

# Reported Investments in Earthquake Mitigation Top \$73 to \$80 Billion in the San Francisco Bay Area, California, Since the 1989 Loma Prieta Earthquake



Open-File Report 2018-1168

U.S. Department of the Interior  
U.S. Geological Survey

**Front cover.**

The single largest investment in seismic resiliency in the San Francisco Bay Area was the replacement of the eastern span of the San Francisco-Oakland Bay Bridge (\$9 billion), a portion of which collapsed during the 1989 Loma Prieta earthquake. The photo shows the old span of the bridge on the left as it was being dismantled; the new span is seen at the right edge of the photo.

**Back cover.**

An estimated \$19 billion has been spent to retrofit or rebuild acute-care hospital facilities in the San Francisco Bay Area, the second-largest amount by sector. The photo shows the construction phase of the retrofit of the Priscilla Chan and Mark Zuckerberg San Francisco General Hospital and Trauma Center, in San Francisco, which cost about \$631 million.

Both photos by Scott Haefner, U.S. Geological Survey.



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By Thomas M. Brocher, Kerri Gefeke, John Boatwright, and Keith L. Knudsen

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**U.S. Department of the Interior**  
RYAN K. ZINKE, Secretary

**U.S. Geological Survey**  
James F. Reilly II, Director

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# Reported Investments in Earthquake Mitigation Top \$73 to \$80 Billion in the San Francisco Bay Area, California, Since the 1989 Loma Prieta Earthquake

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## Summary

The damaging 1989 Loma Prieta and 1994 Northridge earthquakes caused a considerable number of fatalities and economic losses in the San Francisco Bay Area and the Los Angeles region, respectively. In both earthquakes, elevated freeways collapsed, hospitals and unreinforced masonry buildings were damaged, and some multistory buildings having weak first floors (soft-story buildings) collapsed. A span of the eastern section of the San Francisco-Oakland Bay Bridge collapsed during the 1989 Loma Prieta earthquake.

The earthquake hazard in the San Francisco Bay Area remains high. The most recent earthquake forecast for the San Francisco Bay Area is a 72 percent likelihood of a magnitude 6.7 or greater earthquake in the next 30 years (Aagaard and others, 2016). The damaging 2014 South Napa earthquake was a recent reminder of the ongoing hazard posed by earthquakes in the San Francisco Bay Area (Brocher and others, 2015).

As a result of this and prior earthquake forecasts by the U.S. Geological Survey, and the losses sustained in the 1989 earthquake, government agencies as well as groups in the private and nonprofit sectors have invested in more than 700 structural retrofits and replacements to older structures, motivated by desire to mitigate the impacts of future earthquakes in the San Francisco Bay Area and to improve the resiliency of the Bay Area community. Many of these are public investments that were supported by the electorate.

The purpose of this report is to provide a compilation of structural retrofits and replacements of older buildings in the San Francisco Bay Area that have either been completed since 1989 or that are in progress as of October 2018. For the purposes of this report, all or parts of nine Bay Area counties were included: Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma. Santa Cruz County was not included. The compilation of 700 investments is presented as a table in the appendix. We consider this table as version 1, as we urge that those familiar with additional projects contact the report authors with information to update the table.

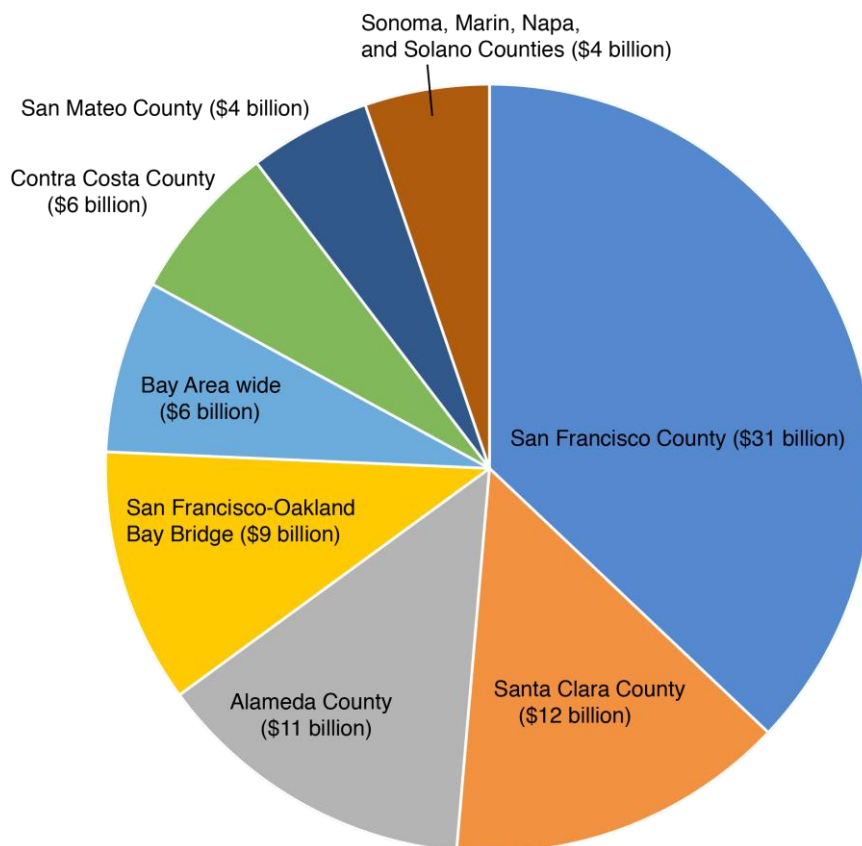
In total, we have identified \$73 to \$80 billion in investments to retrofit or replace structures to mitigate the impacts of future San Francisco Bay Area earthquakes. These totals represent an average investment of \$2.5 to \$2.8 billion per year in retrofits and replacement of

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\*Deceased.

structures since 1989. The total investments in each county are summarized in figure 1. They included:

- San Francisco (City and) County (\$31 billion; includes retrofits of the Golden Gate Bridge and all water supply seismic improvements),
- Santa Clara County (\$12 billion; includes \$4.3 billion for San Jose and \$3.5 billion for Palo Alto),
- Alameda County (\$11 billion; includes \$5.2 billion for Oakland and \$3.2 billion for Berkeley),
- San Francisco-Oakland Bay Bridge retrofit and replacement (\$10 billion),
- San Francisco Bay Area-wide retrofits (\$6 billion; includes Pacific Gas and Electric Company upgrades throughout the Bay Area, Bay Area Rapid Transit (BART) system upgrades, retrofits of Caltrans elevated freeways, and the California Earthquake Brace + Bolt program for single family houses),
- Contra Costa County (\$6 billion; includes \$1.4 billion for the Antioch Bridge, Benicia Bridge, Carquinez Bridge, and Richmond-San Rafael Bridge retrofits and replacements),
- San Mateo County (\$4 billion; includes \$0.3 billion for the Dumbarton Bridge and the San Mateo-Hayward Bridge retrofits),
- Sonoma County (\$1.6 billion), Marin County (\$1.0 billion), Napa County (\$0.7 billion), Solano County (\$0.7 billion).



**Figure 1.** Pie chart showing distribution of \$80 billion in investments for seismic improvements or replacements in the San Francisco Bay Area by county. Investments considered “Bay Area wide” include retrofits by Pacific Gas and Electric Company throughout the Bay Area, upgrades to the Bay Area Rapid Transit System, retrofits by the California Department of Transportation (Caltrans) to strengthen elevated freeways throughout the Bay Area, funds provided by the California Earthquake Brace + Bolt Program to retrofit single family homes, and work by Verizon on their telecommunication infrastructure.



In addition to the upgrades compiled here, many other structural retrofits are planned, but we exclude any projects for which funds have not yet been allocated. Similarly, we have attempted to exclude investments for expansion, routine maintenance, sale, or other code upgrades (for example, fire), or for the mitigation of other hazards (for example, climate change, wildfires, and sea level rise). Whenever uncertain in the percentage of the investment devoted for seismic improvements, we provide a range of possible investments.

The Earthquake Engineering Research Institute (EERI, 2009) compilation of 1,430 San Francisco Bay Area seismic retrofits since the 1989 Loma Prieta earthquake is a useful summary of seismic retrofits through 2009. That report describes the type of construction, the date of retrofit, and the retrofit method. Of the buildings in the EERI (2009) compilation, 61 percent are residential, 21 percent are institutional (includes church and cultural facilities, government buildings, museums, and school facilities), 9 percent are commercial, and 5 percent are hospitals, police stations, and fire stations. As described below, we used generic costs to estimate the investment for retrofitting some of the private residences and commercial buildings.

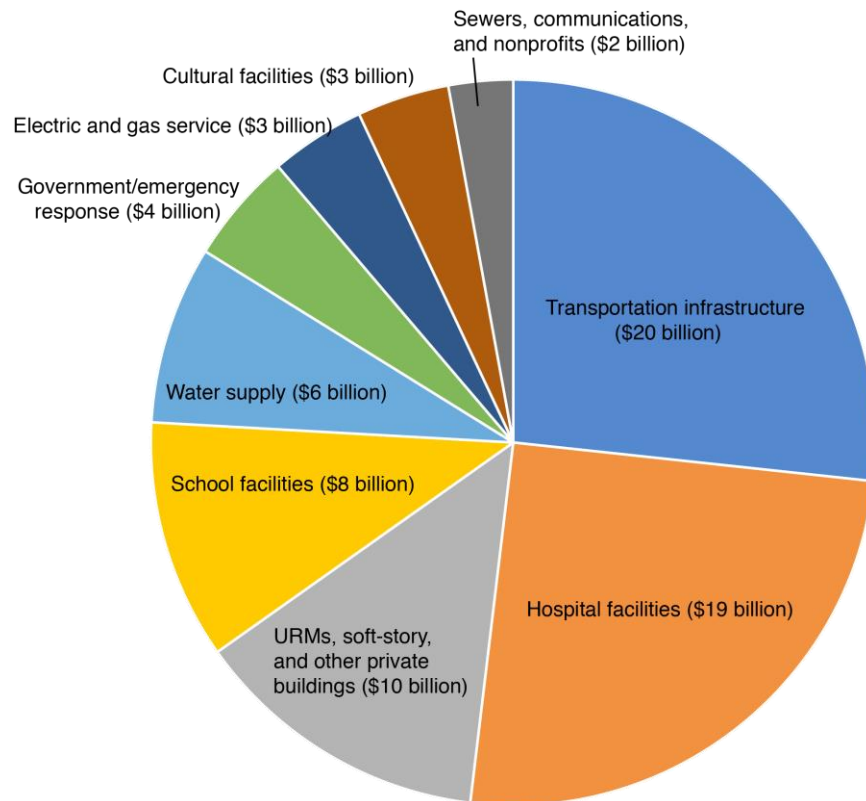
Many other seismic investments, including those by Caltrans, Bay Area Rapid Transit, East Bay Municipal Utility District, Pacific Gas and Electric Company, San Francisco Public Utility Commission, Stanford University, and the University of California, Berkeley, were already known to us. To find others, we primarily searched the web for terms such as “seismic retrofit,” “seismic upgrade,” “cost of retrofit,” and so on.

Roughly 60 percent of the investments compiled in this report (\$50 billion) were made by the public sector, and the remaining 40 percent reflects investments made by the private sector. The \$30 billion in private sector investments include those (1) made by private healthcare providers to upgrade acute care facilities at hospitals (\$14 billion), (2) to retrofit unreinforced masonry, soft-story, and other privately owned buildings (\$10 billion), (3) by the Pacific Gas and Electric Company to upgrade electric power systems and gas pipelines (\$3 billion), (4) for the upgrade of telecommunications and data center facilities (\$1 billion), (5) made by the Presidio Trust to upgrade historical buildings (\$0.6 billion), (6) made by private schools (\$0.4 billion), and (7) made by nonprofits groups (\$0.2 billion). This balance likely reflects the way that we gathered information. Because we primarily relied on publically available sources, largely websites and news reports, we likely have underestimated earthquake-related investments by the private or nonprofit sectors.

We divided the 700 investments into the 13 sectors identified below (ordered by the amount of the investment). As illustrated in figure 2, the largest investments have occurred in (1) the retrofit and replacement of transportation infrastructure, primarily State toll bridges, by Caltrans and Bay Area Rapid Transit (BART) (\$20 billion); (2) the retrofit and replacement of acute care facilities as mandated by California Senate Bill 1953 (\$19 billion); (3) the upgrade of unreinforced masonry, soft-story, and other privately owned buildings (\$10 billion); (4) the retrofit and replacement of public and private schools (\$8 to 12 billion); and (5) the seismic strengthening of water supply and sewer systems (\$7 to 10 billion). Other investments have sought to improve the response of emergency providers and our governments, ensure continuity of operation of communication and data centers, maintain life safety in low-income residences owned by nonprofit agencies, and to allow the Bay Area’s cultural assets (for example, libraries, museums, and theaters) to recover as swiftly as possible following a Bay Area earthquake. The 13 sectors and their total investments are:

- Transportation infrastructure (\$19.6 billion)
- Acute care facilities at hospitals (\$18.8 billion)

- School facilities (\$8 to 11.8 billion)
- Water supply system (\$5.9 billion)
- Unreinforced masonry building retrofit or demolition (\$5.1 billion)
- Private sector buildings (\$4.1 billion)
- Cultural facilities (\$3.2 billion)
- Electric power and gas infrastructure (\$3.1 billion)
- Government buildings (\$2.2 billion)
- Emergency response systems and facilities (\$1.7 billion)
- Soft story residential building retrofits (\$1.2 billion; additional to those included in the private sector building sector)
- Communication and data center infrastructure (\$1.1 billion)
- Sanitation (sewer) systems (\$0.8 to 3.6 billion)
- Nonprofit sector buildings (\$0.2 billion)



**Figure 2.** Distribution of \$74 billion in investments for seismic improvements/replacements in the San Francisco Bay Area by sector. Note that the \$10 billion invested in the improvement of private buildings includes retrofits of unreinforced masonry (URM) buildings, soft-story buildings having a structurally weak first floor, nonductile and ductile concrete frame buildings, and the brace and bolt retrofit of single-family residences. Investments in the improvement of school facilities are for both public and private sector, and include K-12, community colleges, and four-year universities. The \$8 billion estimated for school facilities is a minimum value, it could be as much as \$12 billion. Investments in cultural facilities include the retrofit or replacement of churches, libraries, historical buildings of mixed use at the San Francisco Presidio, museums, theaters, park and recreation facilities, and other facilities. The minimum investment for sanitation (sewer) upgrades, \$0.8 billion, is assumed here, it could be as much as \$3.6 billion.

All investments are quoted at their original value, that is, they have not been adjusted for inflation.

In the remainder of this report we describe in more detail the investments made in each sector.

## **Transportation Infrastructure (\$19.6 Billion)**

Following collapse of a span of the eastern section of the San Francisco-Oakland Bay Bridge and of the elevated Cypress freeway structure of Interstate 880 during the 1989 Loma Prieta earthquake, as well as elevated freeway collapses in the 1994 Northridge earthquake, the State of California Department of Transportation, or Caltrans, instituted an \$16 billion seismic retrofit and replacement program for State toll bridges and elevated freeways (Caltrans, 2014). The entire \$16 billion investment in this program was dedicated to seismic upgrades.

Of that \$16 billion total, \$12.5 billion has been invested in the upgrade of State toll bridges and elevated freeways located in the San Francisco Bay Area (see appendix). This \$12.5 billion was divided into \$11.4 billion for the retrofit and replacement of State toll bridges, and \$1.1 billion for strengthening the vertical columns that support elevated freeways (Cliff Roblee, written comm., 2005; Caltrans, 2014; TBPOC, 2018). By far the largest single Caltrans investment, \$9 billion, was for the replacement of the east span of the San Francisco-Oakland Bay Bridge. A recent report by the Toll Bridge Program Oversight Committee (TBPOC) provides a complete accounting of the cost of these investments (TBPOC, 2018). The seven State toll bridges that were either retrofit and (or) replaced, at a total investment of \$11.4 billion, include:

- Antioch Bridge (retrofit, \$71 million),
- Benicia-Martinez Bridge (retrofit, \$178 million),
- Carquinez Bridge (northbound bridge was retrofitted, southbound bridge was replaced; \$354 million),
- Dumbarton Bridge (retrofit, \$118 million),
- Richmond-San Rafael Bridge (retrofit, \$795 million),
- San Francisco-Oakland Bay Bridge (east span replaced, west span retrofit; \$9.7 billion),
- San Mateo-Hayward Bridge (retrofit, \$163 million),

In addition, the Golden Gate Bridge Authority replaced ramps on both ends of the iconic Golden Gate Bridge (\$260 million).

As detailed in the appendix, substantial other investments in transportation infrastructure were made in ongoing retrofits at the Ports of Oakland and San Francisco to strengthen sea walls (\$0.4 billion), and ongoing work at the Oakland, San Francisco, and San Jose International Airports to harden terminals, air traffic control towers, and infrastructure (\$1.7 billion).

Bay Area voters approved a \$1.2 billion bond measure to allow the Bay Area Rapid Transit Authority (BART) to seismically retrofit BART stations and tracks. This work is scheduled to be completed in 2022.

The replacement of Doyle Drive in San Francisco, the approach to the Golden Gate Bridge, cost \$1 billion.

Other smaller transportation facility investments in Santa Clara and Sonoma counties are listed in the appendix.

## Acute Care Facilities at Hospitals (\$18.8 Billion)

Following the 1994 Northridge earthquake, State of California Senate Bill 1953 (The Alfred E. Alquist Seismic Safety Act) was signed into law in September 1994, and as amended, mandates that acute care facilities in California hospitals meet life safety criteria by 2013 (with some extensions allowed to 2020) and remain fully operational following earthquakes by 2030 (California Office of Statewide Health and Planning Department [OSHPD], 2018). The bill was motivated by losses of life due to the collapse of acute care health facilities and (or) their loss of operability following the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes. This state law has resulted in an investment of \$2.3 billion to retrofit 50 hospitals in the San Francisco Bay Area and \$16.5 billion to replace 32 other acute care facilities there to meet the 2030 deadline for operability following earthquakes (OSHPD, 2018). Sutter Health alone has invested more than \$7 billion to meet the requirements of California Senate Bill 1953 at their northern California facilities (Sutter Health, 2014).

We include the entire investment in each replacement hospital in our total. We believe this inclusion is reasonable given that California Senate Bill 1953 requires that by 2030 an acute care facility not only meets life safety requirements but also remains fully operational following an earthquake. This requirement results in the need to invest in nonstructural elements such as water and other piping, elevators, communications, emergency power, and so on, as well as in the basic structure of the facility.

Detailed information on these investments in the appendix is taken from websites of the California OSHPD, which collects data about California's healthcare infrastructure, and monitors the seismic safety of hospitals and skilled nursing facilities (OSHPD, 2018). Thirty-two acute care facilities and one outpatient building were replaced (40 percent of the total number of hospitals retrofitted or replaced) to comply with the California Senate Bill 1953 requirement for full functionality following an earthquake by the year 2030. These replacement investments, totaling \$16.5 billion, include:

- Alta Bates Summit Medical Center, Oakland (Sutter Health, \$250 million),
- California Pacific Medical Center—St. Luke's Hospital, San Francisco (Sutter Health, \$325 million),
- California Pacific Medical Center—Van Ness and Geary Hospital, San Francisco (Sutter Health, \$2.1 billion),
- Chinese Hospital, San Francisco (\$110 million),
- Contra Costa Regional Medical Center, Martinez (\$51 million),
- Eden Medical Center, Castro Valley (Sutter Health, \$320 million),
- El Camino Hospital, Mountain View (\$480 million),
- Highland Hospital, Oakland (Alameda Health System, \$293 million),
- John Muir Medical Center, Concord (\$112 million),
- John Muir Medical Center, Walnut Creek (\$283 million),
- Kaiser Foundation Hospital—Antioch (\$148 million),
- Kaiser Foundation Hospital—Oakland/Richmond (\$600 million),
- Kaiser Foundation Hospital—Redwood City (\$270 million),
- Kaiser Foundation Hospital – San Leandro (\$500 million),
- Kaiser Foundation Hospital—Santa Clara (\$269 million),
- Kaiser Foundation Hospital and Rehab Center—Vallejo (\$281 million),

- Kaiser Permanente San Francisco Medical Center—Mission Bay Campus (outpatient only) (\$200 million),
- Laguna Honda (Residential) Hospital, San Francisco (City of San Francisco, \$458 million),
- Lucile Packard Children’s Hospital—Stanford, Palo Alto (\$735 million),
- Marin General Hospital, Greenbrae (Marin County, \$290 million),
- Mills-Peninsula Medical Center, Burlingame (Sutter Health, \$368 million),
- Priscilla Chan and Mark Zuckerberg San Francisco General Hospital and Trauma Center, San Francisco (City of San Francisco, \$631 million),
- Queen of the Valley Hospital, Napa (\$85 million),
- Santa Clara Medical Center, Santa Clara (Santa Clara County, \$850 million),
- Sequoia Hospital, Redwood City (Dignity Health, \$118 million),
- Seton Medical Center, Daly City (Dignity Health, \$126 million),
- Stanford University Medical Center, Stanford (\$2.5 billion),
- Sutter Santa Rosa Regional Hospital (Sutter Health, \$150 million),
- University of California, Berkeley (UC Berkeley), Tang Medical Center, Berkeley (\$18 million),
- University of California, San Francisco (UCSF), Helen Diller Medical Center, San Francisco (\$500 million),
- University of California, San Francisco, Mission Bay Medical Campus, San Francisco (\$1.5 billion),
- Valley Medical Center, San Jose (\$1.2 billion),
- Washington Hospital, Fremont (\$339 million).

Kaiser Permanente’s San Francisco Medical Center is one of the City’s designated emergency response facilities following a major disaster (San Francisco Planning Department, 2013, p. 5.34). Although the recently constructed (in 2016) Kaiser Permanente Mission Bay Campus Medical Office Building (at 1600 Owens Street) is for outpatient use only, and is not an acute care facility, it will be used following an earthquake (San Francisco Planning Department, 2013, p. 5.34). We therefore include its \$200 million construction cost in our total (Rauber, 2016).

In response to California Senate Bill 1953, some healthcare providers either consolidated their operations into fewer hospitals or removed acute care facilities from substandard hospitals. For example, Kaiser Permanente demolished their South Hayward hospital, replacing it with a new acute care facility in San Leandro. Kaiser Permanente also delicensed their French Campus acute care facility at 4131 Geary Street in San Francisco, converting it to outpatient use and dormitory rooms for UCSF students. Sutter Health will close their acute care facilities in the Alta Bates Summit Medical Center at Berkeley by 2030, transferring these services three miles south to their Alta Bates Summit Medical Center at Oakland (Rainey, 2016). In San Francisco, Sutter Health will replace acute care facilities currently at California Pacific Medical Centers at their California West and Pacific Campuses with newly constructed acute care facilities at their St. Luke’s and Van Ness Campuses. Doctors Medical Center in San Pablo closed its hospital and emergency room in 2015 to be compliant with life safety requirements in Senate Bill 1953 (Rainey, 2016).

## School Facilities (\$8 to \$12 Billion)

We identified nearly 85 public and private schools or school districts, including K-12, community college, four-year universities (California State University, UC Berkeley, Mills College, and Stanford University), and other schools such as the Conservatory of Music (San Francisco), that have or are planning to retrofit or replace school facilities (see appendix). These upgrades were made primarily for life safety, although some may have been retrofit for immediate occupancy so that they could be used as shelters following an earthquake. For the public schools, a primary source for this information came from the California Elections Data Archive available from the California Secretary of State (2018) for the years 1995 to 2017, so we have no information about investments made between 1990 and 1994. The chief funding mechanism for this renewal of public school facilities are general obligation bond measures, although tax increases are also used (Secretary of State, 2018).

Retrofits to school facilities have been identified in the following communities in the nine Bay Area counties:

- Alameda County: Alameda, Albany, Berkeley, Cal State East Bay, Dublin, Emeryville, Fremont, Hayward, Mills College, Newark, Oakland, Oakland Diocese (46 facilities), Ohlone Community College, Piedmont, San Leandro, UC Berkeley
- Contra Costa County: Crockett, Martinez, Moraga, Pittsburg, Richmond, San Ramon
- Marin County: College of Marin, Larkspur, Mill Valley, Novato, Reed, Ross, San Anselmo, San Rafael, Tamalpais, Tomales
- Napa County: Napa
- San Francisco County: Archdiocese of San Francisco (24 schools), City College of San Francisco, San Francisco State University, San Francisco Unified School District (160 schools)
- San Mateo County: Atherton, Belmont, Burlingame, Foothill-De Anza Community College District, Foster City, La Honda, Laguna Salada, Millbrae, Portola Valley, Redwood City, San Bruno, San Mateo, Woodside
- Santa Clara County: Cupertino, Franklin, Fremont, Loma Prieta, Los Altos Hills, Los Gatos, Milpitas, Mountain View, San Jose, San Jose State University, Santa Clara, Santa Clara University, Stanford University, Sunnyvale
- Solano: Cordelia, Vallejo, Solano Community College
- Sonoma: Annapolis, Rohnert Park, Santa Rosa, Santa Rosa Junior College, Sebastopol, Sonoma, Sonoma State University, Saint Helena

The \$7 billion in investments detailed in the appendix were used solely for the seismic retrofit or replacement of school facilities in several school districts. These school districts included the Berkeley Unified School District, the University of California, Berkeley (for its Seismic Action plan for Facilities Enhancement and Renewal [SAFER] and Memorial Stadium retrofit), California State East Bay, Oakland Unified School District, Diocese of Oakland, San Francisco State University, the Archdiocese of San Francisco, San Mateo Union High School District, San Jose State University, and Stanford University. These retrofits addressed seismic vulnerabilities identified in these facilities, many of which are proximal to the San Andreas or Hayward Faults.

For the remaining \$10 billion in school bond or tax measures passed for Bay Area school districts, seismic upgrades were only one use for the bond money. Other common investments were for asbestos abatement, expansion of classrooms, updating wiring, plumbing, or fire alarms,

repair of leaky roofs, furnishing computer and science laboratories, and so on. Thus, we estimate that between 10 and 50 percent of these bond measures were used for seismic retrofits or replacements. Using this range results in an additional investment in school facilities between \$1 and \$5 billion.

## **Water Supply System (\$5.9 Billion)**

Several Bay Area water districts have completed analyses of system and component vulnerabilities, and based on these results, performed seismic retrofits or replacements of their vulnerable dams, pipelines, and tunnels (see appendix). These districts include the City of Berkeley (\$5 million), East Bay Municipal Utilities District (EBMUD, \$358 million), Marin Municipal Water District (\$85 million), Redwood City (\$2 million), San Francisco Public Utility Commission (SFPUC), the Santa Clara Valley Water District (\$559 million), and the Sonoma County Water Agency (\$58 million). By far the largest single investment (\$4.8 billion) was made for the upgrade of the SFPUC system delivering water to the San Francisco Peninsula from the Hetch Hetchy Reservoir and Aqueduct (SFPUC, 2018).

The currently proposed (but as yet unfunded) underground pipelines beneath the Sacramento-San Joaquin Delta in Sacramento and San Joaquin Counties, called California WaterFix, has the primary motivation of securing fresh water supplies to California in the event of a Bay Area earthquake that could harm the levees protecting the fresh water rivers. The cost of this future potential project has been estimated at about \$17 billion (Sunding, 2018). We do not include this investment in our total as funds for it have not yet been allocated.

## **Unreinforced Masonry Buildings (\$5.1 Billion)**

Unreinforced masonry (URM) buildings are older buildings constructed using bricks, stones, and mortar only and that lack adequate structural framing to ensure that the building will not collapse during earthquakes. This type of building fares poorly during earthquake and is the cause of many building collapses and fatalities. In 1986 the State of California passed a voluntary unreinforced masonry legislation that resulted in very few retrofits of such buildings (EERI, 2004).

Because of this sluggish response, the cities of Berkeley, Oakland, San Francisco, and San Jose mandated URM building retrofits, which has resulted in the retrofit of nearly 4,000 URM buildings since 1989. In 1992, the City of San Francisco passed an ordinance requiring the mandatory retrofit of 1,987 dangerous unreinforced masonry buildings, and voters approved a \$350 million bond measure to help building owners lower their costs (representing an investment of about \$175,000 per building) (EERI, 2004). As of 2013, all but 158 of these buildings had been retrofitted to improve their life safety (Arroyo, 2013). Similarly, mandatory seismic retrofits of more than 2,000 URM buildings in Oakland, Berkeley, and San Jose resulted in their compliancy with the 1991 Uniform Code for Building Conservation (UCBC) (EERI, 2004). An additional 380 URM buildings have been retrofit in other parts of Alameda and Contra Costa Counties, plus others in Marin, Napa, Solano, and Sonoma Counties (EERI, 2004), for a total of 4,380 URM buildings retrofit in the Bay Area since 1989.

The estimated total investment for these retrofits is based on the assumption that 82 percent of these 4,380 soft-story retrofits are for small one-story buildings, and we assume an average cost of \$175,000 per building (EERI, 2004). We assume that 10 percent of the retrofits were for two-story URM buildings, requiring more extensive work at an average cost of \$1

million per building. Finally, we assume that 8 percent of the retrofits were made in larger, multi-story or high-value URM buildings at an average cost of \$10 million per building. These estimated costs are based on the reported costs to retrofit URM buildings shown in the appendix.

Our total also includes the investment of about \$500 million for 40 individual URM building retrofits that were identified during our search (see appendix).

## **Private Sector Buildings (\$4.1 Billion)**

We identified investments in seismic upgrades of more than 130 privately owned commercial or large residential buildings by searching the websites of structural engineering and construction firms (see appendix). In this section we discuss retrofit investments in the following categories of facilities: (1) concrete frame office buildings dating back to the 1900s, 1910s, and 1920s, (2) oil refinery facilities, (3) vintage 1960–1994 high-rise buildings in San Francisco, (4) older hotels, and (5) single family homes.

We identified about \$1.8 billion invested for the retrofit of nearly 100 office buildings dating back to the 1900s, 1910s, and the 1920s (see appendix). These are primarily ductile and non-ductile concrete frame buildings largely located in San Francisco.

The largest single earthquake mitigation investments in private industry are the estimated \$1.1 billion to retrofit the Shell Martinez Refinery marine terminal and the Chevron Richmond Refinery (see appendix).

A 2018 New York Times article states that 39 high rise buildings in San Francisco, built between 1960 and 1994, used a weak connection system in steel-frame buildings that makes them vulnerable in future earthquakes (Fuller, 2018). The 39 structures include iconic buildings such as the Transamerica Pyramid, Embarcadero Center, Salesforce West, and others in San Francisco’s Financial District. At least two of the buildings have already been retrofit (Fuller, 2018). The cost to retrofit a single high-rise building for life safety is estimated to be tens of millions of dollars, suggesting that the cost to retrofit all 39 buildings will be at least \$400 million. We have included these potential future investments in our total because the City of San Francisco is considering a mandate that they be retrofit and the building owners are already beginning to retrofit these high-rise buildings (Fuller, 2018).

Tourism is an important industry in the San Francisco Bay Area. Presumably to help protect this industry, at least 28 older hotels in the Bay Area have been seismically updated at a total investment of \$700 million. These include 20 hotels in San Francisco: the Argonaut Hotel, Beresford Arms Hotel, Clift Hotel, Fairmont Hotel, Hilton San Francisco at Union Square, Hotel Abri, Hotel Brittan, Hotel Montgomery, Hotel Nikko, Hotel Palomar, Grand Hyatt Union Square, Mark Hopkins Hotel, the Metropolitan Club (private), Omni Hotel, Palace Hotel, Renoir Hotel, Ritz-Carleton Hotel, Westin St. Frances Hotel, and the Wyndham Canterbury at San Francisco. We identified eight more older hotels retrofit in other parts of the Bay Area: the Carquinez (Richmond), Durant Hotel (Berkeley), Epiphany Hotel (Palo Alto), Hampton Inn Petaluma (Petaluma), Hotel Chauvet (Glen Ellen), the Hotel De Anza (San Jose), Hotel Montgomery (San Jose), and the Villas at Hamilton (Novato).

Bay Area homeowners and government agencies have invested at least \$63 million in the retrofit of single-family homes. The California Earthquake Brace + Bolt program (EBB) offers incentives up to \$3,000 per house for single-family home retrofits, and has helped finance 5,000 such retrofits statewide since 2013 (EBB, 2018). We assume half of these have been in the Bay Area, at a total cost of \$10,000 per house, resulting in a total investment of \$25 million. The Oakland New Homeowner Program provided financial support for the brace and bolting of 270



Oakland residences between 2007 and 2009 (EERI, 2009), at an estimated cost of \$10,000 per residence for a total expense of \$3 million. The City of Berkeley's transfer tax rebate program has invested \$29 million for single house retrofits since 1991. The EERI (2009) retrofit compilation lists an additional 564 residences that were braced and bolted in the Bay Area between 1989 and 2009 at an estimated cost of \$6 million.

## **Cultural Facilities (\$3.2 Billion)**

We identified 65 separate investments made to retrofit and replace facilities to increase seismic safety that contribute to the cultural fabric of the San Francisco Bay Area including churches, historical buildings having mixed uses at the Presidio of San Francisco, libraries, museums, theatres, and other facilities, (see appendix). These investments are discussed in more detail below.

- Churches and temples (\$155 million): Buddhist Temple (San Francisco), Congregation Emanu-El (San Francisco), Covenant Presbyterian Church (San Francisco), First Church of Christ (San Francisco), First Presbyterian Church (Palo Alto), First Unitarian Church of Oakland, First United Methodist Church (Napa), Archdiocese of San Francisco (more than 10 parishes and schools), Diocese of Oakland (79 facilities retrofit), St. Joseph's Cathedral (San Jose), St. Mark's Lutheran Church (San Francisco), Old St. Mary's Cathedral (San Francisco), and Temple Sherith Israel (San Francisco).
- Historical buildings at the San Francisco Presidio with mixed uses (\$570 million): Between 1998 and 2013, \$570 million was invested in historic Presidio buildings by private sources to rehabilitate them for public and private use (The Presidio Trust, 2013). This work included the renovation of buildings now occupied by the Walt Disney Family Museum and by the Lucas Digital Arts Center. Although not all the investments were specifically for seismic upgrades, seismic upgrade was clearly required for these historic buildings.
- Libraries (\$529 million): Alameda, Berkeley Central and branch libraries, Gilroy, Millbrae, Newark, Palo Alto library system, San Francisco Main and branch libraries, Saratoga Library, Sonoma County Community Library.
- Museums (\$1.1 billion total); in San Francisco: Asian Art Museum, Beat Museum, California Historical Society, Conservatory of Flowers, Contemporary Jewish Museum, the California Academy of Sciences, the de Young Museum, the Exploratorium, Geneva Car Barn and Powerhouse, the Old Mint Building, the Legion of Honor, Randall Museum, and the Walt Disney Family Museum (three buildings). Museums upgraded elsewhere in the Bay Area include the African American Museum and Library at Oakland, Bay Area Discovery Museum (Sausalito), Berkeley Art Museum and Pacific Film Archive (Berkeley), California Shakespeare Theater's Bruns Amphitheater (Orinda), Hayward Area Historical Society Museum of History and Culture (Hayward), Petaluma Adobe State Historic Park (Petaluma), Rosie the Riveter WWII Home Front Museum (Richmond), the San José Museum of Art (San Jose), and San Mateo County History Museum (Redwood City). Note that although life safety was likely the primary motivation for most of these upgrades, in 1997 the Federal Council of the Arts and Humanities ruled that the old de Young Museum would no longer be able to host large international traveling art exhibitions due to insurance liability in case of an earthquake (Whiting, 2015). This ruling made replacing the museum a financial necessity.

- Theatres (\$479 million): Empress Theatre (Vallejo), Fillmore Auditorium (San Francisco), Fox Theatre (Oakland), Geary Theater (San Francisco), Grand Theatre Center for the Arts (Tracy), Jose Theater (San Jose), Malonga Casquelourd Center for the Arts (Oakland), Novato Theater, San Francisco War Memorial Opera House, San Francisco War Memorial and Performing Arts Center (San Francisco), and William Randolph Hearst Greek Theatre (Berkeley).
- Other cultural facilities (\$345 million): This category includes other historical buildings of mixed uses, consulates, memorial halls, and park and recreational facilities.

## **Electric Power and Gas Lines (\$3.1 Billion)**

Since 1989, the Pacific Gas and Electric Company (PG&E Company) has invested \$3.1 billion for the seismic retrofit of buildings, substations, dams, power plants, gas pipe shut-off valves, and pipeline inspections.

Between 1989 and 2010, PG&E Company invested \$2.54 billion for the seismic retrofit and replacement of buildings, electric substations, dams and related hydropower facilities, power plants, and gas pipe replacement (Salas, 2010). This total also includes the repair of damage caused by the 1989 Loma Prieta earthquake and the retrofitting of the historical headquarters building at 245 Market Street, San Francisco (Salas, 2010).

Since 2010, and at the recommendation of the National Transportation Safety Board following the 2011 gas line explosion in San Bruno, PG&E Company has installed 235 automatic, remote gas pipe shut-off valves (PG&E, 2016) at an estimated cost of \$225 million (Upton, 2011). The cost to simply inspect their aging pipelines in 2011 alone was \$300 million (Upton, 2011). In addition, PG&E Company built a state-of-the-art gas control facility at San Ramon, California (PG&E, 2016), and has replaced many miles of older gas pipelines. These last two post-2011 gas line upgrades are not included in the \$3.1 billion total, but could easily represent an investment of another \$1 billion or more.

## **Government Buildings (\$2.0 Billion)**

To promote the functioning of government following an earthquake, Bay Area governmental agencies since 1989 have used Federal, State, and local funding to strengthen 44 facilities, including animal shelters, city halls, civic centers, community centers, courthouses, government office buildings, and jails and prisons (see appendix). Publically available capital improvement plans were an important source of information for the seismic upgrades made by many Bay Area governmental agencies, as was the statewide compilation of prior bond and tax measures (Secretary of State, 2018).

Investments totaling \$1.6 billion were made for the retrofit or replacement of city halls, civic centers, or other municipal buildings in Alameda, Berkeley, Fairfax, Fremont, Hayward, Los Gatos, Newark, Oakland, Palo Alto, Richmond, San Francisco, and San Jose. Investments totaling \$350 million for the retrofit or replacement of county court houses and other county offices in Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma counties were also made. Investments included upgrades of State owned (non-hospital) buildings at San Quentin State Prison (\$31 million) and the California State Building at 350 McAllister Street in San Francisco (\$45 million). Seismic upgrades of Federal (non-hospital) buildings included the James R. Browning Courthouse, which houses the U.S. Court of Appeals for the Ninth Circuit (San Francisco, \$91 million).

## **Emergency Response Facilities and Systems (\$1.7 Billion)**

Local governments throughout the Bay Area have used Federal, State, and local funding to strengthen fire and police stations and emergency communication systems since the 1989 Loma Prieta earthquake (see appendix). Some of these renovations were also motivated by the devastating 1991 Oakland Hills fire. We include all of these expenses in our total because improved earthquake resiliency was a primary motivation for this construction, and will result in facilities that will be usable immediately after an earthquake.

Fire and police stations have been upgraded in the following 22 communities: Alameda, Albany, Belmont, Berkeley, Burlingame, El Cerrito, Fremont, Hayward, Livermore, Marin, Menlo Park, Milpitas, Oakland, Palo Alto, San Francisco, San Jose, San Leandro, San Mateo, San Rafael, Santa Rosa (Sonoma County), Sausalito, South San Francisco, and Woodside.

## **Soft-Story Residential Building Retrofits (\$1.2 Billion)**

Soft-story residential (and other) buildings are those older multistory buildings that have a weak first story due to a large number of openings for windows, garages, or doors, resulting in inadequate structural framing. They are vulnerable to strong shaking in earthquakes and were responsible for many building collapses and fatalities in both the 1989 Loma Prieta and 1994 Northridge earthquakes (Grad and Lin, 2017).

Based on recommendations by Community Action Plan for Seismic Safety (CAPSS, 2012), the City and County of San Francisco passed an ordinance mandating the retrofit of 4,400 soft-story residential buildings having 5 or more residential units and originally built prior to 1976 (Larsen, 2017). Such buildings house more than 115,000 San Francisco residents (Larsen, 2017; DBI, 2018). The Cities of Alameda (100 buildings), Berkeley (270 buildings), and Fremont (22 buildings) also mandated retrofit of similar soft-story residential buildings. Mountain View and Oakland are considering adopting a similar ordinance for their 488 and 1,500 soft-story residential buildings, respectively (Forestieri, 2018; Tadayon, 2018). Palo Alto is also considering a soft-story retrofit mandate for 300 residential buildings (Sheyner, 2018).

The cost to retrofit these soft-story buildings has been variously estimated. The San Francisco Department of Building Inspection (DBI) estimates that these buildings will require a retrofit investment between \$60,000 and \$130,000 per building, depending on building size, to make them compliant with life safety requirements (DBI, 2018). A local TV station reported the average retrofit cost of \$100,000 to \$400,000 each, with some costing up to \$1 million each (Larsen, 2017). We have estimated the cost for 4,400 buildings to comply with San Francisco's soft-story mandate as follows: 70 percent required \$100,000 each, 20 percent required \$400,000 each, and 10 percent required \$1 million each for a total of \$1.1 billion (see appendix), for an average cost of \$250,000 per building. The investment in the retrofit of the 392 soft-story buildings in Alameda, Berkeley, and Fremont is estimated to be \$100 million, assuming an average cost of \$250,000 per building. Future potential soft-story retrofit mandates in Mountain View, Oakland, and Palo Alto may result in investments of an additional \$500 million, but we do not include this amount in our total.

## **Communication and Data Center Infrastructure (\$1.1 Billion)**

The San Francisco Bay Area is the third largest data center market in the United States, behind only Washington, D.C., and Dallas, Texas, and is the home of 120 data centers, 355

service providers, and 9 network fabrics (Cloudscene, 2018). “Service providers and data centers operators” have invested “significant capital towards constructing facilities that can cope with large seismic events” (Cloudscene, 2018). This investment has included the retrofit of several data centers in the Bay Area to the standard of immediate occupancy as well as the installation of backup generators and fuel supplies. At an investment of \$460 million, 11 data centers or switching centers in Oakland, Palo Alto, Redwood City, San Francisco, and Santa Clara have been retrofit, and the large data center at 365 Main Street, San Francisco, was retrofit using base isolation techniques (see appendix).

The collapse of radio broadcast towers, including KGO, during the 1989 Loma Prieta earthquake required commercial radio stations to replace their towers. The Sutro Tower in San Francisco has been seismically retrofit twice since (see appendix). Telecommunications companies such as AT&T, Comcast, Verizon, and others have incurred expenses to harden their infrastructure to mitigate ground shaking (Lifelines Council, 2015, table 2). Verizon alone has invested \$641 million since 1989 to expand and retrofit their network. We have been unable to obtain firm estimates of the expenses to retrofit infrastructure by AT&T and Comcast since 1989.

## **Sanitation (Sewer) Systems (\$0.8 to 3.6 Billion)**

The San Francisco Public Utility Commission (SFPUC) of the City of San Francisco has initiated the three-phase, \$7 billion Sewer System Improvement Project, now scheduled to be completed between 2025 and 2033 (Kubick, 2015). The goal of the sewer improvement program is to provide “a compliant, reliable, resilient, and flexible system that responds to catastrophic events” including earthquakes, “integrate green and gray infrastructure to manage stormwater and minimize flooding, provide benefits to impacted communities, adapt to climate change, achieve economic and environmental sustainability, and maintain ratepayer affordability” (Kubick, 2015, slide 7). The program addressed improvements to an aging infrastructure consisting of 1,000 miles of sewer pipes, 3 treatment plants, and 27 pump stations. Given the multiple motivations for the project, we estimate that between 10 and 50 percent of the total cost is motivated by the need to improve the seismic resiliency of the San Francisco sewer system. Unfortunately, available online sources do not allow us to more precisely estimate the percentage of the total project investment devoted for seismic upgrade. Other municipalities, including Alameda, Burlingame, and San Jose, have invested \$100 million in the seismic upgrade of sewer systems.

## **Nonprofit Sector Buildings (\$200 Million)**

Nonprofit agencies have invested \$200 million for the seismic retrofit of 21 older multi-story buildings used for low-income housing in Oakland and San Francisco (see appendix). These examples indicate that nonprofit agencies have played a role in the seismic upgrade of Bay Area buildings. It is likely that this estimate substantially underestimates the total investment by nonprofits in the Bay Area.

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# Appendix. Spreadsheet of Known Investments in Earthquake Resiliency Made in the San Francisco Bay Area Since the 1989 Loma Prieta Earthquake

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The appendix is a table containing more details about each of the retrofit or replacement projects compiled here, with each row for each project. The investments are grouped by sector and list the project status (as it was known when the item was added to the spreadsheet, during mid-2018), location, name of the structure, the cost, and whether it was a retrofit or replacement. The table also provides links to the sources of the funding whenever possible. In the table, the investment sectors are ordered from largest to smallest investments in dollars.

Please note that this list represents a snapshot of the expenses found to date, that it is incomplete, and that in some cases the investment amounts and completion dates are estimates and are uncertain. In aggregate, however, the total costs for each investment category seem reasonable given the numbers of investments that have been made and the scope of the projects that were funded.

In the majority of cases we have given what we presume to be the primary reason for the retrofit (life safety, continuity of operation, and so on). We believe that these assumptions are reasonable, but it is important to note that we have not verified them.

This compilation is intended to be updated when new seismic upgrades are reported. The authors welcome any suggestions for additional projects not included here, so that a new version of this report may be released. Please email [bayareaeqmitigation@usgs.gov](mailto:bayareaeqmitigation@usgs.gov).

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