BUILDING AND NONSTRUCTURAL COMPONENT PERFORMANCE IN THE 2014 SOUTH NAPA EARTHQUAKE

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Abstract

It is common to focus post-earthquake reconnaissance on observations of damage rather than performance, both bad and good. Without systematically collecting and analyzing data, it is not possible to correlate the relationships between ground shaking severity and the performance of buildings. On August 24, 2014, a magnitude-6.0 earthquake struck northern California. The epicenter was located 9 km (6 miles) south southwest of the city of Napa, which was significantly impacted by the event. The peak recorded horizontal ground accelerations in Napa were as high as approximately 0.6 g. This earthquake provided an excellent opportunity to evaluate and calibrate existing earthquake hazard reduction methodologies and to expand existing knowledge and databases on the performance of buildings and other structures. The Federal Emergency Management Agency (FEMA) contracted with the Applied Technology Council (ATC) to document the performance of buildings in the earthquake. The focus of this investigation was the collection of data to comprehensively examine the nature and scope of building performance in the earthquake. The investigation centered on a ground motion instrument located in downtown Napa, and included every building within 1,000 feet, whether it was damaged or not. Many of the buildings investigated are unreinforced masonry (URM) construction, and a significant number of these had already been seismically retrofitted. This provided a unique opportunity to explore the effectiveness of seismic hazard mitigation efforts, and develop recommendations to further improve mitigation. The performance of buildings designed in accordance with more recent building codes, including healthcare and school facilities, residential construction, manufactured housing, and the performance of nonstructural components and systems were also investigated. The earthquake had a significant impact on the world famous wineries around Napa, and the performance of these facilities is also discussed. The Napa Valley has approximately 400 wine production facilities, and estimated 50 wineries were exposed to significant seismic ground shaking and sustained measurable damage to tanks, barrels and/or buildings. The paper will also provide an update on the status of some of the more significant building repairs one year later.

Keywords: nonstructural; napa; data collection; retrofit; performance 5

1. Introduction

California is subject to frequent damaging earthquakes, and each one presents an opportunity to study the impacts, improve the understanding of how buildings perform when subject to strong ground shaking, and to update building codes and standards to improve building performance. A number of past earthquakes have resulted in significant improvements in building codes, including the 1933 Long Beach earthquake (schools and unreinforced masonry structures), the 1971 San Fernando earthquake (hospitals and non-ductile concrete structures), the 1989 Loma Prieta earthquake (soft story structures), and the 1994 Northridge earthquake (steel moment frame structures), to name a few. This paper summarizes observed performance of buildings and nonstructural components in order to lead to improvements of future building codes.

It is common to focus post-earthquake reconnaissance on observations of damage rather than performance, both bad and good. Without systematically collecting and analyzing data, it is not possible to correlate the relationships between ground shaking severity and the performance of buildings. In order to evaluate and calibrate existing earthquake hazard reduction methodologies and to expand existing knowledge and databases on the performance of buildings and other structures, FEMA contracted to have information on the performance of buildings and nonstructural components in the South Napa earthquake gathered and analyzed under a Special Project as part of the National Earthquake Technical Assistance Program (NETAP) Task Order with the Applied Technology Council (ATC), under contract number HSFE60-12-D-0242. The project resulted in the publication of the FEMA P-1024 report, *Performance Assessment of Buildings and Nonstructural Components in the 2014 South Napa Earthquake* [1].

2. The Earthquake

On August 24, 2014, a magnitude-6.0 earthquake struck northern California. The epicenter was located 9 km (6 miles) south southwest of the city of Napa, which was significantly impacted by the event. The peak recorded horizontal ground accelerations in Napa were as high as approximately 0.6g. The cities of Napa and Vallejo, as well as the surrounding areas, were significantly impacted by the event. The earthquake struck at 3:20 in the morning, which was the primary reason for the occurrence of only one fatality and the low number of serious injuries. Had the earthquake struck 12 hours earlier, during a street festival in downtown Napa, the number of fatalities could have easily been in the hundreds due to falling hazards from masonry buildings and nonstructural components.

The earthquake was recorded by at least eight strong-motion recording instruments at which horizontal ground motions were significant (exceeded 0.1g) and three of those instruments were located within the City of Napa. Availability of recorded ground motions and documentation of the impact of the earthquake provides an excellent opportunity to calibrate and evaluate existing earthquake hazard reduction methodologies.

3. Performance of Buildings within 1,000 feet of Station N016

One of the primary focuses of this investigation was the collection of data for all buildings within a 1,000 foot radius of USGS-NCSN strong motion recording device at Station N016, Main Street Napa. This station was identified as the most important for systematic data collection for a number of reasons:

- The level of ground shaking was sufficient to cause damage to some buildings,
- The area contains a large number of commercial and civic buildings, both historic and modern, and
- There are a number of retrofitted unreinforced masonry buildings in the building population.

The source-to-site distance for Station N016 was 3.9 km, the peak PGA [2] was 0.65g (North South), 0.32g (East West), and 0.24g (Vertical). While much of the investigation was focused on a single instrument site, the reconnaissance included collection of data for select buildings outside the 1,000 foot radius to comprehensively examine the nature and scope of building performance in the earthquake.

The ATC-38 methodology was used to collect data on buildings. The ATC-38 methodology was developed following the 1994 Northridge earthquake to systematically collect and analyze data from buildings located in the vicinity of strong motion recording devices and was documented in the ATC-38 report, *Database on the Performance of Structures Near Strong-Motion Recordings: 1994 Northridge, California, Earthquake* [3]. Building survey forms were created to collect data at each building site including the structure size, age, location, structural framing system and other important structural characteristics, nonstructural systems and performance, fatalities and injuries, ATC-20 posting classification and estimated time to restore the facility to pre-earthquake usability. The forms developed and used for the Northridge earthquake were expanded to describe irregularities in terms consistent with the FEMA P-154 methodology [4] and to expand the scope of nonstructural systems and components examined.

A total of 68 buildings were surveyed within 1,000 ft of Station N016. Interior and exterior surveys were conducted for 50 of the buildings, with the remaining 18 having only exterior surveys. The median age of these buildings is 1930, with 77% of the buildings constructed in 1950 or earlier. Buildings with unreinforced masonry (URM) construction make up 40% of the 68 buildings within 1,000 feet of Station N016. Over two-thirds of these buildings were seismically retrofitted prior to the earthquake. The second most prevalent building type is reinforced masonry, which makes up one quarter of the inventory, followed by concrete shear wall buildings. Beyond the 1,000 foot radius from Station N016, additional buildings of interest throughout the affected area were also surveyed, including residential buildings, healthcare facilities, schools, and wineries.

Buildings constructed to recent codes (1997 UBC or later editions of the IBC) generally performed well structurally. The vast majority of older, non-URM structures also performed well structurally, although known vulnerabilities, such as poor wall-to-roof connections, did result in significant damage and loss of use. More than half the non-URM buildings were undamaged, and another third of the buildings sustained insignificant damage. Less than 10% of the buildings suffered damage characterized as minor.

Of the 26 URM buildings within 1,000 foot of Station N016, 19 had been retrofitted, and 7 were not. The primary goal of the Napa municipal code requirements for rehabilitation and abatement of existing seismically unsafe buildings [5] is "… to provide alternative economically feasible construction regulations designed to reduce the risk of death or injury resulting from earthquake hazards in existing masonry or concrete buildings, while preserving the historic character of the community". This objective is similar to the "Collapse Prevention" performance objective in ASCE/SEI 41-06 [6]. Buildings meeting this performance objective may experience significant structural damage, but should not collapse when subject to a design earthquake. Significant risk of injury due to falling hazards from structural debris may exist.

Of the un-retrofitted URM buildings, five were posted UNSAFE. One of the un-retrofitted buildings suffered heavy damage, one was moderately damaged, one had insignificant damage, and two of the buildings were inaccessible for inspection; the nature and severity of the structural damage to these buildings could not be determined. None of the un-retrofitted URM buildings collapsed. A significant amount of exterior masonry fell from the moderate and heavily damaged buildings. Among the retrofitted URM buildings, 13 buildings suffered no structural damage or the damage was deemed insignificant; three buildings suffered minor damage, one building moderate damage, and two were heavily damaged. None of the retrofitted buildings collapsed, and some exterior masonry loosened or fell from three of the damaged buildings.

Based on the performance of the URM buildings within 1,000 feet of Station N016, the URM hazard mitigation efforts in Napa were successful in reducing damage and protecting life safety; 68% of the retrofitted URM buildings suffered either no damage or insignificant damage, compared to 28% of the un-retrofitted buildings. A number of different approaches were used to retrofit URMs, and partial retrofits of URM buildings were less successful in limiting damage compared to those that received more comprehensive upgrades.

4. Performance of Buildings

This section provides a summary of the performance of selected building types within and outside of the 1,000 ft radius and recommendations.

4.1 Healthcare Facilities

Hospitals in California are classified as essential facilities and high standards are set for their seismic performance. Unlike most commercial buildings, hospital buildings are designed to remain operational after an earthquake. The Office of Statewide Health Planning and Development (OSHPD) serves as the building department for all acute care hospitals and skilled nursing facilities in California. In addition to oversight of design and construction of these facilities, OSHPD performs post-earthquake assessments of buildings under its jurisdiction.

Five general acute-care hospitals and 13 skilled nursing facilities were located between 4 and 10 miles from the epicenter of the South Napa Earthquake. The buildings at these facilities include a wide range of structural types, some over 50 years old. In general, none of the facilities suffered serious damage, although nonstructural damage did interfere with the delivery of some healthcare services.

Structural damage to general acute care hospitals was insignificant, even in older buildings. Structural damage was limited to minor cracking in older reinforced concrete structures. Skilled nursing facilities, which are generally single-story light frame buildings, had no reported structural damage. Minor nonstructural damage was widespread, and included partition cracking, loss of tiles in suspended acoustical ceilings, and damage to stucco exterior finishes and storefront systems. These damage patterns occurred in both older and newer construction. Minor piping leaks were noted at one hospital and two skilled nursing facilities. Two hospitals reported some of their elevators out of service following the earthquake. Some damage to the supports of rooftop equipment was observed, but the equipment continued to function. Many facilities lost utility power, and their back-up emergency power systems functioned without any major problems. Damage to contents, bookshelves, smaller storage cabinets, computers, and unanchored countertop equipment was reported.

Although the nonstructural damage was minor, issues did arise that impacted the operations of some facilities. At one hospital, cracking of drywall ceilings and the unintended opening of ceiling access doors in some of the operating rooms compromised the ability to maintain a sterile environment, resulting in the loss of use of the rooms.

4.2 Public Schools

There are 30 public school sites in Napa County and 21 in Vallejo. There was little or no structural damage to any of the schools affected by the earthquake. Several schools did, however, experience nonstructural damage to architectural, mechanical and/or electrical components, including suspended ceilings, light fixtures, and furniture. Some of the damage could have been life threatening had the earthquake occurred during school hours. Pendant light fixtures fell, and overturned cabinets and furniture blocked egress pathways. All but one school in the Napa Valley Unified School District (NVUSD) resumed classes by August 27th, three days after the earthquake.

Following the earthquake, NVUSD developed an updated master plan [7] for the improvement of the school facilities, including relocation of two schools (Stone Bridge and Napa Junction Elementary Schools) and completion of nonstructural seismic safety upgrades at nine schools. The estimated cost for this work is $150 million. Two schools are being relocated requiring the construction of all new buildings rebuilt because the existing campuses have been determined to be located on top of a previously unknown fault.

4.3 Residential Construction

Homes make up one of the most important components of a community's building stock. The downtown Napa study area, as defined by the 1,000 foot radius around Station N016, does not include any residential construction. In order to understand the performance of this important class of buildings, the study area was expanded to include additional neighborhoods. In particular, homes in the Browns Valley neighborhood located to the west of downtown Napa were included based on their proximity to the fault rupture. In lieu of the more rigorous procedure used to survey each of the buildings in the downtown area, residential buildings were examined with a combination of drive-by surveys, exterior inspections, and when possible, exterior and interior inspections coupled with interviews of occupants and construction crews.

Based on data maintained by the City of Napa as of August 27, 2014, a total of 3,915 buildings were tagged and of these approximately 4% (152 buildings) were posted UNSAFE. Of these, approximately 40% were residential buildings. Damage to residential construction was concentrated heavily on two key deficiencies: unbraced chimneys and unbraced cripple walls. Also noted in the placarding data damage descriptions were fire, damaged gas lines, façade damage, and carport collapses.

As expected, unreinforced or inadequately reinforced masonry chimneys performed poorly with many observed cases of significant damage or collapse. In some cases, chimneys fell out onto exterior areas, endangering adjacent homes, passersby on sidewalks, and parked cars. In other cases, chimneys fell into homes, endangering occupants. In one instance, a teenage boy who was asleep in the living room, was struck and seriously injured by falling bricks from a collapsed fireplace. This was one of the most serious injuries caused by the earthquake and required air evacuation.

In response to the prevalence of chimney damage in this earthquake, FEMA developed a Recovery Advisory recommending best practices for reconstruction of earthquake-damaged masonry chimneys using light-weight metal flue chimneys [8]. The information provided is advisory and building permits are required when conducting the work described.

Many homes with tall, unbraced cripple walls experienced large lateral displacements or collapse of the crawl space. Some structures, typically older homes, fell almost 5 ft and moved laterally an equivalent amount. Damage was also observed to some homes constructed with shorter unbraced cripple walls. These homes often had lateral movement of a few inches. Buildings with retrofitted tall cripple walls were reported to perform well. In response to this type of damage, FEMA developed a Recovery Advisory addressing the earthquake strengthening of cripple walls and foundation anchorage in one- and two-family dwellings, supported by elevated concrete foundation systems and cripple walls not taller than approximately seven feet [9]. The *FEMA Plan Set for Earthquake Strengthening of Cripple Walls in Wood-Frame Dwellings* accompanying this Recovery Advisory is intended to be used as a template for strengthening common cripple wall and foundation anchorage vulnerabilities in California and throughout the United States. It provides pre-engineered strengthening solutions with step-by-step instructions for use by a knowledgeable and skilled contractor or homeowner.

4.4 Manufactured Homes

Significant damage was observed to manufactured homes in some mobile home parks (MHPs) located in northwest Napa. Observations of home support systems were limited to homes where surrounding skirts had been fully or partially removed, either for inspection (by others) or because reinstallation or re-leveling of the home was required; as a result, observations primarily focus on homes that experienced damage. A total of eleven MHPs were visited, and detailed data was available for 10 of them.

Building code regulations for manufactured homes differ from site-built homes. New manufactured homes currently fall under the jurisdiction of the U.S. Department of Housing and Urban Development (HUD). Regulations for home installation in the state of California fall under the code adoption authority of the State of California Department of Housing and Community Development (HCD). Enforcement of installation requirements is permitted to be under the jurisdiction of the local building department (city or county); where the local building department chooses not to take jurisdiction, enforcement authority remains with HCD. Since September 1994, a lateral tiedown system must be installed on new manufactured homes in California. The tiedown system can either be a listed assembly, approved by HCD, or an engineered system. Existing homes are not required to meet this requirement retroactively, except in two circumstances; when a home is relocated to a new lot, or if the home requires reinstallation due to damage caused by wind or seismic forces and federal funds are available for the additional installation costs.

In the eleven parks surveyed, the majority of the homes were installed prior to the requirements for bracing systems. Some bracing systems were observed on a limited number of the homes, due to those homes being more recently located or relocated, or due to owners choosing to voluntarily install bracing. The severity of earthquake damaged varied significantly between different MHPs. The five MHPs in mid-town Napa include over 340 homes. While some homes were reported to have shifted several inches, only one home was observed to obviously require reinstallation. Of the six MHPs at the northwest side of Napa, data was available for five parks; of the 829 homes in these parks a total of 122 of the homes had some form of bracing, either a wind tiedown system or an earthquake-resistant bracing system. Following the earthquake, a total of 157 homes were reported to require reinstallation, 18% of the unbraced homes, and 25% of the braced homes. There were also several fires that consumed individual manufactured homes. As a result of a nearby water main break that impacted firefighting operations, one of these fires consumed four homes. In most cases, these fires were believed to have been caused by the home sliding and impacting the natural gas service piping.

A significant number of manufactured homes suffered substantial damage, and the frequency of damage was similar for braced and unbraced homes. This performance was due primarily to the lack of ground anchorage, but may also be due in part to the presence of unapproved or uninspected bracing systems. The earthquake performance of the lateral bracing systems needs further evaluation.

4.4 Wineries

The Napa Valley has approximately 400 wine production facilities, with an estimated 300 built since 1966. An estimated 50 wineries were exposed to significant seismic ground shaking and sustained measurable damage to tanks, barrels and/or buildings. Damaged facilities were concentrated north-west of the epicenter, west of highway 29, reaching approximately 10 miles north of the epicenter. Wineries located more than 10 miles north suffered only minor contents damage or suffered no measureable damage to wine tasting or production facilities.

The Napa Valley wine industry is comprised of a diverse mix of wineries. Winery ownership ranges from larger production facilities producing millions of cases annually to smaller operations producing thousands of cases. Larger wineries and wine co-ops often stack barrels 5 or 6 levels high; smaller facilities generally do not have to stack as high, and losses to barrel stacks were generally less with these facilities due to the lower fall heights and durability of the wine barrels. The earthquake risk profile of a winery is varied based on the time of year. The only constant in the risk profile is the seismic vulnerability of the winery buildings. The contents are in constant motion throughout the year as the wine industry is an agricultural business on an annual cycle. The earthquake occurred about two weeks into the harvest and wine grape crush season. The majority of stainless steel wine tanks and a significant proportion of wine barrels were empty, ready to be filled with the new harvest. The earthquake occurred in the middle of the night. If the earthquake occurred during normal operating hours the threat to life safety would have been significant in the barrel rooms.

Four winery facilities suffered significant structural damage. A historic three-story timber-framed winery building built in 1886 was posted UNSAFE, after experiencing residual inter-story drift of approximately 15% at the first story, with virtually no permanent drift at the second and third stories. Full wine barrels, stacked on portable steel barrel racks (three levels high), were stored on the second floor level. The mass of the barrels contributed to the failure of the wall sheathing on the first floor. Two facilities suffered significant structural damage due to the impact of toppling stacks of wine barrels. A single-story masonry shear wall warehouse with a wood-frame panelized roof system experienced connection failure between a roof beam and the supporting wall pilaster, which resulted in collapse of a portion of the roof.

Due to the timing of the earthgquake relative to the harvest cycle, direct loss of wine and damage to the production equipment varied by location, but was relatively low for Napa Valley as a whole. Wineries are reporting wine losses from as little as 0.5% (bottles and some barrels) to as high as 15% (barrel stack collapse only). Wine loss due to damaged wine tanks was reported as minimal, as most tanks were empty. Business disruption was minimal. Wine tasting facilities were able to clean up broken bottles and displaced contents on Sunday and Monday and open for business on Tuesday, two days following the earthquake.

5. Performance of Nonstructural Components

Damage to nonstructural components and systems in buildings accounts for the majority of repair costs in earthquakes, and can contribute to extended downtime for repairs. While most modern structures suffered little or no structural damage in the South Napa earthquake, several experienced significant nonstructural damage. The only death and the only injury serious enough to require air evacuation attributable to the earthquake were both caused by nonstructural damage.

The seismic provisions of the building codes in general have undergone significant changes in the last two decades, and the requirements for nonstructural components in particular have change dramatically. The types of nonstructural components subject to the seismic provisions have increased, the design forces for components have increased, and the requirements for attaching the components to concrete and masonry construction are much more comprehensive. These changes complicate the post-earthquake evaluation of nonstructural damage, since the rules under which the component was originally installed may be much different than those recommended today. Care must be taken when drawing conclusions on the adequacy of current code requirements, if the component in question does not fully conform to those current requirements.

5.1 Glazing and Cladding

Damage to glazing and cladding systems was fairly widespread. Of the 68 buildings within the survey area around Station N016, 22 reported damage to 5% or more of the exterior glazing; four buildings experienced damage to 50% or more of the glazing. In some cases the glass did not crack or shatter, but the gaskets holding the glass in frame loosened, allowing the pane to shift. In retrofitted URM buildings, storefront damage was more pronounced on elevations where lateral resistance was provided by moment frames. Older buildings, which tended to have open storefronts with large panes of glass, suffered most of the glazing damage.

The performance of light curtain wall systems varied significantly, with some modern structures suffering substantial cracking and loss of veneer. In at least one case, the exterior wall system, consisting of studs and stucco, appears to have been designed without a mechanism to accommodate interstory drift without damage. Consequently, the wall initially tried to act as a shear wall and was significantly damaged. The performance of adhered veneer was directly related to the performance of the substrate and the strength and condition of the adhesive material. In locations where exterior stucco cracked, veneer if present also suffered damage.

5.2 Interior Partitions

Partition damage was present in many buildings, but most damage was incidental with a very small number of buildings experiencing substantial partition damage. Within the survey area around Station N016, the interiors of 50 buildings were observed. In 90% of the buildings, partition damage was described as “Incidental” or “None”. Damage was reported as “Minor” in 6% of the buildings. One building was reported with “Moderate” damage. A building outside the Station N016 study area suffered “Heavy” damage. In both buildings with moderate and heavy partition damage, damaged sprinkler piping caused water release for an extended period. Large areas of gypsum wallboard sheathing required removal and replacement in these buildings as a result of water damage. In virtually all other cases, partition repair could be accomplished with local patching and painting. Older buildings with lath and plaster wall finishes suffered some damage in the form of cracking and spalling of the plaster finish.

5.3 Ceilings

Gypsum wall board ceilings generally performed well, with minor cracking observed at some locations. Older plaster ceilings did not perform as well as gypsum ceilings, with spalling and cracking observed in multiple buildings. Within the Station N016 survey area 15 buildings (22%) were identified as having at least some area with suspended acoustical tile ceilings. Some damage to the ceilings of these buildings was common; only one building was assessed as having no ceiling damage. Three buildings were classified as having “moderate” or “heavy” ceiling damage. The most commonly observed form of damage to suspended acoustic tile ceilings was fallen tiles. Failure of grid member splices, as well as damage at the “fixed” and “free” ends of the ceiling grid was observed in several buildings. While many acoustical ceilings were repaired relatively quickly by reinstalling or replacing fallen tiles, failure of the ceiling grid itself required an extended period to restore. In extreme cases of damage, removal and replacement of the entire ceiling was required.

5.4 Mechanical, Electrical and Plumbing Equipment

The performance of mechanical, electrical and plumbing (MEP) equipment varied widely in the buildings investigated. Some unanchored or lightly restrained equipment shifted or overturned, as expected. There were failures observed in anchored equipment, but based on the estimated age of the equipment installation, the failures occurred in components that would not comply with current code. Rooftop equipment was more heavily damaged than equipment located elsewhere in the building. MEP components installed to recent standards generally performed well. One exception is pendant light fixtures. In several schools and grocery stores, suspended pendant light fixtures became dislodged and dropped. Had the earthquake occurred during business hours, injuries due to falling light fixtures would have been likely. At one building constructed in the mid-1970s, nearly all vibration-isolated components suffered anchorage failures. For components installed on housekeeping pads, the failures were often associated with splitting of unreinforced concrete housekeeping slabs. In some cases, anchor bolts partially pulled out, but did not fail completely.

5.5 Automatic Fire Sprinkler Systems

Piping systems were the source of a considerable portion of nonstructural damage sustained in the earthquake. Automatic fire sprinklers and their piping were responsible for substantial damage, in some cases causing significant flooding. Failures were noted of both the automatic sprinkler heads as well as threaded pipe connections, often due to impact with surrounding equipment or building components. A two-story concrete shear wall structure with a mezzanine suffered extensive damage when a single sprinkler head on third floor above the ceiling began discharging water after it impacted either a U-hanger for the branch line or an adjacent wood beam. The sprinkler system could not be shut off, and the sprinkler ran for five hours. All the partition walls and floor coverings suffered extensive water damage. The building was out of service for several months. In a restaurant and theater, a single sprinkler line failed at a threaded fitting and flooded the first floor of the structure. The failure occurred above the walk-in refrigerator in the first floor food preparation area. The hardwood flooring in the first floor warped and in some areas buckled. In addition, some of the partition finishes were damaged by the water and had to be replaced. As with first example, the water to the fire sprinkler system could not be shut off. The fire pump activated and continued to run, and the flooding continued for about nine hours. The building was closed for a week to dry out the flooring and repair water damage. In a retail building, five sprinkler lines suspended from the roof reportedly broke and remained on for several hours. The sprinkler piping had threaded connections and damage appears to have been related to swaying and interaction with adjacent HVAC components. The elevator and escalator pits were flooded and both systems required repair. Contents were damaged as a result of the water, and a considerable amount of gypsum wallboard was water damaged and required removal.

5.6 Contents

Contents refers to components that are not part of the building architecture or MEP systems and that are generally not regulated by the Building Code. This includes temporary or movable items, equipment that is not permanently attached to the structure such as desktop items (computers, copiers, lamps, etc.), and most furniture except permanent floor-supported storage cabinets, and shelving or book stacks over 6 feet tall. Virtually all buildings within the study area experienced some contents damage. In some cases, the damage was limited to shelf-mounted items shifting or falling. In others, larger furnishings overturned or shifted. Some contents damage would have caused injury or death had the earthquake occurred at another time of day. The one death attributable to the earthquake was caused by a television that shifted off a table and struck the victim in the head, who then refused medical aid.

6. Summary

The South Napa earthquake provided an opportunity to expand existing knowledge and databases on the performance of buildings and other structures. The earthquake demonstrated the effectiveness of seismic mitigation efforts for URM structures. Further study is needed to improve the seismic performance of manufactured homes. The vulnerability of buildings, even modern buildings, to disruptive damage caused by nonstructural failures was again demonstrated. Methods for reducing the vulnerability of buildings to flooding from damaged fire sprinkler systems should be explored.

7. Acknowledgements

The authors of this paper are members of the FEMA/ATC Special Project team. Maryann Phipps and John Gillengerten are Technical co-Directors of the Special Project team; Michael Mahoney the FEMA Project Officer, and Ayse Hortacsu the ATC Project Manager. The work forming the basis for this publication was conducted pursuant to a contract with the Federal Emergency Management Agency. The substance of such work is dedicated to the public. The authors are solely responsible for the accuracy of statements or interpretations contained in this publication. No warranty is offered with regard to the results, findings and recommendations contained herein, either by the Federal Emergency Management Agency, the Applied Technology Council, its directors, members or employees. These organizations and individuals do not assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any of the information, product or processes included in this publication.

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