OPINION

LOOKING BACK FROM THE YEAR 3,000

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Many people have asked me how I can justify living with the earthquake threat in the Los Angeles area. My answer is usually that we have some reasonably strict building codes and that the threat of earthquakes to life safety is minimized if our buildings survive our coming quakes. The current building code calls for buildings to sustain at most repairable damage from the strongest shaking that is anticipated with a 10% probability in 50 years. If the building is a critical structure, such as a hospital, then the requirement is increased to 10% in 100 years. Furthermore, buildings of both classes should not collapse for the strongest ground shaking that can be anticipated at the location of the building. If the building code works as it's supposed to, then we endure far greater risks from other factors than from earthquakes.

Although it is comforting to know that our buildings are designed so that they will not collapse for the strongest shaking that can be anticipated at a site, it is also disturbing that we have seen important deficiencies in our building practices following each strong earthquake located close to our urban regions. For example, the 1971 San Fernando earthquake (M_W6.7) revealed fundamental deficiencies in the ductility of reinforced concrete frame buildings. Concrete frame buildings that seemed perfectly adequate to designers 25 years ago are now viewed as potential collapse hazards, and there are several committees struggling with the question of how to identify and strengthen these buildings. The recent Northridge earthquake (M_W6.7) provides another disturbing example; cracks were observed in many of the welded connections in steel frame buildings. Prior to the earthquake, it was generally believed that the steel beams would yield over many cycles before any of these connections failed. Unfortunately, it is not yet clear what should be done to repair damaged buildings or to prevent such behavior in future earthquakes in the thousands of steel frame buildings in California. Other examples are the generally poor performance of parking structures (even new ones) in the Northridge earthquake, and the collapse of freeway bridges in both the Northridge earthquake and the 1989 Loma Prieta earthquake (M_W6.9).

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It is not only the engineering community that has received uncomfortable surprises. The Northridge earthquake also revealed deficiencies in our understanding of earthquake phenomena. For example, how well can we recognize the size of earthquakes that may occur at a given site? I don't believe that anyone was planning on an earthquake on a south-dipping buried thrust fault beneath the San Fernando Valley. About 15 years ago, I recall working on the seismic design criteria for a liquefied natural gas facility proposed at the west end of the Santa Barbara Channel. Although there was abundant evidence of late Quaternary folding of sedimentary rocks in the area, no clear evidence could be identified for major faults that cut Holocene deposits. We argued that the folding process was likely to be benign, and we concluded that a major earthquake was unlikely directly beneath the site. Since that time, we have seen important earthquakes on blind faults beneath analogous areas of folded rocks, such as Coalinga and/or Northridge. Worse yet, consider the 1952 Kern County earthquake (M_W7.5). There was very little surface faulting considering the large magnitude of this earthquake. How can we exclude the possibility of similar earthquakes in other regions such as the Los Angeles or Ventura basins?

It was also a mere dozen years ago that I reviewed a safety analysis report to the Nuclear Regulatory Commission for a power plant in coastal Washington. The applicant argued strongly that the Cascadia subduction zone is completely aseismic. While there is still much to be learned about the earthquake potential of the Cascadia subduction zone, I think few would still argue so confidently that there is no potential for large earthquakes.

Even if we can anticipate future earthquakes, how well do we know the ground motions that will result? In the case of the Northridge earthquake, ground motions were generally higher than acknowledged by building codes, especially for sites located above the northern part of the rupture zone where longer period ($\geq$1 sec) ground motions were especially large. Fortunately, taller buildings, which were vulnerable to this type of motion, were not located in this region of intense long-period shaking. Well, maybe it's unfortunate that tall buildings were not located in this region. If they had been, we might have learned some important lessons. Since the earthquake was at 4:30 AM, the lessons would have been expensive, but few lives would have been endangered. Even with the important new records from Northridge, we have relatively few near-source recordings of large earthquakes. We have all read intriguing tales of extremely strong shaking in close to large earthquakes (objects thrown significant distances). Are we really so perceptive that we understand how to interpret these anecdotal reports? Do we really know how strong the maximum shaking can be at a given site, even if we could anticipate the earthquake?

Can you see where this discussion is leading? Our building codes are supposed to insure safety for the worst shaking that can be anticipated at a site, but in mere decades, we are changing our understanding of the types of earthquakes that can occur at a particular site, the nature of earthquake ground shaking that would result, and of the corresponding building response to that ground motion. How can we claim to build for events that might happen in the next 1,000 years, when our ideas don't hold up for 20 years? ("I'm sorry, but the warranty on that research expired last year.")

I wonder what scientists and engineers in the year 3,000 will think about the understanding that we are employing to design large buildings and bridges that will withstand the intervening earthquakes.

Fortunately, writers of our codes have used some common sense wisdom to circumvent our very incomplete understanding of the physics of both earthquakes and buildings. That is, the code is based largely on past experience. Design practices that produced unacceptable behavior in past earthquakes were modified. If one has enough experience with buildings and earthquakes, then if one finds a design that works, is it critical that we understand why it works? I suspect that it is this experience factor that has allowed engineers to feel "comfortable" with their designs.

But how good is our experience? In a sense, the $M_w6.7$ Northridge earthquake is the largest one to occur beneath a modern urban area of the US, and in that case taller buildings were not in the region of the strongest long-period shaking. If we could look back from the year 3,000, would we be surprised to hear that several of our cities had been visited by much larger earthquakes? How about several $M_w \geq 7.5$ earthquakes in Los Angeles, San Francisco, and Oakland? Or perhaps a $M_w \geq 9.0$ on the Cascadia subduction zone? Have we learned the lessons that these earthquakes will teach us? I suspect that the answer is no.

I am particularly skeptical of our current understanding of moment-resisting-frame buildings. These are the flexible buildings that are usually built with a rectangular skeleton of either steel or reinforced concrete columns and beams. These buildings appear more susceptible to large ground displacements than stiffer buildings are. Since moment-resisting-frame buildings have not yet been in the near-source area of a very large earthquake, I don't think we can claim that they have ever been field tested. How large can the ground motions be close to a $M_w \geq 7.5$ earthquake? 3 meters in several seconds seems perfectly reasonable. How about 6 meters? Do we understand what will happen if the base of a tall structure is displaced a large distance in a short time? When these large earthquakes occur beneath our cities, we may pay a very high price for codes that are based on lessons from smaller earthquakes.

Frankly, I am surprised at the boldness of those who have designed tall buildings with such a partial understanding of earthquakes and building responses. If a future large urban earthquake renders a large number of buildings useless, or worse, if a significant number of them collapse, then it is almost certain that society will demand dramatic changes in design criteria.

Is it only through the experience of future large earthquakes that we can learn about our shortcomings? Of course not; that is what basic research is all about. More complete modeling and testing could tell us quite a bit about the capacity of buildings to survive different types of shaking. We should use this research to decide which building designs most practically respond well to a wide variety of ground motions, including ground motions with large displacements or long durations. Of course, support for this research has been a big problem, and it will continue to be unless we more clearly state the fundamental shortcomings of current understanding. Perhaps earthquake professionals should declare a moratorium on the approval of types of design until their capacity is well understood. For example, we might allow only those buildings for which we have the greatest confidence of their capacity, such as concrete shear-wall construction with a height limit of 5 stories (and don't skimp on the concrete and rebar). I suspect while such a move would be painful, it would also make it clear that far more research is required to confidently erect tall buildings. If society wants more daring designs, then it should invest far more in research about the consequences of those designs. Wouldn't it make sense to plow some reasonable percentage of the cost of a building (perhaps 1%) back into research about the overall performance of buildings?

In 1995, I look back on arguments made in the 1970's that now seem pretty poorly founded. I wonder what scientists and engineers in the year 3,000 will think about the understanding that we are employing to design large buildings and bridges that will withstand the intervening earthquakes. I think that the next time someone asks how I can justify living with the earthquake threat in the Los Angeles area, I will simply answer by telling them that I work in an office converted from a wood-frame house. Besides, I ride a motorcycle to work.

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