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 region. Although the region was then sparsely populated, this quake on the Hayward Fault was one of the most destructive in California's history. Recent studies show that such powerful Hayward Fault quakes have repeatedly jolted the region in the past. U.S. Geological Survey (USGS) scientists describe this fault as a tectonic time bomb, due anytime for another magnitude 6.8 to 7.0 earthquake. Because such a quake could cause hundreds of deaths, leave thousands homeless, and devastate the region's economy, the USGS and other organizations are working together with new urgency to help prepare Bay Area communities for this certain future quake.

Strong shaking during the 1868 Hayward Fault earthquake caused the second story of the Alameda County Courthouse in San Leandro to collapse and severely damaged the building (photo courtesy of the Bancroft Library, University of California). The inset photo shows the building before the quake (photo courtesy of San Leandro Public Library). The 1868 quake 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 region. 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 very soon.

The Earthquake of 1868

The 1868 earthquake on the Hayward Fault was the last of a decade-long sequence of seven increasingly strong quakes in the Bay Area. Surface rupture of the ground in 1868 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 movement of about 6 feet (2 meters).

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

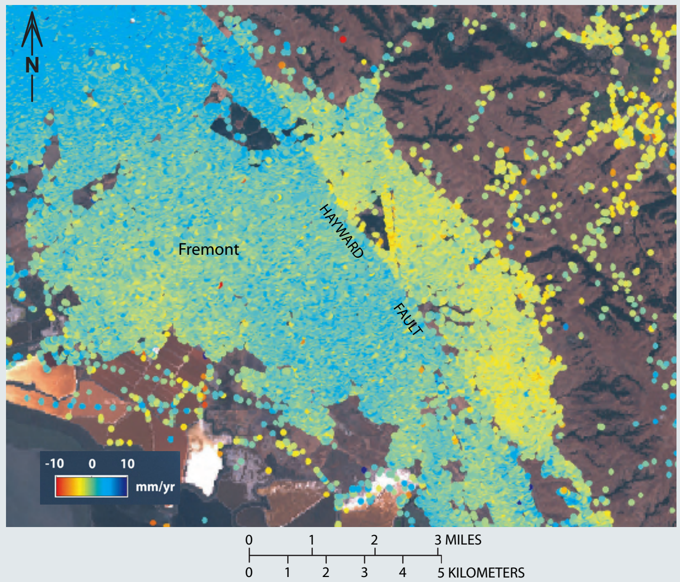
Shaking from the 1868 quake was the strongest that the new towns and growing cities of the Bay Area had ever experienced. Until overshadowed by the 1906 earthquake, the 1868 event was known as the "great San Francisco quake." The area of strongest shaking covered about 1,000 square miles (2,500 km^2). San Francisco, then the largest city on the West Coast with a population of 150,000, suffered five deaths and experienced $350,000 in property loss (in 1868 dollars). Many brick walls, cornices, and other heavy architectural elements of buildings in the city fell, and the Custom House and several other structures built on landfill reclaimed from the former Yerba Buena Cove (today's Financial District) sustained severe damage. However, as in 1906,

THE HAYWARD FAULT IS CREEPING

The Hayward Fault is one of a number of "creeping" earthquake faults in the San Francisco Bay region. Ample evidence for the steady slip or "creep" of the fault is seen in roads, curbs, and buildings that are being progressively offset. U.S. Geological Survey and other scientists have shown that the two sides of the Hayward Fault are creeping past each other at the surface at a rate of about 1/5 inch (5 mm) per year. Faults like the Hayward Fault are near-vertical planes that extend deep beneath the surface. Creep generally appears to be limited to the topmost 3 miles (5 km) of a fault plane; 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—the remaining two-thirds must happen in large earthquakes like the 1868 event.

Recently, scientists at the University of California at Berkeley began using a new technique called Interferometric Synthetic Aperture Radar (InSAR), which is based on satellite radar surveys of the Earth's surface, to monitor creep on the Hayward Fault. 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.

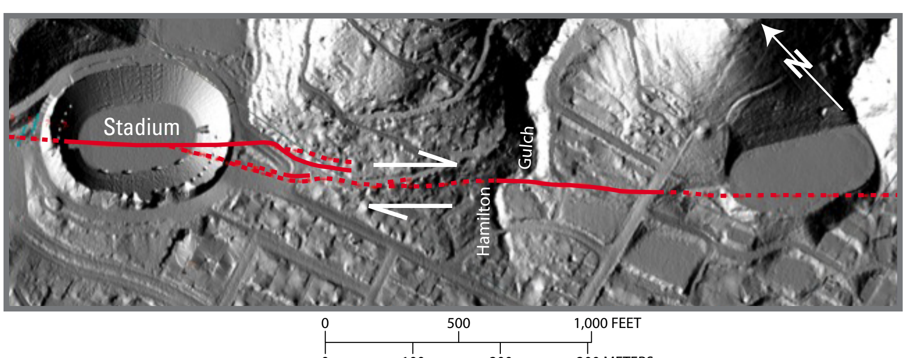
Creep on the Hayward Fault has broken and offset this curb in the city of Hayward.



An InSAR image of part of the East Bay clearly shows creep on the Hayward Fault. Repeated passes by satellites to the south record the change in distance between the satellite and recognizable points on the ground (dots). In general, warm colors mean the points are moving to the southeast (closer to the satellite), 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 mm = 0.04 inch).

well-constructed buildings on firm ground sustained much less damage.

The most severe damage in 1868 was in East Bay towns. 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 an earthquake 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. Damage in Oakland, a town of about 12,000 with mainly wood-frame buildings, was much less than observed farther south at San Leandro and Hayward, but San Jose, a South Bay town of about 9,000, lying several miles west of the fault trace, had many wrecked buildings and fallen chimneys.



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.

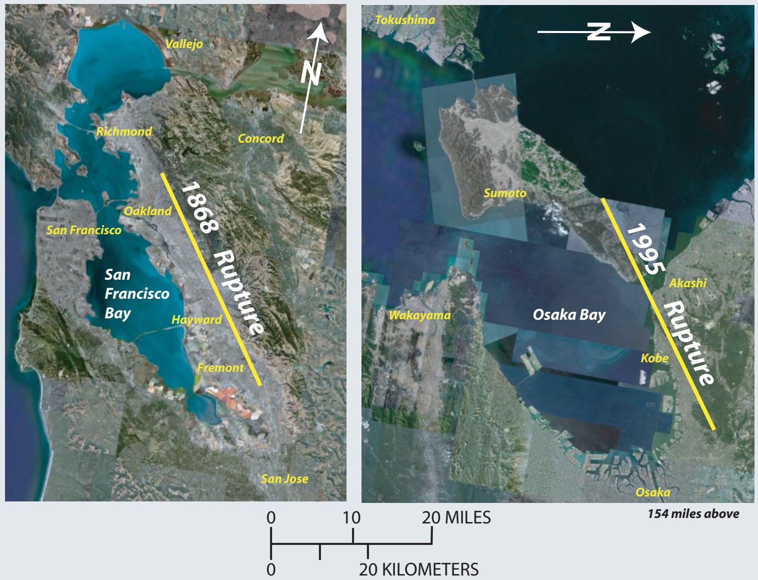
Understanding the 1868 Quake

Because seismographs did not exist then, there are no recordings of the 1868 earthquake. A committee that included scientists studied the quake at the time, but no report on the event was published. Much of what we know about the 1868 quake is documented in the famous 1908 Lawson Report on the 1906 San Francisco earthquake. As part of that report, the Hayward Fault was reexamined and some survivors of the 1868 quake were interviewed. The 1908 report also included photographs taken in 1868 of damage to buildings in San Francisco, San Leandro, and Hayward.

In recent years, U.S. Geological Survey (USGS) and other scientists have used the Lawson Report, as well as historical newspaper accounts and pioneer diaries and letters, to better understand the size and the effects of the 1868 earthquake. Evaluating the extent of damage throughout the Bay Area and the types of buildings that were damaged (brick, stone, and adobe) is critical to determining the local shaking intensity of the 1868 quake. Combined with modern knowledge of earthquake effects and geology, these historical data have been used to

ANALOGY TO THE 1995 KOBE EARTHQUAKE

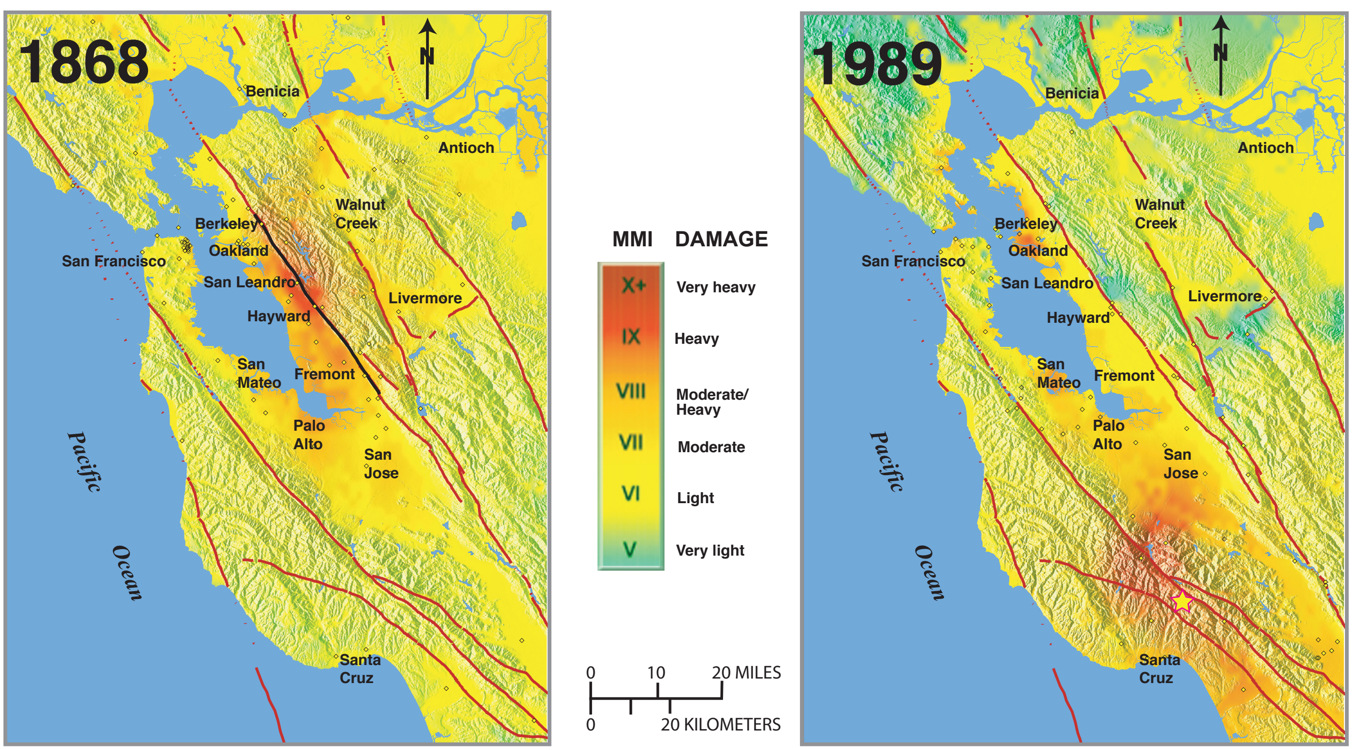
Studies of past earthquakes allow scientists to forecast the effects of future quakes. A similar quake to the anticipated next large Hayward Fault earthquake may be the magnitude 6.9 earthquake that struck Kobe, Japan, in 1995. The geography of Kobe, a port city built along the Nojima Fault on Osaka Bay, is strikingly similar to that of the East Bay, and the Nojima Fault and the Hayward Fault are both strike-slip faults of about the same length. The 1995 Kobe quake and subsequent fires caused more than 5,000 fatalities. Shaking and ground failures, including liquefaction (in which shaken soils behave like a liquid and cannot support 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. More than a decade later, large segments of the lower income areas of Kobe have yet to be rebuilt.



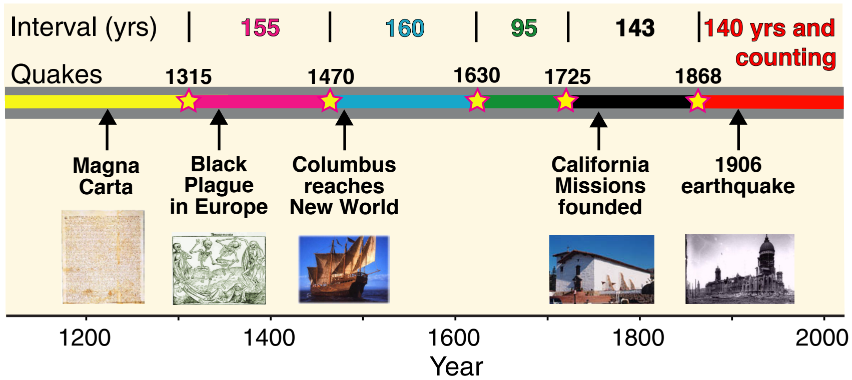
The urban geographic settings of the Nojima Fault of Kobe, Japan, and the Hayward Fault, California, are very similar, as were the lengths of rupture in their most recent strong earthquakes. The 1995 Kobe earthquake caused more than 5,000 deaths and widespread devastation. (satellite images from Google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

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

create a "ShakeMap" that depicts the inferred intensity of shaking throughout the region in 1868. The map shows that shaking was strongest in Hayward, Fremont, and San Leandro and weaker in Oakland, San Francisco, and San Jose. Scientists now estimate that the magnitude of the 1868 quake was 6.8. Comparing the ShakeMaps from the 1868 Hayward and 1989 (magnitude 6.9) Loma Prieta earthquakes shows that a repeat of the 1868 quake will produce much higher levels of shaking and damage in the East Bay than did the 1989 quake.



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



Study of excavations across the Hayward Fault has provided a record of strong earthquakes, all estimated at magnitude 6.3 or greater, going back hundreds of years—some historical events are shown for reference. The dates of earthquakes before 1868 are based on radiocarbon dating. Note that the interval between successive quakes has varied from 95 to 160 years (average 138 years), and it is now 140 years since the 1868 earthquake.

Impact of the 1868 Hayward Quake on Building Practices

Engineers realized after the 1868 quake that structures in the Bay Area needed to be made more resistant to earthquakes. Buildings built in the 1870s for the fledgling University of California Berkeley campus along the Hayward Fault, as well as others in San Francisco, included special features designed to strengthen them against quakes. Many such buildings built in San Francisco between 1868 and 1906 fared well during the powerful shaking produced by the 1906 San Francisco earthquake.

Sadly, other important engineering lessons from the 1868 quake, though openly discussed at the time, were not heeded. The hazards of building on landfill (“made land”) reclaimed from the San Francisco Bay and the admonition to “build no more cornices” were largely forgotten by the time of the 1906 quake.

Is the Hayward Fault our Nation’s Most Dangerous?

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 people living near the fault in Alameda County, now there are more than 2.4 million. Hundreds of homes and other structures are built directly on the fault’s 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. A September 2007 U.S. Bureau of Labor Statistics Report determined that more than 1.5 million people with combined annual wages exceeding $100 billion work at sites that would experience strong or very strong levels of shaking from the next powerful Hayward Fault quake.

A second factor making the Hayward Fault so dangerous now is that its most recent damaging earthquake was 140 years ago. USGS scientists have found evidence for 12 quakes on the southern Hayward Fault during the past 1,900 years. Ominously, the last five events (in 1315, 1470, 1630, 1725, and 1868) occurred at intervals of 95 to 160 years, with an average interval of 138 years.

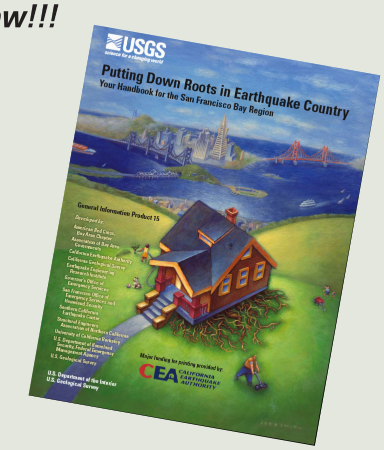
The Next Major Hayward Fault Earthquake

The 140th anniversary of the 1868 Hayward Fault earthquake will be observed this year (2008), and scientists are convinced that the Hayward Fault has reached the point where a powerful, damaging quake can be expected at any time. According to a 1996 Earthquake Engineering Research Institute report, the next major Hayward Fault quake is expected to cause significant loss of life and extensive damage to homes, businesses, and infrastructure, such as transportation and utilities. Several hundred thousand people are likely to be homeless after the quake.

As demonstrated by the aftermath of 2005’s Hurricane Katrina, recovery from such catastrophic events can take years. According to another recent study, a repeat of the 1868 earthquake could cause economic losses (including damage to buildings and contents, business interruption, and living expenses) exceeding $120 billion, with more than 90% of both residential and commercial losses being uninsured. Also, damage to infrastructure and other long-term economic effects could substantially increase the total losses.

The 1868 Hayward Fault earthquake is a stark reminder of the awesome power that lurks beneath the Earth’s surface in the San Francisco Bay region. Other large quakes, like the 1995 Kobe earthquake in Japan, offer sobering glimpses 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 now 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. Modern earthquake science tells us that it is 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 inevitable quake.

Prepare Now!!!



Information in several languages on earthquakes in the San Francisco Bay region and how to prepare for them can be found in USGS General Information Products 15, 41, and 42 . Order your copy from http://earthquake.usgs.gov/regional/nca/prepare.

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See also *Is a Powerful Quake Likely to Strike In the Next 30 Years?* (USGS Fact Sheet 039-03, http://pubs.usgs.gov/fs/2003/fs039-03/)

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