

EERI Special Earthquake Report

M 6.0 South Napa Earthquake of August 24, 2014



This report describes the findings of members of the Earthquake Engineering Research Institute (EERI) and their colleagues who conducted reconnaissance through the California Earthquake Clearinghouse. The California Earthquake Clearinghouse is managed by the California Geological Survey (CGS), EERI, the United States Geological Survey (USGS), the California Office of Emergency Services (CalOES), and the California Seismic Safety Commission (CSSC). Many other organizations participated in reconnaissance activities including, Geotechnical Extreme Events Reconnaissance (GEER) Association; Pacific Earthquake Engineering Research Center (PEER); California Department of Transportation (Caltrans); the American Society of Civil Engineers' Technical Council on Lifeline Earthquake Engineering (TCLEE); and the Structural Engineers Association of California's Post-Disaster Performance Observation Committee. The EERI Reconnaissance Leader, Marko Schotanus, coordinated reconnaissance efforts and

led the development of this summary report as well as the EERI briefing (hosted jointly with PEER). The following members served as Disciplinary Leads to coordinate the compilation of observations in their topic area for both the briefing and this report: Ibrahim Almufti, Andre Barbosa, Jonathan Bray, Timothy Dawson, Joshua Marrow, Mike Mieler, Charles Scawthorn, and Mark Yashinsky. Each of the leads worked together with numerous other reconnaissance volunteers to incorporate a broad spectrum of observations. Though this report intends to be comprehensive, it is not exhaustive.

EERI's coordinating role as a part of the California Earthquake Clearinghouse was made possible by funding from FEMA. This report is published as part of EERI's Learning from Earthquakes Program.

Introduction

The Mw 6.0 South Napa earthquake struck at 3:20 am (PDT) on August 24, 2014, just north of San Francisco,

California. The cities of Napa, American Canyon, and Vallejo are located in the area of strongest ground shaking, and had the most damage. Figure 1 shows the epicentral area of the earthquake, with MMI shaking intensities overlaid on population density. The total population within MMI VI is estimated to have been about 200,000, with approximately 36,000 subjected to shaking at the level of MMI VIII (Table 1).

≥ MMI	Population
VI	199,000
VII	90,000
VIII	36,000

Table 1. Estimated population with MMI isoseismals (source: Charles Scawthorn, published sources).

One fatality and approximately 200 injuries were attributed to the earthquake; many more minor injuries were caused by cleanup activities. The number of severe injuries and fatalities would have been much higher had the earthquake struck during the day. Fallen debris from collapsed walls and façades, and toppled heavy building content did pose life safety risks.

Much of the fault rupture extended to the ground surface, and it crossed through the western neighborhoods of Napa, causing damage to streets, sidewalks and houses. The event also caused strong ground shaking, in some locations exceeding design ground motions.

There was significant damage to lifelines and structures, and disruption to businesses. Damage to lifelines consisted mainly of pipe breaks, and there was generally

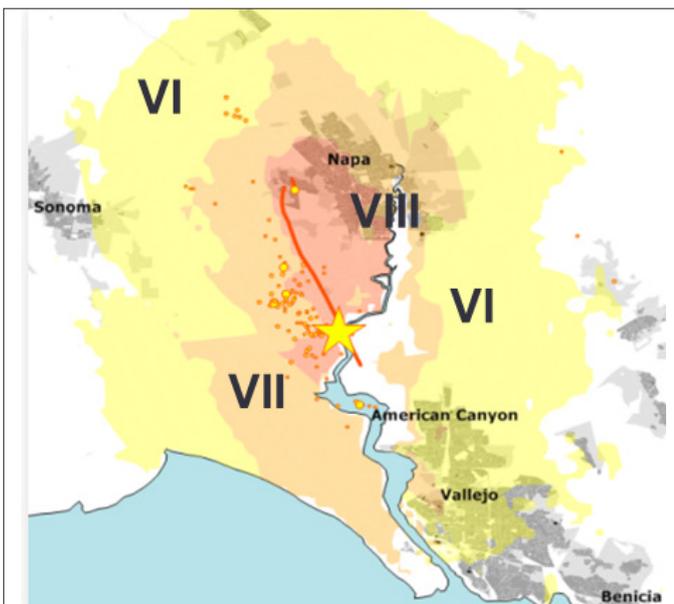


Figure 1. Epicentral area of South Napa earthquake, showing location of fault rupture and after-shocks, and MMI intensities overlaid on population density (source: Charles Scawthorn, SPA Risk).

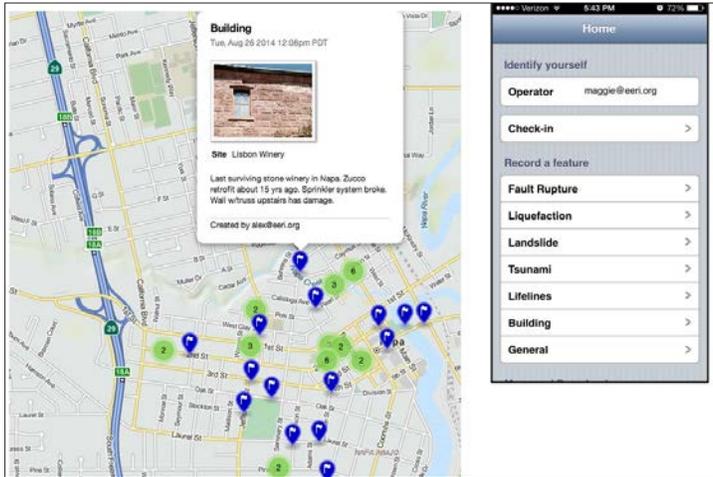


Figure 2. Clearinghouse Field-notes Tool map interface and data collection screen (source: EERI).

scientific and engineering communities with agencies and organizations responsible for emergency response and recovery so that their findings can inform the response and recovery efforts. During its three days of operation, over 100 experts visited the clearinghouse location and participated in reconnaissance activities. Their expertise spanned many disciplines: geosciences, geotechnical engineering, structural engineering, nonstructural components, insurance, lifelines, transportation, government, risk analysis, and business continuity. They represented over 40 organizations.

This was the first California earthquake with a magnitude and damage sufficient to trigger the establishment of a clearinghouse since the 1994 Northridge earthquake. However, in the intervening years, regular exercises and activities of the California Earthquake Clearinghouse managing partners allowed for the establishment of a timely, relevant response that utilized modern approaches to data collection, visualization and sharing. This is the first earthquake in California where data were collected and displayed in near-real time through the clearinghouse, and where many layers of data, collected by different individuals and organizations, were all accessible through one data viewer. Essentially a breakthrough in terms

only limited loss of service. Severe structural damage was mostly limited to older wood-frame houses and unreinforced masonry buildings with known vulnerabilities. Non-structural damage was more widespread, and included a few large engineered buildings of the last decade in downtown Napa. Non-structural damage was the primary cause of business interruption.

In the following sections, the authors who contributed to each section are listed at the start of each disciplinary topic area. Complete acknowledgements for each section are summarized at the end of the document.

Clearinghouse Operations

(Heidi Tremayne, EERI; Maggie Ortiz, EERI; Alex Julius, EERI; Marjorie Greene, EERI; Anne Rosinski, California Geological Survey; Luke Blair, U.S. Geological Survey; Fred Turner, California Seismic Safety Commission)

After a major earthquake in California, the California Geological Survey (CGS) is mandated to establish a clearinghouse, along with its managing partners, EERI, the United States Geological Survey (USGS), the California Office of Emergency Services (CalOES), and the California Seismic Safety Commission (CSSC). Within four hours of the South Napa

earthquake, the California Earthquake Clearinghouse was activated and a physical clearinghouse location was operational by 3:00 pm on August 24. The CGS serves as the lead organization and provides all coordination for state resources required for clearinghouse activation. The clearinghouse was located at the Caltrans Maintenance Facility on Jefferson Street in Napa, with a Caltrans mobile satellite communications truck providing phone and internet connectivity. The physical clearinghouse was operational from Sunday August 24 through Tuesday August 26.

The purpose of the California Earthquake Clearinghouse is twofold: (1) it allows all agencies in the field to coordinate reconnaissance efforts, administer access to restricted areas, share findings, and make plans for teams in the field each day; and (2) it links the



Figure 3. Clearinghouse online multi-disciplinary data map, managed by EERI, as captured on September 6, 2014 (source: EERI).

of managing field observations, the gains made during the Napa event will inform scientific and engineering data collection and analysis in future events.

A key element to the response was the establishment of a virtual clearinghouse website at <http://www.eqclearinghouse.org/2014-08-24-south-napa/> to record scientific and engineering observations, photos and data from the earthquake (Clearinghouse, 2014). This website hosted notifications about reconnaissance efforts, instructions and links to data collection and visualization tools, links to media reports, and preliminary reports by scientific/engineering experts as they became available.

EERI members and expert visitors were encouraged to use a suite of data collection tools, developed in support of the California Earthquake Clearinghouse:

1. Clearinghouse Fieldnotes Tool for geo-tagged photos is a web-app developed by Scott Haefner and Luke Blair of USGS for field data collection and photo documentation using a web-enabled phone (Figure 2). This tool has an easy-to-use interface that allows users to enter a field observation using one of several simple forms and attach a relevant photo (Haefner and Blair, 2014). See <http://bayquakealliance.org/fieldnotes/>

2. EERI Photo Upload Tool for non-geotagged photos is ideal for post-processing photos from a desktop upon return from the field. This tool has an easy point-and-click map interface that allows users to upload photos, observations, and reports at any clicked upon map location or typed-in address. See <http://www.eqclearinghouse.org/map/?eventid=29>

3. EERI Batch Photo Upload Tool for geotagged photos is ideal for post-processing and annotating large numbers of photos from a desktop upon return from the field. This is a .jar application that can quickly add annotation and meta-data to photos including photographer name, type of observation, date of acquisition, and caption text.

Data from these tools and other geo-located data submitted by many experts, was visualized via an online multidisciplinary data map (<http://bit.ly/1smi6so>), shown in Figure 3. Each of the tools described allows upload of image and pdf files, and live updates to the visualization map. Otherwise experts could also submit KMZ or KML data layers that were uploaded to the visualization map by EERI staff. The backend database that hosts these data, along with the visualization map and virtual clearinghouse website, will serve as an ongoing and longterm repository and archive for scientific and engineering observations and reports from the earthquake.

The California Earthquake Clearinghouse for the South Napa earthquake had several important accomplishments:

- Field team coordination was supported by EERI staff who operated from the clearinghouse location to link disparate volunteers and experts conducting reconnaissance in the field.
- Nightly briefings were held at the clearinghouse location and webcast so that reconnaissance teams and volunteers could share synthesized daily findings with the research community, the State Emergency Operations Center, the Regional Emergency Operations Center, and FEMA Region 9.

- The clearinghouse helped the earthquake community make notable progress towards coordinated, longitudinal data archiving of earthquake damage observations by encouraging data sharing and collaboration among the scientific/engineering communities, avoiding duplication of field efforts, and providing the data collection and visualization tools that facilitate sharing.
- With support of the California Highway Patrol, multiple overflights were flown with clearinghouse experts onboard to acquire high-resolution aerial imagery on Sunday and Monday.
- The Clearinghouse Chair, Anne Rosinski, coordinated a coalition of USGS, CGS, Department of Water Resources (DWR), Pacific Earthquake Engineering Research Center (PEER), and Geotechnical Extreme Events Reconnaissance (GEER) to acquire LiDAR high-accuracy imagery in the most critical areas.

Many lessons from this California Earthquake Clearinghouse activation will influence and enhance the response to future earthquakes. Notably, improved communications, training, and advanced coordination are needed to encourage additional organizations and experts to participate more fully in reconnaissance activities. Further improvements are needed in the robustness of the data collection tools and the functionality of visualization tools. The California Earthquake Clearinghouse managing partners are preparing an After-Action Report that will more completely outline lessons and recommendations for future activations.

The following sections of this EERI Special Earthquake Report reflect the collaborative reconnaissance observations, findings, and outcomes facilitated by the California Earthquake Clearinghouse.

Geosciences

(Timothy Dawson, California Geological Survey; Keith Kelson, U.S. Army Corps of Engineers; Ken Hudnut, U.S. Geological Survey; Dan Ponti, U.S. Geological Survey; John Wesling, State of California Office of Mine Reclamation; Bill Barnhart, U.S. Geological Survey)

Tectonic Setting. The earthquake ruptured the ground surface along several strands of the West Napa fault zone, a 43-km-long zone of discontinuous faulting (Bryant, 2000). The West Napa fault is part of the system of northwest-trending faults in the San Francisco Bay



Figure 4. Active faults in the San Francisco Bay Area. Red lines are faults with previously observed historical surface ruptures or that are actively creeping, orange lines are faults with Holocene activity; green lines are faults active in the Late Quaternary, and purple lines are faults active in the Quaternary. Base map from ESRI, fault traces from USGS Quaternary Fault and Fold Database (source: Timothy Dawson).

region that accommodates approximately 40 mm/yr of dextral shear (Figure 4). The fault has been the subject of several studies that have examined evidence for recency of activity (Bryant, 1982; Wesling and Hanson, 2008; Clahan et al., 2010; Rubin and Dawson, in progress). The fault zone displays evidence of Holocene activity in the American Canyon area (Bryant, 1982; Wesling and Hanson, 2008), and reported Holocene activity along portions of

the fault in the Napa area (Wesling and Hanson, 2008; Clahan et al., 2010). Geomorphic expression has been used to estimate a slip rate of ~1 mm/yr, and geodetic models estimate slip rates ranging from 1 mm/yr to as much as 4.5 mm/yr (Field et al., 2013). The recurrence and timing of past surface rupturing earthquakes is unresolved due to an absence of quality paleoseismic sites.

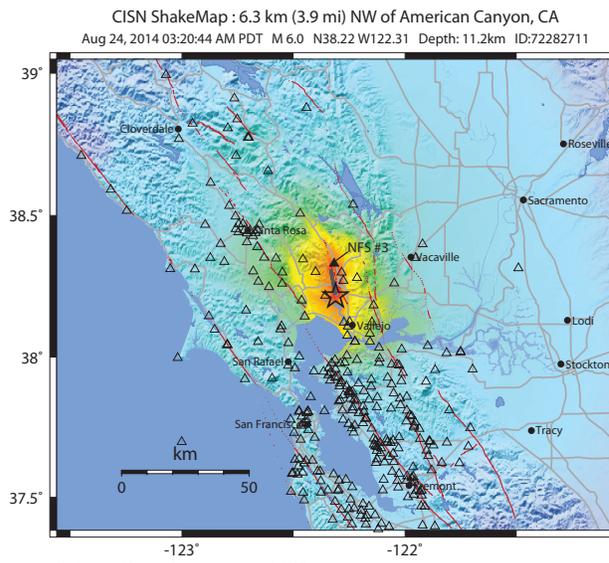


Figure 5. ShakeMap showing instrumental intensity data recorded by the California Integrated Seismic Network (CISN). (source: USGS, 2014b)

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.1	0.5	2.4	6.7	13	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	11	22	43	83	>160
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al., 1999

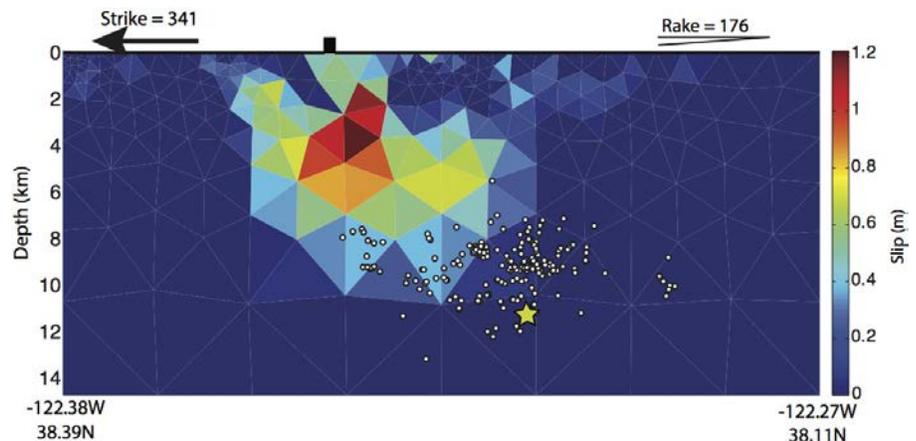


Figure 6. Finite fault model from joint inversion of seismological waveform data, geodesy, and InSAR estimated surface displacements. Yellow star is earthquake hypocenter, dots are relocated aftershocks, black rectangle at surface is location of maximum slip recorded at surface, which is coincident with peak modeled slip at depth. Note that aftershocks are clustered in the southern part of the rupture (source: USGS 2014a).

Seismology. The earthquake was recorded by the relatively dense network of seismographs in the region, which resolved the hypocenter to be near the Cuttings Wharf area at a depth of 11.3 km. The moment tensor solution is consistent with right-



Figure 7. Map showing location of observed and inferred South Napa Earthquake fault rupture. Image base from Google Earth (source: Dawson et al., 2014).

lateral slip on a northwest-trending, steeply west-dipping fault plane, and an estimated magnitude of Mw 6.0 (USGS, 2014a). Strong shaking was recorded throughout the Napa Valley region, with a peak instrumental intensity of IX recorded at Napa Fire Station Number 3, located at 38.330, -122.318 (Figure 5).

Fault slip models derived from seismological waveform data or joint inversions of waveform, geodetic, and satellite interferometry data indicate that the rupture propagated up-dip and northwest from the hypocenter. The maximum slip of ~1 m at depth was about 8 km north of the hypocenter, and aftershocks occurred predominantly south of, and deeper than, the area of maximum slip (Figure 6).

The earthquake was centered in an area of historical seismicity associated with the West Napa fault zone. The 2000 M 4.9 Yountville earthquake is associated with the West Napa fault zone (Langenheim et al., 2006) and had a zone of aftershocks about 4 km northwest of the 2014 South Napa earthquake rupture. The M 6.3 1898 Mare Island earthquake caused extensive damage in the Vallejo area, near the southern end of the West Napa fault zone. Although the

location of the 1898 Mare Island earthquake is not known precisely, intensity data suggest it was about 10 km southeast of the epicenter of the 2014 earthquake (Bakun, 1999).

Surface Rupture. The earthquake produced more than 14 km of surface rupture from the Napa River at Cuttings Wharf in the south, to beyond the northern boundary of Alston Park in the city of Napa, in the north (Figure 7). The surface rupture is largely west of most mapped traces of the West Napa fault zone, although it is coincident with the western-most Quaternary trace of the West Napa fault, and locally with mapped bedrock faults (Clahan et al., 2004). The fault was previously unrecognized where it was covered by younger sediment, particularly near its northern end in Browns Valley, and at its southern end near the Napa River.

Displacements along the surface rupture are predominantly right-lateral and the rupture is highly variable in terms of expression at the surface. However, rupture is typically expressed as a zone of en echelon left-stepping fractures (Figure 8), varying from less than



Figure 8. Surface rupture west of Buhman Avenue, showing left-stepping en echelon fractures and mole-tracks. Right-lateral displacement was on the order of 40 cm, with a small amount (~12 cm) of up-on-the-west vertical displacement. GPS location: 38.2924°, -122.3432° (photo: Dawson et al., 2014).



Figure 9. Surface fault rupture through vineyard about 6.7 km NW of epicenter, showing offset vineyard rows in area of maximum measured right-lateral offset of 40-45 cm (source: NSF-GEER; GPS N38.2776 W122.32377; 08/25/14: 2:23 pm) (photo: Keith Kelson, USACE).

one meter to tens of meters wide. Right-lateral offsets are as high as 40-45 cm measured in the area near the intersection of Buhman Avenue and Congress Valley Road (Figure 8).

At the latitude of Browns Valley Road, the rupture was observed along two subparallel, northwest trending strands approximately 500 m apart (Figure 9), with offset of 10- 20 cm on the western strand, and about 2- 8 cm on the eastern strand. North of Browns Valley, these strands appear to merge a few hundred meters south of Alston Park. The northern end of the rupture has been verified approximately 1.2 km north of Alston Park.

Minor right-lateral offset, likely less than a few centimeters, also was observed crossing two taxiways at the Napa County Airport (Figure 10). This rupture is located on the mapped trace of the Airport Section of the West Napa fault zone as designated by Bryant (2000), and the rupture was first identified by X-band InSAR results from NASA's Jet Propulsion Laboratory Advanced Rapid Imaging and

Analysis (ARIA) mission, using the Agenzia Spaziale Italiana's COSMO-SkyMed satellite. Rupture at the airport was verified by geologists in the field (Figure 10). Uninhabited aerial vehicle synthetic aperture radar (UAVSAR) imagery flown five days after the earthquake proved to be useful in identifying other areas of possible faulting, and was especially useful in identifying linear zones of deformation that would likely have been missed in the field without the benefit of the InSAR and UAVSAR imagery.

Afterslip. Within the first 24 hours, afterslip was expressed as the continued development of the rupture on the ground and the growth through time of observed offsets across roads and other cultural features. The USGS was able to establish four alignment arrays across the fault in order to monitor afterslip. Although results are not yet finalized, based on episodic field observations in the 26 days following the earthquake, afterslip is continuing at the four stations located within the primary, 7-km-long epicentral part of the rupture (Lienkaemper, 2014). Little or no offset was observed within a few hours of

the main shock at some locations that exhibited as much as 20 cm of right-lateral afterslip 48 hours afterward.

Opportunities to Advance Knowledge.

The South Napa quake was the largest one in the San Francisco Bay region since the 1989 M 6.9 Loma Prieta earthquake, and several research opportunities arise from this event. Following the earthquake, new techniques such as post-earthquake campaign and continuous GPS monitoring, mobile LiDAR scanning systems (MLS), and various SAR techniques were deployed in order to record the distribution of surface rupture and the amount of coseismic slip and afterslip. The amount of total post-earthquake offset is relatively large for a M 6 main shock and has implications for the interpretation of standard empirical relationships between surface displacement and earthquake magnitude, because these relationships are developed using total slip (including unknown amounts of afterslip). Because the cross-fault distribution of slip can be documented with a high degree of precision, we have better information on the patterns and relative amounts of slip for mitigating fault rupture to pipelines, levees, and other infrastructure.

Geotechnical Engineering

(GEER-PEER: Jonathan Bray, UC Berkeley; Julien Cohen-Waeber, UC Berkeley; Tim Dawson, CGS; Tadahiro Kishida, PEER; Nicholas Sitar, UC Berkeley; Christine Beyzaei, UC Berkeley; Les Harder, HDR; Ken Hudnut, USGS; Keith Kelson, USACE; Robert Lanzafame, UC Berkeley; Roberto Luque, UC Berkeley; Dan Ponti, USGS; Michelle Shriro, GEI; Nathaniel Wagner, UC Berkeley; and John Wesling, CA OMR)

Earthquake Ground Motions. The earthquake produced strong ground motions in the northern San Francisco Bay area (Bray et al., 2014).

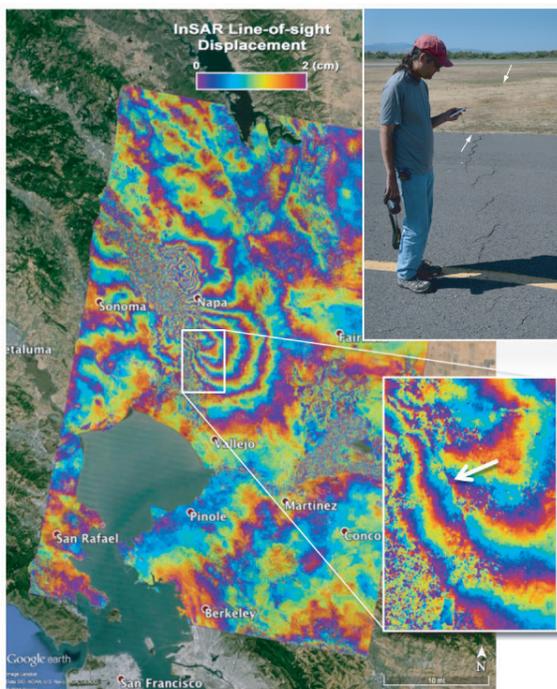


Figure 10. COSMO-SkyMed X-band InSAR image overlain on Google Earth Imagery showing discontinuity (white arrow) corresponding to minor faulting at the Napa County Airport. Upper right photo shows en echelon cracks on airport taxiway (source: Ken Hudnut, USGS). Arrows denote pre-earthquake vegetation lineament and low scarp (source: NASA Jet Propulsion Laboratory Advanced Rapid Imaging and Analysis (ARIA) mission http://photojournal.jpl.nasa.gov/figures/PIA18798_fig1.jpg).

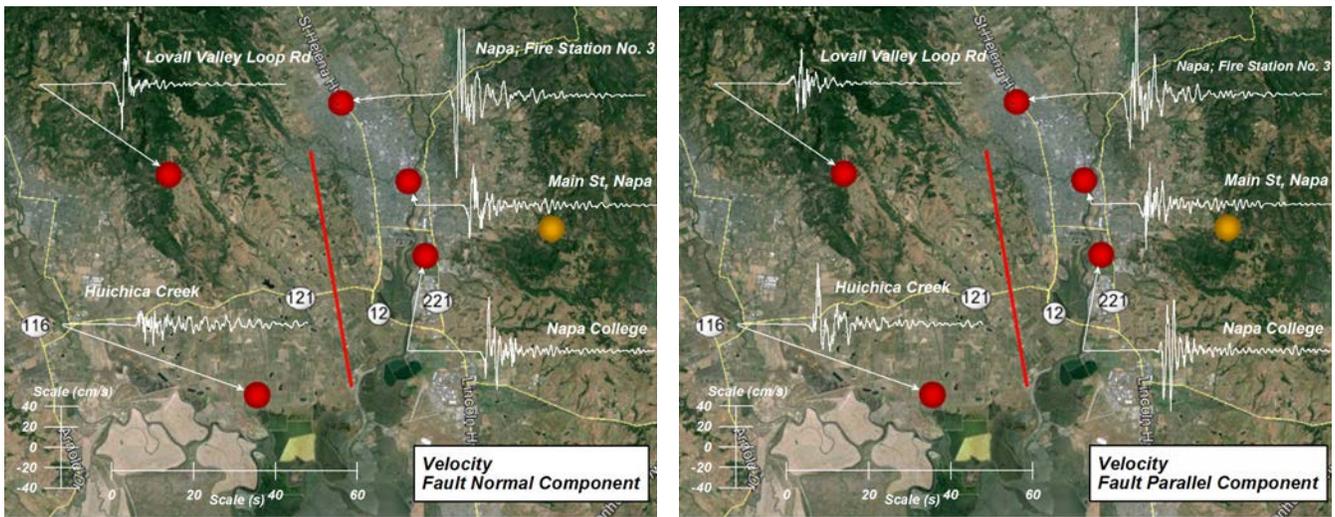


Figure 11. Fault normal and fault parallel velocity time series recorded in the near fault region (source: Bray et al., 2014).

A total of 214 three-component uncorrected digital accelerograms were downloaded from the Center for Engineering Strong Motion Data (CESMD) and processed using PEER standard procedures (Ancheta et al., 2014).

Of particular importance were intense ground motions in the heavily damaged areas in and around Napa. Pulse-like waveforms were observed in several of the velocity time series at the near-fault stations shown in Figure 11. The maximum recorded peak ground velocity (PGV) was 92 cm/s at the Napa Fire Station No. 3 strong motion station (SMS). Several stations exhibited pulse-like motions in both horizontal components (Napa Fire Station No. 3, Lovall Valley Loop Road, and Napa College). The Main Street and Huichica Creek SMS exhibited velocity pulses in their fault normal and fault parallel components, respectively. The velocity time series of five near-fault records contained velocity pulses with periods within the expected range of 0.7- 2.0 s for soil sites shaken by a M 6 event (Bray et al., 2009), but they also contained longer-period pulses significantly higher than this range. It is not clear if the longer-period pulses were due to fault rupture mecha-

nisms or site effects (e.g., deep basin response).

The 5% damped pseudo-spectral acceleration response spectra of the recorded ground motions at the Napa Fire Station No. 3 SMS and Napa College SMS sites are compared to ASCE 7-10 design spectra and USGS uniform hazard spectra (UHS) in Figure 12. The square root sum of squares (SRSS) of the two horizontal components, and the RotD50 (median rotated direction component)

and RotD100 (maximum rotated direction component) were calculated for each recording station. The spectral values of these records exceeded the ASCE-10 MCE spectra within the range of 1-2 s. Peak spectral values approach or exceed the 2475-year return period UHS values at these two Napa stations.

High-frequency spikes were observed in the Carquinez Bridge Geotechnical Array #1 records, which reached approximately 1.0 g

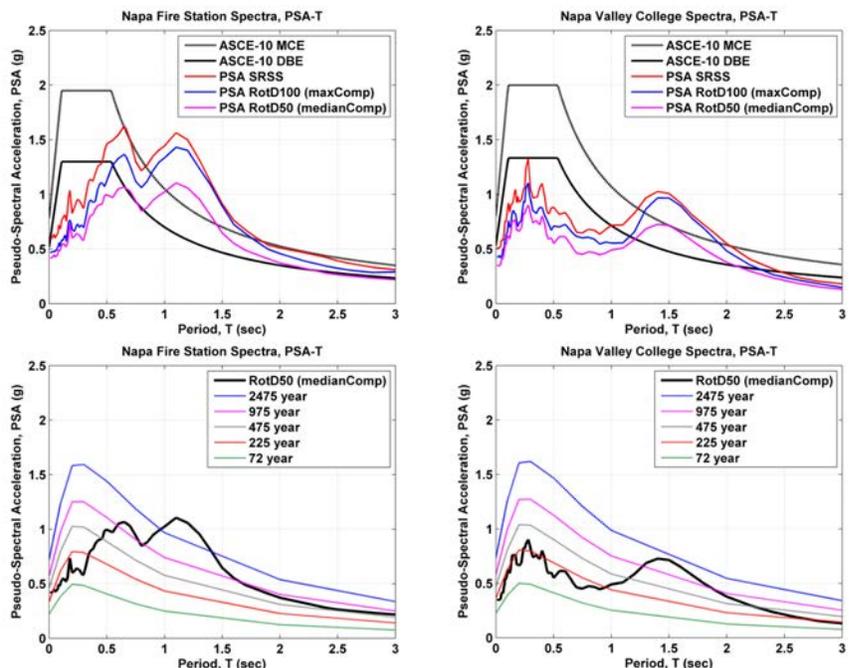


Figure 12. Comparison of code spectra and UHS for the Napa Fire Station and Napa Valley College (source: Bray et al., 2014).



Figure 13. Surface fault rupture in Browns Valley area (fault trace mapped by NSF-GEER team members overlain on GoogleEarth™ image; source: Bray et al., 2014).

for the NS component. The spikes were investigated by comparing the acceleration time series at several stations along the path from the epicenter to the sites and the downhole array records. The spikes were observed in the S-wave portion of several of the records. This suggests that the spikes could be a result of path effects. The spikes increase in amplitude from the Vallejo–Hwy 37/Napa River East Geotechnical Array to the Carquinez Bridge Geotechnical Array #1. Downhole records show that two

high-frequency spikes are observed in the S-wave portion of the waveform from a depth below 100 m to the surface. This observation suggests that the large PGA observed at Carquinez Bridge Geotechnical Array #1 is in part a result of site amplification due to local soil conditions. However, these observations do not exclude the possibility of soil-structure interaction effects on the measured recordings.

The 5% damped pseudo-spectral accelerations from the recorded ground motions compared well to those estimated with the recent NGA-West2 Ground Motion Prediction Equations (GMPE; Bozorgnia et al., 2014). The comparison shows generally a good agreement for both horizontal and vertical components near the fault, with the exception of the large high-frequency motions observed near the Carquinez Bridge and the large velocity pulses observed in the near-fault region, as discussed above.

Geotechnical Effects. Surface faulting damaged homes, underground utilities, and other infrastructure where the fault traversed developed areas, such as the Browns Valley residential area in western Napa (Figure 13). Right-lateral surface fault rupture deformation in this area was on the order of 10 - 20 cm. The surface fault rupture damaged the house structure shown in the left photograph of Figure 14. The right photograph shows where the surface fault ground

movement displaced another house structure 6 cm from its foundation. Structures that were tied into the ground, e.g., pier and grade beam foundations, were damaged at a higher rate than ring-wall with suspended timber floor foundations.

A distinct damage mode involved compressional and extensional failures within relatively new, stiff concrete sidewalks and curbs off of the primary fault trace throughout the Browns Valley area (Figure 15). Newly placed sod with a geotextile backing was warped in places similar to what one might see when a rug is shaken from one end. The sidewalk failures appeared to be a manifestation of localized zones of compression and extension distinct from the surface fault rupture, and possibly induced by intense transient surface waves. Other potential mechanisms are ground deformations associated with surface faulting or lurching of compacted earth fills.

Although the Napa area was strongly shaken by this event, there was a noticeable lack of liquefaction and liquefaction-induced ground failure, even in areas previously identified as being susceptible to the hazard. Dam and levee performance was generally excellent, and only a few cases of minor cracking were observed. Similarly, underground storage caverns at local wineries performed well, with only minor cracking reported at some of the installations.



Figure 14. Effects of surface fault rupture on infrastructure in Browns Valley area; left--home severely damaged (NSF-GEER; N 38.3025 W122.3436; 08/25/14), and right--foundation offset 6 cm (NSF-GEER; N 38.3038 W 122.3430; 08/25/14) (source: Bray et al., 2014).





Figure 15. Top--buckled sidewalk (NSF-GEER: N38.3039 W122.3430; 08/25/14); middle--sidewalk cracks (NSF-GEER: N38.3064 W122.3456; 08/28/14); and lower--warped sod (NSF-GEER: N38.3065 W122.3455; 08/28/14) indicating compressional and extensional zones in compacted fill near fault trace in Browns Valley area. (source: Bray et al., 2014).

Opportunities to Advance Knowledge. Much can be learned from a comprehensive study of the ground motions produced by this earthquake, including near-fault velocity-pulse effects, the unusually intense high-frequency spikes in the acceleration time series at the Carquinez Bridge site, and the effects of the Napa basin and local

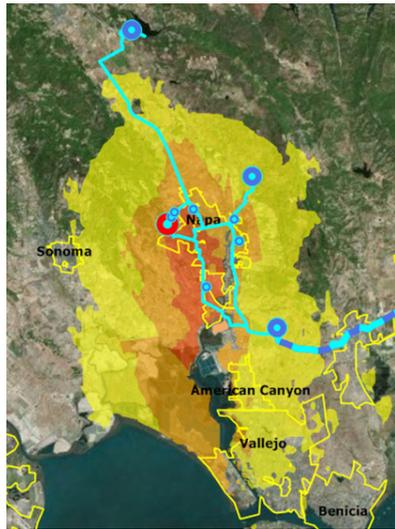


Figure 16. Schematic of City of Napa water system overlaid on MMI and showing three sources (large dark blue circles) and main transmission lines, locations of distribution tanks (smaller circles) and damaged Montana “B” tank. The California Water Project’s North Bay Aqueduct, which feeds Barwick Jamieson WTP, is shown as dashed light-dark blue (source: Charles Scawthorn, SPA Risk).

site effects on ground motion characteristics. Most of the strong motion sites require shear wave velocity measurements to characterize the Vs30 of the sites. The characteristics of surface fault rupture were well captured, and they offer the opportunity to better understand the characteristics of ground deformations in close proximity to the fault rupture. The effect of surface fault rupture on homes and other infrastructure is a particularly fruitful avenue of further study. Structures with different foundations can be investigated to better understand how each foundation system responds to, and performs in areas of ground deformation from surface faulting. The alternating patterns of sidewalk compression zones and extension zones are relatively unique and may provide insights regarding transient ground motions in the very-near fault zone. Conversely, the ground deformation recorded in the sidewalks in the Browns Valley area may be a result of secondary ground deformation resulting from surface faulting, compacted earth fill,

or slope movements; hence, further study is warranted. Sites that were mapped as being liquefiable that did not exhibit liquefaction should be better characterized and added to the liquefaction-triggering database. The cause of damage to buried utilities in areas that did not undergo significant permanent ground displacements should be investigated. Lastly, the documented performance of dams, levees, other earth structures, and natural slopes provides the opportunity to evaluate commonly employed analytical procedures.

Lifelines

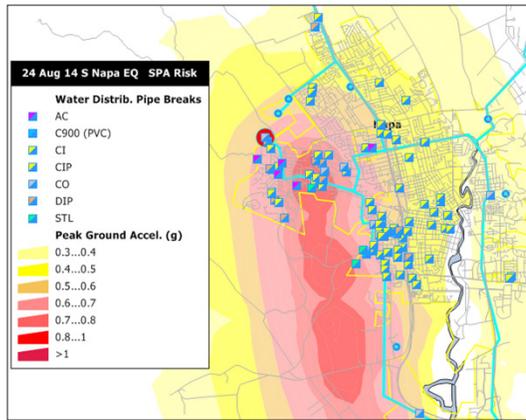
(ASCE TCLEE: Charles Scawthorn, SPA Risk; John Eiding, G&E Engineering Systems; Mark Yashinsky, Caltrans)

Utilities serving the affected area include potable water, wastewater, electric power, natural gas and communications. There are no petroleum refineries or major pipelines within the zone of MMI VI shaking,

	C900	DIP	CI	AC	RCCP	STL		
Under 20 years	6,600	225,600				100	232,300	13%
20-40 years	24,300	370,500	83,400	14,100		100	492,400	28%
40-60 years		12,300	466,700	167,200	9,900	59,800	715,900	40%
60-80 years			173,100			100,400	273,500	15%
80-100 years			55,100				55,100	3%
Over 100 years			10,300				10,300	1%
Sum	30,900	608,400	788,600	181,300	9,900	160,400	1,779,500	100%
	2%	34%	44%	10%	1%	9%	100%	

Table 2. City of Napa distribution piping—length of pipe (% in red) by age and material. Key: C900 = PVC, DIP = Ductile Iron Pipe, CI = Cast Iron, AC = Asbestos Cement, RCCP = Reinforced Concrete Cylinder Pipe, STL = Steel (source: Scawthorn, after City of Napa).

Figure 17. City of Napa water system overlaid on PGA, showing locations of breaks and Montana “B” tank (data: City of Napa; map: Charles Scawthorn, SPA Risk).



Material	Breaks	% Brks	Brks/mile
Asb. Cement	8	5%	0.23
C900 (PVC)	2	1%	0.34
Cast Iron	123	75%	0.82
Concrete	1	1%	0.53
Duct. Iron	18	11%	0.16
Steel	3	2%	0.10
Other/Unknown	7	4%	
Total	163	100%	

Table 3. Number, percentage, and per mile breaks, City of Napa Water Distribution system (data: City of Napa; table: Charles Scawthorn, SPA Risk).

but there are several major facilities within the MMI V zone (see Figure 1). Transportation lifelines serving the affected area include roads and highways, rail, airports, marine ports and ferry.(Eidinger, 2014).

Potable Water. The City of Napa’s water system, which serves approximately 80,000 persons, is shown in Figure 16 and has three sources:

- Lake Hennessy (31,000 A-ft), Water Treatment Plant (WTP, 20 mgd, built1982)
- SWP/Barwick Jamieson WTP (21,900 A-ft pa entitlement, WTP 20 mgd, built 1967)
- Milliken Reservoir (1400 A-ft), a seasonal backup source

The distribution system includes 12 tanks and 337 miles of distribution pipe, which is made up of several types and vintages of pipe, as shown in Table 2. Table 3 and Figure 17 show the locations of



Figure 18. Milliken line, broken by rock slide (photo: City of Napa)

breaks in the system; there were 163 breaks, 75% of which were in cast iron pipe. Among the more significant breaks was that in the main transmission pipe from the Milliken source, which was broken by a rock slide, Figure18.

Of the 12 tanks in the system, one (termed Montana “B”) sustained significant damage, Figure 19. The tank is an unanchored 67’ diameter, 37’ high circular welded steel tank with corrugated iron (CGI) roof supported by redwood beams on steel columns. The water sloshed with approximately 6’ amplitude, damaging the roof. There was no buckling of the walls, but some rocking was evidenced by motion at the outtake slip joint. The tank drained immediately following the event due to a nearby pipe break.

While there were a relatively large number of breaks, and loss of pressure at some locations, service was maintained for much of the city due to a decision by the city to continue the flow from both Lake Hennessy and Barwick Jamieson sources. It was later estimated that the total loss of water due to this policy was approximately 100 Acre-feet.

Pipe breaks were repaired relatively quickly, with half completed in less than five days, Figure 20. The City of Napa was aided in making repairs by regional utilities through the Cal-WARN (www.calwarn.org) system, as follows:

- Alameda County WD – 1 truck crew
- City of Fairfield – 1 truck/ 2 crews
- CCWD – 1 truck/crew
- EBMUD – 5 truck/crews

These crews arrived with their own trucks and equipment fully stocked with spare parts. All were released by August 29. The city estimates it spent about \$200,000 on spare parts for repairs.

American Canyon reported no damage to its system, while the City of Vallejo sustained approximately 51 distribution pipe breaks.



Figure 19. Montana “B” tank. Upper photo--roof damaged by sloshing; lower photo-- outtake exhibiting evidence of motion at slip joint (photo: City of Napa).



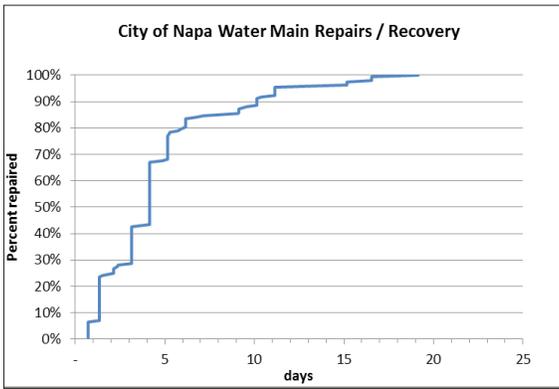


Figure 20. Left, water distribution pipe break repairs (%) vs. number of days following the earthquake (data: City of Napa; chart: Charles Scawthorn, SPA Risk).

Table 4. Right, Napa Sanitation District Pipe Material breakdown (source: Napa Sanitation District)

Type of Pipe	Miles	% system
ABSPlastic	2	0.7%
Asb. Cement	124	45.9%
Cast Iron	1	0.4%
Concrete	3	1.1%
Polyvinyl chloride	61	22.6%
Reinf. Concrete pipe	7	2.6%
Vitreous clay pipe	70	25.9%
Other	2	0.7%
Total	270	100.0%

Napa Sanitation District. Napa's sanitation district (NSD) provides sewer service for 75,000 people over 23 square miles with a system of 270 miles of sewer lines (Table 4), 5,651 manholes, and three lift stations. NSD reported 11 breaks in its sewer mains, all in asbestos cement pipes. Nine of these breaks are believed to have been along the fault trace, while two were due to water main breaks (causing soil erosion and loss of support to the sewer line).

Napa's wastewater is treated at the 7 mgd (dry weather) Soscol Water Recycling Facility (SWRF), where there was sloshing and spillage at the sand filters. Additionally, minor cracking was observed in several reinforced concrete structures at the plant.

SWRF did not lose PG&E service, but wastewater treatment operations were significantly disrupted due to an inflow of an estimated 334,000 gallons of wine spilled from

damaged barrels that flowed to the sewers and then SWRF. The wine is acid and disrupted normal anaerobic bacterial processes in the digester, increasing biochemical oxygen demand (BOD) to as high as 15,000 mg/l (normal is 175 mg/l), and upsetting treatment operations for about 48 hours. Air was blown into the digester for 24 hours (using normal blowers), and the process recovered. No untreated water or solids were released to the environment.

Electric Power. The affected region contains several 60 kV–230 kV transmission lines and 30 substations, Figure 21, as well as some relatively unique structures such as the Carquinez Straits crossing structures.

Damage to the distribution system (12-21 kV), included 12 pole transformers, 15 cross arms, 63 spans of conductors, and 28 downed overhead wires (though no poles were damaged). Initial investigations estimated that more than 90% of all outages were related to wire-wire contact of the electrified lines, which caused

the fuses to blow and the power outage.

Approximately 70,000 PG&E customers had one or more power outages during and after the earthquake, with a peak around 3.75 hours after the quake. Over 99% of these customers had power restored within 24 hours (Figure 22).

Natural Gas. The affected region is traversed by two natural gas transmission lines (Figure 23). PG&E reported two non-hazardous leaks on these lines, but no rupture of line.

In the distribution system, PG&E reported no loss of service to customers due to damage to their facilities; 160 customers lost service due to damage to customer facilities. PG&E responded to 5,810 service "tags" (report of gas odor, leak, safety check) and performed 2,818 relights (with 926 in Napa and 110 in Vallejo), which were all completed ~24 hrs following the

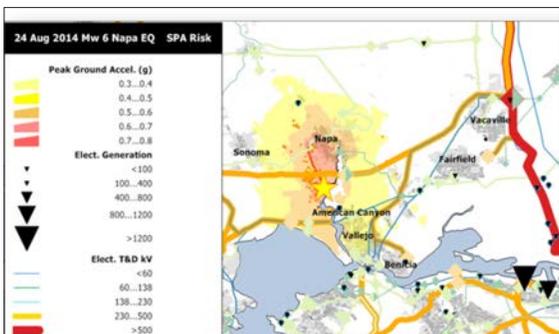


Figure 21. Affected region EHV electric system (source: Charles Scawthorn, SPA Risk)

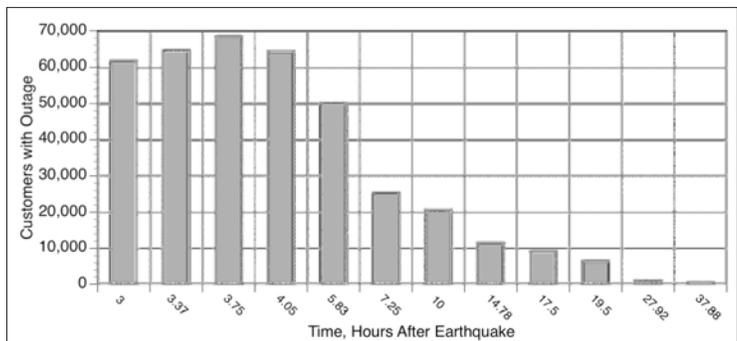


Figure 22. Number of customers without power, versus hours after the earthquake (source: TCLEE)

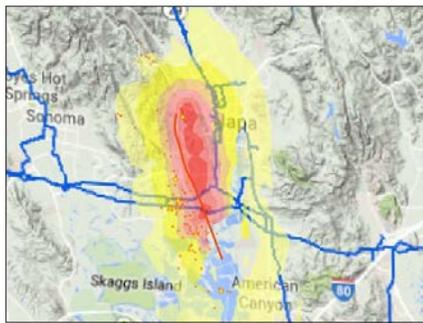


Figure 23. Fault rupture, aftershocks and PGA intensities superimposed on PG&E map of natural gas transmission lines shown as blue lines (transmission data: PG&E; source: Charles Scawthorn, SPA Risk)

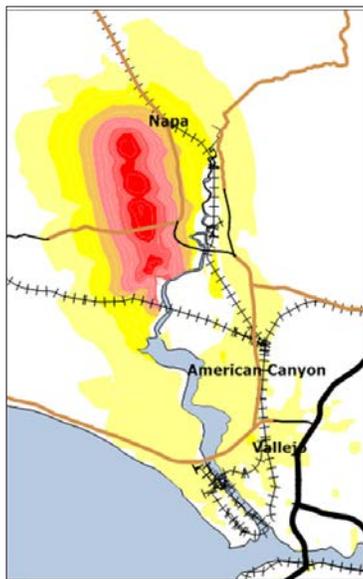


Figure 24. Railroads within the affected area, overlaid on PGA (source: Charles Scawthorn, SPA Risk).

event. PG&E also reported 26 priority leaks (blowing gas, immediate response), 425 non-hazardous leaks, 886 non-hazardous meter reset leaks. PG&E inspected 76 gas regulators in the affected area, finding no damage.

No information is currently available regarding the presence, performance, or impacts of seismic shut-off valves.



Figure 25. Napa airport with inferred fault trace in red (epicenter star), and mapped trace of W. Napa fault in black (base map: Virtual Earth; annotations: Charles Scawthorn, SPA Risk).

Telecommunications. Telecommunications systems generally performed well. The AT&T building in downtown Napa sustained damage to a concrete wall panel, attached to the building using eight bolted angles, which fell due to connection failure during the earthquake and disrupted power to the building. Emergency generators did not work, but the equipment and operations were sustained by battery systems.

Verizon reported no loss of service; however, they had to bring in backup power for several cell towers.

No disruption of 911 service was reported.

Rail. California OES reported that the Union Pacific inspected its lines and found no issues; BNSF opened most tracks; Cal Northern Railroad reported no damage; and Sonoma-Marin Area Rail Transit (SMART) stopped trains running until at least Tuesday (see Figure 24). The Napa Valley Railroad reported heavy damage to its Napa Station. Amtrak reported its Capitol Corridor was suspended for “a time;” its Los Angeles–Seattle Coast Starlight was held while track and bridges were inspected; its Northbound train No. 14 was stopped near Emeryville, and the southbound No. 11 stopped near Chico for several hours; and its California Zephyrs

were also significantly delayed. (Trains, 2014)

Air. The Napa County airport reported no damage to any of its own facilities, although minor cracking was reported on one runway (see Figure 25). Operations were suspended from normal opening time (7:00 am) for 30 minutes to allow inspection and then were resumed. The airport lost normal commercial power, but backup power functioned satisfactorily.

The Air Traffic Control (ATC) tower at Napa airport is owned and operated by the Federal Aviation Administration (FAA); it sustained no structural damage, there was glass breakage in its main control room windows. Local ATC was not available for four days until a temporary tower was brought in; the temporary tower will be required for several weeks, pending delivery of replacement glass. Operations continued without ATC, and pilots communi-



Figure 26. Sonoma Creek Bridge (photo: Mark Yashinsky).



Figure 27. lower photo--Napa Slough Bridge; upper photo--typical damage to pile extensions on the Napa Slough Bridge (photos: Mark Yashinsky).



cated directly via radio, which is the normal procedure at airports that do not have ATC.

Bridges. State-owned bridges in the area had been retrofit in the 1990s. Out of 412 state bridges in Solano, Napa, and Sonoma Counties, 54 bridges had been retrofitted and the others were screened and found not to be vulnerable. The benefits of this retrofit program could be seen following the earthquake.

The Sonoma Creek (State Route 37) Bridge is a 22-two span precast girder bridge on battered (tilted) and poorly confined pile extensions. This type of substructure had been identified as vulnerable during the retrofit program,

so the substructure was retrofit with large-diameter cast-in-steel shell (CISS) piles supporting the ends of the enlarged bent cap when it was widened in 1999 (Figure 26). The bridge is two miles from the local agency-owned Napa Slough Bridge (Figure 27), which had a similar substructure, similar soft soil, and a similar level of ground shaking during the earthquake. There was no damage to the Sonoma Creek Bridge while the Napa Slough Bridge had serious damage (Figure 27).

The ends of the pile extensions on the Napa Slough Bridge had deep cracks and spalls into the core region. Fortunately, the #4 hoop reinforcement at 12 inches was strong enough to hold onto the longitudinal reinforcement and prevent the failure of the piles. If the earthquake had been of longer duration, the piles may have failed.

Most of the damage to state bridges was due to opening and closing of expansion joints, and the banging of wingwalls and barrier rails



Figure 29. Retrofitted Napa River Bridge with large foundations, steel column casings, and strengthened precast girder connections (photo: Mark Yashinsky).



Figure 28. Banging at abutments on the Napa River (W. Imola Ave) Bridges (photo: Mark Yashinsky).

against abutments (Figure 28). This kind of damage is a nuisance to repair, but it doesn't normally affect a bridge's ability to carry traffic.



Figure 30. Fault offset across State Route 12 (photo: Mark Yashinsky).

The Napa River (State Route 37) Bridge, a 33-span precast girder bridge on flexible two-column piers and stiff four-column piers, was built in 1963 (Figure 29). The 1989 Loma Prieta earthquake was centered 100 km away, but the bridge was damaged due to the long-period shaking on deep bay mud. The precast girders started to pull out of the diaphragms, but fortunately didn't move far enough to collapse. The bridge was retrofitted in the 1990s with larger foundations, containing more piles, steel column casings, and end diaphragms strengthened with transverse prestressing and concrete bolsters.

The ground motion during the South Napa earthquake was low, but the bridge shook enough to damage the expansion joints at its crest. However, no primary member

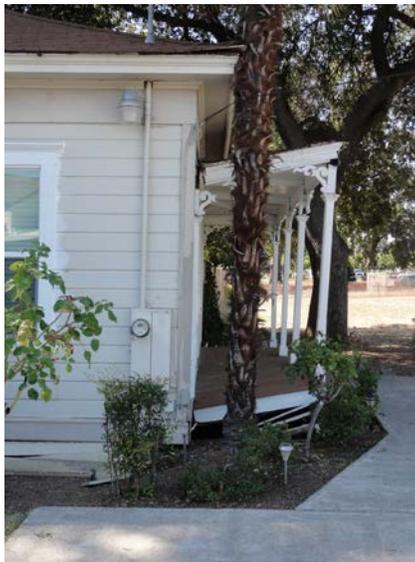


Figure 31. Cripple wall failure of single-story house west of downtown Napa. House fell in northwesterly direction (photo: Betsy Mathieson).

was damaged and the bridge was quickly returned to service after being briefly closed for inspection.

Roads. Road damage was due to surface fault offset. Traffic was so busy in Napa that vehicles were allowed on roads with significant cracking (Figure 30). Fortunately, there was little vertical offset across the West Napa Fault and the horizontal offset was usually less than a foot.

Other transportation. No damage was reported at the Napa Marina (on the Napa River), the marine terminals in Vallejo, Martinez or Benicia, or the ferry landing in Vallejo.

Performance of Structures

Housing

(Mike Mieler, Johns Hopkins University; Janiele Maffei, CEA; Betsy Matheson, Exponent; Danielle Hutchings Mieler, ABAG; Larry Stevig, State Farm Insurance; Warner Chang, IBHS)

The housing stock in Napa and Solano Counties comprises mostly single-family homes. Of the 207,000 housing units in the region, over two-thirds are detached single-

family units. In Napa County, nearly 30% of the housing stock was built before 1959, while in Solano County only 20% of residences predate 1959. The median house price in Napa County is \$460,000; in Solano County it is \$290,000 (USA.com, n.d.a; USA.com, n.d.b). Napa County also has a significant population of mobile homes, many of which were damaged in the earthquake.

Most single-family homes in the region are one- or two-story wood-frame structures with either wood or stucco exterior siding. Many homes built before 1950 have cripple wall foundations, where the first floor of the structure is elevated several feet off the ground on short perimeter walls that are vulnerable to collapse in earthquake ground shaking. The area surrounding downtown Napa has a high concentration of such structures, and several cripple wall failures were observed (see Figure 31). Some cripple wall structures had been retrofitted prior to the earthquake, but we have not identified them all or studied them in detail. In addition to cripple wall distress and failure, many residential masonry chimney failures were reported throughout



Figure 32. Chimney collapse near downtown Napa. Chimney failed at roof line of two-story Victorian house (photo: David McCormick).



Figure 33. Foundation collapse in Salvador Mobile Estates northwest of downtown Napa. Mobile home displaced in westerly direction (photo: Mike Mieler).

Napa and the surrounding region, as far south as Vallejo (Fimrite, 2014). Chimney failures included both crumbling of masonry and toppling of entire chimneys (see Figure 32). Many masonry chimneys in residential neighborhoods north of downtown Napa had been removed or replaced before the earthquake, possibly due to damage from the 2000 Yountville earthquake. In the residential neighborhoods along the West Napa fault, several relatively new homes had concrete foundation damage due to surface fault rupture (Bray et al., 2014).

Many mobile homes in Napa County had extensive foundation damage as a result of earthquake ground shaking. Typical mobile home foundations comprise stacked concrete blocks that are vulnerable to collapse in an earthquake. An exterior survey of more than 80 mobile homes (both damaged and undamaged) in the Salvador Mobile Estates community in Napa revealed that nearly a quarter of homes had either significant permanent displacement or partial foundation collapse (see Figure 33). In the Napa Valley Mobile Home Park, earthquake shaking ignited fires that destroyed four homes and damaged two. Following the earthquake, reconnaissance teams identified and briefly surveyed a small number of mobile homes whose foundations had been retrofitted with steel braces. They

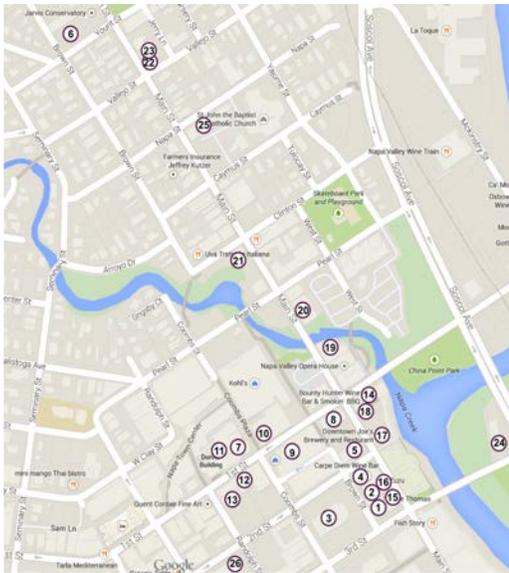


Figure 34. URM buildings observed by EERI team members/contributors (source: Andre Barbosa).



Figure 36. Turret damage in retrofitted stone masonry building (No. 12 in Figure 34; photo: Matt Schoettler).

masonry buildings (URMs) in the downtown area of Napa. Most buildings with retrofits appeared to perform well with respect to global life safety or collapse prevention, but a number of localized life safety hazards were identified. Damage was variable, but over 30 retrofitted URM buildings generally outperformed the three remaining nearby unretrofitted buildings. Because interior access was not available for most buildings, interior damage and the extent of retrofit was only partially documented. Some cases certainly warrant detailed follow-up inspections to assess all structural and nonstructural damage, and to determine the details and performance of the retrofits.

Figure 34 shows the location of URM buildings inspected by the team in the three to four days following the earthquake. Buildings in other portions of the city were not visually inspected.

Two historic retrofitted stone masonry buildings, the Vintner’s Collective (Figure 35) and the Goodman Library (Figure 36), posed life-safety risks from falling hazards. Interestingly, these were the only two buildings that were reported to have suffered minor damage in the 2000 Yountville earthquake (Miranda and Aslani,

showed less foundation damage, but several instances of incomplete or inadequate retrofit installations were observed. More detailed studies are recommended to verify both the quality and performance of mobile home retrofits.

A limited number of multi-family apartments have been surveyed following the earthquake, including one with a potential soft-story. In general, only minor structural damage was observed, though at one apartment complex several detached carports collapsed,

severely damaging the cars parked underneath. Additional reconnaissance is required to more fully understand the broader performance of multi-family residences throughout the region.

Unreinforced Masonry Buildings
(Andre R. Barbosa, Oregon State University; David McCormick, SGH; Marko Schotanus, Rutherford+Chekene; Bill Tremayne, Holmes Culley; Fred Turner, California Seismic Safety Commission)

Several teams performed rapid visual inspections of unreinforced



Figure 35. Historic stone masonry building damage (No. 21 in Figure 34; photo: Andre Barbosa).

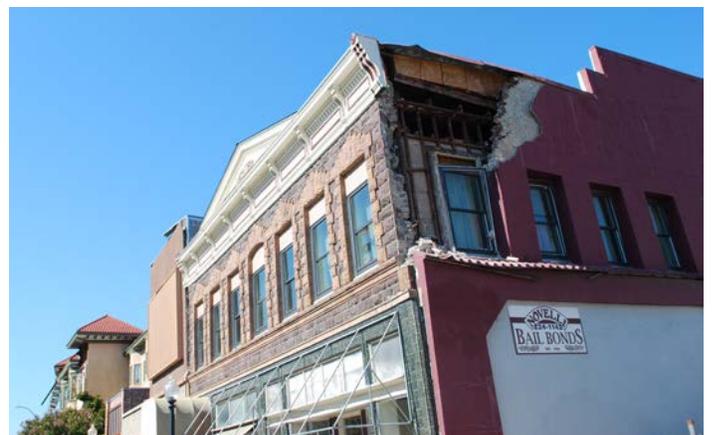


Figure 37. Out-of-plane failure in URM building (No. 1 in Figure 34; photo: Andre Barbosa).



Figure 38. Out-of-plane failure in two-wythe masonry wall with brick veneer connected with straight adhesive anchors (No. 4 in Figure 34; photo: Karl Telleen).



Figure 39. In-plane shear failure of masonry piers (No. 22 in Figure 34; photo: Andre Barbosa).

2000), while all other URM buildings were reported as undamaged in that event.

Figure 35 shows the partial collapse of the front wall of the Vintner’s Collective building. Though there is interior wood framing with hold-downs, no connectivity to the masonry was observed. It is not clear whether the wood framing was part of the retrofit and if it was intended to function as a secondary gravity system to protect the interior. In-plane shear cracks in the north and south walls (not shown) were also observed, but damage was moderate. The Goodman Library (Figure 36) was retrofitted with a 2004 design. While roof diaphragm strengthening and parapet bracing was visible, the extent of other retrofit measures was hidden to avoid compromising the histori-



Figure 40. Retrofitted building with shifted cornice stone (No. 14 in Figure 34; photo: Marko Schotanus).

cal integrity of the building. The damaged turret received limited retrofit due to historic preservation issues. Subsequent review of the seismic retrofit drawings indicated that the retrofit included the addition of two concrete shear walls in the transverse direction (one interior and the other located at the front façade), and perimeter floor and roof diaphragm ties. The only documented intervention at the turret tower was the addition of a 5” thick concrete slab at the mid-height.

Out-of-plane failures were observed in several buildings, but in-plane shear failures were less prominent. Figure 37 shows the out-of-plane failure in an unretrofitted building adjacent to a parking area where a car was destroyed by the falling walls and parapets. Figure 38 shows damage to a corner of a building that was retrofitted in 1984, well before the city and the state had adopted minimum retrofit codes. The exterior wall was a two-wythe wall with a brick veneer. The retrofit included straight adhesive anchors that were embedded only in the collar joint and did not perform as intended.

Figure 39 shows damage to a building that had an interior braced frame along the open

front. In-plane shear cracks were clearly visible. Wall-to-floor ties performed well. However, the out-of-plane demand exceeded the out-of-plane flexural capacity of the exterior walls at the second story.

Several buildings had comprehensive retrofits. Though these retrofits generally appeared to have performed well, some buildings were red-tagged immediately after the earthquake mainly due to falling hazards. In one URM building with a comprehensive retrofit, we observed roof and ceiling-to-wall anchors with thru-

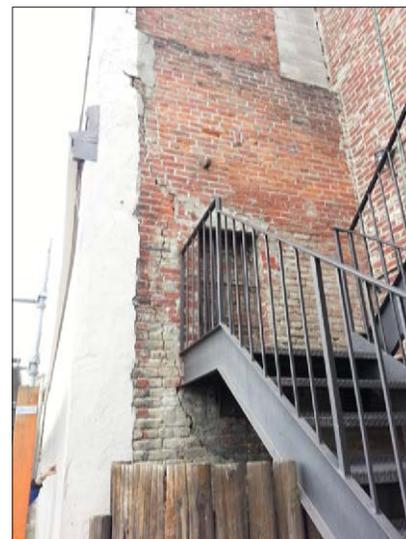


Figure 41. Wall damage caused by exit stair (No. 14 in Figure 34; photo: Bill Tremayne).



Figure 42. Comprehensive retrofit with minor damage in parapets (left), which led the building to be yellow tagged since the building was still accessible from the back (photo: Bret Lizundia); and (right) interior view showing no business interruption (No. 20 in Figure 34; photo: Bill Tremayne).

bolts on the east façade and steel concentric braced frames at the first and second story along the front wall (Figure 40). The only notable damage at the front of the building was a cracked/loose cornice stone at the center of the wall, which created a falling hazard and required repair. The building’s tenants reported that the only interior damage was some broken wine bottles. Interestingly, the front entrance of the building was red-tagged, though the building was accessible from the rear, where localized damage was

observed at the shared URM wall. A relatively modern steel framed stair was supported at the mid-height landing from the shared wall, and was also rigidly attached at the top landing. The stair stringers appear to have acted as braces, inducing out-of-plane demands on the URM wall, causing the localized out-of-plane failure, as shown in Figure 41.

ary support posts to roof trusses, and perimeter roof diaphragm-to-wall anchorage. These retrofit measures were successful even though there was front and rear parapet damage, making access from the front impossible.

A building located less than 200 yards from the Napa netquake station that recorded a peak-ground acceleration of 0.61g seems to have performed as expected (Figure 43). Damage consisted of cracks on the non-structural façade wall elements near the brace base connections, while structural elements also showed damage in the chevron braces and gusset plates which

Figure 42 shows another successful retrofit-- a single-story URM structure with a single owner and multiple tenants. The retrofits consisted of steel moment frames at the front of the building, shotcrete overlay at the rear interior wall, second-



Figure 43. Buckled brace in URM with steel braced frame retrofit (No. 19 in Figure 34; photo: Andreas Schellenberg).



Figure 44. Steel frame with masonry infills: left--rocking wall pier with permanent offset (photo: Bill Tremayne); right--shear failure in wall pier (No. 26 in Figure 34; photo: Andre Barbosa).

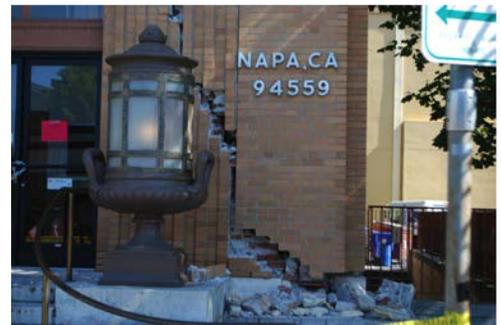




Figure 45. Observed damage in Queen of the Valley Hospital (photos: OSHPD).

showed localized buckling at the first story. This building was allowed to be occupied 30 hours after the earthquake.

A few damaged buildings were identified as having steel or concrete framing with URM infills. The post office building in downtown Napa, a steel frame building with URM infill walls, showed shear cracking in end-wall piers, such as the stair-stepped bed joint sliding seen in Figure 44, interior/slender wall piers damage, and permanent offset in sliding bed-joints.

The performance of URM structures confirmed their high seismic vulnerability, and demonstrated the difficulty of addressing all potential falling hazards even

when comprehensive retrofits are implemented. Of the over 30 URMs in Napa that had been retrofitted, ages of the retrofits varied from over 40 years ago to the present. Most were intended to comply with the various editions of the Uniform Code for Building Conservation with city amendments and/or the California Historical Building Code, as well as applicable sections of the California Building Code for new construction. Several retrofits were completed many years before the city had adopted its mandatory retrofit ordinance. This offers a great opportunity to investigate the performance of different retrofit



Figure 46. Left and right, precast beam and diaphragm connection damage at one location (photos: OSHPD).

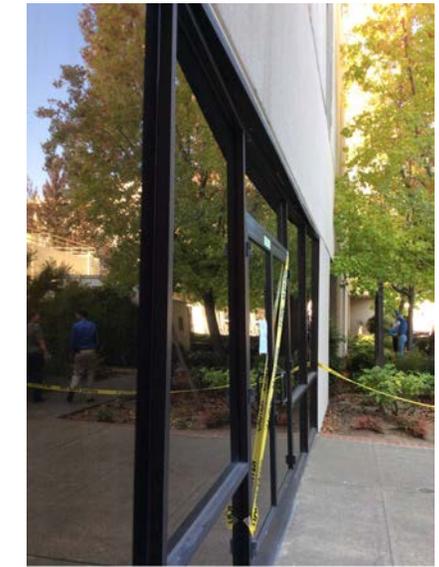
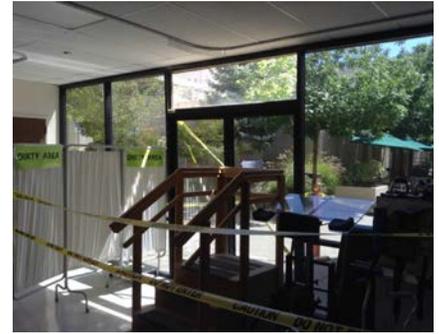


Figure 47. Top and bottom, storefront damage (photos: OSHPD).

systems and details, provided that detailed information is made available. Some key vulnerabilities were not addressed adequately: (a) parapets and tops of walls were left vulnerable; (b) corners of buildings at the roof level appeared to be more susceptible to damage, likely due to the lack of confinement and overburden as well as deformation incompatibilities between orthogonal walls; and (c) some adhesive anchors in older retrofits—particularly with short and straight embedments—intended to connect walls to floor and roof diaphragms did not perform well. Recent acceptance criteria for adhesive anchors prohibit such short and straight embedments. Stone masonry performed below average, even when retrofitted.

Hospitals

(Ali Sumer, OSHPD)

Six general acute care hospital facilities (comprising 58 buildings) and 16 skilled nursing facilities were within 25 miles of the epicenter. The Queen of the Valley Medical Center (QVMC) was the closest to the fault trace (2.3 miles away) and had the most damage. A few buildings lost limited functionality temporarily due to minor structural and/or nonstructural damage. The facility was on emergency power immediately after the event due to loss of power. Three buildings at the QVMC were yellow tagged by OSHPD engineers, and the rest of the buildings were green tagged.

The QVMC buildings had seismic joint damage, plaster cracks, dropped ceiling tiles, and content damage in several rooms. The most extensive ceiling damage was in the North Acute Care Corridor building near the seismic joints at the third floor. A ¾" diameter water line break caused water damage to a few nonstructural



Figure 48. Collapsed stacks of barrels on “two-barrel racks” (top); stable stacks of barrels on four-barrel racks (bottom) (photos: Andy Yiu, Joshua Marrow).

walls in the main hospital building (Figure 45).

In the main hospital building, built in 1957, two elevators were out-of-service, and there was some damage in the precast floor slabs/ beams (see cracks in Figure 46). In the South Nursing Wing building, the storefront bowed in and off the top track (Figure 47). The stucco exterior walls at the ICU rooms pulled down from upper deck at the top of wall approximately ½” causing disruption of services in these rooms. In the North Acute Care building, a humidifier above the corridor ceiling leaked causing water damage to the ceiling tiles underneath.

Wineries

(Joshua Marrow, Partner Engineering and Science, Inc.; Andy Yiu, Partner Engineering and Science, Inc.)

The Napa Valley has approximately 400 wine production facilities, about 300 of which have been built since 1966. An estimated 50 wineries sustained measurable damage to tanks, barrels and/or buildings



Figure 49. Collapsed barrel stacks leaning on interior column (top); a column knocked out of plumb by collapsed barrels (bottom) (photos: Andy Yiu, Joshua Marrow).

(CBS SF, 2014). Damaged facilities were concentrated northwest of the epicenter, west of Highway 29, for about ten miles north of the epicenter. Other wineries had only minor damage to bottles and contents in the tasting facilities.

The earthquake risk profile of a winery is varied based on the time of year. Direct damage and loss of life was minimized due to the time of day and of year. In late August the wineries are preparing for crush, with most of the wine tanks and barrels empty, ready to receive newly crushed grapes and fermented wines. Had the earthquake struck a couple months later, the damage to the production facilities and loss of wine would have been considerably higher.

Early analysis reveals damage to wine barrel storage at facilities located in areas with a PGA greater than 0.20g, less than ten miles from the epicenter. Loss of wine stored in barrels was still being tabulated. Damage to wine barrel storage



Figure 50. Stainless steel wine tank ruptured anchors, shifted 12inches, and buckled tank wall (bottom); tank-supported catwalk collapsed when tank (off to the left) collapsed (top) (photos: Joshua Marrow).

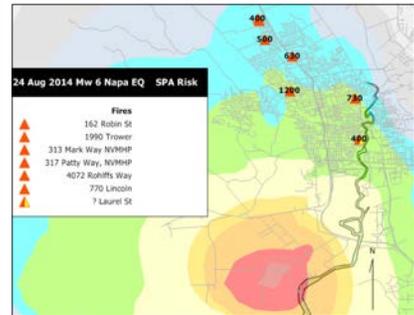


Figure 51. Fires and approximate times overlaid on PGA (half shaded triangle indicates street number unknown) (source: Charles Scawthorn, SPA Risk).

was significant in wineries using the two-barrel portable steel barrel rack system. Stack collapse was not directly tied to the height of the stack (up to six barrels tall, 18-foot long). The vulnerability of the two-barrel rack was previously demonstrated in the 2000 Yountville and 2003 San Simeon earthquakes. The two-barrel racks tend to slide off the supporting barrel below and result in the collapse of the stack above (Figure 48, top). Barrel stacks using the four-barrel rack sustained damage limited to ejection of the top-level barrels, with no reported stack collapse (Figure 48, bottom). Pyramid stacks and other proprietary storage methods

performed well, with no reported damage.

Full 600-pound barrels from collapsed stacks damaged interior building columns and collapsed the exterior wall of a facility 10 miles north in Oak Knoll (Figure 49). Interior stud-frame partition walls separated regions of collapsed barrels, reducing the total collapsed barrel count and wine loss.

Stainless steel wine tanks used in the wine industry are generally not anchored or inadequately anchored. Proper anchorage design is complicated by the tight spacing of the tanks, minimal concrete edge clearance and anchor embedment, and thin bottom course tank walls. Damage limited to full tanks with limited base anchorage. The majority of tanks were empty in preparation for the harvest and crush in September. At a facility located 9.5 miles directly north of the epicenter, three 20,000-gallon tanks were damaged beyond repair, resulting in loss of 75% of the wine (Figure 50, bottom). At the same facility, the tank failure resulted in partial collapse of the catwalk and ruptured PVC cooling lines (Figure 50, top).

Figure 52. lower photo--locations of fires in NVMHP (damaged buildings outlined in red); upper photo--panoramic image of damaged mobile homes (photo: Virtual Earth; annotations: Charles Scawthorn, SPA Risk).



A more complete assessment of winery damage is on-going and will be published as part of the FEMA-funded Applied Technology Council publication ATC-66-8 in early 2015.

Emergency Response

Fire Following Earthquake

(Charles Scawthorn, SPA Risk)

Fire sites were surveyed on the day following the earthquake (August 25), and senior officers of the Napa Fire Department (NFD) were interviewed. A complete list of incidents to which the NFD responded was not available at the time of the interview, but fires attributable to the main shock are summarized in Table 5 and shown in Figure 51 and Figure 52.

The Orchard Avenue fire was the largest in the earthquake. First dispatch was of T1 to a report of gas odor, but en route T1 observed a fire in the Napa Valley Mobile Home Park (NVMHP) off Hwy 29

No.	Time of report (approx)	Location	Description (see below)
1	0330	Orchard Ave	Napa Valley Mobile Home Park (NVMHP) – actually two ignitions – see narrative
2	0400	Laurel St. (no. street number)	2 story, 2 unit residence, roof collapse, started fire
3	0500	162 Robin at Solano	Dbl wide home
4	0630	1990 Trower	Smoke inside structure
5	0730	770 Lincoln x Soscol	Electrical fire in substructure of a mobile home
6	1200	4072 Rohlffs Way x Fair	Kitchen fire in single story multi-unit senior housing complex

Table 5. Fires attributed to the main shock (source: NFD).

at Orchard Road, and diverted to this incident. T1 encountered a broken water main spewing water at the entrance to the park and proceeded to enter. T1 then encountered a single structure fire at 313 Mark Way, with the structure 50% involved; simultaneously, T1 observed a second fire at 317 Patty Way, which was 100% involved and impinging on neighboring buildings, see Figure 52 top). Wind conditions were calm.

Approximately 20 minutes into the incident (at about 0400), Water Tenders 15 and 25 arrived from the Napa County Fire Department. NFD E6 had also arrived and suppressed the Mark Way fire. T1 and WT 25 similarly suppressed the Patty Way fire.

At 1990 Trower there was a report of smoke inside. At this site, which is a restaurant, employees reported some equipment had fallen onto other equipment in the kitchen, causing a call to the fire department. No significant damage.

Rohlffs Way was a report of smoke in a kitchen area of a senior citizens residence.

As reported above, the Napa County FD responded quickly with water tenders. By noon, two OES strike teams had arrived in Napa.

Barricading

(Danielle Hutchings Mieler, ABAG; Ibrahim Almufti, Arup; Janiele Maffei, CEA; Marko Schotanus, Rutherford+Chekene; Bill Tremayne, Holmes Culley; Fred Turner, California Seismic Safety Commission)

In the immediate aftermath of the earthquake, city officials used yellow caution tape around the most hazardous buildings to keep people away from falling debris. This was a temporary measure, and the caution tape could easily

be circumvented. Its use for preventing access to buildings, as well as for closing streets, caused some confusion among residents.

Within several days of the earthquake, city officials replaced the caution tape with chain link fencing barricades and scaffolding. The officials had to weigh their responsibility to protect the well-being of residents while recognizing that barricades in streets could block traffic and affect businesses. When possible, the chain link barricading was placed on the sidewalk in order to keep the streets passable. This practice recognized the falling hazard, but not the potential for debris to be flung in aftershocks. Scaffolding next to a damaged building partially collapsed on October 1st windy day, suggesting the need for engineered designs and strict regulation of temporary structures to ensure their stability and protective capability. Recent California Building Officials, CALBO, (2013) guidance on cordoning and barricading damaged buildings recommends placing either “hard barriers “ (designed for impact loads) immediately adjacent or “soft barriers” at “up to 1.5 times the building’s height” away from it. In most cases, this necessitates installing hard barriers or placing barricades in the street. The CALBO guidance was developed following experiences in Christchurch, New Zealand, where dozens of passersby were killed when brick debris from damaged masonry buildings was flung into streets during aftershocks.

Shelters

(Mike Mieler, John Hopkins University)

Following the earthquake, the American Red Cross established an overnight shelter for displaced residents in Napa at the CrossWalk Community Church which was opened by 10am on August 24 (Napa CountyRed Cross, 2014).

The shelter population grew from eight people the first night to nearly 50 people a week later (City of Napa, 2014; Yune, 2014a; Napa Valley Register, 2014). The shelter recorded 436 overnight stays over the span of two weeks, and closed on September 8 as demand subsided (Rasmus, 2014). On September 8, Napa City and County opened the Local Assistance Center, a one-stop assistance depot with representatives from more than 50 public and private agencies that provide earthquake recovery assistance and information to residents and business owners (Yune, 2014b).

In Vallejo, the Red Cross opened an evacuation shelter on August 24 at the Florence Douglas Center. On account of limited initial demand for the services provided the Vallejo shelter closed soon after its opening but reopened three days later to deal with growing demand and remained opened until September 5, when the Red Cross transitioned the clients in the Vallejo Shelter into long-term housing (American Red Cross, 2014; St. John and Nelson, 2014; Napa County Red Cross, 2014).

Economic Impact

Losses and Insurance

(Mike Mieler, John Hopkins University)

In California, less than 10% of homeowners and businesses with property insurance have earthquake coverage (Buck et al., 2014). In Napa County, less than 6% of homeowners and renters have earthquake insurance (Buck et al., 2014; Carrns, 2014; EQE CAT, 2014). The California Earthquake Authority (CEA) estimates that approximately 15,000 of its policyholders may have experienced moderate to strong shaking from the earthquake (CEA, 2014). While it is still too early to understand the earthquake’s full economic impacts,

a preliminary analysis by EQECAT places the insured losses between \$500 million and \$1 billion, though business interruption costs and contents damage could push the figure higher (EQE CAT, 2014; Pender, 2014a; White, 2014). A report by RMS caps the insured losses at \$250 million (Pender, 2014b).

The City of Napa estimates the earthquake caused at least \$300 million in damage to privately owned homes and commercial properties, and \$58 million in damage to public infrastructure (Pender, 2014b; Kane, 2014). Damage is expected to exceed \$5 million in Vallejo and \$4.5 million in Sonoma County (Fimrite, 2014; St. John and Nelson, 2014; Pender, 2014b; Kane, 2014). On September 11, President Obama declared a partial major disaster for the quake, providing public assistance for both emergency work and the repair or replacement of disaster-damaged public facilities (Napa Local Assistance Center, 2014). Additionally, as



Figure 53. The metal studs supporting this stucco façade pulled away from the floors. The steel connection restraints were bent and the screws were torn out (photo: Lauren Biscombe).

Figure 54. A red-tagged building closed due to hazards posed by an adjacent building (photo: Fred Turner).



part of the declaration, low-interest disaster loans from the U.S. Small Business Administration (SBA) are available to private, nonprofit organizations; the loans provide up to \$2 million to repair or replace damaged or destroyed real estate, machinery and equipment, inventory, and other business assets (Wyatt, 2014). However, the disaster declaration does not include individual assistance to private citizens and households for disaster-related damage, because the federal declaration process for individual assistance is currently under review.

Business Interruption

(Ibrahim Almufti, Arup; Danielle Hutchings Mieler, ABAG; Lauren Biscombe, Arup)

Business interruption in Napa was primarily caused by structural or nonstructural interior damage that triggered the assignment of yellow or red tags. In many cases significant exterior damage also caused adjacent buildings, which were otherwise undamaged, to be yellow or red-tagged. Businesses could not reopen until sufficient repairs were done to merit a green tag.

Downtown Napa was hit hardest, with many businesses still closed at the time this report was writ-

ten. However, in the days after the earthquake, the business community put out a call for residents to come downtown and patronize open businesses. By the evening of the day following the quake, restaurants were full and many people were strolling around downtown. A tourist industry collaborative—including Napa County economic officials, hotels, and wineries—broadcast that Napa was still open for business. Social media including Twitter and Facebook were used. Tasting rooms in most of the wineries around Napa were re-opened the day after the earthquake, despite substantial damage to their inventory.

In many cases, particularly for URM and non-ductile concrete buildings with significant damage, the decision to red tag was fairly straightforward since a life-safety hazard was readily apparent. The extent of downtime for these businesses will likely be considerable as owners must determine whether their buildings are even repairable.

In cases where there was visible nonstructural damage but little to no evidence of structural damage (either because there was no damage or because it was hidden by nonstructural components), buildings generally were yellow-



Figure 55. *Toppled heavy shelving unit in a toy store (photo: Ibrahim Almufti).*

tagged. In many cases, business owners were left to wonder why their building was tagged a certain way and how they could resolve their status. This was indicative of the fact that the tagging process is ultimately based on the judgment of the individual evaluator. The placards provided no information on follow-up contacts.

Several buildings were yellow-tagged due to potential electrical hazards caused by water damage from broken sprinkler pipes; it is not clear whether the earthquake accelerations directly caused the pipes or sprinkler heads to break or whether the breaks resulted from interaction with other building components. This affected some Napa County buildings and two hotels, the Andaz and the Westin Verasa. The Andaz Hotel had water damage as well as damage to its stone façade that was a life-safety hazard to passersby and required barricading. The Andaz is set to re-open in early November, and the Westin Verasa is re-opening parts of the hotel in stages, with a plan to be fully operational by early December.

Storefront glazing broke in many businesses. In some cases, large shards of glass still remained and posed a life-safety hazard which necessitated a yellow tag. Laminated glazing would likely have performed better and avoided a yellow tag. There were several instances of significant façade damage, even to newer buildings like the Andaz Hotel, as noted above. In one case, the steel connections of the metal studs supporting a stucco façade of a three-story office building pulled out of the floors, causing the building (steel moment frame built recently) to be red-tagged (Figure 53). There was also damage to mechanical equipment on the roof of this building that did not trigger the red tag, but it would have contributed to business interruption nonetheless. Stronger equipment anchorage could have prevented some of the damage. Damage to other nonstructural components was less extensive and did not contribute to tagging for this earthquake. This included relatively minor cracking of partitions and some displacement of acoustic ceiling tiles.

When business owners did not own the building in which they were located, the initiation of repairs was delayed until the building owner decided how to proceed, contributing to business downtime. It was not clear what the contractual obligation of the building owner is in terms of making repairs in a timely fashion.

Some undamaged buildings were also yellow or red tagged because adjacent buildings posed a life-safety hazard either from falling masonry bricks or significant façade damage (Figure 54). It may be appropriate to introduce a new tag color for this scenario to help avoid confusion for evaluators and for owners. The status of many of these businesses is currently in

limbo as their ability to re-open is generally out of their control. Some were reinforcing their roofs to prevent masonry bricks from adjacent buildings falling through in the hopes that they would be awarded a green tag.

In light of these “adjacency” issues, cities may want to assess whether resilient central business districts could be created to minimize economic impacts. This would entail retrofitting structurally vulnerable buildings and upgrading façades on existing buildings. It would also incorporate enhancements to achieve “beyond code” performance objectives for new buildings, including additional requirements for new façades. While utility disruption was not a major contributor to business downtime in Napa, improvements to utility and other infrastructure would also support resilient business districts.

Most owners in Napa reported damage to building contents and inventory, and while this contributed to financial losses, it generally did not cause extensive business interruption since the damage did not trigger a yellow or red tag. Since the earthquake struck early on Sunday morning when many businesses were closed, many owners took the day to clean up and were able to re-open on Monday if their building was otherwise undamaged. Of more concern are the injuries that could have resulted from content damage to customers and staff had the earthquake struck during business hours. Inside offices many downed file cabinets and heavy bookshelves landed squarely on office chairs that would have been occupied during the day. A printer was thrown approximately 3 feet from the table on which it had been sitting. At a toy store in downtown Napa bookshelves fell into the aisles (Figure 55); had children been in the store, they could have been badly injured. The single fatal-

ity from the earthquake was caused by a falling television. These types of injuries could be prevented by anchoring heavy building contents; currently this is not required by the building code.

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References

American Red Cross, 2014. "American Red Cross opens evacuation centers following Napa quake," August 24. <http://www.redcross.org/news/article/American-Red-Cross-Opens-Evacuation-Centers-Following-Napa-Quake>; accessed September 23, 2014.

Ancheta, T. D., et al., 2014. "NGA-West2 Database," *Earthquake Spectra*, V, 30(3), pp. 989-1005.

Bakun, W.H., 1999. "Seismic activity of the San Francisco Bay region," *Bulletin of the Seismological Society of America*, 89, pp. 764-784.

Bozorgnia, Y., et al., 2014. "NGA-West2 Research Project," *Earthquake Spectra*, V, 30(3), pp. 973-987.

Bray, J.D., A. Rodriguez-Marek, and J.L. Gillie, 2009. "Design Ground Motions Near Active Faults," *Bulletin of the New Zealand Society for Earthquake Engineering*, 42 (1).

Bray, J., et al., editors, 2014. *Geotechnical Engineering Reconnaissance of the August 24, 2014 M6 South Napa Earthquake*. Report of the NSF-Sponsored GEER Association, California Geological Survey, Pacific Earthquake Engineering Research Center, and U.S. Geological Survey, Report No. GEER-037, September 15. http://www.geerasociation.org/GEER_Post%20EQ%20Reports/SouthNapa_2014/GEER_SouthNapa_9-15-2014_reduced.pdf

Bryant, W.A., 1982. *West Napa fault zone and Soda Creek (East Napa) fault, Napa County*. California Division of Mines and Geology Fault Evaluation Report FER-129, scale 1:24,000.

Bryant, W.A., compiler, 2000. *Fault number 36b, West Napa fault, Napa County Airport section*, in *Quaternary fault and fold database of the United States*. U.S. Geological Survey website: <http://earthquakes.usgs.gov/hazards/qfaults>; accessed 09/22/2014.

Buck, C., L. Philip, and P. Reese, 2014. "Napa's 6.0 rumbler brings up another queasy topic: Earthquake insurance," *The Sacramento Bee*, August 26. <http://www.sacbee.com>; accessed September 24, 2014.

CALBO, 2013. "CALBO'S Interim Guidance for Barricading, Cordoning, Emergency Evaluation, and Stabilization of Buildings with Substantial Damage in Disasters." California Building Officials, November.

Carrns, A., 2014. "After Napa jolt, quake-proofing your homeowner's insurance," *The New York Times*, August 29. <http://www.nytimes.com>; accessed September 24, 2014.

CBS SF, 2014. "Napa Valley Wine Industry Reports \$80.3 Million

Damage Toll from Earthquake,” September 9. <http://sanfrancisco.cbslocal.com/2014/09/09/napa-valley-wine-industry-reports-80-3-million-in-damages-from-earthquake/>; accessed September 23, 2014.

CEA, 2014. “CEA policyholders already submitting claims for damage to homes from American Canyon Earthquake,” August 24. <http://www.earthquakeauthority.com/UserFiles/File/Release/American%20Canyon%20Earthquake%20Release%20Aug%2024%202014.pdf>; accessed September 24, 2014.

City of Napa, 2014. “Earthquake Recovery Status Report,” August 29. http://www.cityofnapa.org/index.php?option=com_content&view=article&id=1864%3Acurrent-status-1pm-aug-29-2014&catid=1%3Alatest&Itemid=923; accessed September 23, 2014.

Clahan, K.B., et al, 2004. Geologic Map of the Napa 7.5' Quadrangle, Napa County, California: A Digital Database. http://www.conservation.ca.gov/cgs/rghm/rgm/preliminary_geologic_maps.html

Clahan, K.B., 2011. Paleoearthquake Chronology along the Northern West Napa Fault Zone, Napa County, California. U.S. Geological Survey Final Technical Report, NE HRP Award number 07HQGR0081.

Clearinghouse, 2014. California Earthquake Virtual Clearinghouse website, Earthquake Engineering Research Institute. <http://www.eqclearinghouse.org/2014-08-24-south-napa>

Dawson, T., et al., 2014. “Surface fault rupture associated with the South Napa Earthquake of August 24, 2014,” in Geotechnical Engineering Reconnaissance of the August 24, 2014 M6 South Napa Earthquake. Report of the NSF-

Sponsored GEER Association Team, California Geological Survey, Pacific Earthquake Engineering Research Center, and U.S. Geological Survey. Report No. GEER-037, Section 3. http://www.geerassociation.org/GEER_Post%20EQ%20Reports/SouthNapa_2014/GEER_SouthNapa_9-15-2014_reduced.pdf

Eidinger, J., ed., 2014. ASCE TCLEE Preliminary Reconnaissance Report of the August 2014 South Napa Earthquake, American Society of Civil Engineers Technical Council of Lifeline Earthquake Engineering, September 2. http://www.asce.org/uploadedFiles/Technical_Groups_and_Institutes/TCLEE/NAPA%202014%20ASCE%20Final.pdf

EQE CAT, 2014. Strong earthquake strikes Napa Valley, shakes San Francisco Bay region. August 24. <http://www.eqecat.com/catwatch/strong-earthquake-strikes-napa-valley-shakes-sf-bay-region-2014-08-24/>; accessed September 23, 2014.

Field, E.H., et al. 2013. Uniform California earthquake rupture forecast, version 3 (UCERF3)—The time-independent model. U.S. Geological Survey Open-File Report 2013–1165., California Geological Survey Special Report 228, and Southern California Earthquake Center Publication 1792 <http://pubs.usgs.gov/of/2013/1165/>.

Fimrite, P., 2014. “Northern California earthquake: Blue-collar Vallejo hit hard,” San Francisco Chronicle, August 25. <http://www.sfchronicle.com/>; accessed September 24, 2014.

Haefner, S. and Blair, L., 2014. Clearinghouse Field Notes, United States Geological Survey, <http://bayquakealliance.org/fieldnotes/>

Kane, W., 2014. “Sonoma County declares quake disaster,” San Francisco Chronicle. <http://www.sfchronicle.com/>; accessed September 24, 2014.

Langenheim, V. E., R.W. Graymer, and R.C. Jachens, 2006. “Geophysical setting of the 2000 ML 5.2 Yountville, California, earthquake: Implications for Seismic Hazard in Napa Valley, California.” Bulletin of the Seismological Society of America, 89, pp. 1192-1198.

Lienkaemper, Jim., 2014. Personal communication. U.S. Geological Survey, 9/19/2014

Miranda, E. and H. Aslani, 2000. Brief Report on the September 3, 2000 Yountville/Napa, California Earthquake. http://peer.berkeley.edu/publications/yountville-napa_sep-2000.html; accessed September 28, 2014.

Napa County Red Cross, 2014. In Facebook [Page]. Retrieved October 17, 2014. <https://www.facebook.com/napacountyredcross>

Napa Local Assistance Center, 2014. Frequently asked questions. <http://www.napaquakeinfo.com/faqs.html>; accessed September 24, 2014.

Napa Valley Register, 2014. “Red Cross closes overnight post-earthquake shelter in Napa,” September 8. http://napavalleyregister.com/news/local/red-cross-closes-overnight-post-earthquake-shelter-in-napa/article_cbe9127e-1584-5d5d-8464-91c1feeac2b4.html; accessed September 23, 2014.

Pender, K., 2014a. “Catastrophe-modeling firms view Northern California quake damage.” San Francisco Chronicle, August 27. <http://www.sfchronicle.com/>

Pender, K., 2014b. “Insured losses from Napa quake won’t top \$250 million, RMS says.” Sfgate, September 2. <http://blog.sfgate.com/pender/2014/09/02/insured-losses-from-napa-quake-wont-top-250-million-rms-says/>; accessed September 23, 2014.

Rasmus, A., 2014. "Napa wineries suffered more than \$80 million in quake damage," September 9. <http://www.ktvu.com/news/news/local/napa-wineries-suffered-more-80-million-quake-damag/nhJn4/>; accessed September 25, 2014.

St. John, P. and L.J. Nelson, 2014. "Earthquake damage in Vallejo is put at \$5.2 million in early estimates, Los Angeles Times, August 25. <http://www.latimes.com>.

Trains, 2014. "Napa earthquake shuts down Wine Train, delays Amtrak movements," Trains Magazine, August 25. <http://trn.trains.com/news/news-wire/2014/08/napa-earthquake-shuts-down-wine-train-delays-amtrak-movements>.

USA.com, n.d.a. Napa County,. <http://www.usa.com/napa-county-ca.htm>; accessed September 21, 2014.

USA.com, n.d.b. Solano County. <http://www.usa.com/solano-county-ca.htm>; accessed September 21, 2014.

USGS, 2014a. Updated Finite Fault Results for the Aug 24, 2014 Mw 6.0 Earthquake 6 km NW of American Canyon, California Earthquake (Version 2). <http://earthquake.usgs.gov/earthquakes/eventpage/nc72282711#scientific>; accessed September 25, 2014.

USGS, 2014b. M6.0 - 6km NW of American Canyon, California Shakemap. <http://earthquake.usgs.gov/earthquakes/eventpage/nc72282711#shakemap>; accessed September 25, 2014.

Wesling, J.R., and K.L. Hanson, 2008. Digital compilation of West Napa fault data for the Northern California Quaternary Fault Map Database. Final Technical Report submitted to the U.S. Geological Survey, NEHRP Award number 05HQAG0002.

White, M.C., 2014. Without insurance, Napa winemakers must absorb quake losses. NBC News, August 26. <http://www.nbcnews.com/business/business-news/>

without-insurance-napa-winemakers-must-absorb-quake-losses-n189401; accessed September 23, 2014.

Wyatt, L., 2014. SBA disaster assistance available to California private, nonprofit organizations. Cal OES Newsroom, September 12. <http://caloesnewsroom.wordpress.com/2014/09/12/sba-disaster-assistance-available-to-california-private-nonprofit-organizations-2/>; accessed September 26, 2014.

Yune, H., 2014a. "Napa shelter tends to earthquake's hardest-hit," Napa Valley Register, August 25. <http://napavalleyregister.com>.

Yune, H., 2014b. "Agencies join forces, open Napa earthquake aid center," Napa Valley Register, September 8. <http://napavalleyregister.com>.

Yune, H., 2014c. "Napa tallies earthquake damage across city," Napa Valley Register, September 17. <http://napavalleyregister.com>.