TRANSRE CATASTROPHE RESEARCH

Shaking Things Up (Part II): California and the Next "Big One"

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Executive Summary

The contiguous United States has experienced eight magnitude 7 or greater earthquakes over the last century. Three quarters of these events occurred in California. With more than 70% of Californians living in areas prone to strong ground shaking, better understanding California's seismic risk is a critical concern.

Part II in this series of articles highlights important features of California's seismic risk. These include:

- **San Andreas Fault** – The proximity of the San Andreas Fault to major urban centers like the Bay Area and Los Angeles exposes millions to earthquake damage.
- **The "Big One"** – A prolonged gap in seismic activity suggests California is at risk for a major earthquake that could have widespread impact to both life and property.
- **Exposure** – There are several known vulnerabilities in California's seismic exposure such as soft-story and unreinforced masonry buildings.

Part I in this series reviews the impact of the recent February 6, 2023 Turkey earthquake. Part III gives a global overview of seismic risk.

California Seismic Profile

California straddles the two largest tectonic plates on Earth – the Pacific and North American Plates (Figure 1). At the convergence of these plates is the San Andreas Fault, which stretches for 1,200 kilometers and slips at a rate of approximately 50 mm per year.[1] Associated with the San Andreas Fault is a complex network of secondary faults which share the stress produced by this tectonic motion. In total there are about 15,700 known faults in California of which approximately 500 are active.[2]

27 million Californians live within 30 miles of a fault where strong ground shaking is possible within the next 50 years.[3] It is estimated that earthquakes cause $9.6 billion in average annual losses for California, roughly 65% of total annual losses for the United States.[4] Despite these losses, however, California has a substantial protection gap with only about 10% of Californians having earthquake insurance.[5]

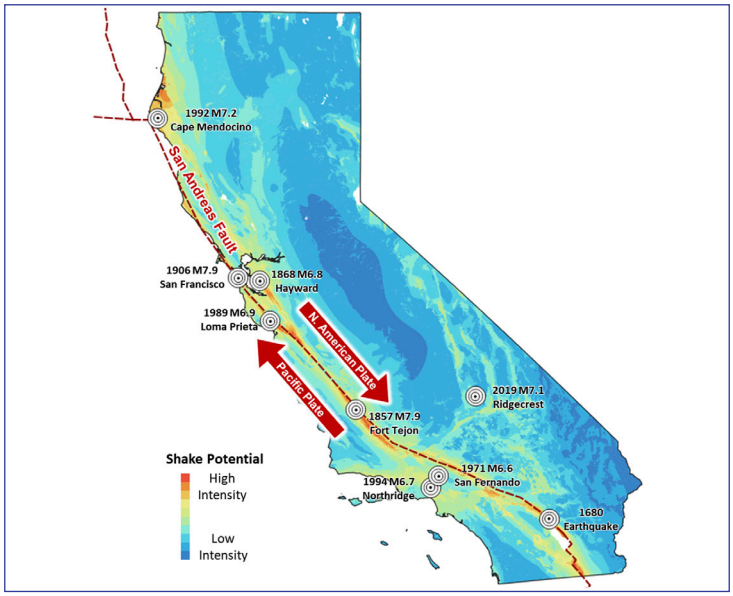

Figure 1 – Seismic shake potential (2500-yr 1-second shake intensity) and major historic earthquakes.[6]

1 USGS (2017). Back to the Future on the San Andreas Fault.
2 California Earthquake Authority.
3 California Geological Survey.
4 FEMA (2023). Hazus Estimated Annualized Earthquake Losses for the United States.
5 FEMA. Earthquake Insurance.
6 California Geological Survey (2016). Earthquake Shaking Potential for California.

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San Andreas Fault

As the driver of the seismic risk in the region, the San Andreas Fault has been intensely studied in recent decades. The San Andreas Fault comprises three segments with distinct seismic behavior (Figure 2):

- **Northern Segment:** Site of the Great 1906 San Francisco (M7.9) earthquake and most recently the 1989 Loma Prieta (M6.9) earthquake. The 1906 earthquake has an estimated return period of 200-240 years.[7] Parallel "sister" faults, notably the Hayward Fault, pose significant seismic risk to the Bay Area.
- **Central Segment:** This segment slips continuously, or "creeps", without accumulating enough stress to generate large earthquakes.[8]
- **Southern Segment:** The last major earthquakes on the northern and southern portions of this segment occurred in 1857 (M7.9) and 1680, respectively. This segment has seen a large earthquake on average every 150 years over the last 1,500 years.[9]

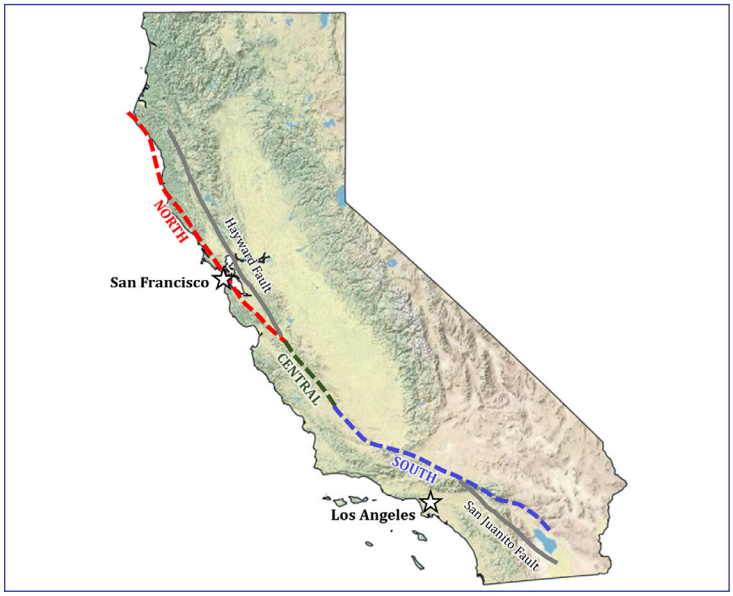

Figure 2 – Segments of the San Andreas Fault.

7 USGS. When will it happen again?

8 Temblor (2021). The Central San Andreas creeps along without a major earthquake.

9 USGS. The San Andreas Fault.

10 Temblor (2021). Overdue? The future of large earthquakes in California.

11 USGS (2018). The HayWired earthquake scenario: We can outsmart disaster.

12 USGS (2008). The ShakeOut Scenario.

13 USGS (2018). Reported investments in earthquake mitigation top $73 to $80 billion in the San Francisco Bay Area.

The "Big One"

While the San Andreas Fault network has historically produced roughly three to four major earthquakes per century, only one has occurred since 1918.[10] This prolonged gap in seismic activity suggests significant stress has accumulated for the next large earthquake. Several "what if" scenarios have been studied to assess the possible impact of a large earthquake impacting California. While not predictions, these scenarios provide useful narratives for assessing seismic exposure and motivating action. Two notable scenarios include:

- **HayWired:** The 2018 USGS HayWired scenario contemplates a M7.0 earthquake rupturing an 84 km segment of the fault near Oakland. The Hayward Fault last ruptured in 1868 (M6.8) and has a return period of approximately 150 years.[11] The economic loss from this event could potentially exceed $110 billion (present value). Physical damage and utility outages could displace up to 500,000 people.
- **ShakeOut:** The 2008 USGS ShakeOut scenario contemplates a M7.8 earthquake rupturing the 300 km southmost portion of the San Andreas Fault. This section of the fault last ruptured with the 1680 earthquake and has a return period of only approximately 150 years. Estimated casualties include 1,800 deaths and 50,000 injuries.[12] The economic loss from this event could exceed $350 billion (present value) split roughly evenly between property damage and business interruption.

Preparedness

California has invested heavily in preparation for its next major earthquake. The Bay Area, for example, has invested as much as $80 billion in earthquake mitigation since the 1989 Loma Prieta earthquake.[13] These investments combined with rigorous construction standards are expected to substantially reduce the impact of earthquakes compared to less developed areas in the world with similar seismicity.

Even with substantial progress, however, there are several known vulnerabilities in California's seismic exposure. These vulnerabilities include:

- **Soft-Stories:** Discontinuities in a building's lateral resistance create "soft-stories" that can initiate building collapse. New construction of soft-story buildings was discontinued following their

widespread failure during the 1971 San Fernando (M6.6) earthquake. Soft-story buildings predating this change, however, remain across California. The city of Los Angeles, for example, has more than 13,000 soft-story buildings (typically residential structures with an open ground floor parking area). In response to this known risk, Los Angeles and other cities have implemented mandatory retrofit programs.[14]

- **Unreinforced Masonry:** Masonry structures constructed without lateral reinforcement are amongst the most vulnerable to ground shaking. Approximately 1 in every 600 Californian buildings is constructed with unreinforced masonry.[15] Mandatory programs over recent decades have retrofitted a substantial number of unreinforced masonry buildings although pockets of high exposure remain. In the Inland Empire region of southeastern California, for example, as many as 640 unreinforced masonry buildings have yet to be retrofitted.[16]
- **Pre-existing Conditions:** Structures damaged by earthquakes can perform poorly in subsequent events unless properly inspected and repaired. A recent survey of 65 San Francisco high-rise buildings discovered a type of steel weld which studies of the 1994 Northridge (M6.7) earthquake found was susceptible to fracture. The vulnerability of this type of weld, however, was unknown when the buildings were inspected immediately following the 1989 Loma Prieta earthquake.[17] Rigorous inspections of critical structures are therefore needed to ensure structures reflect the state-of-the-art in seismic knowledge.

It is important to recognize that even complete adherence to current building standards does not eliminate the potential for building damage. The HayWired study, for example, found that even if all buildings in the Bay Area satisfied the current building code, 0.4% buildings would still collapse, 5% would be unsafe to occupy and 20% would have restricted use.

Contact

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14 CBS (2023). LA Country moves towards retrofits for buildings at risk of collapse during earthquakes.
15 Structural engineers Association of California (2020). Revisiting Earthquake Lessons: URM Buildings.
16 The San Diego Union-Tribune (2018). In shadow of San Andreas fault, hundreds of Inland Empire buildings face collapse in huge earthquake.
17 San Francisco Chronicle (2018). New report finds overlooked earthquake vulnerabilities in some SF high-rises.