Understanding Earthquake Hazards in the San Francisco Bay Region

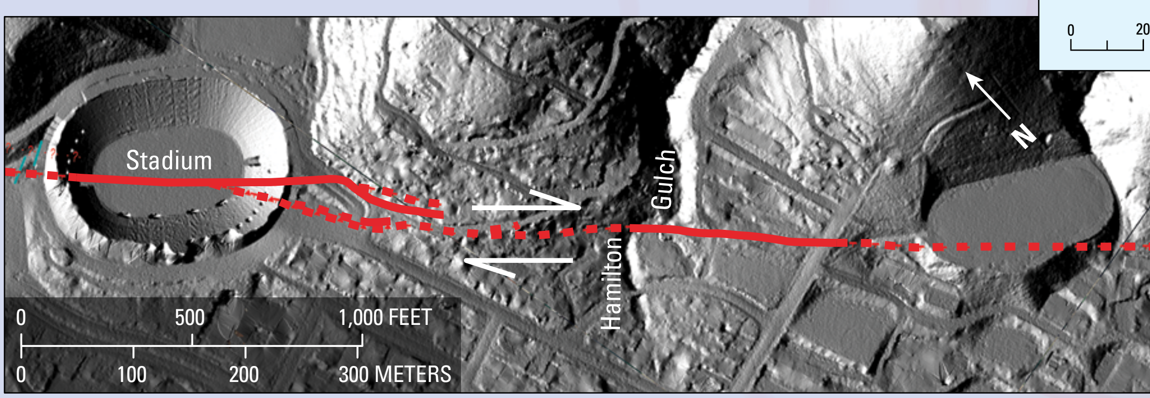
The Hayward Fault—Is It Due for a Repeat of the Powerful 1868 Earthquake?

On October 21, 1868, a magnitude 6.8 earthquake struck the San Francisco Bay area. Although the region was sparsely populated, the quake on the Hayward Fault was one of the most destructive in California's history. U.S. Geological Survey (USGS) studies show that similar Hayward Fault quakes have repeatedly jolted the region in the past and that the fault may be ready to produce another magnitude 6.8 to 7.0 earthquake. Such an earthquake could unexpectedly change people's lives and impact the Bay Area's infrastructure and economy, but updated building codes and retrofits, as well as planning, community training, and preparedness, will help reduce the effects of a future Hayward Fault earthquake.

Strong shaking during the 1868 Hayward Fault earthquake caused the second story of the Alameda County Courthouse in San Leandro to collapse (photo courtesy of the Bancroft Library, University of California). The inset photo shows the courthouse before the quake (photo courtesy of San Leandro Public Library). The 1868 earthquake devastated several East Bay towns and caused widespread damage in the San Francisco Bay region.

In the early morning of October 21, 1868, seismic waves from a powerful earthquake raced through the fog-shrouded San Francisco Bay area. Frightened people ran out of their homes, and cattle and even fire-engine horses panicked and bolted. Strong shaking lasted more than 40 seconds, devastating several East Bay towns. Brick buildings, walls, and chimneys were also shaken down in Oakland, San Francisco, Santa Rosa, and San Jose, and there was serious damage in Napa and Hollister. Numerous witnesses reported seeing the ground move in waves. Shaking was felt as far away as Nevada, and aftershocks rattled the Bay Area for weeks. Even though the region was only sparsely populated at the time, the 1868 quake killed about 30 people and caused great property damage. It still ranks as one of the most destructive earthquakes in California's history, but this is not the end of the story. The Hayward Fault will rupture violently again, and perhaps soon.

Major earthquake faults in the San Francisco Bay region. The section of the Hayward Fault that produced the 1868 Hayward earthquake is highlighted in yellow. Dot size indicates the present relative population sizes of cities.



A filtered vertical laser image, taken using a technique called light detection and ranging (LIDAR), of part of the Hayward Fault (red lines) in the City of Berkeley. The fault passes through the University of California Berkeley football stadium (left), and past earthquake movements have significantly offset Hamilton Gulch (center). Arrows show relative movement on the fault.

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

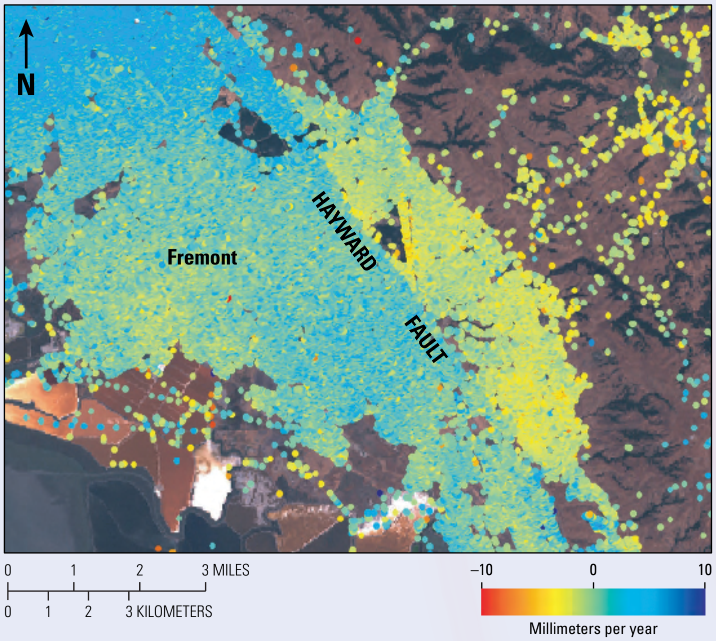
Fact Sheet 2018–3052, August 2018
Supersedes Fact Sheet 2008–3019

The Hayward Fault is Creeping

The Hayward Fault is a near-vertical surface that allows two huge blocks of bedrock to move past each other in the eastern San Francisco Bay region. It is one of a number of "creeping" earthquake faults in the region, meaning the two sides of the fault are constantly moving past each other at a slow rate. Ample evidence for the creep of the fault is provided by roads, curbs, and buildings that are being progressively offset. U.S. Geological Survey and other scientists have shown that the rate of movement is about 1/5 inch (5 millimeters) per year. Creep generally appears to be limited to the topmost 3 miles (5 km) of a fault plane, and below that depth, the fault is locked and building up stress. Creep and small earthquakes account for only about one-third of the long-term (thousands of years) movement on the Hayward Fault, and the remaining two-thirds must be released in large earthquakes like the 1868 event.

Creep (slow, steady movement) on the Hayward Fault has offset this curb in the city of Hayward.

Scientists at the University of California, Berkeley, are using a technique called interferometric satellite aperture radar (InSAR), which uses repeat satellite radar surveys of the Earth's surface to monitor creep along the Hayward Fault. Comparing radar returns from the same points on the ground over time reveals how rapidly the points are moving. This technique allows scientists to determine which parts of a fault are creeping and at what rates, and which parts are locked all the way to the surface and thus may be capable of producing even stronger quakes.



Interferometric satellite aperture radar, or InSAR, uses repeated passes by satellites to record the change in distance between the satellite and recognizable points on the ground (dots). This InSAR image of part of the East Bay clearly shows creep on the Hayward Fault. In general, warm colors mean the points are moving to the southeast (closer to the satellite), and cool colors mean the points are moving to the northwest (farther away). The color scale indicates the rate of this movement in millimeters per year (1 millimeter = 0.04 inch).

The Earthquake of 1868

The 1868 earthquake on the Hayward Fault capped a decade-long sequence of seven increasingly strong quakes in the Bay Area. Ground cracking caused by this earthquake was traced for 20 miles along the Hayward Fault, from Warm Springs in Fremont north to San Leandro. Historical land-survey data suggest that the fault broke as far north as Berkeley, with an average horizontal offset of about 6 feet (2 meters).

Shaking from the 1868 quake was the strongest that the new towns and growing cities of the Bay Area had ever experienced. Until it was eclipsed by the great 1906 earthquake, the 1868 earthquake was known as the "great San Francisco quake." The area of strongest shaking covered about 1,000 square miles. In San Francisco, the largest city on the west coast with a population of 150,000, five people were killed and property losses were significant. Many brick walls, cornices, and other heavy architectural elements of buildings in the city fell, and the U.S. Custom House and several other structures built on land reclaimed from the former Yerba Buena Cove (today's Financial District) sustained severe damage. However, as in 1906, well-constructed buildings on firm ground sustained much less damage.

Towns in the East Bay suffered the most severe damage. Almost every building in Hayward, then a town with about 500 residents, was wrecked or severely damaged—few places have paid so dearly to have a fault named after them. At San Leandro, with a population of about 400, the second floor of the Alameda County Courthouse collapsed, and many other buildings were destroyed. At Mission San Jose, in southern Fremont, the adobe church built in 1809 and other mission buildings were heavily damaged. Oakland, a town of about 12,000 and mainly wood-frame buildings, was much less heavily damaged than San Leandro and Hayward. San Jose, a town of about 9,000 that lies several miles south and west of the fault trace, had few wrecked buildings but many fallen chimneys.

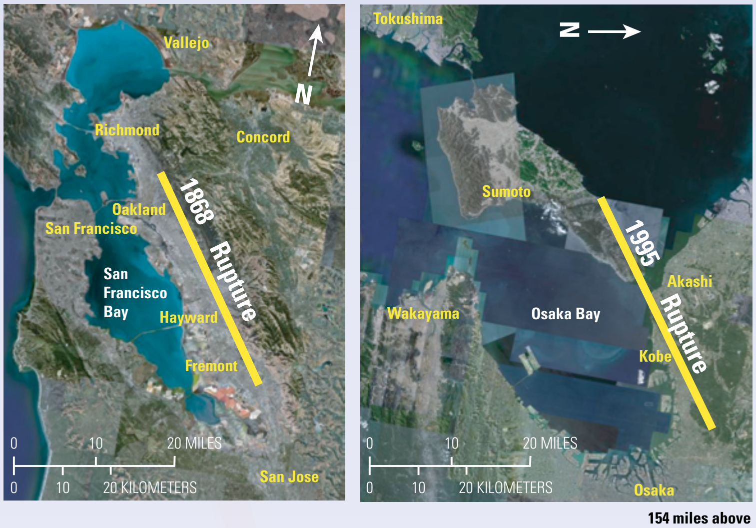
Understanding the 1868 Quake

Because seismographs had not yet been invented, there are no recordings of the 1868 earthquake. Much of what we know about the 1868 quake is documented in a chapter of an important report on the 1906 San Francisco earthquake, which was published in 1908. The chapter reviewed the descriptions of surface faulting, collected damage and felt reports, and interviewed survivors of the earthquake.

USGS and other scientists have used the 1908 report, as well as historical

Similarity to the 1995 Kobe Earthquake

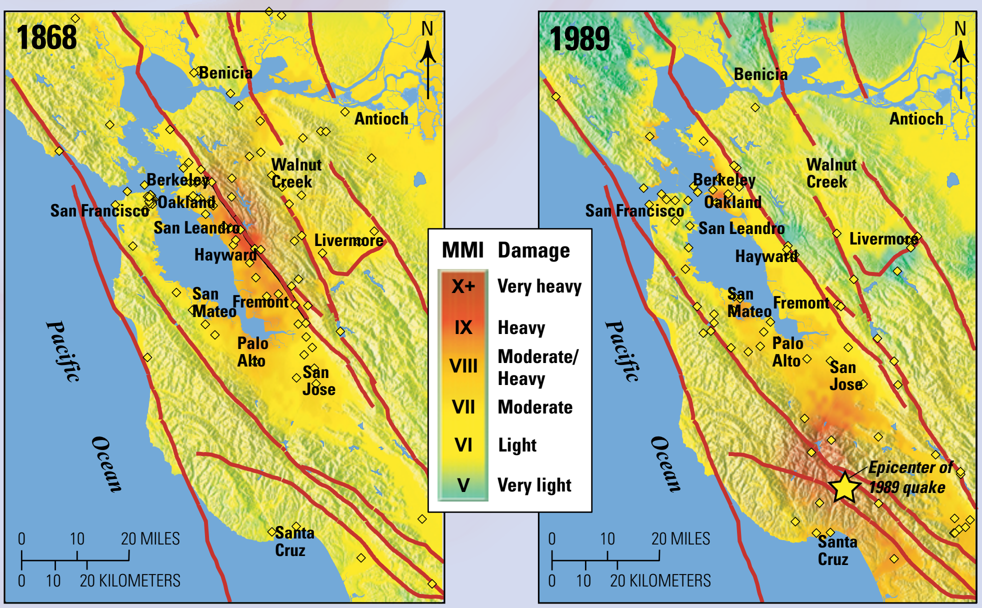
Studies of past earthquakes allow scientists to forecast the effects of future quakes. A quake similar to the anticipated next large Hayward Fault earthquake may be the magnitude 6.9 earthquake that struck Kobe, Japan, in 1995. The geography of Kobe, a port city built along the Nojima Fault on Osaka Bay, is strikingly similar to that of the East Bay, and the Nojima and the Hayward Faults have similar lengths and types of movement. The 1995 Kobe quake and subsequent fires caused more than 5,000 deaths. Shaking and ground failures, including liquefaction (in which shaken sandy soils behave like a liquid and cannot support the weight of structures), devastated residences and infrastructure. Damage to the port facilities in Kobe resulted in a permanent loss of business, because some shipping companies relocated to other undamaged ports in Japan. Many lower income areas of Kobe were not rebuilt for more than a decade.



The urban geographic settings of the Nojima Fault of Kobe, Japan, and the Hayward Fault, California, are very similar, as were the lengths of rupture in their most recent strong earthquakes. The 1995 Kobe earthquake caused more than 5,000 deaths and widespread devastation (satellite images from Google Earth).

Although construction codes and practices for residential buildings in Japan were not as stringent in 1995 as those now in use, and Kobe was not as prepared for earthquakes as the Bay Area is now, it is likely that a repeat of the 1868 Hayward earthquake will also produce significant loss of life and high levels of damage.

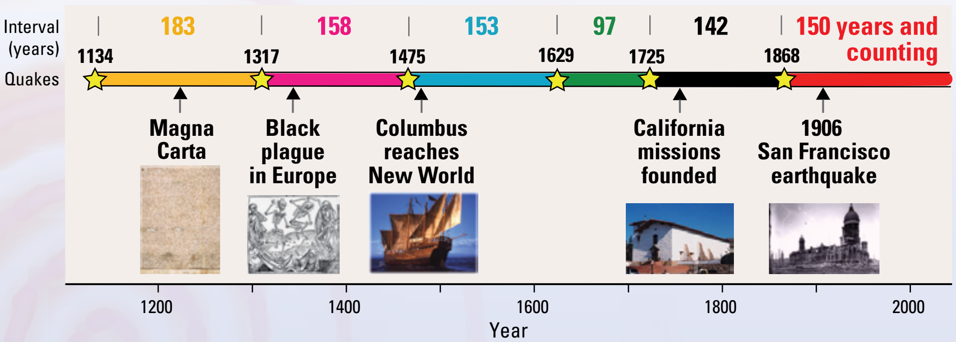
newspaper accounts, photographs, pioneer diaries, and letters, to understand the shaking effects and gauge the size of the 1868 earthquake. To estimate the shaking intensity, it is necessary to consider the construction of the damaged buildings, that is, whether they were adobe, brick, or wood. Combining these intensity estimates with current knowledge of earthquake effects and geology allows researchers to create a "ShakeMap" that depicts the inferred intensity of shaking throughout the region in 1868 and can also be used to predict damage to modern buildings. The map shows that shaking was strongest in Hayward, Fremont, and San Leandro, and weaker but damaging in Oakland, San Francisco, and San Jose. Scientists estimate that the magnitude of the 1868 quake was 6.8. Comparing the ShakeMaps from the 1868 Hayward and the 1989 (magnitude 6.9) Loma Prieta earthquakes shows that a repeat of the 1868 quake would produce much higher levels of shaking and damage in the East Bay than the 1989 quake.



A ShakeMap showing the inferred intensity of ground shaking in the 1868 earthquake (measured as MMI, or Modified Mercalli Intensity), compared to a ShakeMap for the 1989 magnitude 6.9 Loma Prieta earthquake. Red lines are major earthquake faults; black line shows the portion of the Hayward Fault that ruptured in 1868; diamonds show locations of damage reports (1868) and seismic recordings (1989).

Impact of the 1868 Hayward Quake on Building Practice

After the 1868 quake, and a previous one in 1865, damaged San Francisco, engineers worked to strengthen buildings throughout the Bay Area. They retrofit masonry buildings with iron tie-rods and anchors between floors and walls, and they designed and implemented systems to make new buildings more resistant to shaking. Innovations included a stronger course of brick-laying, incorporating iron binders into brick walls, and interior iron framing. But the most significant improvement in shaking resistance was the advent of steel-frame buildings in 1885. These measures combined to ensure that buildings built in San Francisco between 1868 and 1906 survived the powerful shaking of the 1906 San Francisco quake, with the exception of the San Francisco City Hall.



Study of excavations across the Hayward Fault has provided a record of strong earthquakes, all estimated at magnitude of 6.3 or greater, going back hundreds of years—some historical events are shown for reference. The dates for earthquakes before 1868 are based on radiocarbon dating. Note that the interval between successive quakes has varied from 95 to 183 years, averaging 150 years, and it is now more than 150 years since the 1868 earthquake....

Other important engineering lessons from the 1868 earthquake, though actively discussed at the time, were not heeded. The hazard of building on landfill in San Francisco Bay (called "made land" at the time) and the admonition to "build no more cornices" were largely forgotten by the time of the 1906 quake.

Is the Hayward Fault the Nation's Most Dangerous Fault?

Two factors combine to make the Hayward Fault very dangerous. The first is its location in the urban heart of the Bay Area. The Hayward Fault is the single most urbanized earthquake fault in the United States—in 1868 there were only 24,000 residents living in Alameda County; now there are more than 2.4 million people. Hundreds of homes and other structures are built along the fault trace, and mass transit corridors, major freeways, and many roadways cross it at numerous locations. Also, critical regional gas and water pipelines and electrical transmission lines cross the fault. In 2018, the USGS released the HayWired earthquake scenario (see "More Information" box), which included updated forecasts of major impacts of a large earthquake on the Hayward Fault, including the loss of housing resulting from the shaking and fires caused by the quake and long-term outages of drinking water. Ongoing slip and aftershocks along the Hayward Fault may last for months, further damaging buildings and infrastructure that straddle the fault.

A second factor making the Hayward Fault so dangerous is that its most recent damaging earthquake was more than 150 years ago. USGS scientists have found evidence for 12 quakes on the southern Hayward Fault during the past 1,900 years. Notably, the last six quakes (in 1134, 1317, 1475, 1629, 1725, and 1868) occurred at intervals of 95 to 183 years, with an average interval of about 150 years.

The Next Major Hayward Fault Earthquake

The 150th anniversary of the 1868 quake was observed in 2018; scientists are convinced that the Hayward Fault has reached the point where a powerful, damaging earthquake can be expected at any time. According to a 1996 Earthquake Engineering Research Institute report, the next major Hayward Fault earthquake is expected to produce extensive damage to residences, businesses, and to transportation and public utility infrastructure. Several hundred thousand people are likely to be homeless after the quake.

As demonstrated by the aftermath of Hurricanes Katrina, Sandy, and Maria, recovery from catastrophic events can take years. According to a 2013 study (see "More Information" box), a repeat of the 1868 earthquake could cause extensive economic losses (including damage to buildings and contents, business interruption, and living expenses) exceeding $100 billion, with 85 percent or more of both residential and commercial losses being uninsured. Damage to infrastructure, such as transportation and utilities, and other long-term economic effects could substantially increase the losses.

The 1868 Hayward Fault earthquake is a reminder of the tremendous power that lurks beneath the Earth's surface in the San Francisco Bay region. Other large quakes, like the damaging 1995 Kobe earthquake in Japan, offer realistic visions of the destruction that such events can inflict in a densely populated urban region. The population at greatest risk from a Hayward Fault earthquake is 100 times greater than in 1868. The urban infrastructure in the Bay Area has been tested only by the relatively remote, 1989 magnitude 6.9 Loma Prieta earthquake, and the smaller 2014 magnitude 6.0 South Napa earthquake. USGS earthquake science tells us that it's now urgent to prepare for the next magnitude 7 quake on the Hayward Fault. Preparing now can significantly reduce loss of life and property from that coming quake.

More Information:

Magnitude 6.8 October 21, 1868, Hayward Fault Earthquake http://earthquake.usgs.gov/regional/nca/1868

The HayWired Earthquake Scenario—We Can Outsmart Disaster. USGS Fact Sheet 2018–3016, at https://doi.org/10.3133/fs20183016

The 1868 Hayward Earthquake: 145-Year Retrospective, Risk Management Solutions, Inc. White Paper, at https://forms2.rms.com/rs/729-DJX-565/images/eq_1868_hayward_eq_retrospective.pdf

Putting Down Roots in Earthquake Country, USGS General Information Products 15, 41, and 42, at http://www.earthquakecountry.org/booklets/.

Earthquake Country Alliance, Bay Area, https://www.earthquakecountry.org/bayarea/

Thomas M. Brocher, Jack Boatwright, James J. Lienkaemper, Carol S. Prentice, David P. Schwartz, and Howard Bundock

Edited by Claire Landowski
Graphic design by Suzanne Roberts
Banner photograph of the Bay Bridge and San Francisco skyline by Scott Haefner.
Seismogram from 1906 San Francisco earthquake, courtesy of IRIS Data Management Center.

COOPERATING ORGANIZATIONS
Earthquake Country Alliance
University of California at Berkeley

https://twitter.com/USGS
https://www.facebook.com/USGeologicalSurvey

ISSN 2327-6916 (print)
ISSN 2327-6932 (online)
https://doi.org/10.3133/fs20183052
Supersedes USGS Fact Sheet 2008–3019