Chapter 4 Earthquakes and Liquefaction

4.1 Risk Assessment

4.1.1 Description of Hazards

Requirement §201.6(c)(2)(i): The risk assessment shall include a description of the type location and extent of all natural hazards that can affect the jurisdiction.

An earthquake is a sudden release of energy in the earth's crust. Caused by movement along fault lines, earthquakes vary in size and severity. The focus of an earthquake is found at the first point of movement along the fault line, and the epicenter is the corresponding point above the focus at the earth's surface. The size of an earthquake has been measured in various ways, the most familiar being the now obsolete Richter magnitude scale, which determines the amount of ground displacement or shaking that occurs near the epicenter. The Richter magnitude scale has now been replaced by the Moment Magnitude scale for medium and large sized earthquakes. While this scale attempts to characterize the amount of energy released by an earthquake, another scale - the Modified Mercalli Intensity Scale - measures ground shaking intensity in terms of perception and damage and takes into account localized earthquake effects (Table 9).

Intensity	Shaking	Description/Damage
1 (I)	Not felt	Not felt except by very few under especially favorable conditions
2 (II)	Weak	Felt only by a few people at rest, especially on upper floors of buildings
3 (III)	Weak	Felt quite noticeably by people indoors, especially on upper floors of buildings: Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations are similar to the passing of a truck, with duration estimated.
4 (IV)	Light	Felt indoors by many, outdoors by few during the day: At night, some are awakened. Dishes, windows, and doors are disturbed; walls make cracking sounds. Sensations are like a heavy truck striking a building. Standing motor cars are rocked noticeably.
5 (V)	Moderate	Felt by nearly everyone; many awakened: Some dishes and windows are broken. Unstable objects are overturned. Pendulum clocks may stop.
6 (VI)	Strong	Felt by all, and many are frightened. Some heavy furniture is moved; a few instances of fallen plaster occur. Damage is slight.
7 (VII)	Very Strong	Damage is negligible in buildings of good design and construction; but slight to moderate in well-built ordinary structures; damage is considerable in poorly built or badly designed structures; some chimneys are broken.

Intensity	Shaking	Description/Damage
8 (VIII)	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
9 (IX)	Violent	Damage is considerable in specially designed structures; well-designed frame structures are thrown out of plumb. Damage is great in substantial buildings, with partial collapse. Buildings are shifted off foundations. Liquefaction occurs.
10 (X)	Extreme	Some well-built wooden structures are destroyed; most masonry and frame structures are destroyed with foundations. Rails are bent.
11 (XI)	Catastrophe	Few, if any, (masonry) structures remain standing. Bridges are destroyed. Broad fissures erupt in the ground. Underground pipelines are rendered completely out of service. Earth slumps and land slips in soft ground. Rails are bent greatly.
12 (XII)	Enormous Catastrophe	Damage is total. Waves are seen on ground surfaces. Lines of sight and level are distorted. Objects are thrown upward into the air.

Table 9 Modified Mercalli Intensity Scale

Damage from earthquakes varies with the local geologic conditions, the quality of construction, the energy released by the earthquake, the distance from the earthquake's focus, and the type of faulting that generates the earthquake. Ground motion is the primary cause of damage and injury during earthquakes and can result in surface rupture, liquefaction, landslides, lateral spreading, differential settlement, tsunamis, building failure and broken utility lines, leading to fire and other collateral damage. Typically, areas underlain by thick, water-saturated, unconsolidated material will experience greater shaking motion than areas underlain by firm bedrock, but in some cases, relief may intensify shaking along ridge tops.

Fires and structural failure are the most hazardous results of ground shaking. Most earthquake-induced fires start because of ruptured power lines and gas or electrically powered stoves and equipment, while structural failure is generally the result of age and type of building construction.

Past experience has shown that the entire county is vulnerable to earthquake hazards. Within Santa Cruz County there are several active and potentially active faults. Zones of fracture are designated in the Seismic Safety Element of the General Plan/Local Coastal Plan and California State designated Seismic Review Zones. Fault zones designated for review by the County include the Butano, Sargent, Zayante, and Corralitos complexes. State-designated seismic review zones include the San Andreas, San Gregorio, and portions of the Zayante and Butano complexes. No new active or potentially active faults have been identified in the County for this plan update (Figure 8).

Movement along these faults can cause fault-related surface deformation (e.g., surface fault rupture) where the fault reaches the surface of the ground. Within the mapped fault zones in the County, it is likely that movement along these faults will damage structures, roads, utilities, and other fixed facilities. The mapping of these zones has not changed for this plan update.

In addition to these zones, other ground cracking was observed during the Loma Prieta earthquake and the San Francisco earthquake of 1906. Many of these ground cracks can be attributed to movement or consolidation of large and moderate sized landslides while other ground cracks were most likely related to ridge spreading. Although much of the ground cracking was found near the fault zones and in the Summit area of the county, other ground cracking was found on ridge tops throughout Santa Cruz County. During the past five years Santa Cruz County has not experienced similar ground cracking as a result of an earthquake.

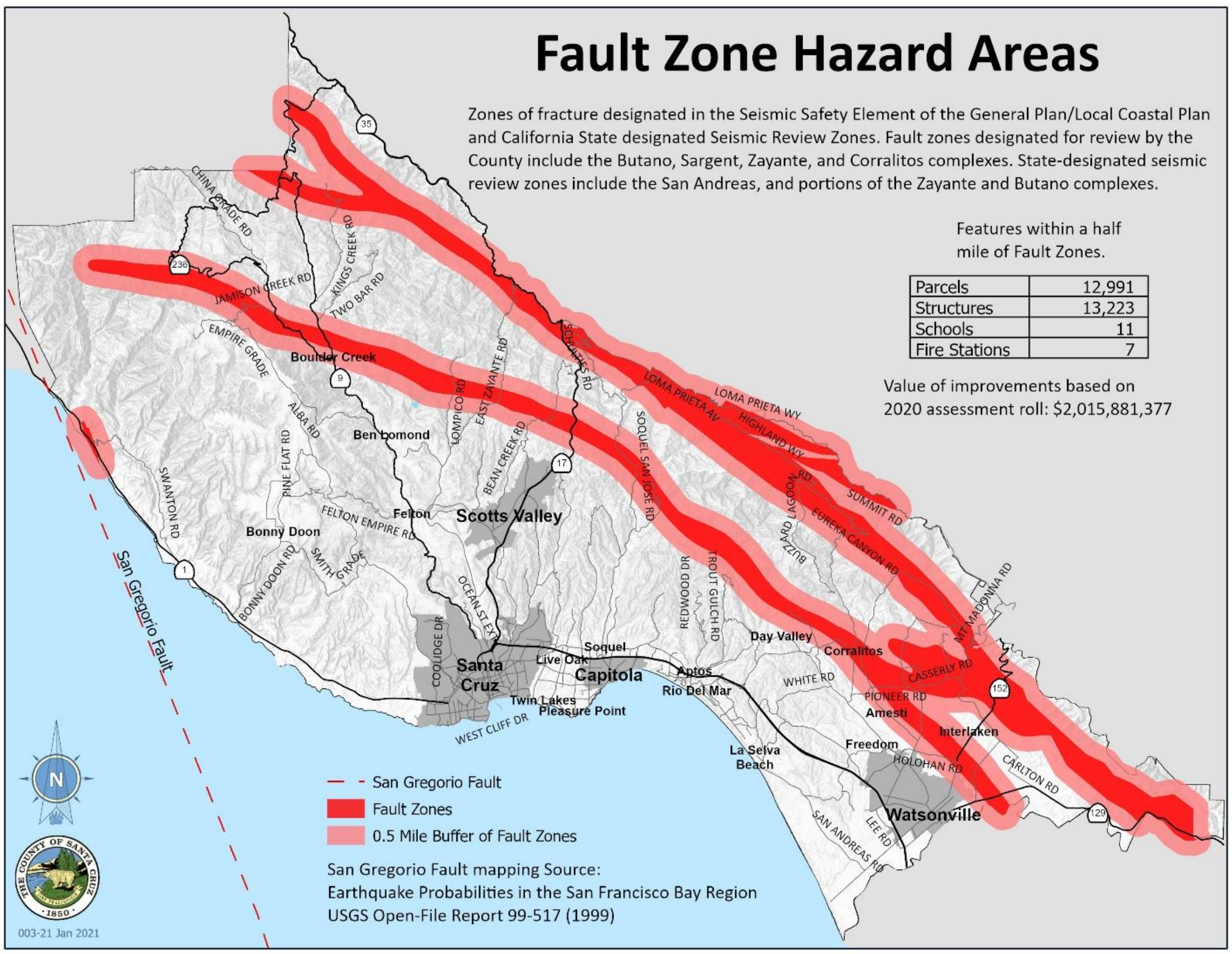

Figure 8 Fault zones of Santa Cruz County

Liquefaction is the transformation of loose, water-saturated granular materials (such as sand or silt) from a solid to a liquid state accompanying ground shaking during an earthquake. Liquefaction commonly, but not always, leads to ground failure. On slopes liquefaction may result in slope failure. Liquefaction potential varies significantly, and site-specific analysis is needed to accurately determine liquefaction potential in earthquake prone areas. Most of the valley bottoms in the southern regions of the County are underlain by alluvium and are considered at very high, high, or moderate risk for liquefaction potential based on the Santa Cruz County Liquefaction Hazard Areas map (Figure 9). Coastline regions also have low to very high liquefaction potential.

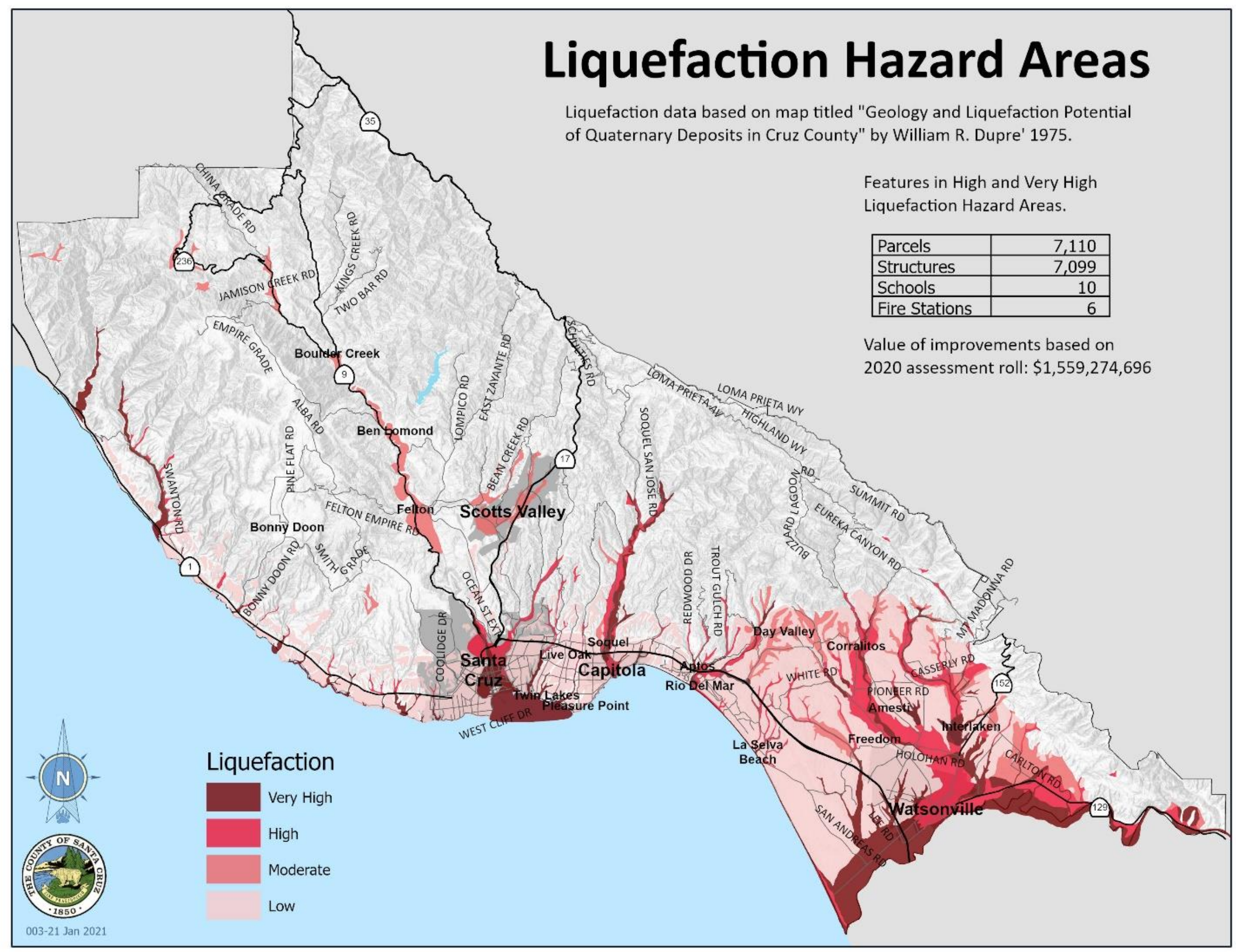

Figure 9 Map of liquefaction potential in Santa Cruz County

4.1.2 Previous Occurrences

Requirement §201.6(c)(2)(i): The plan shall include information on previous occurrences of hazard events and on the probability of future hazard events.

The following is a list of previous events, dates, severity, level of damage, duration, sources of information used, and maps (where available) to show areas affected. While Santa Cruz County has sustained numerous earthquakes throughout its history, the two most destructive ones were the 1906 San Francisco earthquake and the 1989 Loma Prieta earthquake.

Moderate-Sized Earthquakes before 1906: Four moderate-sized earthquakes (estimated Richter magnitude 6 to 6.5) were recorded in Santa Cruz County before the April 18, 1906 earthquake: a Richter magnitude 6 earthquake on February 26, 1864 centered somewhere in the southern Santa Cruz Mountains, a Richter magnitude 6.5 earthquake on October 8, 1865 centered in the Santa Cruz

Mountains, a Richter magnitude 6 earthquake on March 26, 1884 centered in the Santa Cruz Mountains, and a Richter magnitude 6.25 earthquake in the Pajaro Gap on April 24, 1890. All of these together indicate that a pattern of earthquakes nearly the same size of the Loma Prieta earthquake have occurred in the recent past. Each of these earthquakes caused some damage and would cause damage to homes today (all magnitudes cited are estimates based on descriptions of the damage which occurred). Figure 9 shows the intensity of effects from the 1989 Loma Prieta earthquake in terms of the Modified Mercali Scale measurement of level of damage in different locations.

April 18, 1906: (Richter magnitude: 8.3) There were no recorded deaths in Santa Cruz County, but the old courthouse partially collapsed and about 1/3 of the chimneys within the city of Santa Cruz were destroyed or damaged. Landsliding was observed throughout the Santa Cruz Mountains, and fault rupture was nearly continuous along the San Andreas fault zone, and nearby fault zones in Santa Cruz County. Infrastructure, including bridges, were destroyed, and broken mains and pipes shut off the water supply.

October 1926: (Richter magnitude 6.1) Two large earthquakes occurred during this year. Three of the aftershocks cracked plaster in Santa Cruz, almost bringing down the chimneys of numerous buildings. It broke plate glass windows along Pacific Avenue. The city water main broke at Laguna Creek and articles fell from shelves at stores.

October 17, 1989: (Richter magnitude: 7.1) At 5:04 p.m., a magnitude 7.1 earthquake rocked the Monterey Bay and San Francisco Bay regions. The initial quake lasted only 22 seconds, although in the following two weeks, more than 4000 aftershocks were recorded, with 20 of these greater than magnitude 5 on the Richter Scale. The epicenter of the Loma Prieta earthquake was about 10 miles east-northeast of the city of Santa Cruz in the Aptos planning area on the San Andreas Fault. In Santa Cruz County, 674 dwellings, 32 mobile homes and 310 businesses were destroyed in the earthquake. The Loma Prieta earthquake was the largest to strike California since 1906, causing 62 deaths and 3,757 injuries. More than 12,000 people were left homeless, and transportation, utilities and communications were disrupted. There was more than $6 billion in property damage. Figure 10 is a map based on the Modified Mercalli Intensity Scale for the Loma Prieta earthquake.

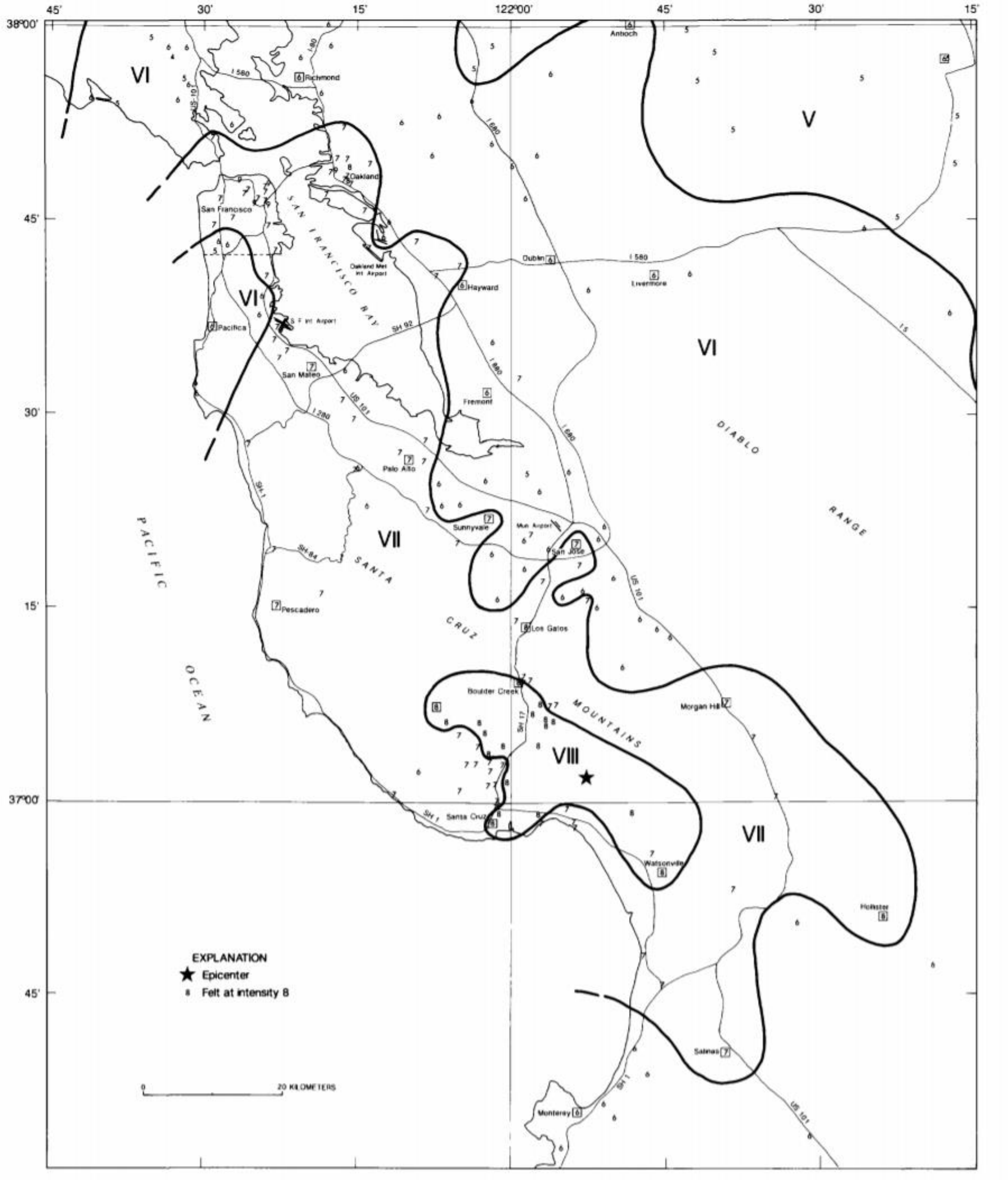

Figure 10 Isoseismal map for the San Francisco Bay region for the 1989 Loma Prieta earthquake

There are at least six major faults and fault systems within or near Santa Cruz County, placing it in an area of high seismic risk. Because earthquakes can cause severe damage over a long distance, the Santa Cruz area remains at risk from continued seismic activity along the many faults in the greater San Francisco Bay region. The reduction of seismic stresses that occurred in the Loma Prieta earthquake did nothing to relieve, and possibly increased, stresses within other faults, including other sections of the San Andreas Fault.

To clarify the extent of future earthquake risk, a partnership of the United States Geologic Survey, the California Geologic Survey, and the Southern California Earthquake Center, known as the Working Group on California Earthquake Probabilities, evaluated, and systemized currently available historic and paleoseismic information to produce a probabilistic seismic hazards analysis to indicate the type of future earthquakes. The resulting model, referred to as the third Uniform California Earthquake Rupture Forecast, or "UCERF3"[1], represents the best available science for estimates of the magnitude, location, and likelihood of potentially damaging earthquakes in California. The UCERF3 was developed in 2013 and represents the latest earthquake rupture forecast model that tells us where and when the Earth might slip along the state's many faults.

The results of the UCERF3 for the San Francisco region are shown in Table 10. The table indicates the average time between earthquakes and the likelihood of having one or more such earthquakes in the next 30 years (starting from 2014). It is important to note that the repeat times are averages and actual repeat times will certainly vary significantly. The fault systems producing these earthquakes are located throughout the San Francisco region and near Santa Cruz County (USGS Fact Sheet 2016-3009).

San Francisco Region		
Magnitude (greater than or equal to)	**Average repeat time (years)**	**30-year likelihood of one or more events**
5	1.3	100%
6	8.9	98%
6.7	29	72%
7	48	51%
7.5	124	20%
8	825	4%

Table 10 Average repeat time and likelihood of earthquakes in the San Francisco region

As noted, the UCERF3 is an earthquake fault rupture forecast model that tells us where and when earthquakes might occur. Combining this information with ground motion prediction models that estimate the ensuing shaking from a fault rupture results in estimates of seismic hazards in the areas where fault rupture might occur. The UCERF3 has been used for the 2014 update of the U.S. Geological Survey National Seismic Hazard Maps. Combining the seismic hazard information with engineering models of the built environment results in estimates of seismic risk, which is the probability of losses or damage to the built environment if exposed to a seismic hazard.

[1] https://www.scec.org/ucerf

4.1.3 Assessing Vulnerability: Overview

Requirement §201.6(c)(2)(ii): The risk assessment shall include a description of the jurisdiction's vulnerability to the hazards described in paragraph (c)(2)(i) of this section. This description shall include an overall summary of each hazard and its impact on the community.

The vulnerability of a community to earthquake hazard is based on a variety of factors including proximity to active and inactive faults, the age of structures, the density of the population and development, the value of property and infrastructure, the construction materials used in residential and non-residential buildings, and the location of critical facilities in a community. Recent history indicates that Santa Cruz County has a very high vulnerability to earthquakes due to proximity to faults, density of population and development within the floodplains of the many creeks and rivers, which are subject to liquefaction.

One or more moderate to large sized earthquakes (magnitude 6.5 to 7.5) will likely shake the entire County of Santa Cruz during the life span of most residents. Many older homes that were damaged but not destroyed in 1989 were improved seismically but still are at a higher risk than newer construction using the latest building code standards. Modern homes will normally fare better in earthquakes but 1989 showed that this is not necessarily the case. Some older homes fared better than newer ones due to location and design.

A great earthquake on the San Andreas Fault or other regional major faults will:

- Damage roads, bridges, and critical structures, and could severely damage most homes in the County.
- Liquefaction could occur along alluvial areas such as Pajaro Valley, parts of Capitola and Santa Cruz, and along streams such as Corralitos Creek, the San Lorenzo River, and other streams throughout Santa Cruz County.
- Fault Rupture may occur near the major faults as zoned by the County and State, and
- Ground Cracking may occur through the hillslopes and near the Fault Zones.
- As indicated in the sections on landsliding and coastal erosion, earthquakes can reactivate landslides and cause coastal bluff failure, and also contribute to the initiation of other landslides and slope failures.

4.1.4 Assessing Vulnerability: Identifying Structures

Requirement §201.6(c)(2)(ii)(A): The plan should describe vulnerability in terms of the types and numbers of existing and future buildings, infrastructure, and critical facilities located in the identified hazard areas.

Large areas of the County are located within 0.5 mile of a State or County designated fault zones or in a liquefaction hazard area, as indicated on the maps in Figures 8 and 9. Estimates of the types and numbers of existing buildings, facilities and infrastructure located in these mapped areas is determined using the County's GIS application. The earthquake hazard layer and 0.5-mile buffer are overlayed on the parcel layer to identify the parcels that fall within the earthquake hazard layers. The liquefaction hazard layer is defined by the mapped high and very high liquefaction hazard areas. Using the County Assessor information for the improvement characteristics for the selected parcels, the number of structures located with the seismic hazard areas is determined. The number of structures is shown on the maps in Figures 8 and 9.

Past experience has shown that the entire county is vulnerable to earthquake hazards including severe ground shaking. Thus, every structure in the unincorporated area of the County is vulnerable to earthquake related hazards. However, the structures identified in Figures 8 and 9 and the value at risk shown in Table 11 are particularly vulnerable because of their location in proximity of a fault zone or high or very high liquefaction area.

4.1.5 Assessing Vulnerability: Estimating Potential Losses

Requirement §201.6(c)(2)(ii)(B): The plan should describe vulnerability in terms of an estimate of the potential dollar losses to vulnerable structures identified in paragraph (c)(2)(ii)(A) of this section and a description of the methodology used to prepare the estimate.

Figures 8 and 9 include information on the number and type of structures located within 0.5 miles of a mapped fault zone or in a liquefaction hazard area and the total value of the structures. Table 11 is a summary of the number, type, and value of all structures located in fault zones and the 0.5-mile buffer and in a high or very high liquefaction hazard area. The methodology used to prepare both estimates is the same. Using the County's GIS application, the earthquake hazard layer and 0.5-mile buffer and the high and very high liquefaction hazard area is overlayed on the parcel layer to identify the parcels that fall within the earthquake hazard layers and their assessed value. There is some overlap of the fault zone layer and liquefaction hazard layer in the southern portion of the County, therefore, the amounts shown in Table 11 include some double counting of parcels and structures and is, therefore, an overestimate. Vulnerability estimates are limited to ground motion-induced losses to buildings only. In other words, the losses to other elements of the built environment, such as transportation, lifeline and communication facilities are not reported. Furthermore, the losses reported are only the direct economic losses due to building damage, which consist of capital stock loss.

Land Use	Parcels	Structures	Total Assessed Value in 2020 Dollars
Agricultural	1,016	1488	$148,191,432
Commercial	419	727	$182,247,585
Government	667	161	0
Industrial	49	136	$30,508,089
Institutional	200	479	$69,619,425
Miscellaneous	624	544	$64,831,045
Residential	16,988	16740	$3,079,653,024
Utilities	138	47	$105,473
Total	**20,101**	**20,322**	**$3,575,156,073**

Population	36,809		
Population is based on the 2010 Census. Unincorporated Block centroids were selected by the hazard area.			

Table 11 Earthquake potential loss inventory

An additional method of earthquake loss estimation has been developed and updated by the California Geologic Survey (CGS). In 2016[2], using the latest Hazus default information for built environment and demographics, CGS updated statewide annualized earthquake losses for California. The annualized earthquake loss (AEL) is the estimated long-term value of earthquake losses to the general building stock in any single year in a specified geographic area. This AEL update is based on ground motions from the 2014 update of the U.S. Geological Survey National Seismic Hazard Model. AEL estimate at the state level is approximately $3.7 billion. AEL estimate for Santa Cruz County is approximately $43 million.

4.1.6 Assessing Vulnerability: Analyzing Development Trends

Requirement §201.6(c)(2)(ii)(C): The plan should describe vulnerability in terms of providing a general description of land uses and development trends within the community so that mitigation options can be considered in future land use decisions.

Santa Cruz County has a number of compact urban communities as well as extensive areas of agricultural land and forested hillsides. A number of rural villages and towns are located throughout the County. As dictated by the 1978 Growth Management Ordinance, most new development has occurred within or adjacent to the urban services line (i.e., the boundary point for such infrastructure as water and sewage service). As with most communities, increased housing costs has resulted in the need to provide higher density housing. In Santa Cruz County, all development of this type occurs where urban services are available. Other development is mostly infill or reuse development, and development of existing rural residential properties.

Growth management policies limit development from occurring where hazards are present and, in most cases, require substantial setbacks from these hazards. Seismic safety standards are a requirement for all building permits. As infrastructure is repaired or replaced, updated seismic safety standards are incorporated.

No changes in these development regulations or patterns occurred that would affect the County's overall vulnerability since the previous plan was adopted in 2010. While the County does not track the number of residential and commercial structures that have been built in earthquake and liquefaction hazards zones since the last LHMP was adopted in 2010, it is a subset of the overall number of new structures built in the unincorporated portion of the County. As noted above, most new development of residential structures and virtually all new development of commercial structures occurs within the urban services line and outside of earthquake and liquefaction hazards zones.

---

[2] Chen, R., K.S. Jaiswal, D. Bausch, H. Seligson, and C.J. Wills (2016). Annualized Earthquake Loss Estimates for California and Their Sensitivity to Site Amplification, *Seismological Research Letters*, v 87 (8), Pre-Issue Publication Article, doi: 10.1785/0220160099.

The County has adopted growth management policies and ordinances that limit growth. According to annual Growth Management Reports, there have been about 900 new residential structures built in the County since 2010, broken down by year in Table 12.

Residential Building Permit Issued				
Year	**Market Rate**	**Affordable**	**Second Units**	**Total**
2010	35	0	24	59
2011	34	89	18	141
2012	55	64	19	138
2013	42	4	29	75
2014	61	2	19	82
Subtotal (2016 LHMP update)	**227**	**159**	**109**	**495**
2015	30	1	29	60
2016	32	66	19	117
2017	76	0	28	104
2018	36	1	36	73
2019	37	2	21	60
Subtotal (2021 LHMP Update)	**211**	**70**	**133**	**414**
Total	**438**	**229**	**242**	**909**

Table 12 Residential building permits issued 2010 to 2019.

As stated above, growth management policies limit and mitigate new development near seismic hazards. Development on existing lots of record is required to avoid hazards and incorporate appropriate setbacks and other requirements to mitigate potential impacts from earthquake and liquefaction hazards. The Environmental Planning Section of the Planning Department, staffed by resource planners, specializes in reviewing each application for new residential and commercial structures to ensure that new development does not occur in earthquake and liquefaction hazards and that development on existing lots of record avoid, minimize, and mitigate potential impacts from identified earthquake and liquefaction hazards. These policies and procedures implement the mitigation strategy described below.

4.2 Mitigation Strategy

Requirement §201.6(c)(3): The plan shall include a mitigation strategy that provides the jurisdiction's blueprint for reducing the potential losses identified in the risk assessment, based on existing authorities, policies, programs and resources, and its ability to expand on and improve these existing tools.

The primary mitigation strategy to avoid or reduce damage from earthquakes is continuation of design review and code enforcement to meet current seismic standards, including adequate geologic engineering and geotechnical monitoring protocols to ensure structural integrity. Current policies that assist in meeting these standards include:

- Continued Enforcement of the Geologic Hazards Section of Santa Cruz County Code: Chapter 16.10 of the County Code requires the assessment of geologic hazards by the County Geologist and/or private engineering geologists for all new development projects. The geologic hazards identified through this assessment process are then mitigated by avoidance or through measures designed by civil engineers using the California Building Code.
- Continued rigorous enforcement of the California Building Standards with regards to seismicity including requiring engineering and liquefaction studies for all affected development.
- Continuing to encourage development adjacent to urban areas: By encouraging development in areas with urban services, the exposure of the population to areas where earthquakes may damage roadways and other utilities is reduced.
- Encourage the State's re-mapping of Santa Cruz County through the Seismic Hazards Zonation Program. Consider sharing the cost of the preparation of these new maps.

An assessment of this mitigation strategy as part of this five-year plan update indicates the strategy is effective for reducing potential losses identified in the risk assessment. The earthquake risk has not changed since the previous plan was adopted. No adjustments are needed to address a change in circumstances. There have been no earthquake-related disasters during the five-year update period.

4.2.1 Mitigation Goals

Requirement §201.6(c)(3)(i): The hazard mitigation strategy shall include a description of mitigation goals to reduce or avoid long-term vulnerabilities to the identified hazards.

Earthquake Goals

Earthquake 1 - Avoid or reduce the potential for life loss, injury, property, or economic damage to Santa Cruz from earthquakes.

Earthquake 2 - Encourage retrofitting and other mitigation activities that increase disaster resilience to earthquake.

Earthquake 3 - Encourage further investigation and evaluation of faults in and near Santa Cruz County and incorporate new information into the County of Santa Cruz site and building design requirements.

4.2.2 Identification and Analysis of Mitigation Actions

Requirement §201.6(c)(3)(ii): The mitigation strategy shall include a section that identifies and analyzes a comprehensive range of specific mitigation actions and projects being considered to reduce the effects of each hazard, with particular emphasis on new and existing buildings and infrastructure.

Earthquake hazards are a significant threat to Santa Cruz County. The following mitigation actions are critical to the future safety of residents of Santa Cruz County. The alpha-numeric identifiers after each action are further described in Chapter 15 Mitigation Strategy.

- Coordinate preparedness efforts with other agencies. (A-1)
- Upgrade roadways, sewer, water, and other infrastructure to withstand seismic shaking. (B-1)
- Promote seismic safety upgrade of all emergency use and critical structures. (B-16)
- Review all new and replacement critical structures to require that they be designed to standards of the California Building and County Geologic Hazards codes. (B-17)
- Train appropriate plan check staff on seismic requirements for structures. (B-18)
- Encourage zoning in geologically constrained areas that reflect the nature and extent of the hazard. (B-19)

2021 Progress Report

The integration of the plan into existing planning mechanisms and the implementation of mitigation actions demonstrate progress in risk reduction. An explanation of how the mitigation plan for seismic hazards has been implemented over the last five years is included in Appendix L and described below for each Mitigation Action related to earthquake and liquefaction hazard reduction.

- Earthquake preparedness and disaster response is coordinated by the Emergency Management Council (EMC) with other agencies and cities within the County. The EMC continues to meet on a bi-monthly basis. (A-1)
- Infrastructure such as roads, bridges, and drainage structures are continually prioritized for upgrade to withstand seismic shaking as allowed by funding resources available to the Department of Public Works. (B-1)
- County staff applies the current seismic design standards to all projects with a view to upgrade emergency uses and critical structures. As critical structures are renovated modern Building Code standards are applied to each renovation by both the design and review staff. (B-16)
- The Planning Department continues to review development applications for emergency use and critical structures, and all other structures, for compliance with the California building code and the Geologic Hazards Ordinance regarding seismic hazards. (B-17)
- Plan review staff and the building inspectors undergo continuous education courses through CALBO that include training in current seismic construction standards. (B-18)
- The County's zoning has not been revised during the reporting period in any manner that would increase or decrease earthquake hazards. The County's permit review process already requires addressing geologic constraints through application of the requirements in SCCC 16.10 Geologic Hazards. The County has adopted the latest version of the California Building Code. (B-19)

The worksheets in Appendix L also describe how the current mitigation strategy, including the goals and hazard mitigation actions, will be implemented over the next five years. There are no recommended changes to the mitigation actions for earthquake hazards, or the priorities of the mitigation actions. The actions will continue to be implemented on an ongoing basis through existing regulatory mechanisms and funding availability.