**Case Study: Earthquake risk in southern California**

**This report was prepared and edited by John Taber, IRIS, and was drawn largely from the following ShakeOut reports:**

Jones, L.M., R. Bernknopf, D. Cox, J. Goltz, K. Hudnut, D. Mileti, S. Perry, D. Ponti, K. Porter, M. Reichle, H. Seligson, K. Shoaf, J. Treiman, and A. Wein, 2008, The ShakeOut Scenario, USGS Open File Report 2008-1150.

Perry, S., D. Cox, L. Jones, R. Bernknopf, J. Goltz, K. Hudnut, D. Mileti, D. Ponti, K. Porter, M. Reichle, H. Seligson, K. Shoaf, J. Treiman, and A. Wein, 2008, The ShakeOut Earthquake Scenario—A Story That Southern Californians Are Writing, USGS Circular 1324.

**Introduction**

Over 22 million people are at risk from earthquakes in southern California. There have been damaging earthquakes in recent memory such as the Northridge earthquake in 1994, that caused 57 deaths and over $20 billion in damage, plus historical records of even bigger earthquakes that go back over 150 years. Given that history, there is considerable awareness of earthquake risk in the region. However awareness that a risk exists does not necessarily lead to preparedness across all sectors of the community.

One of the reasons the ShakeOut Scenario described below was developed, was to break through a common, dangerous misconception that goes something like this: My home/my business made it through the Northridge earthquake so I know what future earthquakes will be like and can rest assured I will make it through the next one, too. There has also been a significant addition to the population in the past 20 years, and none of these people experienced the Northridge earthquake. Natural disasters come in many sizes, and the disasters most likely to cause catastrophes are those large enough to have regional, long-term consequences. No Californians have experienced an earthquake like this except for survivors of the 1906 San Francisco earthquake.

**ShakeOut Scenario**

The ShakeOut Scenario was developed in 2008 by the USGS, CGS, and the Southern California Earthquake Center and a team of over 300 scientists, engineers and others (<http://pubs.usgs.gov/circ/1324/>). It was designed to meet the needs of a range of stakeholders in southern California who asked for disaster scenarios that could extend planning and preparedness beyond the current experience and expected capabilities by detailing and quantifying anticipated consequences of natural disasters. The ShakeOut Scenario estimates that a magnitude 7.8 earthquake on the southern San Andreas Fault will cause over 1,800 deaths, 50,000 injuries, $200 billion in damage and other losses, and severe, long-lasting disruption. The earthquake was selected not because it is the worst earthquake possible but because it is so plausible. Southern California has more than 300 faults capable of producing damaging earthquakes, and includes several faults capable of producing earthquakes with catastrophic consequences.

The ShakeOut Scenario exists to support decision-makers in their efforts to make southern California a safer community, including business owners, homeowners, employees, and tenants, as well as public officials, emergency responders, and planners. Considerable effort had already been expended before the ShakeOut scenario had been created, to mitigate the hazard in the region through stronger building codes, improved engineering, public planning and public awareness campaigns, but it was clear that the region was still in danger of a natural disaster turning into a catastrophe*,* with major disruption over a large region and effects continuing for decades.

The ShakeOut Scenario analyzes how a large, regional earthquake will affect the social and economic systems in southern California, because an earthquake with similar kinds of impacts is an inevitable part of southern California’s future. Thus, appropriate uses of the ShakeOut Scenarioinclude:

* Urban planning;
* Emergency response training;
* School, business, and public earthquake drills;
* Prioritization of preparedness efforts;
* Understanding potential impacts on financial and social systems; and
* Identifying possible vulnerabilities of infrastructure, especially due to interactions among systems that are often considered separately.

**Science and engineering behind the scenario**

The ShakeOut Scenario goal was to identify the physical, social and economic consequences of a major earthquake in southern California and in so doing, enable the users of the scenario to identify what they can change now—*before* the earthquake—to avoid catastrophic impact *after* the inevitable earthquake occurs. To do so, the scenario authors had to determine the physical damages (casualties and losses) caused by the earthquake and the impact of those damages on the region’s social and economic systems. To do that, they needed to estimate the earthquake ground shaking and fault rupture. So they first constructed an earthquake, taking all available earthquake research information, from trenching and exposed evidence of prehistoric earthquakes, to analysis of instrumental recordings of large earthquakes and the latest theory in earthquake source physics. This information was then fed forward into the rest of the ShakeOut Scenario (Fig. 1).



Figure 1. ShakeOut Scenario flow-chart.

*The Earthquake Source*

The ShakeOut Scenario earthquake is a magnitude 7.8 earthquake on the southernmost 300 km (200 mi) of the San Andreas Fault, between the Salton Sea and Lake Hughes. The southern San Andreas Fault was identified as the most likely source of a very large earthquake in California. The southern San Andreas Fault has generated earthquakes of ShakeOut size on average every 150 years—and on a portion of the fault that ruptures in the ShakeOut Scenario, the last earthquake happened more than 300 years ago. The extent of the fault rupture in this earthquake was determined from geologic characteristics, after considerable discussion among geologic experts. The most likely rupture initiation point is one of the endpoints of the fault, so the scenario earthquake starts at the southern end of the San Andreas Fault, and ruptures the fault to the northwest. It was assumed that the average amount of slip to be released anywhere along the fault would be the amount accumulated since the last event on that portion of the fault, ranging from 2 to 7 meters. A randomized variation was then added to the average slip within each 30 km section of fault.



Figure 2. Earth science steps to design and quantify the earthquake

*Ground Motions*

The sudden rupture of a fault produces shaking as one of its effects. This shaking moves the ground, and it is these ground motions that we feel and that cause much of the damage in an earthquake that can also lead to fire following an earthquake. Ground motions were estimated using physics-based computer simulations of the earthquake with computer systems developed by the Southern California Earthquake Center information technology research program. The physics-based simulations modeled numerous factors that effect the shaking, including site effects, directivity, and radiation pattern, and were validated through comparison of multiple methods.

To estimate damages from ShakeOut ground motion, the ShakeOut Scenario next calculated *ground motion parameters* used by engineers to estimate damage to structures. Ground motion parameters describe how the ground moves due to different measures of earthquake waves, and are needed because different kinds of structures are damaged by different kinds of waves. The ShakeOut Scenario created all the standard ground motion parameters: peak ground acceleration (PGA), peak ground velocity (PGV), Modified Mercalli Intensity (MMI), and spectral accelerations at 0.3, 1.0, and 3 seconds.

*Secondary Hazards*

Secondary hazards were investigated that can be triggered by large earthquakes in southern California including liquefaction, landslides, tsunamis, and seiches. All of these have caused significant additional damage in many big earthquakes, but only landslides and liquefaction will produce significant impacts in the ShakeOut Scenario. The ShakeOut Scenario earthquake will produce between 10,000 and 100,000 individual landslides, the vast majority of which will consist of rock falls, rock slides, rock avalanches, soil falls, disrupted soil slides and soil avalanches. Conditions that can lead to liquefaction are potentially widespread in parts of the eight-county area impacted by the ShakeOut Scenario earthquake. However, liquefaction requires both strong shaking and a high ground-water table. Strong ground motions from the ShakeOut Scenario earthquake mostly occur within the inland desert and mountain regions of southern California where ground water levels are typically low year-round. As a result, only the southern Coachella Valley will suffer significant liquefaction impacts in the ShakeOut Scenario earthquake, particularly to buried lifelines and roads and foundations, with localized liquefaction otherwise confined mostly to areas adjacent to perennial stream and river channels.

*Damage and casualty estimates*

The damage and impacts of the ShakeOut Scenario earthquake were estimated through a three-step process. First, FEMA’s loss estimation program, HAZUS < http://www.fema.gov/hazus>, was run using the physics-based ground motion model. For Los Angeles County, HAZUS used a refined database of structures created from tax assessor’s data. For the other counties, this was not available and the default HAZUS database was used. In addition, HAZUS default mapping schemes (the relationships between basic inventory data and the assumed structural characteristics) were modified to reflect available information on unreinforced masonry buildings tabulated by the California Seismic Safety Commission, building density concentrations in urban core areas, and construction pattern changes over time throughout the eight counties. In the second step, expert opinion was collected through 13 special studies and 6 expert panels. Panels generally estimated impacts to public and private utilities, especially where multiple utility companies provide a public service such as water supply or electricity. In the third step, the expert evaluations were merged with the HAZUS results to create the final estimates of probable damages. A fire following earthquake damage assessment was also conducted.

The ShakeOut Scenario identified five major areas of loss:

* Older buildings built to earlier standards.
* Non-structural elements and building contents that are generally unregulated.
* Infrastructure crossing the San Andreas Fault.
* Business interruption from damaged infrastructure, especially water systems.
* Fire following the earthquake.

The study also found numerous areas where mitigation conducted over the last few decades by state agencies, utilities and private owners, has greatly reduced the vulnerability. Because of these mitigation measures, the total financial impact of this earthquake is estimated to be “only” about $200 billion.

Shaking in the ShakeOut Scenario earthquake will kill and injure many people, by causing buildings to collapse, creating falling debris and flying objects, and increasing traffic accidents when drivers lose control of automobiles. Many additional deaths and injuries will result in fires that follow the shaking. Estimating the total number of injuries and deaths is very uncertain particularly because the Scenario posits types of building failures that have not yet been observed. Because of strong life-safety building codes over the years, the ShakeOut Scenario estimates only approximately 1,800 deaths, of which about half occur because of the fires following the earthquake. There will also be about 750 people with very severe injuries who will require rapid, advanced medical care to survive. Approximately 50,000 people will have injuries that need emergency room care. The final mortality could increase if hospitals cannot function because of damage or if the transportation disruptions prevent people getting to emergency rooms.

**Ongoing use of the ShakeOut scenario**

The first ShakeOut drill was held in 2008, known as *the Great Southern California ShakeOut.* It was an effort by scientists and emergency managers to inform the public about earthquake preparedness, and was based on the ShakeOut Scenario. Since then, the Great ShakeOut earthquake drills have become an annual event, and have expanded to 44 states and territories as well as internationally. While other regions may not have a detailed scenario to use during a ShakeOut drill, each area is still able to highlight their local earthquake hazards and recommended mitigation strategies.

The Great ShakeOut drills have had a significant impact on public awareness and preparedness, and are a model for engaging the public, private, and government sectors in earthquake risk mitigation. An evaluation of the effectiveness of the drills to create change found the following:

* Just as real earthquake events prompt behavior, simulated events such as the ShakeOut drill also can prompt information seeking and preparedness action.
* The ShakeOut drill has encouraged individuals to talk to others about the drill itself and about earthquake safety and preparedness.

However

* California schools remain an underutilized resource for promoting household earthquake preparedness.
* Businesses and other organizations also remain underutilized in efforts to promote household preparedness and community resilience (Wood, 2013).

The ShakeOut scenario has prompted a much closer look at lifelines in the region, particularly water distribution. This has led to additional studies of the water sources and reservoirs for the region, and additional employee seismic safety training. An examination of post-earthquake communications between agencies has led to the formation of inter-agency communication groups.

**Improving long term resilience**

The primary earthquake risk in southern California is to buildings and infrastructure (lifelines), with injuries, loss of life, and loss of services resulting from shaking and fire damage. Thus engineering solutions can significantly reduce the risk and great improvements have been made particularly for new buildings, but retrofitting of older buildings can be expensive and building owners need a reason to act. To address this need, the Los Angeles City Council is currently considering how to examine nearly 1,500 buildings that were built before 1976 and to decide whether to require retrofitting. Thus justifying the value of short-term economic costs for a building owner to create longer-term benefits to society remains a complex issue. While mitigation of the hazard by improving existing structures and infrastructure clearly reduces the eventual losses, pre-disaster resilience planning can be a complement to mitigation and can help reduce the overall losses (Wein et al, 2010).

The ShakeOut Scenario found that previous efforts to reduce losses through mitigation before the event have been successful. However there are dozens more actions and policies that could be undertaken at the individual and community levels to further reduce these losses. For instance, actions to improve the resiliency of the region’s water delivery system would reduce the loss from business interruption, as well as reduce the risk of catastrophic conflagrations. Business interruption is a major issue, as these losses are estimated to be nearly half of the total losses from the earthquake. At an individual and business level, actions to secure non-structural items in buildings and retrofitting of existing structures will greatly reduce individual risk. Planning and preparedness can improve personal and business resiliency, and the annual Great ShakeOut and the ShakeOut Scenario are working to achieve the long-term goal of a resilient society.

**Key teaching points:**

* Understanding the basis for, and the limits and uncertainties of the scientific and engineering modeling for the scenario.
* Determining the implications for preparedness where the long-term hazard and risk models are well estimated, but the short-term timing is completely unpredictable.
* Determining the best approaches to convince building owners and government planners that short-term expenditures (e.g. retrofitting, building new structures to a higher standard) will create longer-term benefits to society.
* Analyzing the impact the Great ShakeOut earthquake drills (<http://www.shakeout.org/>) have had on earthquake risk mitigation in the public, private, and government sectors.

**Recommended Reading**

Jones, L.M., R. Bernknopf, D. Cox, J. Goltz, K. Hudnut, D. Mileti, S. Perry, D. Ponti, K. Porter, M. Reichle, H. Seligson, K. Shoaf, J. Treiman, and A. Wein, 2008, The ShakeOut Scenario, U.S. Geological Survey Open File Report 2008-1150. <http://pubs.usgs.gov/of/2008/1150/> .

Perry, S., D. Cox, L. Jones, R. Bernknopf, J. Goltz, K. Hudnut, D. Mileti, D. Ponti, K. Porter, M. Reichle, H. Seligson, K. Shoaf, J. Treiman, and A. Wein, 2008, The ShakeOut Earthquake Scenario—A Story That Southern Californians Are Writing, U.S. Geological Survey Circular 1324, <http://pubs.usgs.gov/circ/1324/> .

Wein, A. Adam Z. Rose, 2010, Economic Resilience Lessons from the ShakeOut Earthquake Scenario, CREATE Research Archive, [NON-PUBLISHED RESEARCH REPORTS](http://research.create.usc.edu/nonpublished_reports), <http://research.create.usc.edu/nonpublished_reports/86/> .

Wood, M. W., 2013, Engaging Californians in a Shared Vision for Resiliency: Practical Lessons Learned from the Great California Shakeout, California Seismic Safety Commission, report 13-02, <http://www.seismic.ca.gov/pub/CSSC_13-02_ShakeOutRecommendations.pdf> .

**Article Citations on resiliency for those with access through their university:**

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**doi:** <http://dx.doi.org/10.1193/1.3581225>

Anne Wein, Adam Rose, (*2011*) Economic Resilience Lessons from the ShakeOut Earthquake Scenario. Earthquake Spectra: May 2011, Vol. 27, No. 2, pp. 559-573. **doi:** <http://dx.doi.org/10.1193/1.3582849>