San Diego Earthquake Planning Scenario

Magnitude 6.9 on the Rose Canyon Fault Zone

DEVELOPED BY THE
EARTHQUAKE ENGINEERING RESEARCH INSTITUTE
SAN DIEGO CHAPTER

This scenario is a project of the Earthquake Engineering Research Institute San Diego Chapter in collaboration with many organizations and individuals. The production of this report was funded by EERI, Federal Emergency Management Agency through cooperative agreements EMW-2018-CA-00005 and EMW-2019-CA-00008, and the Structural Engineers Association of San Diego. The scenario was developed and studied by many local professionals who spent countless hours volunteering their time to improve seismic safety in San Diego.

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This project benefited from the advice, perspectives, contributions, and participation of many individuals and organizations.

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- The early creation of the ShakeMap by the United States Geological Survey allowed development of the remainder of the project.
- Assistance for the geological studies of this project were provided by the San Diego Association of Geologists, a committee of the San Diego Geological Society, Inc.

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Message from the Scenario Team

San Diego County is subject to seismic hazards coming from several regionally active faults, including the local Rose Canyon Fault which runs through the heart of downtown San Diego. An earthquake originated on this fault may produce substantial damage and losses for the San Diego community. San Diegans need to be aware of this hazard.

The Rose Canyon fault and its associated geologic and tectonic forces shaped San Diego County into the landscape it is today. As a community, San Diego needs to address and prepare for those forces to ensure the same fault does not devastate our community in the future.

Over the past five years, a diverse group of practitioners, researchers and stakeholders led by the EERI San Diego Chapter worked diligently to study the impacts of a plausible earthquake on the Rose Canyon fault if it were to strike the San Diego region today. The results presented in this report is the product of this volunteer effort.

A resilient San Diego, a community that can resist, respond and recover promptly to an earthquake, is the goal of this study. We expect that action towards this goal be achieved in the near future, for the safety and prosperity of our future generations.

Jorge F. Meneses, PhD, PE, GE, D.GE, F.ASCE
President, EERI San Diego Chapter

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JOINT LEGISLATIVE COMMITTEE ON
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March 4, 2020

Jorge F. Meneses, PhD, PE, GE, D.GE, F.ASCE
President, EERI San Diego Chapter
California Seismic Safety Commissioner
6976 Convoy Court
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Re: Letter of Support for the EERI San Diego-Tijuana Earthquake Scenario Report

Dear Dr. Meneses:

I am pleased to support the San Diego Regional Chapter of the Earthquake Engineering Research Institute in their work on the San Diego-Tijuana Earthquake Planning Scenario. It is my understanding that the study uncovered the possible outcomes of a magnitude 6.9 earthquake occurring on the Rose Canyon Fault between the cities of San Diego and Tijuana and how the bi-national community could set a framework of resilience strategies to best prepare for it.

Cities across California recognize how crucial the maintenance and fortification of utility infrastructure and public lifelines are to the safety of its residents. Under Resilient Los Angles Mayor Eric Garcetti has prioritized the retrofitting of seismically vulnerable structures around the city. The Port of San Francisco's Waterfront Resilience Program similarly shares the goal of reinforcing seismic resilience.

California Senate Bill 1953 was signed into law in 1994 to ensure that each hospital in state would remain operational after an earthquake. California's Office of Statewide Health Planning and Development ensures that new buildings meet a long list of strict building codes, but all properties, especially those built prior to 1994, are at risk of slight to extensive damage after an earthquake without seismic retrofitting.

Soft-story framed commercial and residential buildings places people at risk. The Structural Engineering Association of San Diego (SEAOSD) counted between 2,850 and 8,100 total seismically vulnerable structures within the county of San Diego. These are the homes that people live in, the businesses that employ them, and the institutions they rely on.

The potential seismic effects of an earthquake occurring at the Rose Canyon Fault could be disastrous without the necessary mitigation and preparation. The State of California can't prevent an earthquake but we can play a positive role in ensuring our constituents are more secure in the case of one.

Sincerely,

BEN HUESO
Senator, 40th District

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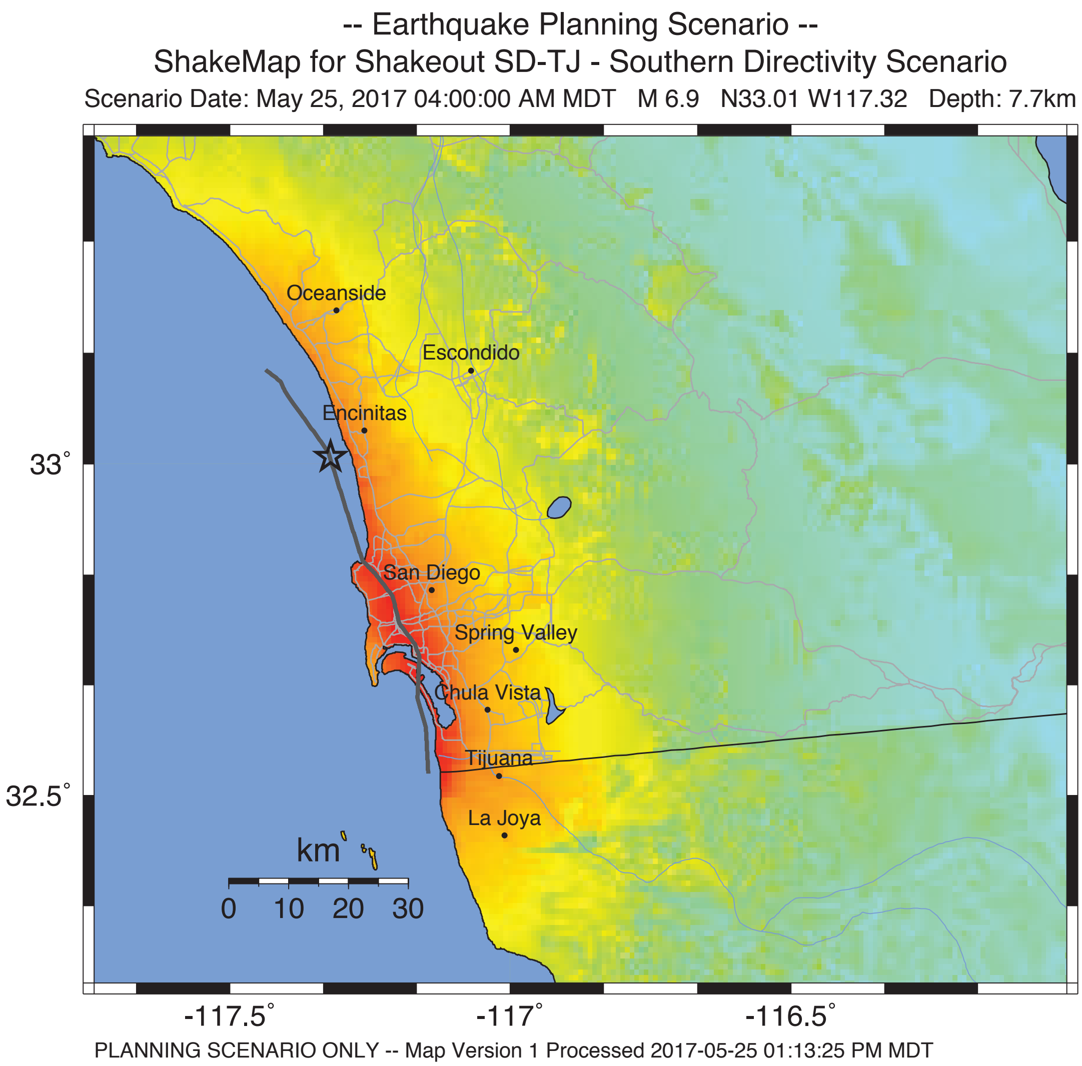
Executive Summary

The Rose Canyon Fault Zone strikes through the heart of the San Diego metropolitan area, presenting a major seismic hazard to the San Diego region, one of the fastest growing population centers in California and home to over 3.3 million residents. The region's large population coupled with the poor seismic resistance of its older buildings and infrastructure systems, make San Diego vulnerable to earthquakes. Best models show San Diego County facing an 18



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	*<0.02*	*0.1*	*1.4*	*4.7*	*9.6*	*20*	*41*	*86*	*>178*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

Figure E–1. USGS ShakeMap depicting the shaking intensity of the scenario earthquake.

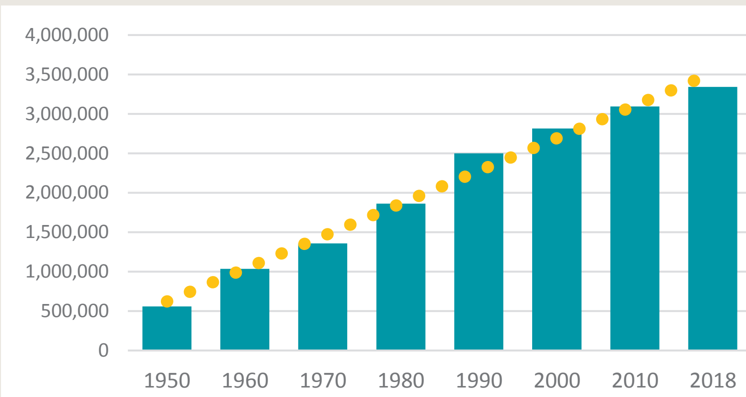
Demographic Profile of San Diego County

400,000
Non-English Speakers

$70,588
Med. Household Income

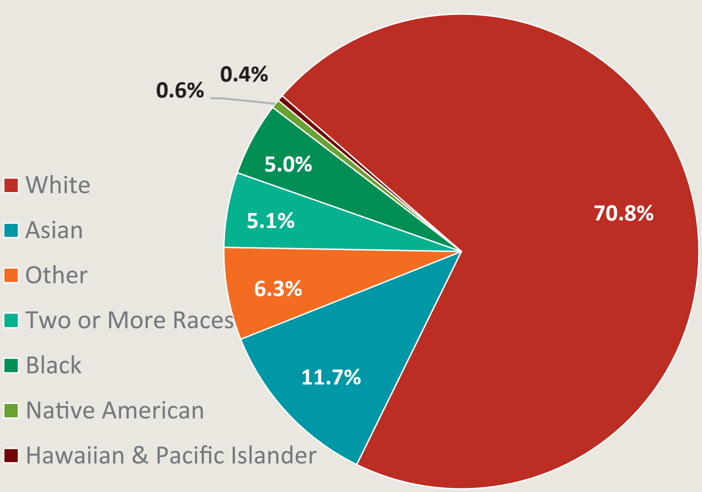
3.3 M
RESIDENTS

Population Growth Over Time, San Diego County**



Population growth by decade, San Diego County (1950-2018).

Race Breakdown, San Diego County*



Population by race, San Diego County (2017).

*U.S. Census Data
**American Community Survey (2012-2017 5-Year Population Estimates)

percent probability of a magnitude 6.7 or larger earthquake occurring in the next 30-year period on a fault either within the County or just offshore (Field et al, 2015).

This earthquake planning scenario examines the potential impacts and consequences of a magnitude 6.9 earthquake occurring on the Rose Canyon Fault Zone. The Rose Canyon Fault Zone is considered to be the greatest potential seismic threat to the San Diego region due to its proximity to population, economic, and government centers. This scenario was developed by a multidisciplinary team of geoscience, structural engineering, and social science professionals and researchers with the primary goal of raising awareness of the seismic risk in the region.

This report intends to paint a broad picture of the regional seismic risk profile to highlight the threat of the Rose Canyon Fault Zone and the many opportunities for earthquake mitigation to make the San Diego region more resilient to seismic hazards.

Geologic and Seismic Effects of the Scenario Earthquake

The magnitude 6.9 scenario earthquake chosen for this analysis is expected to generate major geologic ground failure and ground shaking hazards resulting in severe seismic damage consequences.

Primary geologic hazards include surface fault rupture and severe ground shaking. Surface fault rupture with a lateral offset of approximately 6.6 feet (2 meters) is estimated to occur, extending along the trace of the fault from La Jolla, along the I-5 corridor, through Old Town, the Airport, downtown San Diego, and splintering into the San Diego Bay, Coronado, and the Silver Strand. Severe ground shaking with accelerations up to 0.55g (55% of gravity) will be generated in the near-fault areas, including from La Jolla through downtown San Diego. Severe ground shaking will also extend into South Bay communities and across the international border with accelerations of up to 0.35g in Tijuana.

Secondary geologic hazards include liquefaction, landslides, and potential aftershocks. Liquefaction will be widespread around San Diego Bay, Mission Bay, the airport area, and Mission Valley, with areas suffering up to several feet of lateral spreading and up to about a foot of ground settlement. Seismically-triggered landslides will occur in hilly areas such as Mount Soledad, Point Loma, Mission Valley, and Sorrento Valley.

Impacts to the Built Environment

The population centers, government centers, and economic centers of the San Diego region are concentrated in the near fault coastal areas where severe shaking, fault rupture and liquefaction ground failures are anticipated to occur. Much of the existing infrastructure of the San Diego region was built before recognition of the seismic hazards posed by the Rose Canyon Fault Zone; therefore, widespread impacts are anticipated from the scenario earthquake.

The scenario earthquake is expected to cause widespread damage to buildings, including moderate to severe damage to approximately 120,000 of the nearly 700,000 structures countywide. Economic losses associated with building and infrastructure damage are estimated at more than $38 billion. Business disruptions are expected to extend the economic losses throughout the long, slow process of building safety inspection, building repair, and transportation and utility services restoration.

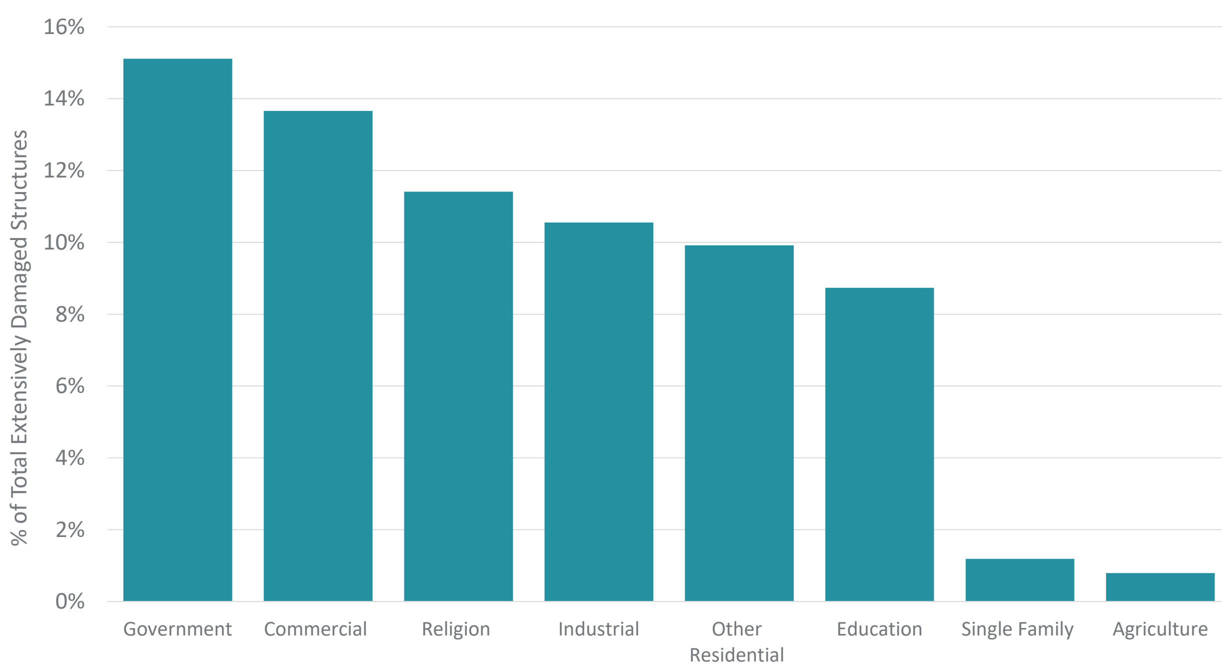


Figure E-2 Extensively Damaged Structures by Building Occupancy Type

Building Type	Standard Description and Typical Failures	Construction Era and Locations	Estimated Number in San Diego[a]
Unreinforced masonry (URM)	Brick or hollow clay tile bearing wall buildings without reinforcement Prone to partial or complete collapse caused by wall separation, parapet collapse, or global structural collapse	1880–1939 Constructed extensively as commercial and institutional buildings 1992 City of San Diego URM Ordinance (implemented in 2001) required limited partial retrofits of ~800 URMs	884 estimated as of 2001 in City of San Diego. ~300 since demolished or recategorized as non-URM buildings Several hundred URMs remain in National City, Downtown San Diego, Chula Vista, El Cajon, Solana Beach, Encinitas, Oceanside, and in unincorporated areas
Nonductile concrete	Concrete frame or shear wall buildings without sufficient reinforcing steel Prone to sudden, brittle failure and collapse	Pre-1980	500–1,000[a]
Tilt-up concrete (poorly anchored)	Constructed by tilting up concrete slabs to act as walls Prone to failure of the wall to roof connection, possibly resulting in wall and roof collapse	1930–1997 Many constructed from the 1960s-1980s Greater Kearny Mesa, Miramar, and Sorrento Valley areas	500–1,000[b]
Soft story	Typically, multi-unit apartments or condominiums with tuck-under parking on the first level and wood-framed residential structures on the upper levels Commercial structures with open storefronts and/or tall first stories at street level Prone to side-sway and potential collapse because of weak first story	1900–1980	1,000–5,000[b] National City has conducted an inventory of multi-unit residential buildings with tuck under parking.
Pre-Northridge steel moment frame	Welded steel frame buildings with insufficiently welded and configured connections Prone to fracture and damage at the connections and potential partial or complete collapse	1960–1995 Office buildings downtown San Diego along B Street, Broadway, and in the City Concourse area and in other downtown areas throughout the County Hotel and residential in downtown San Diego and waterfront districts	Unknown, but likely 50-300[b,c]
Light frame residential with cripple walls	Wood-frame residential home with relatively unbraced foundation cripple wall in the crawl space or basement Prone sideway failure and partial collapse of the cripple wall, causing the house to drop or slide off its foundation	Pre-1950s	Unknown, likely thousands.

Table E-1. Review of seismically vulnerable structures in the San Diego Region by the Structural Engineering Association of San Diego (SEAOSD). [a]Estimates of buildings are developed through expert opinion and best available data.
[b]Estimate based on comparison to other similar jurisdictions or areas in Southern California.
[c]Based on review of aerial photographs. [d]City of San Diego Development Services Department via: https://www.sandiego.gov/department/unreinforced-masonry-buildings.

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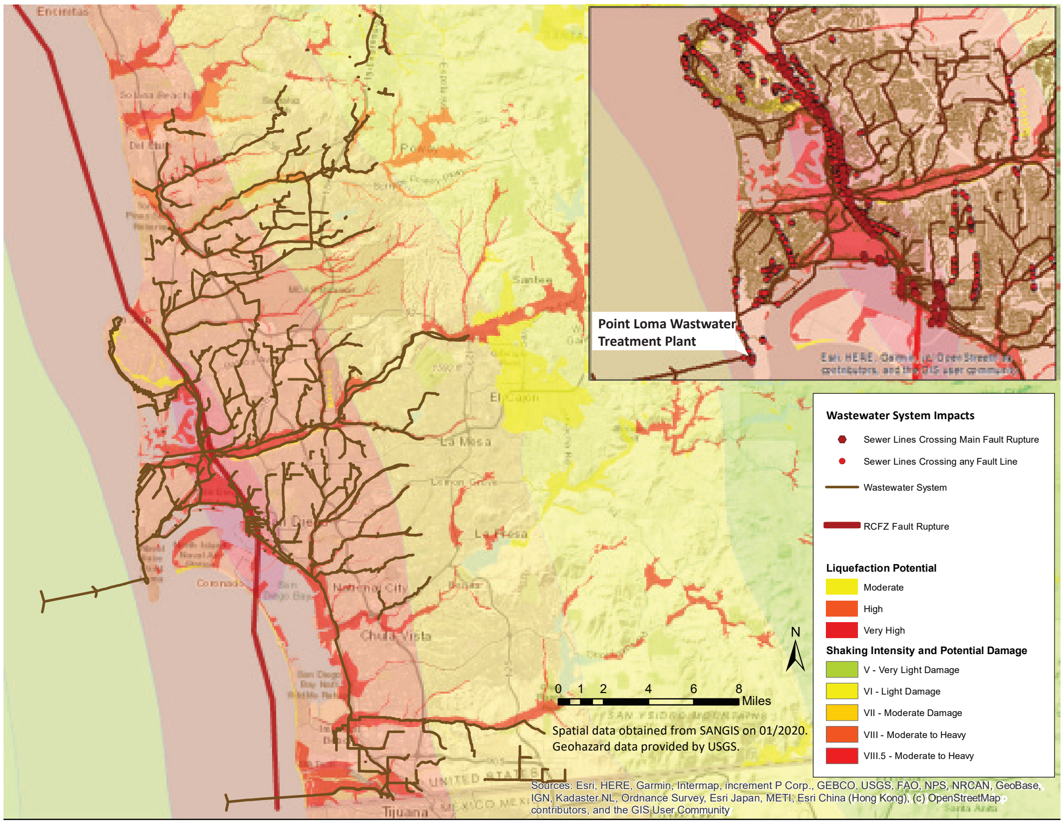


Figure E-3. Impacts of the Scenario Earthquake on the Wastewater System

Impacts to Structures

Damage to buildings is expected to be extensive and widespread, particularly in the heavily populated coastal areas and in the older urban areas. Older, highly vulnerable structure types will be hardest hit, causing extensive damage, many building losses, and many possible casualties. These older structure types including unreinforced masonry (URM) and older non-ductile concrete structures, have a long track record of poor seismic performance and yet, with few exceptions, have not been seismically retrofitted in the San Diego area beyond a partial retrofit program for URM buildings. Collapse or damage of these structures would add complexity to the emergency response, increase the number of human casualties, exacerbate financial loss, and delay recovery for the San Diego Region.

Essential facilities, including schools, healthcare and government facilities, are expected to be disrupted throughout the coastal communities due to high intensity ground shaking, liquefaction, surface fault rupture, and disruption of infrastructure systems. Nearly half of schools and hospitals in San Diego County are expected to suffer limited functionality due to damage in the days following the earthquake. Police and fire stations and operations will also be hard hit as will City government administrative facilities and operations. Department of Defense facilities, particularly those encircling the San Diego Bay, will be exposed to severe ground shaking and liquefaction and will likely face widespread damage to older buildings, waterfront structures, and lifeline utility infrastructure.

Impacts to Utility, Transportation and Communication Lifelines

Much of the utility and communication lifelines, the systems which interconnect every structure in a community, and transportation infrastructure in the San Diego area was built without adequate recognition of the potential surface fault rupture or liquefaction ground failure that could be generated by an earthquake on the Rose Canyon Fault Zone. Many of the pipelines, cables, roadways, rail lines, bridges and transportation centers straddle the RCFZ surface fault rupture traces or cross the liquefaction zones which encircle the densely developed San Diego Bay. These conditions leave the San Diego area highly vulnerable to widespread infrastructure damage and loss of service in the event of the scenario earthquake.

Assessment of the surface fault rupture and liquefaction impacts indicates that the major water supply pipelines supplying the coastal areas and major wastewater interceptor lines feeding to the Point Loma Wastewater Treatment Plant will be disrupted, essentially cutting off service to the coastal communities from La Jolla to Coronado, and compromising wastewater services across much of the county.

Major gas and petroleum supply line breaks and leaks will occur in the fault rupture and liquefaction zones, disrupting natural gas and fuel supplies to coastal areas, Tenth Avenue Marine terminal, and San Diego International Airport.

Electrical transmission lines and transformer substations will be disrupted, particularly in the near fault coastal areas. Communication systems will be similarly disrupted, aggravated by the loss of electrical power.

Surface streets will be damaged in numerous locations where they cross the fault and liquefiable soils. Roads to the airport and the Port District properties will be disrupted by liquefaction. Bridges near the fault will be at risk of damage. The Coronado Bay Bridge and potentially the I-805 viaduct over Mission Valley will be disrupted with structural damage inspection and repair activities. Approach roads to the Coronado Bay Bridge and to many bridges in the Mission Bay and Mission Valley areas will potentially be damaged by liquefaction-induced ground failures.

Operations of the San Diego International Airport will likely be disrupted due to loss of utilities and fuel supplies coupled with liquefaction damage to the runway, taxiways, vehicular approach roads, and buildings. The Port of San Diego facilities are exposed to several seismic hazards from the scenario earthquake and widespread damages to waterfront structures, roads, and utilities due to liquefaction and severe ground shaking are anticipated.

Considerations for Emergency Response and Recovery

Emergency response in the San Diego region is well-coordinated and actively tested by emergency managers for facilities and jurisdictions throughout the San Diego region. Nonetheless, the scale of the potential disaster generated by a scenario earthquake on the Rose Canyon Fault Zone would likely overwhelm local resources and impede the immediate deployment of statewide and national resources in the days and weeks following the event.

Disruption of lifeline utilities will likely cause the greatest challenge to emergency response by limiting essential services such as medical care, police response, fire suppression and search and rescue activities. Damage to communication infrastructure and power outages coupled with a surge in demand by impacted citizens will severely limit connectivity and dissemination of public information in the days following the event. Emergency responders will need to respond to tens to hundreds of fires following the earthquake and should expect to be handicapped by loss of water service and access roads, particularly in coastal communities. Finally, damages to transportation infrastructure, including roadways, railroads, bridges, the San Diego International Airport runway and port facilities will present significant challenges to emergency response.

A major earthquake on the Rose Canyon Fault Zone will impact every aspect of the San Diego region's social, economic, and physical systems. Damages will cause business interruptions across most economic sectors, estimated at $5.2 billion dollars in lost income throughout San Diego County. Additionally, the earthquake will damage a large percentage of the housing stock in the San Diego region, further exacerbating housing affordability issues particularly for more vulnerable populations such as low income residents.

Key Findings

This scenario report concludes that the San Diego region could suffer severe damage to its buildings and lifeline infrastructure with devastating consequences to the communities and economy following a major RCFZ earthquake.

- Many older, more seismically vulnerable buildings constructed before modern seismic design provisions were in place, including several key City of San Diego facilities, may be severely damaged with multiple older buildings potentially suffering partial to total collapse.
- Due to the location of the fault rupture zone, coastal communities, stretching from La Jolla to the Silver Strand, may be cut off from nearly all lifeline utility and infrastructure services. Water, wastewater, and gas line services west of the fault rupture zone are estimated to be out for months.
- Transportation lines along the I-5 corridor could be severely impeded, with potential roadway and bridge failures within the fault rupture and liquefaction zones. Impacts to these systems would present additional challenges to emergency responders.
- Response to fires caused by gas line breaks and electrical failure or malfunction would be challenging with a loss of water pressure from damaged water systems, especially in coastal communities.

Hazus Estimates the Scenario Earthquake will cause . . .

$38 Billion

in Building and Infrastructure Damages

120,000 Buildings

Suffering Moderate to Complete Damage

8,000 Buildings

Damaged Beyond Repair

36,000 Households

Displaced

- Infrastructure critical to the regional economy, including the San Diego International Airport, the Port of San Diego, and several Department of Defense installations may be severely disrupted.
- Damages to over 100,000 residential structures, coupled with current high housing costs and low vacancy rates, may exacerbate existing housing affordability issues in coastal communities and potentially cause residents to leave the region.

Community and economic activity could be disrupted for years until the region's housing stock, commercial and government facilities, and infrastructure are repaired or replaced. Considering these potential consequences, the imperative for resilience planning and mitigation action is clear and pressing.

A Seismically Resilient San Diego

Given the potential impacts of a scenario earthquake, mitigation planning and actions become imperative to avoid potential disaster and provide a resilient San Diego region.

The region already benefits from significant investments in mitigation and community-wide resilience planning efforts, particularly for those hazards most exacerbated by climate change including drought, sea level rise and wildland fires. As seismic resilience is a foundational element of community-wide resilience, addressing seismic risks and vulnerabilities today is of paramount importance to achieving the vision of long-term, community-wide resilience across the region.

To better integrate the vision for seismic resilience with existing climate adaptation and long-range community planning efforts, the scenario development team developed a vision for San Diego in 2050, a vision for San Diego after 30 years of enhanced coordinated and collaborative resilience efforts to address seismic risk in the region (on page xiv).

The Path Forward

To achieve this vision, the scenario development team recommends the following eleven actions and calls for the formation of a Seismic Resilience Working Group that includes governments, earthquake professionals and private sector utilities and stakeholders, to move these actions forward.

1. The San Diego County Resilience Program conducts a county-wide Resilience Review for seismic hazards to identify regional priorities and accountable partners for seismic risk reduction.

2. The newly formed Seismic Resilience Working Group develops a Regional Seismic Mitigation Strategy that identifies seismic mitigation actions, priorities, and funding mechanisms to bolster existing earthquake hazard mitigation planning efforts.

3. Local jurisdictions compile inventories of seismically vulnerable structures and develop customized seismic risk reduction programs capitalizing on the ordinances and retrofit programs adopted by other California jurisdictions to reduce the potential for casualties and economic losses caused by older, seismically vulnerable structures.

4. The San Diego Association of Governments assesses local land use and zoning practices and recommends actions, such as enhanced hazard mapping and triggering requirements for local geologic review to reduce risk to the built environment along the potential fault rupture zones of the Rose Canyon and other active faults and potential ground failure areas.

5. Local emergency management agencies convene public and private utility stakeholders to coordinate resilience planning, emergency response, and mitigation investments to address the resilience of lifeline networks.

6. Wastewater utilities prioritize investments in resilience-building measures like system upgrades or redundancies that alleviate dependencies on the infrastructure most vulnerable to fault rupture including main interceptor trunk lines and the Point Loma Wastewater Treatment facility.

7. Water utilities and local decision making bodies prioritize investments in water supply and distribution infrastructure in areas most vulnerable to fault rupture and liquefaction to protect coastal communities from prolonged utility disruption and ensure fire suppression capabilities are maintained region-wide.

8. The San Diego Unified Port District, in conjunction with applicable stakeholders and partners, outlines and prioritizes risk mitigation strategies in upcoming revitalization planning efforts to address multiple hazards ranging from liquefaction to tsunamis to sea level rise.

9. Emergency managers for governments, utilities, and essential facilities update existing emergency response plans, exercises, and mutual-aid agreements to better prepare for the disruptions to utility infrastructure, extensive impacts to coastal communities, and surface fault rupture and liquefaction hazards from a major damaging earthquake.

10. Local emergency management and disaster relief organizations conduct public preparedness campaigns to educate residents and businesses about the region's earthquake hazards, methods for reducing personal and business risk, and the importance of emergency preparedness planning.

11. San Diego and Tijuana organizations integrate agency counterparts and partners in emergency planning and response exercises to build capacity for cross-border coordination and seismic risk reduction across the entire for the San Diego–Tijuana border region.

Vision 2050: A Seismically Resilient San Diego

By 2050, San Diego organizations have collaboratively enacted a comprehensive set of seismic resilience policies and investments and are prepared for the next major earthquake.

The threat of casualties caused by earthquake-related building collapse is significantly diminished, as all of the seismically vulnerable structures in the region have been inventoried and undergone retrofits or replacements.

Building codes and land use regulations across the region are now a model for other communities, with increased performance goals for new construction, regulatory triggers for retrofit, and enhanced zoning requirements. Financial incentives and grant programs are well-known and widely used by business owners and homeowners to address structural risks and offset mitigation and retrofit costs.

Utility, telecommunications, and transportation lifelines in areas of high seismic risk have been retrofitted or improved with new technologies or systematic redundancies to address multiple natural hazards all while accommodating regional growth. Major infrastructure critical to the regional economy, including military installations, health care facilities, school and university campuses, border crossing infrastructure, the Port of San Diego, and the San Diego International Airport, have developed comprehensive mitigation plans and are regularly investing in the long-term resilience of their infrastructure.

Cross-border government agencies and nongovernmental organizations regularly collaborate on emergency management exercises and planning for region-wide mitigation, response, and recovery. Residents and businesses understand their seismic risk and are prepared to be self-sufficient following a major seismic or other hazard event.

1.0 Introduction

The San Diego region is home to over 3.3 million residents and the second most populous city in the state of California (U.S. Census Bureau 2019). Over the past 150 years, as the region became a dominant player in the state and national economy, the San Diego community has been largely unaware of the local earthquake threat from any fault, and particularly less aware of the active Rose Canyon Fault Zone (RCFZ) that strikes through the heart of the metropolitan area. Today, the majority of San Diego County residents live within 15 miles of an active fault trace; most believe that earthquake hazards are the second highest threat to their neighborhoods after wildfires (San Diego County Office of Emergency Services [SDOES] 2018). San Diego County faces an 18% probability of a magnitude 6.7 or larger earthquake occurring in the next 30-year period on a fault either within the County or just offshore (Field et al. 2015). The region's large population coupled with the poor seismic resistance of its older buildings and infrastructure systems make San Diego particularly vulnerable to earthquakes. It is essential that action be taken now to ensure that San Diego remains a vibrant and resilient community for generations to come.

Disastrous earthquakes do not occur often, making it difficult to imagine the enormity of such an event. What will the severity of damage to the built environment be? What challenges for responders will arise? How long will it take to recover? Scenarios are developed to aid emergency responders, policymakers, and public officials in examining both the known and unknown consequences while planning for a probable seismic event.

This report examines the potential impacts and consequences of a magnitude 6.9 earthquake occurring on the RCFZ. Expert analysis and loss-modeling software provide the basis for anticipating the physical, economic, and social impacts and consequences that will result from such an earthquake. At its conclusion, the report outlines a vision of "seismic resilience" for the San Diego region and includes ideas for initiatives, actions, and plans that will contribute to the overall resilience of the greater San Diego community.

1.1 What is an Earthquake Scenario?

Earthquake planning scenarios provide public officials, policymakers, businesses, and community residents alike with a realistic assessment of a plausible earthquake and its associated impacts. Scenarios develop a model earthquake, which illustrates potential geologic hazards for a region or community. This model is then used to investigate the condition of the built environment and assess the general level of seismic vulnerability. Earthquake planning scenarios can estimate potential consequences of an earthquake in terms of building and infrastructure damages, social disruptions, and economic losses to inform and guide long-term earthquake planning and preparation.

It is important to note that a scenario is not a prediction of a specific earthquake occurrence but rather an illustration of the possible outcome to serve as a visual aid and planning tool to better prepare for future earthquakes.

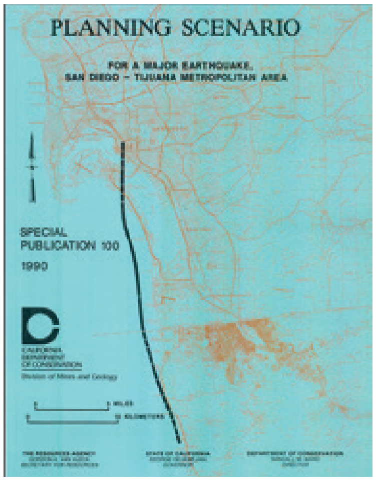


Figure 1-1. 1990 Planning Scenario for a Major Earthquake, San Diego–Tijuana Metropolitan Area

1.2 Scenario Purpose and Goals

The purpose of this earthquake planning scenario is to raise awareness of the region's earthquake hazards and the associated risk to buildings, infrastructure, and the regional community and economy. In 1991, the State of California delineated portions of the RCFZ to be Holocene active, with the potential for generating severe ground shaking, major surface fault rupture, liquefaction ground failures, and landslides. Previous scenario studies for the region were produced 30 years ago in 1990 (Reichle et al. 1990); therefore, an update is warranted to understand the current state of the region and its vulnerabilities from the RCFZ.

The primary goal of this report is to inform planning and inspire mitigation actions to better prepare the region for an inevitable future earthquake. This report is not intended to be a comprehensive study of the San Diego area's seismic vulnerabilities or prediction of specific consequences. The analysis utilizes approximation tools to identify baseline vulnerabilities and relative damages to sectors on a regional scale as well as special studies to characterize risks to critical building and infrastructure systems. This report intends to paint a broad picture of the regional seismic risk profile to highlight the threat of the RCFZ and the many opportunities for earthquake mitigation. With a better understanding of the severity of damage, challenges for repair, and the interconnectedness of structures and their lifelines, communities can take mitigation measures to aid in reducing the potential impacts to life and property and societal disruption in the region following future earthquakes. The conclusion of this report is a call to action in the form of a vision for a seismically resilient San Diego. This report envisions policies, mitigation priorities, and action steps that will inevitably have costs but are also proven to reduce impacts and improve community response and recovery outcomes following earthquakes.

Figure 1-2. San Diego Scenario Development Team workshop hosted in 2015.

1.3 Scenario Scope

This earthquake scenario effort begins by defining a magnitude 6.9 earthquake on the RCFZ and estimates the associated geologic seismic hazards. The report then investigates the probable scale of damages and service disruptions to the

San Diego region in relation to expected shaking, surface fault rupture, liquefaction, and landslide ground failures. For the purposes of this report, the region is defined as the geography and population of San Diego County, including all nested jurisdictions and special districts.

The scenario earthquake was chosen because it is consistent with historical events, can be expected to occur in the foreseeable future, and, while not the largest that can be generated by the RCFZ, is sufficiently large to cause widespread damage. It is considered significantly likely that such an earthquake will occur within the next several hundred years, and there is a distinct possibility that it could occur sooner rather than later. Therefore, the selected scenario earthquake is sufficiently probable to be appropriately considered for earthquake planning.

Importance of Tijuana

The connections between San Diego and Tijuana are deeply rooted in the history, culture, and economies of the region. Though an international border separates the two jurisdictions, the residents and businesses of San Diego and Tijuana are both interconnected and interdependent, supporting major regional industries such as manufacturing and tourism.

In 2000, the United Nations developed an earthquake planning scenario that detailed the potential impacts of a major earthquake on Tijuana (Villacis et al. 2000). The current scenario development team sought to expand on these efforts and designed the RCFZ scenario earthquake to impact both sides of the border. Over the development of this report, team members engaged Mexican partners to identify and analyze impacts to infrastructure and challenges to emergency response for an earthquake. Unfortunately, the Tijuana analysis was not complete at the time of this report release. Nevertheless, the scenario team believes it to be imperative that cross-border coordination and analyses continues and that the M6.9 RCFZ earthquake scenario is not complete until the impacts to Tijuana are fully analyzed.

Figure 1-3. View of infrastructure across the San Diego–Tijuana border. (Credit: Kordian via Wikimedia Commons)

Regional Stakeholders

Stakeholders from the following organizations were interviewed to inform and/or consulted for review of this report:

- American Red Cross
- American Society of Civil Engineers San Diego Chapter
- Bomberos Tijuana
- California Geological Survey
- Caltrans
- City of Carlsbad
- City of Coronado
- City of San Diego
- Cruz Roja Tijuana
- InfraGard San Diego
- Metropolitan Transit System
- Naval Facilities Engineering Command
- Port of San Diego
- Protección Civil Tijuana
- Salvation Army
- Sharp Healthcare Emergency Disaster Preparedness
- San Diego Association of Geologists
- San Diego Building Owners and Managers Association
- San Diego County Water Authority
- San Diego Gas & Electric
- San Diego International Airport
- San Diego County Office of Emergency Services
- San Diego Unified School District
- San Diego Police Department
- San Diego Board of Supervisors, District 1
- Structural Engineering Association of San Diego
- University of California San Diego
- UC San Diego Health Systems
- United States Geological Survey
- US Marine Corps and U.S. Navy

1.4 Scenario Methodology

This report was developed by a multidisciplinary team of geoscience, structural engineering, and social science professionals and researchers led by the San Diego Regional Chapter of the Earthquake Engineering Research Institute (EERI) in partnership with Structural Engineers Association of San Diego (SEAOSD) and several other organizations. Over 40 technical experts were consulted or involved in the project during its development, including structural engineers, geotechnical engineers, seismologists, geologists, emergency managers, and others. These experts were organized into three working groups that conducted the research and analyses to guide the outcomes of this report. The working groups are as follows:

- **Earth Sciences** – Developed, reviewed, and characterized the primary and secondary seismic hazards of the scenario model earthquake.
- **Buildings, Infrastructure, and Engineering Sciences** – Modeled and analyzed the seismic vulnerabilities, probable damages, and economic impacts to the built environment, including building stock, utility lifelines, and transportation infrastructure impacts.
- **Socioeconomic Sciences** – Worked with key stakeholders to identify organizational capacity for and challenges to emergency response and long-term recovery in the greater San Diego community.

Several tools were used to develop the scenario earthquake and estimate associated damages, including, the US Geological Survey's (USGS) ShakeMap, a sample USGS Prompt Assessment of Global Earthquakes for Response (PAGER), and the Federal Emergency Management Agency's (FEMA) Hazus loss estimation software. The scenario team utilized special studies relying primarily on expert opinion, interviews with stakeholders, and focused research to evaluate the critical systems and hazards not captured by the baseline loss estimates by Hazus software. Key stakeholders from the region, including local government officials, emergency response organizations, and utility service providers, were interviewed to better inform potential damage assessments and considerations for disaster response and recovery.

Supplemental materials and further discussion on the methodology for modeling seismic hazards and estimating losses through Hazus are available in the Hazus "Technical Minute" in Section 5 as well as online at **https://sandiego.eeri.org**.

1.5 Key Study Findings

This scenario report concludes that the San Diego region could suffer severe damage to its buildings and lifeline infrastructure with devastating consequences to the communities and economy following a major RCFZ earthquake.

- Many older, more seismically vulnerable buildings constructed before modern seismic design provisions were in place, including several key City of San Diego facilities, may be severely damaged with multiple older buildings potentially suffering partial to total collapse.
- Because of the location of the fault rupture zone, coastal communities, stretching from La Jolla to the Silver Strand, may be cut off from nearly all lifeline utility and infrastructure services. Water, wastewater, and gas line services west of the fault rupture zone are estimated to be out for months.
- Transportation lines along the Interstate 5 (I-5) corridor could be severely impeded, with potential roadway and bridge failures within the fault rupture and liquefaction zones. Impacts to these systems would present additional challenges to emergency responders.
- Response to fires caused by gas line breaks and electrical failure or malfunction would be challenging with a loss of water pressure from damaged water systems, especially in coastal communities.
- Infrastructure critical to the regional economy, including the San Diego International Airport, the Port of San Diego facilities, and several Department of Defense installations may be severely disrupted.
- Damages to over 100,000 residential structures, coupled with current high housing costs and low vacancy rates, may exacerbate existing housing affordability issues in coastal communities and potentially cause residents to leave the region.

Community and economic activity could be disrupted for years until the region's housing stock, commercial and government facilities, and infrastructure are repaired or replaced. Considering these potential consequences, the imperative for resilience planning and mitigation action is clear and pressing.

1.6 Limitations of the Study

This scenario provides a broad analysis of the potential economic losses, timelines for repair, and structural damage that may occur for a large earthquake on the RCFZ. The earthquake loss estimation software, Hazus, a nationally recognized tool, does not account for all seismic hazards, particularly surface fault rupture, or losses for major infrastructure systems, including water, wastewater, natural gas, or petroleum transmission lines. Where limitations existed, this project endeavored to quantify impacts based on expert opinion or supplemental studies and tools. This analysis utilizes custom aggregated building inventory data, derived from 2017 San Diego County Assessor's parcel data, and publicly available, but limited, infrastructure inventories to provide a baseline estimate of damages, disruptions, and economic losses resulting from the scenario earthquake.

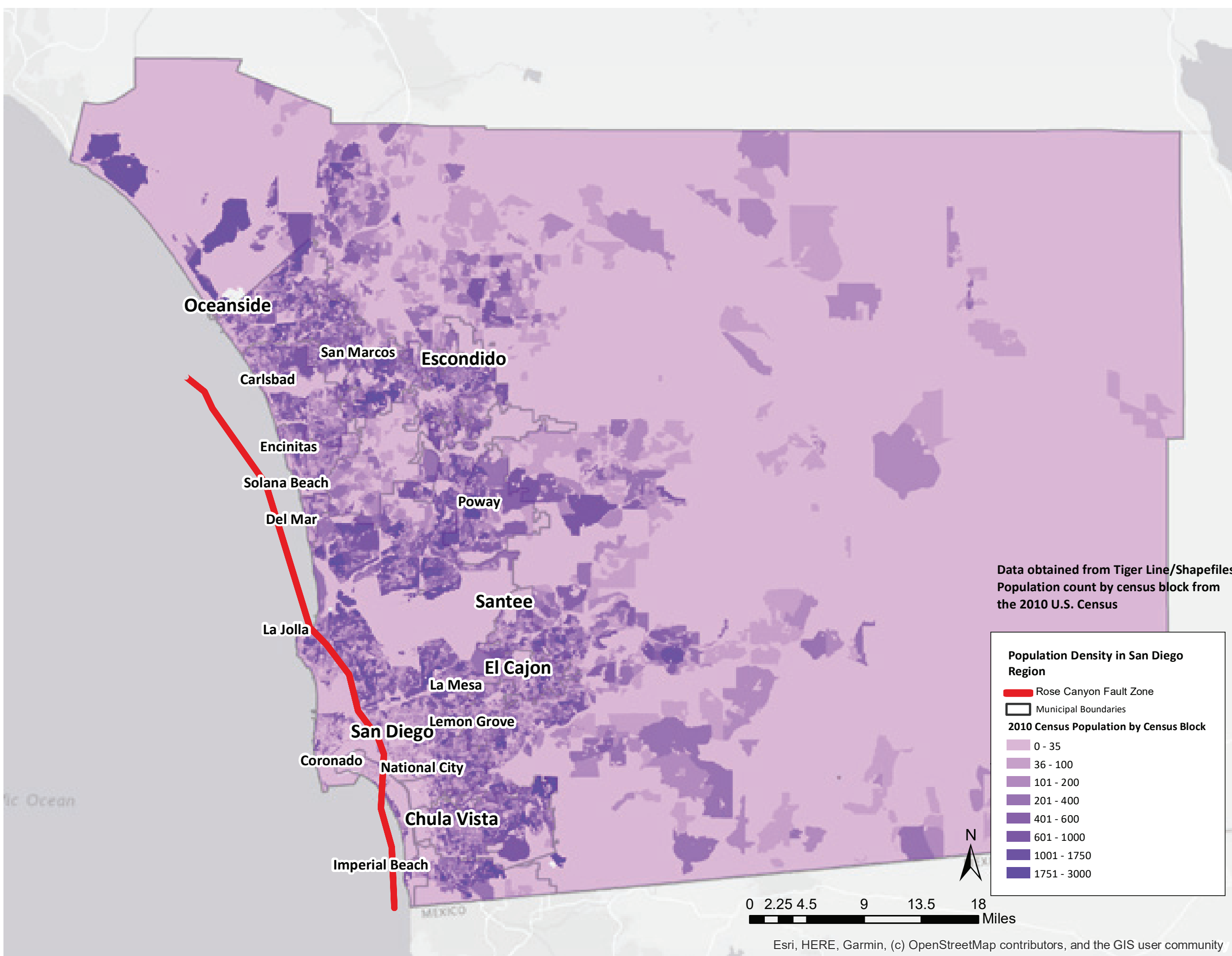
The original scope of the scenario aspired to analyze cross-border impacts of the entire San Diego-Tijuana Metropolitan Area; however, gaps in data and scenario-modeling capabilities made it infeasible for this report. A discussion of potential cross-border impacts is included in this report, and once complete, further analysis will be available through technical supplemental materials.

This report provides a broad, global perspective to the impacts of a scenario earthquake. Technical supplements were developed to provide specific, more technical detail for practitioners on subjects ranging from lifeline and infrastructure system damages to Hazus methodology. These supplemental materials are available on the EERI San Diego Chapter website at **https://sandiego.eeri.org**.

2.0 Introduction to the Region

The San Diego region is located in Southern California along the U.S.–Mexico border. The City of San Diego, the primary economic and governmental center of the San Diego region, is the second largest population center in the state and one of the fastest growing cities in the nation (U.S. Census 2019). The region is home to a diverse economy and vibrant multicultural communities, driven

Figure 2-1. Population Distribution by Census Block, San Diego County (2010 Census)



by both the largest concentration of US Naval forces in the country and one of the largest border crossings in the world. San Diego is well known throughout the nation for its mild climate, attractions such as its beautiful beaches, and close proximity to Mexico.

Because of its proximity to the international border with Mexico, the population of San Diego is considered to be just one part of the population center of the San Diego–Tijuana binational region. Tijuana is situated just 20 miles south of San Diego. Consequently, the people, economies, and infrastructure of Tijuana are strongly tied to the San Diego region. This regional relationship of the two cities grew rapidly after the enactment of the North American Free Trade Agreement in 1994, and today the population of the San Diego–Tijuana binational region is estimated at around 5 million residents (U.S. Census 2019, INEGI 2015).

2.1 Demographic Profile

The regional population is densest along the coastline, with the majority of residents living within 10 miles of the coast. As of 2018, the U.S. Census Bureau estimates that there are 3.3 million people residing in the county and 1.4 million residents of the City of San Diego. The City of San Diego, fronting San Diego Bay, is the largest population hub in the county, followed by the coastal communities of Chula Vista to the south and Oceanside to the north.

Since the 2010 census, the regional population is estimated to have grown much faster than other communities in the nation, expanding by 8% and adding approximately 248,000 residents (American Community Survey 2017). The regional population is generally younger and more educated than the national average. The region is also racially and ethnically diverse, with approximately one-quarter of the residents being immigrants and substantial Hispanic (34%) and Asian (11.7%) populations. Subsequently, many residents in the region do not speak English at home (37.7%) (U.S. Census 2010). The SDOES estimates that there are as many as 400,000 people that do not speak English fluently living in the County (SDOES 2017).

Demographic Profile of San Diego County

400,000
Non-English Speakers

$70,588
Med. Household Income

3.3 M
RESIDENTS

Population Growth Over Time, San Diego County**

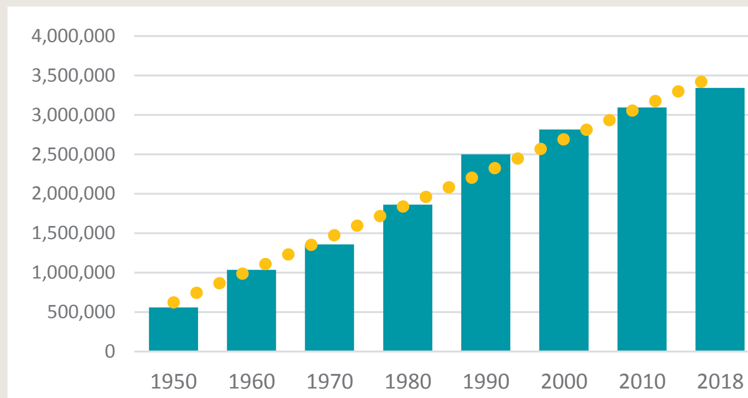


Figure 2-2. Population growth by decade, San Diego County (1950-2018).

Race Breakdown, San Diego County*

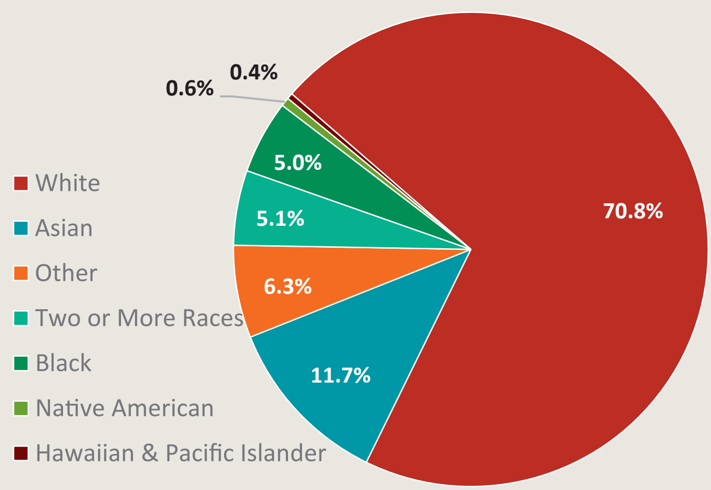


Figure 2-3. Population by race, San Diego County (2017).

*U.S. Census Data
**American Community Survey (2012-2017 5-Year Population Estimates)

Though the median household income for San Diegans is well above the national average at $70,588, poverty impacts approximately 13.3% of the county (American Community Survey 2017). Recent reports released by the San Diego Economic Development Council (SD EDC) found that San Diego is 47% more expensive than the average metropolitan area in the nation, and much of this is driven by high housing costs (SD EDC 2019). The San Diego Unified School District estimates that approximately 60% of the students in the district rely on free or reduced lunch (California Department of Education 2019). The communities most impacted by poverty in the county are El Cajon, National City, and Imperial Beach (The San Diego Association of Government [SANDAG] 2013).

2.2 San Diego's Built Environment

San Diego's population centers, government centers, and economic centers are concentrated in the coastal areas, especially along the natural harbor of the San Diego Bay. San Diego County is composed of 18 incorporated jurisdictions, over 20 census designated places, and several unincorporated communities. Both the City and County government centers are located within the City of San Diego, with city government facilities centered on the City Concourse in downtown San Diego and county government facilities further inland in the Kearny Mesa area.

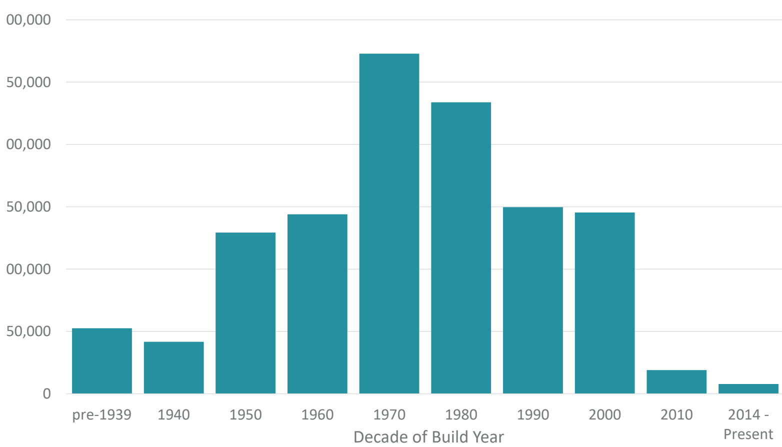


Figure 2-4. Housing Decade of Build, San Diego County (American Community Survey, 2017)

According to 2017 San Diego County Assessor parcel data that was processed for use in Hazus, the San Diego region has approximately 696,000 buildings with an approximate replacement value of 378 billion dollars (in 2018 dollars). San Diego's residential buildings that comprise the vast majority of the structures in the region (96%) are home to approximately 1.1 million households (U.S. Census 2010). The majority of these residences were built between 1960 and 1999 (67%), during the period of greatest population growth (SANDAG 2016), and over half of the structures were built prior to the adoption of modern seismic design standards into the building code in 1979 (American Community Survey 2017). It is estimated that 87% of the total buildings are of wood-framed construction, with the remaining 13% constructed from other material types, including steel, concrete, and masonry, that may be more vulnerable to seismic hazards.

San Diego hosts several regionally and internationally significant transportation hubs, including the San Diego International Airport (SDIA) and the Port of San Diego. The primary commercial airport in the region, SDIA, handles 65,000 passengers per day (SDIA 2019) and is located in the heart of San Diego along

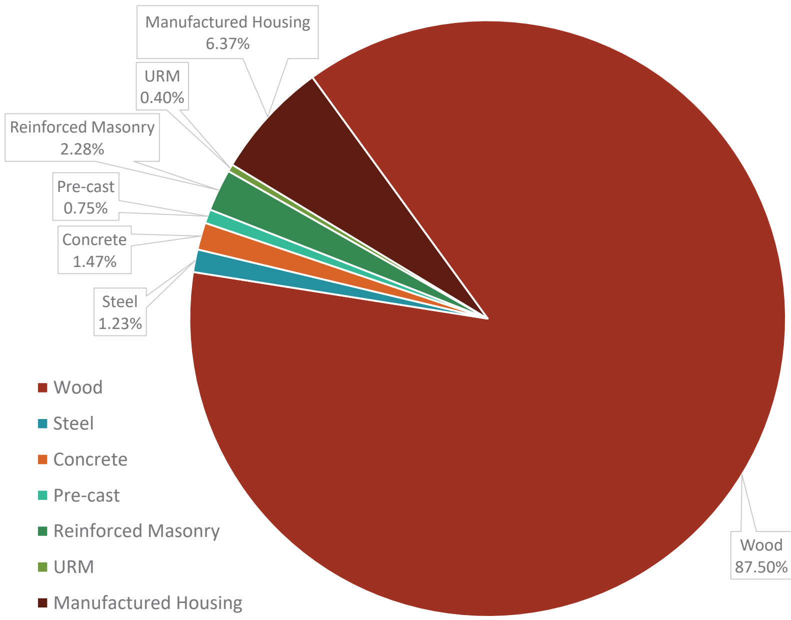


Figure 2-5. Estimated breakdown of structure material types for building stock, San Diego County (Hazus Inventory Estimates)

the San Diego Bay. The Port of San Diego hosts nearly 800 businesses and is designated as a "strategic port" by the U.S. Military (Port of San Diego 2019); it is managed by the San Diego Unified Port District (SDUPD).

In addition, the County hosts a significant amount of federal infrastructure and one of the largest international border crossing facilities in the world. The U.S. Navy and U.S. Marine Corps are a major physical and economic presence in the region. Several military bases are centered on San Diego Bay and Coronado Island, including the Naval Base San Diego (32nd Street), Naval Air Station North Island, Naval Base Point Loma, Naval Amphibious Base Coronado, and Marine Corps Recruit Depot. SANDAG reports that international border crossing infrastructure along the U.S.–Mexico border, primarily the San Ysidro, Otay Mesa, and Tecate crossings, collectively accommodated 48.8 million vehicle crossings in 2018 (SANDAG 2018). Additionally, SANDAG estimates that crossing numbers will increase by up to 80% by 2030. The Otay-Mesa facility, the main commercial gateway for international trade between California and Mexico, facilitated $46.7 billion in bilateral trade in 2018 (SANDAG 2018).

2.3 Regional Economy

The people and built environment of San Diego help support a large and diverse regional economy, relying on economic drivers such as military, tourism, research and manufacturing, and trade and transportation. No industry or sector makes up more than 15% of the regional economy (SANDAG 2018). The importance of the military in the economy of San Diego cannot be overstated. The extensive amount of military infrastructure and landholdings allows San Diego to be home to the largest concentration of military in the world, home port to 60% of the ships in the U.S. Pacific Fleet and one-third of the combat

Industry	Number Employed	% of Total
Construction	**89,800**	**6%**
Construction of Buildings	21,000	1%
Heavy and Civil Engineering Construction	7,600	0%
Specialty Trade Contractors	61,200	4%
Manufacturing	**118,200**	**8%**
Durable Goods	90,100	6%
Nondurable Goods	28,100	2%
Trade, Transportation, and Utilities	**228,900**	**15%**
Wholesale Trade	43,000	3%
Retail Trade	150,800	10%
Transportation, Warehousing, and Utilities	35,100	2%
Information	**23,700**	**2%**
Financial Activities	**75,300**	**5%**
Finance and Insurance	46,200	3%
Real Estate and Rental and Leasing	29,100	2%

Table 2-1. Top industry employment, San Diego County (California Employment Development Department, Labor Market Information, 2019 Q4)

power of the U.S. Marine Corps. Subsequently, U.S. Department of Defense spending is a major driver of the regional economy, responsible for over $28 billion in direct spending (San Diego Military Advisory Council 2019). With major transportation hubs making the region accessible to both national and international tourists, tourism is also a major economic driver, accounting for 15% of the region's economic base. The Port of San Diego and coastal communities support a thriving conference and cruise ship industry (SANDAG 2018).

Bidirectional trade, particularly in manufacturing, is also a large economic driver in the region. Of the $24.3 billion in total exports from San Diego–Tijuana region, approximately one-quarter, or $6.2 billion, is bidirectional trade between San Diego County and Baja California (World Trade Center San Diego 2018). Industries in the San Diego–Tijuana metropolitan are connected by their shared labor force, interdependence for production, and the thriving tourism industry of both cities. As the industries and labor force of San Diego and Tijuana are interdependent, the flow of goods and people through international border crossing infrastructure is essential for the regional economy.

Professional and Business Services	**260,700**	**17%**
Professional, Scientific, and Technical	146,200	9%
Management of Companies and Enterprises	24,500	2%
Administrative and Support and Waste	90,000	6%
Educational and Health Services	**220,900**	**14%**
Educational Services	33,800	2%
Health Care and Social Assistance	187,100	12%
Leisure and Hospitality	**202,200**	**13%**
Arts, Entertainment, and Recreation	30,600	2%
Accommodation and Food Service	171,600	11%
Other Services	**57,200**	**4%**
Government	**260,800**	**17%**
Federal Government (including Department of Defense)	47,500	3%
State Government	55,300	4%
Local Government	158,000	10%
TOTAL EMPLOYMENT	**1,546,800**	

2.4 The San Diego Community and Earthquakes

Though the region has a resilient and diversified economic base, there are several socioeconomic challenges that the San Diego community faces that may be exacerbated in the event of a scenario earthquake. The impacts of disasters are most severe for a communities' most vulnerable residents, which includes approximately half of county residents who do not earn enough to cover their cost of living (SD EDC 2019). During interviews, community stakeholders consistently noted concern about an earthquake's impact on San Diego's low-income residents, who are already living paycheck to paycheck.

The lack of affordability in the region is already a societal stressor; high housing costs in coastal communities have driven many lower income residents to live in the more affordable inland suburbs. The average moderate-income family in San Diego County pays an estimated 55% of total household income to housing and transportation costs (SANDAG 2015). Consequently, residents have a strong reliance on the region's dispersed transportation network, with 71% of residents commuting to work outside of their jurisdiction (SANDAG 2018).

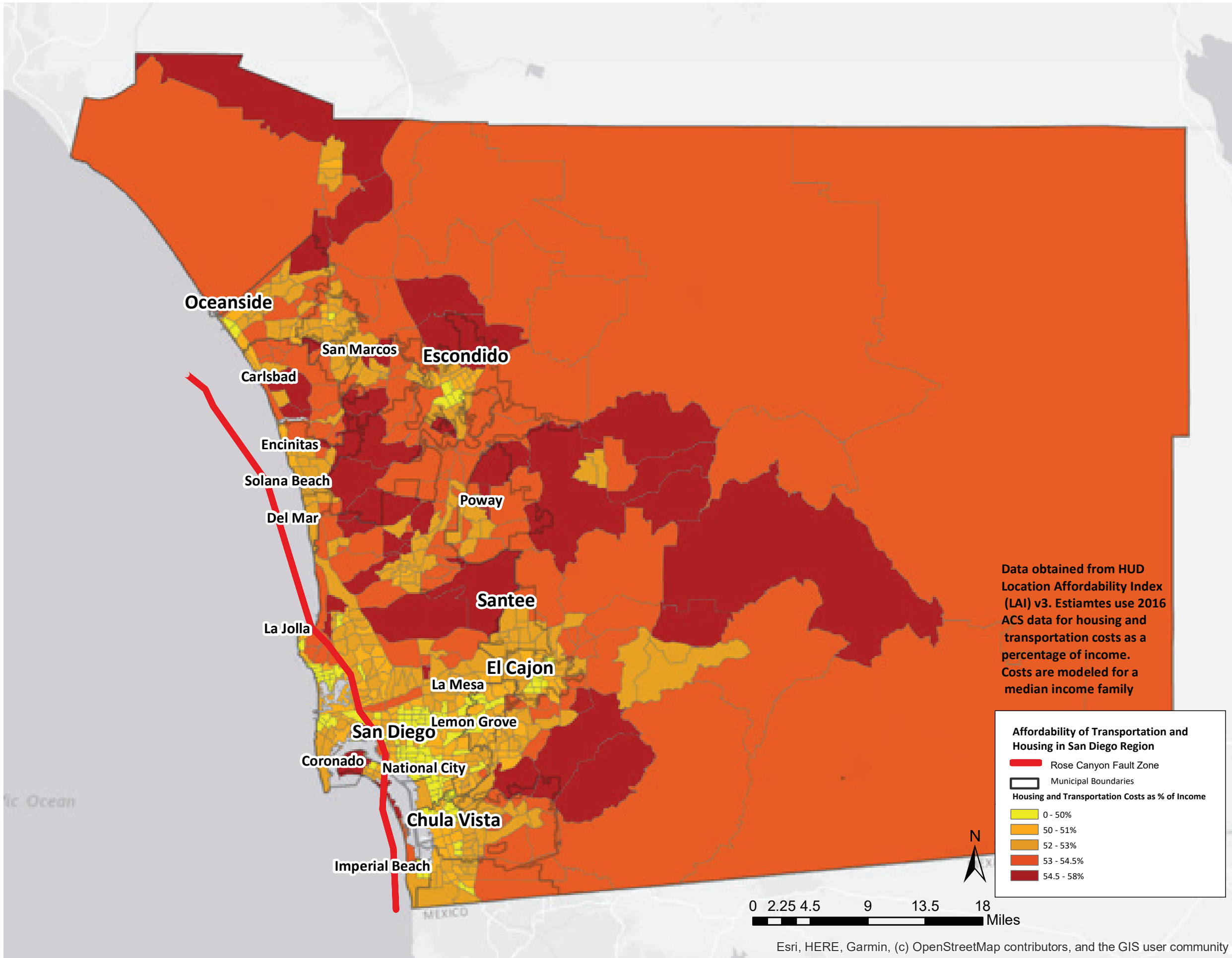


Figure 2-6. Housing and transportation cost burden as percentage of income for a median-income family, San Diego County (HUD Location Affordability Indexv3, 2016).

The regional economy is invariably connected with the built environment. The "innovation" sector is dependent on technologies such as fiber optic transmission lines, whereas tourism is dependent on the airport and the availability of coastal hotels and cruise ship terminal facilities. Bidirectional trade is reliant on the function and access to cross-border ports of entry. The coastal communities from La Jolla to Coronado are heavily dependent on lifeline utility and transportation systems that are highly vulnerable to a major RCFZ earthquake. A discussion of a scenario earthquake's potential impact on the people and economy is provided in subsequent sections of this report.

3.0 Characterizing the Region's Seismic Hazards

3.1 Regional Faults

Earthquakes have long been viewed as a significant hazard in California, though San Diego has historically been considered a lower risk area. These public perceptions have been based largely on the relatively frequent occurrence of earthquakes in the San Francisco and Los Angeles areas contrasted with the infrequent occurrence of significant earthquakes in the San Diego area.

Southern California has many active faults that are capable of generating a large magnitude earthquake in some of the densest population centers. The region sits at the boundary of two tectonic plates, the North American and Pacific Plates, with the main plate boundary faults at the Cerro Prieto, Imperial, and San Andreas faults (Jennings 1994, Jennings and Bryant 2010).

Within Southern California, the plate boundary consists of a complex system of active fault zones that span a 150-mile–wide area from the main San

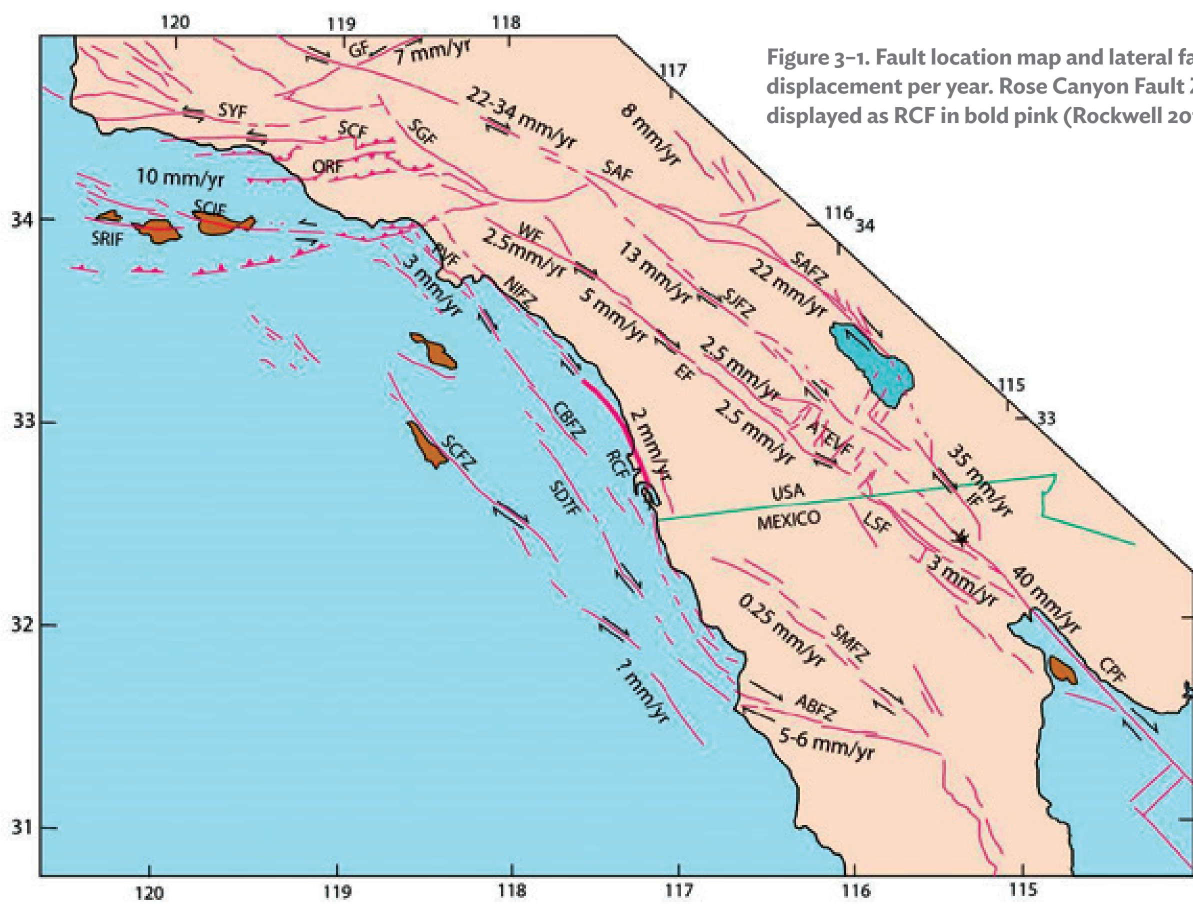


Figure 3–1. Fault location map and lateral fault displacement per year. Rose Canyon Fault Zone displayed as RCF in bold pink (Rockwell 2019).

Andreas fault in the Imperial Valley westward to offshore of San Diego (Powell et al. 1993, Wallace 1990). This plate boundary, known as the San Andreas Fault System, is a transform plate boundary dominated by right-lateral fault displacement (Wallace 1990, Weldon and Sieh 1985). Lateral faulting at transform plate boundaries typically generates smaller maximum magnitude earthquakes than faults at convergent or subduction plate boundaries seen in the 1964 magnitude 9.2 Alaska Earthquake and the 2010 magnitude 8.8 Chile Earthquake. This is the case in Southern California, where expected maximum magnitudes for most faults are typically in the 7 to 7.5 range. In Southern California, only the San Andreas fault and some thrust faults associated with the Transverse Ranges are thought to be capable of generating earthquakes in the magnitude 8 range (Petersen 2014).

From east to west, the major faults of the San Andreas Fault System are the onshore San Andreas, San Jacinto, Elsinore, and RCFZ faults and the offshore Palos Verdes–Coronado Bank, San Diego Trough, and San Clemente faults. The most dominant zone of faulting within the metropolitan San Diego and Tijuana area is the RCFZ, as shown on Figure 3–1. The RCFZ is likely part of a more extensive fault zone that includes the Offshore Zone of Deformation and the Newport–Inglewood fault to the north (Grant and Shearer 2004, Sahakian et al. 2017) and several possible extensions southward, both onshore and offshore (Treiman 1993). According to the Uniform California Earthquake Fault Rupture 3 model, the probability of an earthquake with a magnitude 6.7 or greater occurring on one of the major faults in San Diego County or nearby offshore is 18% in the next 30 years (Field et al. 2015).

3.2 History of Earthquakes in the Region

Most of the seismic energy and associated fault displacement within the San Andreas Fault System plate boundary occurs along the fault structures closest to the plate boundary, which includes the Elsinore, San Jacinto, and San Andreas faults. Of the total 2 inches/year (51 mm/yr) of lateral displacement, 84% can be attributed to the Elsinore, San Jacinto, and San Andreas faults. Within the metropolitan San Diego area, about 0.2 to 0.3 inches/year (5 to 8 mm/yr) of lateral displacement is accommodated by the coastal and offshore system of faults inclusive of the RCFZ.

A number of large earthquakes have historically occurred along these fault zones near or within the San Diego–Tijuana region, as detailed in Table 3–1. The earliest historical record of an earthquake that impacted the region had an epicenter northeast of San Diego County and was attributed to the San Jacinto fault. The 1800 earthquake likely had a magnitude of 7.2, with approximately 10 to 13 feet (3 to 4 meters) of displacement (Salisbury et al. 2012, Rockwell et al. 2015). The San Diego area experienced its strongest shaking and documented damages from the 1862 "Day of Terror" earthquake (LA Star 1862), which may be attributed to the RCFZ. The event likely had an estimated magnitude of 6.0

to 6.2 and caused building damage in Old Town, cracked the Point Loma Lighthouse, and caused liquefaction along the San Diego River, and numerous aftershocks were reported (Legg and Agnew 1979). The San Andreas, San Jacinto, and Elsinore faults are not the only onshore faults capable of producing damaging earthquakes in the San Diego area.

Date	Maximum Intensity	Modified Mercalli Intensity in City of San Diego[b]	Magnitude
11/22/1800	VII	VII	7.2[a]
05/27/1862	VII	VII	6.2[a]
02/24/1892	IX	VIII	7.2[a]
10/23/1894	VI	V	5.0[a]
04/21/1918	IX	Unknown	6.9[a]
05/01/1939	VI	V	5.0
11/04/1949	Unknown	VI	5.7
12/26/1951	Offshore	VI	5.8
03/19/1954	VIII	IV	6.2
02/09/1956	Unknown	VI	6.8
12/22/1964	Offshore	VI	5.4
04/09/1968	IX	V	6.6
06/29/1983	V	III	4.7
07/13/1986	VI	IV	5.5
06/15/2004	V	IV	5.0
04/04/2010	VII	III	7.2
07/07/2010	V	IV	5.4

Table 3-1. Historical seismicity of the scenario planning area

[a] Estimated magnitude based on reported intensities.

[b] See Figure 4-5 of this report for a definition of the modified Mercalli intensity scale.

3.3 The Rose Canyon Fault Zone

Geologic fault investigations in 1985 shed new light on the local earthquake risk, classifying faults in downtown San Diego as active. In 1989, excavations along Morena Boulevard (Rockwell et al. 1991) uncovered evidence of a series of major historic ruptures along the RCFZ in the Holocene Period, or the past 11,700 years (USGS 2019). These findings, historic seismicity, and geomorphic features led the California Geologic Survey (CGS) to declare the fault zone active and to establish Alquist-Priolo Earthquake Fault Zones from La Jolla south and in downtown San Diego. Subsequent excavations downtown have confirmed the presence and extent of active fault strands within the central business district. Additional geologic investigations in the Old Town area of San Diego in 2016 revealed fresh fault ruptures and ground displacements dating from the 1862 earthquake that rattled San Diego. The Old Town investigations further confirmed the pattern of recurring major earthquakes on the RCFZ throughout the Holocene Period, suggesting a recurrence interval of 700 years (Singleton et al. 2019). A recurrence interval is an average, estimated with best available data. The recurrence interval does not mean that only one event will occur in a 700-year period, but rather has a one-in-700 chance of occurring in any one year.

The RCFZ, consisting of a system of crustal, right-lateral, strike-slip faults, presents a particularly high risk to the region, as it bisects the older, more heavily populated and developed areas of the city. The RCFZ trends offshore parallel to the coastline off of Oceanside and then comes on shore in La Jolla, tracking up La Jolla Parkway around Mount Soledad and down the Rose Canyon along Interstate 5. The RCFZ then bisects Old Town, Little Italy, and downtown San Diego. Diverging strands pass under the airport, Seaport Village, Convention Center, and Tenth Avenue Marine Terminal areas of downtown and cross the San Diego Bay through Coronado and under the Coronado Bridge. The RCFZ trace then converges along the Silver Strand and trends into the Pacific Ocean near Tijuana. The metropolitan center, the government centers, and the economic and transportation centers of the San Diego community are effectively located along this RCFZ trajectory.

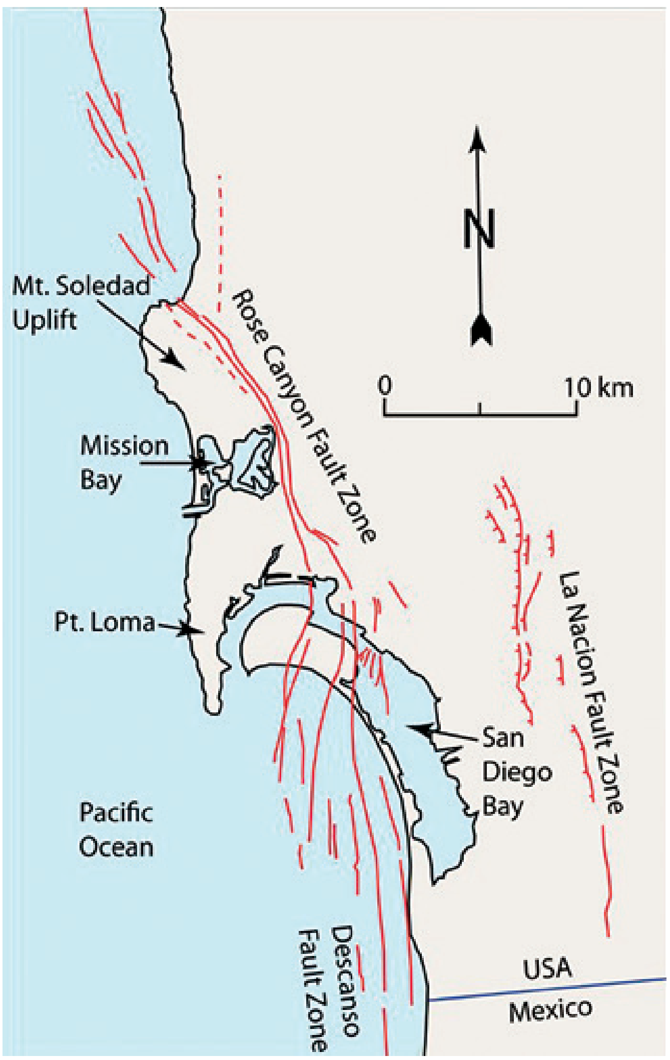


Figure 3-2. Rose Canyon Fault Zone in relation to nearby regional faults.

4.0 The Rose Canyon Fault Zone Scenario Earthquake

4.1 Choosing the Scenario Earthquake

Scenario earthquakes are chosen by teams of experts based on their probability of occurrence and potential impact, among other factors, in order to highlight vulnerabilities in the region's communities, buildings, and critical infrastructure. The RCFZ is considered to be the greatest potential seismic threat to the San Diego region because of its proximity to population, economic, and government centers. The scenario earthquake detailed in this report is a magnitude 6.9, with the epicenter located offshore of Oceanside in northern San Diego County. The resulting fault rupture is 69 km in length, with forward directivity toward Tijuana at a depth of 7.7 km and rupture area of 830 km^2. The recurrence interval for the fault was estimated at 1,000 years or has a one-in-1,000 probability of occurring in any given year. Additionally, the duration of ground shaking from the scenario earthquake was estimated to be between 10 and 30 seconds (Bommer et al. 2009, Kempton and Stewart 2006). The epicenter location was designed along the northern section of the fault so that a southward rupture would impact the populations and built environment of both San Diego and Tijuana.

This type of RCFZ event is considered to be the most likely to strike the population centers of the San Diego–Tijuana binational region and is aligned with the maximum probable RCFZ event (6.9 magnitude) identified in the San Diego County Multi-Jurisdictional Hazard Mitigation Plan. Figure 4–1 shows the location and length of the scenario fault as well as the scenario epicenter location.

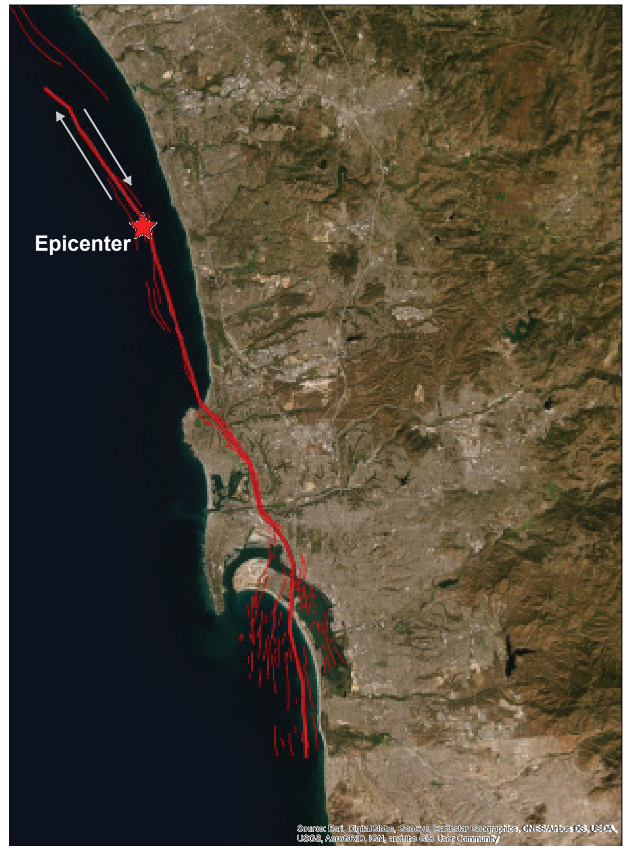


Figure 4–1. Earthquake scenario epicenter and fault location.

4.2 Geologic and Seismic Effects of the Scenario Earthquake

The scenario earthquake, consistent with past RCFZ earthquakes, is expected to generate major geologic ground failure and ground shaking hazards, resulting in severe seismic damage consequences. Primary hazards include surface fault rupture and severe ground shaking. Secondary and tertiary hazards include liquefaction, landslides, aftershocks, and potential submarine landslides. Both primary and secondary hazards were evaluated across the entirety of the San Diego–Tijuana Metropolitan Area, as applicable. Additional technical details of these evaluations are presented in Van Den Einde et al. (2017).

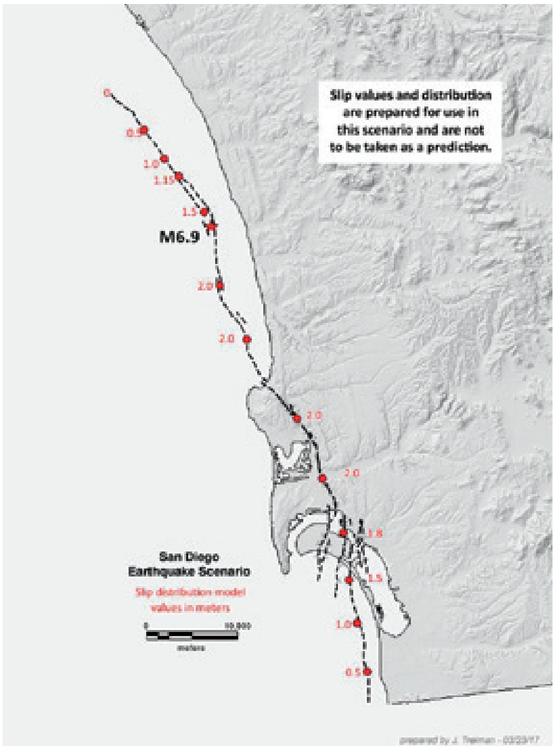


Figure 4–2. Earthquake scenario surface fault rupture distribution along the RCFZ.

4.2.1 Surface Fault Rupture and Slip

Surface rupture is the offset of the ground surface when the fault rupture extends to the Earth's surface. The knife-like displacements associated with surface fault rupture are very damaging to intersecting structures or utilities. Using a scenario earthquake magnitude of 6.9 and a rupture length of 69 km, an average maximum surface displacement of approximately 6.6 feet (2 meters) was estimated based on the Wells and Coppersmith (1994) relationships. The scenario surface fault rupture represents one possible slip distribution and was developed based on the calculated maximum displacement and expert opinion. The two detailed maps (Figure 4–3 and 4–4) suggest how the slip might be distributed along individual fault strands, particularly in the stepovers within downtown and Coronado. Based on the maximum displacement of approximately 6.6 feet (2 meters) and an estimated slip rate of 0.08 in/year (2 mm/yr) as referenced in Rockwell (2010), the recurrence of the scenario earthquake is estimated to be approximately 1,000 years.

4.2.2 Ground Shaking

The most intense ground shaking caused by the scenario earthquake will occur along the coastlines of San Diego and Tijuana, where the populations are the most densely settled. Based on the USGS ShakeMap for the earthquake scenario, as shown in Figure 4–5, peak ground acceleration (PGA) values of up to approximately 0.55*g* (55% of gravity) are estimated in the downtown San Diego area, corresponding to severe earthquake shaking. In the Tijuana area, PGA values of up to approximately 0.35*g*

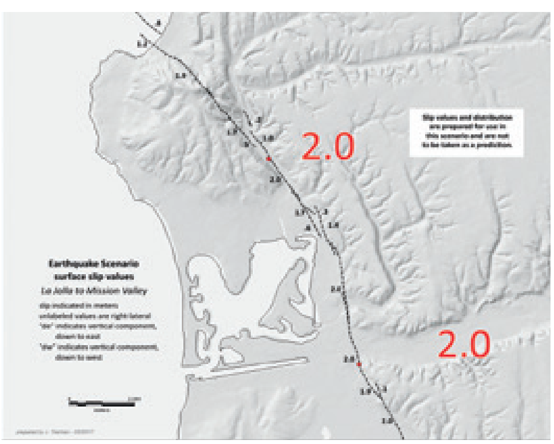


Figure 4–3. Earthquake Scenario Surface Fault Rupture Distribution - North Detail Map

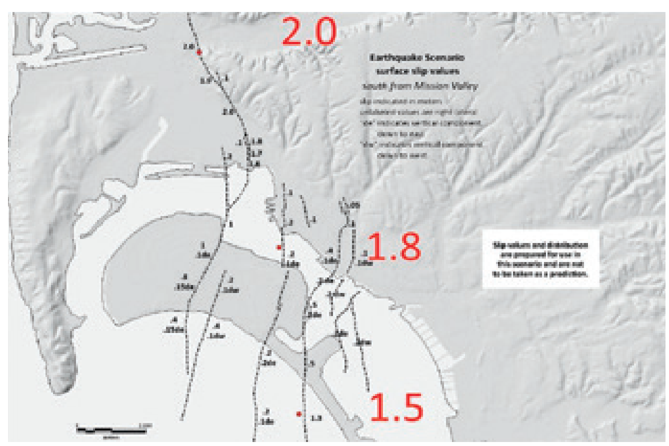
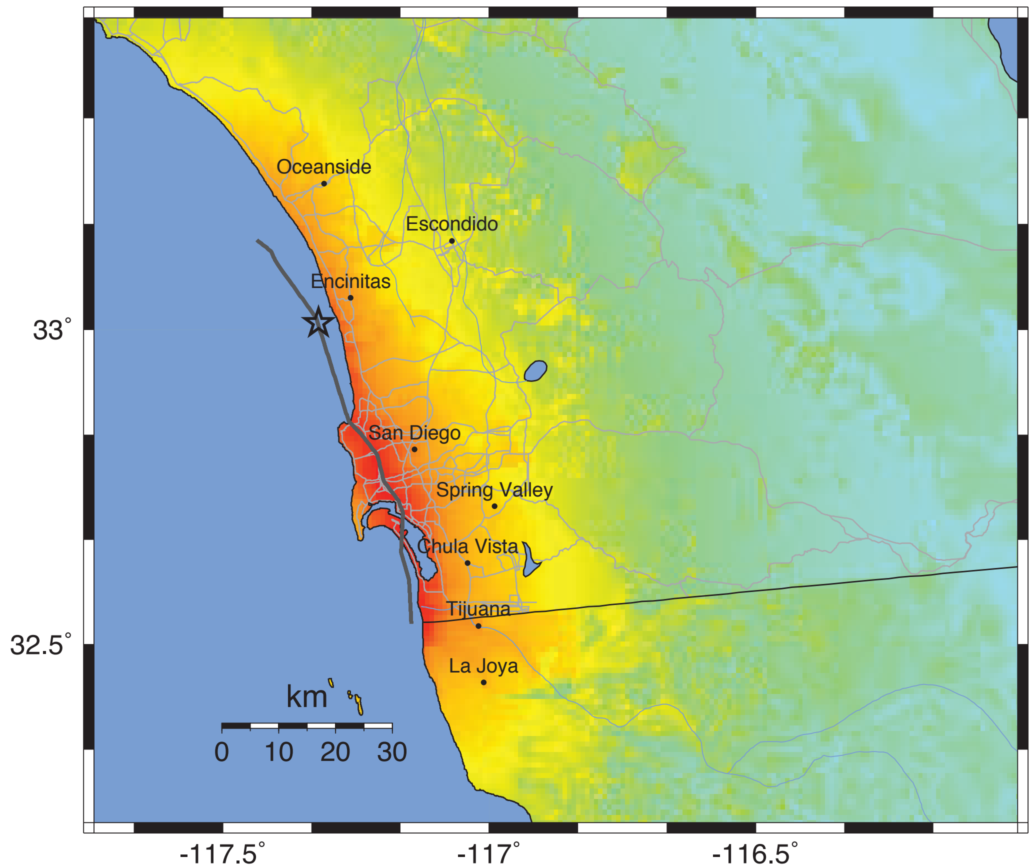


Figure 4–4. Earthquake Scenario Surface Fault Rupture Distribution - South Detail Map

are estimated for the earthquake scenario. PGA values generally dissipate with increased distance from the fault rupture, with PGA values of less than approximately 0.1g in the Ramona and Alpine areas of eastern San Diego County.

Surface ground shaking distribution maps for the earthquake scenario were developed by the USGS using their ShakeMap® software. The USGS ShakeMap intensity measures were computed using the modified Mercalli intensity (MMI) scale (Worden et al. 2012), peak ground motions were computed for PGA (Figure 4–6) and peak ground velocity (Figure 4–7), and peak spectral accelerations were

-- Earthquake Planning Scenario --
ShakeMap for Shakeout SD-TJ - Southern Directivity Scenario
Scenario Date: May 25, 2017 04:00:00 AM MDT M 6.9 N33.01 W117.32 Depth: 7.7km



PLANNING SCENARIO ONLY -- Map Version 1 Processed 2017-05-25 01:13:25 PM MDT

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	*<0.02*	*0.1*	*1.4*	*4.7*	*9.6*	*20*	*41*	*86*	*>178*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

Figure 4–5. Earthquake scenario modified Mercalli intensity map (USGS 2017).

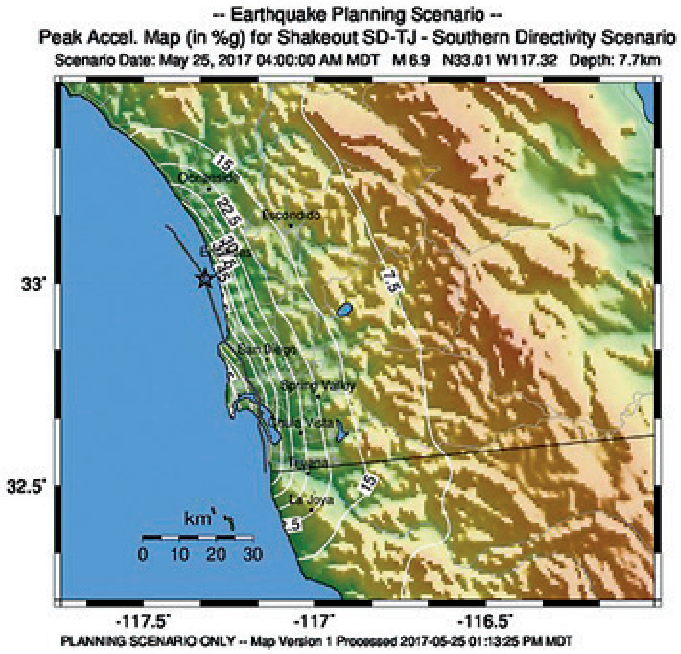


Figure 4–6. Earthquake scenario peak ground acceleration map (USGS 2017).

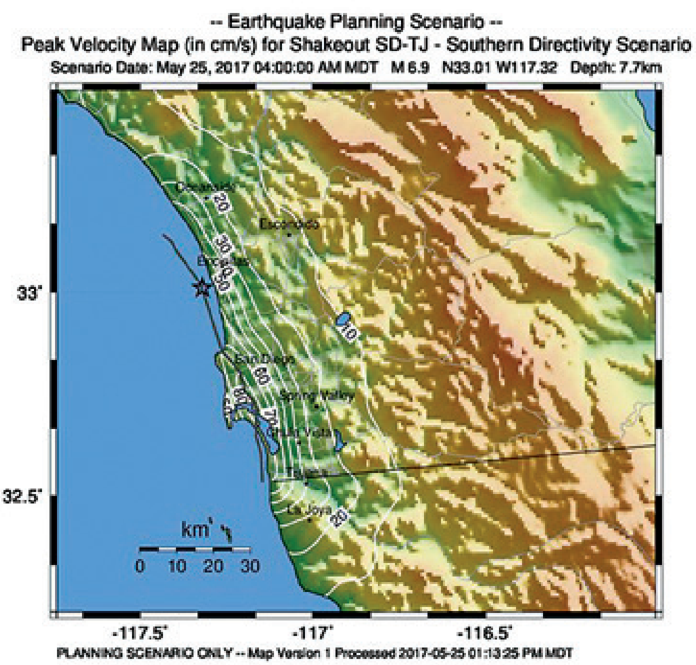


Figure 4–7. Earthquake scenario peak ground velocity map (USGS 2017).

computed at periods of 0.3, 1.0, and 3.0 seconds, which are common acceleration thresholds used in engineering design and required for Hazus analyses.

4.2.3 Liquefaction

Earthquake-induced liquefaction is a phenomenon in which saturated sand-like soils temporarily lose their shear strength (liquefy) because of increased pore water pressures induced by strong, cyclic ground motions during an earthquake. Structures founded on or above potentially liquefiable soils may experience failures caused by temporary loss of foundation support, excessive settlements, and/or lateral spreading. Lateral spreading can occur during an earthquake when soils liquefy at a site with gently sloping ground or with level to sloping ground that is adjacent to a "free face," such as a riverbank or shoreline. The combination of loss of soil strength and stiffness and seismic ground motions results in lateral displacements accumulating in the downslope or free face direction. These lateral displacements are typically highly irregular and are accompanied by ground cracking that separates displaced blocks of soil.

For liquefaction to occur at a given site, three main factors must be present:

1. Liquefaction susceptibility: The soil must be of a type and state that are potentially susceptible to liquefaction.
2. Groundwater depth: The soils must be below the groundwater table or saturated, particularly in the upper 50 ft.
3. Ground motion intensity: Earthquake shaking must be of sufficient amplitude and duration to trigger liquefaction.

These three factors were used in conjunction to inform loss models and discussion of damages. Areas of high liquefaction susceptibility are depicted in Figure 4–10 and are generally concentrated in the San Diego and Mission Bay margins and in low-lying alluvial valleys. These areas are generally co-located in areas that meet shallow groundwater depth conditions required for liquefaction, as depicted in Figure 4–11. Strong shaking is required to trigger seismic soil liquefaction, and many areas already susceptible to liquefaction are located within a few miles of the fault rupture. Liquefaction is expected to be severe in areas where these three risk factors converge.

4.2.4 Earthquake-Induced Landslides

Earthquake-induced landslides consist of lateral and downslope movement of soil and rock in areas of sloping ground because of strong ground shaking. Areas within the San Diego region with large seismic slope displacements include the steeply sloped areas associated with Mt. Soledad in La Jolla and near various drainage features such as the San Diego River within Mission Valley. Though mountainous, eastern San Diego is not close enough to the fault rupture and therefore will likely not experience significant landslides.

Furthermore, well-known localized slope failures along coastal bluffs were widespread during past earthquakes in the region (Griggs and Scholar 1997). Areas susceptible to coastal bluff failures occur in the La Jolla, Point Loma, Solano Beach, and Encinitas areas of the coastline. These coastal bluff failures are not well depicted in the seismic slope stability map (Figure 4–10) because of the localized and shallow nature of these slope failures. Coastal bluff failures were not accounted for in this study but are potentially consequential and should be further considered in future studies.

4.3 Other Potential Hazards

The scenario development team discussed several additional seismic hazards that could have a significant impact on the San Diego region, should they occur. These include submarine landslides, tsunamis, and aftershocks.

Submarine landslides could be triggered by the RCFZ event. Several submarine canyons potentially susceptible to submarine landsliding that exist offshore include Carlsbad Canyon, La Jolla Canyon, and Coronado Canyon. For this study, the Coronado Canyon, located approximately 12 miles offshore of the U.S.–Mexico border, was selected to model a submarine landslide as discussed in the tsunami case study. Please refer to the case study, which modeled a possible submarine tsunami scenario, for further details on the hazard.

Tsunamis are sea waves that result from large-scale seafloor displacements, which are associated with seismic events such as large earthquakes or major submarine slides (USGS 2019). Tsunami events produce multiple surges over hours and have strong, damaging, and dangerous currents. As a coastal community, San Diego is vulnerable to tsunami waves generated by both local and distant earthquakes. Tsunamis from distant earthquakes have caused damage to bays and harbors along the San Diego coastline (Barberopoulou et al. 2010). A tsunami is one of the tertiary seismic hazards that may result from an earthquake on the RCFZ. Unfortunately, not much is known for local

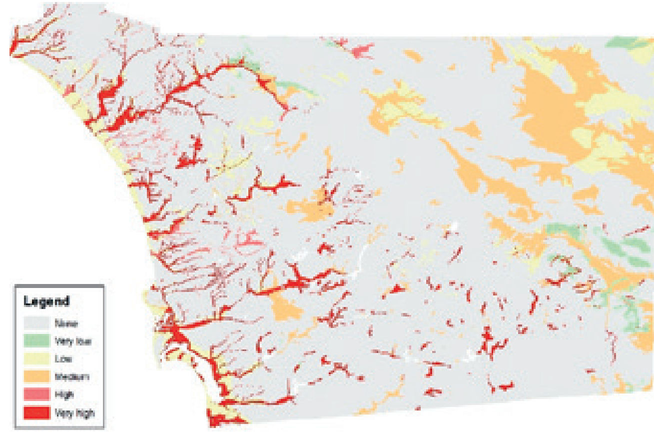


Figure 4–8. Liquefaction susceptibility map for the scenario earthquake, 2018.

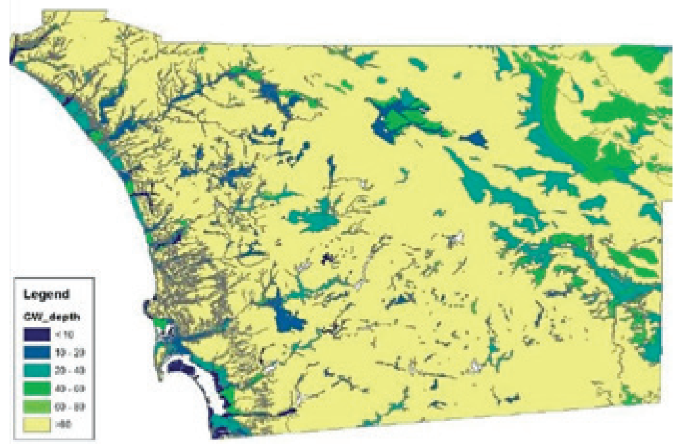


Figure 4–9. Groundwater depth in meters for scenario earthquake, 2018.

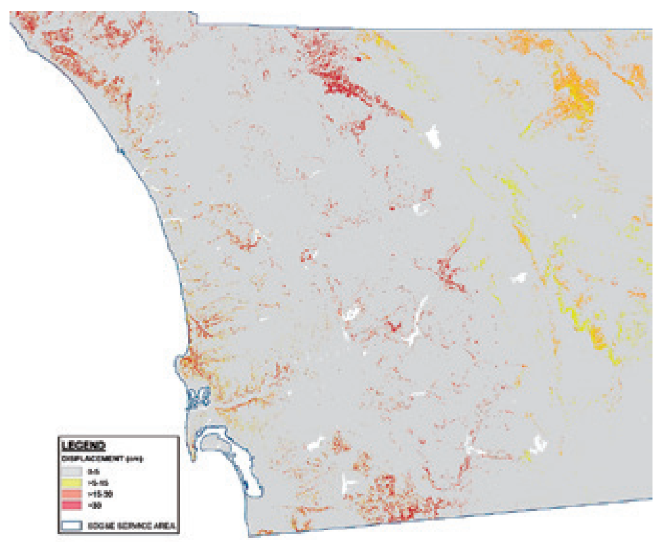


Figure 4–10. Seismic slope stability map for portion of San Diego County for earthquake scenario, 2018.

tsunamis except for an account possibly related to the 1862 local earthquake (Legg and Agnew 1979).

Aftershocks are earthquakes that follow the largest shock of an earthquake sequence and can continue for weeks, months, or years after an event (USGS 2019). Aftershocks cause additional shaking that can damage weakened structures, delay rehabilitation, endanger rescue workers, and undo efforts to restore and rebuild after the earthquake. Aftershocks can also have negative impacts on community health, causing additional anxiety and affecting the mental health of the population. The region should prepare for and anticipate aftershocks as a result of a major event, such as the scenario earthquake.

Case Study – Potential Tsunami off the Coronado Canyon

Early in the development of the scenario, experts discussed the role of secondary or tertiary hazards in the scenario earthquake model. One hazard that was considered was a submarine landslide–triggered tsunami. The recent 2018 Mw7.5 Palu Indonesia earthquake is an example of an induced tsunami that caused significant economic losses and casualties. There is significant uncertainty around the ability of the RCFZ to trigger such an event; tsunamis were ultimately not included in this scenario earthquake model. Nevertheless, to raise awareness about the hazard for long-term disaster preparedness and planning, a tsunami was modeled in Hazus, and a brief analysis is included below.

One of the possible tsunami scenarios included in CGS Tsunami Inundation Maps (California Emergency Management Agency 2009) is triggered by a submarine landslide on the Coronado Canyon. This tsunami was modeled in Hazus, and a map of the potential inundation zone can be found in Figure 4–11. Low-lying coastal areas around San Diego Bay and Mission Bay, particularly along the Silver Strand and in Mission Beach, would be most impacted by a tsunami. Should the potential tsunami occur, consequences could include over-wash of the Silver Strand, which would endanger Naval Amphibious Base Coronado, Naval housing along the Silver Strand, and the Coronado Cays and Imperial Beach communities as well as disrupt roadway access to Coronado for days to weeks.

The occurrence of this event is considered to be a very low probability but has high potential consequences. Model tsunami losses for buildings alone are estimated to be over $100 million based on a preliminary Hazus assessment, which does not include the additional waterfront and military base losses not counted by Hazus. Community preparedness and the awareness of residents to evacuate coastal regions also plays into the scenario. The more prepared community members are in evacuation routes and procedures, such as moving quickly to higher ground after shaking from an earthquake stops, the less likely casualties are during a tsunami event.

Figure 4–11. Hazus model of tsunami inundation zone for submarine landslide off the Coronado Canyon.

5.0 Impacts from the Scenario Earthquake

Much of the existing infrastructure of the San Diego region was built over the past 150 years, largely before recognition of the seismic hazards posed by the RCFZ system. The population centers, government centers, and economic centers are concentrated in the near fault coastal areas within the severe shaking areas of the scenario earthquake, as shown in Figure 5–1. Older buildings close to the fault rupture areas, many of which are significantly under-designed compared to current seismic design standards, will experience very strong shaking from a RCFZ scenario earthquake. Many infrastructure systems, including pipelines, roadways, railways, the Port, and the airport, were originally designed without adequate protection against the potential surface fault rupture and widespread liquefaction ground failures. Infrastructure and buildings built prior to the shift to Seismic Zone 4 and the adoption of higher standards associated with post-1994 building codes were designed to seismic standards approximately 30% to 50% lower than current standards. Please see further discussion in the History of Seismic Design Code Development in San Diego call-out box later in this section.

The scenario earthquake is expected to cause widespread damage. Of utmost concern are the downtown areas, coastal communities west of the RCFZ and the severe anticipated damages to lifeline utility and transportation systems. This section analyzes the anticipated impacts to the built environment, their associated economic losses, and the repercussions these impacts and losses may have to the social fabric of the San Diego community.

5.1 Summary of Losses

Hazus was used in this scenario study to provide a baseline estimate of damages, disruptions, and economic losses resulting from the scenario earthquake. The Hazus model accounts well for general building losses and provides estimates for distributed infrastructure losses. As previously mentioned, Hazus does not account well for other hazards, including the effects of surface fault rupture or landslides, nor does it include major infrastructure systems, such as water and wastewater trunk lines or natural gas and petroleum supply lines. Therefore, Hazus is expected to underestimate or exclude related losses. Those losses are discussed in subsequent sections but are not included in the economic losses summarized below.

science for a changing world

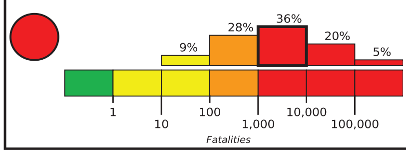
Earthquake Shaking — Red Alert

M 6.9, Shakeout SD-TJ Scenario

Origin Time: 2017-05-25 10:00:00 UTC (Thu 03:00:00 local)
Location: 33.0100° N 117.3200° W Depth: 7.7 km

PAGER Version 1

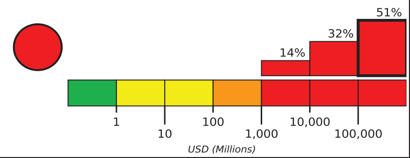
Estimated Fatalities



Red alert for shaking-related fatalities and economic losses. High casualties and extensive damage are probable and the disaster is likely widespread. Past red alerts have required a national or international response.

Estimated economic losses are 0-2% GDP of the United States.

Estimated Economic Losses



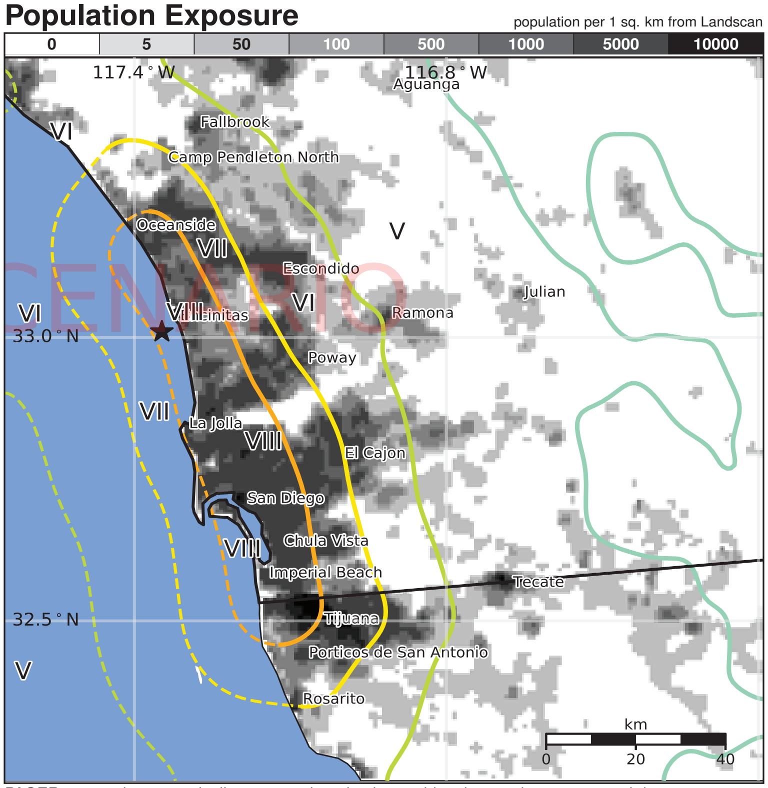
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k=x1000)		–*	–*	6k*	161k	904k	1,947k	1,950k	344k	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	None	None	None	V. Light	Light	Moderate	Mod./Heavy	Heavy	V. Heavy
	Vulnerable Structures	None	None	None	Light	Moderate	Mod./Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per 1 sq. km from Landscan



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/data/pager/

Structures

Overall, the population in this region resides in structures that are a mix of vulnerable and earthquake resistant construction. The predominant vulnerable building types are adobe block with concrete bond beam and unreinforced brick masonry construction.

Historical Earthquakes

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1986-07-13	49	5.8	V(9,528k)	0
1994-01-17	172	6.7	IX(73k)	33
1971-02-09	183	6.6	IX(21k)	65

Recent earthquakes in this area have caused secondary hazards such as landslides and liquefaction that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
IX	**San Diego**	**1,307k**
IX	Coronado	19k
IX	**Imperial Beach**	**26k**
IX	**La Jolla**	**43k**
VIII	Del Mar	4k
VIII	**Encinitas**	**60k**
VIII	Carlsbad	105k
VIII	**Chula Vista**	**244k**
VIII	**Oceanside**	**167k**
VIII	**Tijuana**	**1,376k**
VI	**Escondido**	**144k**

bold cities appear on map. (k = x1000)

Event ID: usshakeout_sdtj2015_hybridvs30_tj_se

Figure 5-1. USGS PAGER estimates impact for both the United States and Mexico. Results differ from Hazus estimates as this product uses different loss estimation methodology.

Economic losses: The Hazus study model estimates the total economic losses in San Diego County resulting from building and infrastructure damages to be approximately **$38 billion,** nearly 10% of the total value of buildings and infrastructure. This number includes $24.3 billion in building damage, $6.8 billion in damage to building contents and commercial inventories, and $5.2 billion in building-damage–related income losses, such as lost wages and business income. These business disruptions are expected to extend economic losses throughout the long, slow process of building safety inspection, building repair, and transportation and utility services restoration. Losses could exceed these values, as the model does not account for true indirect economic losses (i.e., trickle-down losses) or additional losses caused by fault ruptures, landslides, and major infrastructure system damages.

Building damage: Hazus estimates that nearly **120,000 buildings** (approximately 17% of the buildings in the region) will experience moderate to complete damage. This percentage is expected to be higher in the densely developed and older areas around the fault rupture. Hazus estimates that approximately **8,000 buildings** will be damaged beyond repair, including just under 1,800 commercial and industrial buildings.

Casualties: Hazus estimates casualties from the scenario earthquake based on the time of day, with approximately **7,700 injuries, including 300 fatalities,** if the event were to occur at night. If the event were to occur during the day, it would cause an estimated **13,600 injuries, including 800 fatalities**. While actual number of causalities can be expected to vary from Hazus estimates, as they have in past earthquakes, the specific seismic circumstances and vulnerabilities in the region can be expected to result in significant numbers of casualties, potentially approaching the numbers estimated in the Hazus model for the scenario earthquake or a similar event.

Household displacement: An estimated **36,000 households will be displaced**, with 24,000 of those persons requiring temporary shelter assistance from governmental and nongovernmental services. This number can be expected to rise because of the disruption of lifeline utilities, potentially triggering the potential dislocation of many of the 200,000 coastal residents between La Jolla and Coronado.

Hazus Estimates the Scenario Earthquake will cause . . .

$38 Billion

in Building and Infrastructure Damages

120,000 Buildings

Suffering Moderate to Complete Damage

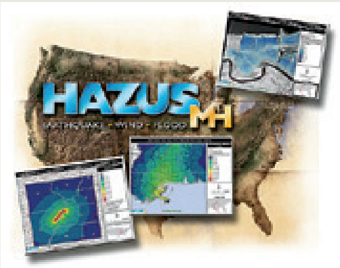
8,000 Buildings

Damaged Beyond Repair

36,000 Households

Displaced

Hazus & Special Study Methodology



The scenario study utilizes FEMA's Hazus v4.2 SP01 loss estimation software as the primary tool for defining the building and infrastructure inventories in the region, defining their vulnerabilities, and estimating the damage and economic impacts resulting from the scenario earthquake. While Hazus typically utilizes national databases of the existing buildings, custom building inventory data were developed for this assessment using San Diego County Assessor Parcel Data (2017). For the remainder of the local infrastructure, the assessment utilized Hazus default inventory data for infrastructure systems with predefined seismic fragilities. This study utilized USGS-generated ShakeMap ground motions and maps of liquefaction susceptibility and depth to groundwater, as detailed in Section 4.3 of this report.

Default inventories for infrastructure systems based on national databases (e.g., for bridges) and generalized estimate models (e.g., for water and wastewater distribution lines) were used for all systems except building inventories. As noted above, the Hazus General Building Stock aggregate inventory data were enhanced with 2018 Hazus replacement cost models and 2017 San Diego County Tax Assessor's data to refine the building count and occupancy distribution. Vulnerability data for all buildings and infrastructure systems were based on Hazus default mapping schemes for structural types and fragilities. Hazus infrastructure fragilities are assigned based on generalized national characteristics.

Hazus does not model the surface fault rupture and was not used to model seismically induced landslides. Hazus is also expected to underestimate certain key losses related to liquefaction effects, particularly on infrastructure systems. Fault rupture, earthquake-induced landslides, and liquefaction-related infrastructure damages and losses are discussed qualitatively in later sections, but quantitative estimates of economic losses are not made for these systems.

The scenario team utilized special studies relying primarily on expert opinion, interviews with stakeholders, and focused research to evaluate the critical systems and impacts not captured adequately by Hazus. These special studies engaged experts with experience-based expertise in specific facilities and systems to address the surface fault rupture and effects on the major transportation and lifeline infrastructure systems. Input, review, and feedback for these studies was provided in consultation with the following experts:

- Structural Engineers Association of San Diego (SEAOSD) College of Fellows - General building seismic assessments and facility-specific expertise for specific bridges, SDIA, Port of San Diego, and U.S. Navy and Marine Corps facilities
- SEAOSD Existing Buildings Committee - Seismic assessment of older, seismically vulnerable buildings, including retrofit status
- American Society of Civil Engineers San Diego Chapter - Utility and transportation infrastructure
- San Diego Department of Public Works - Water and wastewater systems
- California Department of Transportation (Caltrans) Engineering Department and Nonaffiliated Transportation Engineers - Bridge and transportation systems

Note that Hazus loss estimates for this San Diego regional study are higher than for previous CGS studies for several reasons. First, this study utilizes a newer NGA West 2 attenuation model, resulting in dramatically higher ground motions consistent with the current California Building Code design criteria. Second, as a scenario study, this study uses standard ShakeMap ground motion estimates rather than approximate geomean estimates. Third, it applies the more conservative Hazus default fragility curve uncertainties, thought appropriate for scenario studies, rather than less conservative fragility curves typically used in actual earthquake loss assessments. Lastly, it uses updated building inventories with updated cost models. Please see the additional supplemental documents available on **https://sandiego.eeri.org/** for further detail.

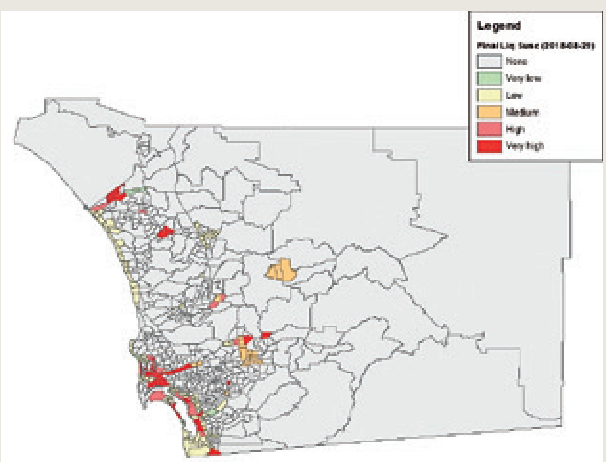


Figure 5-2. Liquefaction susceptibility by census tract to inform Hazus analyses, 2017.

5.2 Summary of Damages and Impacts

5.2.1 General Building Stock

Damage to buildings is expected to be severe and widespread, particularly in the heavily populated coastal areas and in the older urban areas. While most newer buildings, particularly single-family residences, can be expected to survive the scenario earthquake with repairable damage, many larger and older buildings can be expected to be more severely damaged and potentially unsalvageable.

Hazus estimates that 45% of all 668,000 residential buildings will be at least slightly damaged, including at least 23,000 residential units that suffer extensive or complete damage. Hazus estimates that nearly 40% of commercial and industrial buildings will be at least moderately damaged, with 20% extensively or completely damaged.

Occupancy Type	No Damage	Slight	Moderate	Extensive	Complete	Total
Single Family	325,082	168,136	62,547	6,693	1,845	564,302
Other Residential	40,447	26,836	21,572	10,271	4,442	103,568
Commercial	6,448	3,599	4,023	2,424	1,249	17,743
Industrial	1,438	683	748	354	131	3,353
Other	3,731	1,513	1,384	780	402	7,810

Table 5–1. Hazus estimated structure damage by occupancy type

Additional impacts will be experienced by residents because of potential damage to nonstructural building components (e.g., exterior cladding, ceilings, mechanical systems), damage to building contents, and loss of lifeline utility service in the near fault areas for days to months after the earthquake. Nonstructural components of buildings and building contents in commercial buildings have been shown to make in the range of 75% to 85% of building costs and to contribute up to 95% of building economic losses in earthquakes as well as contribute heavily to business disruption (FEMA 2012).

Case Study: History of Seismic Design Code Development in San Diego

A review of the history of seismic design provisions over the last 100 years gives insight into the relative seismic resistance and vulnerability of building stock in San Diego based on date of construction. While the evolution of seismic design provisions to their current sophistication does not assure that all modern buildings will perform well in major earthquakes, it does suggest that modern (post-1994) buildings will generally perform much better than older buildings that have not been seismically retrofitted.

The City of San Diego first adopted simplified seismic requirements for its general building stock in 1939, prohibiting unreinforced masonry buildings and designing structures to resist a seismic force between 0.02g and 0.1g. Incremental enhancements were made until the 1979 Uniform Building Code (UBC) introduced modern seismic design concepts, including improved standards for concrete frame buildings. One of the largest jumps in design occurred with the adoption of the 1994 UBC, which followed the transition of San Diego from Seismic Zone 3 to Seismic Zone 4 (Sec. 1627.2of the 1994 California Building Code) and resulted in a 33% increase of design seismic forces for new construction. By the 1997 UBC, most of the modern detailing requirements for improved ductility and post-earthquake performance were incorporated. Currently, the International Building Code designs for forces in the range of 0.15g to 0.25g and includes provisions for nonstructural systems. The 2019 iteration of the California Building Code further increased seismic design forces in coastal areas close to the RCFZ.

Several devastating earthquakes in the early 20th Century spurred the development of codes and mandates to address seismic hazards statewide. Devastating losses and casualties caused by major earthquakes led to the 1933 Field Act and 1972 California Hospital Act, mandating more rigorous requirements for seismic design and construction for schools and hospitals. "Importance factors" for essential facilities, such as hospitals, police stations, and fire stations, were introduced in 1979, and SB1953, passed in 1994, requires the seismic evaluation of all existing acute care hospital facilities followed by staged seismic upgrade or removal from service by 2030.

Key dates in seismic design provision adoption can be translated into benchmark dates in San Diego, as shown in Table 5–2, for older seismically vulnerable buildings types. Buildings of the specified types constructed before these benchmark dates are considered more vulnerable because of characteristic seismic deficiencies. These dates are useful in evaluating the existing building inventory to help policymakers identify which building types and vintages present higher seismic risks and warrant higher retrofit priority.

Vulnerable Building Type	Replacement Building Type	Benchmark Year in San Diego
Unreinforced masonry	Reinforced masonry	1939 and later
Nonductile concrete wall or frame	Ductile concrete wall or frame	1980 and later
Tilt-up concrete (poorly anchored)	Tilt-up concrete (well anchored)	1997 and later
Steel moment frame (pre-Northridge)	Steel moment frame (post-Northridge)	1995 and later
Soft-story wood-frame residential	Braced wood-frame residential	1979 and later
Soft-story commercial	Braced first-story commercial	1979 and later
Unbraced cripple wall residential	Braced cripple wall residential	1979 and later

Table 5–2. Benchmark years for modern seismic building code requirements in San Diego

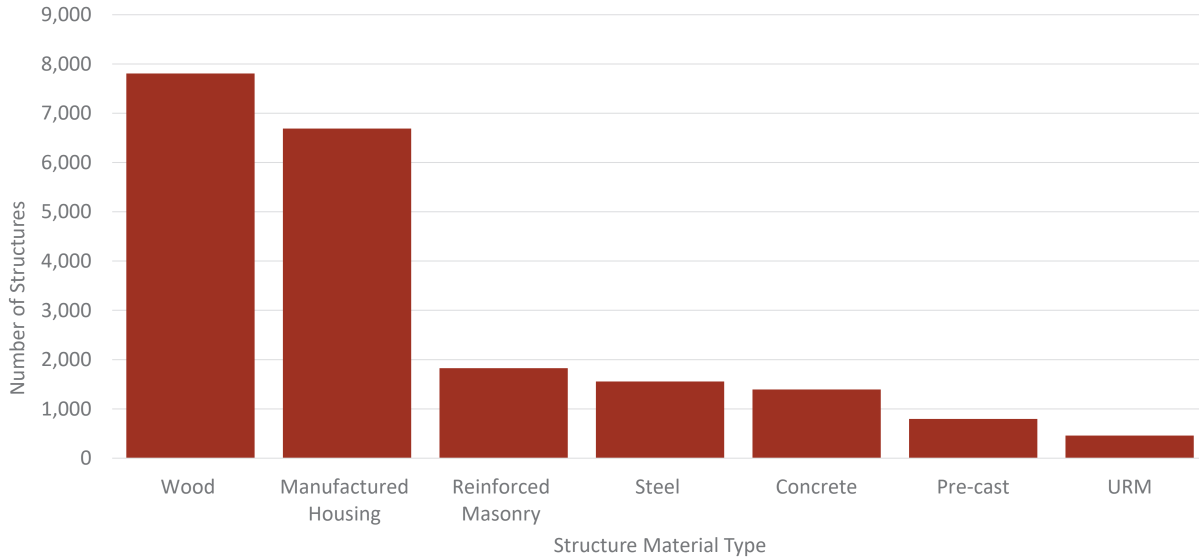


Figure 5–3. Extensive damage to building stock by material type, Hazus estimate.

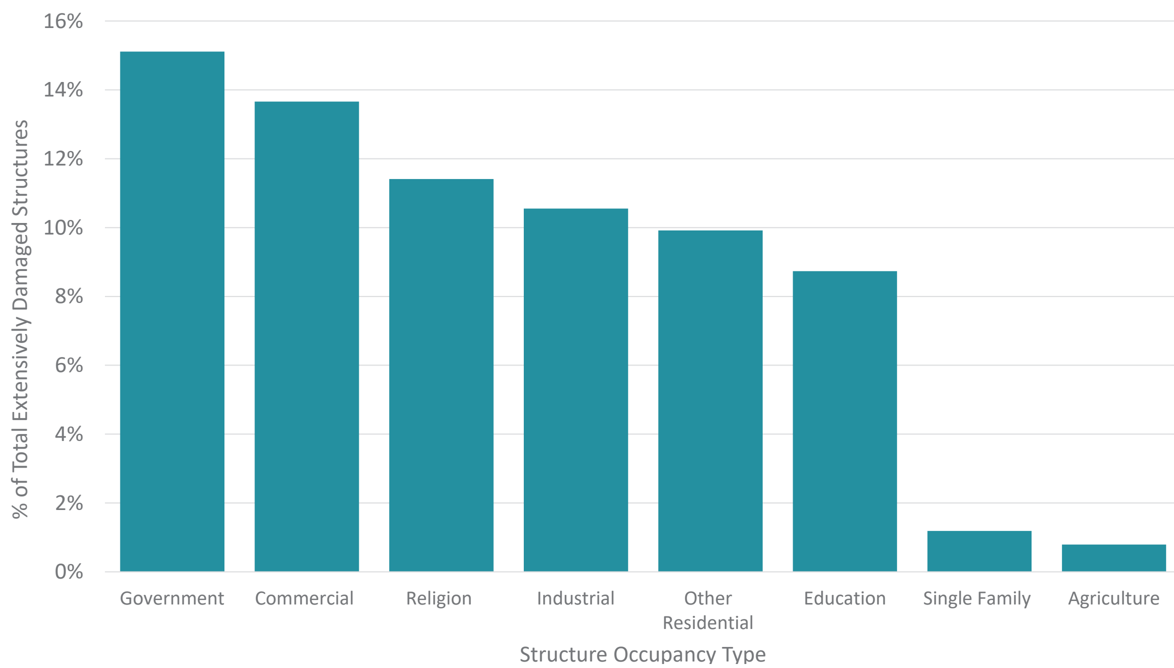


Figure 5–4. Percentage of building stock by occupancy type with extensive or complete damage, Hazus estimate.

5.2.2 Older Seismically Vulnerable Buildings

Older highly vulnerable structure types will be hardest hit by the scenario earthquake, experiencing extensive damages, building losses, and many possible casualties. Years of research and earthquake reconnaissance investigations have thoroughly described a well-known group of particularly vulnerable structural types with a long track record of poor seismic performance. Special studies conducted by local engineering groups estimate that there are between 2,850 and 8,100 total seismically vulnerable structures in San Diego County (Table 5–3). These include unreinforced masonry (URM), older nonductile concrete and infill frame, poorly anchored tilt-up concrete buildings, tuck-under parking residential structures, older steel frame buildings, and older cripple wall and hillside residential structures. Vulnerable structure types have generally not been inventoried or addressed in the San Diego region beyond a partial retrofit program for URM buildings.

Hazus estimates that the damages to vulnerable building types would be significant, estimating that over 30% of the URM structures (approximately 880) in the County would be extensively or completely damaged. This can be compared with the less vulnerable wood structures; less than 2% are estimated to be extensively or completely damaged.

The catastrophic failures of these structure types are well studied from earthquakes both in California and around the world. In the February 2011 Christchurch, New Zealand, earthquake, two concrete frame structures with limited ductility collapsed, causing 133 casualties, approximately 70% of the total casualties during the earthquake (Royal Commission 2012). The extensive damage from these and other buildings led to the closure, demolition, and reconstruction of almost the entire downtown, displacing hundreds of businesses and thousands of workers, with dramatic impacts on the service and hospitality industries (Johnson and Olshansky 2017). In California, soft-story residential building collapses during the 1989 Loma Prieta and 1994 Northridge earthquakes resulted in casualties and ignition of fires and drew extensive resources from emergency response and recovery efforts (NRC 1994). If similar collapses were to occur due to the scenario earthquake, this would add complexity to the emergency response, increase the number of human casualties, exacerbate financial loss, and delay recovery for the San Diego Region.

Figure 5–2. Examples of older seismically vulnerable building types:

Nonductile concrete buildings, 1971 Sylmar.

Soft-story tuck-under parking residential building, 1989 San Francisco.

Tilt-up concrete building, 1994 Northridge.

2014 Christchurch, New Zealand

Building Type	Standard Description and Typical Failures	Construction Era and Locations	Estimated Number in San Diego[a]
Unreinforced masonry (URM)	Brick or hollow clay tile bearing wall buildings without reinforcement Prone to partial or complete collapse caused by wall separation, parapet collapse, or global structural collapse	1880–1939 Constructed extensively as commercial and institutional buildings 1992 City of San Diego URM Ordinance (implemented in 2001) required limited partial retrofits of ~800 URMs	884 estimated as of 2001 in City of San Diego. ~300 since demolished or recategorized as non-URM buildings Several hundred URMs remain in National City, Downtown San Diego, Chula Vista, El Cajon, Solana Beach, Encinitas, Oceanside, and in unincorporated areas
Nonductile concrete	Concrete frame or shear wall buildings without sufficient reinforcing steel Prone to sudden, brittle failure and collapse	Pre-1980	500–1,000[a]
Tilt-up concrete (poorly anchored)	Constructed by tilting up concrete slabs to act as walls Prone to failure of the wall to roof connection, possibly resulting in wall and roof collapse	1930–1997 Many constructed from the 1960s-1980s Greater Kearny Mesa, Miramar, and Sorrento Valley areas	500–1,000[b]
Soft story	Typically, multi-unit apartments or condominiums with tuck-under parking on the first level and wood-framed residential structures on the upper levels Commercial structures with open storefronts and/or tall first stories at street level Prone to side-sway and potential collapse because of weak first story	1900–1980	1,000–5,000[b] National City has conducted an inventory of multi-unit residential buildings with tuck under parking.
Pre-Northridge steel moment frame	Welded steel frame buildings with insufficiently welded and configured connections Prone to fracture and damage at the connections and potential partial or complete collapse	1960–1995 Office buildings downtown San Diego along B Street, Broadway, and in the City Concourse area and in other downtown areas throughout the County Hotel and residential in downtown San Diego and waterfront districts	Unknown, but likely 50-300[b,c]
Light frame residential with cripple walls	Wood-frame residential home with relatively unbraced foundation cripple wall in the crawl space or basement Prone sideway failure and partial collapse of the cripple wall, causing the house to drop or slide off its foundation	Pre-1950s	Unknown, likely thousands.

Table 5-3. Review of seismically vulnerable structures in the San Diego Region by the Structural Engineering Association of San Diego (SEAOSD). [a]Estimates of buildings are developed through expert opinion and best available data.
[b]Estimate based on comparison to other similar jurisdictions or areas in Southern California.
[c]Based on review of aerial photographs. [d]City of San Diego Development Services Department via:
https://www.sandiego.gov/department/unreinforced-masonry-buildings.

5.2.3 Essential Facilities

Though essential facilities compose approximately 1% of the structures in the County, they are essential to operations supporting health, education, safety, and welfare of all citizens. Essential facilities include schools, hospitals, fire stations, police stations, and emergency operations structures. The scenario team utilized default inventory databases available in Hazus to estimate loss of function, which do not characterize specific facilities and do not account for existing seismic assessments, retrofits, or mitigation plans. Consequently, this section highlights the large number of facilities that will be tested by the scenario earthquake and illustrates the potential scope of impacts and possible consequences rather than specific anticipated damages to each essential sector. Hazus determines functionality from damage probability, meaning if a building has a 50 % chance of being damaged, it will be 50 % functional. For this discussion, the estimates of facilities with limited functionality can be interpreted as the total number of damaged facilities.

5.2.3.1 Schools

While newer school buildings in the San Diego region are typically well designed and constructed based on modern seismic standards and Division of State Architecture (DSA) regulations and can be expected to perform well in the scenario earthquake, there are many older school buildings that were designed

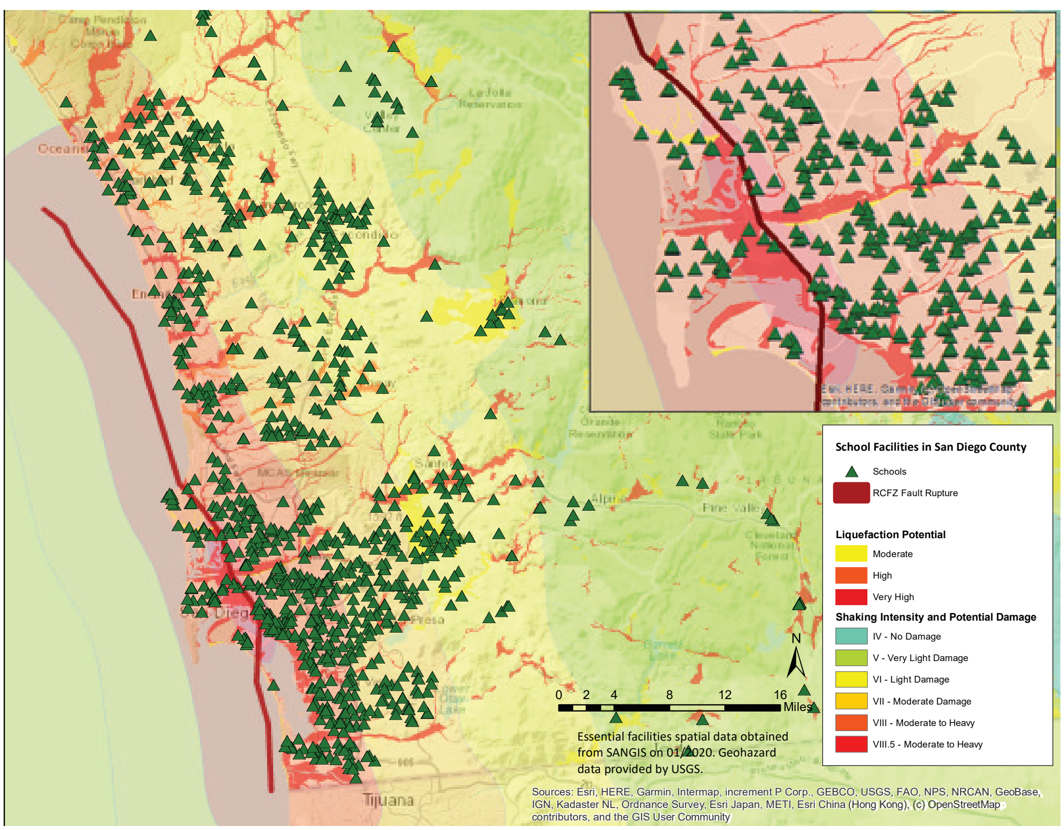


Figure 5-5. School facilities in relation to intensity of the scenario earthquake.

to significantly lower seismic standards. Many of these older structures are wood-framed buildings, but there are also numerous older, heavier, more vulnerable school buildings identified through the Assembly Bill 300 screening process in the early 2000s that have not yet been evaluated in detail, retrofitted, or decommissioned. There are also an estimated 100 private schools and 180 charter schools that are not subject to the Field Act or DSA standards.

Older schools without seismic upgrades are at risk of damage and closure from the scenario earthquake, especially those in high-risk zones such as the liquefiable areas around Mission Bay and San Diego Bay. The Hazus model estimates that approximately half of the 993 public K-12 school campuses in San Diego County will have limited functionality the day after the earthquake. While the Hazus default data does not capture each individual building on the school campus, even a limited number of school closures could have compounding consequences because schools often play a critical role in emergency response when they serve as shelters for the general public. The model also does not account for ground failures, lifeline utility, and transportation infrastructure disruptions that may impact several coastal campuses around Mission Bay, San Diego Bay, particularly west of Interstate 5, and south of La Jolla Shores.

5.2.3.2 Hospitals

New hospitals throughout California are designed and constructed to very high seismic standards under the authority of the Office of Statewide Health Planning and Development (OSHPD) and can typically be expected to perform very well in major earthquakes. However, there are many older, as yet unretrofitted, hospital structures that can be expected to perform relatively poorly. Retrofit measures taken by the State of California and enacted by the San Diego region to address these older hospitals are expected to leave hospitals in very good condition to withstand the scenario earthquake. Senate Bill 1953 (Chapter 740, 1994; Seismic Mandate) requires that all older hospitals be retrofitted sufficiently to a level of structural performance similar to that of a hospital designed to current code or be replaced by 2030. According to OSHPD representatives, an estimated 75% of these older hospitals will have been retrofitted or replaced by 2020. The remainder of the older hospital buildings are scheduled to be addressed by 2030, as long as SB1953 is not revised before the scope of work has been completed. It is important to note that other health care facilities, including nursing homes, outpatient care facilities, and medical office buildings, do not fall under the same construction and retrofit requirements; therefore, these structures are not expected to perform as well as hospitals in the scenario earthquake.

Hospitals have emergency generators and water supplies that are typically intended to last 72 hours but may still be disrupted by severe loss of lifeline services in the region if disruptions extend for longer periods of time. As seen in the 2019 Ridgecrest Earthquake sequence, nonstructural damages can also cause disruptions and loss of functionality, even in newly designed hospital facilities

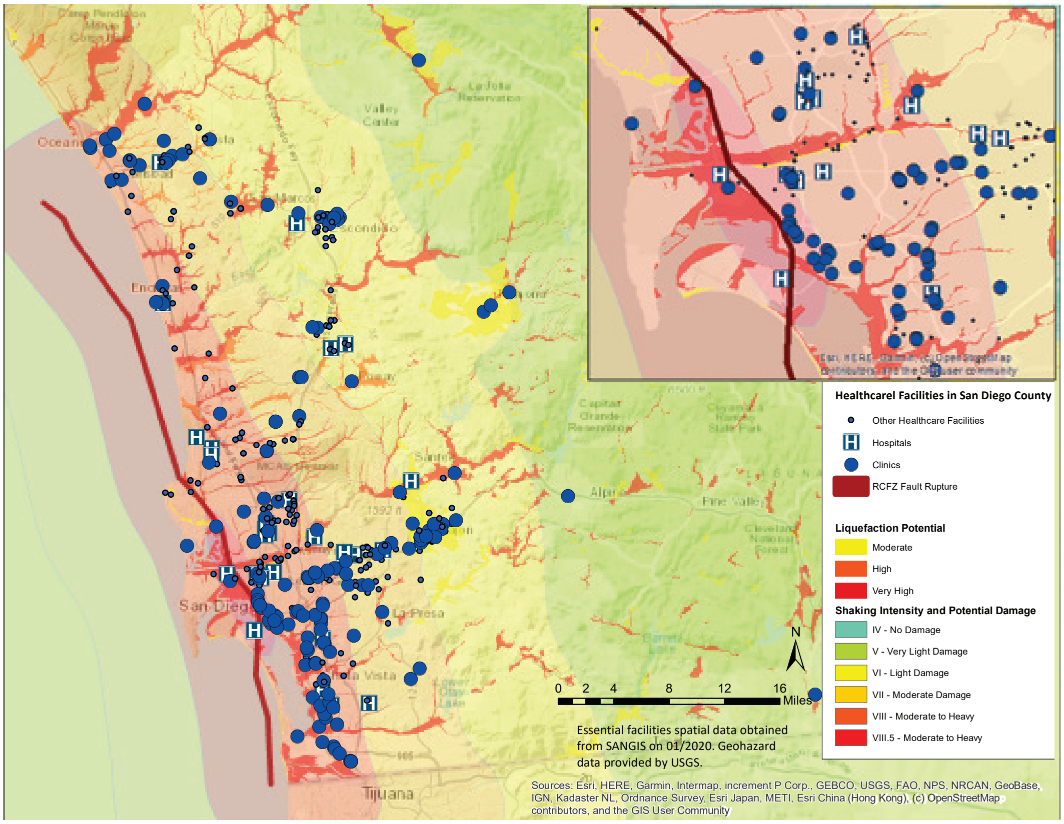


Figure 5–6. Health care facilities in relation to scenario earthquake shaking intensity.

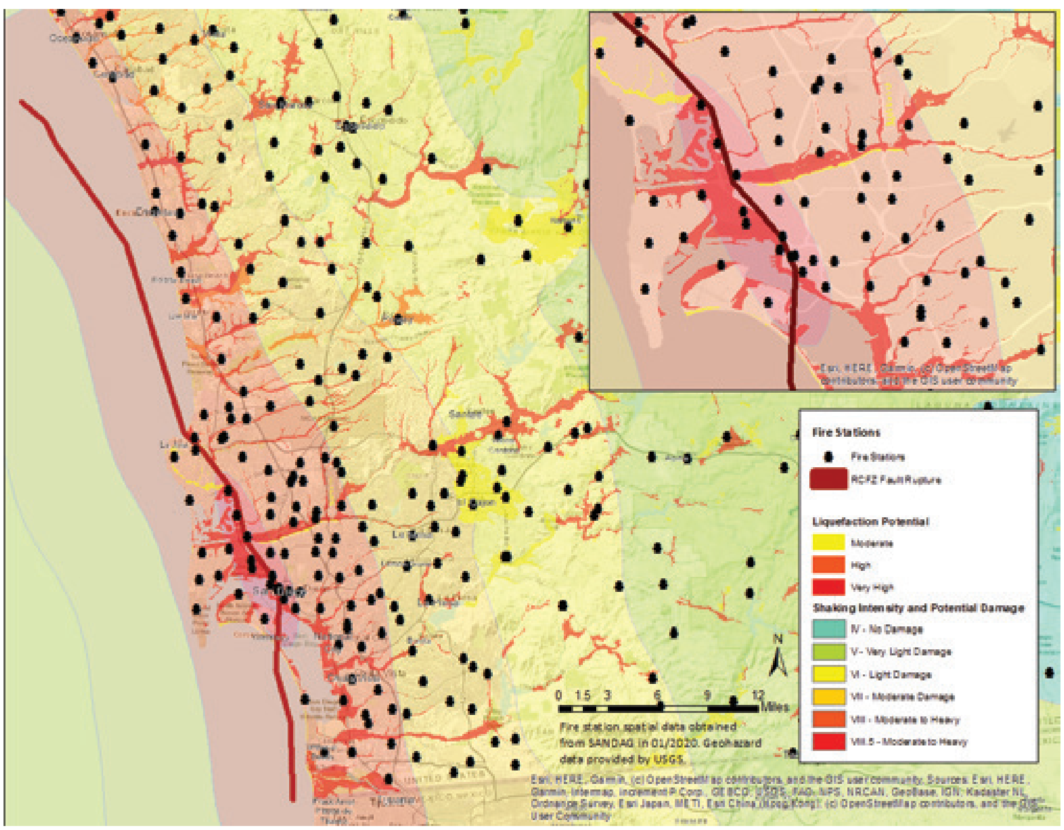


Figure 5–7. Fire stations in relation to scenario earthquake shaking intensity.

(OSHPD 2019). Any reduction in available hospital facilities or services coupled with the expected casualties of the event could have serious implications for public health and emergency response.

5.2.3.3 Police and Fire Stations

Police and fire stations play a critical role in post disaster response and recovery by coordinating emergency response activities after an earthquake. Facilities constructed prior to 1979 in the region were typically constructed to the same standards as ordinary commercial buildings; however, since then, state and local building codes began mandating higher design standards with the goal that police and fire stations remain functional following earthquakes because of their importance in response. Older facilities that still remain in service are more vulnerable than newer facilities.

Police and fire substations are generally well distributed around the region, providing a measure of resiliency and redundancy to essential services; however, damages from the Hazus model are more concentrated in higher hazard areas susceptible to liquefaction. Notably, several fire stations clustered in downtown San Diego may be hit hardest and delay response to fires in the dense population center. Several emergency response agencies have headquarters that are located within the RCFZ, including the SDPD headquarters building downtown, the CHP headquarters off Friars Road, and the SDPD Western Division headquarters also off Friars Road, and can be expected to experience intense ground shaking, potential liquefaction, and fault rupture impacts. Hazus estimates that approximately half of the 73 police facilities and one-quarter of the 62 fire stations in the region will lose at least 50% functionality on the day following the earthquake. Several police stations and fire stations are estimated by Hazus to suffer extensive to complete damage.

5.2.3.4 City of San Diego Government Facilities

The City of San Diego government operations facilities are concentrated in the downtown area close to the fault and areas of high-intensity shaking in the scenario earthquake. Based on the ages, structure type, and proximity to the hazard, City of San Diego facilities are expected to suffer potentially extensive damage in a scenario earthquake, resulting in extended disruption and dislocation of City functions and operations. City government operation facilities, including the City Administration Building, are concentrated downtown in the City Concourse area in older concrete buildings and older high-rise steel moment frame buildings dating from the 1960s and 1970s. Performance of similar, older buildings has historically been poor in past earthquakes in other California communities. Previous studies for the Hayward fault scenario have found that similar steel-framed buildings could be put out of service for 6 to 12 months (USGS 2018) because of a combination of structural and nonstructural earthquake damage.

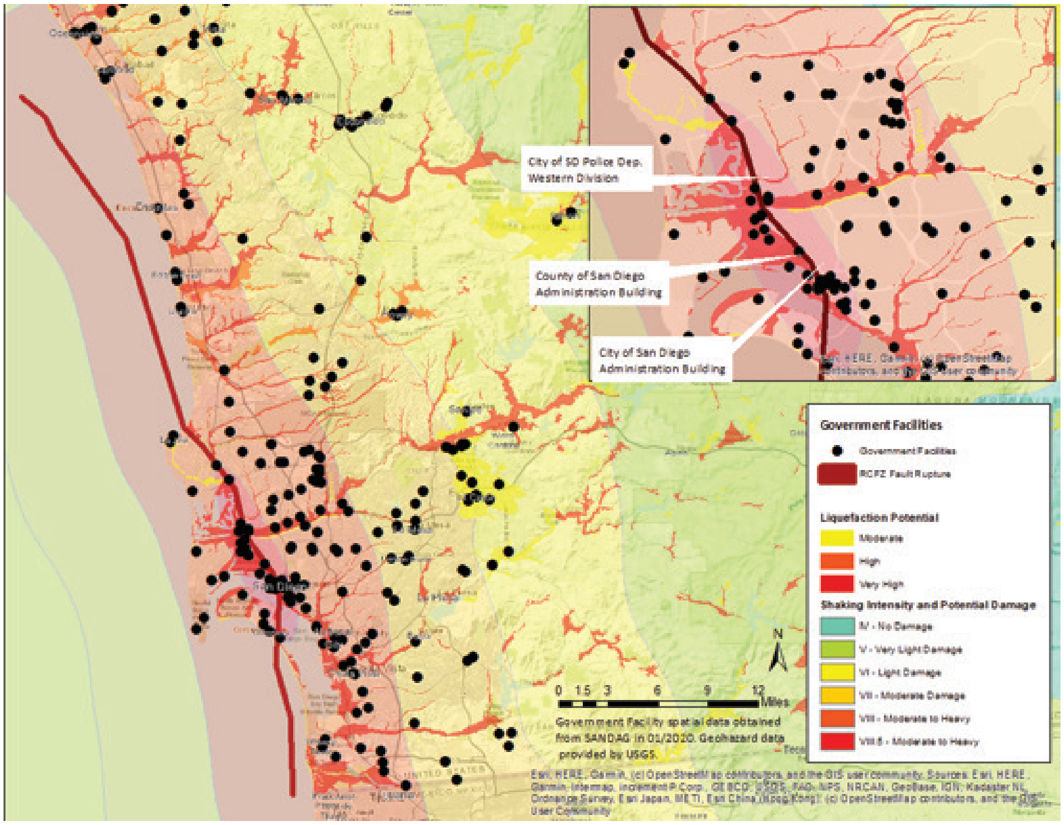


Figure 5–8. Government facilities in relation to scenario earthquake shaking intensity.

These disruptions are expected to be greatly compounded by the transportation and lifeline infrastructure failures in the downtown area. The disruptions to City operations could last weeks to months, depending on the severity of the damage to key facilities, the capacity of the City to evaluate and repair the structures amid the region-wide recovery process, and the condition of infrastructure systems and services. The City currently has plans to vacate and redevelop several of its older operations and administrative facility sites, which could significantly reduce the City's earthquake risk exposure.

5.2.4 Department of Defense Infrastructure Impacts

The U.S. Navy and U.S. Marine Corps have a major physical and economic presence in the region and are located primarily in coastal areas most susceptible to liquefaction and fault rupture of the RCFZ. For national security purposes, structure inventories and mitigation plans are not made publicly available. Therefore, vulnerabilities and loss potentials were qualitatively assessed based on geologic data, publicly available information, interviews with emergency response officials, experience with local facilities, and expertise with similar structures and infrastructure.

Many of the military installations in the region were largely developed prior to the adoption of current seismic standards and contain older, more seismically vulnerable structures, both landside and along the waterfront.

Therefore, it is expected that the facilities that have not undergone seismic retrofits may suffer extensive damages and loss of utility lifeline services. Particularly, older Marine Corp facilities, such as the Marine Corp Recruit Depot, and naval bases situated on hydraulic fill soils are anticipated to experience significant impacts and long recovery times from the scenario earthquake. Newer facilities and those that have undergone retrofit to modern seismic standards are anticipated to suffer some building damage and lifeline utility service interruption but are generally expected to be able to recover in days to weeks.

A critical impact to regional military facilities will likely be these civilian lifeline and transportation infrastructure systems. Loss of lifeline utilities, disruption of access roads, and extensive damage to waterfront structures and buildings will make the Department of Defense (DOD) response very challenging. It is anticipated that the local military bases will be fully occupied with restoring their own mission readiness in the months after a major RCFZ earthquake, and their ability to support immediate response and recovery efforts in the civilian community will be limited. Other DOD assets from around the nation and from the National Guard are expected to be made available when authorized through established emergency response protocols and as local logistical transportation challenges are resolved.

5.2.5 International Border Infrastructure

The San Ysidro and Otay Mesa crossing facilities are currently undergoing or have recently completed renovations and expansions designed to modern seismic standards. The updated border crossing facilities are expected to perform well in terms of seismic resistance but can potentially suffer critical utility and communication infrastructure damage. Additionally, significant damage can potentially occur to the access roads and bridges, particularly on the Tijuana side where they cross the liquefiable soils of the Tijuana River. The Otay Mesa and Tecate border crossings are located on higher, firmer ground and can be expected to perform better than San Ysidro, with most service restored over a period of days to weeks.

In the event of the scenario earthquake, a significant amount of liquefaction damage and bridge damage can potentially occur on the Tijuana side, with a lesser amount expected on the U.S. side of the border. Overall traffic across the border can be expected to be severely curtailed in the short term and gradually restored over weeks to months after the scenario earthquake, with faster potential restoration times for the freight trucks and pedestrian traffic than for passenger vehicles. Economic losses can be expected to be large because of disruptions to manufacturing production and trade and disruptions to the enormous flow of nearly 100,000 workers per day.

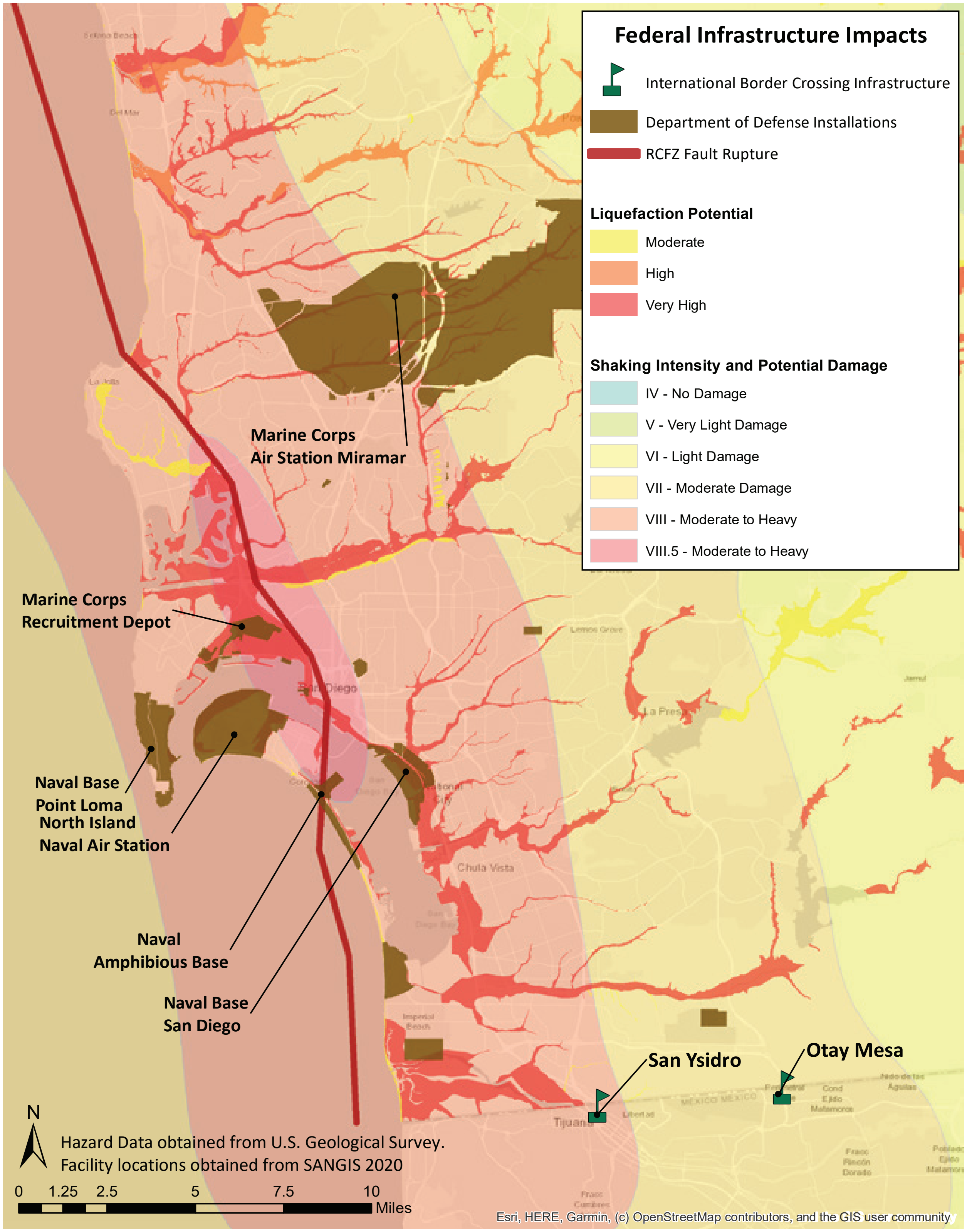


Figure 5-9. Department of Defense and international border infrastructure in relation to scenario earthquake shaking intensity.

5.3 Impacts to Infrastructure

5.3.1 Utility Lifeline Infrastructure Impacts

Lifelines are the system of systems that interconnect every structure in a community, and the dispersed nature of these systems make them particularly vulnerable to seismic hazards. Utility lifelines include water, wastewater, fuel, and electrical power and communications systems, which provide essential services to the buildings and residents within a community. Much of the utility lifeline infrastructure in the San Diego area was built without the full recognition of the potential surface fault rupture or liquefaction ground failure that could be generated by the RCFZ. These conditions leave the San Diego region highly vulnerable to widespread lifeline infrastructure damage and loss of service in the event of a scenario earthquake on the RCFZ.

5.3.1.1 Water Supply and Storage Systems

San Diego's water supply infrastructure has undergone dramatic enhancements in recent decades under the leadership of the San Diego County Water Authority (Water Authority) to provide markedly greater self-sufficiency and resilience. The regional water distribution system generally carries the water from east to west, from a series of aqueducts, reservoirs, and water treatment facilities to the populations concentrated along the coast and in the near-fault inland areas. Major water storage infrastructure, including local dams, reservoirs, and aqueducts, are expected to remain in service because of recent seismic retrofits and their locations away from the anticipated fault rupture. Analysis of the 54 local dams included in the 2018 California Department of Water Resources dam ratings report indicates that there are only two with the potential to experience damage from the scenario earthquake. Though it is considered highly unlikely that the Murray and Sweetwater Main dams will fail because of the moderate PGAs anticipated at those sites, these dams have an "extremely high" downstream hazard rating because of their potential for causing flooding and casualties. However, the major water supply and distribution lines that deliver water to coastal communities from La Jolla to Imperial Beach are at high risk, as they cross the surface rupture and liquefaction zones.

Figure 5–10. Damaged water transmission lines post 2014 South Napa Earthquake. (Credit: Justin Sullivan / Getty Images)

The Hazus model estimates that thousands of leaks and breaks will occur in smaller water distribution pipes because of ground

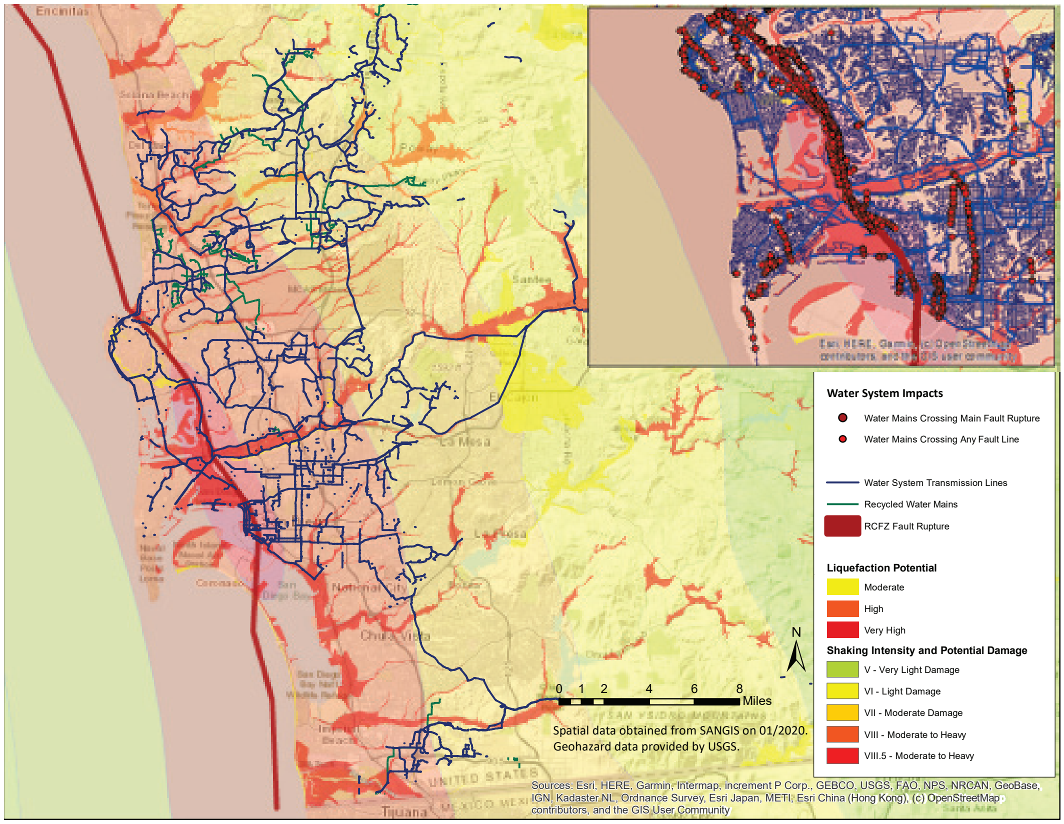


Figure 5–11. Water transmission infrastructure in relation to scenario earthquake shaking intensity, fault rupture, and liquefaction areas.

shaking and liquefaction, not accounting for surface rupture. Hazus estimates the number of breaks and leaks to be more than 14,000; a previous study estimates the number to be less than 5,000 (Eidinger et al. 2001). Major supply pipeline ruptures along the fault are expected to leave the coastal communities west of the fault and south of La Jolla Shores completely without water for weeks to months. Impacted communities include La Jolla, Mission Bay, Point Loma, and Coronado Island areas. Coronado, which is served by water pipelines under the Bay that are potentially exposed to fault rupture, could be without water for months. The scale of the water line damage, cross contamination with wastewater lines, damage to access roads, and the prioritization of repairs will slow the water restoration process to coastal communities and may leave many areas without water supply for weeks to months. The loss of water will also greatly exacerbate wastewater service disruptions and fire suppression capacities, as discussed in subsequent sections.

5.3.1.2 Wastewater Systems

Where the regional water supply system has developed redundancies into its infrastructure, the regional wastewater system is largely reliant on treatment and outflow from the Point Loma Wastewater Treatment Plant located on the coast (Figure 5–12). The scenario earthquake is expected to cause catastrophic consequences to wastewater infrastructure. Fault rupture is expected to sever

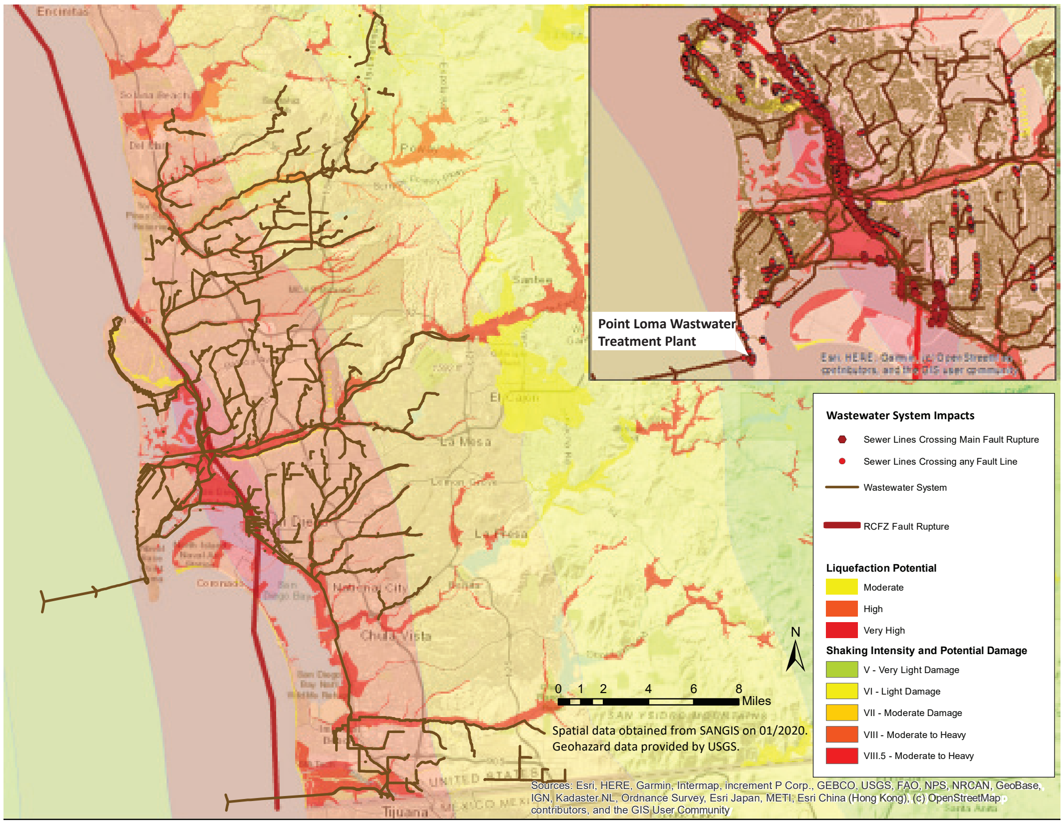


Figure 5-12. Wastewater infrastructure in relation to scenario earthquake shaking intensity, fault rupture, and liquefaction areas.

all three major interceptor pipelines delivering wastewater to the Point Loma facility. Ground shaking, liquefaction, and power disruptions are expected to disrupt pump station operability in the coast areas. These combined impacts are expected to disrupt the functioning of the wastewater treatment system nearly countywide. In addition, the ground shaking and ground failures are expected to cause thousands of pipe breaks and leaks, necessitating excavations and repairs. Line breaks and leaks are expected to cause wastewater to flow out of the Rose Canyon, Mission Valley, and South Bay interceptors into Mission Bay, the San Diego River, San Diego Bay, and the ocean. These flows of raw untreated sewage into bays and rivers would cause significant environmental, health, and safety impacts.

Additionally, all wastewater services in the beach communities, including La Jolla, Mission Bay, Point Loma, and Coronado Island, are expected to be lost for weeks to months because of the upstream loss of water supply and the downstream loss of wastewater systems. The Coronado trunk line is potentially susceptible to fault rupture under the Bay, which may necessitate full replacement of the submarine pipeline. Even service areas east of the fault zone are expected to have impaired service for months, pending repair of the interceptor pipelines and pump stations. Repairs to the major interceptor lines are expected to be particularly challenging because of the continuous flow of wastewater from upstream and the excavation depths (up to 90 feet under downtown San Diego).

The wastewater system may be the "Achilles heel" of San Diego's post-earthquake recovery because of its continuous use, vital function, difficulty of repair, and lack of system redundancy.

5.3.1.3 Natural Gas and Petroleum

San Diego is served by a network of natural gas and petroleum product pipelines typically buried underground (Figure 5–13). The major supply lines come down from the Long Beach area refineries and natural gas facilities and split into both major and minor distribution lines that crisscross the fault and liquefaction zones along the bay and river margins.

The scenario earthquake is expected to result in several petroleum pipeline breaks, 10 to 20 major gas line breaks, and an estimated 2,400 natural gas distribution line breaks caused by fault rupture and liquefaction. These damages are expected to cause major and relatively long-term service disruptions, particularly for beach communities leaving them without gas service for weeks to months. Restoration of service to residential areas is an extended process, starting with repair of all major and minor supply lines followed by door-to-door inspections before the system can be repressurized and service restored. Disruption of petroleum supplies is expected to impact port operations, 10th Avenue Marine Terminal fueling operations, airport operations, and some military operations dependent on fuel supply lines for weeks until service can be restored.

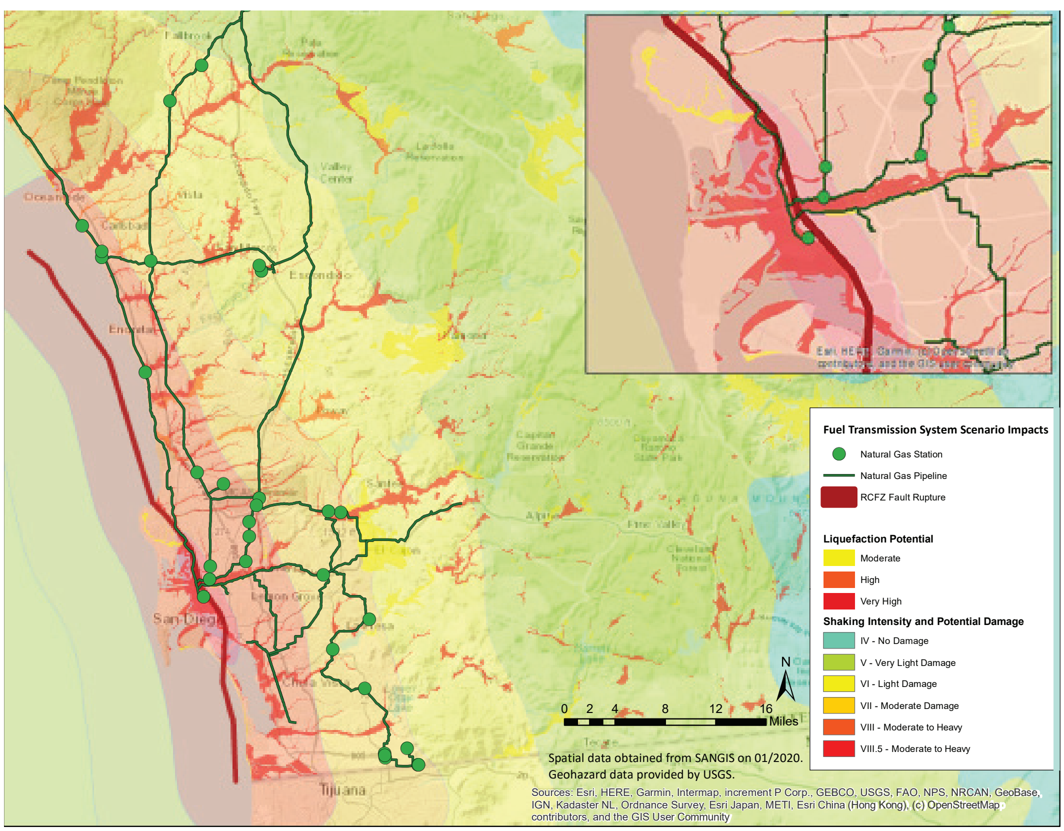


Figure 5–13. Natural gas transmission lines in relation to scenario earthquake shaking intensity, fault rupture, and liquefaction areas.

In addition, the thousands of pipeline breaks, from major supply lines to minor distribution lines, are expected to raise fire hazards, potentially fueling hundreds of fires following the earthquake. Fire suppression capacities are expected to be severely hampered by loss of water service and disruption to service access roads in the liquefaction zones.

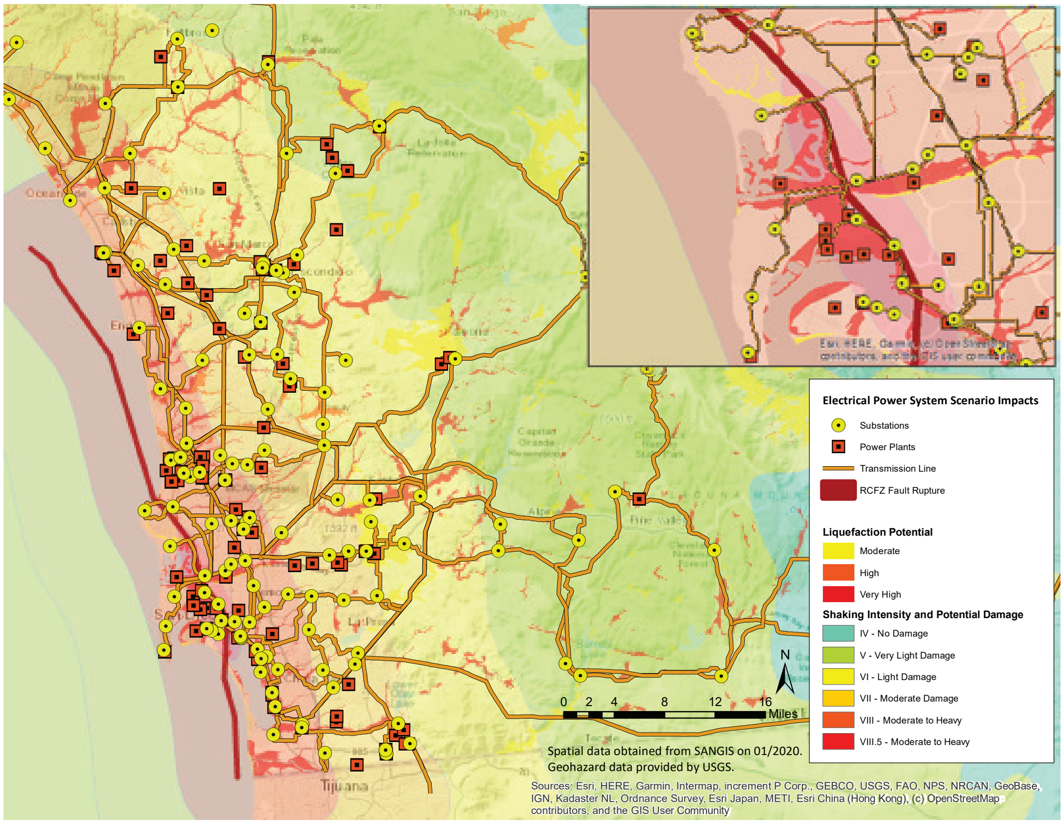


Figure 5–14. Electrical power system in relation to scenario earthquake shaking intensity, fault rupture, and liquefaction areas.

5.3.1.4 Electrical Power

The electric grid and power generation systems in San Diego, operated by San Diego Gas and Electric (SDG&E), have undergone major transformations in the last 20 years. Recent upgrades to major power plants and transmission lines, dispersed generating capacity, and imported power from renewable sources are all factors contributing to the expected resilience of the region's power supply.

In the scenario, some damage and temporary shutdowns for inspection are expected at generating facilities; however, reactivation and other energy sources are expected to quickly fill the gaps over a period of hours to days. Distribution lines and hundreds of substations will be subjected to high-intensity ground shaking and may be vulnerable to damage causing outages or short circuits with the potential to spark fires around the leaking natural gas pipes. The central business district and coastal communities may be hit hardest by the damage because of loss of power connectivity or substation failure (Figure 5–14). Repair or replacement of the substations is expected to take days to weeks, depending on the extent of the damage, the demand for repair crews, and accessibility to the affected areas.

5.3.1.5 Communication and Information Systems

Communication and information systems have evolved rapidly and radically over the past 30 years with the introduction and dissemination of the internet and smart cell phones. As seen after recent earthquakes and public safety power shutoffs, the capacity of communication and information networks are primarily affected by electric power outages. In addition, a surge in demand for communications and information seeking after a disaster exceeds what the networks are designed for and systems are overwhelmed.

Earthquake damages to infrastructure would also reduce network capacity. Cell towers have historically been built to avoid collapse, although not all damages. Cell sites on buildings and poles are affected by performance of those structures and backup power limitations. Below grade fiber optic and traditional transmission lines for landline and internet services are vulnerable to liquefaction and fault rupture. Above grade transmission lines for landline and internet services are vulnerable to pole failure and above ground sway, in addition to liquefaction and fault rupture. In addition, the region relies on potentially vulnerable older central switching stations.

Loss of network capacity and increased demand are expected to impact services to residents, visitors, and businesses. Emergency communications are anticipated to fair better because of regional investments in resilience and redundancy of emergency communication infrastructure including FirstNet.

Restoration of communication and information services is expected to take days to weeks, delayed by difficulty of accessing sites (damaged roads and restricted building entry), high demand for repair technicians, and electric power restoration. Broad areas in the coastal communities and the nearby areas east of the fault are expected to suffer more widespread telephone and internet service impairment for periods of weeks to months while restoration measures are implemented and repairs are completed.

5.3.2 Transportation Infrastructure Impacts

5.3.2.1 Airports

SDIA is built in an area of high seismic risk. The airport and its single runway sit atop soils highly susceptible to liquefaction, where RCFZ strands are expected to undergo several feet of fault rupture offset, creating potential for large lateral displacement. Ground shaking intensity at the airport is expected to be severe (MMI 8) because of fault proximity and nature of the soils (Figure 5–15).

The seismic resistance of the facility has improved because of recent upgrades and additions designed to modern building codes, including the

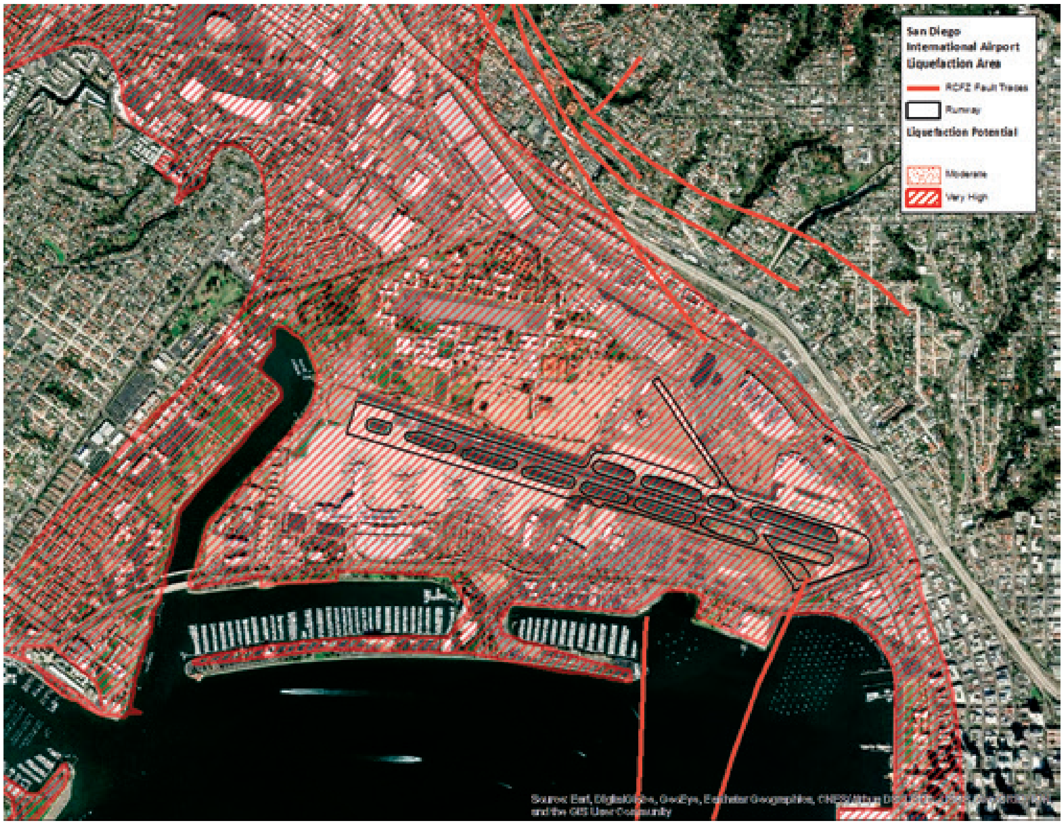


Figure 5–15. San Diego International Airport in relation to liquefaction areas and Rose Canyon fault lines.

expansion of Terminal 2, new parking facilities, rental car facilities, and other infrastructure improvements (San Diego County Regional Airport Authority 2019). However, the single runway and the older Terminal 1 (until planned replacement of the latter by 2026) remain as seismic vulnerabilities. The non-structural systems in Terminal 2 may be vulnerable to sidesway of the large open structures. Non-pile supported floor slabs, baggage handling systems, and utilities may also be vulnerable to soil movement. The single runway is expected to be disrupted by fault rupture and liquefaction displacements. Potential damages to the utility and transportation lifelines of the airport, including access roads, the subterranean aircraft fuel supply line from Tenth Avenue Marine Terminal, and electric transmission lines, are expected to significantly interrupt commercial flight operations. SDIA maintains emergency electrical generation capability, but this is only sufficient to run emergency systems and not airport operations. Unmitigated airport facilities may be severely impaired for weeks to months, with normal air traffic volumes resuming only after many months of repair. Disruptions to tourism and business travel are expected to be severe for weeks and substantial for months.

5.3.2.2 Highways and Surface Roadways

San Diego's highway system is composed primarily of freeways, which provide limited redundancy and run near capacity at rush hours; disruption to one freeway can result in heavy congestion and traffic flow disruption at adjacent freeways and connectors. The highway sections closest to the RCFZ rupture and the liquefaction zones around San Diego Bay, Mission Bay, and in Mission Valley, including the Silver Strand to Coronado Island, are the most vulnerable and most likely to be disrupted in the scenario earthquake (Figure 5–16).

The expected 6.6 feet (2 meters) of fault displacement at several locations, liquefaction settlement, and lateral spreading would likely impact segments of the I-5, Interstate 8 (I-8), and Route 163. Retrofit programs have largely addressed the major freeway bridges, viaducts, and interchanges to prevent collapse but not necessarily all damages. Major highways, including Interstate 805 (I-805), Interstate 15, and Routes 52 and 94, are further away from the scenario earthquake fault lines and are therefore more likely to remain open after the scenario earthquake, pending inspections and repairs.

Surface roads located within the fault rupture zone and within liquefaction zones, particularly around the Port, the airport, and the Naval bases, are expected to be damaged by the ground failures but are generally expected to be made passable in days to weeks. Exceptions to this limited disruption could be in the Rose Canyon and Mission Bay areas, where overpasses could be damaged to the point of disrupting surface road traffic for weeks to months. Repairs to surface roads could take days for temporary repairs and up to months for full repairs,

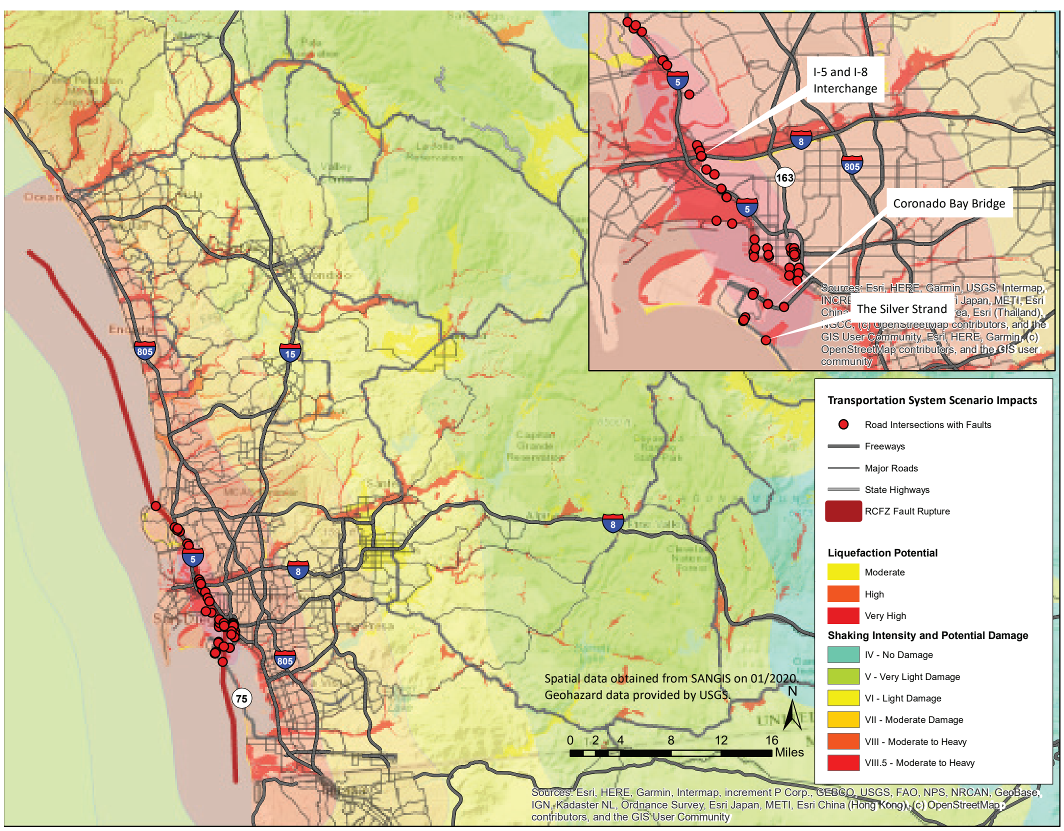


Figure 5–16. Highway and major road infrastructure in relation to scenario earthquake shaking intensity, fault rupture, and liquefaction areas.

depending on the severity of damages, conditions of bridges and overpasses, the availability of resources, and access to the area.

5.3.2.3 Bridges Including Overpasses and Interchanges

Approximately 1,040 state and another 580 local bridges are located in San Diego County according to Caltrans. Of these, an estimated 300 to 400, approximately 20% to 25%, will be exposed to severe intensity shaking areas (MMI 8) for the scenario earthquake, mostly along the I-5, I-8, I-805, and Route 163 highways (Figure 5–17).

Caltrans has retrofitted approximately 270 of the highest risk state-operated structures in San Diego as a part of a statewide retrofit program, including the Coronado Bay Bridge, the I-805 viaduct over Mission Valley, the I-52 interchange at the I-5, the I-805 interchange with Route 163, the Cabrillo Bridge over 163 in Balboa Park, and most of the overpasses and interchanges along I-5. The Caltrans retrofit standards are typically intended to prevent collapse but not necessarily to maintain serviceability because of probabilistic design ground motions (Caltrans 2016), which, in San Diego, are generally slightly less intense than the scenario earthquake ground motions and with less associated surface fault displacement. In the scenario earthquake in near fault areas, retrofitted bridges can be expected to avoid collapse but

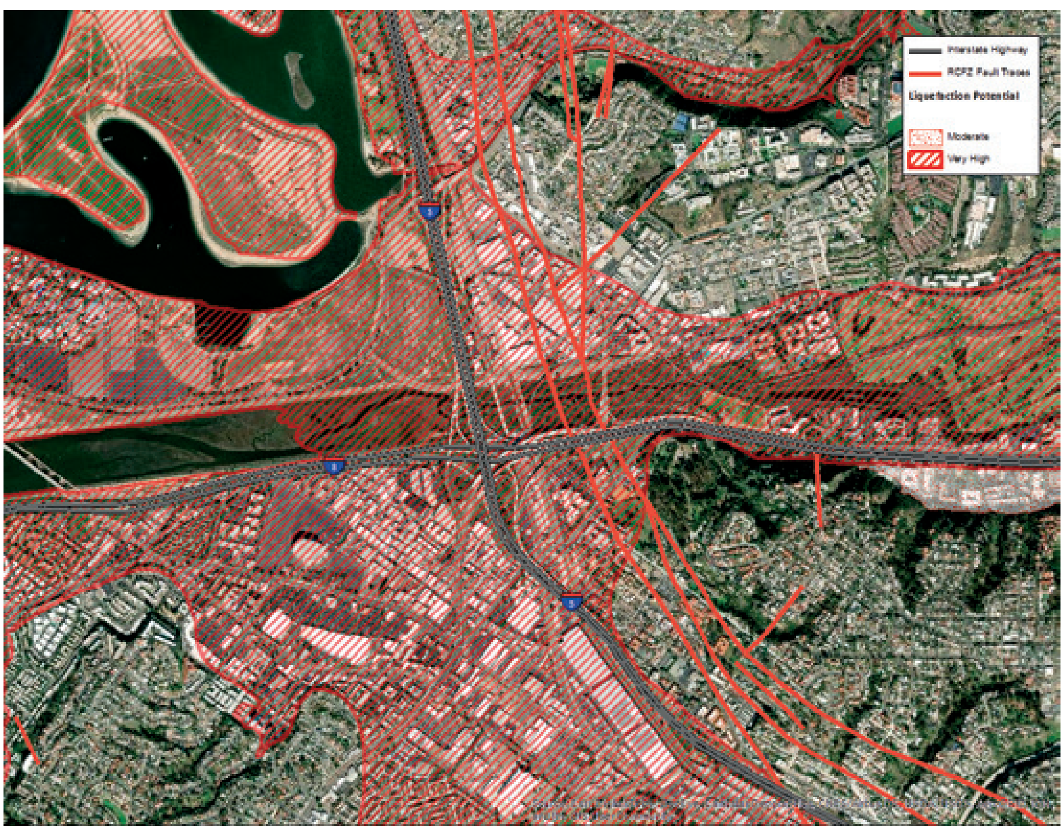


Figure 5–17. Proximity of Interstate 5 and Interstate 8 Interchange to Rose Canyon Fault Zone traces and liquefaction areas.

to experience some damage and to require safety inspections and repairs in order to be made serviceable again.

A few of the retrofitted bridges and potentially an estimated 10% to 20% of the unretrofitted bridges (both state and local) can be expected to require repair. Bridges in the liquefiable areas around the bays and rivers can be expected to have a higher rate of damage to both the bridge structures and the approach roads. Additionally, many City- and County-owned bridges near the coast would be subjected to intense ground shaking and some to liquefaction caused by the scenario earthquake. Among the 500 mostly older, locally owned bridges, those located near the fault that have not yet been retrofitted could lose service for extended periods for inspections and repairs.

5.3.2.4 Railroad and Light Rail Lines

Key passenger service lines, freight service lines, and light rail commuter lines cross the surface fault rupture trace several times between downtown and the top of Rose Canyon at Route 52. In the event of the scenario earthquake, the rail lines are expected to be disrupted at several locations where they cross the fault rupture and potentially in the liquefiable areas along the San Diego River in Mission Valley. Tracks in Del Mar are potentially subject to earthquake-induced bluff failures. Service can be expected to be disrupted for weeks to months while tracks are repaired at damage locations. In addition, older station facilities, including the Santa Fe Depot, may be severely damaged and potentially in need of reconstruction.

Figure 5–18. Repairs to railroad near Del Mar because of landslides (Credit: Hayne Palmour / San Diego Union Tribune).

5.3.2.5 Port Facilities

The SDUPD was established in 1962 to manage San Diego Bay and surrounding waterfront land for its five member cities, which consist of San Diego, Coronado, National City, Chula Vista, and Imperial Beach. SDUPD manages many older waterfront structures as well as 2 marine terminals, 2 cruise ship terminals, and 22 public parks, and it leases land to nearly 800 businesses in the tourism, hospitality, shipping, and fishing industries (Port of San Diego 2019). The port's waterfront structures and other improvements on reclaimed tidelands were designed to older seismic standards or predate seismic design standards entirely. Damages caused by the Port's location along the anticipated fault rupture zone and fill soil susceptibility to liquefaction are expected to be significant for several structures, including the B Street, Broadway, and Navy Piers, Embarcadero Wharf; former Seaport Village site; Convention Center; NASSCO shipyard; Tenth Avenue Marine Terminal; and portions of the National City Marine Terminal.

Of note, the Embarcadero Wharf is expected to experience significant backfill settlement and lateral spreading displacement along Harbor Drive in the scenario. Depending on the extent, the wharf may be open for short-term response and emergency operations but may require comprehensive repair or reconstruction for longer term service. Significant damage to the Tenth Avenue Marine Terminal is anticipated because of settlement, lateral spreading displacement, and its location directly on the path of the fault rupture. Furthermore, the major fuel pipelines serving the Tenth Avenue Marine Terminal fueling facility and SDIA are expected to be ruptured, resulting in extended loss of service and severe fire risks.

Facilities that have not undergone seismic retrofits may be inoperable for months to years, depending on the severity of liquefaction-induced settlement and lateral displacement. Most activities around the Port, including airport activities, tourism and hospitality activities, cruise ship activities, and shipping and ship building, are expected to be disrupted for weeks to months by damage to waterfront structures, surface roads, and lifeline utilities caused by liquefaction and fault rupture.

6.0 Considerations for Emergency Response and Recovery

The scenario magnitude 6.9 earthquake on the RCFZ occurs without warning and in the heart of the regional population center. The County of San Diego has long been lauded as a leader in the field of emergency management, whether by being one of the first local governments to meet the rigorous Emergency Management Accreditation Program standards or through its planning for resilience to wildland fires (SDOES 2007). Nonetheless, the scale of the disaster generated by the scenario earthquake would quickly overwhelm local resources and stall rapid deployment of statewide and national resources in the days and weeks following the event. This section discusses several of the anticipated challenges to emergency response and long-term recovery for the San Diego region. The limitations of emergency response in an event of this magnitude underscore the importance of emergency preparedness and mitigation efforts. Furthermore, these challenges highlight the need for raising awareness of this risk across the community to increase preparedness at the household level.

6.1 Emergency Management in the San Diego Region

Emergency management in the San Diego region is well-coordinated through the San Diego County Operational Area (OA) under the Standardized Emergency Response System and National Incident Management System. Regional organizations conduct extensive emergency response planning efforts and are prepared to mobilize local, state, and national resources through a robust system of mutual aid agreements. Aid through federal government resources, including FEMA and the U.S. DOD, will become available through well-established protocols during a proclaimed state of emergency or declared disaster. Furthermore, local government, fire, and law enforcement agencies have established contacts and protocols to collaborate with Mexican counterparts in cross-border relief and emergency response activities.

The San Diego County OA and local jurisdictions will activate their respective Emergency Operation Centers to serve as operational and logistical hubs for coordinating large-scale response to and recovery from an earthquake. This coordination occurs across a spectrum of agencies at the local, state, and federal level, with binational coordination plans in place for large-scale events. In addition to city- or county-wide emergency management plans, essential facilities and infrastructure management agencies have plans in place to respond to disasters and ensure continuity of operations. These plans are actively tested by emergency managers through scheduled drills, such as the annual Great ShakeOut, and tabletop or other emergency exercises.

Key Emergency Response and Recovery Planning Efforts

- Southern California Catastrophic Earthquake Response Plan (OPLAN)
- The County of San Diego Operational Area Emergency Operations Plan (OA EOP)
- San Diego County Operational Area Recovery Plan
- San Diego Urban Area Threat/ Hazard Identification Risk Assessment (THIRA)
- San Diego County Multi-Jurisdictional Hazard Mitigation Plan
- Regional Security Strategy (RSS)
- Local Continuity of Operations Plans

6.2 Challenges to Response

Response is the period immediately following a disaster event in which actions are taken to save lives, protect property, and prevent further economic losses, considered as the first days to weeks after the scenario earthquake. Even with robust and well-trained systems in place, the scale of the disaster generated by the scenario earthquake would present serious challenges to response. Emergency managers and essential facility operators alike expressed that the extent of anticipated damages, particularly to utility and transportation lifeline infrastructure, would likely overwhelm local resources and capabilities. Disrupted water and electric utilities as well as damaged transportation infrastructure will present serious challenges to responding to the scenario earthquake, increasing complexity of reporting for duty for off-hours emergency responders and increasing difficulty to access injured individuals.

Those most in need of emergency services will be vulnerable populations with access and functional needs and will require special care. This population includes children, older adults, people experiencing homelessness, low-income individuals, and individuals with health problems or disabilities. Emergency services in the county have gone above and beyond state and federal mandates to address these populations, expanding the definition of vulnerable populations to include non-English speakers. The challenges presented below may have the greatest impact on these residents.

6.2.1 Disruption of Lifeline Utility Systems

Damages to utility lifelines will likely present the greatest challenge to emergency response by limiting essential services such as medical care, police response, fire suppression, and search and rescue activities. Reactivation of electric power is anticipated to occur first, with emergency energy sources quickly filling the gaps over a period of hours to days. One-third of the region's

Figure 6–1.
Lifeline utility disruption and repairs, 2014 South Napa Earthquake
(Credit: J.L. Sousa.)

population is anticipated to lose access to water from thousands of expected leaks and breaks to water distribution pipes. Thousands of gas pipeline breaks, from major supply lines to minor distribution lines, are expected to raise fire hazards. Damaged wastewater systems will induce significant environmental, health, and safety impacts, as raw untreated sewage will likely flow into bays and rivers and contaminate the water supply. Emergency management personnel noted that the lack of water or sewer service may cause a secondary dislocation several days after the incident.

6.2.2 Emergency Communications

Experience has shown that after a disaster, a surge in demand coupled with communication infrastructure damage and power outages is expected to overload cell phone systems and severely limit connectivity. Emergency response stakeholders noted that emergency communications systems have been improved significantly, partly because of recent events, including the 2011 power outage. In the days following an earthquake, phone service will largely be limited to texting services with low data demand. Stakeholders have redundant communication capabilities; nevertheless, there is continuing concern that overwhelmed communications systems will limit the ability to provide information to the public and for the public to request support.

Additionally, demand for translators will be extremely high as response organizations seek to assist the large population of non-English speakers in the region. Utilization of communication channels such as the SD Emergency App or no-service communication apps will be critical to receive public safety updates in a disaster.

6.2.3 Fire Hazards

Studies of fires following earthquakes across the State of California have shown that high-magnitude events can trigger hundreds of ignitions, with over 100 ignitions for both the 1971 San Fernando and 1994 Northridge earthquakes (Scawthorn 2011). According to crude estimates from the Hazus Fire Following Earthquake simplified ignition model, damages to fuel and gas lines are estimated to spark 39 fires within San Diego County, not accounting for damaged fuel lines in fault rupture zones. Emergency responders should be prepared to address tens to hundreds of fires after an event such as the scenario earthquake. Additionally, fire suppression activities are expected to be handicapped by loss of water service and disruption of service access roads because of water and transportation infrastructure damages in the liquefaction zones. Capacity of fire departments to respond to multiple incidents is constricted by limited personnel and health and safety requirements, such as the "two-in, two-out" policy. Correspondingly, health care providers noted concerns regarding capacity to handle burn-related injuries, as there is only one burn unit in the region, UC San Diego Regional Burn Center.

Figure 6–2.
Granada Hills Fire Following Earthquake, 1994 Northridge Earthquake
(Credit: Patrick Downs / Los Angeles Times)

6.2.4 Potential Transportation and Dislocation Challenges

Impacts to transportation infrastructure may inhibit rapid response activities in the region. Experience has shown that temporary repairs to roads and highways can be made in a matter of hours to days after an earthquake. Most surface roads, highways, and bridges are generally expected to be made passable in days to weeks. Many residents will likely evacuate from the area—an estimated 36,000 households or approximately 103,000 individuals (multiplying by the U.S. Census identified average persons per household)—and there is potential for even more to be displaced by loss in lifeline service. Lower travel speeds and potential for thousands of dislocated residents searching for temporary housing outside the region may cause congestion on operable roadways. Several roadways that cross the fault rupture or liquefaction areas, particularly at Rose Canyon, Mission Bay, and the Silver Strand to Coronado Island, may take weeks to months to repair.

Functionality of the main airport runway and port facilities may be severely impaired because of their vulnerabilities to liquefaction. Additionally, though the Port District and its tenants have individual continuity of operations plans in place, there is no comprehensive plan to receive or distribute special shipments in a time of crisis. In the case of severe damages to these facilities, response plans should identify alternate facilities capable of receiving large shipments of food, water, and emergency supplies.

6.3 Challenges to Regional Recovery

In the months to years following the scenario earthquake, the San Diego region will face serious challenges to overcoming the impacts of the event. Recovery is the period of time after immediate life safety issues have been addressed and when a community begins to restore, repair, and rebound from the disaster. Recovery activities include the restoration of essential services and the repair of physical, social, and economic damages caused by the event. An influx of

Case Study – Coronado Island and the Coastal Communities

Figure 6-4. Aerial view of the Coronado Bay Bridge. Lifeline utilities for Coronado Island cross the San Diego Bay to provide service to Coronado Island. (Credit: Frank McKenna via Wikimedia Commons)

Coronado Island and the coastal communities west of the RCFZ will suffer the greatest impacts from the scenario earthquake. The RCFZ bisects many coastal communities, running directly under the Silver Strand and with diverging strands of the fault run through Coronado and under the Coronado bridge. The utility and infrastructure systems serving the coastal areas are anticipated to suffer widespread damage and disruption of services, particularly due to the anticipated surface fault rupture and several feet of liquefaction-induced lateral soil spreading.

The loss of utility lifelines may be particularly devastating west of the fault rupture, with power, water, sewage, and fuel service outages causing comprehensive disruptions to the coastal communities. Electrical outages may be the first to be repaired; however, residences, businesses, healthcare facilities, grocery stores, communications systems, internet services, traffic lights, airport operations, and water and wastewater pumping systems will be adversely affected in the meantime. Fuel, wastewater and water services are anticipated to be lost or disrupted for weeks to months.

Damages to transportation systems may further delay the ability to assess and repair damages in coastal communities. For example, the Coronado Bay Bridge was retrofitted to withstand an earthquake similar to the scenario earthquake without collapse but with potential damage and loss of use. In the scenario event, with 2 to 3 feet of fault offset extending under the bridge and with extensive liquefaction likely around the Coronado approach, the bridge and its approach roads may be out of service for weeks for inspection and minor repairs or potentially for months to years for major repairs or replacement, if required.

In addition to mass displacement caused by damaged structures, loss of water and wastewater service may trigger a secondary wave of displacement and dislocation for many of the 200,000 coastal residents between La Jolla and Coronado. Shelter facilities in coastal communities such as the Del Mar Fairgrounds, may be damaged and delay or prohibit sheltering operations. Non-governmental organizations noted that residents with insurance, viable transportation and money in savings do not typically rely upon disaster relief services as they tend to evacuate. However, low income residents already burdened by the high cost of living in the coastal communities of La Jolla, Coronado, and Del Mar may be unable to afford to relocate in the region.

Of note, emergency responders expressed concerns for a major disruption of the utility lifelines serving Coronado Island that may be exposed directly to fault rupture. If compromised, these submarine water, wastewater and fuel lines may require extensive repairs to full replacement leaving emergency responders and residents without water or wastewater service for months. If liquefaction or fault rupture is severe, roadway access via the Coronado Bridge or Silver Strand may be delayed significantly due to inspections and repairs.

This disruption would greatly impact emergency services including the Coronado Fire Department which relies on water distribution lines for 100 percent of its water. Without functioning pump systems, water and wastewater systems may be compromised. As a result, firefighters would not be able to access the water needed to combat post-earthquake fires. Regional fuel planning efforts are in place to address potential losses of fuel supply in case of emergency, but loss of additional utility lifelines would remain a challenge for emergency response operations. The potential for a domino effect across lifeline infrastructure would greatly hamper emergency response and recovery efforts, impacting safety and quality of life for residents of the island.

resources will become available to restore the normal operations of households, businesses, and organizations across the region; however, recovery timelines may be long, and impacts to the community may be severe.

Recovery of the built environment from the scenario earthquake is estimated to take anywhere from days to years depending on the severity of impacts in high hazard areas such as liquefaction zones and fault rupture areas. The greatest immediate challenge the region will face is the widespread damages to the dispersed networks of lifelines underlying the regional landscape. The region has made significant investments in the resiliency and redundancy of power and water infrastructure, such as the Emergency Water Supply project, which can support water needs of the County population for several months. Nevertheless, transmission of the water supply to residents will be disrupted by thousands of estimated leaks and breaks in the system. Hazus estimates 30% of the population of San Diego County is expected to be without water for at least 3 months. After overcoming the immediate threats of fire because of natural gas pipeline breaks, the process to repressurize the system is anticipated to take months and require extensive door-to-door safety inspections. Damaged wastewater systems will cause significant public and environmental health impacts from untreated sewage flowing into local bodies of water and contaminating the water supply. For example, stakeholders noted that critical wastewater pipelines were installed over 50 years ago up to 80 feet below ground surface. These systems are complex and difficult to access; the anticipated damages will shut down wastewater service to the entire County.

Damages to communication and transportation infrastructure will cause significant economic impacts by limiting access and connectivity of the region. Damaged bundled communication lines may cause business disruptions across most industries but specifically to the IT sector, one of the largest employers in the region. Though border infrastructure will likely experience minimal damages, the access roads on either side of the border may be closed, disrupting the multi-billion-dollar trade industry and barring access to residents and employees living across the border. According to the San Diego Region Chamber of Commerce, a temporary border closure for only 5 hours in late 2018 caused San Ysidro shop owners to lose an estimated 5.3 million dollars in sales (Nikolewski and Weisberg 2018). Structural impacts to the main airport and port facilities will disrupt the massive tourism and service industries, likely causing hotel, conference, and cruise terminal cancellations in the short to medium term (months to years).

In a region that already faces a housing affordability crisis, the loss of housing stock and population displacement will have significant and long-term impacts on the San Diego community. With Hazus-estimated displacement of 36,000 households, damages to 120,000 structures, and current low vacancy rates, a shortage in housing may cause residents to leave the region. Disasters like Hurricane Katrina can provide perspective on the possibility of mass migration after a catastrophic loss of housing. Surveys found that of the 400,000 residents displaced after Hurricane Katrina, approximately half returned within a year, and

Figure 6–5. Recovery of Cathedral Square in Christchurch, New Zealand, after the 2011 earthquakes. (Credit: Gabriel Goh via Wikimedia Commons)

less than one-third of those who returned were able to reoccupy their old homes (Sastry and Gregory 2014). Unlike New Orleans, housing for the most vulnerable populations in San Diego is located further away from the areas of greatest impact in the more affordable inland suburbs. Nevertheless, loss of income because of business disruption and impaired transportation networks in coastal employment centers could have severe implications for residents already living paycheck to paycheck.

Repair and reconstruction in impacted communities, especially in coastal and near-fault areas, will be costly and require outside resources. Funding through large federal programs under the Stafford Act (U.S.C.§ 5121) may provide grants to aid public infrastructure repair and removal of the Hazus-estimated 7.5 million tons of debris from building damage alone. Other federal, state, local, private, and nongovernmental funding sources will become available to support regional recovery. Repair and reconstruction may also be fully or partially funded through insurance claims, depending on the extent of coverage for each policyholder. In 2017, there were over 237,000 insurance policyholders with earthquake coverage in San Diego County, which is higher than the state average (California Department of Insurance 2017). It is important to note that the cost of repair and reconstruction is anticipated to be high by many stakeholders. The cost of construction in San Diego is 3.59% above the national average (RSMeans 2019), and these costs will be compounded by high demand for contractors and timelines required for permitting and regulatory review.

Recovery for the San Diego region will be a challenging and long process, as a major earthquake on the RCFZ will impact every aspect of its social, economic, and physical systems. This discussion presents just a sample of the major challenges the community will need to address to get back to a "new normal." Ensuring that this "new normal" can continue to sustain the vibrant and diverse community of present-day San Diego will be a function of preparation, mitigation, and community resilience developed before the next event.

7.0 Envisioning a Seismically Resilient San Diego

The main reasons for developing this scenario of a magnitude 6.9 earthquake occurring on the Rose Canyon Fault is to raise regional awareness of seismic hazards and illuminate opportunities to build community resilience to earthquakes. The scenario depicts the widespread impacts anticipated by a magnitude 6.9 earthquake on the Rose Canyon Fault system if it occurred today. Each vulnerability detailed in this report represents an opportunity for mitigation and preparation. This report now leaves the domain of possibilities of the next earthquake to focus on current risk reduction efforts and what seismic resilience could look like for the region in the future. Though earthquake disasters cannot be averted entirely, their impacts can be lessened significantly with planning initiatives and strategic investments.

7.1 Mitigation and Resilience in San Diego Today

Organizations around the region are already taking action to increase their resilience and prepare for the next major earthquake. Community resilience can be defined as a region's ability to withstand, respond to, and recover from a disaster with reduced casualties, costs, and disruptions (NIST 2017). Resilience is inherently connected with mitigation or the actions taken to lessen the impacts of disaster and prevent loss of life and damages to property. These investments have repeatedly been shown to be cost effective. For every $1 invested in seismic mitigation, $4 were seen in returns according to a recent nationwide mitigation study (NIBS 2017).

The San Diego Multijurisdictional Hazard Mitigation Plan outlines mitigation goals, objectives, and priorities for all jurisdictions within the region. This plan identifies priority actions to address earthquakes, including regularly updating building codes to reflect current seismic standards, development of retrofit

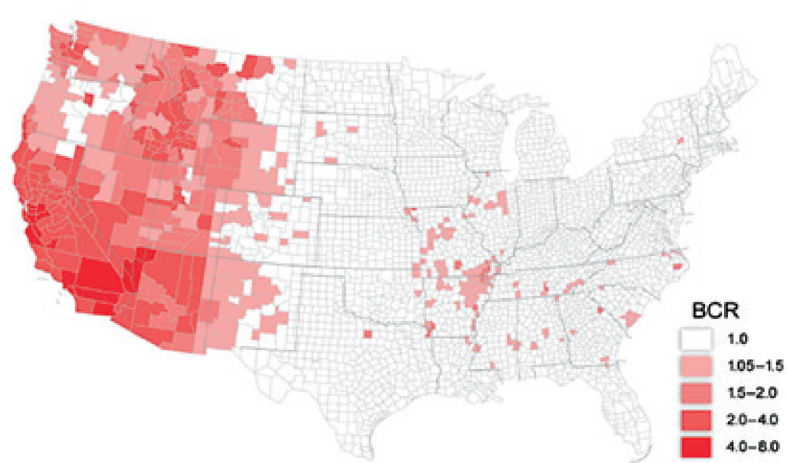


Figure 7–1. Mitigation Saves 2.0 Report identified benefit cost ratio (BCR) for mitigation projects by county. San Diego County mitigation return is between $2 and $4 per $1 spent on seismic mitigation (NIBS 2017).

incentive programs, and increasing community preparedness to seismic hazards (SDOES 2017).

In addition to the actions taken by governments and organizations to mitigate infrastructure and increase community preparedness, the region is also planning for resilience on a broader scale. San Diego serves as a good example of resilience planning for many other communities. Both the County and City of San Diego have resilience programs in place that are addressing issue areas, such as water conservation, sea level rise, urban forest canopy cover, and climate adaptation. It is important to note that although existing planning efforts in the region are robust, the resilience-related plans do not place seismic hazards in their top priorities and goals for resilience.

Table 7–1 highlights some of the efforts already taken or underway to bolster resilience in the San Diego region. It is important to note that many of these mitigation initiatives were spurred by threats of hazards other than earthquakes, including drought, wildfire, and sea level rise. Though these projects may not have been designed specifically to address earthquake hazards, many of these projects have the cobenefit of improving the seismic resilience of the built environment.

Issue Area	Mitigation Initiatives
Water and wastewater distribution infrastructure	• San Diego County Water Authority (SDCWA) Emergency Storage Project (ESP) will supply 6 months of water through enhanced reservoir reserves. ESP will address water supply disruption concerns if regional aqueducts are severed during a major earthquake. • The Pure Water San Diego program is investing in water reclamation, reuse, and recycling technologies. One-third of City potable water will come from reuse and recycling technologies by 2035. • Development of the Carlsbad Desalination Plant to supply 8% of County's potable water (SDCWA 2019). • Investments are improving regional resilience to drought and enhancing water supply security.
Power transmission	• SDG&E developed a Comprehensive Wildfire Mitigation Plan. • SDG&E investments in renewable energy with the goal of 100% renewable sources by 2045 (Sempra Energy 2018). • Implementation of "smart-grid" technology in new investments (SDG&E 2016).
School campuses	• 2008 Proposition S Ballot Measure provided funding for seismic retrofits. • Mission Bay High School stadium recently renovated to mitigate liquefaction. • Solar power energy upgrades are planned for many school campuses.
Community preparedness	• SD Emergency App won the Association of Emergency Managers' 2013 Global Technology and Innovation Award for emergency communication. • SD County OES Partner Relay program to improve communication with limited English-speaking populations during a disaster.
Resilience planning	• City and County of San Diego Climate Adaptation Plans • City of San Diego Climate Adaptation and Resiliency Plan (in development) • 2019 County of San Diego Resilience Program

Table 7–1. Existing Mitigation and Resilience Initiatives in the San Diego Region

Vision 2050: A Seismically Resilient San Diego

By 2050, San Diego organizations have collaboratively enacted a comprehensive set of seismic resilience policies and investments and are prepared for the next major earthquake.

The threat of casualties caused by earthquake-related building collapse is significantly diminished, as all of the seismically vulnerable structures in the region have been inventoried and undergone retrofits or replacements.

Building codes and land use regulations across the region are now a model for other communities, with increased performance goals for new construction, regulatory triggers for retrofit, and enhanced zoning requirements. Financial incentives and grant programs are well-known and widely used by business owners and homeowners to address structural risks and offset mitigation and retrofit costs.

Utility, telecommunications, and transportation lifelines in areas of high seismic risk have been retrofitted or improved with new technologies or systematic redundancies to address multiple natural hazards all while accommodating regional growth. Major infrastructure critical to the regional economy, including military installations, health care facilities, school and university campuses, border crossing infrastructure, the Port of San Diego, and the San Diego International Airport, have developed comprehensive mitigation plans and are regularly investing in the long-term resilience of their infrastructure.

Cross-border government agencies and nongovernmental organizations regularly collaborate on emergency management exercises and planning for region-wide mitigation, response, and recovery. Residents and businesses understand their seismic risk and are prepared to be self-sufficient following a major seismic or other hazard event.

Figure 7-2. City of San Diego skyline at dawn. (Credit: Nserrano via Wikimedia Commons)

7.2 Vision for a Seismically Resilient San Diego

Communities around the nation are planning for and investing in resilience. The County of San Diego Resilience Program aims to be at the forefront of this movement by working "to transform the County of San Diego into the most resilient County in the nation" (Resilience Review Working Group 2019). **Seismic resilience is a foundational element of community-wide resilience.** San Diego has the opportunity now to build on existing efforts and embrace seismic resilience within its vision of becoming the most resilient County in the nation.

The scenario development team envisions resilience as a comprehensive framework of strategies and programs to make the San Diego region as a whole more resilient to natural hazards and other shocks and chronic stresses. To better incorporate the vision for seismic resilience with existing climate adaptation and long-range community planning efforts, this section envisions San Diego in 2050 after 30 years of enhanced coordinated and collaborative resilience efforts to address seismic risk in the region. It is intended to be a resource for resiliency planners and policymakers to utilize in setting priorities to make the San Diego region more resilient to future earthquakes (see "Vision 2050" to the left).

7.3 The Path Forward

If the vision to reduce the threat of earthquakes is to be achieved by 2050, action must begin now. Damages caused by a natural disaster, such as an earthquake, are in part a function of decisions made by policymakers, politicians, and leaders across public, private, and social sector organizations. Some of the most resilient infrastructure in the region is the direct result of policies made on the state level in reaction to the devastating impacts of earthquakes in the 20th century. The California Field Act, requiring earthquake-resistant design and construction inspection of public schools across the state, was a direct result of the 1933 Long Beach earthquake that destroyed 70 school buildings, damaged 120 more schools, and caused high casualty rates (CGS 2019). The 1972 California Hospital Act was spurred by 60 fatalities and hundreds of injuries caused by collapse and severe damage to hospitals during the 1971 Sylmar-San Fernando Earthquake. These policies have improved the seismic resilience of essential facilities across the state.

Policy decisions do not need to wait, however, until after casualties or extreme devastation occurs. Jurisdictions around California are proactively enacting measures to reduce seismic vulnerability within their communities. The cities of Los Angeles, West Hollywood, and Santa Monica have undertaken comprehensive programs to inventory and retrofit seismically vulnerable structures, including URM, nonductile concrete, tilt-up, older steel moment frame, and soft-story structures (City of Los Angeles 2016, SEAOSC 2016). In the Bay Area, San Francisco, Berkeley, and Oakland have enacted similar measures (Comerio 2006, UCSF 2019). The Port of San Francisco has recently launched *A Waterfront*

Plan to revitalize its waterfront infrastructure while addressing seismic hazards and threats from climate change (Port of San Francisco 2019). San Diego is not alone in the process of bolstering seismic resilience. The San Diego region can benefit from the lessons learned by other jurisdictions and use these programs as models to customize a program that is appropriate for the region's unique building characteristics and community needs.

Addressing seismic risks and vulnerabilities today is of paramount importance to achieving the vision of long-term, community-wide resilience across the region. Decisions made now will dictate the severity of earthquake damage and consequences in the future. To achieve this vision, the scenario development team recommends the following actions and calls for the formation of a Seismic Resilience Working Group that includes governments, earthquake professionals, and private sector utilities and stakeholders to move these actions forward. These recommended actions are a starting point for greater resilience and more effective seismic risk reduction efforts in the San Diego region.

1. The San Diego County Resilience Program conducts a county-wide Resilience Review for seismic hazards to identify regional priorities and accountable partners for seismic risk reduction.

2. The newly formed Seismic Resilience Working Group develops a Regional Seismic Mitigation Strategy that identifies seismic mitigation actions, priorities, and funding mechanisms to bolster existing earthquake hazard mitigation planning efforts.

3. Local jurisdictions develop customized seismic risk reduction programs capitalizing on the ordinances and retrofit programs adopted by other California jurisdictions to reduce the potential for casualties and economic losses caused by older, seismically vulnerable structures.

4. The San Diego Association of Governments assesses local land use and zoning practices and recommends actions, such as enhanced hazard mapping and triggering requirements for local geologic review to reduce risk to the built environment along the potential fault rupture zones of the Rose Canyon and other active faults and potential ground failure areas.

5. Local emergency management agencies convene public and private utility stakeholders to coordinate resilience planning, emergency response, and mitigation investments to address the resilience of lifeline networks.

6. Wastewater utilities prioritize investments in resilience-building measures such as system upgrades or redundancies that alleviate dependencies on the infrastructure most vulnerable to fault rupture, including main trunk lines and the Point Loma Wastewater Treatment facility.

7. Water utilities and local decision-making bodies prioritize investments in water supply and distribution infrastructure in areas most vulnerable to fault

rupture and liquefaction to protect coastal communities from prolonged utility disruption and ensure fire suppression capabilities are maintained region-wide.

8. The San Diego Unified Port District, in conjunction with applicable stakeholders and partners, outlines and prioritizes risk mitigation strategies in upcoming revitalization planning efforts to address multiple hazards, ranging from liquefaction to tsunamis to sea level rise.

9. Emergency managers for governments, utilities, and essential facilities update existing emergency response plans, exercises, and mutual-aid agreements to better prepare for the disruptions to utility infrastructure, extensive impacts to coastal communities, and surface fault rupture and liquefaction hazards from a major damaging earthquake.

10. Local emergency management and disaster relief organizations conduct public preparedness campaigns to educate residents and businesses about the region's earthquake hazards, methods for reducing personal and business risk, and the importance of emergency preparedness planning.

11. San Diego and Tijuana organizations integrate agency counterparts and partners in emergency planning and response exercises to build capacity for cross-border coordination and seismic risk reduction across the entire San Diego–Tijuana border region.

This report is seen as a foundational step in advancing such an agenda, which will be expanded on by local governmental, nongovernmental, for-profit, and nonprofit organizations over time. As these actions are undertaken and further analysis is conducted, supplemental material will become available to support further resilience planning efforts. Please visit the EERI San Diego Chapter website, at **https://sandiego.eeri.org**, to find updates, additional mitigation actions, Technical Supplements, and expanded methodology to aid mitigation and resilience planning efforts for the region.

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