Preparing for the Big One

A plan released by Eric Garcetti, the mayor of Los Angeles, recommends ways to make the city's buildings, water infrastructure, and telecommunications systems more resilient to a significant seismic event. The goal is to help the city quickly recover from a massive earthquake along the San Andreas Fault, which could affect Los Angeles today in much the same way that it did San Francisco in 1906.

By Catherine A. Cardno, Ph.D.

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A resiliency plan released by the mayor of Los Angeles aims to protect lives, improve disaster response capabilities, streamline the city's short-term recovery, and protect its long-term economic capacity.

THE SAN ANDREAS FAULT SYSTEM, which is formed where the North American Plate meets the Pacific Plate, is actually a network of faults 800 mi long. Extending along much of the length of California, the system is named for its "master" fault, the San Andreas, a right-lateral strike-slip fault that can experience slow creep or sudden, extensive offsets during an earthquake. It is this fault that experienced one of the world's most famous earthquakes, the 1906 San Francisco earthquake, which is thought to have reached a magnitude of 8.3 on the Richter scale, the equivalent of 7.9 on the currently used moment magnitude scale.

Unlike San Francisco, the modern city of Los Angeles has never experienced a truly catastrophic earthquake. But with a network of faults that crisscross the region, including the San Andreas system, it is just a matter of time before Los Angeles will be forced to cope with a massive seismic event. Resilience by Design, a plan released by Los Angeles's mayor, Eric Garcetti, seeks to strategically retrofit buildings and infrastructure within the city and to do so before disaster strikes.

The plan calls not only for the retrofitting of pre-1980 nonductile reinforced-concrete buildings and pre-1980 soft-first-story wood-framed buildings but also for seismic upgrades to protect water systems and telecommunications infrastructure. By making the necessary retrofits before a natural disaster occurs, the mayor hopes to save time, money, and the community itself.

"Challenges of this magnitude simply cannot wait," said Eileen M. Decker, who is a deputy mayor of Los Angeles and wrote in response to questions from *Civil Engineering*. "The cost of not being ready—both in the long term and the short term—could be enough to permanently change Los Angeles, like we've seen in cities hard hit by disasters like hurricanes Katrina and Sandy," she said. "With this in mind, we have to take action now."

The mayor's plan is a significant departure in that it focuses on preparation rather than on response efforts, according to Decker.

Garcetti chose Lucy Jones, Ph.D., a seismologist and science adviser at the U.S. Geological Survey (USGS), for a one-year appointment in 2014 as the city's science adviser for seismic safety. (The city and the USGS entered into the project through a technical assistance agreement by which the USGS would donate Jones's time and the city would donate staff time to support her.) In this role, Jones oversaw the mayor's Seismic Safety Task Force, a group of experts representing academia, industry, business, government, and the community who were brought together to call attention to vulnerabilities and suggest solutions for the mayor to consider in developing his plan.

Jones was a natural choice for the role because of her leadership during the ShakeOut Earthquake Scenario, an exercise held in Southern California in 2008. As part of that exercise, a multidisciplinary team representing the USGS, the California Geological Survey, the Federal Emergency Management Agency, the Southern California Earthquake Center, and nearly 200 additional entities from government, academia, and industry came together to assess the effects of an earthquake of magnitude 7.8 on the southern part of the San Andreas Fault.

Prior to that exercise, the most recent significant earthquake to hit the city was the Northridge temblor, which struck in 1994 with a magnitude of 6.7. Many people within the city still believe that since their buildings withstood that event, they would do the same in a massive San Andreas rupture, according to Jones. However, seismologists do not consider the Northridge temblor a particularly large event. "That message, that Northridge was not a big earthquake, was one that needed explaining," Jones says.

The Northridge earthquake occurred along a 10 mi fault, lasted seven seconds, and caused strong shaking in about 20 percent of the city of Los Angeles, according to the mayor's plan. The earthquake defined in the ShakeOut exercise, which has a magnitude of 7.8 and lasts about two minutes, is the one for which the city must prepare. It is expected to occur along 200 mi of the San Andreas Fault, and its shaking intensity will be the same as during Northridge but will encompass thousands of square miles.

If nothing is done to prepare the city, that earthquake is expected to cause approximately 1,800 deaths and economic losses within Southern California of approximately $213 billion, according to the mayor's plan. Of these losses, it is estimated that $47.7 billion will come from shaking damage, $65 billion from fire damage, $96.2 billion from business interruption, and $4.3 billion from traffic delays.

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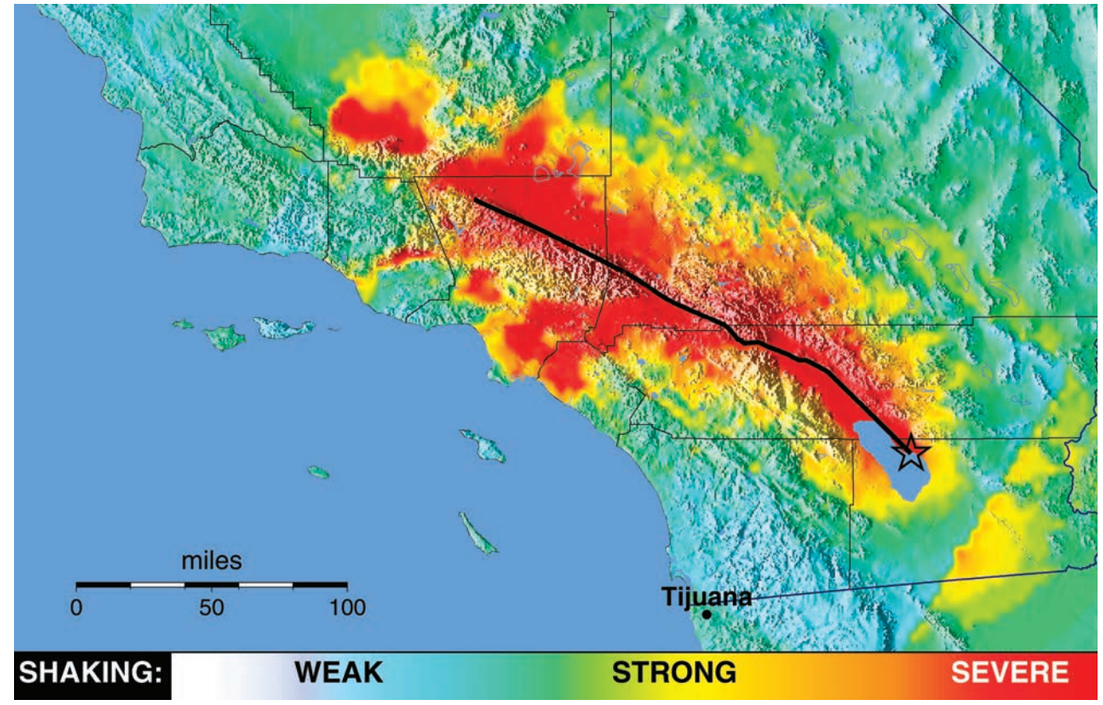
Approximately 1,500 unreinforced masonry buildings and pre-1980 nonductile concrete and soft-first-story wood-framed buildings are expected to collapse in the Los Angeles region if no action is taken, according to the ShakeOut exercise cited in the mayor's plan. The San Andreas Fault experienced surface offsets of as much as 20 ft in the 1906 San Francisco earthquake, and it is expected that infrastructure that currently crosses the fault would be completely severed in the earthquake discussed in the plan, according to Jones. Damage on this scale would seriously compromise Los Angeles's earthquake recovery efforts.

The ShakeOut study found that "there were hundreds, maybe thousands, of things that we could be doing," Jones notes, to improve the city. But trying to address every vulnerability that was revealed "doesn't make sense, because we don't want to protect the economy after the earthquake by destroying it beforehand," she says. Instead, the mayor's plan is focusing closely on developing what she refers to as "urban disaster resilience," which will enable an urban area to continue to function in the wake of a major natural disaster.



The city is preparing for an earthquake that is expected to occur along 200 mi of the San Andreas Fault, have a magnitude of 7.8, and last about two minutes. The shaking intensity will encompass thousands of square miles.

USGS

Given the potential for such significant damage, the mayor's plan focuses closely on those elements deemed the most crucial for protecting lives, improving the city's immediate response capabilities, streamlining the city's short-term recovery, and protecting its long-term economic capacity.

The plan gives particular importance to three facets of the city's infrastructure: buildings, water, and communications.

With regard to the city's building stock, the plan calls for assessments and mandatory retrofits of the types of buildings seen as susceptible to collapse in a major event. A voluntary rating system would encourage building owners to spend money retrofitting their buildings and designing new ones that would be able to withstand a massive earthquake and remain usable.

Soft-first-story wood-framed buildings built before 1980 in accordance with codes less exacting than today's should be retrofitted within five years to strengthen their first stories and to protect them from pancaking during a major seismic event, according to the mayor's plan. Nonductile concrete buildings constructed before 1980 also are singled out for mandatory retrofitting because of their brittleness. Building owners would have a total of 30 years—5 to evaluate and an additional 25 to retrofit—to upgrade their concrete buildings to meet the basic safety objectives set forth in ASCE's standard 41 (*Seismic Evaluation and Retrofit of Existing Buildings*). The mayor's plan also specifies that the types of buildings that are excessively damaged by low-level shaking would have to be retrofitted.

What is more, the plan calls for the adoption of a "back to business" component that would prequalify engineers to inspect buildings and other structures so that they could supplement the city's building inspection force in the event of an earthquake.

"Many people have an unrealistic expectation of how their buildings will perform in a major earthquake," notes Kevin D. O'Connell, P.E., S.E., M.SEI, M.ASCE, an associate principal in the Los Angeles office of the engineering firm Simpson Gumpertz & Heger. O'Connell is also the current president of the Structural Engineers Association of Southern California and was a member of the mayor's Seismic Safety Task Force.

"The biggest change that needs to be implemented is to get the general public talking about earthquakes and the seismic performance of their buildings," O'Connell says.

This conversation is complicated, however, by the public's general assumption that a building built to code is "bulletproof," says Michael Cochran, S.E., SECB, M.ASCE, an associate principal in the Marina del Rey, California, office of the engineering firm Weidlinger Associates, Inc., a former president of the Structural Engineers Association of California, and a member of the mayor's Seismic Safety Task Force.

"The building code really just addresses life safety, which means that you can get out of the building alive," Cochran notes. "If you have a very large population with a very large economy, and most of the buildings have been built to just this standard and thirty percent, twenty percent are wiped out by the disaster and no longer usable, that economy is going to be decimated for years in trying to recover," he says. "If you look at

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a city almost as being like a business entity trying to continue on in its operations [after a seismic event], you need to do whatever it takes to put that business in the best position so that it can move forward after the event." For Los Angeles, these efforts, according to Cochran, need to focus on designing buildings to a higher earthquake performance standard than is possible with the current minimum building code requirements.

The mayor's plan also outlines voluntary measures that could help strengthen the city's building stock. Of greatest significance here is a voluntary rating system for all buildings that would be aligned with the efforts of the U.S. Resiliency Council, a new body that, according to its website, will function as "the administrative vehicle for implementing rating systems for buildings subject to natural and man-made disasters and [will] educate the building industry and the general public about these risks."

The rating system developed by the U.S. Resiliency Council is the first of its kind anywhere in the world to address seismic performance, says Ronald L. Mayes, Ph.D., P.E., M.ASCE, a staff consultant in the San Francisco office of Simpson Gumpertz & Heger and the acting executive director of the council. Conceptually, the seismic resiliency rating system is similar to the U.S. Green Building Council's Leadership in Energy & Environmental Design (LEED) rating system, which assesses the extent to which the design of a building conforms to the principles of sustainable development, Mayes notes.

"We're providing building-specific information that will help decision makers in their quest to solve the resiliency issues either for a city on a citywide basis or for an individual owner for a particular building," notes Mayes. "We're providing a lot of information that can be used to help with the bigger picture of resilience questions," he says. "Is a building going to collapse in the design earthquake or is it going to be usable? Could it be used for shelter after an earthquake?"

The rating system "will encourage developers and owners of buildings to build to a higher standard than the basic building code," Mayes notes. "What we're hoping is to educate the public," he explains. "When they're looking to rent or lease a building, they get information on the LEED rating, they get information on asbestos or lead paint, but they know nothing about how the building will perform in an earthquake—so the rating system will be that missing piece."

The second major focal point of the mayor's plan concerns the resiliency of the city's water infrastructure, as well as access to water in the wake of an earthquake, particularly for fighting fires.

"We have an almost unique dependence on external water," Jones says. "L.A. gets eighty-eight percent of its water—[last] year it [was] eighty-eight percent—from outside the region, and every drop of that has to cross the San Andreas Fault to get here."

"It's the water system that could really shut down our economy," Jones continues. "We have six-month storage on this side of the San Andreas as long as we have pretty strict rationing [and full reservoirs], but the analysis suggests that we're going to lose all of our aqueducts at the same time . . . and a new analysis suggests that it's going to take up to eighteen months to get all the aqueducts back." As she sees it, "There just won't be water here."

To create a backup water system that could be used for firefighting purposes in the immediate aftermath of a massive earthquake given the anticipated distribution pipe breaks, the mayor's plan calls for the development of an alternative water system, which will require a detailed knowledge of streams, ponds, lakes, and even swimming pools.

"The fire issues are always big in a big earthquake," Jones says. "In L.A. we get the possibility of combining the earthquake with the Santa Ana winds, which puts fire at a whole new level."

Other efforts to strengthen the water system include seismic upgrades to protect aqueduct and water storage systems, a progressive replacement of older pipes with a network of pipes offering seismic resilience, and the development of local water supplies.

"Earthquakes have always been recognized as one of the greatest risks to the [L.A.] water system," said Craig Davis, Ph.D., P.E., G.E., M.ASCE, a trunk line design manager for the Los Angeles Department of Water and Power (LADWP) who is heading the technical efforts to develop a system that can make the city's water network more resilient. He was also a member of the mayor's Seismic Safety Task Force and chairs the executive committee of ASCE's recently established Infrastructure Resilience Division. Davis wrote in response to written questions posed by *Civil Engineering*.

"The difficulty lies in the extreme seismic hazards that threaten Los Angeles, coupled with the continued evolving knowledge gained through scientific studies," Davis said. The LADWP has been working for the last century to resolve seismic risks while maintaining water supplies that are reliable on a day-to-day basis, according to Davis.

To protect the water carried by the only city-controlled aqueduct, which crosses the San Andreas Fault, the LADWP is currently "designing a very ductile high-density polyethylene pipe to reduce the risk of losing all water through our aqueduct in the event of a San Andreas Fault rupture," Davis explained. The pipe will take up a small portion of the existing Elizabeth Tunnel, which crosses the San Andreas Fault. The polyethylene pipe should be able to withstand an offset of as much as 9 ft and still bring safe drinking water to the city.

Replacing aging pipes within the city's distribution network is complicated by the sheer size of that network, which includes more than 7,000 mi of piping, noted Davis. But efforts are indispensable if seismic resilience is to be attained, and the work is already under way as part of standard maintenance upgrades.

"The main business disruption costs [revealed] in the ShakeOut are from damage to distribution pipes preventing individual businesses from getting water," Jones notes.

Current LADWP efforts include setting priorities in replacing critical pipe segments and using materials and designs that are considered "seismic resistant," Davis said. This includes a 2013 pilot program to incorporate into the LADWP system ductile iron pipe developed in Japan that is earthquake resistant. "The [pipe] had never been used outside of Japan even though it has a 40-year history of experiencing large earthquake-induced ground movements without damage—and it has not even leaked after earthquake forces have caused the pipe to move up to 6 to 9 feet," Davis noted.

The mayor's plan also calls for the creation of a task force that would be charged with developing measures to impart seismic resilience to the city's water supply. The group would be established by water supply agencies within the region and would develop a collaborative approach for protecting the city's water supply and water reserves.

It is noteworthy that the plan also calls for reducing reliance on outside water through the development of local water supplies by, for example, storm-water capture, water conservation, and water recycling. "The best defense against the water coming across the fault is to not need that water in the first place," Jones notes.

IT IS NOTEWORTHY THAT THE PLAN ALSO CALLS FOR REDUCING RELIANCE ON OUTSIDE WATER THROUGH THE DEVELOPMENT OF LOCAL WATER SUPPLIES BY, FOR EXAMPLE, STORM-WATER CAPTURE, WATER CONSERVATION, AND WATER RECYCLING.

Within the third category, enhanced reliability of telecommunications networks, the mayor's plan focuses on protecting power systems at fault crossings, requiring stronger cell towers that would remain operational in the immediate aftermath of a seismic event, and fostering cooperative efforts by service providers to maximize telecommunication coverage during and after a disaster. "There wasn't as big a vulnerability as I had thought there might be going into it," Jones says. "So that was good news."

The city is in the process of developing a free Wi-Fi system as a public service to all of its residents and would use solar power, according to Jones. This would act as a backup disaster communication system because it would not rely on the electrical grid. Because Wi-Fi based on solar power would enable residents to communicate over the Internet, the burden on cell phone providers in the immediate aftermath of an earthquake would be greatly lessened.

Furthermore, the mayor's plan calls for the advancement of an early warning system for earthquakes. It would require the city and the USGS to begin implementing such a system in Southern California and would see the city working with members of Congress to support an early warning system for the entire West Coast. Such a system would provide sufficient warning for gas line shutoff valves to engage at fault crossings and would enable other equipment and pipelines to shut down before the most damaging earthquake waves arrived at highly sensitive locations.

Implementation of the mayor's plan will unfold in a variety of ways. Executive orders will be supplemented by ordinances from the city council and by the work done by outside groups. The state legislature also will be involved, according to Jones.

Of course, any effort to effect significant change will require money. "The engineering solutions can be resolved, but there is a cost involved," Cochran says. "What is the risk that people are willing to take to have all of this implemented?"

According to the mayor's plan, incentives to make the recommendations a reality could include adapting the requirements for particular sites in the interests of seismic safety, waiving fees, offering tax exemptions and credits, providing access to private lending sources, and creating bond measures.

"We have hundreds of faults with twenty million people in Southern California," Jones says. "Swiss Re [one of the world's largest reinsurance companies], has ranked L.A. as fourth in the world for seismic risk—this is after Tokyo, Jakarta, and Manila," she notes. "So of all American cities, we have the [most] to lose."

These losses would extend to a number of industries and would not be confined to, say, the entertainment, aerospace, and technology companies in Los Angeles. A number of other industries that thrive in urban environments also would be affected.

The good news is that Los Angeles is not alone in its desire for disaster resilience. Helping communities quickly recover from natural disasters is to an increasing extent gaining the attention of both the public and the private sector. President Obama's Climate Action Plan, released in 2013, called for the National Institute of Standards and Technology to develop a disaster resilience framework for communities. The framework would cover all natural disasters, not just earthquakes. In a similar vein, the Rockefeller Foundation's program 100 Resilient Cities was created to help cities around the globe better meet the physical, social, and economic challenges of the 21st century.

The mayor's plan for Los Angeles and the city's participation in 100 Resilient Cities are "inextricably linked," according to Decker. "The Resilience by Design report, spearheaded by Dr. Jones, was just the first step," she said.

Support from 100 Resilient Cities is expected to help Los Angeles implement the mayor's plan and hire an executive who would oversee the city's efforts to increase resiliency, according to Decker.


Cardno

"Our partnerships with Dr. Jones, the USGS, and the Rockefeller Foundation's 100 Resilient Cities program highlight the importance of collaboration in taking on important issues," Decker said. "We are incredibly grateful to all of them for helping make L.A. a stronger and more resilient city." **CE**

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