Learning from Earthquakes

The M_w 6.5 Offshore Northern California Earthquake of January 9, 2010

From January 14th to 16th, 2010, an EERI team investigated the effects of the Eureka, California, earthquake. The team comprised San Francisco structural engineer David Bonowitz, Lori Dengler of Humboldt State University, Bret Lizundia of Rutherford and Chekene Consulting Engineers, and Nick Sherrow-Groves of the University of California, Berkeley. This report was authored by Bonowitz, Dengler and Lizundia.

Many individuals and organizations assisted our reconnaissance effort: Fred Turner of the California Seismic Safety Commission; Stephen Mahin of UC Berkeley Civil & Environmental Engineering; Peggy Hellweg and Doug Dreger of the UC Berkeley Seismological Lab; Bob McPherson and Mark Hemphill-Haley of Humboldt State University; David Oppenheimer and Ross Stein of USGS; Mike Knight and Brian Gerving of the City of Eureka; Kimberly Comet of the Humboldt County Office of Education; Nat Chauhan of the Division of the State Architect; Diane Waters of the California Department of Education; Michael Mahoney of FEMA; Ken Luttrell of Cole Yee Schubert; Randy Giroud of Zucco Fagent Associates; and Jerry Unterkoefler of the California Administrative Office of the Courts (AOC). Valuable information was provided by the USGS, the UC Berkeley Seismological Laboratory, the Times-Standard Newspaper*, the Eureka Fire and Building Departments, the Humboldt County Sheriff's Department, CalEMA, the California Strong Motion Instrumentation Program (CSMIP), and Humboldt State University.*

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The Earthquake

At 4:27 PM PST January 9, 2010 (00:27 UTC 1/10/10), an M_w 6.5 earthquake struck offshore from Humboldt County, California. It was located 34 km NW of Cape Mendocino, 37 km WNW of Ferndale, and 47 km WSW of Eureka within the deformation zone of the southernmost Juan de Fuca plate, known as the Gorda plate. The depth was estimated at about 22 km, but the depth accuracy is relatively poor for offshore earthquakes. There was an estimated 2.4 meters of slip on an unnamed, near-vertical, left-lateral fault oriented about N46°E within the Gorda plate (Figure 1). Inversion of seismic waveforms by the UC Berkeley Seismological Laboratory estimated a fault length of about 25 km, and rupture proceeded unilaterally to the southwest.

Tsunami: As with most strike-slip earthquakes, this one did not cause a tsunami. The NOAA/National Weather Service West Coast/Alaska Tsunami Warning Center issued a Tsunami Information Statement four minutes after the earthquake stating that a tsunami was not expected. There was no

M≥6 earthquakes offshore northernmost California since 1980

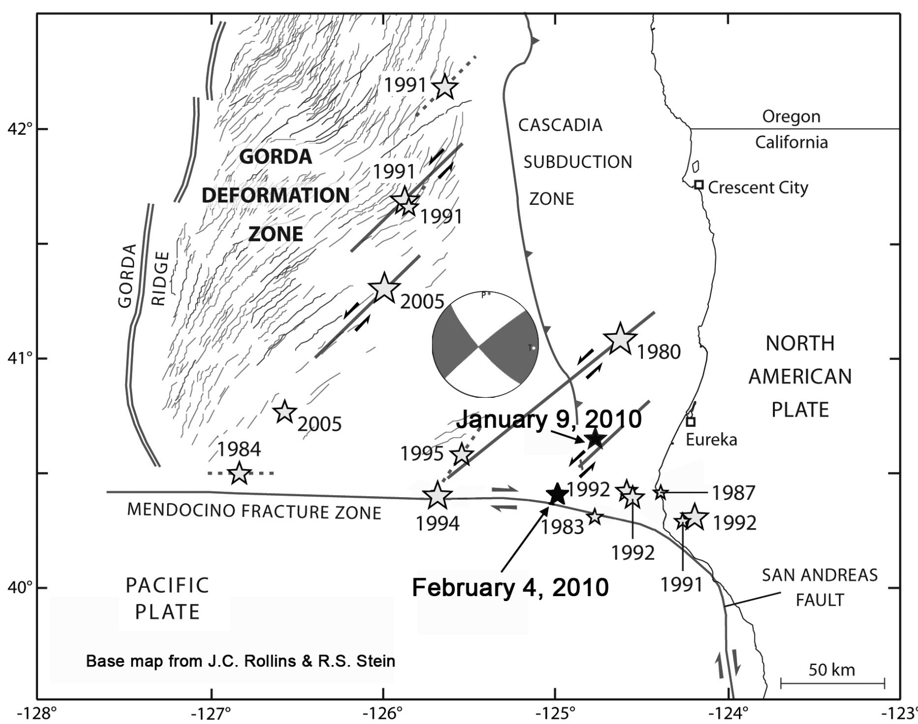


***Figure 1.** Epicenters (stars) of significant northern California earthquakes since 1980. Lines show Gorda plate fault ruptures and arrows show the direction of slip. The January 9 and February 4 earthquakes are shown by solid stars. NCSS (Northern California Seismic System) focal mechanism shows the best fit double couple for the January 9 event. Adapted from base map of J. Collins and R. Stein, **http://quake.usgs.gov/research/deformation/modeling/papers/2009/rollins.html**.*

evidence of any water level disturbance on the nearest tide gauge located just inside Humboldt Bay.

Aftershocks: Fifty-nine aftershocks were detected in the week after the earthquake. Most were located along the trend of the fault rupture, but some were in the southeastern Gorda plate south of the rupture and along the Mendocino fault. The largest, an M4.4 about 90 minutes after the mainshock, was felt in the Humboldt Bay and Cape Mendocino areas.

On February 4, an M_w 5.9 earthquake struck about 43 km west of Cape Mendocino and 28 km southwest of the January 9 epicenter. This earthquake appears to have been a triggered event on a different Gorda plate fault, but there is still uncertainty as to its orientation due to its offshore location and a lack of aftershocks.

Tectonic setting: The earthquake's epicenter was northwest of the Mendocino Triple Junction, the intersection of three plates (the Gorda, Pacific, and North American) and three plate boundaries (the Mendocino fault, the San Andreas fault, and the Cascadia subduction zone). The January 9 earthquake was an intraplate earthquake within the Gorda plate beneath the locked Cascadia megathrust.

Table 1: Earthquakes with MMI ≥ VII since 1900 in Eureka, California

Date	Magnitude*	Latitude	Longitude	Peak MMI Petrolia	Peak MMI Ferndale	Peak MMI Eureka
18 Apr 1906	7.8	37.70	122.50	IX	≥VIII	VII
18 Aug 1908	5.0	40.83	124.17	V	VII	VII
29 Oct 1909	6.4	40.58	124.17	VIII	VIII	VII
23 Sep 1930	5.5	40.80	124.20	VI	VI	VII
6 Jun 1932	6.4	40.87	124.02	VII	VIII	VIII
3 Oct 1941	6.4	40.54	125.00	V	VI	VII
21 Dec 1954	6.6	40.85	123.96	V	V	VIII
3 Feb 1979	5.2	40.92	124.42	V	V	VII
8 Nov 1980	7.2	41.12	124.67	V	V	VII
25 Apr 1992	7.2	40.37	124.31	IX	VIII	VII
26 Dec 1994	5.4	40.74	124.31	V	V	VII
10 Jan 2010	6.5	40.65	124.69	VI	VII	VII

* Moment magnitudes for earthquakes from 1980 to present. See Dengler et al., 1992 for details on earlier events.

Historic seismicity: Over the past 150 years, the coastal and offshore areas of Humboldt and Del Norte counties have been the most seismically active region of the coterminous United States (Dengler et al., 1992).

Since 1900, 27 earthquakes have damaged structures in Humboldt County. Table 1 shows those with MMI ≥ VII in Eureka. Most have been centered offshore or near Cape Mendocino, sparing the more populated Humboldt Bay region the strongest shaking. The greatest impact to the Eureka area was most likely caused by the 1932 M 6.4 earthquake, which toppled hundreds of chimneys and caused one death (Dengler et al., 1992).

The January 9 earthquake was the largest to affect Humboldt County since the June 15, 2005, M_w 7.2 offshore Eureka earthquake and the first to cause damage since an M_w 5.4 earthquake on December 26, 1994. The most significant recent earthquake sequence was on April 25-26, 1992, when the M_w 7.2 Cape Mendocino earthquake struck onshore near Petrolia, followed by M_w 6.6 and 6.7 earthquakes in the next 18 hours. The sequence caused at least $60 million in damage and resulted in a federal disaster declaration (Oppenheimer et al., 1993).

Strong Motion: The California Strong Motion Instrumentation Program (CSMIP) recorded the earthquake at 37 sites (22 free field, 10 on bridges, and five in buildings), seven of which were in central Eureka and one in Ferndale. Maximum recorded accelerations were 0.44g at the free field site in Ferndale (see Figure 3) and 0.33g at a site in Eureka.

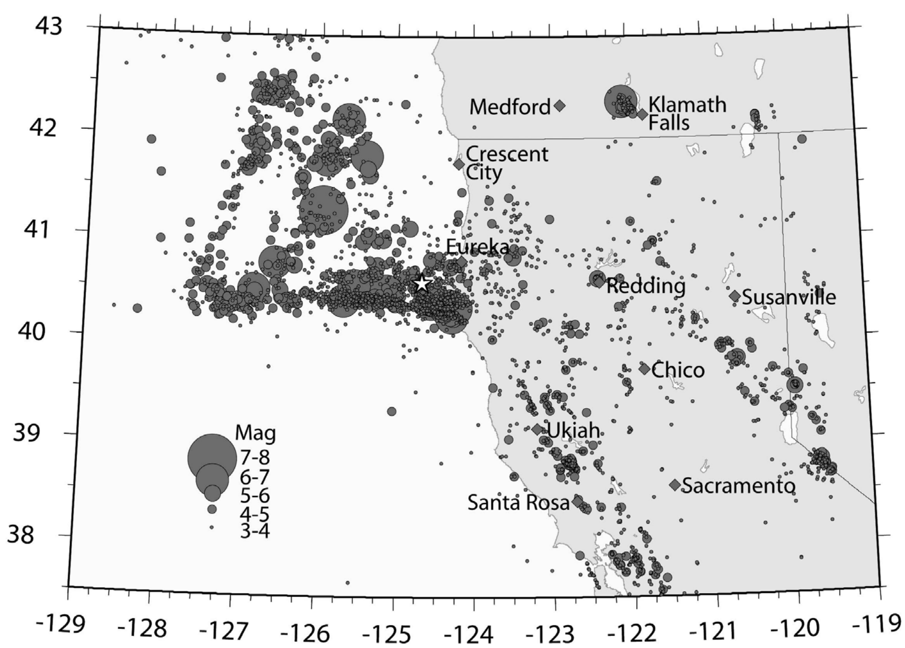


__Figure 2.__ Historic North Coast earthquake epicenters 1975 to 2010. Star shows the location of the January 9 earthquake. Figure by D. Oppenheimer, USGS.

The earthquake was felt as far south as Capitola, California; as far north as Eugene, Oregon; and

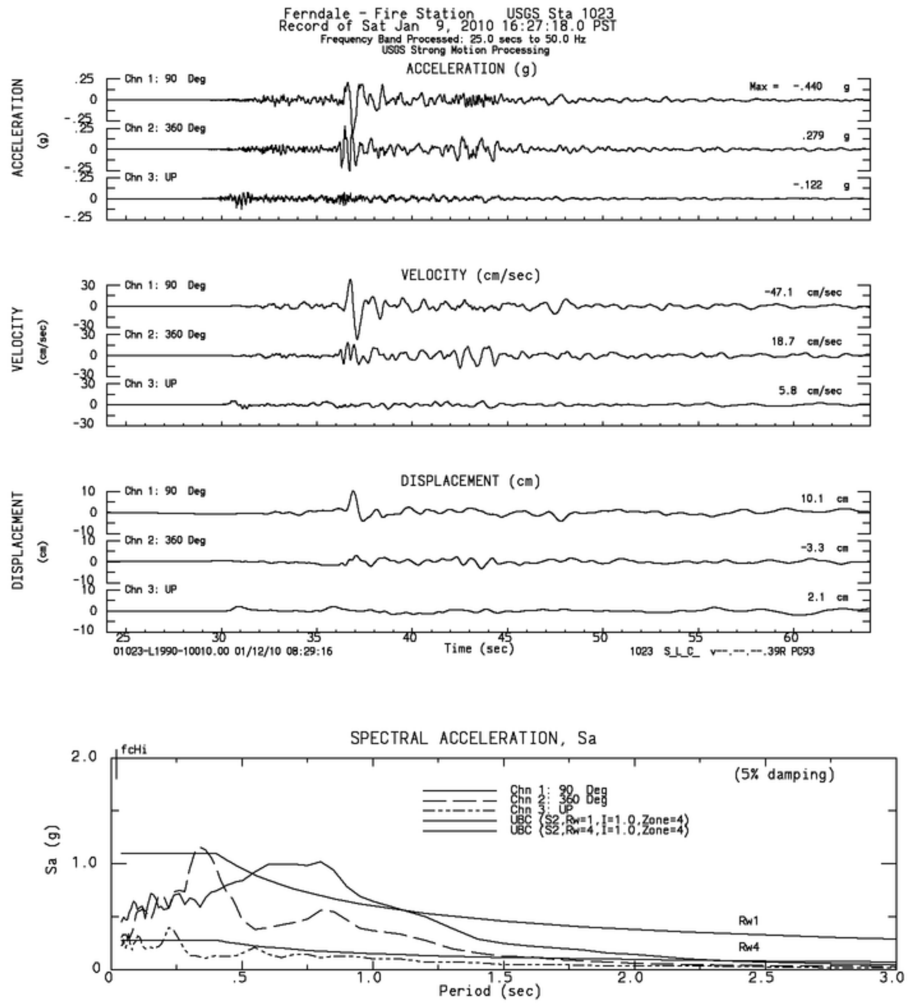


Figure 3. *Strong motion recording at the Ferndale station.*

Geotechnical Aspects

Landslides: Large bluff failures were observed south of the Eel River (Figure 6). A number of small slips were seen in the Humboldt Hill area and on the bluffs adjacent to Highway 101 south of Eureka. Several bank failures caused damage to the Mattole Road south of Ferndale.

Liquefaction and spread failures: Liquefaction was observed on Centerville Beach and along the Eel River (Figure 7). The Centerville Beach features were subtle and had been overtopped by high tide washover. Small sand boils were better preserved on the banks of the Eel River and associated with spread failures ranging in length from less than one meter to 20 m. Spread failures were observed at King Salmon and along the banks of the Eel River. The most developed spread failures were located on the spit north of the mouth of the Eel River, where some features extended 10 m or more with offsets up to 40 cm. Heavy rainfall on January 12 likely erased surface features elsewhere.

as far east as Reno, Nevada. About 20% of the vertical monuments at the Ferndale Cemetery were toppled or displaced, and preliminary analysis suggests an east-west alignment (Figure 4). Cemetery monuments in Eureka, Table Bluff and Loleta show similar, but smaller, amounts of displacements.

Implications: The January 9 rupture affected the stresses on adjacent plate boundaries (Figure 5). Ross Stein of the USGS calculated that the slip increased the stress on the Cascadia megathrust boundary to the west of the rupture by about 0.2 bars and decreased it to the northwest by a similar amount. The slip also increased the stress on the Mendocino fault to the south of the rupture by 0.6 bar.

Figure 4. *Toppled monument at the Ferndale Cemetery.*

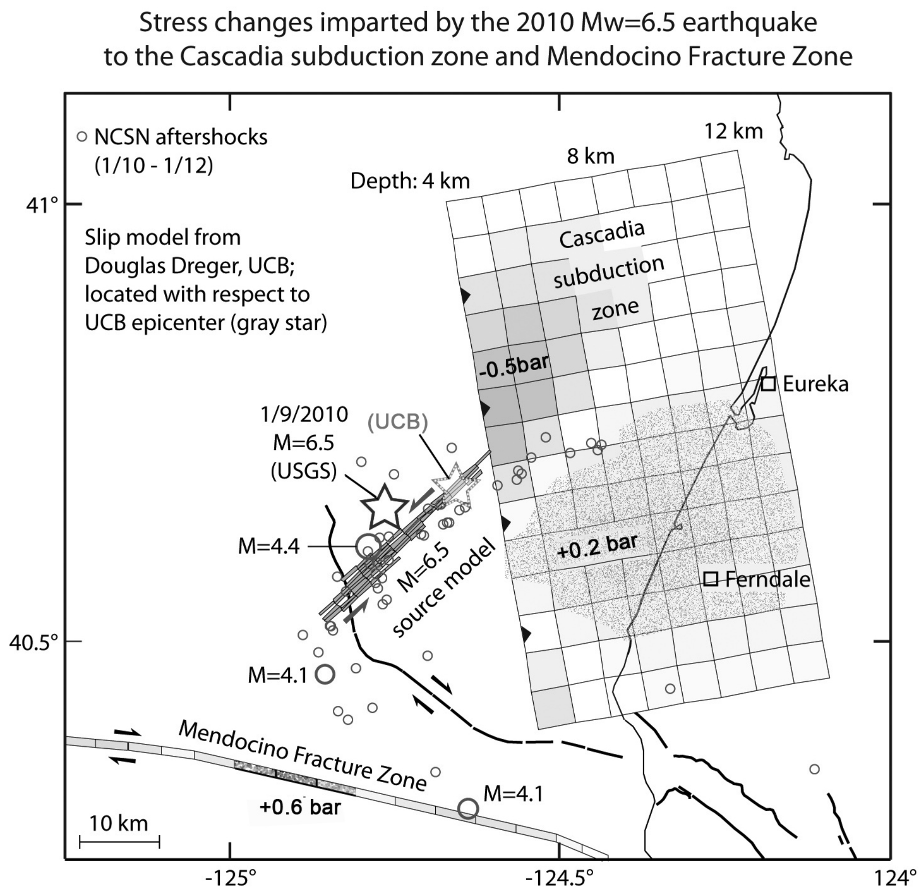


***Figure 5.** USGS calculated stress changes on the Cascadia subduction zone and Mendocino fault. Star is the location of January 9 mainshock, and circles show aftershocks through January 15. The dappled areas show regions of stress increase on the Cascadia megathrust interface above and to the east of the fault rupture, and along the Mendocino fault south of the rupture. Grey areas show regions of stress decrease. Adapted from figure by R. Stein, USGS.*

Building Damage and Fragility

Eureka, the largest city affected by the earthquake (population 27,000), reported nearly 800 structures damaged, ten seriously. Damage to structures was also observed in Ferndale, Loleta, and Fields Landing. Earthquake losses for all of Humboldt County (as of January 15) were estimated to approach $30 million (Larkin, 2010), down from estimates in mid-January of over $40 million (Greenson, 1/15/2010).

Overall, there was damage to only a small fraction of the building stock, and its familiar patterns offer no new lessons. Retrofitted buildings performed well, but with low damage in general, a statistical distinction is not clear.

Local construction characteristics and history: Buildings in Eureka are low-rise structures built in relatively low density. In the Old Town area, brick and wood structures date back to the 1860s. Many have shops and restaurants on the ground floor with office or residential space above. Outside the historic section, commercial buildings present the range of mid- to late-twentieth century construction types, including tilt-ups and reinforced block masonry. There is a small inventory of concrete buildings. There are no high-rise structures and few areas of recent development. The housing stock is predominantly single-family, and nearly all woodframe construction.

Ferndale (population 1,380) has a building stock that is now nearly exclusively woodframe. Structures built in the 1870s through the 1890s remain along Main Street. About three quarters of Ferndale's present commercial building stock was damaged in both the 1906 Northern San Andreas earthquake and in the 1992 Cape Mendocino earthquake (Dengler, 2008).

Unreinforced masonry buildings: Only two URMs were ever built in Ferndale. One was demolished due to damage in the 1906 earthquake (Dengler, 2008). The remaining building was damaged in the 1992 earthquake and replaced with a woodframe structure (SSC, 2006).

A 1989 ordinance mandated seismic rehabilitation of Eureka's URM bearing wall buildings, which reportedly numbered about 40, but compliance has been incomplete, and deadlines have been extended several times. By 2006, demolitions and fires had brought the number of URMs down to 27, fifteen of which were identified as rehabilitated (SSC, 2006). Our reconnaissance found that several of these are not actually URM; some are cast stone (concrete) intended to simulate masonry; others have wood siding textured to look like stone. Our count includes 19 remaining URMs, five seismically rehabilitated and 14 either not strengthened, partially strengthened, or locally repaired after previous earthquakes.

Visible seismic rehabilitation elements include steel moment frames (likely pre-Northridge) and braced frames at open fronts, and diaphragm-to-wall ties with exposed anchor plates.

Most buildings were surveyed from the exterior only and classified by judgment using ATC-13 (ATC, 1985). Table 2 provides a summary of damage estimates. EERI (1994) developed expert opinion estimates of the expected damage to seismically rehabilitated URM buildings. These predictions are listed in

Figure 6. ▲ *Above: Bluff failures south of the Eel River Valley.*
▼ *Below: Bank failure on the Mattole Road.*

the table for the MMI = VII shaking level experienced in Eureka. Table 3 provides a summary of the ATC-20 (ATC, 1989) tagging.

None of the five rehabilitated URMs saw significant damage in this earthquake. Four of the 14 not strengthened URMs did suffer significant damage. Overall (though the small numbers are of limited statistical significance), both groups performed better than experts would have expected.

At the vacant, three-story Old Town Bar and Grill, a long length of the parapet and top of the east side wall fell and destroyed the wood roof of the adjacent single story building. No one was in the adjacent building at the time. In addition, the front (south) façade was leaning toward the street, leading the city to fence off most of the block. This URM had been damaged in a previous earthquake, and roof-to-wall and roof-to-parapet through-wall ties had been installed as a repair measure. No ties were installed on the side walls, including the wall that fell (Figure 8).

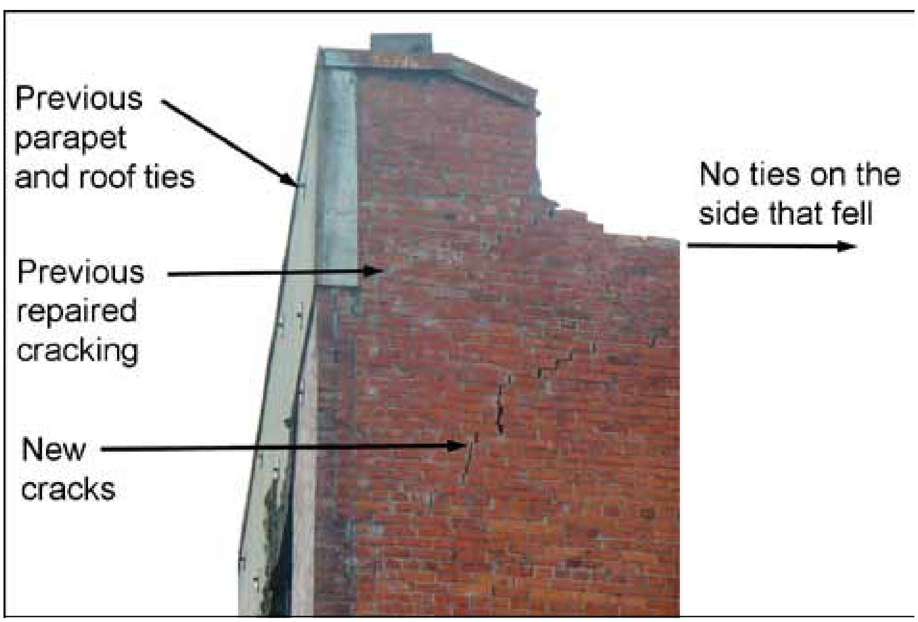
At the Lloyd Building, the front (south) façade was leaning toward the street, resulting in closure of one lane in the 200 block of 5th Street (which is also Highway 101 North). It too showed evidence of previous damage at the rear, where it appeared that local steel roof-to-wall and roof-to-parapet ties and

Figure 7. ▲ *Above: Sand boils along the Eel River, 25 centimeters in length. Right: Spread failures on spit north of Eel River mouth.* ►

Table 2: URM Building Damage in Eureka

Observed Damage					Predicted Damage	
ATC-13 Damage State	Seismic Rehabilitation Status				for Retrofitted Buildings	
	Unretrofitted/Partial		Retrofitted		Damage State	MMI = VII
	Number	%	Number	%		%
None	2	14	2	40	None	40-60
Slight	9	64	2	40	Slight	20-40
Light	2	14	1	20		
Moderate	1	7	0	0	Moderate	10-20
Heavy	0	0	0	0	Extensive	2-10
Major	0	0	0	0		
Destroyed	0	0	0	0	Complete	<1
Totals	14	100	5	100		
Source on damage state observations: EERI Reconnaissance Team					*Source: EERI (1994)*	

Figure 8. *▲Top: Unreinforced masonry damage to the Old Town Bar and Grill, Eureka. ▼Bottom: Close up of damage at southeast roof corner.*



steel straps had been installed as repairs. Bed joint sliding of the masonry walls was observed, as was repeat damage at the roof corners, in same locations as the previous repairs.

The front (west) wall of 123 F Street, built in 1882, is all windows except for one wide brick pier. A renovation in 1977 added a mezzanine within a tall upper story and installed cable "X"-bracing in the window bays between west side columns. Through-wall diagonal tension cracking was observed in the lone brick pier, but no damage was observed to the cables, which were apparently too flexible to prevent the brick pier from resisting a substantial portion of the load. Though the building was eventually green-tagged after an engineering inspection, the pier damage would be classified as "Moderate" per the criteria in FEMA (1999).

Large woodframe (commercial): Downtown Eureka has several multi-story woodframe buildings. A four-story Renaissance Revival building built in 1903 on E Street (Figures 9 and 10) has a front (west) façade that is largely glass, particularly in the ground story. Plumb bob measurements found ground story north-south permanent drift of 1.4% on this line, with only 0.6% along the rear (east) wall. Ground story north-south windows and interior partitions were also damaged.

Investigation revealed that the rear property line wall was made of what is locally called "laminated wood construction," built of 2x6 (5 cm x 15 cm) studs nailed together on their wide face for the entire length of the wall, effectively creating a solid wood wall of 6" (15 cm) nominal thickness. Reportedly, the thick laminated wall is relatively effective during fires, behaving like heavy timber construction, and was used in a number of buildings along property lines.

Table 3: Postearthquake Safety Tagging for URM Buildings				
ATC-20 Initial Tag	Seismic Rehabilitation Status			
	Unretrofitted/Partial		Retrofitted	
	Number	%	Number	%
Red	4	29	0	0
Yellow	1	7	0	0
Green/None	9	64	5	100
Totals	14	100	5	100

Source on tagging: City of Eureka (2010)

Figure 9: *Base of a portion of the front façade of 333 E Street with damaged glazing. Residual ground story interstory drift of 1.4% was to the left.*

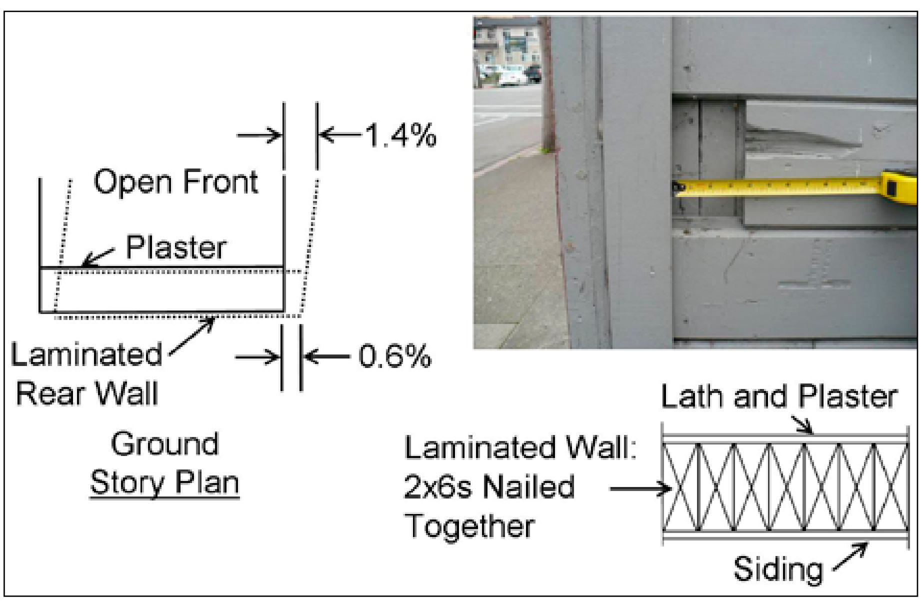


Figure 10. *Plan view of ground story drift and detail of rear laminated wall construction at 333 E Street.*

In Ferndale, most of the buildings on the historic Main Street are multi-story wood structures. While many sustained damage to plate glass windows, none was visibly out-of-plumb or initially tagged for restricted use. Several of these buildings present archaic construction; for example, the two-story Post Office has a thick sawn sill plate but no anchor bolts into its concrete footing. Light-gage hold-down straps have been added to the original wood studs, but these cannot act as adequate anchor bolts or hold-down hardware. While the building's storefront window was broken, there was no sign of structural damage.

Elsewhere in Ferndale and Fernbridge, we observed one-story warehouse sheds with only post and pier foundations but no apparent earthquake damage.

Small woodframe (residential): A collapsed cripple wall house in Eureka represented the most complete loss of any structure in this event (Figure 11). The collapse of unbraced cripple walls is not surprising; in 1992, several collapsed in Ferndale and Petrolia (EERI, 1992). The City of Eureka Building Department received 56 reports or inspection requests for foundation damage within a week of the earthquake, but only the collapsed house and one other were red-tagged. Six others were yellow-tagged, and ten had not yet been inspected but remained occupied. One house outside the city was reported "knocked off its foundation" (Greenson, 1/13/2010).

The collapsed house did have a taller cripple story than its neighbors, with eight steps to the porch instead of the more commonly observed three or five. Still, similarly tall cripple walls were observed in Ferndale, with no apparent damage.

What remains unknown is which of the undamaged houses might have been retrofitted. After the 1992

Figure 11. *The only structure to collapse in this event. Note the large number of front steps, indicating a cripple story taller than that of neighboring houses.*

earthquake, FEMA funded some cripple wall retrofits through an Individual Assistance program, but we did not have records to support a study of those properties.

There was no apparent damage to manufactured or mobile homes in four parks visited.

"Tuck-under" woodframe (residential): Many multistory residential buildings with ground floor parking present soft or weak story deficiencies. As Eureka and Ferndale have low density building stocks, we found only two buildings typical of this style, and neither showed any sign of significant earthquake damage.

Concrete tilt-up: We visited two Eureka tilt-ups, one with a wood truss roof and one with more modern glulam roof framing. Each was shaken hard enough to sustain significant nonstructural and contents damage, but no structural damage was found or suspected. Several other tilt-ups in or near downtown were observed only from the outside. Their re-occupancy suggests no significant damage.

Pre-1980 concrete frame and wall: Eureka has about a dozen pre-1980 concrete buildings (not counting tilt-ups) that might be roughly grouped as pre-World War II and post-World War II. None presented significant structural damage related to their concrete structures.

The auditorium wing of Eureka High School (built in 1929, modified in 1964, and partially retrofitted in 2006) was temporarily red-tagged after some wood ceiling framing members were found fractured. However, the concrete lateral system sustained no apparent damage.

Post-war concrete buildings include several public facilities.

The county coroner's office, built originally as the county hospital, showed no apparent damage. City Hall, which was home to the emergency operations center for this event, also showed no structural damage, though some first story exterior tile veneer was cracked and delaminated.

The six-story Humboldt County Courthouse is one of the largest facilities in the city (Figure 12). Built in the 1960s and retrofitted with concrete shear walls after the 1992 earthquake, the structure showed only insignificant cracking along a horizontal construction joint in an original stairwell, as well as partition damage around a door opening to that stairwell.

The St. Joseph Hospital complex in Eureka includes a concrete frame structure and a 1978 concrete shear wall structure. The shear wall structure is instrumented by CSMIP

Figure 12. *Humboldt County Courthouse, showing shear wall added in left bay as part of a seismic retrofit after the 1992 earthquake.*

(Station 89770); peak accelerations were 0.33g in the free field, 0.29g at the building basement, and 1.18g at the roof, with one upper level sensor recording over a 5% damped spectral acceleration of over 5g at about 0.35 seconds. No structural damage was reported.

Steel: We are aware of only one steel moment frame structure in the area of strong shaking: a wing of St. Joseph Hospital built after the 1994 Northridge earthquake. Damage to adjacent gypsum board partitions and at seismic joints between hospital wings was reported, but hospital operations reportedly were not affected. Hospital staff reported a perceived increase in nonstructural damage from aftershocks (Mahin, 2010). Engineers from the Office of Statewide Health Planning and Development (OSHPD) were to inspect the complex further.

A three-story special concentric braced frame was in construction at St. Joseph Hospital. There was no evidence of structural damage, but cosmetic damage was observed at seismic joints between structures, especially those adjacent to the steel SMRF.

Nonstructural Components and Building Contents

Damage to nonstructural components repeated patterns observed in many past earthquakes:

- Extensive damage to reinforced and unreinforced brick chimneys, including cracking, collapse, and shifting above the roof line.

  Within a week of the earthquake, Eureka's building department had logged 197 reports or inquiries about chimney damage, 78 of which received yellow tags suggestive of a remaining risk. We found additional chimney damage that owners were unaware of (see Figure 13), so these figures likely undercount the actual damage. On January 22, the city posted on its web page an advisory about the possibility of unseen chimney damage.
- Water heater or related gas line damage. While no fires were caused by this damage, the city received 23 reports of damage within a week of the earthquake.
- Isolated damage to exterior brick veneer.

Figure 13. *Chimney damage in Eureka was both ◄ obvious and ▲ unnoticed.*

- Damage or loosening of theater marquees, signs, and building ornamentation.
- Cracking and damage of plaster partitions and ceilings.
- Damage to interior stone veneer and partitions at the U.S. Court House and Post Office, a structurally damaged URM building.
- Falling ceiling panels and integrated light fixtures, with extensive damage reported in some parts of the Bayshore Mall.
- Broken windows and storefront glazing. While there was little structural damage in Ferndale, there was extensive breakage of large untempered display windows along historic Main Street. Glaziers performing repairs said they had replaced many of the same windows after the 1992 earthquake.
- Ruptured gas lines at equipment interfaces. PG&E crews responded to 75 reports of residential gas line breaks.
- Ruptured or broken sprinkler heads or fire suppression piping in one shop at the Bayshore Mall, leading to substantial property damage and downtime of one month (White, 2/12/2010).
- Elevators at St. Joseph Hospital had to be reset but were otherwise undamaged.
- Two 6,000-gallon auxiliary potable water tanks at St. Joseph Hospital were damaged at their supports, but hospital operations were not affected, presumably because the main water supply remained intact.

We heard no reports of significant damage to mechanical equipment or vibration-isolated equipment within buildings. Similarly, while Ferndale residents rely on individual propane tanks, we observed no damage to any tanks, including some not bolted to their pads.

We heard no reports of damage to manufacturing equipment. However, at the Lost Coast Brewery in Eureka, two elevated tanks not bolted to their pads slid and had slightly buckled legs. One shifted tank led to some minor piping damage.

As with the nonstructural damage, reported and observed contents damage was largely predictable, familiar, and insignificant to safety and downtime. One hazmat team responded to a small chemical spill in a lab at the College of the Redwoods (White and Driscoll, 1/11/2010).

Initial Response and Emergency Services

Emergency Operations Center: Both the Humboldt County and the City of Eureka Emergency Operations Centers were activated and conducted assessments and information gathering. The California State EOC was not activated. Governor Schwarzenegger declared a State of Emergency for Humboldt County on January 12.

Eureka has designated its retrofitted main fire station as the site of its emergency operations center. Though it did not appear to affect response, a suspicion of damage (later ruled out) prompted a relocation of the EOC to City Hall, a pre-1980 concrete building.

Hospitals: Twenty-seven people with injuries were treated at St. Joseph Hospital the night of the earthquake, with only one major injury reported (a broken hip) (*Times-Standard*, 2010). St. Joseph, the main hospital in Eureka, saw peak ground accelerations of about 0.3g. As noted above, the facility comprises a variety of structure types; it sustained minimal structural damage and was not compromised by nonstructural or contents damage. Engineers from OSHPD were to inspect the complex further. Hospital staff reported they were able to implement their response-and-recovery plan without difficulty.

Private sector preparedness: Numerous security cameras and home videos captured the January 9 event. Most footage shows people running out of buildings, failing to follow the accepted advice to "drop, cover, and hold on."

Many people were aware of the potential tsunami hazard and recognized the ground shaking as a natural warning sign. In Samoa (an unincorporated community on the jetty northwest of Eureka), at least a dozen people evacuated by foot. Many more chose to evacuate by car, causing traffic backups.

Schools: School officials recognized that their emergency response plans cover situations during school hours and outside school hours when facilities are vacant, but did not cover events like this one, during which several school buildings were in use by outside groups. The Humboldt County Office of Education plans to develop instructions for these cases.

Public safety and building assessment: Emergency response plans typically include inspecting essential service facilities and quickly surveying the jurisdiction for safety hazards. In Ferndale, members of the volunteer fire department mobilized immediately to nail plywood over broken storefront windows.

Because it was Saturday, Eureka Fire Department personnel performed the initial survey and damage assessments, restricting access to certain areas. Based on previous earthquake experience, they focused on URM buildings and chimneys. The next day, inspection teams of building department staff and private engineering consultants began damage inspection and ATC-20 tagging.

The city established hotlines for residents to report damage and created an ad hoc electronic damage inspection file with the following fields: date and time of call/report, name of caller, address, short summary of reported damage, priority,

Table 4: City of Eureka Building Damage

	1/13/2010	1/19/2010	2/2/2010	2/10/2010
Estimated Total Damage	$21.3M	$24.2M	$20.1M	$23.7M
Total Damage Complaints	NA	648	761	775
Total Inspected	NA	253	438	501
Inspections Remaining	NA	395	323	274
Engineering Evaluation Required	NA	41	53	63
Permit Required for Repairs	NA	97	214	235
No Follow-up Needed	NA	115	171	203
Red Tags	9	10	7	5
Yellow Tags	22	93	180	195
Green Tags	411	468	455	513

Source: City of Eureka (2010)

whether an inspection had been completed, if follow-up by an engineer was required and then completed, whether a permit would be needed for repairs, the building occupancy, an estimate of the cost of damage repair, and the tag assigned to the building.

The log was used to tabulate damage estimates for the city, and the status and progress of inspection, repair and tagging. The process can be seen in Table 4. As days went by, the rate of new reports and their severity diminished, and the number of completed inspections increased. With follow-up inspections, some initial tags were reclassified, usually to a less severe level. In addition, as repairs were made, tags moved to the green designation.

City staff had received training in the ATC-20 process (ATC, 1989) but implemented it with two significant local variations. First, they used the red "Unsafe Area" placard, discontinued with ATC-20-2 (ATC, 1995) to designate certain areas or exits not to be used, typically because of remaining falling hazards such as loose masonry. This led to some buildings having multiple tags for different areas.

Second, they tagged some buildings with the green "Inspected" placard even while requiring additional inspection or engineering review. With the relatively small number of affected buildings, department staff were able to track these requirements, which are normally reserved for yellow or red tags.

Recovery Tracking: Special Occupancies

Housing: Many houses and apartment buildings saw cosmetic and contents damage, and about 36,000 PG&E customers were without power overnight (Thompson, 1/11/2010), but practically all of the housing stock remained safe to occupy without disruption. Aside from rooms or areas rendered unsafe due to chimney damage, one apartment building in Eureka was red-tagged but was reoccupied within days, and three houses became uninhabitable. Fewer than 20 people in an affected population of about 47,000 required immediate alternative housing or temporary shelter (*Times-Standard*, 1/11/2010). There were no reports of housing losses to vulnerable or assisted populations.

Local government: Three city facilities in Eureka sustained "major" damage (Greenson, 1/15/2010). Still, city and county staff we spoke with said there was no lost capacity within city or county government offices charged with assisting in recovery.

Humboldt County Department of Health and Human Services was forced to relocate an office with 24 nurses and social service staffers when a block of Second Street was closed due to one red-tagged URM building (White, 1/25/2010).

Schools: All public schools implemented their response plans using custodial staff and re-opened without delay, two days after the Saturday earthquake (Greenson, 1/12/2010), except for the Auditorium wing of Eureka High School (see above).

In Ferndale, initial damage reports were limited to minor nonstructural (lights) and contents damage. After rains, however, new roof leaks at the elementary school were identified as earthquake-related. Other Humboldt County schools reported some new pavement cracks, but no structural damage or significant losses.

Workplaces: Eureka's Bayshore Mall, the largest commercial property in Humboldt County, was closed for four days after sustaining nonstructural damage. One store in the mall was closed until mid-February due to damage from a ruptured sprinkler line. A few businesses closed because of damage at the mall or because of adjacent red-tagged URM buildings were no doubt affected, but city and regional commerce apparently will suffer no long-term effects. This contrasts somewhat with the 1992 experience, in which Pacific Lumber Company faced a three- to six-week shutdown due to damage to their boilers and steam plant (Stoner and Turner, 1992).

Recommended Study

The following projects are underway at Humboldt State University:

- Detailed isoseismal study to better understand damage patterns in Eureka.
- Analysis of displaced monuments in the Ferndale Cemetery.
- Examination of actions taken in Ferndale after the 1992 earthquake and their effects on 2010 performance, including development of fragility curves for window damage on Main Street.

Additional studies are recommended:

- Detailed documentation of URM building damage and study of seismic rehabilitation effectiveness.
- Survey of cripple wall houses with and without seismic rehabilitation, including an effectiveness review of incentive programs after the 1992 earthquake.
- Correlation of damage with soil type.
- Review of the 1992 Humboldt County damage repair ordinance, including its history, implementation and results.
- Development of a model resilience "scorecard" for setting jurisdiction- and event-specific recovery targets and for tracking performance.
- Installation of additional strong-motion instruments in Eureka buildings, given the town's high frequency of earthquake shaking.

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