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THE 2014 SOUTH NAPA EARTHQUAKE AND ITS RELEVANCE FOR NEW ZEALAND

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ABSTRACT

The South Napa earthquake occurred on Sunday, 24 August 2014 at 3.20 am local time at a depth of 10.7 km, having MW 6.0 and causing significant damage to unreinforced masonry (URM) buildings in the City of Napa and generating strong ground shaking in a region well known for its wine production. Parallels exist between the damage in past New Zealand earthquakes, particularly to unreinforced masonry buildings, and the disruption in the Marlborough region following the recent 2013 MW 6.5 Seddon earthquake. Furthermore, the event was the largest to have occurred in Northern California since the 1989 Loma Prieta earthquake 25 years earlier, and hence was an important event for the local community of earthquake researchers and professionals regarding the use of a physical and virtual clearinghouse for data archiving of damage observations. Because numerous URM buildings in the City of Napa had been retrofitted, there was significant interest regarding the observed performance of different retrofitting methods.

Following a brief overview of the earthquake affected area and previous earthquakes to have caused damage in the Napa Valley region, details are provided regarding the characteristics of the 2014 South Napa earthquake, the response to the earthquake including placarding procedures and barricading, and more specific details of observed building and non-structural damage. Aspects of business continuity following the South Napa earthquake are also considered. One conclusion is that in general the seismic retrofitting of URM buildings in the Napa region proved to be very successful, and provides an important benchmark as New Zealand begins to more actively undertake seismic assessment and retrofitting of its earthquake prone building stock. It is also concluded that there are sufficient similarities between New Zealand and California, and a rich network of contacts that has developed following the hosting of many US visitors to New Zealand in conjunction with the 2010/2011 Canterbury earthquakes, that it is sensible for the New Zealand earthquake engineering community to maintain a close focus on ongoing earthquake preparedness and mitigation methods used and being developed in USA, and particularly in California.

MISSION OBJECTIVES

Prior to visiting the earthquake affected region the authors were provided with a mission summary of objectives prepared by members of the NZSEE Learning from Earthquakes Committee. Collecting field data was not a primary objective of the mission, but instead emphasis was placed on distilling and interpreting available data in a New Zealand context. Specific objectives were listed as:

- Derive lessons from a U.S. emergency building management response to a moderate level earthquake event. Correlate this experience with the newly published MBIE field guide [1], as well as the draft (unpublished) post-earthquake emergency management manual.
- Develop NZ's connections with ATC (noting that the ATC-20 team is using this event to review their manual for the post-earthquake safety evaluation of buildings, ATC-20 [2]), to ensure that NZ practice remain at the forefront and consistent with international best practice.
- In the area of URM buildings, if viable to participate in field data collection to address area of interest to NZ, such as the performance of retrofitted structures. Develop linkages with researchers on the ground that were collecting data on the performance of unreinforced masonry buildings.
- Wine is a top export commodity in NZ. The mission should not only collect data on systems and practices that failed, but also on systems that performed well. Apart from collecting engineering information, an objective of this mission is to reinforce the heighten awareness of seismic risk to NZ winemakers following the Seddon earthquake.
- Derive lessons on non-structural component performance in earthquakes from an architectural perspective. Collect quantitative data on business interruption from a community that is tourism focussed and derive lessons for NZ.

BACKGROUND AND CONTEXT

Napa and Surrounding Area

The Napa Valley is considered one of the premier wine growing regions of the world, and is located northeast of the San Francisco Bay area in California (see Figure 1). Within the valley, the City of Napa was founded in 1847 and incorporated as a city in 1872 [3], and is the principal city of Napa County, with a population of 76,915 recorded in a 2010 census [4]. The first commercial winery in the county began in 1859, and in the late 1850s the city flourished in conjunction with the California Gold Rush, with many disheartened miners

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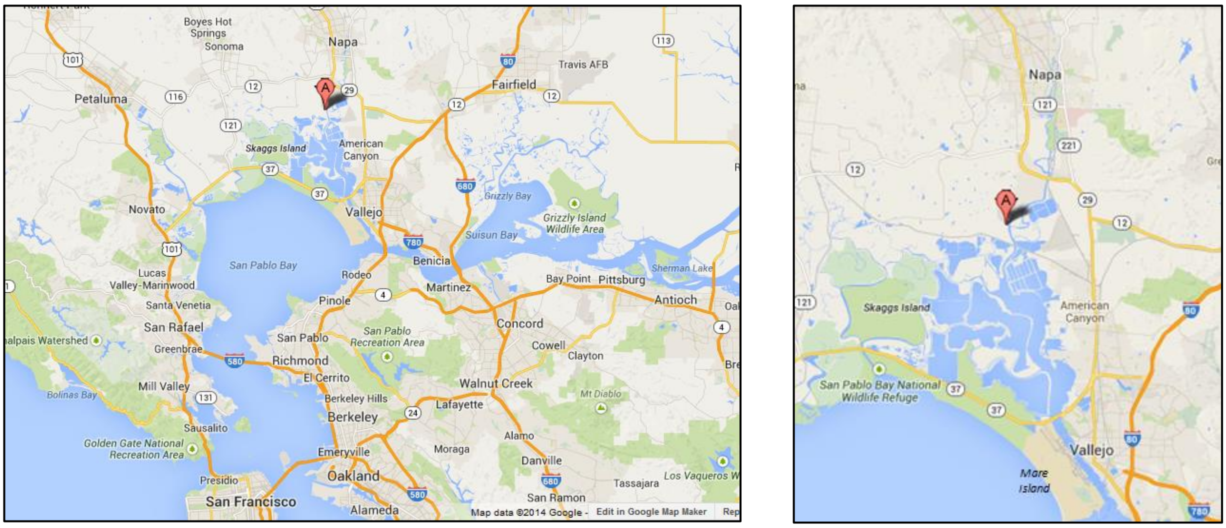


(a) View of San Francisco bay area *(b) Cities in close proximity to the epicentre*

Figure 1: Napa and surrounding district, showing location of epicentre (Google maps).

(a) Napa Main Street, looking south to First Street, late 1800s [10] *(b) 1870 Naval Hospital at Mare Island, demolished after the 1898 Mare Island earthquake [11]*

Figure 2: Early photographs Napa and Mare Island.

taking up other trades in the region. These events were closely followed by the discovery of silver and the opening of silver mines in the Napa Valley. Napa has a significant number of heritage buildings (see Figure 2(a)) that are an important feature of the Napa tourism industry, and consequently the community has a strong preservation spirit, with little desire to demolish damaged historic buildings.

South of the City of Napa and also in Napa County is the city of American Canyon, with a 2010 population of 19,454 [5]. The city was incorporated in 1992 [6] and hence lacks the historic buildings found in Napa. Further south of American Canyon is the city of Vallejo, which is the largest city of Solana County with a 2010 population of 115,942 [7], and also has numerous historic buildings in the central city. The city has twice been the state capital in 1852 and then in 1853, and between May 2009 and November 2011 the city was declared bankrupt [8]. Nearby to the city of Vallejo is Mare Island, which is not an actual island but instead is a peninsula. Mare Island was first surveyed in 1850 as the site for the nation's first Pacific coast naval station. In 1872 the navy began construction of its first dry dock with a foundation of cut granite blocks, and construction of a second dry dock of concrete was begun in 1899 [9]. The shipyard closed in 1993 and Mare Island is today an historical park.

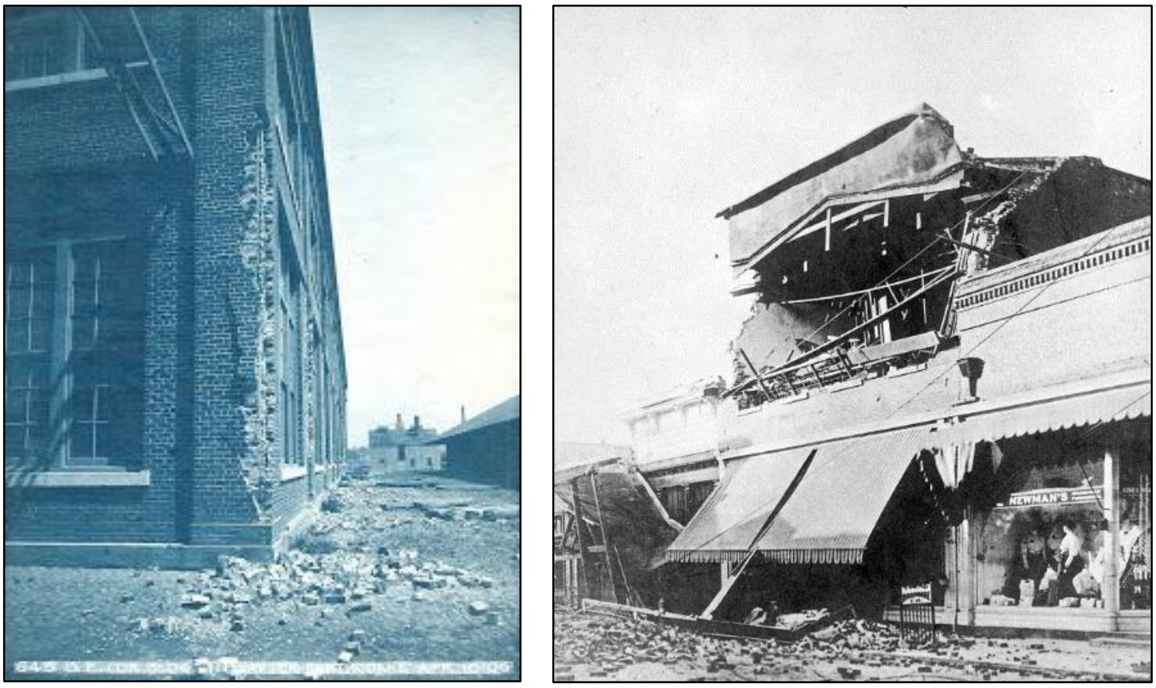
Property Values in Napa and Vallejo

Although located in close proximity, Napa and Vallejo are in different counties and are subject to distinctly different economic conditions. In particular, Napa is a popular tourist destination and there is strong demand for property in the area. The 2009-2013 median value for owner-occupied housing units in Napa is US$403,000, with the corresponding value in Vallejo being US$218,300 [4, 7].

Previous Earthquakes

Northern California is an area of high seismicity, and buildings located in and around the Napa Valley have experienced significant shaking in past earthquakes. On 31 March 1898 a M 6.3 earthquake was centred at Mare Island (see Figure 1b), causing the partial or total collapse of several buildings [12] (see Figure 2(b)). On 18 April 1906 the MW 7.8 San Francisco earthquake caused extensive damage in San Francisco, but also caused damage in the Napa Valley region. In Vallejo there were reports of chimney damage [13] and at Mare Island there was damage to several buildings [11] (see Figure 3(a)). In Napa there was significant damage to a number of buildings and the loss of numerous masonry chimneys [14] (see Figure 3(b)).

The 1989 MW 6.9 Loma Prieta earthquake was located to the south of San Francisco and appears to have resulted in little or no damage in the Napa Valley area, but the 2000 MW 5.0 Yountville earthquake which had an epicentre located 14 km northwest of the City of Napa caused exterior damage to several unreinforced masonry buildings in Napa and resulted in damage to the masonry chimneys of several hundred homes, with 16 buildings in Napa being red tagged and 168 being yellow tagged [15]. There were no fatalities but a 5 year old child was struck by bricks falling from a chimney and required critical medical attention.



(a) Damage at Mare Island [13] *(b) Damage in Napa [14]*

Figure 3: Building damage in the Napa Valley region due to the 1906 San Fernando earthquake.

Seismic Retrofit Activity in Northern California

In 1986 the State of California passed the 'URM Law' which is a state law referred to as Section 8875 et seq, of the California Government Code [16] that for high seismic zones required local jurisdictions to prepare an inventory of URM buildings, and to have loss reduction programs in place for URM buildings by 1990. In addition, the law recommended that local governments adopt mandatory strengthening programs by ordinance, establish seismic retrofit standards, and enact measures to reduce the number of occupants in URM buildings. Jurisdictions were to submit progress reports to the California Seismic Safety Commission [17]. The Commission periodically requested voluntary updates at approximately two year intervals until 2006, at which time mitigation progress had slowed to less than 1% improvements annually.

In 1990 the City of Vallejo passed an Unreinforced Masonry Ordinance [18] which required floor to wall securing to be carried out within a period of 24 to 36 months (depending on occupancy/risk category), and for URM buildings to be fully retrofitted by August 31, 1994. By 1992 Vallejo had identified 45 URM buildings, while Napa City had carried out a survey of 42 URM buildings but had not yet developed an ordinance requiring retrofit of URM buildings [19]. By 2003 16 URM buildings in Vallejo had achieved compliance with the mitigation program and retrofit plans had been submitted for a further 25 buildings. At the same time, 11 URM buildings in Napa had been retrofitted, and plans for the retrofit of just 3 further buildings had been received [20].

In 2006 the City of Napa passed an Unreinforced Masonry Ordinance [21] which required unreinforced masonry buildings to be retrofitted within a period of 3 years. This period was extendable by up to a year in legitimate circumstances, or longer at the discretion of the Building Official, under the condition that the owner vacate the building without further appeal if the works were not complete by the agreed date. Once the City of Napa issued a notice to correct deficiencies, the owner was obliged to notify the tenants, and to post a notice stating "This is an unreinforced masonry building which constitutes a severe threat to life safety in the event of an earthquake of moderate to high magnitude". Financial incentives were also offered, including contributions to the preparation of plans and specifications, and completion of retrofit work. Further details pertaining to these issues are reported in a companion article [22].

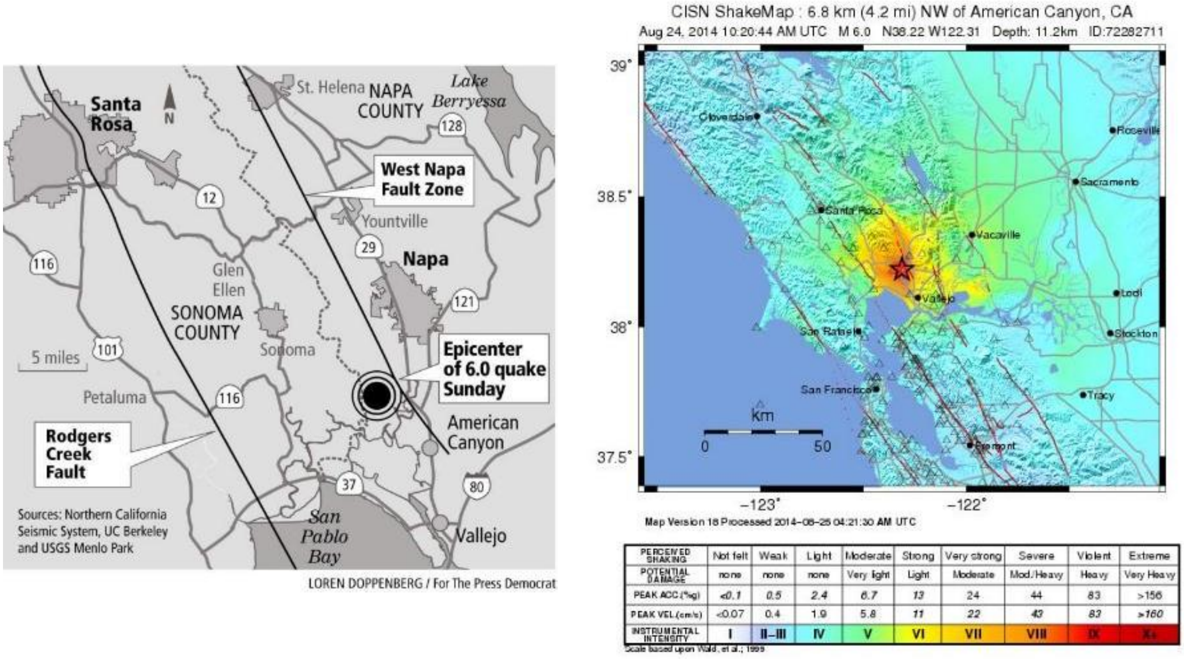
2014 SOUTH NAPA EARTHQUAKE

Earthquake Characteristics

The South Napa earthquake occurred on Sunday, 24 August 2014 at 3.20 am local time and was the largest earthquake in the San Francisco Bay area since the 1989 Loma Prieta earthquake, 25 years earlier. The main earthquake was MW 6.0 at a depth of 10.7 km, with the epicentre located approximately 6.0 km northwest of the city of American Canyon near the West Napa Fault, just west of the Napa County Airport [24] (see Figure 4(a)).

The West Napa fault was a previously mapped fault [25], and is included in the national seismic hazard models, with an estimated slip rate of 1 mm/year [26]. A maximum lateral slip of 45 cm was measured at the surface, with slips of up to a metre at depth [27]. The rupture propagated north from the hypocentre towards Napa City, located some 9 km away. Strong shaking was primarily confined to the area containing of Napa City, American Canyon, Vallejo, and Mare Island (see Figure 4(b)). Aftershocks were relatively minor in comparison to the size of the main shock, with the largest being an M3.9 occurring on 26 August.

Response spectra show that the 2014 South Napa earthquake had a dominant north-south component, which is consistent with the direction of fault rupture. The spectra recorded in Napa displayed accelerations that ranged between 50% and 100% of the design loads required by ASCE-7 (see Figure 5), whereas the shaking in Vallejo and Mare Island were typically in the order of 30-50% of current code design loads.



(a) Details of West Napa fault zone [23] *(b) USGS shake map [24]*

Figure 4: Epicentral location, felt intensity and fault details for the 2014 South Napa earthquake.

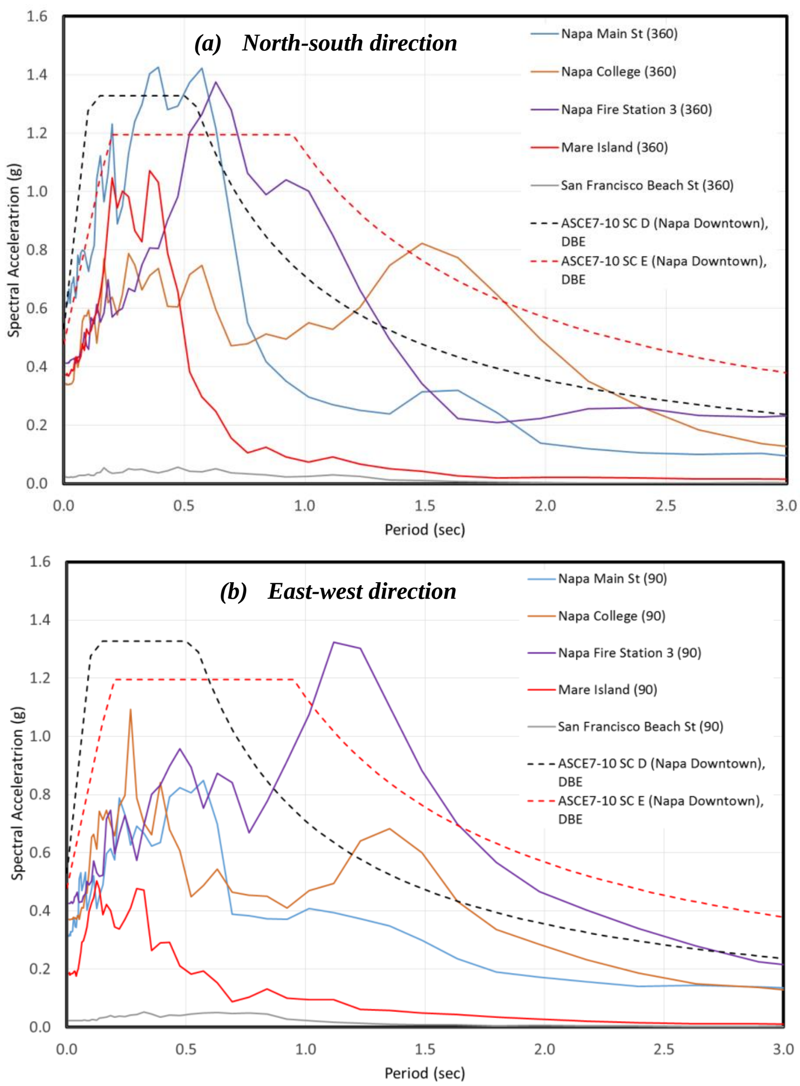


Figure 5: Acceleration response spectra for the 2014 South Napa earthquake (Source: Holmes Culley).

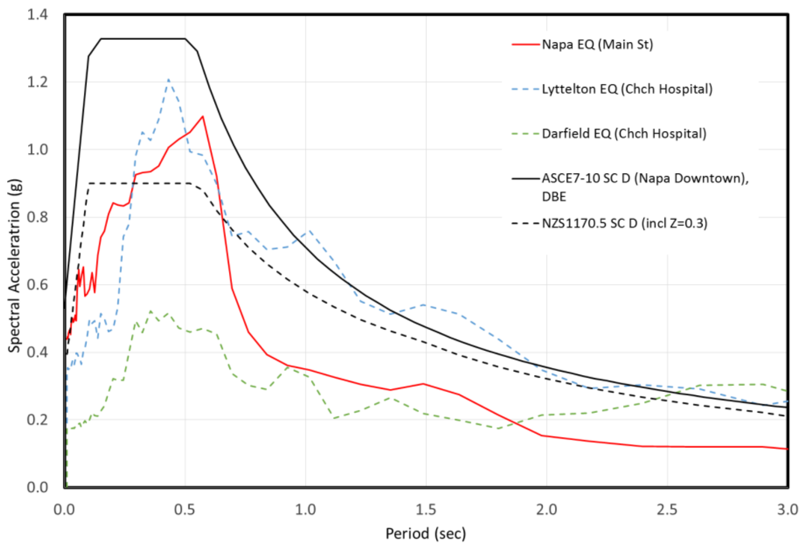


Figure 6: Comparison of geometric mean for Napa and Canterbury events (Source: Holmes Culley).

To provide a New Zealand context to the severity of shaking, Figure 6 compares the response spectra recorded in the Napa CBD to those recorded in the Christchurch CBD at Christchurch hospital for the 2010 Darfield and 2011 Christchurch (Lyttleton) events. The geometric mean of the response spectra generated for orthogonal directions of shaking has been used to provide an effective non-directional comparison between the events. From the information available it appears that the shaking in Napa was of a similar intensity to the 2011 Christchurch event in the short period range, although Christchurch experienced a significantly larger long period component.

Land Damage Observations

The 2014 South Napa earthquake was the first earthquake in the San Francisco Bay region to produce significant surface rupture since the 1906 San Andreas Fault earthquake, and the first earthquake in northern California to rupture through a densely populated area [27]. Surface rupture extended approximately 12 to 15 km from the town of Cuttings Wharf in the south to beyond the northern boundary of Alston Park in the city of Napa, in the north. The deformations resulted in buckling and tearing of sealed roads and concrete pavements, as well as some damage to mainly residential housing that was located across the fault zone (see Figure 7). A geologist was on the scene within hours of the main shock and took measurements across the surface expression of fault rupture. After-slip effects were observed, with the initial slip of 5 cm measured 7 hours after the earthquake, widening to 12-13 cm after 24 hours, and 20 cm after a few days.

Figure 7: Buckling of pavement on Patrick Road, Napa.

Liquefaction was observed but the extent was very limited, although the area was previously considered highly susceptible to liquefaction [28-30]. The lack of observed liquefaction may be due to three years of drought.

Other Impacts

Structural damage was generally concentrated to unreinforced masonry buildings and residential properties, although several newer commercial buildings also suffered damage. Several road pavements and footpaths buckled, but no significant damage was reported to bridges forming part of the public road network. Six major fires broke out, and firefighting efforts were hampered in at least one case due to broken water mains [31, 32]. Direct costs associated with damage have been estimated at US$362M [33], with economic costs to Napa County estimated at up to US$1B. Approximately 200 people were injured and 1 person died (2 weeks later on 5 September, but as a result of injuries sustained in the earthquake).

BUILDING ASSESSMENTS

City Response

A state of emergency was declared by the Governor of California shortly after the earthquake, due to the extent of damage and the possibility of aftershocks [34]. A safety assessment program (SAP) [35] was implemented by both Napa and Vallejo Cities, and by 9 September 10,748 buildings had been inspected in Napa County, with 2,458 yellow or red placards issued and 8,326 green placards issued [33]. Damage cost estimate data was also requested from the SAP assessors working in Vallejo to quantify the expected loss in order to qualify for FEMA funding. On 11 September (almost 3 weeks after the initial earthquake), a Major Disaster was declared by the President of the United States, in order to make Federal funds available through FEMA for the recovery [36].

Deployment of Assessors

Responsibility for carrying out a rapid building assessment programme rests with the local city having jurisdiction. In this case, the cities of Napa, Vallejo, American Canyon, and Sonoma were each affected and declared a state of local emergency. The cities of Napa and Vallejo requested assistance from the California Office of Emergency Services (Cal OES) in the form of the Safety Assessment Program (SAP). In turn, Cal OES contacted its supporting professional organisations SEAOC (Structural Engineers Association of California), ASCE (American Society of Civil Engineers), CalBO (California Building Officials), ACIA (American Construction Inspectors Association), and AIA (American Institute of Architects). Following receipt of the requests, SEAOC and ACIA/CalBO in turn contacted their registered SAP evaluators, and solicited responses to fill the required positions.

At 10 am on Sunday 24th August, Napa City requested 8 engineers and 8 building officials for a five day deployment. The request was non-specific with regards to the specialisation of the engineers required (i.e. structural, geotechnical, civil). SAP evaluators reported that structural engineers were assigned to residential areas, with the local building officials carrying out assessments in the downtown area. In contrast, Vallejo made three separate requests for SAP assessors over a period of three weeks, with the first request submitted on Monday 25th August. Responses were requested via a web-based form, and SAP evaluators responding to the request indicated that they received no feedback as to whether their response was received, or whether their presence was required. The SAP assessors arrived in Vallejo along with a SAP coordinator – a government official trained to coordinate such an operation. However, the assistance of the SAP coordinator was turned down by the Vallejo city building official.

Some difficulty was encountered finding volunteer assessors for the later deployments to Vallejo. The SAP coordinators indicated that this difficulty may have been due to reasons such as the elapsed time since the earthquake, a lack of reimbursement for travel costs, requirement for a minimum 5 day voluntary deployment, and the relatively moderate nature of the damage observed.

It is understood that the cities of American Canyon and Sonoma determined that they had sufficient local resources to respond and did not make a request for SAP assistance.

SAP evaluators responding to the event were sworn in as deputies to the local building official, and were deployed in teams of 2 or 3. Teams were typically comprised of an engineer and a building official.

SAP Evaluators

SAP evaluators are a trained resource, with regular training and refresher courses [35]. Qualification as a SAP evaluator typically comprises an initial one day course, followed by a requirement to carry out online training every five years. As a result, SAP evaluators carry a registration ID card issued by Cal OES and their names are listed on a publically accessible website. The deployment of an associated SAP coordinator with a team is intended to allow the calibration of the evaluators to ensure that all have a good grasp of the structural types in the area.

Liability of SAP evaluators is covered by the 'Good Samaritan' law [37]. In essence, this law protects evaluators from personal liability where they are volunteering their time for the benefit of others. Privately employed SAP evaluators typically take annual leave during the period of their SAP deployment, as being paid by their own company is considered to disqualify them from this protection (regardless of whether the company volunteers the evaluator's time to the response effort). State employees are generally paid, as they are afforded State liability protection in any case.

Building Assessment Process

Initial priorities for building assessments were the downtown areas of Napa and Vallejo. As time progressed, wider residential areas were also assessed. Rapid assessments were carried out as defined in ATC-20 [2] (equivalent to New Zealand Level 1 assessments [1]). Detailed assessments (equivalent to New Zealand Level 2 assessments) were generally not carried out as part of the initial building assessment program, although placards noted that internal access had been achieved for many of the buildings observed in downtown Napa.

In Vallejo, the city building official instructed the SAP evaluators to complete their assessments and to record only the building address, placard status and a brief description of the damage on a simple form. At the building official's instruction, ATC-20 forms [2] were not used – although some evaluators chose to fill them out anyway.

Where wide areas of buildings were found to be largely undamaged (such as in areas of residential housing), drive-by surveys were carried out until a damaged building was spotted. A Rapid Assessment was subsequently completed for the damaged building, before attaching a yellow or red placard and recommencing the drive-by survey.

Evaluation teams reported being confronted with a difficult resident approximately once a day. In the worst case a resident threatened to get their shotgun, at which point the evaluators made a hasty exit.

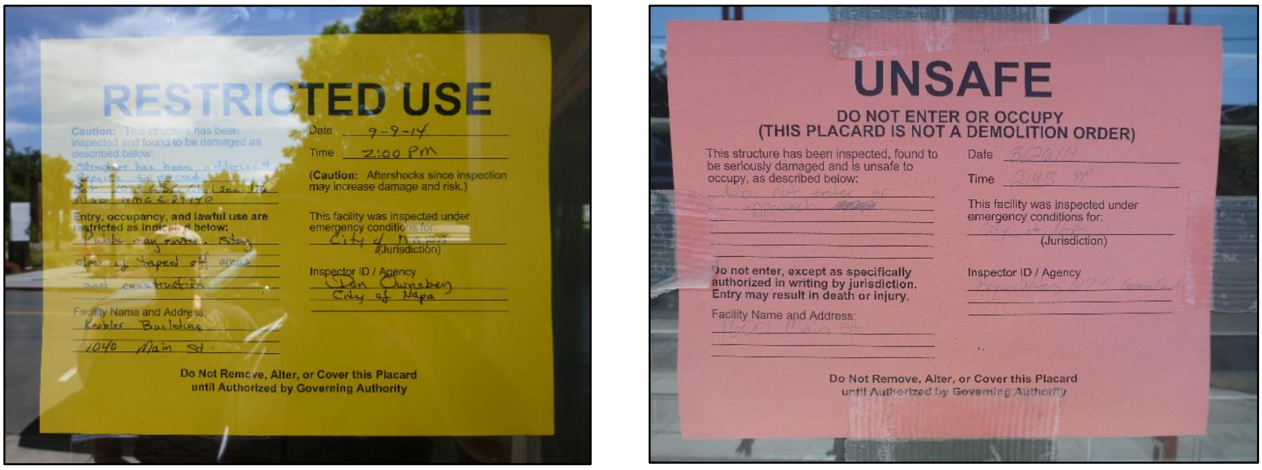
Placarding

In California each city can dictate through local ordinances whether to treat placards as a legal document, or public information. While no relevant ordinances could be located for Napa City, Chapter 12.05 of the Vallejo Municipal Code [38] enables the use of standard placards to indicate the condition of a structure for continued occupancy. The ordinance enables the placement of placards by the Chief Building Official (and authorised representative) in a large scale natural event, single accident, or dilapidated property maintenance which may cause harm or jeopardize the safety of the occupant. The ordinance is not tied to a state of emergency, therefore enabling the placards to retain their status beyond the period of a declared emergency.

Both Napa and Vallejo used the standard ATC-20 placards, with Vallejo inserting the city crest into the top left corner. In Napa the full system of red, yellow and green placarding was rolled out in the downtown area. However, while all buildings in the downtown area of Vallejo were assessed, only yellow or red placards were placed on buildings. In this case, the absence of a placard was taken to represent 'green'. SAP evaluators noted that they observed property owners cleaning up their buildings with the hope of swaying officials to avoid getting a red or yellow placard.

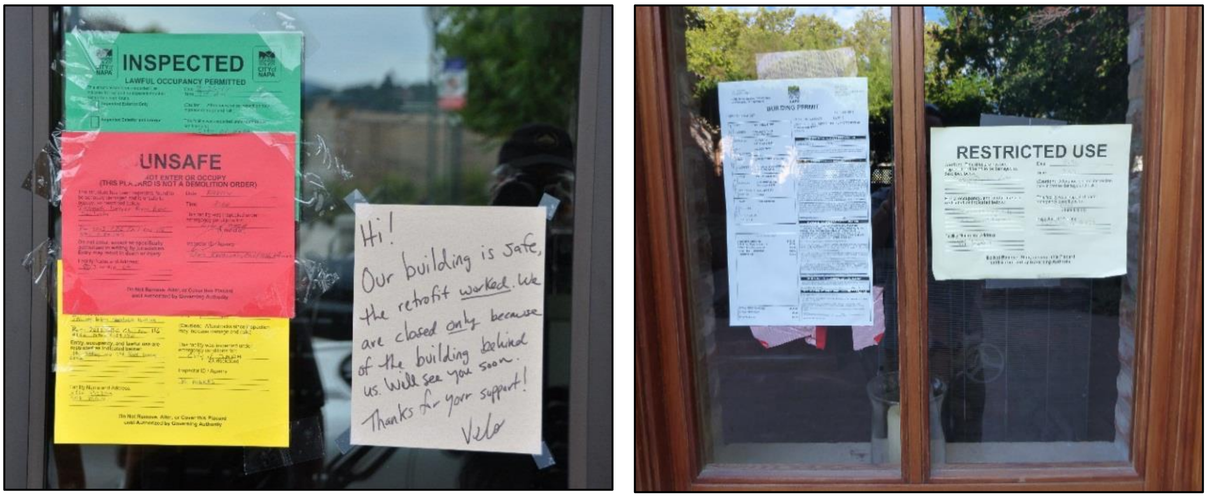
Placarding was also carried out in surrounding residential areas of both Napa and Vallejo. Typically only yellow or red placards were issued in these areas, in order to expedite the large number of assessments in a timely manner.

The yellow and red placards observed in the downtown area of Napa were often ambiguous with regards to the description of the form and location of damage observed. Figure 8(a) shows the yellow placard for a damaged building which indicates that the "Structure has been addressed. Repairs to proceed", but does not describe what the damage is. The placard also indicates that "Public may enter. Stay clear of taped off areas", without describing where these taped off areas are. Figure 8(b) shows a red placard for a badly damaged building (being worked on by contractors) which notes simply "Do not enter or approach".



(a) Yellow placard *(b) Red placard*

Figure 8: Examples of placard comments and restrictions.



(a) Multiple placards (Source: Fred Turner) ***(b) Building permit***

Figure 9: Placarding issues and building permits for repairs.

Problem that had been encountered with placarding in conjunction with the Canterbury earthquakes were also encountered in Napa, such as placing different placards on different entrances to the same building, as well as not removing placards that had been superseded by a reassessment. Figure 9(a) shows multiple placards affixed to the door of a single building. While the placard status of a building may change over time, the current version of ATC-20 does not define a policy as to whether placards should be supplemented or replaced.

Napa City was issuing building permits for repairs (Figure 9(b)) by early September. The City opted to waive inspection and permit fees for earthquake related works, and created a one-stop permit centre to make processing as easy as possible. Napa shared the placard status of evaluated buildings with the public via an interactive web viewer (Figure 10). This viewer enabled any member of the public to locate any yellow or red placarded building, as well as providing the location of reported water leaks, and debris drop-off sites. This information was not readily available in Vallejo.

Napa City also hosted a website to provide earthquake related information to the public. The website contained a brief description of each of the placards as follows:

- A green tag means that either the building has either not been affected or has slight damage. The building is structurally safe to enter.
- A yellow tag means "cautionary."
- A red tag means the building structure has been damaged and is not safe to enter

A process for changing placards was described on Napa City's website (http://www.cityofnapa.org/index.php?option=com_content&view=article&id=1850&Itemid=915), and was clearly happening as evidenced by the multiple placards observed

Barricading

Building officials and SAP evaluators were equipped with hazard tape which was used to initially mark out hazardous areas. SAP evaluators noted that the public largely tended to ignore the barrier tape, in order to take a closer look. An EERI reconnaissance team observed residents walking around downtown Napa on the afternoon of the earthquake accompanied by children and pets, with dangerous buildings barricaded off only with hazard tape at the edge of the sidewalk. The hazard posed by these buildings was identified by the EERI team, and by 7 am on the 25th August, the California Seismic Safety Commission had passed on information and a copy of the 2013 California Building Officials (CalBO) barricading guidelines [39] in order to rectify the situation. The CalBO guidelines recommend that barriers initially be set at 1.5 times the height of the building to allow for the possibility that falling items can bounce and

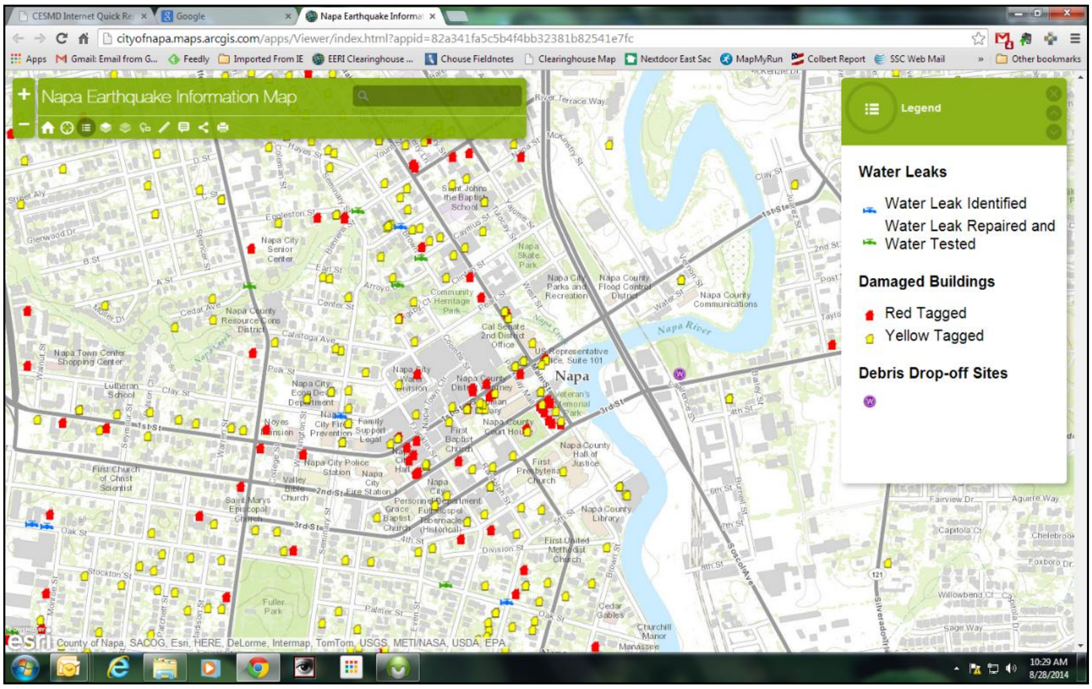


Figure 10: Napa interactive web viewer showing status of yellow and red placards.

shatter. The guidelines also recommend that detailed evaluations should be carried out before refining barricade distances, ideally comprising interior and exterior site investigations, drawing and calculation reviews and testing of damaged components.

The Goodman Library displayed significant damage to the feature on top of the front elevation (see Figure 11(a)), which at first viewing could have had the potential for full collapse of this wall. Hazard tape was initially used to barricade off the footpath (well inside 1.5 times the height of the building), and fences were subsequently erected at the edge of the roadway in lieu of the hazard tape. By 18 September, more was presumably known about the global stability of the front elevation and the fences had been moved back to the inside of the sidewalk (Figure 11(b)). This reduction in barricade and associated erection of a light scaffold over the sidewalk indicates that the building officials expected only minor fall hazards (ie a brick or two) rather than a partial collapse of the feature atop the facade. The purpose and effectiveness of the scaffold walkway was unclear.

Similar issues to those discussed above were encountered in Vallejo, where hazard tape was observed more than three weeks after the earthquake barricading off only the footpath width below a partial collapse of what appeared to be a brick veneer wall (Figure 12).

Wider cordons were erected around whole streets in some situations, although this was generally not required over a large area. Individual streets were cordoned off in central Napa on Wednesday 27 August, and Georgia Street in Vallejo was cordoned off while damaged parapets were removed from several damaged masonry buildings.

Temporary Propping

Very little temporary propping was observed by the authors in either Napa or Vallejo, given that over three weeks had elapsed since the earthquake. Where partial out-of-plane failures had occurred in masonry walls, the upper portion had occasionally been removed, but no additional support had been provided to restrain the remaining walls. The lack of any significant aftershocks may have contributed to this outcome, as the lack of aftershock activity may have induced complacency that propping was not required. Where temporary propping had been carried out, the methods used appeared to be relatively ineffective. Figure 13 shows propping with long, slender timber props, having no anchorage to the wall or ground surface and no lateral bracing to prevent buckling.

Throughout Napa scaffold had been constructed over public access routes with thin timber planks or steel decking, presumably to provide protection from fall hazards. The amount of fall protection afforded by the lightweight elements was somewhat questionable, and appeared to lead to further complacency from the public as they assumed that the damage was in hand.

Performance of URM Buildings

It is widely recognised in both New Zealand and California that unreinforced masonry (URM) buildings are typically the class of building to suffer greatest damage in moderate level earthquake shaking. In New Zealand there is a history of URM construction that started with the 1833 Stone Store in Kerikeri and rapidly declined following the 1931 MW 7.9 Hawke's Bay earthquake [40]. Similarly, URM construction in the Napa valley area commenced in the 1840s and all URM construction in California was banned by the Field Act following the MW 6.4 1933 Long Beach earthquake [41]. Consequently there are distinct similarities in the age profile of the URM building stock of New Zealand and regions of California, with the general architectural characteristics of these buildings also having strong similarities.

One distinction between URM buildings found in Northern California and those in New Zealand is the absence of cavity construction. It has been suggested [42] that this absence of cavity construction is due to the warmer drier conditions in Northern California, with average monthly temperatures in Napa ranging from 13.9° to 28.3° C. Similarly, simple inspections of mortar quality suggest that as a generalisation the mortar found in Napa URM buildings is sounder than that typically encountered in New Zealand URM buildings, perhaps because of less aggressive weathering over the life of the building.

(a) Barricading of Goodman Library on 24 August (Source: Bill Tremayne)　*(b) Barricading of Goodman Library on 18 September*

Figure 11: Barricading in Napa.

(a) Ineffective Barricading　*(b) Close-up view*

Figure 12: Barricading in Vallejo on 16 September.

A second distinction between the URM building stock of the Napa region when compared to New Zealand's URM buildings is the apparent reduction in parapet height in Napa. Parapet heights were initially influenced primarily by architectural, weather, roofing, and fire resistance considerations and can be observed to vary by region. In the 1800's Napa was a relatively poor town that relied on an agricultural economy and experienced comparatively modest demands for prominence in its building facades. Those factors perhaps influenced choices toward lower parapets. Napa also has no snow load and relatively light rainfall intensities. These factors could at times have influenced decisions about roof slopes, leading to a reduced parapet height required to hide the relatively flat roofs. Furthermore, the 1906 San

(a) Raking props　*(b) Combination of props and fall protection*

Figure 13: Temporary propping in Napa.

Francisco earthquake caused considerable damage in Napa such that this may have led to parapets constructed after 1906 being much more modest in height, although such ideas are speculative as no evidence has been found to support this possibility [42].

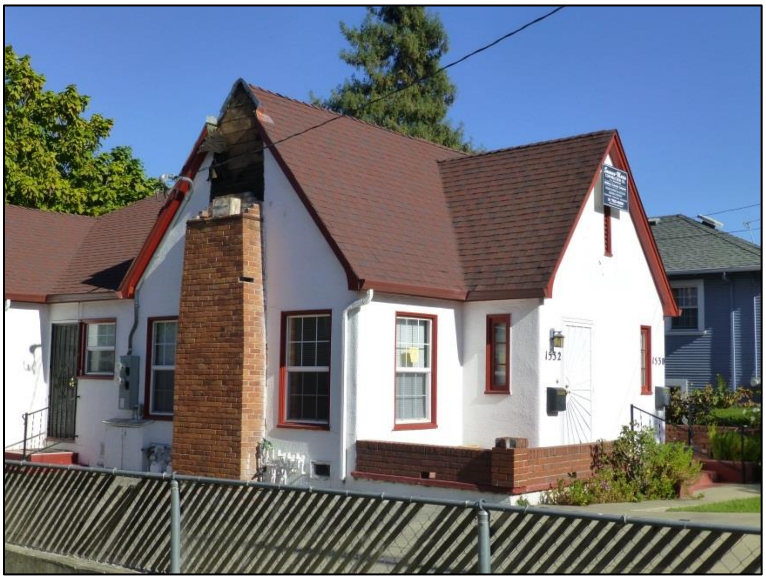
A further distinction between the URM building stock of California is related to the more active uptake of hazard mitigation strategies in California, with respect to the passive approach taken by most New Zealand Territorial Authorities. A review of URM hazard mitigation activities on the US West Coast is reported elsewhere [22]. The URM stock on Napa is a mix of both older stone masonry building and clay brick buildings.

Register of URM Buildings in Napa

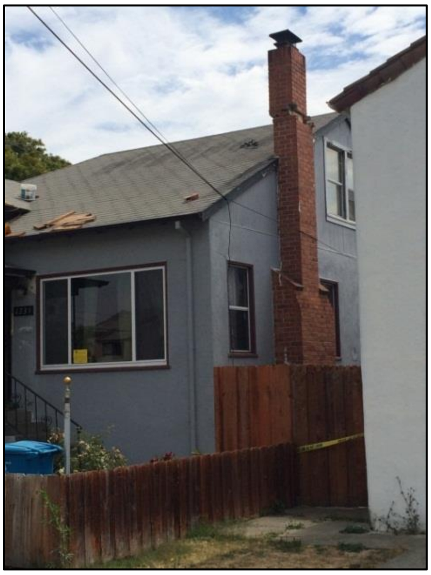
The California Seismic Safety Commission has a register of URM construction for jurisdictions in high seismic zones and directly after the South Napa earthquake was able to produce a list of known URM buildings in the City of Napa and details of whether or not these buildings were known to have received any form of seismic retrofitting. In conjunction with earthquake inspections several buildings were able to be culled from this list, typically because walls were found to be constructed of reinforced concrete or had been demolished, with the updated list containing 40 entries. 20 buildings were thought to have received some form of retrofit and the remaining 20 were thought to be unretrofitted (note that more recently revised information is provided in [22]).

Unreinforced Masonry Chimneys

There is a history in the Napa valley region of unreinforced masonry chimneys having collapsed in earthquakes. The most significant event was the 2000 Yountville earthquake that caused widespread damage to several hundred chimneys in Napa [15], such that many of the houses in Napa had already had their chimneys either partially or completely removed. Nevertheless, in the 2014 South Napa earthquake there was extensive damage to chimneys throughout the Napa valley region, including in American Canyon and Vallejo, with one person having been crushed by a falling chimney and requiring 9 hours of surgery to repair his crushed pelvis [43]. Because most home owners do not have earthquake insurance there is no immediate mechanism for collating damage data



(a) Chimney damage in Napa



(b) Chimney damage in Vallejo (Source: Laura Whitehurst)

(c) Chimneys in Napa removed to roof level

(d) Chimney completely removed (CA EQ Clearinghouse / Source: David McCormick)

Figure 14: Unreinforced masonry chimney damage resulting from the 2014 South Napa earthquake.

related to chimneys and instead home owners either attend to the damage themselves or employ contractors to reduce the chimney to the roof line and cap over the chimney opening, or alternatively completely remove the chimney. Examples of chimney damage are shown in Figure 14.

Parapets and Capstones

There were numerous observed examples of parapet failure or the loss of capstones and other ornamental features, usually located at the highest level of the building and with the greatest height to fall. However, the extent of parapet damage was far less than in the Canterbury earthquakes, and was presumed to be due to the generally lower height of parapets when compared to those typically found in New Zealand.

Because the earthquake occurred at 3.20 am there were no reported cases of people being hit by falling masonry (with the exception of residential chimneys as described above), but it is obvious that the situation would have been very different for a daytime earthquake, particularly in the Napa central city where there is a steady stream of tourists visiting the city. Several examples of damage to masonry ornamental features are shown in Figure 15.

On the few occasions where parapet failure was observed, it was generally noted that securing was either absent or had been reliant upon original or historic sub-standard securing.

(a) Loss of parapet at the Mare Island shipyard

(b) Damage to the ornamental feature atop the Goodman Library in Napa

(c) Loss of capping bricks to a building in Vallejo

(d) Loss of capping stones to a stone masonry building in Napa

Figure 15: Loss of unsecured ornamental features during the 2014 South Napa earthquake.

(a) Parapet failure in Vallejo

(b) Parapet failure at Mare Island

Figure 16: Examples where parapet failure was attributed to sub-standard (original or historic) securing.

Two such examples are shown in Figure 16.

Corners and End-Wall Separation

The corners of URM buildings frequently attract greater damage than do other parts of the building due to the confluence of in-plane and out-of-plane load actions and possible torsional building response. Two such examples are shown in Figure 17.

(a) Alexandria Hotel

(b) Napa Courthouse

Figure 17: Examples of corners of URM buildings having poor anchorage and attracting significant damage.

(a) Out-of-plane failure including end-wall separation

(b) Impending end-wall separation

Figure 18: Examples of end-wall separation or distress.

End wall separation is another common failure mode observed in URM buildings. As shown in Figure 18, this failure mode is associated with out-of-plane wall failure where out-of-plane loads must be transmitted to the perpendicularly-oriented end walls.

Performance of 'Bolts-Plus' Retrofits

Appendix Chapter A1 of the 2013 California Existing Building Code [44] prescribed seismic strengthening provisions for unreinforced masonry bearing wall buildings, with similar provisions having existed in earlier documents such as the 2007 San Francisco Building Code [45]. Whilst the regulations of the San Francisco Building Code specifically apply only to buildings located within the San Francisco jurisdiction, one category of seismic strengthening prescribed by this code is referred to as 'bolts-plus' and has been adopted more widely throughout Northern California, and further afield. The bolts-plus procedure may be adopted when a URM building has:

- Multi-wythe construction where not less than 10% of the exposed face area has solid units oriented as full-length header units that have a clear spacing distance not exceeding 610 mm horizontally or vertically;
- No vertical or horizontal irregularities;
- Does not have an important occupancy class, including essential and hazardous facilities, private school buildings and qualified historical buildings;
- Has adequate mortar strength. The quality of mortar shall be determined by performing in-place shear test and any mortar having a shear strength less than 0.2 MPa shall be either removed, entirely repointed and retested, or treated as a non-structural wall;
- Has timber diaphragms;
- Contains a maximum of 6 stories;
- Has crosswalls at no greater than 12.2 m;
- Has at least 2 lines of vertical elements in each principal load direction;
- Has piers that do not exceed a height/length ratio of 2 and occupy not less than 40% of the wall length;
- For party walls it is necessary that each building sharing the wall individually complies with these limitations and that all segments sharing the party wall be strengthened at the same time whenever feasible.

(a) Post office in central Vallejo

(b) Shops in central Vallejo

(c) A generally well-performing building

(d) Loss of brickwork above one pier, resulting in a falling hazard

Figure 19: Examples where the bolting philosophy appeared to have worked well, other than the loss of individual bricks. Note that none of these buildings comply with the specific restrictions of the bolts-plus ordinance.

Several of these criteria are routine, such as storey height limitations and the presence of timber diaphragms, but the large openings and slender piers typically encountered on the street frontage result in this criteria being quite restrictive. Consequently it appears that many buildings have strictly not been retrofitted in compliance with the bolts-plus ordinance, but instead have been retrofitted in a manner that is consistent with the bolts-plus philosophy whereby efforts are made to secure all walls to their adjoining diaphragms to develop ‘box-like’ response. Extending this logic further, it would therefore be expected that more severe damage would occur on the street frontage having the large wall openings and more slender piers, and as a generalisation this expectation is supported by the observed earthquake damage.

The bolts-plus standard of strengthening specifically requires the provision of wall-diaphragm tension anchorages, wall-diaphragm shear anchorages, the checking of wall out-of-plane stability, and the bracing of parapets and other appendages. The base shear loading on the building is assumed to be 0.1g in each principal direction. When the parapet height above the lower of either the level of tension anchors or the roof sheathing does not exceed 1.5 times the parapet thickness then the parapet need not be removed, stabilized or braced. Complying wall-diaphragm anchorages consist of bolts installed through the wall (or an approved equivalent) and are spaced at a maximum of 1.8 m.

When inspecting the condition of URM buildings in the earthquake affected area a striking feature was the extensive implementation of heavy bolting to secure external masonry walls. In general, where the bolting philosophy had been comprehensively implemented the URM building had performed admirably, as illustrated below in Figure 19.

As observed in the recent Canterbury earthquakes, there were cases where it was evident that wall diaphragm anchorages had been placed under severe load and in some places failed, emphasising that it is preferable to replace any aged anchorages or undertake a proper load testing regime to confirm their adequacy if a decision is made to rely upon existing anchorages as part of a strengthening scheme. Two such examples are shown in Figure 20.

(a) Apparent rupture of the anchor rod or failure at the diaphragm connection

(b) Example of anchorage shift during wall movement

Figure 20: Examples where wall-diaphragm anchorages (or 'bolts') have been severely loaded.

Note however that Figure 20(a) may depict a so-called "dog tie" [46] which was designed with the intent that if a joist were to lose strength in a major fire then the tie would release, thereby avoiding the wall falling inward and potentially harming firefighters. These ties were an early attempt at fire response enhancement and were not intended to resist forces generated from earthquakes.

Case Study URM Buildings

Several URM buildings were of particular interest, either because of distinct failure modes or the performance of implemented seismic retrofits. Selected examples are presented below. In general the full retrofits to URM buildings in the Napa valley region have employed various versions of steel framing, and there are no known examples of surface overlays of such materials as fibre reinforced polymers or textile reinforced mortars. Similarly, and presumably because of the community's interest in retaining the heritage

(a) Sam Kee Chinese laundry [48]

(b) 2012 condition of the building [49]

(c) View of damaged front face

(d) Close up of rubble fill

(e) Side wall showing presence of mid-height wall-diaphragm anchorages

(f) Distressed stonework around the anchor plate of side-wall anchorage

Figure 21: Damage to the Pfeiffer building in Napa.

character of the city for the promotion of tourism, there are no known examples of external shotcreting, although internal shotcreting has been reported.

Pfeiffer Building

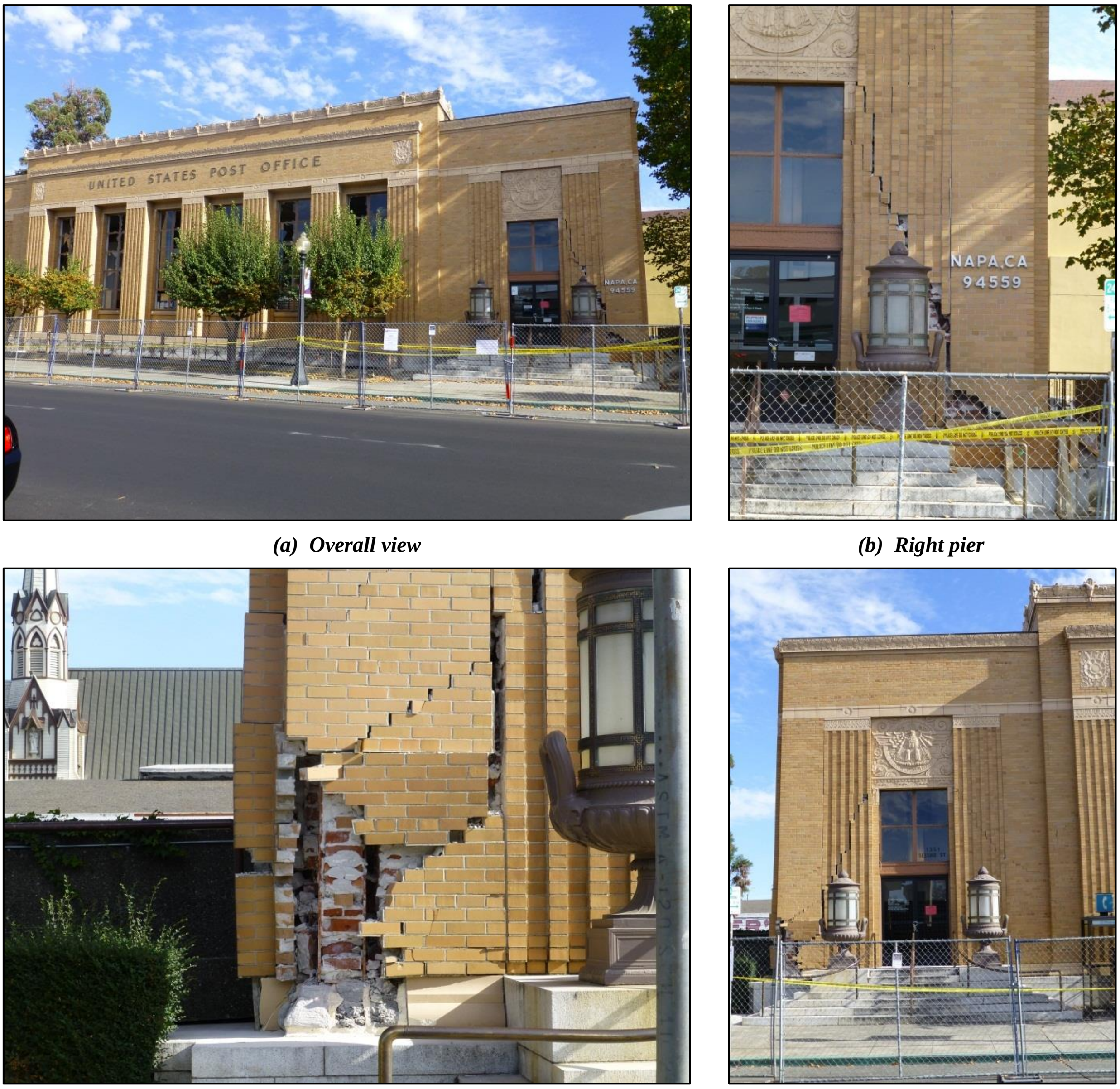
A widely reported failure was to the Pfeiffer Building in Napa. This building was constructed in 1875 and is known as the Pfeiffer Building after its first owner, who was a Bavarian brewer [47]. From 1937 to 1977 the building was known to locals as the Sam Kee Laundry Building, and was listed on the National Register of Historical Places in 1974 because of its importance to Chinese American history. As shown in Figure 21 the building is constructed of a rubble fill masonry with an exterior leaf of dressed stone. On both side walls there were mid-height wall diaphragm anchorages spaced further apart than prescribed by the bolts-plus ordinance. However on the front wall there appears to be an absence of mid-height wall-diaphragm ‘bolt’ anchors and only 2 anchors at the roof line, with no anchors in the vicinity of the top corners of the wall. Whilst this is not a definitive example, and there was evidence to suggest that earthquake directionality was inclined to cause greatest damage to the front face, it is illuminating to see the condition of the wall in the absence of the recommended bolts-plus ordinance.

Napa Post Office

The Napa Post Office is a 1933 Art Deco building designed by architect William H. Corlett and listed on the National Register of Historical Places in 1985 [50]. Miranda and Aslani [51] identified that approximately 14 windows of the Napa Post Office were broken in the 2000 Yountville earthquake. In the 2014 South Napa earthquake the building was severely damaged, with many windows again broken, and with exterior piers exhibiting classic diagonal cracking (see Figure 22). The close-up view shown in Figure 22(c) indicates that the wall morphology is of mixed form, having dark red internal bricks and an external light brown veneer brick. Also, it appears that the building may employ cavity construction as shown in Figure 22(c). Although not visible, it is known that a steel frame is behind the front masonry façade wall.

Sushi Mambo

The Sushi Mambo store is located in Napa on a corner site at 1202 1st Street, and has a URM masonry frame running in two orthogonal directions. CSSC records indicate that the building was constructed in 1905 and seismically retrofitted in 2004, with the retrofit consisting of steel moment frames (along 1st



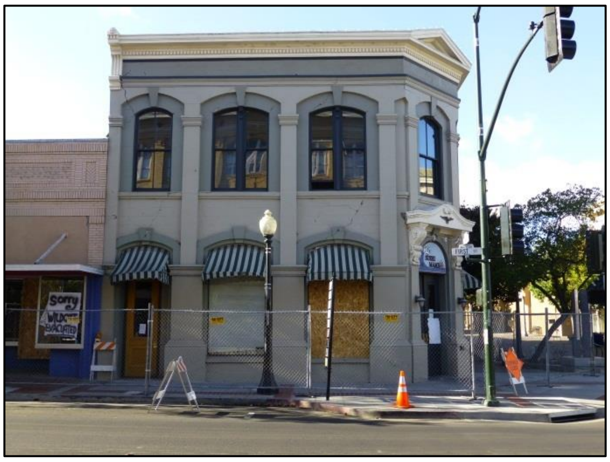
(a) Overall view

(b) Right pier

(c) Close-up of left pier

(d) Left pier

Figure 22: Prominent diagonal pier cracking in Napa Post Office.



(a) View of masonry frame

(b) Close-up view of distinct spandrel failure

(c) Spandrel failure wrapping around corner of building

(d) Cracking at base of piers, suggesting pier rocking

Figure 23: Damage to the Sushi Mambo building in Napa.

Street and Coombs Street façades) and the addition of wall-to-diaphragm anchorages, although no details of these improvements were visible from exterior observation. Miranda and Aslani [51] noted that the building exhibited damage in the 2000 Yountville earthquake, with published images suggesting significant spandrel damage. In the 2014 South Napa earthquake it was further evident that masonry frame response had occurred in both orthogonal actions, attributable to torsional response when recognising that the two off-street walls are typically solid with few or no penetrations. The building is particularly noteworthy as a case-study because the damage pattern appears to indicate distinct rocking at the bases of the piers and in the spandrels, as illustrated in Figure 23.

Main Street Exchange Building

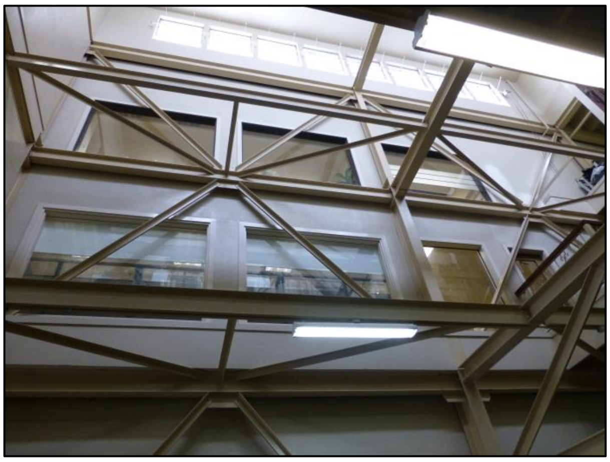
The Main Street Exchange building (also known as the Keebler building) located in Napa at 1040 Main Street is an historic URM building built in 1906. From the building's exterior, diagonal bracing could be seen in several windows (see Figure 24(a)) and there was evidence of deformation incompatibility, with visible tearing of surface linings around an exposed retrofit member (see Figure 24(b)). When entering the central atrium of the building a complex arrangement of 3-dimensional steel bracing was evident, comprised of Ordinary Concentrically Braced Frames (OCBF) using both tube steel and double-angle braces, hybrid steel moment frames that utilized deep trusses at the second floor to form the horizontal beam elements, and conventional steel moment frames at the upper levels, as partly shown in Figure 24(c). Similarly to the external observations, there was clear evidence that the steel framing had been subjected to significant deformations, with bolted connections showing plastic deformation and a number of diagonal bracing remaining in a plastically deformed shape, but also clear evidence that buckling had been in the order of 50 mm or more and restricted by contact with window framing (see Figure 24(d) and (e)). Comments were conveyed to the authors that the observed brace and gusset buckling are performance characteristics that would typically be expected of older retrofit systems, where capacity design principles were not explicitly considered, nor where ductility demands were likely to be concentrated if the frames were loaded inelastically [52]. Many of the connections between the steel framing and the internal face of the street-front wall showed significant distress (see Figure 24(f)) and it was concluded that whilst the retrofit had cleared aided in transmitting earthquake loads in a manner that enabled the building to be re-occupied after the earthquake, it was also clear that section sizes had been too small to provide adequate stiffness and ensure that excessive masonry deformations were avoided.

Borreo Building

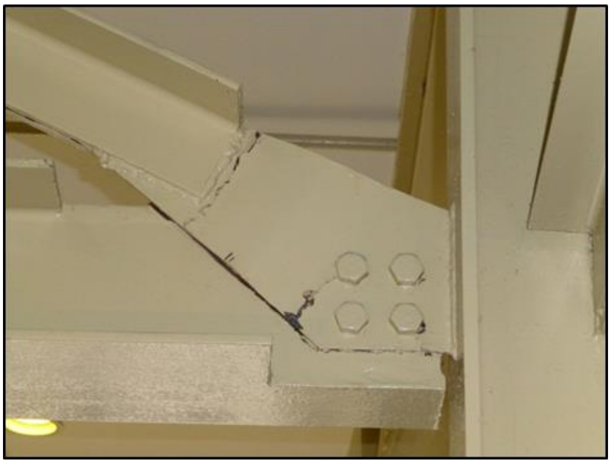
Named after the Borreo family who once owned the historic stone structure, the Italianate Renaissance Borreo Building was built in 1877 and constructed of native cut stone. The building is located across Napa River and approximately 150 m from an accelerometer site that recorded a Peak Ground Acceleration (PGA) of 0.61g. The building is located on a corner section and was purchased by the City of Napa in conjunction with a road realignment that impinged on the section where the building is located. The City of Napa decided to invest in earthquake strengthening of this historic building before reselling, with the strengthening having only recently been completed. Funding for the project was secured in 2006/2007, including a $600k contribution from CalOES. These circumstances allowed for direct viewing of the

(a) Street view of building, with diagonal bracing visible in some windows

(b) Evidence of building deformation visible in recess on building exterior



(c) Partial view of interior atrium



(d) Distress at bolted connection

(e) Evidence that brace had buckled and come into contact with window frame

(f) Distress at connection between steel framing and URM exterior wall

Figure 24: Performance of the steel bracing retrofit of the Main Street Exchange building in Napa.

installed strengthening and an assessment of the performance of the strengthening solution.

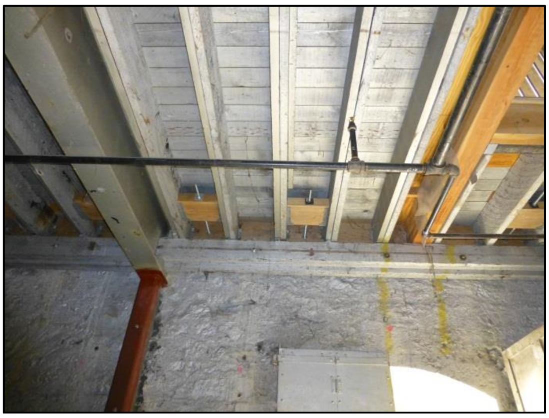
The retrofit strategy appeared to involve the following features:

- Cross-wall securing of the multi-leaf stone masonry walls using ¾ inch (19 mm) epoxy grouted anchors at regular spacings (see Figure 25 (a) and (b)), finished flush with the interior surface and extending to 3 inches (76 mm) from the exterior wall surface
- Comprehensive securing of walls to diaphragms, including horizontally-oriented timber blocking to transfer loads into the diaphragm (see Figure 25(c))
- The addition of supplementary concrete walls to strengthen the building in the transverse direction (see Figure 25(d))
- Steel framing around openings (see Figure 25(d))
- Supplementary securing of joists to walls (see Figure 25(e))
- Stiffening of timber diaphragms using horizontally-oriented steel braced frames (see Figure 25(f))

- Supplementary steel framing to transmit vertical loads to the ground (see Figure 25 (a), (c), (d)). Figure 25(a) shows steel framing that was intentionally skewed to align with roof trusses above and floor girders below

(a) Lay-out of through-wall anchors

(b) Close-up of through wall anchor

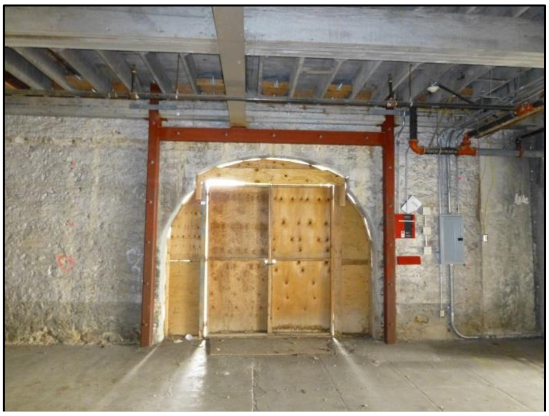


(c) Wall diaphragm anchorages with horizontally oriented timber blocking

(d) Supplementary concrete walls to provide added strength and stiffness in the transverse direction

(e) Supplemental securing of diaphragm joists

(f) Stiffening of diaphragms using steel bracing



(g) Steel framing around openings

(h) Steel framing to support vertical pier loads

Figure 25: Details of seismic strengthening used in the Borreo building.

(a) Isolated fallen stone on building exterior

(b) Loose stones above window opening

(c) Internal spandrel damage

(d) Overall appearance of building

Figure 26: Limited earthquake damage to the Borreo building.

(a) Remediation of shop frontage

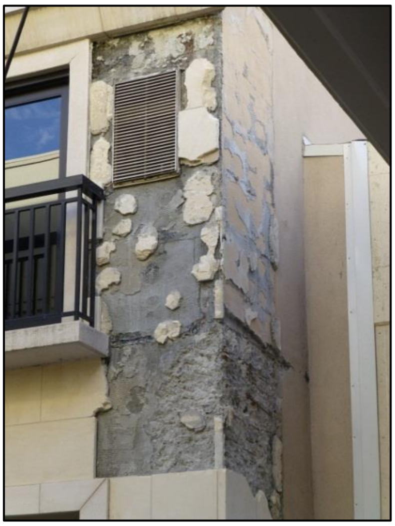
(b) Water sprinkler that was activated during earthquake

(c) Hotel furnishing covered while non-structural damage was attended to

(d) Removed floor linings due to water damage

Figure 27: Examples of non-structural damage.

(a) *Interior walls*



(b) *Loss of exterior cladding*

Figure 28: Non-structural wall damage to the Andaz Hotel.

Post-earthquake observations confirmed that despite experiencing very high ground accelerations, the building was effectively undamaged. Several discrete stones had spalled from the exterior leaf of the building on the north and south facades (see Figure 26(a), (b)), and damage had accumulated at the spandrels of the masonry framed wall that received no supplementary bracing (see Figure 26(c)). However, the overall condition of the building is shown in Figure 26(d), indicating that the strengthening appeared to have been extremely successful.

NON-STRUCTURAL COMPONENTS, RESIDENTIAL BUILDINGS AND BUSINESS INTERRUPTION

Non-Structural Damage

The authors had limited opportunity to comprehensively review non-structural damage, although several store fronts were in the process of having broken windows repaired and cosmetic improvements being made, as shown in Figure 27(a). Of particular note was the Andaz Hotel, where a fire sprinkler was activated during the earthquake and continued to cause water damage for several hours before being identified and turned off (see Figure 27(b)). This water damage resulted in extensive damage to furnishing and floor linings (see Figure 27(c), (d)).

Further non-structural damage within the Andaz Hotel was observed in the form of damage to wall linings (see Figure 28(a)) and significant loss of cladding stonework (see Figure 28(b)).

Fixtures

The performance of fixtures was of particular significance, as the one fatality from the earthquake occurred when a woman had fallen asleep in her home and was struck by a falling wall-mounted television [53]. Similarly, the authors were informed by staff of the Andaz Hotel that 48 wall-mounted televisions had fallen during the earthquake. Movable cabinets within the guest rooms were subjected to significant motions, with the scratch marks associated with one such cabinet shown in Figure 29(a). A pedestrian bridge linking a shopping complex and parking structure adjacent to the hotel exhibited pounding damage as shown in Figure 29(b).

In a complex of historic URM buildings it was observed that an exterior access staircase at the rear of one building (see Figure 30(a)) had stiffened a perpendicular wall, resulting in punching damage as shown in Figure 30(b).

(a) Scratch marks due to cabinet motion

(b) Pounding damage for a pedestrian overpass

Figure 29: Examples of damage due to relative motion.

Residential Buildings

The residential building stock in Napa typically comprises single family dwellings of timber framed construction and was observed to perform very well. The majority of residents spoken to indicated that they had no damage to their homes, although a number of damaged masonry chimneys were observed. Cripple walls are short wood stud walls that enclose a crawl space between the ground and first floor in order to elevate the dwelling above ground and allow access to utility

(a) Exterior stairs

(b) Punching of walls

Figure 30. Punching damage due to stiff staircase.

lines or to level a dwelling built on a slope. Several residential houses were observed with cripple wall failures, as typically expected from Californian building stock (Figure 31(a)). Just three weeks after the earthquake several of these cripple wall failures were already in the process of being repaired, with the houses jacked up on cribbing while the foundations were replaced (Figure 31(b)). At one such construction site the contractor advised that the replacement of the foundation wall would be complete within 3 weeks at a cost of US$50,000.

Lifelines

Lifelines performed relatively well. Water reticulation was largely restored within 10 days, with the majority of breaks being in cast iron pipes. One large water storage tank was damaged due to sloshing actions from earthquake shaking.

Camera inspections were immediately carried out of all sewer lines crossing the fault zone in order to identify the locations of likely damage. Only 11 breaks were reported in the sewerage system, with 9 of these breaks occurring across the fault trace. The biggest issue was ‘plant upset’, where flooding of the sewerage system by wine losses resulted in deactivation of the bacteria. This problem was resolved by pumping oxygen into the plant over 24 hours to reactivate the bacteria.

No damage was observed to the electricity transmission network, but 70,000 customers were affected by outages in the distribution system. 99% of these faults were restored within 26 hours.

All public roads and bridges remained open, although warnings were in place regarding travel on the roads crossing the fault zone due to the potential for damaged tyres from pavement tearing. Roads and pavements crossing the surface ruptures were typically repaired within the first few weeks. The lack of bridge damage was considered to be largely due to an extensive program of strengthening undertaken over the last 20 years, in which 54 bridges in the Napa, Sonoma and Solana Counties were retrofitted and the remainder were assessed as being not significantly vulnerable [54]. Damage was observed to two old concrete bridges, although these did not form part of the public roading network.

Insurance

Less than 6% of Napa homeowners and renters have earthquake insurance, with the state-wide average being approximately 10% [55] and the uptake for commercial property insurance understood to be similarly low (in the order of 10%). This low insurance coverage is largely due to the high annual premiums demanded for earthquake cover, and deductibles which may be in the order of 15% of the insured value [56, 57]. As such, the losses in Napa were largely uninsured. While the total economic loss is expected to approach US$1B, the insured losses are not expected to exceed US$250M [58].

(a) Cripple wall failure in Napa

(b) House foundations under repair

Figure 31: Failure and repair of house foundations in Napa.

Although this absence of earthquake insurance places a larger burden on the local community, it also gives uninsured homeowners more responsibility for their own recovery. As such, many home owners and business owners were observed to be proactively arranging for immediate repairs rather than waiting around for an insurance assessment. The lack of insurance coverage may also have affected the general attitude towards damage as the majority of home owners spoken to indicated that they had no damage whatsoever to their homes. However, it is considered likely that the shaking intensity would have at least cracked the paint of internal linings. It is therefore possible that some home owners have considered this to be non-critical damage that will disappear in the next redecoration, and therefore aren't concerned about immediate repair.

Surveys of Napa wine industry representatives indicate an almost total absence of earthquake or business interruption insurance, primarily because earthquake insurance for wineries costs about three times as much as property insurance and has a high deductible that is typically 15 percent of the total value of the property and all its contents [59]. Napa County officials estimated that the total cost of damage to wine facilities was approximately $48M whereas an independent financial assessment estimated the loss as approximately $80M, derived from damage to buildings and infrastructure such as wastewater ponds and private bridges, winemaking equipment, clean-up and removal costs, vineyard irrigation, bottled inventory in current release, bottling supplies, finished inventory ready for bottling, bulk wine, barrels, lost revenue from damaged tasting rooms, losses from business interruption and loss of wine held in wine libraries [60].

Preparedness

The local population's awareness of earthquake risk is considered to be relatively high. This awareness is partly a result of the regular earthquakes occurring in California, and in particular the 2000 Yountville event. As a result of a number of ordinances, building owners are required to strengthen buildings that are assessed as having poor earthquake performance, or notify the public of the potential danger (Figure 32).

Figure 32: Warning notice in Napa.

Anecdotal evidence from residents suggests that the 2000 Yountville earthquake caused more widespread damage than the 2014 South Napa event. However, the accelerations in the 2014 South Napa event were generally larger (particularly in the long period range), and comparison of the performance of buildings with that observed in the Yountville event [61] showed them to have suffered more damage in the recent event. As such, it is likely that a significant amount of strengthening was carried out between 2000 and 2014, and that the building stock as a whole performed substantially better as a result of this strengthening.

Business Continuity

Many local businesses were observed to have been cleaning up immediately following the earthquake, and reopened for business on the Monday. While their stocks were at times severely compromised, there was little business interruption to wineries who continued to host cellar door tours. A consistent message was broadcast to tourists to encourage them to continue to visit the region (Figure 33). There was a large political aspect to this activity, as the region relies on tourism and the wine industry.

Figure 33: Open for business.

Positive messages were observed all over town, with Napa Strong being a key theme (Figure 34(a)). This messaging has many parallels with Kia kaha (Stay strong) which became a popular phrase in Christchurch. Local businesses also engaged with their community through makeshift noticeboards erected in shop windows. Figure 34(b) shows a local business not only providing information to their customers, but also enabling their customers to leave messages of support for them.

A case study of the Mustard Seed Clothing Co. was presented by the EERI reconnaissance team for which the building had suffered only minor damage in the form of breakage of the shop front glazing, and cracking of the plaster ceilings. However, the tenant was forced to relocate while the owner took more than a week to repair the relatively minor damage. While the tenant could theoretically have carried out these works themselves, there was also some uncertainty about the hazard posed by a neighbouring building which had a red placard. It was unclear whether the Mustard Seed Clothing Co. would have been permitted to reopen if the minor damage had been fixed, due to a lack of details of who to contact at the local authority to ask such questions.

The benefits of earthquake strengthening were outlined at Downtown Joes, which is a local brewery and restaurant. The single storey, unreinforced terracotta masonry building was retrofitted in 2010. The retrofit cost approximately US$600k, and was carried out in stages to enable continued use of the building throughout. The loss of business revenue during the construction period was estimated to be US$200k but the building did not close following the 2014 Napa earthquake.

One shortfall of repairing quickly to resume business is that some repairs appeared to be ill-conceived. Figure 35 shows the internal repairs to a badly damaged unreinforced masonry building being largely complete, while the exterior walls still pose a collapse hazard.

(a) Positive messages

(b) Message board

Figure 34: Local business engagement with public support.

(a) Status of internal repairs

(b) Status of external repairs

Figure 35: 1600 Main Street.

PERFORMANCE OF WINERY FACILITIES

Background

The NZSEE team did not visit the Napa Valley wineries. As such, our comments herein are based on information obtained from the California Earthquake Clearinghouse, and discussions with EERI reconnaissance team members.

The Napa Valley wine industry largely extends northwards up the valley from Napa City. Figure 36 shows the wineries surrounding downtown Napa, and plots an approximate line delineating the extent of damage observed to barrel rack storage facilities. The earthquake occurred at approximately the least inconvenient time for the wine industry. Being just before harvest, the majority of the steel tanks were empty, as were the barrels, which is likely to have significantly limited the economic loss.

Steel Tanks

It is understood that building departments in the US typically do not require anchorage of steel storage tanks, as they may be considered as contents. Many wine industry sources were reported as believing that allowing the tanks to slide freely will result in better seismic performance. As such, the as-built condition of steel tanks varies widely, and often depends on the inclination of the facility manager.

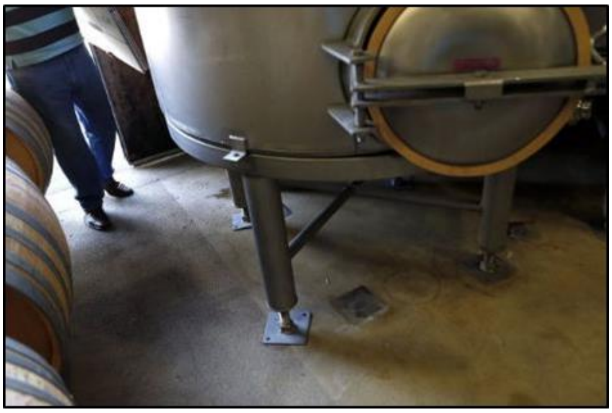
An EERI reconnaissance team observed damage to steel storage tanks, including global sliding failure (Figure 37a), anchor bolt pull-out, and elephants foot buckling of the base of the tank walls. However, failure of steel storage tanks wasn't widespread and may have been due to the fact that most tanks were empty at the time of the earthquake. Observed steel tank failures were reported to have not posed a major life safety concern.

A common issue encountered involved the provision of only nominal fixings, whereby excessive overturning forces resulted in tearing the few anchor plates from the face of the tanks with subsequent tank failure. Catwalks supported on top of rows of tanks were also susceptible to collapse due to relative movement of the supporting tanks.

Wine Barrels

Wine barrels are typically stacked in two barrel racks which were observed to perform poorly in the earthquake (Figure 37b). In one storage facility alone, 20% of their 12,000 barrels were lost, with an estimated 5-6 weeks work required to salvage the barrels. With some of the wine barrels valued in

Figure 36: Napa Valley wineries (from http://www.mappery.com/map-of/Napa-County-Wineries-California-Map).



(a) Sliding of steel tanks [63]

(b) Collapse of two barrel racks [64]

Figure 37: Wine storage failures.

the order of US$50-$100k, this represents a substantial loss.

Previous research has shown that 4 barrel racks perform significantly better than 2 barrel racks [62]. This was evidenced in the South Napa earthquake by comparison between the performances of two adjacent wineries. The first winery stored approximately 3,000 barrels on two barrel racks and lost over 1,000 barrels, whereas the second stored nearly 10,000 barrels on four-barrel racks and lost only two barrels [61].

Most wineries are currently restacking the barrels in the same manner as prior to the earthquake, due largely to the time constraints in the middle of harvest season. It was noted that high costs can be involved in changing to four barrel rack systems, due not only to the additional cost of the racks, but also to the increased forklift requirements and extra manoeuvring room required to lift the larger racks into position, and to the investment in existing barrel wash facilities which are often specific to the two barrel racks. As an alternative measure, mitigation techniques have been proposed with regards to the stacking direction of 2 barrel racks, and the provision of strong walls at the ends of barrel stacks to confine overturning in the weaker direction.

Storage Facilities

Several steel portal frame storage facilities were found to have internal columns without hold-down bolts. In one case, a wine barrel stack toppled into an internal steel column resulting in a displacement of the column supporting the roof of more than half a metre.

Poor anchorage of roof rafters to external concrete masonry walls in one storage facility resulted in the collapse of the relatively low value roof, onto the extremely high value wine barrel stacks. With wine barrels fetching up to US$50k per barrel, the roof had to be carefully deconstructed, with the wine siphoned out of each barrel before removing the barrels one at a time.

A heavy timber barn-type structure used for barrel storage at the Trefethen Winery was full with barrel stacks at ground and first floor levels. The mass of full barrels stored at first floor level resulted in a permanent lean of the building due to significant displacement of the first floor (Figure 38). This issue was also identified following the 2000 Yountville earthquake, where deformation of the first floor structure was observed to a lesser extent.

Figure 38: Timber barn at Trefethen family vineyard [65].

RESEARCH PROGRAMME

California Earthquake Clearinghouse

The California Earthquake Clearinghouse (http://www.californiaeqclearinghouse.org/) is mandated (although not funded) in Californian law as a function of the California Geological Survey (CGS). It is a collaboration between the California Geological Survey (CGS), the California Governor's Office of Emergency Services (CalOES), the California Seismic Safety Commission (CSSC), the Earthquake Engineering Research Institute (EERI) and the US Geological Survey (USGS), and was established in 1972 following the 1971 ML 6.6 San Fernando earthquake [66].

At 7 am on 24 August 2014 (approximately 3.5 hours after the main shock) a phone conference of the California Earthquake Clearinghouse management was held and a decision was made to respond to the South Napa earthquake, with EERI staff arriving in Napa County to set up the Clearinghouse by 2 pm that same afternoon. The physical clearing house was established in the maintenance facility of the California Department of Transportation (Caltrans), who also provided a satellite communications vehicle. The presence of these researchers was solely to capture lessons and to undertake research in the aftermath of the earthquake and they played no role in the city's response.

A physical clearinghouse was established in Napa on the afternoon of 24 August and in parallel a website was developed to share the data collected in the field. The role of the physical clearinghouse was to capture and share initial data between researchers in order to focus attention on the most important areas and subjects. Daily briefings were held to facilitate the coordination of data collection and were broadcast as webinars. Reconnaissance needs could be shared such that requests could be made for missing data from those planning to go into the field. Once the physical clearinghouse was dis-established on 26 August, the virtual clearinghouse continued to capture this data (http://www.eqclearinghouse.org/2014-08-24-south-napa/).

At a webinar held on 15 September 2014 (22 days after the earthquake) it was reported that the physical and virtual clearinghouses were deemed to have been very successful in facilitating collaboration and sharing of acquired data.

Data Gathering

The mobilisation of the California Earthquake Clearinghouse for the 2014 South Napa earthquake was particularly relevant as this was the first mobilisation since the 1999 Hector Mine earthquake, and in the intervening 15 years there had been significant development of new tools to assist with data collection and processing. EERI had developed a field app for geocoding of field notes as well as a geocoded photo upload tool, with USGS having developed an ArcGIS online map viewer (Figure 39). Where network coverage or mobile devices were not available, an alternative option to upload data from a desktop computer was also available from EERI. The captured data was turned into a .kmz file that can be viewed in Google Earth. As a result, the geocoded data was immediately available in the public domain across the web.

Various organisations implemented new technologies in the reconnaissance efforts. Of particular note was the use of mobile truck mounted Lidar surveys (capable of scanning a 500 m radius), the use of drones to capture aerial video and images, laser scanning and 'Structure from Motion' technology to generate 3D point cloud data beyond the capabilities of photogrammetry.

Information Sharing

Napa County took a proactive approach to publically sharing data on their placard operations. Their placard data was stored in a .kml format, which was easily imported to the virtual clearinghouse so that all data could be shared in a single file. The clearinghouse posted data in both Google Earth, and ArcGIS formats. The ArcGIS data was available in real time, but had a more limited dataset than the Google Earth files. Conversely, using the more comprehensive Google Earth data required users to download a file that is immediately static as of that time.

OBSERVATIONS AND RECOMMENDATIONS

Preparedness

California has a long history of public policy related to retrofit of unreinforced masonry buildings. However, despite a general public awareness of seismic activity, implementation of URM retrofits in Napa and Vallejo was relatively limited until the passing of mandatory URM ordinances. This highlights the need for enforcement of retrofit programmes with clearly defined timeframes.

Observations from the South Napa event indicate that California appears to be well prepared to recover from a small earthquake, noting the ability to access significant support from neighbouring communities. However, the fact that Napa was impacted in the 2000 Yountville earthquake may have played a part in this, and it would be interesting to see how another region faired in a similar event.

California maintains a large pool of volunteer SAP building assessors. Initial training is provided, with requirements to carry out online refresher training every 5 years. The deployment of registered evaluators is managed through CalOES. The system was clearly effective in that evaluators were able to be deployed with minimal training required on the day.

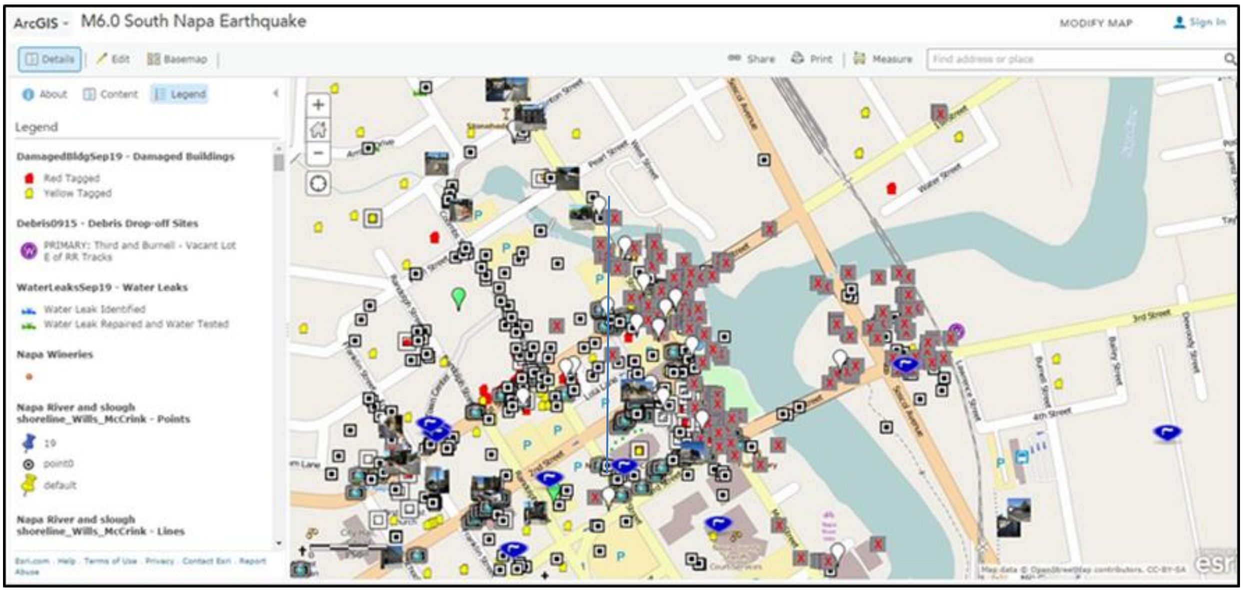


Figure 39: USGS ArcGIS online map viewer displaying collected reconnaissance data.

Rapid Building Assessment Programme

Positive interactions were achieved with ATC and FEMA teams in the field, with respect to sharing knowledge and observations of building management after earthquakes.

Placarding issues were encountered in the response to the South Napa earthquake, including the placement of multiple placards on a single building, and the posting of different placards on different entrances to the same building. A lack of a description on the placards of the damage observed, or details of the occupancy restrictions, was also common. This highlights the importance of clearly outlining the expectations of building evaluators, and providing regular briefings.

Public information provided about the meaning of the various placards was not particularly clear following the South Napa earthquake and highlights the need to prepare clear and accurate information to be disseminated following an earthquake event.

Excellent systems were observed in Napa City for recording the results of building evaluations, and for publically sharing the outcomes. Such systems require significant investment, and should be developed at a national level, rather than requiring each individual jurisdiction to develop their own systems.

Barricading and Shoring

Despite the recent publication of barricading guidelines by CalBO [39], the implementation of barricading following the South Napa earthquake was overly optimistic and drew parallels to the response to the 2010 Darfield earthquake. The absence of any aftershock activity may have contributed to this relaxed attitude to barricading. Evaluation teams should be briefed on setting safe distances for barricades, with a conservative approach taken for the initial rapid evaluations. As more details become known with time, these barricades can be progressively moved back where justified.

Very little temporary shoring was carried out following the South Napa earthquake, but the shoring that was implemented was considered to be relatively ineffective. Scaffolding providing inadequate fall protection and poorly conceived timber shoring was observed. These efforts reflected those observed in Christchurch and highlight the need to develop guidance for temporary shoring methods. Significant guidance already exists in the Urban Search and Rescue space, and the publication of this along with other concepts recently developed for securing of URM facades would be a valuable resource.

Perhaps the most distinguishing difference between the response to the 2014 South Napa earthquake when compared to the response to the Canterbury earthquakes was associated with the absence of aftershock activity in Napa and therefore the apparent lack of attention to best-practice barricading and shoring, plus the general attitude of the public. This lack of aftershock activity led to many businesses in Napa continuing to provide their services directly after the earthquake, and members of the public being largely unaware of the potential hazard associated with occupying or being in close proximity to partly damaged buildings that had not received the level of inspection and barricading that most probably would have occurred if authorities and the public were more alert to the possibility of aftershock activity.

URM Performance

URM buildings in Napa were subjected to significant ground shaking and as a whole performed exceptionally well. This excellent response is believed to be largely due to the presence of heavy bolting of external walls to horizontal diaphragms to prevent out-of-plane façade failures, plus possible hazard reduction efforts (most notably associated with parapets) that may have occurred in conjunction with past earthquake activity in the region spanning back over a century. Failure of masonry chimneys was responsible for the greatest number of injuries, and the loss of individual bricks from a number of buildings emphasised the difficulty of securing all masonry units during an earthquake. The Pfeiffer building had not received comprehensive bolting and was one building where out-of-plane façade failure was observed.

Instituted retrofits generally performed very well, with several cases of recommended best-practice having resulted in the building being returned to immediately occupancy after the earthquake (recalling the absence of aftershock activity). Observed examples of current best-practice included internal pinning to the exterior façade of multi-wythe stone masonry walls, the use of supplementary steel framing and supplementary concrete walls to provide vertical load paths and added lateral stiffness, effective detailing of wall-diaphragm anchorages, and stiffening of timber floor and roof diaphragms. There was one observed case where a steel frame retrofit used section sizes that were insufficient to prevent buckling of diagonal braces, resulting in distinct lateral deformation of the URM façade.

Business Continuity

The South Napa earthquake could be described as a 'routine' earthquake, in that the damage was limited to the extent that the focus was on maintaining business as usual. This brings interesting political pressures to play, whereby the balance of safety with continuity can lead to interesting results.

A lack of insurance cover was observed to result in extremely rapid repairs, where building owners could afford to carry these out themselves rather than waiting for insurance assessors and full scopes to be prepared. However, hurried repairs can be poorly conceived, and this is a risk with rushing into a recovery.

Strong messages of community support were evident in Napa, and a consistent message to tourists was important to maintain the winery industry. Due to the timing of the earthquake just before harvest, the impact on the winery industry was much less significant than it could have been, although it showed up significant weaknesses in the current barrel storage racks widely used throughout the region.

Reconnaissance Efforts

The research communities in California have developed strong relationships and systems for carrying out reconnaissance following a significant disaster. New Zealand can learn much from the collaborative reconnaissance effort, and should continue discussions with these organisations with regards to utilising some of the tools that the California research community has developed for future events.

LESSONS FOR FUTURE LFE MISSIONS

Considerations for Future LFE Missions to California

Local contacts in California are likely to be widely spread, such as:

- Most State Government officials (CalOES, CSSC, OSHPD, etc) are based in Sacramento.
- EERI is based in Oakland, but does not have facilities for large briefings (they typically use UC Berkeley).
- Many consulting engineers are based in San Francisco (or Los Angeles).
- Other people of interest for our mission were based in the wider Bay Area, including Concord (CalOES), Newark (RMS), and others.
- The team will also want to visit the regions worst affected by the shaking.

As such, any LFE mission to California will need to be mobile, and may need to travel to meet with people of interest.

Access to building plans in California is relatively difficult, as approval is required from both the building owner and the engineer of record (due to copyright restrictions). The public are typically allowed to view plans and specifications, but are not allowed to copy or photograph these documents without this permission. Coordination with local organisations will likely be required in order to gain access to building plans, and a substantial delay should be expected before these documents become available.

Selection of Accommodation

Some thought should be given to choosing safe accommodation for the team. This was an issue in Padang, and ironically, the accommodation in Berkeley was deemed to be a 'soft storey' building although the reality was much different (see Figure 40). As such, selecting single storey motel-style accommodation is recommended, given that having reliable information on the seismic performance of potential hotels is unlikely.

(a) Warning sign

(b) Photo of the building

Figure 40: Team accommodation in Berkeley.

EPILOGUE

At the time of print much of the data derived from the Napa earthquake is still being processed. On 8 October 2014 California's Alfred E. Alquist Seismic Safety Commission held hearings in Napa to gather input from public officials and members of the public on the impacts and lessons learned from the Napa earthquake, with the intent that information presented at the hearing will be used to make policy recommendations to reduce losses in future earthquakes [67]. For the 2014 fiscal year the Applied Technology Council has a special project underway to investigate the impacts of the Napa earthquake [68], with a web site having been pre-selected for the eventual hosting of the report [69]. ASCE 41 is the US standard for Seismic Evaluation and Retrofit of Existing Buildings [70], with the updating of the chapter associated with masonry being chaired by Fred Turner and Vice-Chaired by Bill Tremayne. The ASCE-41 Masonry Team are tracking the ATC special project, with the authors continuing to have a close working relationship with Turner, Tremayne and others participating in this process.

Upon return from the earthquake affected area the authors made a public presentation in Auckland on 10 November 2014 that was recorded and can be accessed at: http://www.nzsee.org.nz/napa-lfe-seminar-recording-now-available-online/

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REFERENCES

1 MBIE (2014). "*Field Guide: Rapid Post-Disaster Building Usability Assessment – Earthquake*". www.dbh.govt.nz/UserFiles/File/Publications/Building/pdbm/earthquake-field-guide.pdf. Accessed 2 February 2015.

2 Applied Technology Council. "*Post-Earthquake Damage and Safety Evaluation of Buildings*". https://www.atcouncil.org/component/mijoshop/category/12-postearthquake-damage-and-safety-evaluation-of-buildings. Accessed 30 October 2014.

3 Wikipedia. "*Napa, California*". http://en.wikipedia.org/wiki/Napa,_California. Accessed 16 September 2014.

4 United Stated Census Bureau. "*Napa (City), California*". http://quickfacts.census.gov/qfd/states/06/0650258.html. Accessed 2 February 2015.

5 United Stated Census Bureau. "*American Canyon (City), California*". http://quickfacts.census.gov/qfd/states/06/0601640.html. Accessed 2 February 2015.

6 Wikipedia. "*American Canyon, California*". http://en.wikipedia.org/wiki/American_Canyon,_California. Accessed 16 September 2014.

7 United Stated Census Bureau. "*Vallejo (City), California*". http://quickfacts.census.gov/qfd/states/06/0681666.html. Accessed 2 February 2015.

8 Wikipedia. "*Vallejo, California*". http://en.wikipedia.org/wiki/Vallejo,_California. Accessed 16 September 2014.

9 Wikipedia. "*Mare Island*". http://en.wikipedia.org/wiki/Mare_Island. Accessed 16 September 2014.

10 City of Napa. "*The History of Napa*". http://www.cityofnapa.org/index.php?Itemid=300. Accessed 18 September 2014.

11 Calbricks. '*California Bricks*'. http://calbricks.netfirms.com/brick.jordanmare.html. Accessed 18 September 2014.

12 USGS. "*Historic Earthquakes*". http://earthquake.usgs.gov/earthquakes/states/events/1898_03_31.php. Accessed 18 September 2014.

13 Vallejo Museum. "*The Great Earthquake of 1906*". http://vallejomuseum.blogspot.com/2008/04/great-earthquake-of-1906.html. Accessed 18 September 2014.

14 Napa Valley Register. "*1906: The Day the Earth Trembled in Napa*". http://napavalleyregister.com/news/local/the-day-the-earth-trembled-in-napa/article_8e5993fc-390a-11e3-8c73-0019bb2963f4.htm. Accessed 18 September 2014.

15 Wikipedia. "*2000 Yountville Earthquake*". http://en.wikipedia.org/wiki/2000_Yountville_earthquake. Accessed 18 September 2014.

16 California Legislature (1986). "*The URM Law*". Section 8875 *et. seq.*, Government Code, California Statutes of 1986.

17 California Seismic safety Commission (2000). "*Status of the Unreinforced Masonry Building Law*". 2000 Biennial Report to the Legislature. http://www.seismic.ca.gov/pub/CSSC_2000-02.pdf. Accessed 18 September 2014.

18 City of Vallejo (1990). "*Vallejo Municipal Code Chapter 12.07: Seismic Hazard Identification and Mitigation Program for Unreinforced Masonry Buildings*". https://www.municode.com/library/ca/vallejo/codes/code_of_ordinances?nodeId=TIT12BUCO_CH12.07SEHAIDMIPRUNMABU_12.07.010FIDE. Accessed 30 October 2014.

19 Hoover CA (1992). "*Seismic Retrofit Policies: An Evaluation of Local Practices in Zone 4 and their Application to Zone 3*". http://nisee.berkeley.edu/documents/elib/www//documents/201205/hoover-retrofit-policy.pdf. Accessed 2 February 2015.

20 California Seismic Safety Commission (2003). "*Report to the Legislature - Status of the Unreinforced Masonry Building Law*". http://www.seismic.ca.gov/pub.html. Accessed 30 October 2014.

21 City of Napa (2006). '*Napa Municipal Code Chapter 15.110: Review, Rehabilitation and Abatement of Existing Seismically Unsafe Buildings*". http://qcode.us/codes/napa/view.php?topic=15-15_110&frames=on. Accessed 30 October 2014.

22 Paxton B, Turner F, Elwood K and Ingham JM (2015). "URM Bearing Wall Building Seismic Risk Mitigation on the West Coast of the United States: A Review of Policies and Practices", *Bulletin of the NZ Society for Earthquake Engineering*, **48**(1): 31-40.

23 Petaluma360.com. "*Fault Suspected in Napa County Quake Fairly Obscure*". http://www.petaluma360.com/news/2581318-181/fault-suspected-in-napa-county. Accessed 16 September 2014.

24 Wikipedia. "*2014 South Napa Earthquake*". http://en.wikipedia.org/wiki/2014_South_Napa_earthquake. Accessed 16 September 2014.

25 Wesling JR and Hanson KL (2008). "*Mapping of the West Napa Fault Zone for Input into the Northern California Quaternary Fault Database*". http://earthquake.usgs.gov/research/external/reports/05HQAG0002.pdf. Accessed 30 October 2014.

26 Cao T, Bryant WA, Rowshandel B, Branum D and Wills CJ (2003). "*The Revised 2002 California Probabilistic Seismic Hazard Maps*". California Geological Survey, http://www.consrv.ca.gov/CGS/rghm/psha/fault_parameters/pdf/2002_CA_Hazard_Maps.pdf. Accessed 30 October 2014.

27 Geotechnical Extreme Events Reconnaissance (2014). "*August 24, 2014 South Napa, California Earthquake*". Report No. GEER-037, http://www.geerassociation.org/GEER_Post%20EQ%20Reports/SouthNapa_2014/index.html Accessed 30 October 2014.

28 Sowers JM, Noller JS and Lettis WR (1998). "*Quaternary Geology and Liquefaction Susceptibility, Napa, California, 1:100,000 Quadrangle: A Digital Database*". US Geological Survey, Open File Report 98-460.

29 Knudson K, Sowers J, Witter R, Wentworth C and Helley E (2000). "*Preliminary Maps of Quaternary Deposits and Liquefaction Susceptibility, Nine-County San Francisco Bay Region, California*". US Geological Survey Open file Report 00-444, V. 1.0.

30 Eidinger J (2014). "*South Napa M 6.0 Earthquake of August 24, 2014*". ASCE TCLEE Preliminary Reconnaissance Report, http://cms.asce.org/uploadedFiles/Technical_Groups_and_Institutes/TCLEE/NAPA 2014 ASCE Final.pdf. Accessed 30 October 2014.

31 Levs J, Capelouto S and Berlinger J (2014). "*Northern California Earthquake is Area's Strongest in 25 Years*". http://www.cnn.com/2014/08/24/us/california-earthquake/, Accessed 30 October 2014.

32 Brown C (2014). "*Water Main Break Hindered Firefight Following Napa Quake*". http://sacramento.cbslocal.com/2014/08/24/water-main-break-complicated-firefight-following-napa-quake/. Accessed 31 October 2014.

33 Techel J and Ghilarducci M (2014). "*2014 South Napa Earthquake Individual Assistance Supplemental Information*". www.countyofnapa.org/Individualassistance/. Accessed 31 October 2014.

34 Office of Governor Edmond G. Brown Jr. (2014). "*Governor Brown Declares State of Emergency for South Napa Earthquake*". http://gov.ca.gov/news.php?id=18664. Accessed 30 October 2014.

35 Cal OES. "*Safety Assessment Program (SAP)*". http://www.calema.ca.gov/recovery/pages/safety-assessment.aspx. Accessed 30 October 2014.

36 FEMA (2014). "*President Declares Disaster for California*". http://www.fema.gov/news-release/2014/09/11/president-declares-disaster-california. Assessed 30 October 2014.

37 Wikipedia. "*Good Samaritan Law*". http://en.wikipedia.org/wiki/Good_Samaritan_law . Assessed 30 October 2014.

38 City of Vallejo (2007). "*Vallejo Municipal Code Chapter 12.05: Placards Used to Denote Conditions Related to Continued Occupancy of Buildings*". https://www.municode.com/library/ca/vallejo/codes/code_of_ordinances?nodeId=TIT12BUCO_CH12.052PLUSDECORECOOCBU_12.05.01IN. Accessed 30 October 2014.

39 Turner F (2013). "*CalBO's Interim Guidance for Barricading, Cordoning, Emergency Evaluation and Stabilization of Buildings with Substantial Damage in Disasters*". http://www.calbo.org/uploads/CALBOABMBarricadingEmergencyEvaluationandStabilizationofDamagedBuildings.pdf. Accessed 30 October 2014.

40 Russell AP and Ingham JM (2010). "Prevalence of New Zealand's Unreinforced Masonry Buildings". *Bulletin of the New Zealand Society for Earthquake Engineering*, **43**(3): 182-201.

41 Wikipedia. "*Field Act*". http://en.wikipedia.org/wiki/Field_Act. Accessed 18 September 2014.

42 Turner F (2014). *Personal Communication*. 29 October 2014.

43 CBS (2014). "*Teen Crushed by Collapsed Chimney in Napa Earthquake Recovering at UC Davis Hospital*". http://sanfrancisco.cbslocal.com/2014/08/25/teen-crushed-by-collapsed-chimney-in-napa-earthquake-recovering-at-uc-davis-hospital/. Accessed 18 September 2014.

44 California Building Standards Commission (2013). "*2013 California Building Code. Appendix Chapter A1– Seismic Strengthening Provisions for Unreinforced Masonry Bearing Wall Buildings*". http://www.ecodes.biz/ecodes_support/free_resources/2013California/13Building/PDFs/Appendix%20Chapter%20A1%20-%20Seismic%20Strengthening%20Provisions.pdf. Accessed 3 February 2015.

45 The City and County of San Francisco (2007). "*2007 San Francisco Building Code, Chapter 16C: Seismic Strengthening Provisions for Unreinforced Masonry Bearing Walls Buildings*".

46 California Seismic Safety Commission. "*Failure of Wall Anchors during Earthquakes*". http://www.earthquakecountry.org/core/public/showcontext.php/2558/13550. Accessed 3 February 2015.

47 Wikipedia. "*Sam Kee Laundry Building*". http://en.wikipedia.org/wiki/Sam_Kee_Laundry_Building. Accessed 31 October 2014.

48 Napa Valley Register (2010). "*May Howard's Brothel in the Sam Kee Laundry Building*". http://napavalleyregister.com/may-howard-s-brothel-in-the-sam-kee-laundry-building/image_7064d1e0-347c-11df-91b5-001cc4c002e0.html. Accessed 18 September 2014.

49 Synopsis Today (2014). "*Quake-Hit Napa Starts Putting Things Back Together*". http://www.synopsis.today/news-special-reports/quake-hit-napa-starts-putting-things-back-together/. Accessed 18 September 2014.

50 Wikipedia (2014). "*US Post Office (Napa, California)*". http://en.wikipedia.org/wiki/U.S._Post_Office_(Napa,_California). Accessed 31 October 2014.

51 Miranda E and Aslani H (2000). "*Brief Report on the September 3, 2000 Yountville/Napa, California Earthquake*". Pacific Earthquake Engineering Research (PEER), http://peer.berkeley.edu/publications/yountville-napa_sep-2000.html. Accessed 16 September 2014.

52 Tremayne B (2014). *Personal Communication.* 30 October 2014.

53 Ho V (2014). "*Woman Hit on Head by TV is 1st Napa Earthquake Death*". http://www.sfgate.com/bayarea/article/Woman-hit-by-TV-is-first-Napa-earthquake-death-5746343.php. Accessed 3 February 2015.

54 Caltrans (2014). "*Post-Earthquake Investigation Team Report for the August 24, 2014 South Napa Earthquake*". http://www.dot.ca.gov/hq/esc/earthquake_engineering/damage_report/SouthNapaEQ-PEQITReport.pdf. Accessed 31 October 2014.

55 California Earthquake Authority (2014). "*CEA Policyholders Already Submitting Claims for Damage to Homes from American Canyon Earthquake*". http://www.earthquakeauthority.com/UserFiles/File/Release/American%20Canyon%20Earthquake%20Release%20Aug%2024%202014.pdf. Accessed 31 October 2014.

56 Abkowitz A (2014). "*Why 8 Out of 9 Californians Don't Buy Earthquake Insurance*". http://www.businessweek.com/articles/2014-08-25/88-percent-of-californians-dont-have-earthquake-insurance. Accessed 31 October 2014.

57 O'Conner L (2014). "*More Than 90 Percent of Napa Residents Don't Have Earthquake Insurance: Report*". http://www.huffingtonpost.com/2014/08/25/napa-earthquake-insurance_n_5710739.html. Accessed 31 October 2014.

58 RMS (2014). "*RMS Estimates Insured Losses from the South Napa, California Earthquake Will Not Exceed $250 Million*". http://www.rms.com/about/newsroom/press-releases/press-detail/2014-09-02/rms-estimates-insured-losses-from-the-south-napa-california-earthquake-will-not-exceed-250-million. Accessed 31 October 2014.

59 Stein J (2014). "*A Quake Reminds Napa Winemakers of California's Faults*". http://www.businessweek.com/articles/2014-08-28/napa-winemakers-forgo-quake-insurance-face-cleanup-costs. Assessed 31 October 2014.

60 Franson P (2014). "*Financial Impact of Napa Quake Rising*". http://www.winesandvines.com/template.cfm?section=news&content=138673. Accessed 31 October 2014.

61 McDonald C (2014). "*Avoiding a Tragic Wine Crush: Seismic Expert Urges Safer Barrel-Stacking Method*". http://alumni.berkeley.edu/california-magazine/just-in/2014-09-10/avoiding-tragic-wine-crush-seismic-expert-urges-safer-barrel. Accessed 29 September 2014.

62 Marrow J (2002). "Experimental Studies on the Earthquake Performance of Wine Barrel Stacks". *Proceedings of the EERI 7th National Conference on Earthquake Engineering*, Boston, Massachusetts, USA.

63 Bonné J (2014). "*Winemakers Evaluate Napa Earthquake Damage*". http://www.sfgate.com/bayarea/article/Winemakers-evaluate-Napa-earthquake-damage-5708999.php#photo-6767334. Accessed 2 November 2014.

64 Puckette M (2014). "*Earthquake Proof Your Wine*". http://winefolly.com/update/earthquake-proof-wine/. Accessed 2 November 2014.

65 Swindell B (2014). "*Quake Damages Historic Napa Winery Building*". http://www.pressdemocrat.com/business/2594322-181/quake-damages-historic-napa-winery. Accessed 2 November 2014.

66 California Earthquake Clearing House (2009). "*California Post-Earthquake Information Clearinghouse: Draft Operating Plan*". http://www.californiaeqclearinghouse.org/wp-content/uploads/2009/06/chplan090324.pdf. Accessed 18 September 2014.

67 Alfred E. Alquist Seismic Safety Commission (2014). "*Impacts and Lessons Learned from the South Napa Earthquake*". http://www.seismic.ca.gov/minutes/2014_1008_Agenda.pdf. Accessed 11 February 2015.

68 Applied Technology Council (2014). "*National Earthquake Technical Assistance Program (NETAP) Fiscal Year 2014*". https://www.atcouncil.org/36-projects/projects/258-atc-66-6-netap. Accessed 11 February 2015.

69 Applied Technology Council (2014). "*FEMA P-1024, South Napa Earthquake Mitigation Report*". https://www.atcouncil.org/images/FEMAP1024Cover.pdf. Accessed 11 February 2015.

70 ASCE 41 (2013). "*Seismic Evaluation and Retrofit of Existing Buildings*". http://dx.doi.org/10.1061/9780784412855. Assessed 11 February 2015.