The ShakeOut Scenario

A Hypothetical M7.8 Southern San Andreas Fault Earthquake

By Keith A. Porter, P.E., Ph.D.

Under the leadership of the US Geological Survey and California Geological Survey, a group of more than 300 practitioners, academics, and government technical experts from more than 50 organizations prepared the most extensive earthquake planning scenario ever created for the United States. It was desired that the scenario event occur in California; be scientifically realistic and consistent with current knowledge; be large enough and close enough to population centers to have regional, long-term consequences worth planning for; be likely enough not to be dismissed as a rare or extreme event; and that it comprise a single, specific outcome, as opposed to a probabilistic range. That is, it represents one rupture and one outcome in terms of shaking intensity and ground failure, building damage, casualties, and other consequences. This overview summarizes the work of those 300+ experts, and it is therefore not possible to give proper credit for their contributions. The interested reader is referred to Jones et al. (2008) and other detailed studies cited in the online version of this article (**www.STRUCTUREmag.org**) for further detail.

Earth Science Aspects

The scenario begins with a Magnitude 7.8 (M7.8) event on a 300 kilometer segment of the Southern San Andreas Fault, beginning at the Salton Sea (*right edge of Figure 1*) and rupturing north to Lake Hughes (*left side of Figure 1*) near Interstate 5. The Southern San Andreas is known to have generated earthquakes of approximately this size on an average of every 150 years. The fault segment where the rupture initiates (from Bombay Beach to the San Gorgonio Pass) last ruptured in 1680, the middle segment (around the San Gorgonio Pass) in 1812, and the northernmost third was part of the 1857 Ft Tejon earthquake.

Three independent finite-element models were created to model the propagation of seismic energy from the rupture surface through the earth's crust and up to the earth's surface, resulting in 3-component ground-motion time histories throughout the affected region. Measures of shaking in various forms Peak Ground Acceleration, Peak Ground Velocity (PGA, PGV), 5%-damped spectral acceleration response at several periods) were extracted from these models; measurements were in general agreement. The URS model was used for the final maps of shaking (*e.g., Figure 2*). Such physics-based modeling of ground motion contrasts with the use of empirical attenuation relationships. Although attenuation relationships are probabilistically accurate on average – and generally agree with the physics-based modeling employed by the scenario – they tend to ignore directionality in the fault rupture and details of path by which the ground motion propagates from the fault to various points on the earth's surface. Directionality matters here: even the latest attenuation relationships would fail to capture the strong, long-period motion affecting downtown Los Angeles (*e.g., Figure 2, right*).

Figure 1: Scenario fault rupture. Height of the red fence indicates the fault offset at the surface. At Bombay Beach, where the fault last ruptured in 1680, the surface slip is 13 meters (40 feet).

Physical Damages and Socioeconomic Losses

FEMA's HAZUS-MH software was used to characterize overall effects on the building stock, and resulting deaths and injuries and some lifeline damage (Porter and Seligson 2008). Eighteen additional studies were performed to examine physical damage to various aspects of the built environment in more detail. Each study was performed either by a small research team, an expert panel, or both. These included 10 lifeline studies: telecommunications, highways, ports, wastewater, surface streets, oil and gas pipelines, rail, mass transit, water supply, dams, electric power, and hospitals. Four building types were examined in detail (unreinforced masonry, older concrete buildings, highrise steelframe construction, and woodframe buildings). Finally, special studies were performed to consider elevators, hazardous material release, critical facilities in Palm Springs (a particularly strongly shaken community), and fire following earthquake.

In each case, researchers were provided with the earth-science results described above, and asked to posit a single outcome for their subject area and to describe two or three measures that might realistically reduce the negative effects of the scenario earthquake. In some cases the special-study authors used computer models to generate their scenario outcomes, but always applied their experience and engineering judgment to arrive at a final result. Lifeline interaction was considered to the extent practical. In many cases, researchers were provided with physical damages posited by other groups. For example, early among the special studies were studies to characterize the performance of electric power, water supply, and highways, which have downstream impacts on fire following earthquake, telecommunications, elevators, and other aspects of the built environment.

Highrise Buildings

Space does not permit providing details of most of these studies, but a brief summary of one study is of interest: highrise steelframe

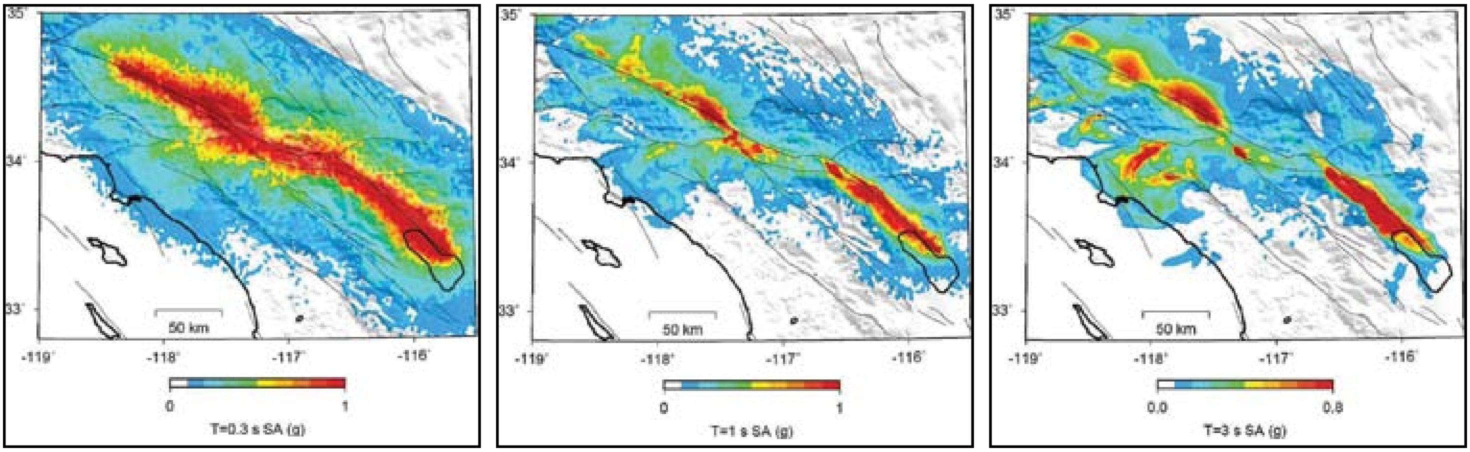

Figure 2: 5%-damped spectral acceleration response at 0.3-second (left), 1.0-second (middle) and 3.0-second (right) periods. Maps were also created of peak ground acceleration, peak ground velocity, Modified Mercalli Intensity, liquefaction, and landsliding. 3-component accelerograms were also used in some subsequent analyses.

building damage. Note that steelframe buildings are posited to perform much better than unreinforced masonry buildings, older concrete buildings, and some other types. The highrise study is summarized here primarily because readers may be interested in the sophisticated modeling employed. Researchers at the California Institute of Technology created 3-D nonlinear finite element models of 3 highrise steelframe buildings (*Figure 3*): an 18-story roughly rectangular building designed to meet the 1982 Unified Building Code (UBC), the same building designed to meet the 1997 UBC, and a 19-story L-shaped building designed to meet the 1997 UBC. All three were analyzed using FRAME3D (Krishnan 2003), a finite element analysis program created at Caltech that treats material and geometric (P-delta) nonlinearities. The models were subjected to the 3-component waveforms described above, at each of 784 points on an approximately 2 kilometer grid. Each building was analyzed at each point, in each of two orientations, and each with and without brittle (pre-Northridge) moment-frame connections, for a total of 9,408 nonlinear time-history structural analyses.

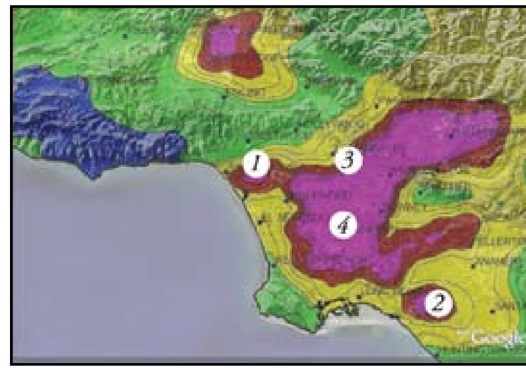

Figure 4: Locations of 4 out of the 5 hypothetical steelframe building collapses. Color overlay from Krishnan and Muto (2008).

Maps were created showing peak transient interstory drift at each gridpoint and each model. *Figure 4* shows the drift value averaged over the 3 buildings, 2 orientations and 2 connection susceptibilities. In the figure, yellow corresponds to peak transient interstory drift of 2.5 - 5.0%, red to 5.0 - 7.5% drift, and dark pink to drift in excess of 7.5%. Consistent with FEMA 356 (ASCE 2000), drift in excess of 5% is deemed likely to result in red tagging, and drift in excess of 7.5% is deemed to be associated with collapse.

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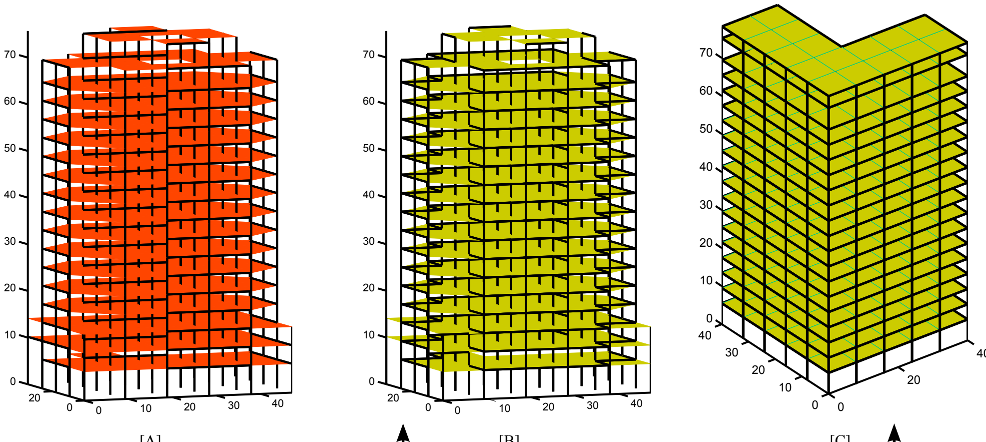

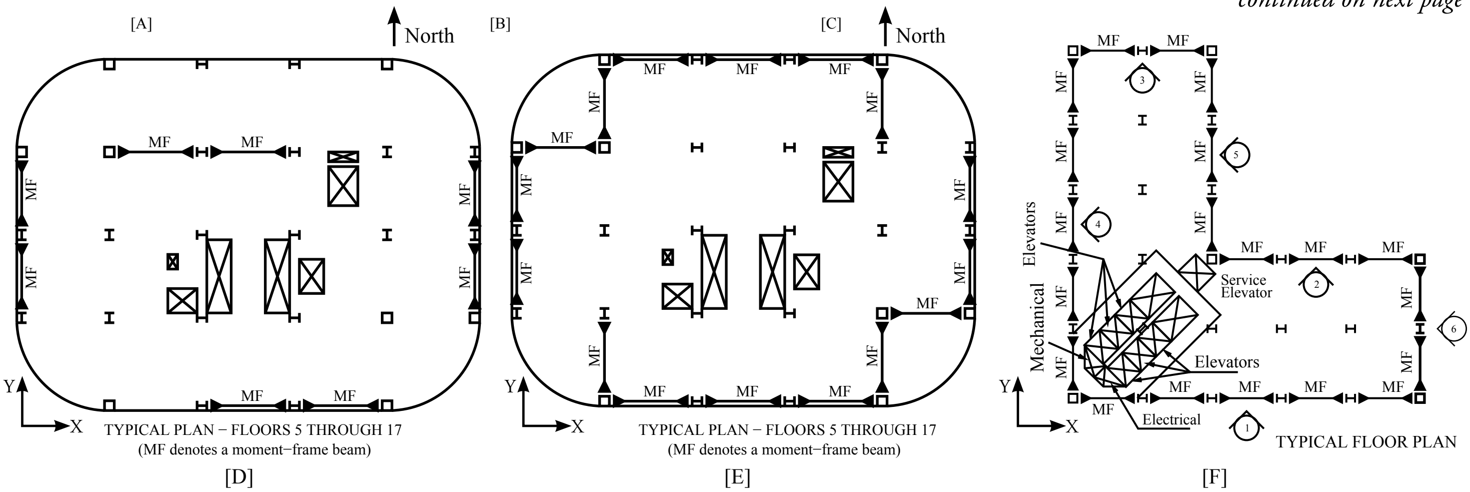

Figure 3: Steelframe buildings modeled by Krishnan and Muto (2008).

Considering the existing stock of steelframe buildings, the Caltech authors considered 8 collapses to be realistic for a planning scenario, while a panel of experts drawn from the SAC Steel project (**www.sacsteel.org**) deemed it realistic that at least one highrise steel building would collapse. The scenario posits five collapses in Los Angeles, San Bernardino, and Orange Counties; four of these locations are shown in *Figure 4*. In each case, there are pre-1994 highrise buildings located within 500 meters of the selected site.

Fire Following Earthquake

The largest single cause of loss in the scenario is the hypothesized destruction of 200 million square feet of buildings due to fire, equivalent to 130,000 single-family dwellings. Scawthorn (2008) has developed a sophisticated stochastic computer model of fire ignition, discovery, reporting, response, and suppression (Scawthorn et al. 2005), illustrated in *Figure 5*. Applying to it the available data from the scenario, Scawthorn posits fires to result in $65 billion in property damage and 900 deaths. The catastrophic fire losses occur largely because the number of fires – 1,600 ignitions requiring fire-department response, of which 1,200 require more than one engine to suppress – exceeds the region's total firefighting capability, at a time when the water supply system is severely impaired by pipeline damage and the loss of electric power, and when the 911 system is impacted by an overwhelmed telecommunications system. This damage occurs despite the fact that the earthquake is not posited to occur during Santa Ana winds, which would make the situation much worse.

Other notable aspects of the physical damage and socioeconomic consequences of the scenario include:

- 1,800 deaths and 53,000 nonfatal injuries requiring emergency-room treatment. For a sense of scale, the 8 counties in the strongly shaken area are home to 20 million people, which means that approximately 1 in 10,000 residents is killed and 1 in 400 is injured to the extent of needing emergency-room care.
- Hospital damage resulting in the loss of up to ⅔rds of hospital beds in some counties.
- Economic losses of approximately $213 billion (equivalent to 13% of the $1.6 trillion annual gross regional output – 1.6 months of output – of the 8 strongly shaken counties). This figure results from costs to repair shaking-related damage to buildings ($35 billion in building repairs and $11 billion in content and inventory loss), fire following earthquake ($40 billion in building damage and $25 billion in content loss), lifeline damage ($2 billion), business interruption ($96 billion), traffic delays ($4 billion), and other lesser costs. As another point of reference, the building inventory in the 8 affected counties has a replacement cost of approximately $2 trillion.
- Total economic loss of more than 45,000 buildings (1% of the region's total) from shaking-related effects, with 300,000 more (1 in 16 buildings) requiring repairs in excess of 10% of the building's replacement cost.
- Complete economic loss of more than 900 unreinforced masonry buildings.
- Collapse of 50 older concrete buildings.
- Collapse of 5 highrise (10+ story) steel buildings. There are approximately 800 buildings in the area of 10 stories or greater.
- Temporary loss of electric power throughout Southern California, lasting from a few hours to several days.
- Nearly 300,000 sewer leaks or breaks.
- Loss of water supply in the strongest-shaken areas lasting from a few days to several weeks, partly because of 350,000 water pipeline leaks and breaks, partly from the loss of electric power to operate pumps, and partly from physical damage to pumps and other water supply or treatment equipment.
- Damage to water supply aqueducts and canals at 32 places where they cross the fault.
- Widespread damage to highway abutments and bridges taking up to 7 months to repair, and damage to two major interstates (I-15 and I-10) where they cross the fault.
- Damage to 3 dams serious enough to warrant emergency evacuations.
- Three train derailments and 10-20 rail breaks at fault crossings, resulting in the loss of freight rail service for up to 2 weeks, followed by periodic rail damage due to afterslip.
- Dozens or hundreds of people trapped in elevators for several hours or more.
- Four hazardous material releases (1 ammonia and 3 chlorine gas releases) affecting 315,000 people in Los Angeles, San Bernardino, and Riverside counties.
- Widespread impairment of telecommunications, largely because call volume overwhelms service capacity, and because of damage to fiber optic lines and other equipment.

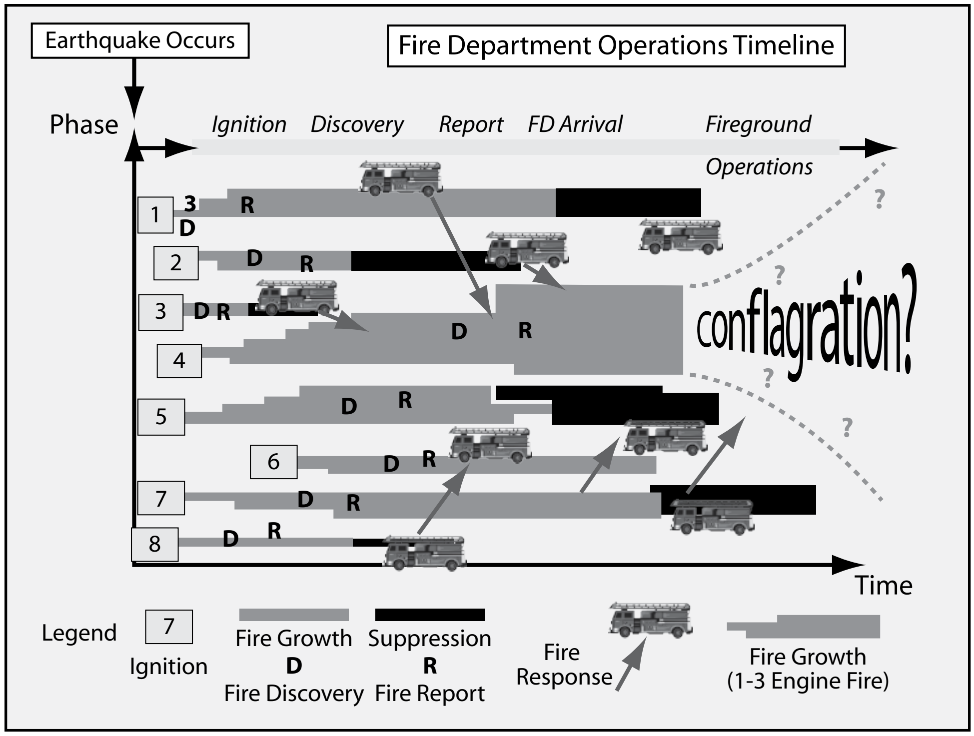

Figure 5: Fire department operations timeline (Scawthorn et al. 2005). The horizontal axis represents time, beginning at the time of the earthquake, while the horizontal bars each depicts the development of one fire, from ignition through growth or increasing size, with the width of the bar indicating the size of the fire.

Emergency Response

Two scenario researchers characterized the emergency response and communication activities that take place at 5 different time periods after the earthquake in each of 17 response functions, which can be generally categorized in 8 groups: crisis information (by news media, scientific organizations, emergency response organizations, etc.); search and rescue; victim services (shelter, food and water, etc.); traffic and law enforcement; emergency operations centers; fire suppression; emergency medical services; and restoration of lifelines. For each response function, the authors describe in a matrix the activities in the minutes after the earthquake; 30 minutes later; 2 hours after the earthquake; and 1, 3, and 7 days after the earthquake. *Table 1* presents as an example the emergency-response matrix for firefighting.

Table 1: Sample emergency response matrix: firefighting (Mileti and Goltz 2008).

	Organized	Spontaneous
Impact (2-5 Min.)	None.	Escape Fire.
30 Minutes	Begin to locate fires. Priorities being considered.	Localized fires being fought with any available resources such as fire extinguishers.
2 Hours	<u>Western Region</u>: Fire departments responding to ignitions within jurisdictional boundaries. <u>Eastern Region</u>: Fire deparments are working to suppress fires on a prioritized basis while requesting mutual aid to fight additional fires. Problems in fire suppression due to low water pressure (water system damage) and transportation. (Fire departments cannot get equipment across fault rupture or disrupted roads.)	Small fires that were discovered early have been extinguished. Larger fires are either being fought by local fire departments or are burning out of control. While some neighborhood residents are assisting organized fire fighters, local emergent response is currently focused on other response needs (such as transport of injured).
24 Hours	First wave of fire mutual aid equipment and personnel arrive at some accessible locations of critical incident. Other areas that have been seriously damaged and have fires are inaccessible.	Emergent groups continue to fight smaller fires ignited due to aftershocks and accidents. Larger fires are now mainly being fought by organized fire services.
72 Hours	Most fire mutual aid in place. Most of the major fires in the impacted areas are either being fought or have been extinguished.	Groups of residents are monitoring their immediate areas for fires. They suppress the small fires themselves but report the larger ones to local fire departments.
1 Week	Most major fires in the region have been extinguished. Fire departments and mutual aid responders are available if needed.	Groups of residents are still monitoring their areas for the eruption of fires.

Summary and Conclusions

A hypothetical M7.8 earthquake on the Southern San Andreas Fault was studied by more than 300 leading academics, professionals, and government experts, for purposes of creating a realistic, not-worst-case, earthquake emergency planning scenario. The research team found it to be realistic that such an event kills 1,800 people, seriously injures 53,000, and produces losses in excess of $200 billion (6% of the annual gross regional product), of which the largest contributors are fire following earthquake ($65 billion), and business interruption ($96 billion). Despite the size of these losses, they would be much greater were it not for steadily improving buildings codes, widespread mitigation efforts for buildings, and extensive efforts by highway and roadway departments and various utilities to prepare for and reduce the impacts of future earthquakes.▪

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