Damage in Rio Dell from Ferndale Earthquakes
20 December 2022 and 1 January 2023

Bruce Maison, S.E., M.EERI

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1. Introduction

The city of Rio Dell (population 3,400) is located in northern California next to the Eel River (Humboldt County). It has mostly residential homes with its main commercial district situated along a single avenue (Figure 1.1). The epicenters for the 20 December 2022 (M6.4), and 1 January 2023 (M5.4) earthquakes, respectively, were located west and southeast of the city (Figure 1.2). The earthquakes caused much damage in Rio Dell. Other nearby communities were also affected but to a much lesser extent (e.g., Fortuna and Ferndale). This report covers the following topics for Rio Del:

- Seismicity (Section 2.)
- Ground Shaking (3.)
- Housing Inventory (4.)
- Site-Built Homes (5.)
- Masonry Chimneys (6.)
- Mobile Home Parks (7.)
- Building Inspection Database (8.)
- Municipal Water Systems (9.)
- Key Findings (10.)

On-site reconnaissance was conducted one week after the M6.4 earthquake (week of December 25) pursuant to the Earthquake Engineering Research Institute (EERI) Learning from Earthquakes (LFE) effort having the mission of documenting valuable earthquake observations for future reference. Rio Dell had most of its buildings inspected shortly after the earthquakes. A review of the inspection database was conducted in April 2023 to quantify the overall damage and some results are also presented here. Additional on-site reconnaissance was conducted during the week of May 21, 2023.

The author is most appreciative of the contributions of the City of Rio Dell personnel including Debra Garnes (Mayor) and Kyle Knopp (City Manager) with providing interest in the earthquake damage documentation. Special thanks to Kevin Caldwell (Community Development Director) and Randy Jensen (Water/Roadways Superintendent) for valuable input to this report.

Figure 1.1. View of Rio Dell main commercial district along Wildwood Avenue.

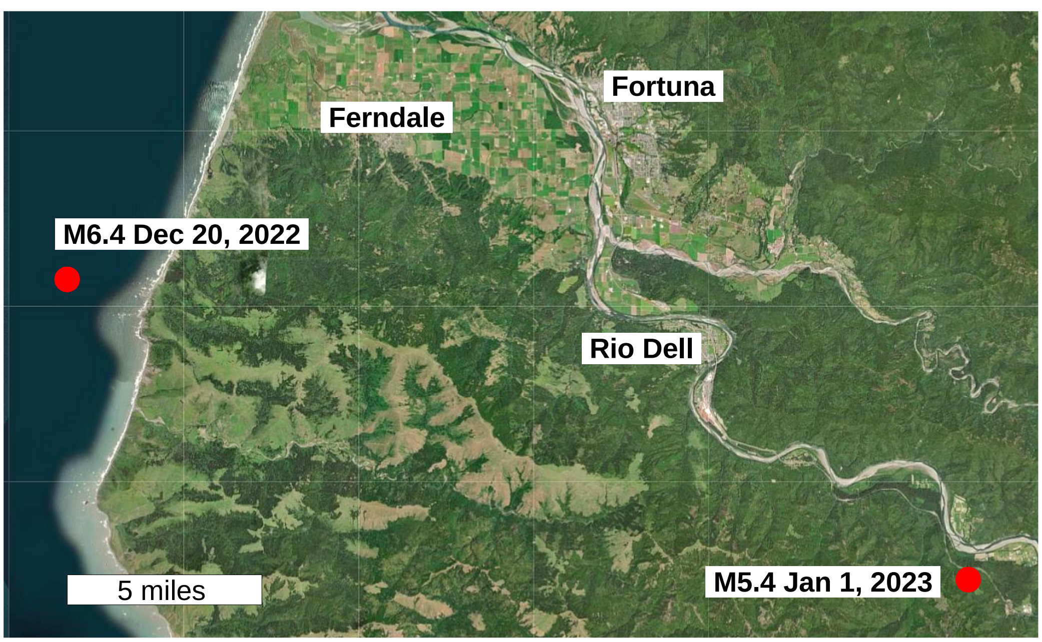


Figure 1.2. Aerial view showing the earthquake epicenters (source USGS).

2. Seismicity

The Cape Mendocino region of Humboldt County and the adjacent offshore area is the most seismically active region in California. Since 1981, there have been about 45 earthquakes in the area having M5.9 or greater (per USGS database) translating to about one per year on average. This is further illustrated by comparing the Design Earthquake response spectra used in building codes (Figure 2.1). A Design Earthquake for Rio Dell can have intensity as much as twice that for San Francisco.

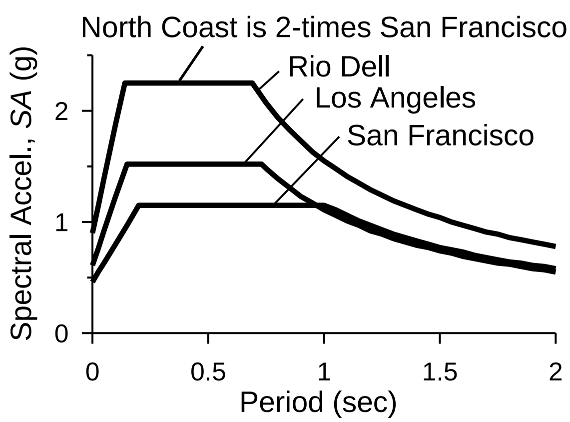


Figure 2.1. Comparison of Design Earthquake response spectra from ASCE 7-22 for three sites in California. The sites are at the City Hall locations.

Rio Dell has experienced significant ground shaking from numerous prior quakes and three are mentioned below. The first is relatively recent and the others were damaging quakes that occurred many years ago.

M6.2 Petrolia Earthquake of December 20, 2021. The earthquake occurred exactly one year prior to the M6.4 event. The epicenter was offshore about 40 miles west of Rio Dell and significant shaking was recorded in the city: 0.45g peak ground acceleration and 10 in/sec peak ground velocity (near the Painter Street overpass of Highway 101). USGS Shakemap assigned Modified Mercalli intensity of VII for Rio Dell generally meaning very strong shaking possibly causing slight to moderate damage in well-built ordinary buildings. The shaking intensity was less than the M6.4 event occurring one year later.

M7.2, M6.7, M6.6 Cape Mendocino Earthquakes of April 25 and 26, 1992. The epicenter of the M7.2 event was about 8 miles southwest of the city. No ground motion recording stations were in the city but surveys documented damage in the area.[1] Modified Mercalli intensity of VIII was assigned to Rio Dell meaning severe shaking possibly causing damage in ordinary substantial buildings. About twenty residences sustained major damage and 40 homes sustained some damage.

M5.2 Fortuna Earthquake of June 7, 1975. The epicenter was about 5 miles south-southwest of the city. No ground motion recording stations were in the city but surveys documented damage in the area.[2] Modified Mercalli intensity of VII was assigned to Rio Dell. Damage included more than 36 masonry chimneys that required removal translating into about 10% of the total chimney population. During the current survey, it was observed that some masonry chimneys were damaged, but many homes had their chimneys removed or replaced prior to the earthquake. This undoubtedly was an outcome from prior earthquakes consistent with the high seismicity of the region.

3. Ground Shaking

There were no reports of noteworthy soil liquefaction in Rio Dell and none was observed during the on-site reconnaissance. Therefore, damage caused by the earthquakes was mainly due to ground shaking. Ground accelerations were recorded by a station located in the Highway 101 right-of-way about 320 feet north of the Painter Street overpass (station CGS-CSMIP-89462). The site is alluvium over sedimentary rock, and is classified as stiff soil (site class D). The M6.4 quake produced more intense shaking than the M5.4 event (Figures 3.1

[1]Reagor BG and Brewer LR, *The Cape Mendocino Earthquakes of April 25 and 26, 1992*, U.S. Geological Survey, Open File Report 92-575.
[2]Two reports on the 1975 earthquake were provided courtesy of Robert McPherson (Cal Poly Humboldt University), (1) J.F. Meehan, *June 7, 1975 Fortuna Earthquake*, Structural Safety Section, Office of Architecture and Construction, State of California, and (2) R. Nason, E.L. Harp, H. LaGesse, and R.P. Maley, *Investigations of the 7 June 1975 Earthquake in Humboldt County, California*, U.S. Geological Survey, Open File Report 75-404.

and 3.2). It had about 5 seconds of strong shaking with a peak ground acceleration of 1.4g. Shaking was intense when the response spectra are compared to the design earthquake (DE) used in building codes (Figure 3.2). However, most buildings in Rio Dell were built via building code prescriptive conventional construction methods that did not necessitate custom engineering design and analysis. This is typical for light wood-frame residential buildings.

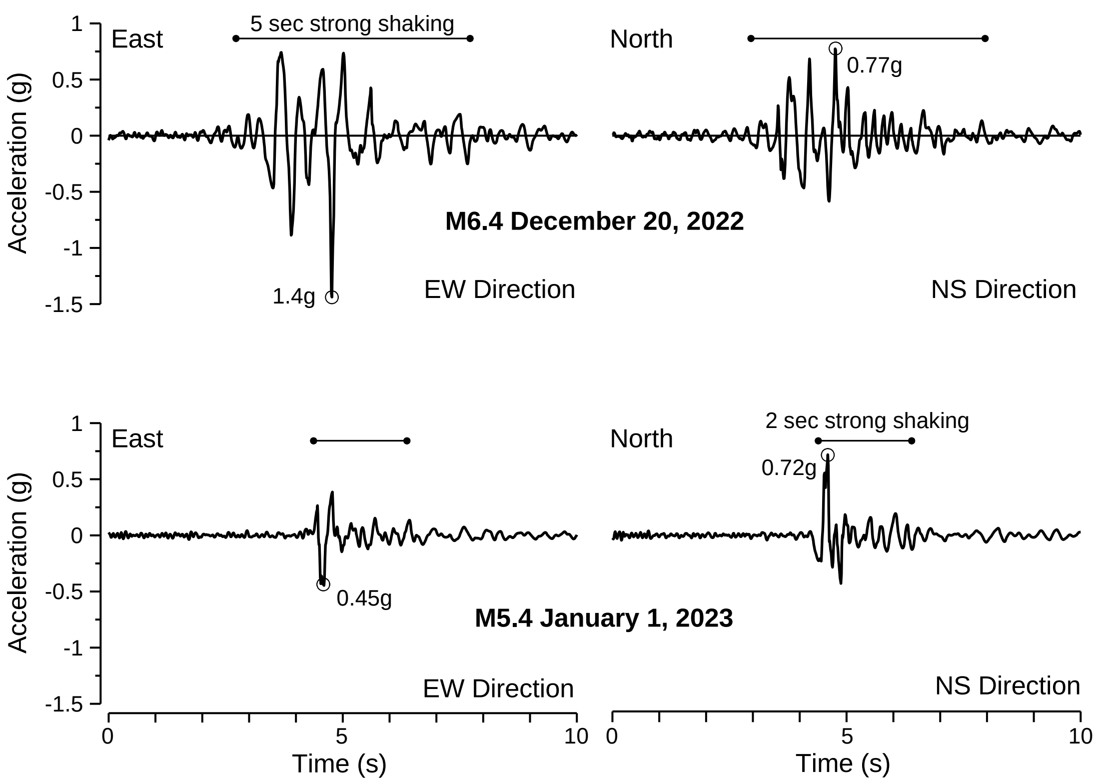


Figure 3.1. Recorded earthquake acceleration time history records from station located near Painter Street overpass.

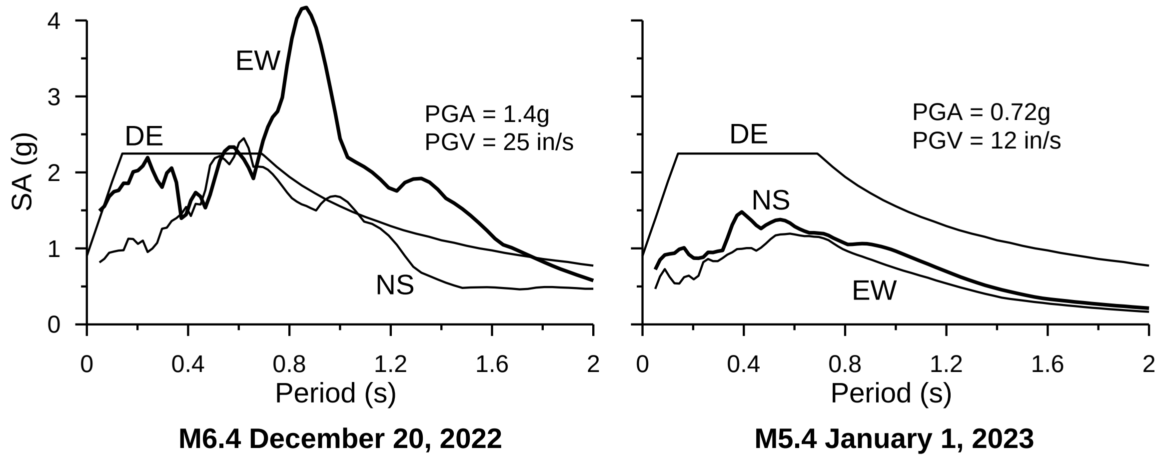


Figure 3.2. Response spectra from records in Figure 3.1. The ASCE 7-22 design spectrum (DE) is also shown as a benchmark. DE is two-thirds of the maximum considered earthquake (MCE). Notice how the M6.4 earthquake EW spectrum exceeds the DE spectrum for period range from 0.7 sec to 1.7 sec.

For the M6.4 earthquake, the recorded accelerations indicate that shaking was more intense in the east-west direction. Figure 3.3 shows a heavy planter pot that was shifted toward the east consistent with the recorded accelerations. Offsets toward the east were also observed in many houses and mobile homes.

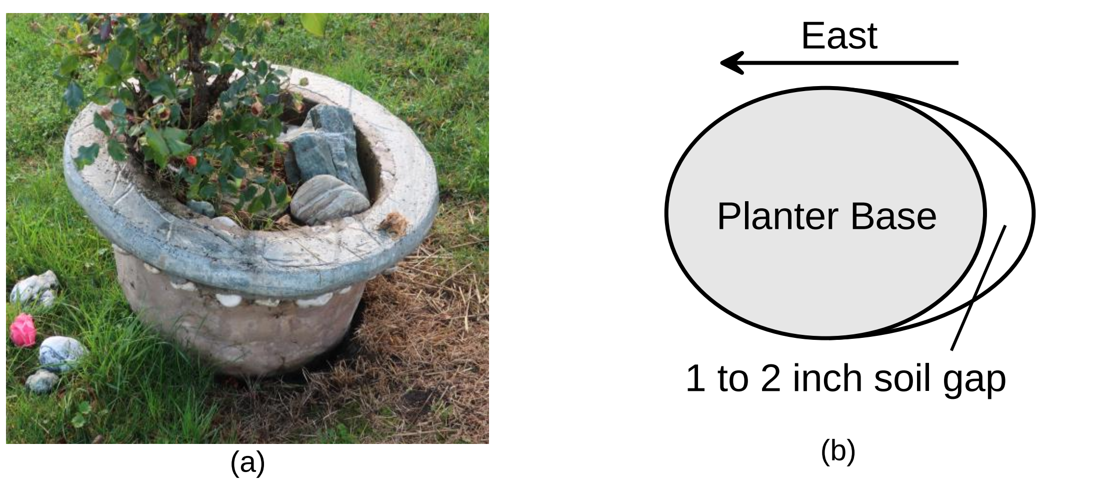


Figure 3.3. Heavy concrete planter pot in front yard of home on Painter Street. Home owner specifically pointed out how planter was shifted toward the east by the earthquake. (a) Notice gap in soil at base of pot (at lower right). (b) Depiction of deformation at planter base.

4. Housing Inventory

Rio Dell with a population of 3,400 has about 1,550 housing units situated on 2.3 square miles (based on 2020 U.S. Census). The housing inventory consists mostly of two- and three-bedroom homes having a median age of about 55 years (Figure 4.1). There are about 1,273 separate dwelling structures (homes, duplexes, apartment buildings, etc.), and 112 mobile homes as estimated from the census data.

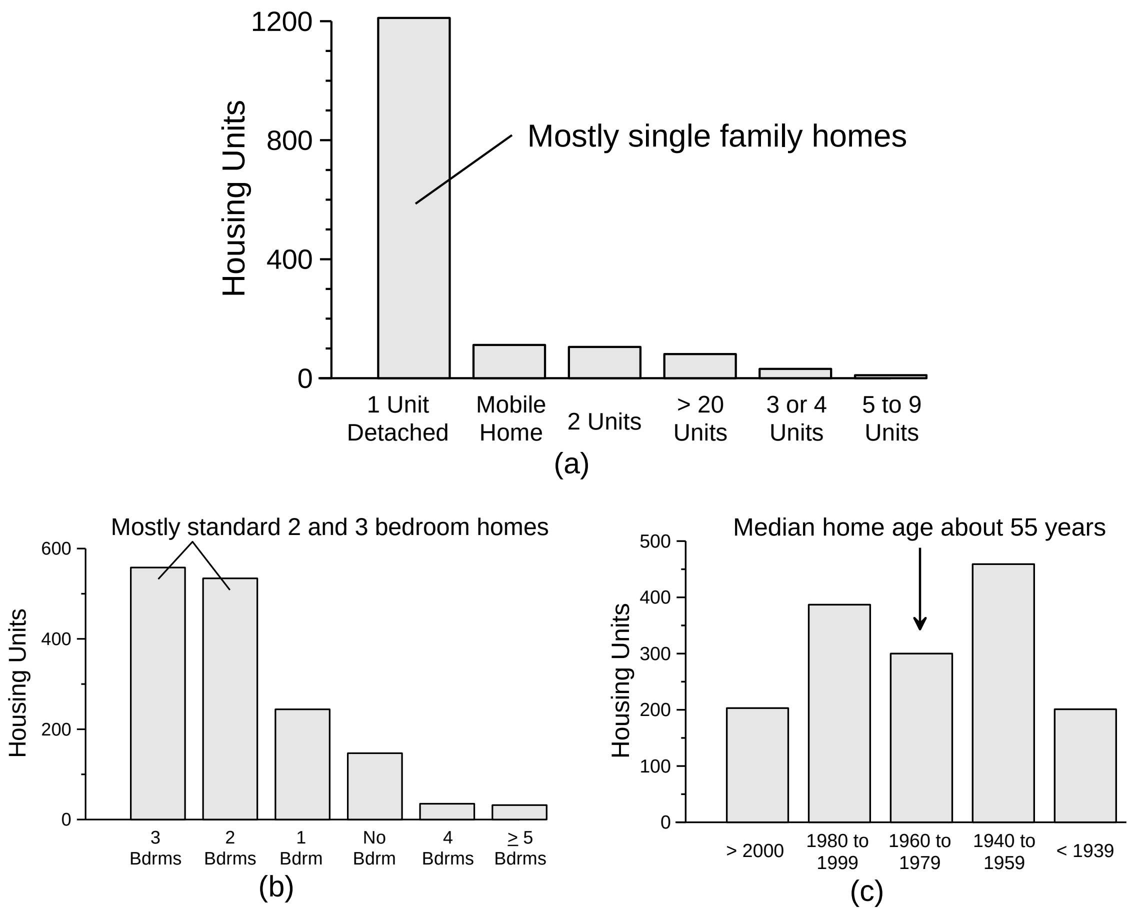


Figure 4.1. Rio Dell housing inventory from 2020 U.S. Census Data. Housing unit is defined as separate living quarters. (a) Type of housing unit. (b) Number of bedrooms. (c) Year when built.

5. Site-Built Homes

Many site-built homes of various ages had no apparent damage as illustrated in Figure 5.1. Virtually all newer homes like that shown in Figure 5.1a performed well by having no apparent structural damage.

(a)

(b)

(c)

(d)

Figure 5.1. Examples of homes located within 2000 feet of Painter Street Bridge (large recorded accelerations) having no apparent damage. Notice green-tags posted in windows. (a) Home built circa 2000. (b) Home built circa 1940. (c) Home built circa 1930. (d) Home built circa 1910, but resident says home was moved to current location many years ago. Many older homes have appearance of remodeling that might have included structural improvements.

The majority of observed structural damage was associated with raised-floor foundation systems in which the wood floor is elevated above grade (Figure 5.2). The area below the floor level can be a weak point vulnerable to damage if not properly strengthened. Such areas are often referred to as “crawl spaces.” Newer homes generally have adequate design because of modern building code requirements, but many older homes are deficient.

(a) (b)

Figure 5.2. Examples of raised-floor foundation systems. (a) Newer home with sheathing consisting of siding that simply fell off. (b) Older home with sheathing consisting of horizontal boards that split.

A common damage pattern observed was where the home behaved like a rigid box, but shifted at the foundation level (Figure 5.3). Such homes can often be repaired (Figure 5.4).

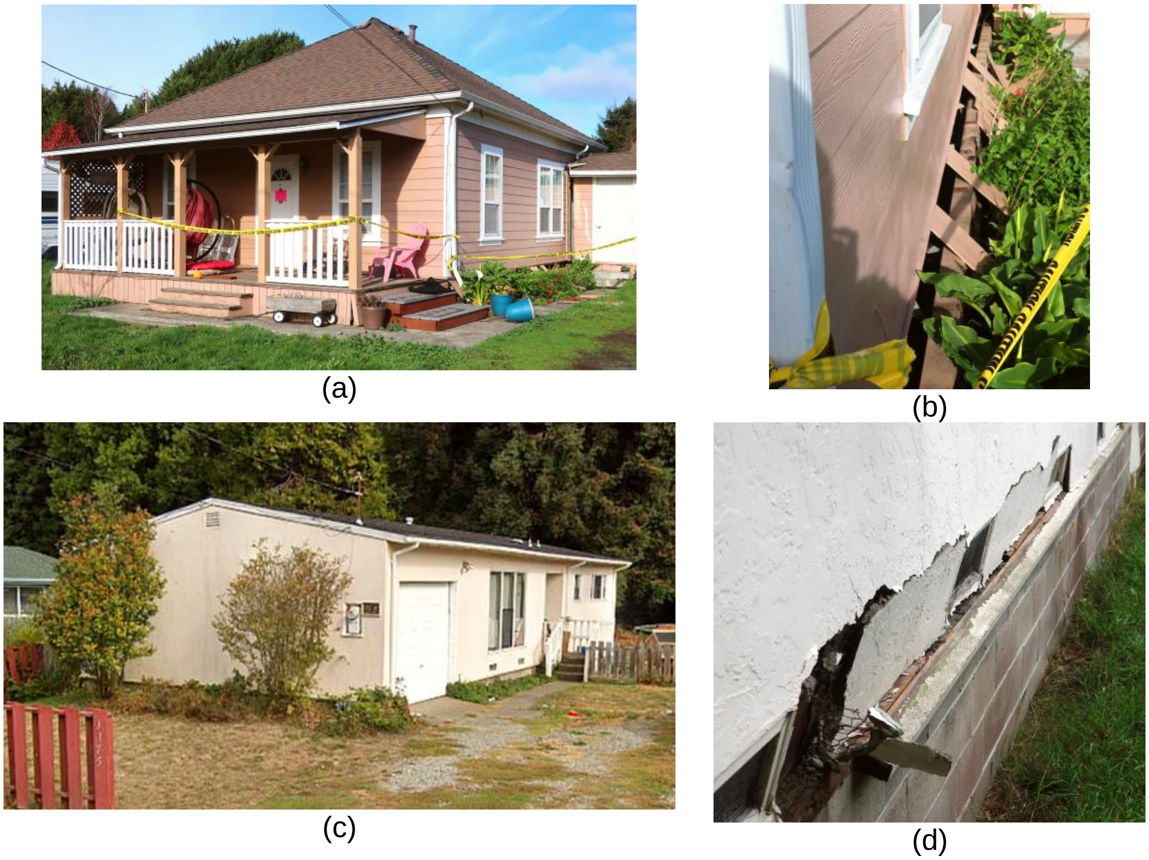


Figure 5.3. Examples of homes that shifted at floor level of raised-floor foundations. (a) Home that was offset west (to the left). (b) Close-up showing home shifted off foundation. (c) Before earthquake view of home having perimeter concrete masonry unit (CMU) wall foundation (undated Bing maps street view image). Home built circa 1948. (d) After earthquake view showing offset at foundation level.

Figure 5.4. Home undergoing repairs in May 2023. This was the home that shifted off it foundation shown in Figure 5.2a. The home was lifted up and placed back on a new foundation.

Figure 5.5 shows a home that had offset at the raised-floor foundation as well as cracking of perimeter concrete footing. This was one of the few cases observed having significant damage to the footing.

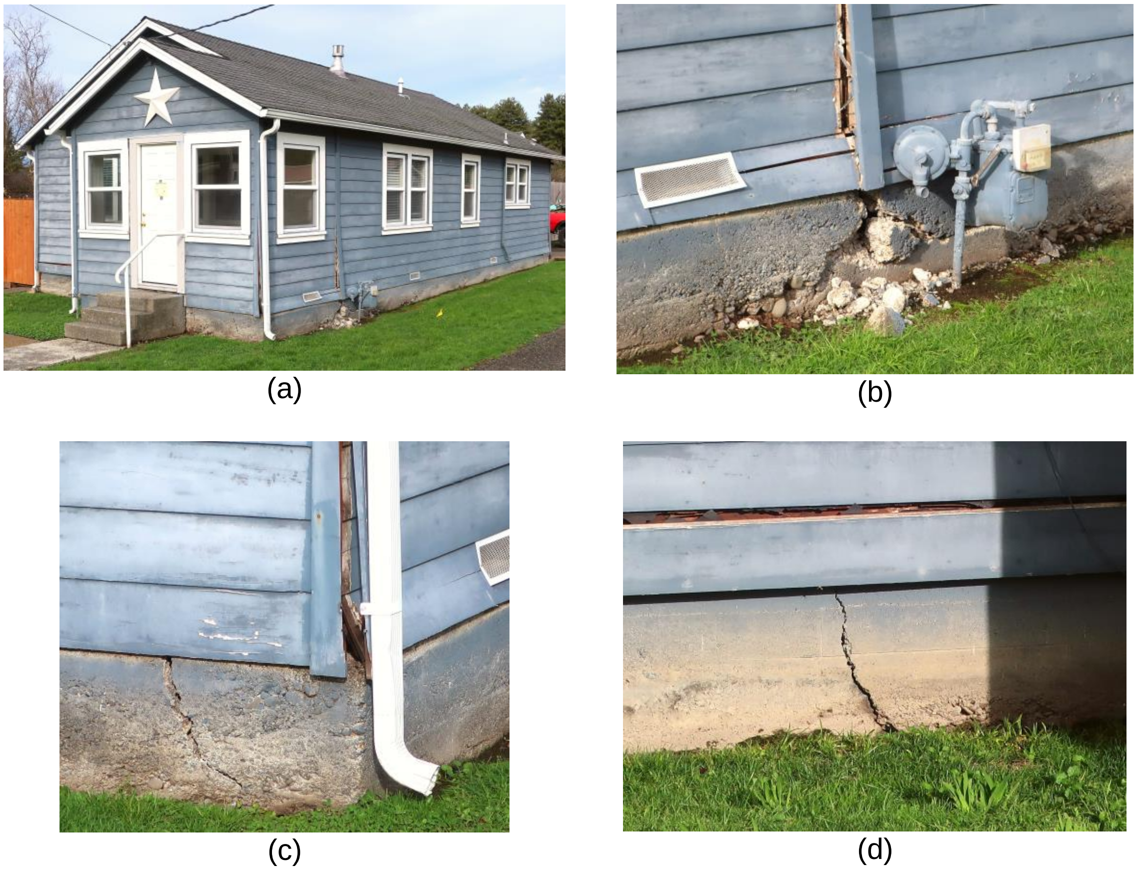


Figure 5.5. Example of home having offset at raised floor and cracking of perimeter concrete footing. (a) Exterior view of home. (b) Close-up view of fracture at cold joint apparently having inadequate bonding between layers of concrete. Home offset indicated by gap behind vertical molding. (c) Vertical crack in footing. Home offset indicated by splitting of molding at corner of home. (d) Vertical crack in footing.

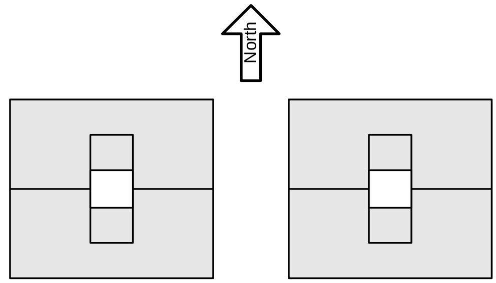
One of the few newer homes observed that suffered significant damage is shown in Figure 5.6. The porch roof broke off, but the house itself appeared to have no structural damage.

(a) (b)

Figure 5.6. Example of home that suffered porch roof collapse (home built circa 2000). (a) Before earthquake (undated Google maps street view image). (b) View after earthquake with porch roof on ground and crushing fence.

Figures 5.7 and 5.8 show the damage observed in newer apartment buildings. Such apartment buildings are rare in Rio Dell (Figure 4.1a). The buildings have rigid fiber-cement siding that suffered much cracking from building lateral drifts during the earthquakes. Such siding is brittle and readily cracks under excessive deformations.

(a)



(b)

(c)

(d)

Figure 5.7. Damaged apartment buildings (built in 1992). Photos taken in May 2023 during repairs. (a) View prior to earthquakes (undated Google maps street view image). There are two identical buildings each having eight apartment units (second building is in background to the right). Both buildings suffered damage. (b) Building plan views. (c) Building undergoing replacement of window and siding. (d) Damage to fiber-cement siding at corner of building at base (photo center).

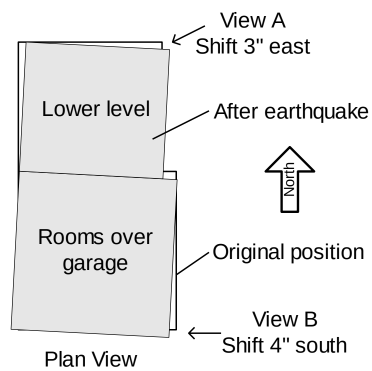
(a)

(b)

Figure 5.8. Examples of damage to rigid fiber-cement siding. Buildings had extensive siding damage. (a) Diagonal crack in siding. (b) Broken vertical molding.

Figure 5.9 shows a relatively modern style split-level home that suffered damage resulting in pronounced offsets. The foundation consisted of concrete footings with stem walls. Short wood sheathed walls (cripple walls) were situated under the upper level having rooms over the garage. Figures 5.10 and 5.11 show the damage caused by the earthquakes.

(a)



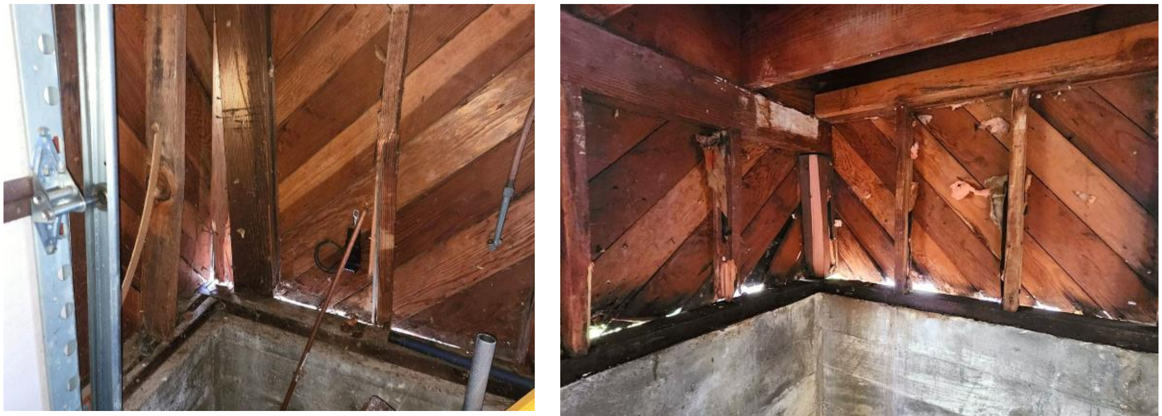
(b)

Figure 5.9. Split-level home that suffered damage. (a) Street view of home before earthquake (undated Google maps street view image). Home built in 1962. The upper level rooms over garage (on the left) are situated on stepped concrete footing stem walls with cripple walls extending from top of walls to floor elevation above. Cripple walls are shorter toward the back of garage. The lower level (on the right) has floor joists sitting on wood sill plates situated on top of footing stem walls (no cripple walls). (b) Plan view depicting shifting of home caused by earthquakes.

(a) View A

(b) View B

Figure 5.10. Close-up views of home showing offsets caused by earthquakes (Figure 5.9b). (a) View A (Figure 5.9b). Sill plate was split and home moved to the east at this corner (to the left). (b) View B. Sill plate was split and home moved to the south at this corner (to the left). Cripple wall above was also tilted to the south. There were some anchor bolts connecting sill plates to concrete foundation.



(a) (b)

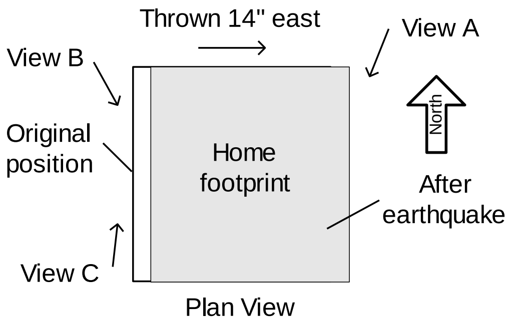
Figure 5.11. Views of cripple walls from inside garage. Cripple walls were sheathed by diagonal wood boards. (a) View toward corner next to garage door. Notice sunlight in gap where sheathing pulled away from sill plate. Some 2x4 wall studs were fractured. (b) View toward back corner. The cripple walls are shorter here that those near garage door. Notice the separation of sheathing from sill plate. There was evidence of wood deterioration even though redwood has good decay resistance. Deterioration might have been caused by wood shake siding trapping moisture (Figure 5.10b).

Figure 5.12 shows an older home built circa 1910 that suffered damage. Neighbors stated that home was relocated to current site many years ago. The raised floor foundation system consisted of precast concrete piers and short wood posts supporting the wood floor system (post-and-pier system). The home was completely thrown off its foundation. The home itself behaved like a rigid box and appeared to have no significant structural damage (Figure 5.12b). Figures 5.13, 5.14 and 5.15 show damage at the foundation level caused by the earthquakes.

(a)

(b)

Figure 5.12. Home that fell due to failure of post-and-pier foundation system (east side is on left). (a) Before earthquake (undated Google maps street view image). (b) After earthquake. Home fell in the east direction. Notice tilting of porch posts and gutter downspout (at right) indicating large displacement of home.



(a)

(b)

Figure 5.13. (a) Plan view indicating that home fell directly toward the east. (b) View A along east side of home. Home fell to the left and now sitting on siding that is lying flat on ground.

(a)

(b)

Figure 5.14. Views along west side of home. (a) View B (Figure 5.13a). Home fell to the ground and post and piers broke through siding as home shifted east (to the left). (b) View C. Close-up showing post and piers that broke through siding as home shifted east (to the right).

(a)

(b)

Figure 5.15. Detailed views of post-and-pier foundation system. (a) Close-up view of precast concrete pier with short 4x4 block on top. Siding sitting on top of post as home shifted to the right. (b) Close-up view of short 4x4 post lying on its side on top of pier. The assembly broke through siding as home shifted east (to the right). Post was toe-nailed to pier. Siding nailed to home but not connected to ground.

6. Masonry Chimneys

Many homes appeared to have chimneys replaced prior to the quakes. Figure 6.1 shows a case where a masonry chimney collapsed yet the home and adjacent houses were unscathed.

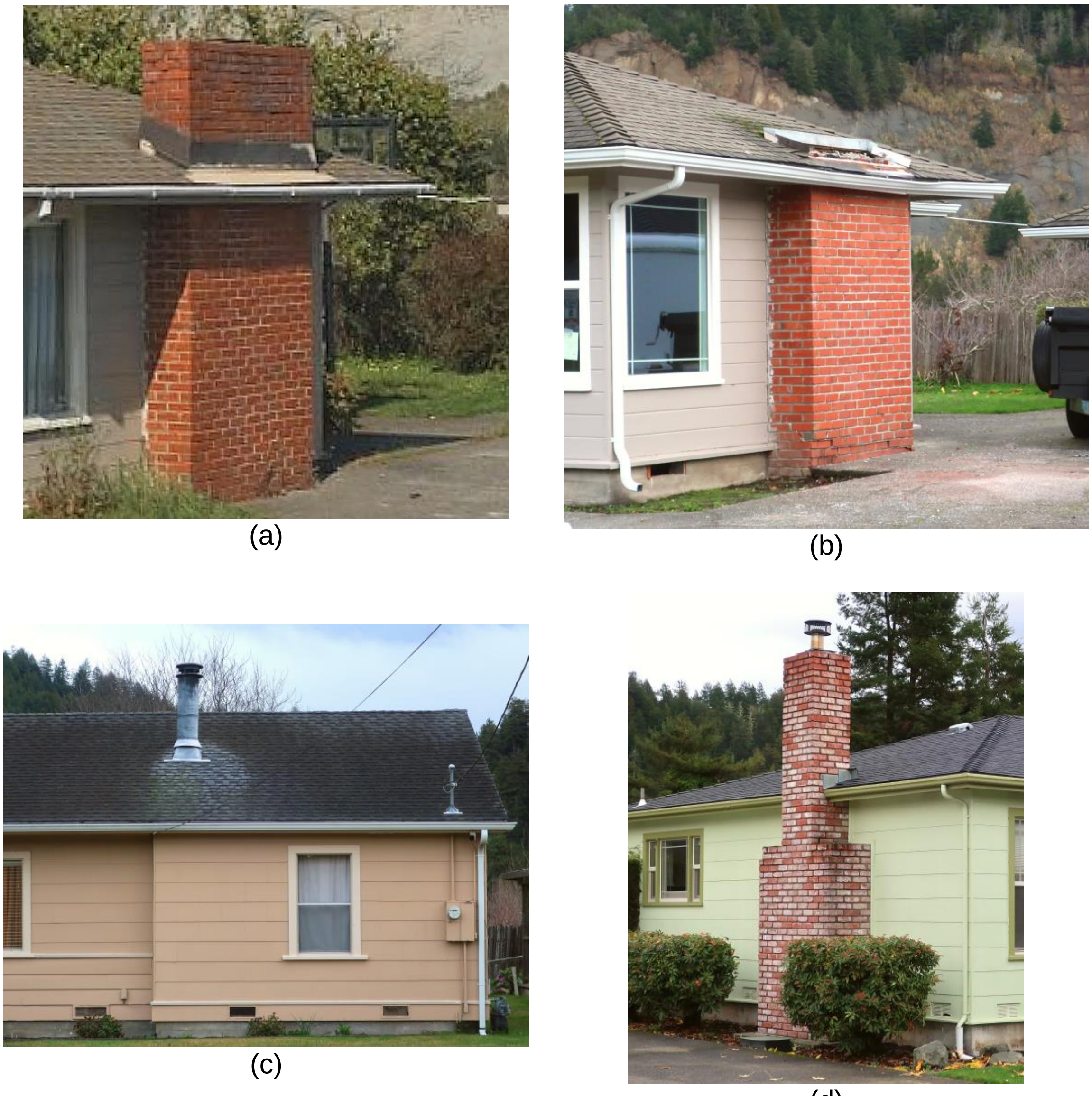


Figure 6.1. Examples of Rio Dell chimneys. (a) Before earthquake (undated Google maps street view image). Home built circa 1955. (b) After earthquake and clean-up. Chimney broke at roofline and had offset near base. Notice that home had a Green tag in window (at left). (c) Undamaged metal flue chimney on adjacent home. Likely a replacement for an original masonry chimney done some time after home originally built. (d) Undamaged masonry chimney on adjacent home. It has the appearance of newer construction installed some years ago and likely a replacement chimney.

Two striking examples of masonry chimney collapses are shown in Figures 6.2 and 6.3.

(a) (b)

Figure 6.2. Example of masonry chimney collapse. (a) View before earthquake (undated Bing maps street view image). Home built circa 1935. (b) View after earthquake. Chimney collapsed and fell through attached carport roof. No signs of straps connecting chimney to home.

(a) (b)

Figure 6.3. Example of masonry chimney collapse. (a) View before earthquake (undated Google maps street view image). (b) View after earthquake. Chimney fell away from home and now lying on its side in yard. It was fortunate that no adjacent structures were present that would have been impacted.

Figure 6.4 shows additional photos of chimney collapse in Figure 6.3.

(a) (b) (c) (d)

Figure 6.4. Additional photos of chimney collapse in Figure 6.3. (a) Cracking through bricks indicating good quality mortar. (b) Chimney broke off near base. (c) No signs of strapping to home. (d) Exposed rebar indicating pull-out. Four #4 bars present. Notice the good quality of mortar and use of modern deformed rebar. It is likely that the chimney was a replacement constructed some time after home was built circa 1935.

Figure 6.5 shows a replacement chimney during home renovation. This is home that suffered chimney collapse shown in Figure 6.3.

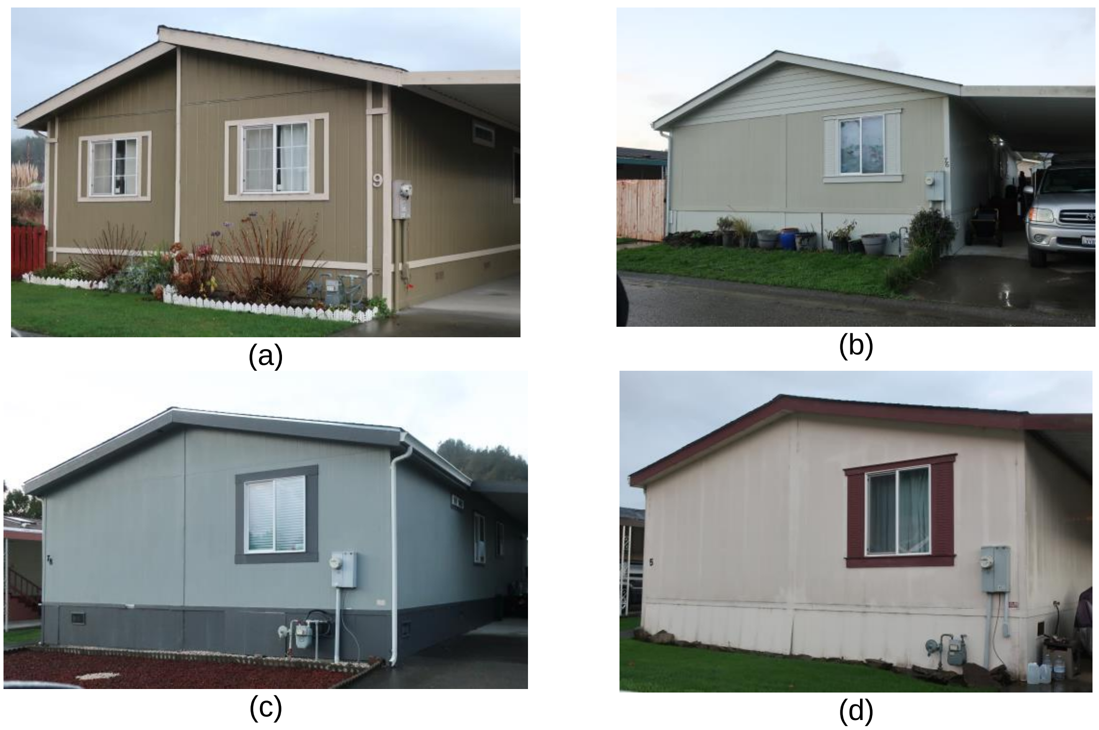
Figure 6.5. Home undergoing renovation in May 2023. This is the home that had its chimney tip over (Figure 6.3). The replacement chimney consists of a metal flue within a wooden enclosure. This is common chimney replacement practice.

7. Mobile Home Parks

Three mobile home parks in Rio Dell were surveyed. All were within 2000 feet of the Painter Street overpass where large ground accelerations were recorded: Mobile home park A (MPH-A) was a newer MHP established in 1994 having about 36 homes; MHP-B was an older MHP established circa 1960 having about 25 homes (a mix of mobile homes and RV homes); and MHP-C was an older MHP established circa 1960 having about 17 mobile homes. In addition, there was a recreational vehicle (RV) park, but it was not surveyed.

Mobile Home Park A (MHP-A)

Virtually all the homes had no apparent damage as illustrated in Figure 7.1.



(a) (b) (c) (d)

Figure 7.1. Examples of homes having no readily apparent damage. Damage usually indicated by significant offset or distress in skirting at base, and some homes might have very slight shifting from earthquake. Wood or composite material siding as opposed to metal sheathing typically indicates newer style home.

Homes installed after 1994 are required by California to have either engineered tie-down systems (ETS) or optional earthquake resistant bracing systems

(ERBS). ETS typically consist of metal straps connecting the chassis girder to ground anchors (Figure 7.2).


(a)


(b)


(c)


(d)

Figure 7.2. Conventional tie-down system. (a) Example of home showing no apparent signs of distress. (b) View underneath home showing standard practice of having tie-down strap wrapped around chassis girder (for tie-downs oriented in home transverse direction). (c) Tie-down connected to bracket at chassis girder bottom flange (for tie-downs oriented in home longitudinal direction). (d) Typical connection of tie-down to ground anchor.

ERBS are optional proprietary systems designed for earthquakes and vary according to manufacturer. Since MHP-A was established in 1994, it is virtually certain that all homes had ETS or ERBS. Figure 7.3 shows examples of proprietary bracing systems observed underneath some homes.

(a)

(b)

Figure 7.3. Some homes had proprietary bracing systems. All homes that allowed observations underneath had concrete masonry unit (CMU) piers. (a) Diagonal steel bracing system connecting chassis girder to concrete mat with CMU pier on top (at left). CMU pier provides dead load thereby clamping mat to ground. (b) Steel stanchion system connected to chassis girder and secured to ground by steel rods driven into soil.

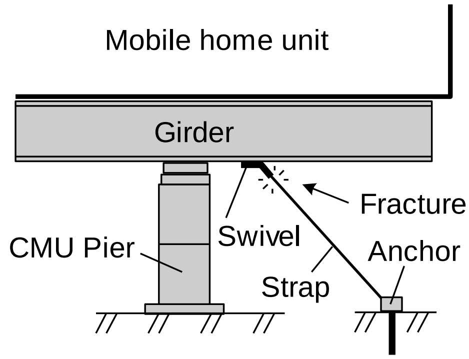
An example of home having subtle signs of damage is shown in Figure 7.4.

(a)

(b)

Figure 7.4. One of the few homes showing signs of distress in skirting. Offset of home is barely perceptible. (a) Splitting of vertical wood molding trim at corner of home at base. (b) Broken molding trim at opposite corner.

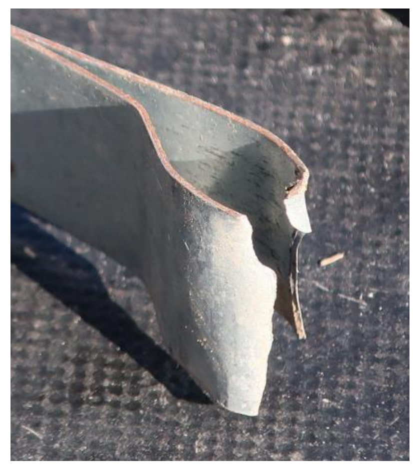
Tie-down straps were fractured in at least one home having no signs of damage from the exterior. Figure 7.5 shows the broken straps.



Steel strap attached to swivel bracket at girder bottom flange and tightened at ground anchor
(a)

(b)

(c)



(d)

Figure 7.5. Broken tie-down straps taken from home having no signs of visible damage from the exterior. Tie-down arrangement for home longitudinal direction. Some straps were broken by earthquake. (b) Straps did not break at ground anchor spooling devices where straps were tightened. (c) Straps broke at swivel brackets where strap looped through slot in bracket. (d) Close-up view of broken strap.

Mobile Home Park B (MHP-B)

Typical homes are shown in Figure 7.6. MHP-B was established at the time when lateral force resisting systems such as tie-downs were not required. Homes that allowed access for underneath observations had no tie-downs. It is likely that few, if any, homes had tie-downs.

(a) (b) (c) (d)

Figure 7.6. Examples of homes having no apparent damage. However, some might have had slight shifting from earthquake. Appearance of homes suggests that they are of similar age and likely installed at the time when tie-downs were not required by California (pre-1995 installations).

Examples of homes that suffered considerable offsets to the east are shown in Figures 7.7 and 7.8.

(a)

(b)

(c)

Figure 7.7. Home that was in an incipient collapse condition (shifted to the east) necessitating emergency shoring. (a) Home with shoring in place. (b) Close-up of shoring. (c) Close-up of gas and electric meters sets. Notice that home has pushed against electrical tower. This illustrates the hazard posed by a collapsing home that damage utility systems thereby possibly causing ignitions and fire following earthquake.

(a)

(b)

(c)

Figure 7.8. (a) Mobile home that was in an incipient collapse condition (shifted toward the east). (b) Close-up showing large displacement. Notice the distortion of skirting. (c) Gas and electrical utilities at end of home where home shifted away from meter sets thereby stretching connections.

Views underneath damage homes are shown in Figure 7.9.

(a) (b) (c) (d)

Figure 7.9. Examples of mobile home damage. (a) Tilted CMU pier resulting from home shifting. (b) CMU pier disengaged and leaning on water jet-ski stored under home. Notice wood boards resting on top of jet-ski. Before earthquake, chassis girder rested on boards situated on top of CMU. (c) CMU pier lying on side (CMU and boards at left). Precast concrete pad where CMUs were situated (at right). Sanitary pipe (at center) was located to the right of pad prior to earthquake thus indicating large movement of home. (d) Exterior view of skirting consisting of wood boards that were tilted as home shifted to the left. Many boards attached to home with one nail thus allowing boards to rotate. Such skirting if rigidly attached to home and ground possibly can help provide lateral support to home, but skirting not intended as structural elements.

Mobile Home Park C (MHP-C)

Typical homes are shown in Figure 7.10. MHP-C was established at the time when lateral force resisting systems such as tie-downs were not required. However, some homes had tie-downs. This was unexpected suggesting that some homes installed prior to 1995 used tie-downs, even though not strictly required. Alternatively, some homes might have been installed after 1994.

(a)

(b)

(c)

(d)

Figure 7.10. View of homes. (a) Before earthquake (undated Google maps street view image looking west). (b) View looking across street (to east). (c) and (d) Homes having no apparent damage. Appearance of many homes suggests that they are of similar age and were installed at the time when tie-downs were not required by California (pre-1995 installations). However, some homes had tie-downs.

An example of collapsed home is shown in Figure 7.11. The home did not have tie-downs.

(a) (b)

Figure 7.11. Collapsed home. (a) Home has dropped below staircase elevation. (b) View underneath home showing CMUs lying on their sides indicating that home was thrown a large distance to the east (to the left). Home did not have tie-downs.

Figure 7.12 shows home undergoing repairs including new bracing system.

(a) (b)

Figure 7.12. Home undergoing repairs in May 2023. This was the home that collapsed shown in Figure 7.11. (a) Home was lifted up and placed on piers with skirting yet to be installed. (b) View underneath home showing new bracing system.

Offset CMU piers underneath other damaged homes are shown in Figure 7.13, and some homes having tie-downs that suffered damage as shown in Figure 7.14.


(a)


(b)

Figure 7.13. Views underneath damaged homes showing piers. (a) CMU pier that was offset (slid) between units. (b) CMU pier that slid on precast concrete pad and then tilted.


(a)


(b)


(c)


(d)

Figure 7.14. Examples of damaged homes having tie-downs. This was unexpected for the older homes in park since California required tie-downs for homes installed after 1994. (a) and (b) Tie-down (at left) did not prevent sliding and tilting of CMU piers (at right). (c) Old tie-down as evidenced by weathering. (d) Tie-down (one shown at right) and offset CMU pier (at left).

8. Building Inspection Database

Rio Dell had extensive inspection of its buildings and some results are presented here to quantify the overall damage. The inspections used the guidelines in ATC-20, *Procedures for Post-Earthquake Safety Evaluation of Buildings*. The procedure is a standardized rapid evaluation method mainly dealing with structural integrity. Trained inspectors enter their quick visual evaluations into a database (Figure 8.1).

ATC-20 Rapid Evaluation Safety Assessment Form

Inspection

Inspector ID: ________ Inspection date and time: ________ ☐ AM ☐ PM

Affiliation: ________ Areas inspected: ☐ Exterior only ☐ Exterior and interior

Building Description

Building name: ________

Address: ________

Building contact/phone: ________

Number of stories above ground: ____ below ground: ____

Approx. "Footprint area" (square feet): ________

Number of residential units: ________

Number of residential units not habitable: ________

Type of Construction

☐ Wood frame ☐ Concrete shear wall
☐ Steel frame ☐ Unreinforced masonry
☐ Tilt-up concrete ☐ Reinforced masonry
☐ Concrete frame ☐ Other: ________

Primary Occupancy

☐ Dwelling ☐ Commercial ☐ Government
☐ Other residential ☐ Offices ☐ Historic
☐ Public assembly ☐ Industrial ☐ School
☐ Emergency services ☐ Other: ________

Evaluation

Investigate the building for the conditions below and check the appropriate column.

Observed Conditions:	Minor/None	Moderate	Severe
Collapse, partial collapse, or building off foundation	☐	☐	☐
Building or story leaning	☐	☐	☐
Racking damage to walls, other structural damage	☐	☐	☐
Chimney, parapet, or other falling hazard	☐	☐	☐
Ground slope movement or cracking	☐	☐	☐
Other (specify) ________	☐	☐	☐

Estimated Building Damage (excluding contents)

☐ None
☐ 0 –1%
☐ 1 –10%
☐ 10 – 30%
☐ 30 – 60%
☐ 60 – 100%
☐ 100%

Comments: ________

Posting

Choose a posting based on the evaluation and team judgment. *Severe* conditions endangering the overall building are grounds for an Unsafe posting. Localized *Severe* and overall *Moderate* conditions may allow a Restricted Use posting. Post INSPECTED placard at main entrance. Post RESTRICTED USE and UNSAFE placards at all entrances.

☐ **INSPECTED** (Green placard) ☐ **RESTRICTED USE** (Yellow placard) ☐ **UNSAFE** (Red placard)

Record any use and entry restrictions exactly as written on placard: ________

Further Actions Check the boxes below only if further actions are needed.

☐ Barricades needed in the following areas: ________

☐ Detailed Evaluation recommended: ☐ Structural ☐ Geotechnical ☐ Other: ________

☐ Other recommendations: ________

Comments: ________

Figure 8.1. Evaluation form used by inspectors.

Evaluations have three condition levels: Minor/None, Moderate, and Severe. A posting is chosen based on the evaluation and team judgment:

- “Severe” conditions endangering the overall building are grounds for an Unsafe posting (“red-tag”).
- Localized “severe” and overall “moderate” conditions may allow a Restricted Use posting (“yellow-tag”).
- “Minor/None” conditions indicate no apparent hazard found although repairs may be required, then no restriction on use or occupancy is necessary, and an Inspected posting (“green-tag”) is appropriate.

Inspectors use subjective judgments and they understandably tend to err on the conservative side (over-state damage severity), and initial posting of a yellow- or red-tag might be changed after later more thorough investigation.

Evaluations were made after the December 20, 2022 and January 1, 2023 earthquakes. Much of the data were entered into the California Governor’s Office of Emergency Services (CA-OES) database system (Table 8.1). Those made after the January earthquake included re-evaluation of buildings that were posted after the December earthquake since the latter quake might have cause additional damage requiring changes to prior postings. Results from the database after the January earthquake are reported here. The evaluations took place from Tuesday, January 3 thru Wednesday January 11. There were 64 red- and 257 yellow-tags issued meaning that 321 structures were judged as having some sort of significant damage. This translates to about one-in-four (24%) of all the buildings that were inspected (321/1361).

Table 8.1. Numbers of placard postings made after earthquakes.

Earthquake Date	Red	Yellow	Green	Total
Dec 20, 2022	27	96	459	582
Jan 1, 2023	64 (5%)	257 (19%)	1040 (76%)	1361
Inspections made after the Jan 1 earthquake included re-inspection of buildings that were inspected after the Dec 20 earthquake.				

Building Inventory

Site-built dwellings were the vast majority (Table 8.2). The database numbers are in reasonable agreement to the total numbers of dwellings estimated from the 2020 census data in Section 4 above (within 10%). A very high percentage of Rio Dell buildings were therefore inspected. The database numbers were taken here as the total numbers of buildings.

Table 8.2. Numbers of different types of buildings.

Building Types[1]	Inspection Database[2]	Estimate from 2020 Census[3]	Percentage Difference[4]
Site-Built Dwellings	1172	1273	+9%
Mobile Homes	106	112	+6%
Other	83	--	--
Total	1361	1385	--

[1]Site-built dwellings are separate structures that contain living quarters such as houses, duplexes, apartment buildings, etc. Mobile homes are dwellings built in factories and moved to sites. Other buildings are those not serving as living quarters such as churches, government, commercial buildings, garages, etc.
[2]Numbers taken from inspection database created after Jan 1 earthquake. Some judgments were necessary since database entries were not always clear (e.g. blank entries in some fields)
[3]Census data reports housing units (e.g., apartment buildings have multiple housing units) and translation to separate dwelling buildings required some judgments.
[4]Percentage difference is the variation from the inspection database values.

Yellow- versus Red-Tags

Much of the observed damage to site-built and mobile home dwellings were in the lower part of the structures. For site-built dwellings, this was at the raised-floor foundation locations, and for mobile homes, in the support systems under the homes. Such damage often leaves the upper part of the home intact even if it has shifted or fallen to ground. Whether such homes receive a yellow- (restricted use) or red-tag (unsafe) requires much judgment, and different inspectors can have differing opinions. Therefore, yellow- and red-tags were lumped together herein indicating readily apparent significant damage was observed (referred to here as simply “damaged”).

Many (perhaps most) of the damaged homes were unfit for occupancy on a long-term basis until repairs were enacted (tilted floors, broken utilities, etc.).

However, in the post-earthquake short-term recovery period (say weeks to months), many damaged homes appeared to be adequate for shelter-in-place. ATC-20 type evaluations do not specifically address this aspect. Further discussion of post-disaster dwelling habitability can be found elsewhere[3].

Types of Damaged Buildings

Figure 8.2 summarizes the types of structures that received yellow- or red-tags (referred here as "damaged").

- About one-in-five (22%) of all site-built dwellings were damaged (257/1172).
- About one-in-three (36%) of all mobile homes were damaged (38/106).

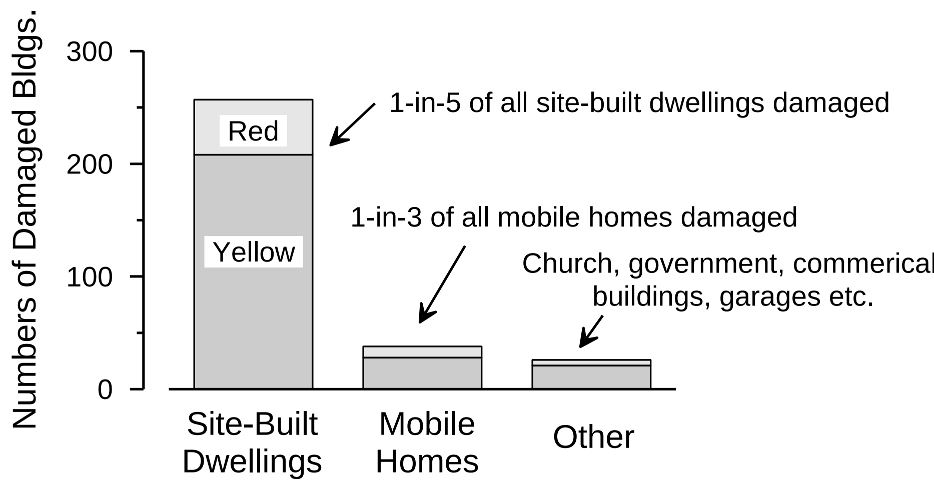


Figure 8.2. Structures receiving yellow or red tags (referred here as "damaged"). A site-built dwelling defined as house, duplex, apartment building, etc. Mobile homes are dwellings built in factories and transported to sites as complete units.

Site-Built Dwellings

Typical site-built dwellings that were damaged (yellow- or red-tagged) were one-story single-family wood-frame homes (Figure 8.3).

[3]For background see *Post-disaster Building Safety Evaluation Guidance*, FEMA report P-2055 (2019); and, *Safe Enough to Stay*, San Francisco Bay Area Planning and Urban Research Association (SPUR) report 01/2012.

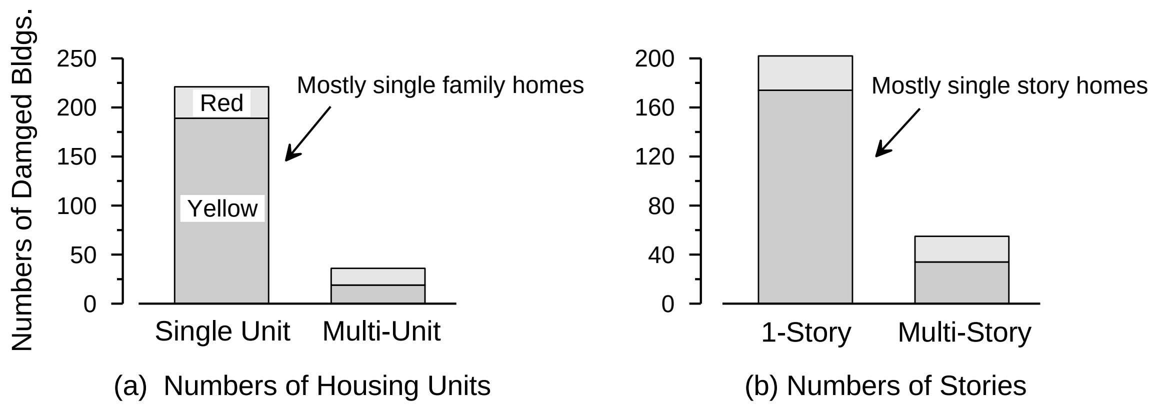


Figure 8.3. Site-built dwellings that were damaged (receiving yellow- or red-tags). (a) Numbers of housing units. (b) Numbers of stories.

An evaluation had several categories of damage. Figure 8.4 shows the six categories and the numbers of "severe" and "moderate" assignments. Yellow-tagged homes had relatively more "moderate" than "severe" ratings, and vice-versa for red-tagged homes (Figures 8.4b and 8.4c) consistent with the instructions given on the evaluation form (Figure 8.1).

As observed in the reconnaissance above as well as found in prior earthquakes, a frequent damage mode associated with wood-frame homes was at the raised-floor foundation systems (cripple walls or post-and-pier systems). This was consistent with the database by having "…building off foundation" (category A) with the largest number (Figure 8.4). It is likely that many instances of "building or story leaning" (category B) as well as "racking damage…" (category C) were also due to problems with raised floor foundation systems. The database thus indicates that majority of damage was associated with raised floor foundations.

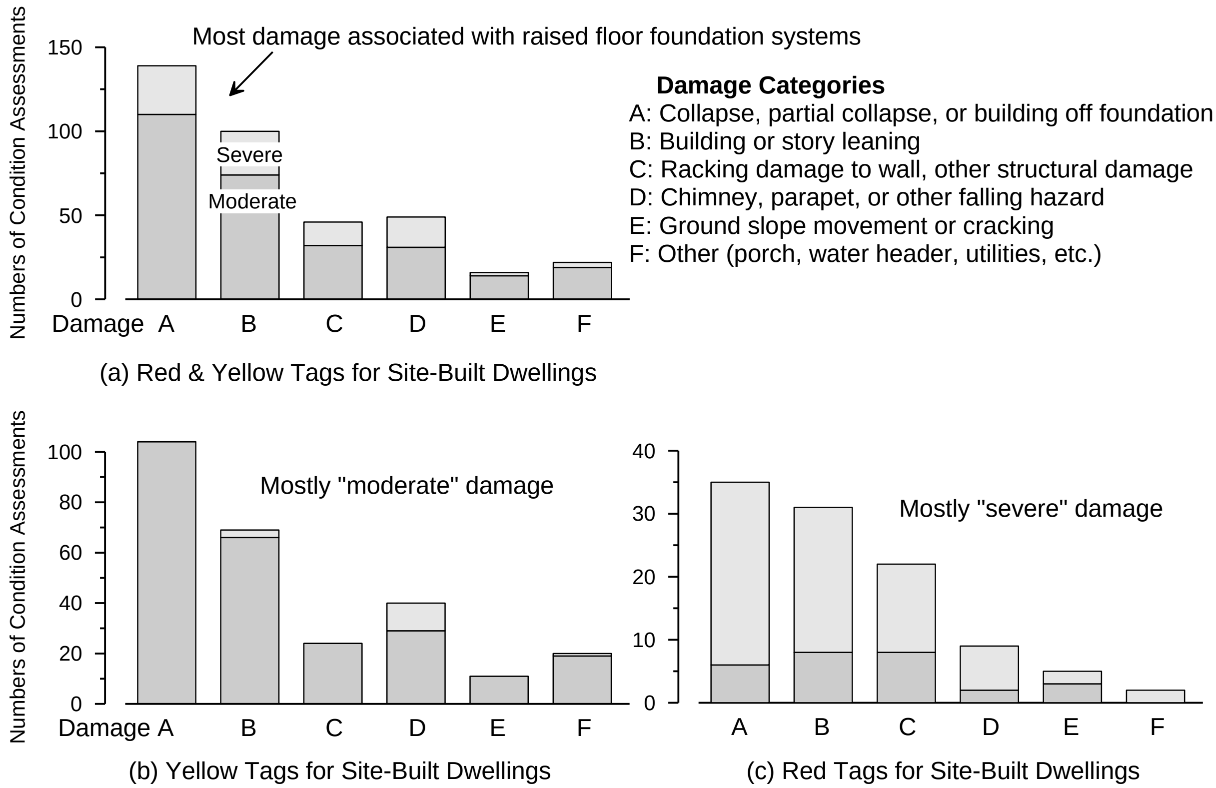


Figure 8.4. Evaluation categories for site-built dwellings having damage (yellow- or red-tags). Damage had multiple categories. For example, a dwelling might have both "severe" racking (category C) and "moderate" chimney damage (category D).

Mobile Homes

Typical damage was in the support system underneath the home leading to shifting on piers and/or falling to the ground. The home unit itself behaved like a rigid box, and likely could be repaired and re-installed after the earthquake. The database indicates (Figure 8.2) about one-in-three of all mobile homes likely had this type of damage (38/106). This is a higher damage rate compared to site-built dwellings (about one-in-five). Considering both dwelling types experienced the about same shaking intensity, mobile homes suffered disproportionate damage versus site-built dwellings.

Masonry Chimneys

Damage to brick masonry chimneys was observed in the reconnaissance. Damage category D includes chimneys, and it was reported as having "moderate" or "severe" damage in 49 inspections (Figure 8.4a). A search of the database comments indicates chimney damage was specifically mentioned in 39 inspections. Hence, most of the category D evaluations were for damage to brick masonry chimneys. Only about one-in-seven of damaged site-built dwellings had reported chimney damage (39/257). However, many masonry chimneys appeared to have been removed or replaced prior to the earthquake as noted above. Also, newer homes are often built without masonry chimneys in recognition of their vulnerability.

9. Municipal Water Systems

This section document damage to Rio Dell municipal water systems: drinking water, wastewater (sewage), and storm drains. Rio Dell has 1,450 service accounts (customers) associated with its population of about 3,400.

Drinking Water System

The system consists of a network of water mains, valves and storage tanks that deliver water from a water treatment plant (WTP) and metropolitan wells (Figure 9.1). Recent annual water usage is about 90 million gallons (MG) of which about 95% is taken from infiltration galleries under the Eel River upstream from the plant, and about 5% from a backup water supply derived from metropolitan wells. The wells are located north of the Eel River and water is brought across the river via a pipe located in the Highway 101 Bridge. Distribution and transmission system consists of about 26 miles of pipe of various types. Distribution pipes are mostly asbestos cement (AC) and steel pipe.

- 2 inch galvanized steel pipe having threaded joints.
- 4, 6, 8 & 10 inch AC pipe having push-on joints.
- 8 & 10 inch polyvinyl chloride (PVC) pipe having push-on joints.
- 8 & 10 inch high density polyethylene (HDPE) pipe having fused joints.

There are four water storage tanks located in the hills west of the city of which three are active. Highway 101 bisects the city and there are seven pipe highway crossings.

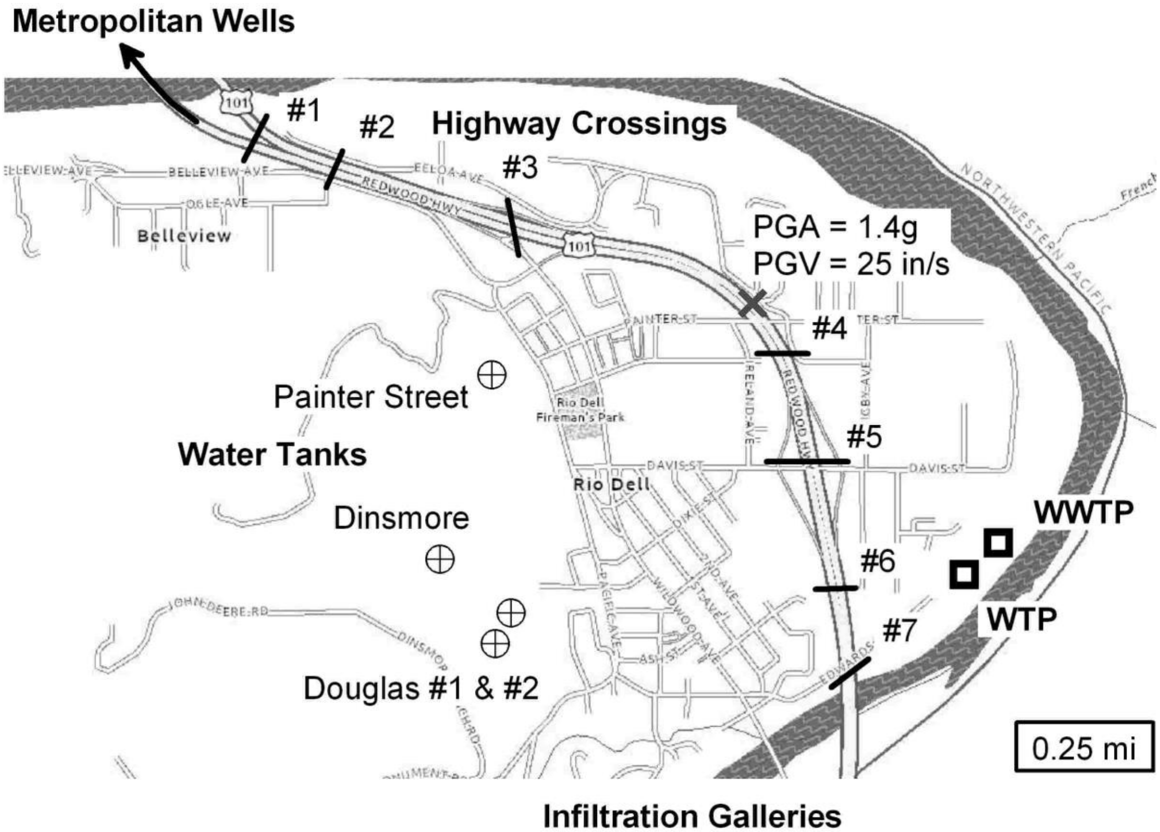


Figure 9.1. Map of Rio Dell showing features of water system.

Water Main Damage. Eleven water mains were damaged requiring repairs shortly after the earthquake. Figure 9.2 shows the repair locations and Table 9.1 describes pipe types. Repairs were to steel and AC pipe.

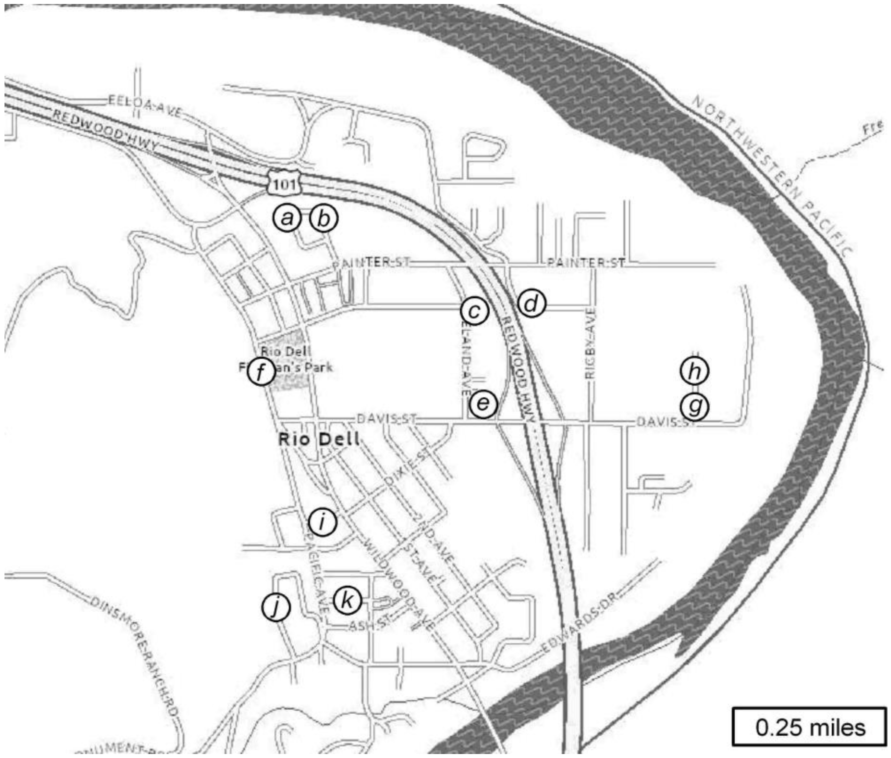


Figure 9.2. Locations of water main repairs.

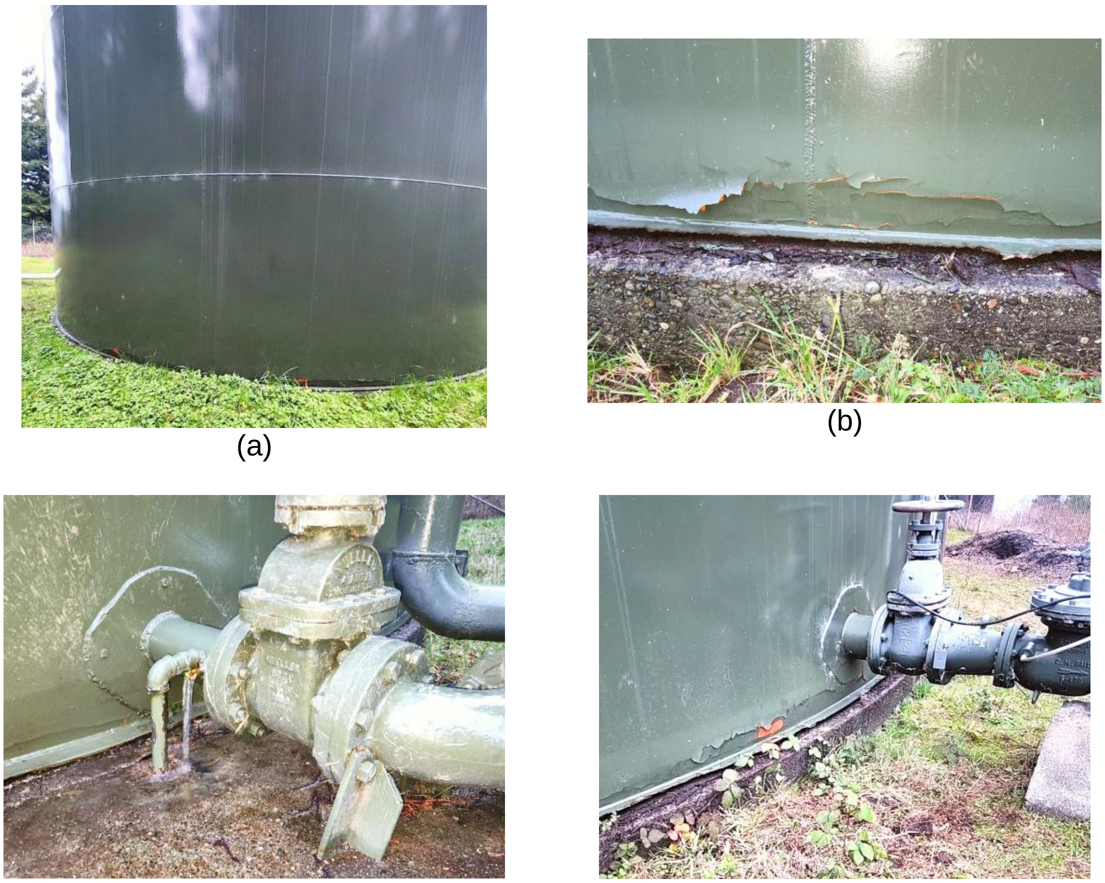
Table 9.1. Pipe repairs following earthquake.

ID	Street	Pipe Type
a	North Street	2 inch steel
b	North Street	2 inch steel
c	Center Street	6 inch AC at highway under-crossing
d	Center Street	6 inch AC at highway under-crossing
e	Davis Street	6 inch AC at highway under-crossing
f	Pacific Avenue	2 inch steel
g	Walnut Drive	6 inch AC
h	Walnut Drive	6 inch AC
i	Elm Street	2 inch steel
j	Cherry Lane	6 inch AC
k	Birch Street	2 inch steel

Water Tank Damage. One welded steel tank suffered damage and was shut down immediately following the earthquake (Table 9.2). Figure 9.3 shows photos of the Painter Street tank damage.

Table 9.2. Water tanks.

Name	Capacity	Construction	Comment
Painter Street	250k gal	Welded steel tank with no tie-downs.	Damaged in earthquake. Shell wall buckled. Broken pipe.
Dinsmore	200k gal	Bolted steel tank with tie-downs.	Some leakage at bolted joints that was remedied by bolt tightening.
Douglas #1	250k gal	Redwood tank.	Not in use at time of earthquake.
Douglas #2	500k gal	Bolted steel tank with tie-downs.	No damage.



(a) (b)

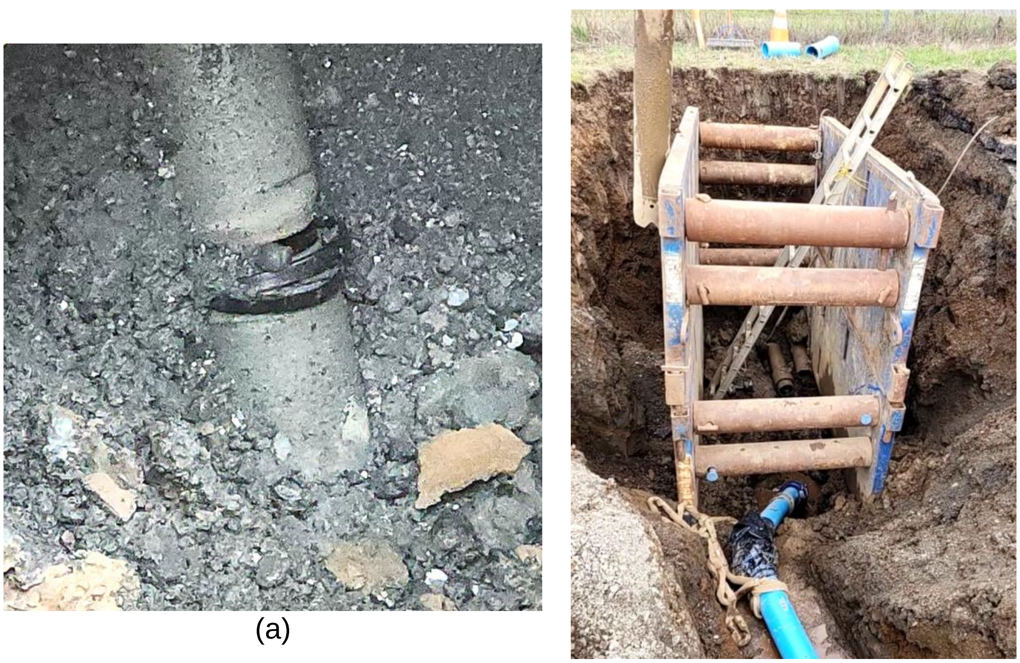
(c) (d)

Figure 9.3. Painter Street tank damage (photos courtesy of Randy Jensen). Tank constructed in 1956. (a) View of tank. Notice tank shell buckling at base. (b) Close-up view of tank wall buckling. (c) Water leaking from fracture of small diameter pipe (at center). (d) Tank shell buckling near outlet piping.

Pipe Damage at Highway Crossings. Table 9.3 contains the post-earthquake status of the crossings. Pipes at two crossings were severely damaged necessitating immediate valve closures to isolate the breaks. Damage was near the thrust blocks where the pipe had angle changes. Figure 9.4 show photos of crossing #4 at Center Street.

Table 9.3. Pipe highway crossings.

Number	Pipe Type	Comment
#1	8 inch AC	No damage.
#2	10 inch HDPE	No damage.
#3	10 inch HDPE	No damage.
#4	6 inch AC	Pipe broke on both sides of highway near anchor blocks where pipe dipped down under roadway.
#5	6 inch AC	Pipe broke at west side of highway near anchor block where pipe dipped down under roadway.
#6	6 inch AC	No damage.
#7	10 inch HDPE	No damage. Transmission main from WTP to Douglas reservoirs
#7	8 inch steel	No damage. Raw water main from river infiltration galleries to WTP.
See Figure 9.1 for location of crossings. Highway 101 forms an underpass at Painter and Davis Streets where the highway lies below street elevations. Crossings #4 and #5 require pipes to dip down significantly to be below highway pavement.		



(a) (b)

Figure 9.4. Photos of pipe at highway crossing #4 (courtesy of Randy Jensen). (a) Separation of AC pipe at inclined run as it dips down under highway. (b) Installation of replacement PVC pipe. Notice the deep burial depth.

Wastewater System

The Rio Dell wastewater system consists of a network of sewer pipes and associated appurtenances that convey sewage to the wastewater treatment plant (WWTP) located adjacent to WTP (Figure 9.1). Typical annual operations treat about 100 million gallons (MG) of wastewater. The WWTP utilizes an aerated activated sludge process to provide secondary treatment of wastewater. Secondary effluent is chlorinated in a concrete contact basin, then de-chlorinated and discharged to the Eel River (October-May) or flood irrigation fields (May-October). The sewer system consists of about 20 miles of clay tile and asbestos cement (AC) pipe.

Typical inflows are 170,000 gallons per day (GPD) during dry summer season, and 400,000 GPD during wet winter season with a maximum wet season flow of 2.2 million GPD. The earthquake damaged sewer pipe and the WWTP concrete contact basin. Pipe damage was evidenced by increased inflow and infiltration (I&I) shortly after the earthquakes as monitored at the WWTP. Pipes requiring repair have yet to be identified at the time of this writing. The damage to the contact basin appears to be in underground piping as evidenced by treated wastewater leakage appearing at ground surface adjacent to basin.

Storm Drain System

Rio Dell has storm drains located in some of its city streets. The total length of drainage pipe is about 10 miles. Pipe consists mostly of galvanized steel pipe (mostly 12 inch but some 18 and 24 inch). Some pipes were apparently damaged as evidenced by pavement settlements and ponding of rain water noted after the earthquake. It appears that some pipes were weakened by corrosion and were damaged by the earthquakes so that subsequent rain flows leaked into the ground causing settlements. Pipes requiring repair have yet to be identified at the time of this writing.

10. Key Findings

On-site reconnaissance of Rio Dell was performed to document damage caused by the earthquakes. Attention was given to site-built homes, chimneys, mobile homes, and municipal water systems. Key points follow.

- About one-in-four of all the buildings suffered some sort of damage that warranted posting with either yellow- (restricted use) or red-tag (unsafe).
- About one-in-five of all site-built dwellings (house, duplexes, apartment buildings, etc.) were damaged (yellow- or red-tag). The most common building type was a one-story single-family wood-frame home. Damage was mostly in raised-floor foundation systems found in older homes resulting with home permanent offsets at the foundation level.
- Some masonry chimneys suffered damage. It was noticeable that numerous masonry chimneys were removed or replaced prior to the earthquakes likely as consequence of previous earthquakes. Hence, many vulnerable chimneys were mitigated prior to the subject earthquakes.
- About one-in-three of all mobile homes were affected (yellow- or red-tags). Some homes had barely perceptible offsets while others slid off their supports and fell to the ground. Mobile homes had higher damage rates when compared to the many site-built homes in their immediate vicinity.
- The municipal water systems suffered damage including reservoir steel tank wall buckling, contact basin leakage, and multiple buried pipe breaks.
- Earthquake shaking was intense from a building code perspective (PGA = 1.4g, PGV = 25 in/s). The EW response spectrum from recorded ground accelerations exceeded the design earthquake (DE) for Rio Dell (ASCE 7-22). However, most buildings were built via building code prescriptive conventional construction methods and thus did not have custom engineering design and analysis.