Napa M5.2 Earthquake of September 3, 2000

Evaluation of Lifeline Performance

by

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1.0 Introduction

The City of Napa was shaken by a moderate-sized earthquake (M_L 5.2, M_W 5.0) on September 3, 2000 at 1:36 am local time. Recorded peak ground accelerations in the Napa area were as high as 0.49g, with recorded peak ground velocity of 15 inches per second.

The Technical Council on Lifeline Earthquake Engineering (TCLEE) investigated the performance of lifeline systems to this earthquake. The team included Mark Yashinsky, John Eidinger and Anshel Schiff. This report presents the preliminary findings for the following lifelines: water, telephone, highways, railroads, ports, hospitals, airports, fire department response, radio communications, highway bridges, electric, natural gas.

2.0 Ground Motion and Geotechnical Considerations

The earthquake occurred on Sunday, September 3, 2000 at 1:36 am pacific daylight time. The epicenter of the earthquake was at 38.3770 degrees latitude, 122.3137 degrees longitude (Figure 1). The hypocentral depth is 9.4 km. The epicenter is located 3 miles west south west of Yountville, and 9 miles northwest of central Napa. The earthquake occurred on an unnamed fault. The earthquake had a strike-slip mechanism. For a M_W 5.0 event, the likely length of fault rupture is 3.5 kilometers. The strike of the fault was in a north-northwest direction. Table 1 provides some of the recorded ground motions in the epicentral area.

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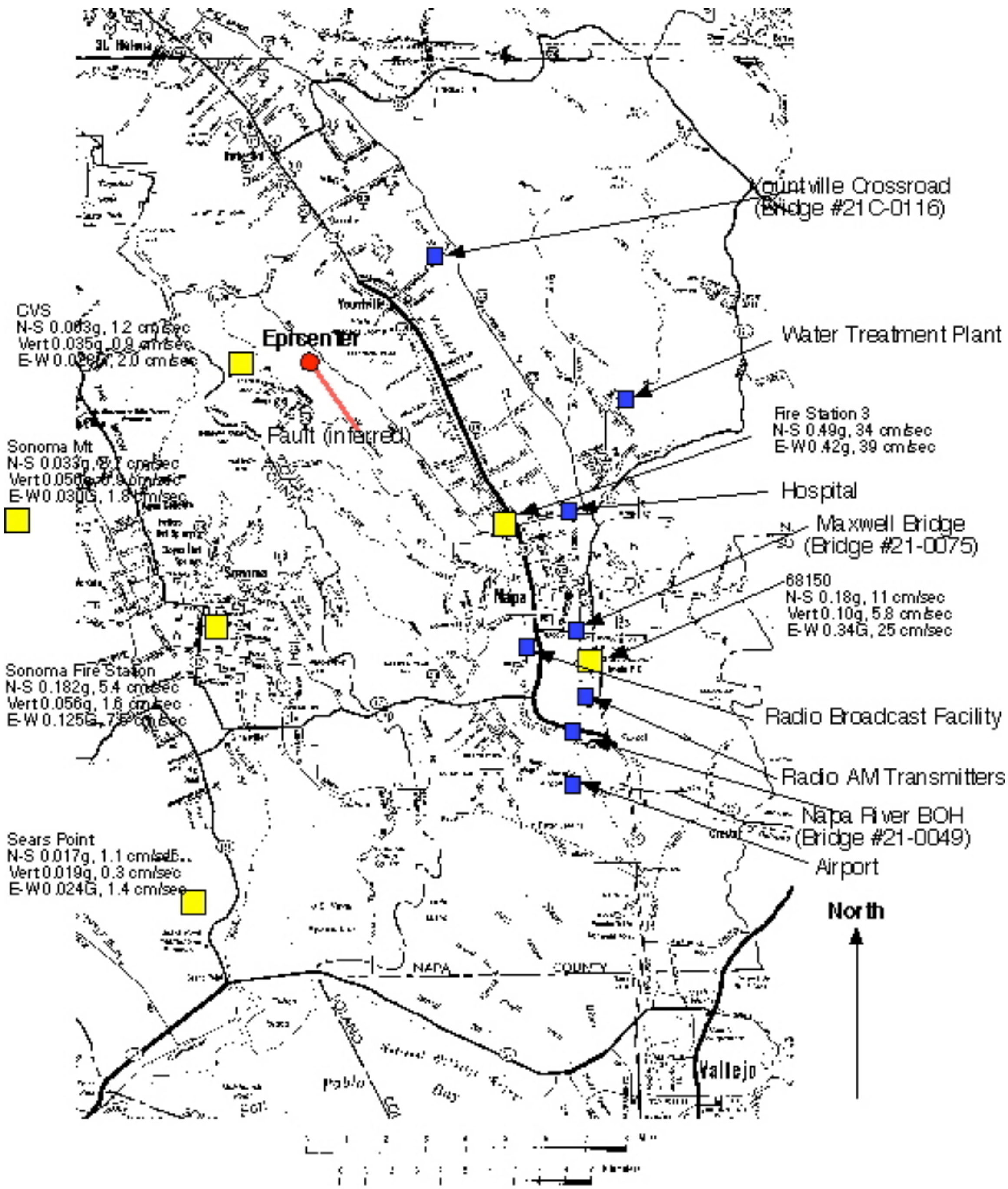

Figure 1. Map of Napa Area and Key Locations

Instrument	N. Lat	W. Long.	Closest Distance to Inferred Fault (km)	PGA (g)
Napa Fire Station 3 (1765)	38.33	122.32	7	0.49
Napa College 68150 (CSMIP)	38.27	122.28	14	0.337
Sonoma Fire Station (1761)	38.29	122.46	9	0.182
CVS	38.39	122.46	3	0.063
Sonoma Mt (MSN)	38.35	122.58	14	0.033
Sears Point (NSP)	38.20	122.46	20	0.024

Table 1. Instrumented Motions Near Epicentral Region

Figure 2 shows the ground motion time histories for instrument 68150. The motions suggest a site period of about 0.4 seconds, typical of a deep alluvial site. In fact, the instrument is located at Napa Junior College, just east of the Napa River.

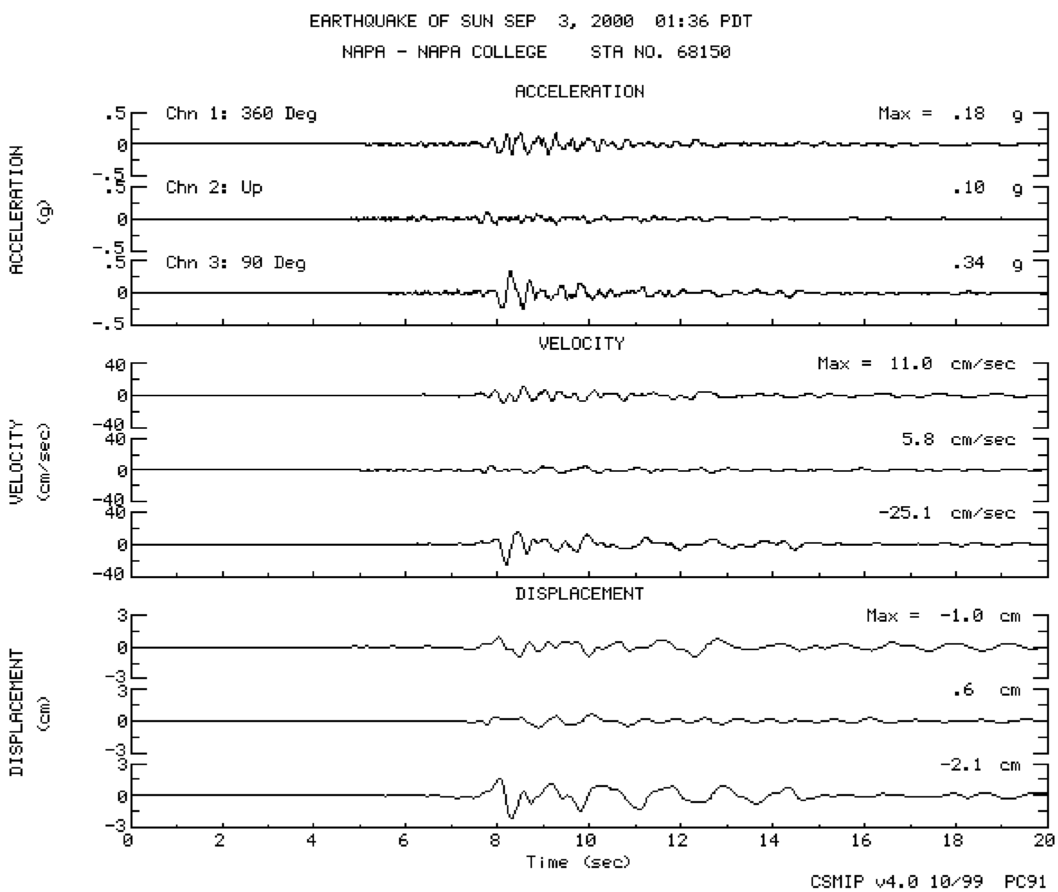

Figure 2. Recorded Ground Motions - CSMIP Station 68150

Using standard attenuation models [Sadigh et al, Sadigh and Egan], the ground motions at various locations in the Napa area would be calculated (as shown in Table 2) for a M_w 5.0 earthquake:

Closest Distance to Fault (km)	PGA (Rock) g	PGA (Firm Soil) g	PGV (Rock) cm/sec	PGV (Firm Soil) cm/sec
3	0.41	0.33	10	13
6	0.25	0.21	6.3	8.3
10	0.15	0.13	4.0	5.4
13	0.11	0.10	3.0	4.2
17	0.08	0.08	2.2	3.2
20	0.06	0.06	1.8	2.6

Table 2. Median Level Horizontal Ground Motions Based on Attenuation Models

The three highest recorded ground motions in Table 1 (Napa Fire Station, Napa College, Sonoma Fire Station) appear to be for instruments on soil sites. The other three recordings appear to be for instruments on rock sites. As can be seen, the recorded motion at CSMIP 68150 (0.34g, 25 cm/sec) is significantly higher than the median level motions (0.11g, 5.4 cm/sec) as predicted for either rock or firm soil sites. The maximum motion from attenuation models for any single horizontal direction would be about 21% higher than those listed in Table 2. With actual recorded pga's of 0.18g and 0.34g and pgv's of 11 and 25 cm/sec, this suggests the following possible explanations:

- The site instrument is located on soft soils subjected to considerable amplification (possible, given its location near a river prone to frequent flooding). For rock-level motions of about 0.1g, soft soil amplifications in the range of 2.5 to 3 have been seen in prior earthquakes, such as the San Francisco bay margins in the 1989 Loma Prieta earthquake.
- The closest distance to the causative earthquake is less than 13 km (but 13 km seems about as close as possible, given the epicentral distance).
- The high level of recorded motion is an artifact of uncertainty in ground motion predictions. Since the attenuation models have a coefficient of variation of about 50%, the recorded motions would seem to reflect a "two standard deviation" (or more) event.
- The site is subjected to complex basin effects or there was a strong directivity effect from the fault rupturing to the south leading to higher amplification of ground motions.

Most of the developed area of the City of Napa is in an alluvial valley. The Napa River runs northwest to southeast through the city and the river is flood prone. There are several creeks that traverse the City of Napa and feed into the Napa River, including Napa Creek, Redwood Creek, Dry Creek, Tulocay Creek, Camille Creek, Browns Valley Creek, and Milliken Creek. The City of Napa extends into the foothills (rock sites) at the far western and far eastern parts of the city.

Based on a preliminary review and discussion with lifeline operators, no widespread evidence of liquefaction or landslides is known to have occurred in developed areas. There was no fault rupture in the developed area (and unlikely in the epicentral area). In one section of town with known high ground water table (Westport), liquefaction was not known to have occurred, and there was no readily observed increased evidence of failure of buried utilities.

3.0 Water System

The City of Napa operates a water distribution system. Raw water is from two dams on the north and east of town and the North Bay Aqueduct. There are three water treatment plants. Typical summer time usage is in the range of 20 million gallons per day. There are about 350 miles of buried pipeline in the water system.

There were 22 pipe breaks and leaks reported for the water system. These 22 do not include numerous leaks on the customer side of the water meter. 18 of these repairs were reported on September 3; 4 more repairs were reported by September 8. The 22 pipe repairs include: 18 mains (4 inch to 8 inch diameter) and 4 0.75-inch service connections (up to the meter); for the mains, 17 of 18 repairs were to cast iron pipe; and 1 repair was to ductile iron pipe. Damage to mains included: holes in pipe (9); cracks or splits in barrel (9). Repair methods for mains used full circle clamps (7), bell clamps (3), cut-in sections of pipe (7), cut-in new fitting (1). Repair methods for the four damaged laterals included new laterals (3) and a clamp (1).

The water utility repaired nine of these damaged pipes on September 3. This required 3 field crews (city crews) plus one contractor crew. Each crew had 4 people. The crews worked longer than normal hours to make these repairs. After the first day, the City released the contractor crew. The remaining pipe repairs were completed as follows: five on September 4; four of September 5; two on September 7 and two on September 8.

At some locations where pipes were damaged, the City hooked up some customers using flex hose attached to hose bibs. This was reportedly done to more rapidly restore water supply to a few houses. All customers had some sort of water supply restored by 11:30 pm September 3.

City repair crews started to be assembled at 3:00 am September 3. From 4:00 am to 8:00 am, the repair crews responded to emergency shut-offs for customers that experienced water leaks within their houses. From 8 am to 10 pm, 3 crews of 4 workers each repaired 8 pipes; one contractor crew repaired one pipe during this time frame.

About 234 field labor hours were expended in making the first nine repairs. About 152 field labor hours were expended in making the next five repairs. About 256 field labor hours were expended in making the last eight repairs, under normal work shifts. On average, it required 29 field labor hours to make the average pipe repair.

There was no reported damage to the water treatment plants, and no sloshing of water out of the basins was reported (all treatment plants had ground motions under 0.10g based on attenuation relationships and distance from the epicenter). There was no reported damage to the City's six water storage tanks (ranging in capacity from 1 to 5 million gallons); these include steel and prestressed concrete tanks. There was no reported damage to the City's pumping plants. There were no reported known electric power outages to the pumping plants, at least when the pumping plant had to operate. There was no reported damage to impoundment dams.

There was no damage to the largest diameter transmission pipelines in the city; these are mostly 36 inch diameter welded steel pipe, plus one 36 inch diameter rubber gasketed asbestos cement pipe. The 36 inch AC pipe traverses the west side of the city; this pipe has been known to fail in the past (non-earthquake conditions), and the City said it was fortunate that it did not break during this earthquake.

Of the 22 pipe repairs, preliminary statistics indicate the following:

- The bulk of the damage occurred on the west side of the City (west of Highway 29)
- Most repairs were to 6 inch to 8 inch diameter cast iron pipe
- Distribution pipe includes older cast iron, some asbestos cement, and some newer ductile iron pipe.
- Damage occurred to pipe joints and pipe barrels. About half the damage was holes in the pipe, with the remaining half as splits and cracks.
- No known damage could be attributed to obvious ground settlements or lateral spreads. More detailed investigations would be required to confirm this trend.
- The pipes were repaired first for those locations with significant breaks / customer outages. During the first day, pipes which were leaking (water seeping to the road) but otherwise seemed to be working were not repaired; these were eventually repaired in the days following the earthquake.

An informal telephone survey was conducted of private plumbing contractors in the Napa area, on September 13, 2000. One plumber contractor replaced 10 water heaters that were damaged but did not tip over. This plumber repaired about 75 water heaters and still has about a one week backlog. Many of the water heaters that developed water piping leaks were anchored, but there was sufficient play or stretching of the straps that significant loads were applied to the attached piping. Based on this survey it is estimated that over 1,000 water heaters in the area required some type of repair service. There were no reports of water heaters actually falling over. There was one report of a gas leak associated with the water heater.

4.0 Fire and Hazardous Material Response

There was one fire ignition caused by the earthquake. It happened in a hotel, reportedly due to falling items that somehow created a fire ignition requiring fire department response. The City of Napa fire department responded and had this fire controlled before it spread (reportedly a room and contents fire).

The City of Napa and the County of Napa fire departments and law enforcement agencies responded to about 400 non-fire related incidents following the earthquake. These included about 30 medical incidents.

There were 30 natural gas leaks that the City of Napa Fire Department and PG&E responded to. These were primarily (possibly all) related to water heaters within buildings that toppled or slid, breaking their gas flex hose connection. There were no fire ignitions from these leaks.

The Fire Department also reported several instances of minor hazardous material spills; the Napa County Hazardous Materials Team responded to these incidents.

The City of Napa obtained mutual aid for law enforcement and fire department strike teams. The law enforcement aid was released by the morning of September 3. Five fire department strike teams (25 engines) were obtained through mutual aid to supplement the City of Napa fire department (10 engines); the fire department mutual aid teams were released the night of September 3.

5.0 Telephone

Wire-based telephone system in Napa is provided by Pacific Bell. There is one large Central Office (CO) in downtown Napa. It is reported that the office sustained no significant structural damage; some covers fell off equipment but did not damage the equipment; backup power was available, although PG&E power reportedly did not go off at the CO location. There were no toppled switches, distressed cable tray runs, etc. reported within the CO.

Pacific Bell reported that there was no congestion of the phone system following this earthquake. (Congestion occurs when too many calls are attempted at the same time, and the central office switches can only process a portion of all the call attempts). The exact level of calls placed (or percentage over normal) is not available. It might be noted that the reasons for lack of system congestion is that the early hour of the earthquake limited the number of calls immediately after the event and in the morning broadcast coverage indicated that the damage was relatively minor.

It was reported that the cell phone systems serving the area worked normally on September 3.

6.0 Radio and Other Broadcast Communications

The City of Napa and surrounding communities are served by KVON 1440 AM radio station. This station provides the emergency broadcast network for the Napa Valley area. The broadcast studio for KVON 1440 AM also serves as the broadcast studio for KVYN 99.3 FM.

At the time of the earthquake, it was reported that a power surge in the PG&E network caused the emergency generator at the broadcast studio to "kick in". Apparently, the PG&E power surge was severe enough to fail a critical part of the automatic transfer switch / emergency generator (possibly the voltage regulator), with the net result that the 15 kW emergency generator was turning, but no power would go into the broadcast studio. The net result was that the broadcast studio was off the air for lack of electric power.

The studio attempted to obtain a spare emergency generator from a local supplier. But due to the grape crush season (September), all spare generators were in use. Once a spare generator could be found, it took extra time to hook it up, as the studio did not have "quick connect couplings" or "pig tails" available for supplemental external emergency power, and had to rely on an electrician to hook up the equipment.

Once power was restored to the broadcast studio, it was determined that a variety of other equipment had failed due to the same power surge. The microwave systems that send the signals from the studio to the transmission towers had failed. Several UPS systems within the studio had failed. Once a microwave link to the transmission towers could be re-established, it was determined that the backup power supply (25 Kw) at the AM transmission towers also failed due a similar power surge, so the studio was still not able to transmit its signal.

Figure 3. AM Transmission Towers - Guy Wires and Mast

Given all these factors, it took almost 24 hours before KVON was able to broadcast again. This was considered a breakdown in a key lifeline for the community, in that this station serves as the emergency broadcast network for the area. In the course of restoring power in the area, PG&E apparently repaired the circuit serving the transmission towers as a low priority, which prolonged the duration of the outage.

The radio station plans to work with PG&E to reset the priority for power restoration. It is unclear if this will happen.

Other than some minor items falling on the floor, the radio station had no other ground-shaking-induced damage at the broadcast studio. At the AM transmission site, the radio station operates four towers. Each tower is a steel truss with guy lines (Figure 3). Apparently, the guy lines experienced high loading during the earthquake, and three of the four towers were displaced sufficiently such that their signals were no longer being broadcast in optimal directions. The fourth tower experienced some damage to the central tower itself, which will need to be replaced. As of 5 days after the earthquake, the transmission towers were not yet repaired, but remained operable with signals going off in non-optimal directions. The exact cause for the tower damage is not clear, but could be due to settlements of some of the guy wire anchors; and/or high transient loading of the guy wires during the earthquake.

Other local communication companies were not visited; however, it was reported that the local cable television operator suffered some level of damage that resulted in the loss of cable TV.

7.0 Hospital

The main critical care hospital serving the City of Napa and surrounding communities is the Queen of the Valley Hospital (QVH) (see Figure 1 for the location of the hospital).

The hospital is comprised of several buildings of various vintages of construction. As of the time of the earthquake, the hospital was not yet in conformance with all current seismic retrofit requirements mandated by the State of California.

The hospital suffered various types of structural and non-structural damage. Structural damage was slight. Performance of non-structural items was as follows:

- Suspended ceiling systems. In the older parts of the hospital, there was extensive dropping of tiles out of t-bar type suspended ceilings in hallways. At the time of inspection, all tiles had been replaced. A rough estimate is that 25% of all tiles dropped to the floor. According to hospital staff, no light fixtures or HVAC equipment within the suspended ceilings dropped to the floor. The damage was most prevalent near edges with walls.
- Fire sprinklers. The hospital has an extensive sprinkler system. No sprinkler heads were damage to the point where they went off. However, many sprinkler heads had moved sufficiently to knock off / dislodge the metal annulus caps around the sprinkler heads and the suspended ceiling tiles (Figure 4). Dozens of these caps were being replaced 5 days after the earthquake. In one case, the sprinkler head had lifted up through the suspended ceiling, and ended up resting atop the suspended ceiling.

- Air chiller. One air chiller unit located at a rooftop fell off its vibration isolation mounts. When it fell off its mounts, it also broke the inlet/outlet water pipes. This air chiller unit served the administration building, and was thus not "critical" to hospital operations. It was temporarily repaired within days following the earthquake (see Figure 4) by mounting the unit on wooden blocks and repairing the attached pipes.

Figure 4. Hospital - Air Chiller Isolator, Sprinkler Head

- There were two emergency generators. Both generators started up after the power surge, but PG&E power was restored to the hospital within several seconds, and the generators were not used. A walkdown inspection noted that one generator was on manufacturer-snubbed isolators and the other was directly anchored to its foundation. The battery systems for the emergency generators did not include suitable spacers to prevent battery movements under strong ground shaking.

The hospital reported a total of one in-patient admission due to earthquake-related injuries and forty out-patient visits. (All hospitalizations included two in-patient admissions). The in-patient admission was due to falling bricks from an unreinforced masonry fireplace falling on a child. It was noted that many dozens of brick chimneys may have fallen in the Napa area in this earthquake, but only one serious injury occurred from such falling debris. Hundreds of brick chimneys were damaged, but not all collapsed (Figures 5 and 6). These broken chimneys remain a hazard to people inside or near the houses should aftershocks occur.

Figure 5. Damaged Chimney.

Figure 6. Broken Chimney.

9.0 Electricity and Gas

The Pacific Gas and Electric Company provided service to the earthquake impacted area. The transmission voltage is 230 kV, the sub-transmission voltage is 60 kV and the distribution voltage is 12 kV. A 230 kV to 60 kV substation is located about 18 miles south of the epicenter. The Napa 60 kV to 12 kV distribution substation is located about 15 miles south of the epicenter. The substations were inspected by PG&E engineer and maintenance personnel and there were no signs of damage or distress.

The Napa distribution station has two banks of 60 kV to 12 kV transformers and seven 12 kV feeder circuits. Immediately after the earthquake three of the seven feeder circuit breakers tripped and locked out. These circuit breakers are designed to reclose after a short delay when a short circuit is sensed. After several attempts to reclose and the fault persists, the circuit break locks out, that is stays open. Thus, momentary touching of the lines will only cause a few second disruption of power. Circuit breaker lock out is usually caused by lines an adjacent phases wrapping around each other, or when they momentarily touch a line burns through and drops to the ground. The three circuits with locked out circuit breakers served about 10,000 customers.

Power outages were reduced to 120 customers by 10:00 am on September 3, and to 15 customers by 3:00 pm September 3. In at least one case (radio station KVON) suffered an electric power surge that destroyed circuitry and rendered backup generators useless. After the earthquake, service crews went out and manually closed the switches, and by Monday morning essentially full service was restored. PG&E said that no transformers, insulators, or circuit breakers were damaged during the earthquake.

Similarly, no gas mains were broken during the earthquake, no major gas leaks occurred, but many hot water heaters toppled or slid sideways, breaking residential gas and water lines (even flex hose lines). The percent of damaged water heaters that were braced to walls or equipped with seismic shut-off valves was unknown. Gas crews were busy on Sunday manually turning-off residential gas lines until repairs could be made. No gas-fed fire ignitions occurred.

The good performance of the buried gas main lines can be attributed to the modest level of shaking, the lack of soil problems such as liquefaction and landslides, and to the absence of surface faulting. The relative good performance of gas pipes versus water pipes remains a topic for further investigation; no cast iron gas distribution mains are known to exist in the Napa area, which may explain some of the good observed performance.

10.0 Transportation

Napa Valley has two closely related industries, wine and tourism. The greatest demand on the transportation system is in the fall when both of these industries are most active. The Napa Valley has the following transportation facilities:

- a small airport just south of the City of Napa,
- two railroads are currently in operation in Napa Valley. The biggest railway is the California Northern Railroad with trains running between Suisin City, Napa, and Vallejo. The Napa Valley Railroad goes from the City of Napa to St. Helena and carries the popular 'Wine Train' several times a day. A third railroad with tracks running west of Napa, the Northwestern Pacific Railroad, is not currently in service.
- The Napa River carries barges that supply sand and gravel to Syart Construction in the City of Napa. A 200 foot cruise ship and a variety of pleasure craft travel along the Napa River between San Pablo Bay and the City of Napa. There are dolphins, marinas, and even dry docks for these vessels in the City of Napa.
- State Route 29 is the largest capacity road running north and south through the Valley, becoming a four lane limited access expressway in the city of Napa. Routes 121, 128, and a local road, the Silverado Trail provide some redundancy; running parallel to SR 29 in Napa. State Route 12 goes across the Valley and connects Interstate 80 to 101. Because the Napa Valley is surrounded by steep mountains, all of the two-lane State Routes become steep and winding as they climb out of the Valley.

There was no significant damage to any transportation facility during this earthquake. The airport sustained no significant damage: there was no structural or mechanical damage to the runway, the administrative building, or to the control tower. Only a few minor items (radios) fell off shelves, but remained undamaged. The airport was not operational at the time of the earthquake (normal operational hours from 7 am to 8 pm), and it is unknown if PG&E power was temporarily lost to the airport or if the two backup diesel generators worked as intended. The control tower was reported to have suffered slight cracking of a non-structural wall.

Both the California Northern Railroad and the Napa Valley Railroad immediately dispatched inspection crews after the earthquake and reported no damage had occurred. In fact, the Napa Valley Railroad ran a 'Wine Train' several hours after the earthquake. The Northwestern Pacific Railroad has a handsome vertical lift railway bridge over the Napa River just south of the City of Napa. This bridge remains raised to allow boat traffic since the railroad is currently out of service. An inspection crew went out on Monday, September 11th and reported that no damage had occurred.

We contacted ports and marinas from Mare Island in Vallejo to the City of Napa and they all reported no damage from the earthquake.

There was some interesting (but very minor) damage to three highway bridges:

- **The Napa River Bridge and Overhead** (Br. #21-0049) was built in 1977. It is a 13 span precast, segmentally constructed, concrete box girder bridge that carries State Route 29 over the Napa River (see Figure 1). The bridge is supported on tall single-column bents and end-diaphragm abutments; all on pile caps that were retrofitted in the 1990's. The structure is composed of four frames separated by three unusual hinges. Instead of a bench for the longer cantilevered span to rest on, they are supported by concrete pistons with steel stoppers (Figure 7). The earthquake widened the hinge openings (and moved the bearings) an inch or two, but the very large gaps (Figure 8) are a pre-existing condition.

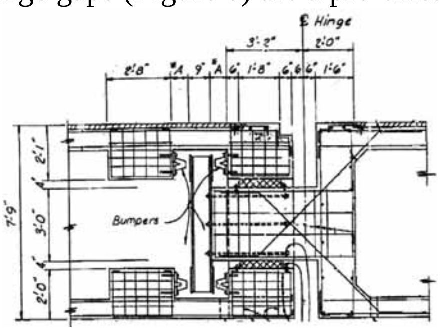

Figure 7. Hinge Detail.

Figure 8. Hinge Opening at Napa River BOH.

- **The Maxwell Bridge** (Br. #21-0075) is a two-lane vertical lift bridge (with a main span of 130 ft) that was.built in 1949 (Figures 9 and 10). It was recently retrofitted to provide greater seismic resistance for the maximum credible earthquake. This retrofit included some work to the towers that carry large concrete counterweights to lift the bridge. The main vertical tower members are 'double (back-to-back) angle sections from which small squares were (almost completely) gas-cut out to allow the counterweight to move freely both transversely and longitudinally after knocking out the cut pieces (instead of banging against the tower legs during the earthquake). The metal squares were left in so the guides on the counterweight wouldn't bind against the holes. During the earthquake, the retrofit worked perfectly, with the guides knocking out the cut metal squares, thus allowing it to swing without hitting the tower legs (Figure 11). However, the metal squares fell onto the roadway, which could have banged up a vehicle or even endangered a driver if the earthquake had occurred when someone was on the road. Therefore, the designer has asked that the plates be tack-welded back onto the channels (to help guide the counterweight) and that little chains should be attached to keep the plates from falling onto the roadway during the next earthquake.

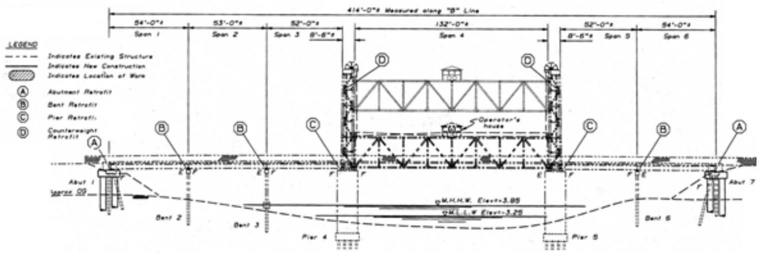

Figure 9. Elevation View of the Maxwell Bridge.


Fig. 10 Tower.


Fig. 11 Retrofit.

- **The Yountville Crossroad Bridge** (Br. ##21C-0116) is a two-lane, locally owned bridge that crosses over the Napa River and Conn Creek just east of Yountville. The superstructure is six simple spans of five precast concrete I-girders on elastomeric rubber pads and with a continuous deck. The substructure is pier walls and seat-type abutments. There was a pre-existing problem at this bridge. The elastomeric bearings had delaminated, allowing the deck to settle onto the exterior shear keys of the eastern abutment and causing the concrete to spall and expose some reinforcement. However, the bearings were never replaced and during the earthquake, the precast I-girders of the eastern span moved sufficiently to spall the exterior shear keys again. Otherwise, the bridge was in good condition.

There was no other bridge damage. All of the bridge damage was on longer river crossings. There are many other bridges in the area including several old stone arch structures that had absolutely no damage. There was no damage to any road from landslide or settlement (except a slight bit of settlement at a few bridge approaches).

11.0 Structural Damage and Earthquake Recovery

As previously mentioned, the most prominent feature of this earthquake was the number of chimneys that were damaged or fell. There was a lot of other damage including broken plumbing, broken windows, and in one case a house fell off of its foundation. We saw many houses with yellow ribbons and some office buildings in downtown Napa wrapped in blue plastic and closed due to moderate damage. Estimates of the cost to repair this damage are still sketchy but public officials are suggesting between $50 to $100 million dollars, largely based on a HAZUS, computer-generated risk analysis. Based on field observations, the bulk of the direct damage could be attributed to chimney failures (200 to 400 of these), a few structural failures, various non-structural failures, and various lifeline damages; this would suggest (very roughly) total direct losses due to this sort of damage in the $15,000,000 range. Repairs or maintenance for cosmetic or other non-structural damage (cracks in paint, repair of water heaters, etc.) may amount to substantially higher total losses. There were no fatalities and few injuries, however the Red Cross was busy providing temporary shelters to families, surveying the damage, and providing counseling as well as food, clothing and medicine. City inspectors are also busy due to the estimated 3,000 to 5,000 buildings that are thought to be damaged. Inspecting and recording damage is important to the City because they need to document the damage to receive assistance from the federal government. Governor Davis has asked the President to declare Napa a federal disaster area. If Napa qualifies, FEMA would come in and provide grants and loans to people impacted by the earthquake.

Although a M_w 5.0 earthquake would seem too low to cause more than light damage, our survey suggests that the damage is more widespread and more diverse. Research should be done to explain the high level of recorded motions from those expected from a M_w 5.0 earthquake; to establish maps of the community with observed levels of amplified ground motions; to explain the large variation in damage to two buried pipe systems (water and gas); to validate loss models (such as those in HAZUS) for wood frame construction with brick chimneys. If a relatively small earthquake can cause this level of damage in Napa Valley, the community should be concerned about the expected M_w 7.0 earthquake on the Rogers Creek Fault and how it will affect the City of Napa.

12.0 References

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13.0 Acknowledgements

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