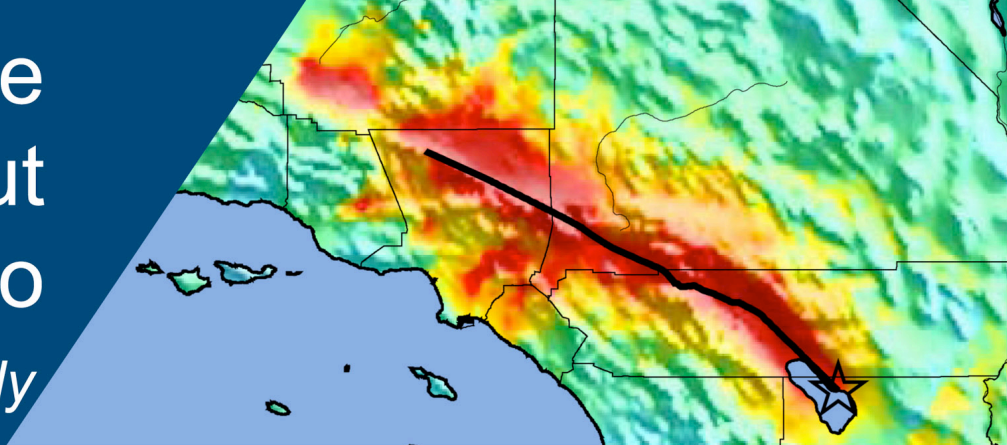


The ShakeOut Scenario

Supplemental Study



Elevators

Prepared for
United States Geological Survey
Pasadena CA

and

California Geological Survey
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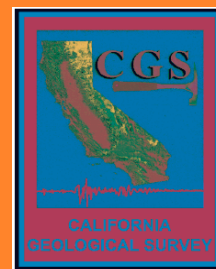
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Note: over the course of the ShakeOut Scenario, the project name evolved. Where a study mentions *the SoSAFE Scenario* or *San Andreas Fault Scenario*, it refers to what is now named the ShakeOut Scenario.

Assessing the impacts of a M7.8 Southern San Andreas Fault earthquake: elevators

by

Anshel Schiff
Precision Measurement Instruments

I have been a member of the ANSI A17.1, Earthquake Safety Committee for about 30 years to provide guidance related to earthquake issues. Notwithstanding my long tenure on the committee, my knowledge of elevators is limited. Following two earthquakes I have conducted surveys of the elevator maintenance companies to assess elevator performance. The content of this report reflects my personal views.

Executive Summary

- Elevator damage will probably have less of an impact than items listed below
- Loss of electric power could cause large numbers of elevator occupants to be trapped and require first responders to remove them from the elevators
- The tripping of seismic switches would require large numbers of elevators to be inspected by elevator mechanics before being put back into service and cause long restoration times
- The slow restoration of elevator function in critical facilities, such as hospitals, is a life-safety issue
- Some measures that could mitigate the effects identified above are discussed

Summary of Past Performance

Injuries in elevators due to earthquakes are extremely rare and can be counted on one's fingers. Based on survey reports, damage rates are low with about 200 elevators damaged in the Loma Prieta earthquake and 700 in the Northridge earthquake. Damage assessments however, were based on reports from companies that service only about half of the elevators in the area and completeness of the reports that were received is questionable. Because damage reports did not indicate details about the cause of the damage and buildings where damage occurred were not identified, damage could not be correlated to shaking intensity. Following the 1971 San Fernando earthquake, public policy changed and damage reports became public documents and could be used by ambulance chasers resulting in increased liability exposure and a drop in report submittals. The trapping of people in elevators has not been a documented problem, but this is probably due to luck and circumstances.

The most common types of significant damage were counterweights coming out of their guide rails, fouled ropes or governor cables, cable damage to door operating mechanisms, and movement of equipment or control cabinets. The largest risk of severe injury is when safety systems are overridden (probably by building engineer) and the elevator put into

service after a counterweight came out of its guides. This can result in the counterweight striking the elevator cab. (This has happened with unoccupied elevators.)

From an emergency response perspective, the loss of electric power causes the elevator to stop and trap occupants, which usually requires rescue personnel for extraction.

Demands on elevator mechanics to inspect elevators in buildings with tripped seismic switches will exceed their ability to respond in a timely manner. Traffic congestion will exasperate the problem. This will even be a problem for critical facilities, such as hospitals, that are given high priority for service.

Background on Elevator Industry

The elevator code is a very proscriptive code so that for elevators in low-rise structures the code effectively provides the design using parts from elevator supply companies.

The industry has a two-tiered structure in which one tier consists of large elevator companies with engineering staffs that provides the elevators in high-rise structure as well as other structures. The second tier consists of smaller companies that provide elevators for low-rise structures. These smaller firms often have limited engineering capability.

Large elevator companies also generally provide maintenance service for elevators. There are many small, independent elevator maintenance companies.

California was the first jurisdiction to adopt seismic elements into its elevator code and the national code followed several years latter. Recently California adopted the ANSI 17.1 code with some modifications. Unlike the ANSI Code, when the seismic elements were introduced into the California code, they required some retrofit to improve seismic performance of existing elevators, but there was a procedure that allowed this provision to be circumvented.

Background on Elevators

Other than for anchorage, the code generally uses a maximum of 1/2 g horizontal acceleration for linear performance of structural elevator components. Because earthquake induced motions in buildings can exceed this level, two seismic safety devices were incorporated into elevators, a counterweight-derail detector and a seismic switch. As the name indicates, the derail detector sense this conditions and initiates a shut down procedure.

The seismic switch is a device that senses acceleration and shuts down the elevator if the acceleration exceeds the trigger level. If the counterweight-derail detector triggers, the shut down procedure is modified. While horizontal acceleration initiate damage to elevator components, the acceleration sensed by the switch is orientated in the vertical direction and the level is set below the expected damage threshold for horizontal motions.

The seismic switch serves two functions. It will shut down the elevator if the level of the vertical motion would indicate that horizontal motion would approach the damage threshold. It also is configured to shut down the elevator early so that it can be stopped and the doors opened before it is stopped for some other reason. The seismic switch sensor is orientated in the vertical direction to sense the arrival of the P wave, which precedes the arrival of the damaging S waves. If the site is some distance from the epicenter, there will be a short time before the structure response to the S wave build and the arrival of the P wave, so there may be an opportunity for the elevator to stop at a floor, open the doors and allow passenger to leave the elevator and avoid being trapped. It is also hoped that this will occur before there is a loss of power that would immediately stop the elevator and trap the passengers. It should be noted that because of the confinement in a small space, the general fear of many of elevators, and the added concerns after an earthquake, being stuck in an elevator after an earthquake holds a level of terror for many.

The performance of the seismic switches can be problematic in that extraneous non-earthquake vibrations, such as nearby construction or truck traffic vibrations can cause a false trigger that disrupts elevator service. A more serious problem is that the switch may trip in a critical facility, such as a hospital, that needs the elevator to provide critical services. After a severe earthquake, hospitals will have extraordinary demands placed on them. The impact on the ability of a hospital to provide service, when they will have to transport patients between floors using the stairs may be very severe. The switch is designed to trip below the damage threshold, so that even though the switch tripped, there may be no damage. The intent of the code was to have the elevator checked out by an elevator mechanic prior to being put back into service after the seismic switch trips. When this requirement was initiated, hospitals and buildings with many elevators typically had a resident elevator mechanic on site. With the switch to electronic from electrical mechanical controls and the increase in system reliability, resident elevator mechanics are now rare. It may take hours for a mechanic to get to the hospital, even if it is his or her first service call. After the Loma Prieta earthquake, it took over two hours to go from campus to my home, which is normally an eight-minute drive.

The elevator code committee has developed a procedure that provides guidance for a non-elevator mechanic to safely put elevators back into reduced-speed service without an inspection by an elevator mechanic. Unfortunately, it has not been able to get approved for various reasons. It seems to me that it provides a high degree of safety. It must be realized that the loss of elevators in a hospital is itself a life-safety issue. It should be noted that some medical facilities do provide some elevators with emergency power, so that the disruption of elevator service due to the action of the seismic switch will be the main cause for the loss of service.

For the purpose of this report, elevators will be divided into two classes, direct plunger lift hydraulic elevators and all others. Two and three-story buildings typically use hydraulic elevators. For buildings less than about 7 stories, hydraulic elevators cost less than traction machines. The actuator on a direct plunger lift hydraulic elevator may

extend below the foundation of the building. From the maps provided, the area east of the fault has a moderate susceptibility of liquefaction, and this could impact the hydraulic elevators with actuators that extend below the building foundation. It should be noted that hospitals in California typically have tractions elevators and seismic switches.

It should be noted that the dynamic response of a building can amplify the ground motion. Peak horizontal acceleration at the top of moderate height buildings has typically exceeded the peak horizontal ground motion by a factor three and often by a factor of four. Thus, horizontal accelerations will exceed the 1/2g used in the design of elevators.

Some elevators are provided with a means to lower the elevator to the nearest floor after power is lost and open the doors. It would appear that this capability is rather uncommon. In tall buildings some elevators will be provided with emergency power.

An elevator mechanic would be able to mechanically lower a stopped elevator to a landing from the machine room. He or she would then be able to open the doors at the landing to free trapped passengers.

Summarize of Assets Exposed to Loss

Because elevators are inspected by a governmental organization (state, county or city), an official elevator count should be available. The request for this report was initiated just before the Christmas-New Years holidays so this information could not be obtained in the two week submittal deadline. Because of the size of the jurisdiction relative to the areas that are susceptible to earthquake effects, it is not clear that this information would be of much value. It is important to note that the main impact on elevators in a post-earthquake environment will be disruption to hospitals and the need to extract people trapped in elevators because of the loss of power rather than repair costs. The power loss can extend over a much larger area than that impacted by the earthquake and distant from the power system elements that were damaged. Because I come from an academic background, I have no information on repair costs. It should be noted that the magnitude of the earthquake in the earthquake scenario is larger than actual earthquakes observed, so the longer period of shaking may cause more damage than previously observed.

Generally, elevators are inspected by the state in California. The inspector indicated that in the general area of the earthquake there are about 100,000 conveyance devices that include passenger and freight elevators, moving walkways, and escalators. There are about 60,000 elevators (freight and passenger). This does not include Los Angeles, as they have their own inspectors. In Los Angeles there are about 26,000 conveyance devices. Assuming that the same percentage are elevators, this would mean that there are about 16,000 elevators. Thus, in Los Angeles if all power was suddenly disrupted in the scenario event, and from 5% to 10% of the elevators were occupied at the time, about 800 to 1,600 elevators would be stopped containing one or more passengers.

Summarize of Vulnerability of Assets

The vulnerabilities of elevators are discussed above. Injuries in earthquakes related to elevators are extremely rare. Damage to elevators has been very small compared to the large number of elevators in service, although there has not been a study to relate damage to ground motion intensity or building characteristics. Extensive disruptions can be expected from the action of seismic switches and the loss of power. Restoration of service after a seismic switch has triggered requires that the elevator be inspected by an elevator mechanic. This will overwhelm the available resources and transportation delays will exasperate the situation. Generally fire service personnel have been trained to extract people who are trapped in elevators. With proper training elevator doors can be opened without damaging the doors and people can be extracted. In general, local building “engineers” will not know how to get elevator doors open without caused expensive damage.

Depict a Realistic Damage Scenario

As noted above, it is my view that it is not the damage to elevators that is most important. Rather, the disruption of service associated with the loss of power and delays in restoring service that requires the inspection of an elevator mechanic is the major problem. The lack of restart procedures for critical facilities, such as hospitals, could have a significant life-safety impact. The timing, location and size of the scenario event suggest to me that large numbers of people will be trapped in elevators. While it is my view that people being trapped does not present a life-safety issue, the demands on elevator mechanics and fire fighters will result in significant damage to elevator doors that are prided open by people who are nor familiar with methods to open doors and a potential hazard if not executed properly, as discussed below.

Lifeline Interaction

Two lifeline interactions can affect the performance of elevators. The loss of power will have a major impact on elevator performance. Some high voltage power system components have been demonstrated to be very vulnerable to earthquake damage, as demonstrated in the estimated extent and duration of power disruptions in the earthquake scenario. Although there is an improved voluntary standard (IEEE 693) that should improve power system performance as qualified equipment finds its way into service, this will be a 20 to 30-year process. A protective devise in most power transformers can be activated by earthquake motions and shut down transformers and the power system, even if there is no damage. The disruption of high voltage system elements, such a power transformers, at a given location can impact a large area distant from the power system substation. Since the affects of power system disruptions are instantaneous, the loss of power can eliminate the benefits of seismic switches that allow passengers to quickly exit an elevator. The timing of the loss of power is critical, as a 5 to 10 second delay would allow elevators to stop, open doors and avoid trapping passengers. Unfortunately the times of power disruptions cannot be predicted.

For the disruption of power to trap people in elevators requires several factors to come into play. The earthquake must be close to a location that has many elevators, such as a large city. The earthquake must occur at a time when elevators are being used. The disruption of power must occur within a 5 to 10 seconds after the shaking starts, so that the action of the seismic switch to stop the elevator and open the doors has been disrupted. Historically, we have only had three earthquakes that have impacted major metropolitan areas: 1971 San Fernando, 1998 Loma Prieta, and 1994 Northridge earthquakes. The San Fernando earthquake occurred at 6:01 in the morning. The Loma Prieta earthquake occurred a few minutes before the World Series was to start at about 5:00 pm. The Northridge earthquake occurred at 4:30 am. While the number of people trapped in elevators in these earthquake is not known, and the timing of the loss of power relative to the start of shaking is not know, the lack of press reports of people being trapped in elevators suggests that large numbers were not trapped. The timing of these events suggests a large factor that may have contributed to the few people trapped in elevators.

Delays in transportation due to traffic congestion will probably significantly impact timely service to elevators after earthquakes. There are numerous examples in which fire service personnel were unable to negotiate traffic even with flashing lights and sirens. I have found that in earthquake investigations after moderate earthquakes in urban areas, traffic can be jammed for days from damage to just a few important roads.

Mitigation

Mitigation actions have been ordered by my assessment of their importance, ease of implementation, and estimate of the success of their implementation. Items with an* should be given high priority.

1* Restoration of Service after Triggering without Inspection in Hospitals and other Facilities where Disruption is a Life-Safety Issue

It is my view that the proposed guidelines for restarting elevators that were stopped due to the action of a seismic switch provide a reasonable degree of safety for all concerned and should be implemented for facilities where the loss of elevator service is a demonstrated life-safety issue.

As noted above, elevators are vital to the operation of hospitals and there are currently no procedures for restoring service without an elevator mechanic that conform with the intent of the code. Normal elevator maintenance service is more or less uniformly distributed over time and the number of service personnel in an organization reflects this situation. After an earthquake there is a sudden demand to inspect many elevators at once, so that elevators mechanics will probably not be available in a timely manner. There service can be delayed traffic congestion.

It should be noted that elevator companies feel strongly that only elevator mechanics should enter an elevator hoist way because of the dangers that are involved. Experience

shows that when there are long delays in restoring service, a building “engineer” can be very resourceful in getting the system to operate, but their resourcefulness may go beyond their knowledge of the safe operation of elevator systems and result in additional damage or injuries. For this reason informed guidance provided by the industry would be useful if it could be accompanied by proper training.

Since many large hospitals will provide emergency power to some elevators, the delay in seismic switch trip restoration will be the cause of disruption. A good procedure has been developed by the ANSI A17.1 national elevator committee that can be used, even though it has not been officially approved. There is an organization in California, which could promulgate such a procedure (OSHPD), if they could be so motivated.

2* Extricating People from Elevators Trapped Due to Power Disruption

The parameters (timing, size and location) of the earthquake suggest that there is a high probability of having many people trapped in elevators due to the loss of power in the scenario event. This of course is the scenario event and a change in timing (the earthquake could occur at any time so that windows of high elevator usage are not as likely) would have a large impact. Elevator mechanics and fire fighters, who would be knowledgeable about opening elevator doors will probably not be available. The procedures are not complex and an effort to educate building engineers would largely solve this problem. While not the best procedure, public service announcement could be made, but I feel that it would be not a good thing for the general public know how to gain access to elevator shafts, as this would be a hazard. The stopping of an elevator due to the loss of power will be a random event and for most structures the elevator will not be stopped at a floor landing. Few buildings have blind sections of shaft (no access to elevator doors) and it should not be difficult to locate the position of an elevator, as occupants would be shouting or banging on the walls of the cab. With some training the building engineer can be taught how to open the outer and inner door without damaging the elevator so that passengers can be removed from elevators without having to leave through the ceiling access door. There is one serious hazard. If the floor of an elevator is over 4 feet above the floor on which the door is opened, access to the shaft will be exposed. Thus, a person who jumps from the elevator could lose their balance and fall into the shaft. Thus, in this situation it is best to open the door on the upper floor to provide egress from the elevator. Again, an educational program would address this issue.

3 Code does not Require Key Parts to be Tested or Qualified

The code covers structural elements, such as rails, rail supports, and anchorage. Some important elements, such as roller guides are not governed by specific design criteria and may not be designed for impact loading. Elevator parts suppliers supply these parts to the second tier companies and even first tier companies. The first tier suppliers may have design specification or test the parts that they get, but this is generally beyond the capability of second tier companies. The elevator business is very competitive and I would be surprised if some of these parts are not manufactured off shore (e.g., in China), so quality assurance is an issue.

4 Detailed Reports of Damage to Local Elevator Jurisdictions

Although it would be desirable to reinstate the limited disclosure of damage reports, this would appear to reside with the judicial system and sunshine laws. Mandating a damage report be submitted to elevator authorities has good and bad features. A simple one-page report with a fill-in-the-blank format could be completed in about two minutes and could provide needed information. The elevator inspectors could use the report to verify that repairs have been made. The reports could be summarized and the results passed on to the code committee so that deficiencies could be identified and addressed.

At a meeting of elevator maintenance companies after the Loma Prieta earthquake a complaint that was voiced by several companies was that some building owner refused to authorize a repair, thinking that that it was not needed. The maintenance company would like to have the owner sign a release to eliminate their liability, but it is a competitive business and there was a concern that the owner would switch companies. Having to document the damage may eliminate occasional exaggerated damage reports and assure that repairs are made. There is a downside about liability exposure, but damage is seldom associated with personal injury so it is not clear if this is a major issue. Elevators are not designed to be damage-free in earthquakes; rather, they are designed to provide a safe, cost-effective vertical conveyance. Thus, some damage can be expected, as demonstrated by the use of seismic switches.

5 Seismic Switch Trigger and Central Triggering to Shut Down Elevators

As noted above, seismic switches provide a safety function and a means for stopping elevators before they are otherwise stopped to prevent passengers from being trapped. Because of their safety functions, switches cannot be eliminated. For the purpose of stopping elevators and allowing occupants to exit requires that the elevator site be located some distance from the epicenter so that propagation times allow time to stop the elevator after the arrival of the P wave. With modern strong-motions systems in California, it is possible that the signal to initiate a shut down could come from a central system. This could increase the time for the elevator system to stop, open the doors and lockout, as the electronic signal would have a shorter propagation time than the P wave. This has the potential to eliminate some problems and create others, depending on how it is implemented. If the central system replaced the local seismic switch, local false triggers would be eliminated. As noted above the switch cannot be eliminated. The central system could reset the elevator without inspection if the seismic switch trip was not due to an earthquake. To provide faster trip signal, the central trigger would have to sense the earthquake, calculate its location and magnitude and quickly send out the signal to shut down quickly. The local trigger associated with the elevator in a building would have to estimate the likely local intensity by using an attenuation relationship and the relative locations of the epicenter and the site. It may be possible for the central control system to identify which elevators should be triggered and send out the appropriate code that the building site can identify. If this generates a circular action area surrounding the epicenter, there could be many false triggers. There may be more sophisticated methods

of central trigger selection where a computer at the site could assess the magnitude and locations data to determine if a unit should be triggered. There are other options but the limited space here does not allow them to be explored. It must be emphasized that because of safety reasons, and reliability, the seismic switch cannot be eliminated.

6 Mutual Aid

Today's competitive environment means that organizations retain only the personnel they need to meet normal workloads. As a result, the organization will probably not be able to respond to a severe event in a timely fashion. Major California utilities, such as large power and communications companies have large service areas that stretch for hundreds of miles. Because an earthquake only impacts a small portion of their system, they can draw on remote resources to aid in restoration. Even with this ability, they also have mutual aid agreements with other utilities to get additional assistance. Large service organizations affiliated with the major manufacturers may be able to draw on assets outside the damage area, but this will not be available for the smaller independent maintenance companies. This may be an advantage in going with the larger company and the issue may be relegated to one of commercial interest. However, very long delays in elevator inspection and restoration will have a societal impact and may be an issue appropriate for consideration in the analysis of the earthquake scenario. While many of the features of elevators are uniform and differences in rail supports and the like can be observed, car construction may require some familiarity with the specific manufacturer. Mutual aid is complex as there are financial issues of who pays and other issues such as workers compensation.