimate can be made, but it is clear that a very large proportion of the total deaths and injuries resulted from debris falling on people who were in the streets, at the time, or who ran into the streets at the first shock (13). Preliminary studies of Coalinga show that injuries in and around unreinforced masonry buildings occurred either outside or just as people were leaving the buildings. Such evidence indicates that those who try to leave the building may face increased threat of injury.

## ALTERNATIVE METHODS FOR HAZARD REDUCTION

From the previous discussion, we see the desirability of considering a mix of engineering and non-engineering approaches when attempting to improve seismic safety in a given unreinforced masonry building. These alternative (non-engineering) methods stem from planning, architectural, functional and operational perspectives. The exact combination of methods ultimately chosen should depend on an estimation of the expected seismic performance of a specific type of unreinforced masonry building in a specific urban context and the resulting threat to the safety of occupants and passersby.

For instance, a one story commercial building, sandwiched between a two story building and a one story building, might present the principal threat to those on the sidewalk or in the rear. The two story adjacent structure presents the added risk of parapet and partial wall collapse onto the roof of the neighboring building. The first situation might be countered by building a colonnade or canopy (hardened to protect those outside from falling bricks) at both ends of the structure. The second situation might require the strengthening or removal of all parapets and the reattachment of ornamentation.

The L configured, multi-story building, located on a commercial corner, would seem to pose an even greater threat to life safety and may call for complete structural retrofit. However, in such cases where one building is deemed more hazardous than others in a central business district, community resources might be directed at addressing this problem first.

In another case, a multi-story residential structure might be treated differently than a lightly occupied manufacturing building. The apartment house might call for a mix of structural retrofit, non-structural securing and stabilizing and an occupant training program, where people would be encouraged to stay inside during a tremor. The manufacturing building might call for reinforcing of work tables and benches and training workers to use them as a shelter; increasing the number of interior columns and interior walls to act as a buffer against falling roof trusses might also be appropriate, as well as anchoring heavy equipment, such as air conditioning units located on rooftops.

Another non-structural method, involving no design intervention, is the "use downgrading" of a particular building to a lower occupancy class.

In short, rather than rely on a uniform approach to seismic safety in unreinforced masonry buildings, composite approaches should be tailored to the unique characteristics of subcategories of these buildings, the kinds of life safety hazards posed and the available resources of building owners and of the local community.

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