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First the Earth Quakes, then the Law Suits

By Keith Porter and Edward Thomas

Older steel-frame buildings built between about 1960 and 1994 pose a very high collapse risk in earthquakes, owing to unexpectedly brittle welds. There are probably thousands of these buildings in seismically active states, including some of California's biggest buildings. The structural engineering community has known about the risk for 25 years and has widely publicized it. Detailed studies have explained the risk and offered practical retrofit measures. Unless remediated, most of these buildings will be at serious risk when (not if) a big earthquake occurs and potentially causes some of them to collapse.

The retrofits will be very costly, but not retrofitting them will be far more expensive, both in lives lost and money wasted. Only a few must collapse to render the rest suddenly worthless, just as it took only two crashes of Boeing 737 MAX aircraft to ground the rest. Owners, lessors, employers, property management agencies, and even government officials, many of whom are aware of the problem, could face serious civil or criminal legal liability if they fail to act on the threat.

A Serious Earthquake Problem with Older Steel-Frame Buildings in the United States

Several typical classes of buildings suffer from well-known seismic vulnerabilities that make them far less safe than other buildings, dangerous enough to make several California communities require costly building evaluation and remediation for the sake of public safety and welfare. E.g., San Francisco, Cal., Ordinance 66-13, Building Code (2013), https://bit.ly/2MuKYCi; Oakland, Cal., Ordinance No. 12966 C.M.S. (2009), https://bit.ly/31cjtlb; Los Angeles,

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Cal., Mayoral Seismic Task Force, *Resilience by Design – Building a Stronger Los Angeles* (2015), https://bit.ly/2kdRTE7; Santa Monica, Cal., Ordinance No. 2537 (2017), https://bit.ly/33cH72O. These ordinances address, among others, certain classes of older reinforced concrete buildings, larger wood-frame apartment buildings, and—the subject of this article—some older steel-frame buildings that pose a serious, potentially catastrophic, seismic risk.

A recent *New York Times* article called attention to the "big seismic gamble" of constructing high rise buildings in earthquake country, eliciting responses from structural engineers ranging from serious concern to dismissal. T. Fuller, A. Singhvi, and J. Williams, *San Francisco's Big Seismic Gamble*, N.Y. Times, Apr. 17, 2018, p. 1., https://nyti.ms/2J0VtYX. The article quotes one highly regarded structural engineer as saying that "[b]uildings falling on top of other buildings—that's not going to happen." That sounds very comforting, but "that" has in fact happened many times, Figure 1 being one of many examples. The structural engineering community has known for decades of strong evidence that a serious problem exists, that a particular class of high-rise buildings could realistically collapse in large, but not-exceedingly-rare, earthquakes.

Several studies by reputable researchers and practitioners conclude that steel buildings built between about 1960 and 1994 could collapse in a sizable earthquake, with potentially several collapses in a single earthquake. A single high-rise collapse could kill 1,000 or more occupants. Structural engineers and the US Federal Emergency Management Agency (FEMA) have known about this issue at least since the magnitude-6.7 1994 Northridge earthquake. Because the problem garnered national attention after the 1994 earthquake, the problem buildings are usually referred to as pre-Northridge welded-steel moment frames.

Engineers have studied and written extensively about these buildings, both within professional publications and through interviews in the general press, but owners and responsible governments have done little to solve it. This is not a problem of inadequate information, but one of insufficient money and short-term financial planning, and the limited (and somewhat conflicted) role of engineers in addressing the seismic safety of existing buildings.

Figure 1. Collapsed steel-frame Pino-Suarez Towers after the July 28, 1985 Mexico City earthquake. A 14-story building collapsed on top of an adjacent one. Photo by E.V. Leyendecker, UC Berkeley NISEE e-Library, with permission.

How to Identify a Pre-Northridge Welded-Steel Moment Frame

Any licensed professional engineer specializing in structures should have the skill set to identify whether a particular building falls into the class of buildings addressed here. The necessary data are commonly available from design documents, especially structural drawings. Some building owners keep such drawings in their own files. Structural engineers ordinarily maintain architectural drawings of the buildings they have designed. City building departments maintain files of structural drawings that engineers can examine to determine the age and structural system of a building.

Real estate investors who buy large buildings in earthquake country regularly engage structural engineers to perform seismic risk assessments, sometimes called probable maximum loss (PML) studies, as part of their due-diligence evaluation of the risk of buildings they are considering buying. Standardized procedures exist to guide such studies, documented in standards, guidelines, and training materials by ASTM International and others. See ASTM Int'l, *E2026 – 07 Standard Guide for Seismic Risk Assessment of Buildings* (2007), https://bit.ly/2meOsOh; Fed. Emergency Mgmt. Agency, *FEMA P-154: Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook, Third Edition* (2015), https://bit.ly/2OvFyJN; Am. Soc'y of Civil Eng'rs, *Seismic Evaluation and Retrofit of Existing Buildings: ASCE/SEI 41-13* (2013), https://bit.ly/2JwCDg7.

The Welds at the Root of the Problem

The problem arises from the unexpected fragility of welds that connect beams to columns in steel buildings commonly erected between the 1960s and the mid-1990s. The 1994 Northridge earthquake revealed that these welds are far more likely to break than engineers had previously thought, fracturing at levels of earthquake shaking as low as one-twelfth the values that their designers had assumed (Figure 2, page 36). Laboratory tests at least as early as 1988 hinted at the problem when welds in a test specimen suffered a brittle fracture like the ones observed in real buildings just a few years later. K.C. Tsai, and E.P. Popov, *Steel Beam-Column Joints in Seismic Moment-Resisting Frames*, UC Berkeley Earthquake Engineer Research Center Report UCB/EERC-88/19 (1988).

Figure 2. The 1994 Northridge earthquake revealed fragility in the welds that connect beams to columns in a kind of steel frame construction commonly used in tall buildings for the previous few decades. This figure shows an actual fracture observed in a building after the earthquake. Photo by J.C. Anderson, 1994, from the Earthquake Engineering Online Archive NISEE e-Library, UC Berkeley, with permission.

Chemistry and Geometry Contribute to the Weak Welds

The welds that connect the beams and columns proved to be brittle for several reasons. Part of the problem was chemical: the so-called flux-cored arc welding process produced welds with very low toughness, meaning it took unexpectedly little energy to break them. Several other problems also contributed to making these welds brittle. Straddling a beam, welders had to reach down to either side to connect the lower beam flange to the column, making it difficult to make a high-quality weld on the lower flange (the bottom horizontal part of the I-beam). This method tended to leave various defects in the welds. The defects could be hard for inspectors to see. Also, some of the engineers' assumptions about how forces were transmitted from the beam to the column were wrong, and the welds carried forces that engineers had assumed were carried by the bolted connection on the beam web (the vertical part of the beam). There are other causes, but these are a few of the leading ones.

How Engineers Know That Brittle Welds Make Collapse More Likely

Buildings are designed for much weaker shaking than they are expected to experience in a design-level earthquake. To ensure that a steel-frame building does not suffer life-threatening damage despite that weakness, engineers count on the steel beams' ability to tolerate a great deal of deformation through damage to their microscopic crystal structure without breaking. The same phenomenon can be observed by bending a paper clip. If bent just a little, the paper clip snaps back to its original shape. When bent more, it does not snap all the way back, but also does not break. At a microscopic level, the crystal structure of the steel in the paper clip has been damaged, but not enough to cause the steel to break.

Ductility is the ability to tolerate damage without breaking. Ductility is reflected in the International Building Code with a factor currently called R. Engineers divide design-level shaking by R to calculate the required strength at which the steel frame begins to endure damage. That factor R for steel moment frames has varied over time. At the time of the 1994 Northridge earthquake, it had a value of 12, meaning that steel frame buildings were believed to be so ductile that they could tolerate 12 times the shaking that it would cause the steel in the beams to begin to witness damage to their crystal structure, without life-threatening damage. The welds were believed to be stronger than beams, so the beams would act as a fuse, protecting the welds from damage.

That assumption proved wrong. In several buildings studied after the 1994 Northridge earthquake, 10 to 25 percent of welds fractured when they were exposed to the level of shaking that would cause damage to the attached beams. In a sense, the welds had a ductility of one, although they were expected to be stronger than the beams. The welds became the weak link. That weakness eliminated the advantage of ductile beams, invalidating the assumption that the building as a whole had a ductility of 12. With a ductility of one rather than 12, a building that just met code at the time of the earthquake can be expected to suffer life-threatening damage at one-twelfth the design-level shaking. Buildings tend to be slightly stronger than the code requires, so, in the case of a typical building, a pre-Northridge steel frame might suffer life-threatening damage at perhaps one-tenth or one-eighth design-level shaking.

Hundreds, Probably Thousands, of Problem Buildings in California Alone

According to a real estate database published by Emporis GMBH, California contains approximately 740 buildings of at least ten stories in height and built between 1960 and 1994. These buildings contain more than 200 million square feet and perhaps one million occupants. Most of them are pre-Northridge welded-steel moment frames. Many shorter buildings use the same structural system and probably add many times these figures, meaning perhaps thousands of problematic buildings with millions of occupants. The same problem applies to buildings of the same era built outside of California.

Not a Problem of Uncertainty or Incomplete Information

The problem is not one of uncertainty or lack of information. FEMA sponsored a multimillion-dollar study by a consortium of engineering researchers and practitioners called the SAC Joint Venture. By 1997, the SAC Joint Venture had published several documents on why the welds broke and what to do about the problem. E.g., SAC Joint Venture, *FEMA* 267 *Interim Guidelines: Evaluation, Repair, Modification, and Design of Welded Steel Moment Frame Structures,* SAC Report 95-02 (1995). These reports largely eliminated uncertainty about the nature of the weld problem. As three leading earthquake engineers put it in 1996, "[t]he Northridge earthquake of January 17, 1994, has fundamentally shaken engineers' confidence in the seismic performance and safety of WSMF buildings." S.A. Mahin, J.O. Malley, and R.O. Hamburger, *Phase 2 of the SAC Steel Project,* Proceedings: 65th Annual Convention, Structural Engineers Association of California, Oct. 1–6, 1996. US engineers quickly stopped designing steel buildings with the problematic weld, but the change in construction practice *after*

1994 did not fix the welds in buildings built *before* the 1994 earthquake.

Of course, collapse involves more than welds: the earthquake matters, as does the configuration of the building. But little doubt should remain that realistic earthquakes can cause the collapse of realistic buildings with the bad welds. Shortly after the 1994 Northridge earthquake, a Caltech study found that a magnitude-7.0 Los Angeles earthquake could realistically cause the collapse of a 20-story steel-frame building, even without accounting for the problem with the welds. T.H. Heaton, J.F. Hall, D.J. Wald, & M.W. Halling, *Response of High-Rise and Base-Isolated Buildings to a Hypothetical Mw 7.0 Blind Thrust Earthquake,* Science, New Series, 267 (5195), Jan. 13, 1995, 206-11, https://bit.ly/2lQUpAU.pdf. Several other studies by a variety of practitioners and scholars did account for the brittle welds, building configuration, and earthquake, using various building designs and locations. Each found a significant chance of collapse in realistic, even inevitable, earthquakes near Los Angeles, San Francisco, and Seattle. E.g., B.F. Maison, and D. Bonowitz, *How Safe are Pre-Northridge WSMFs? A case study of the SAC Los Angeles 9-story Building,* Earthquake Spectra 15 (4), 765-89. And not in small, isolated pockets of these urban areas, either. As a recently published study by the University of Colorado Boulder for the US Geological Survey (USGS) shows, a hypothetical magnitude-7.0 earthquake on the Hayward fault in the San Francisco Bay area would produce shaking up to 50 percent stronger than design-level shaking over a wide section of the urbanized East Bay as shown in Figure 3. K.A. Porter, *Societal Consequences of Current Building Code Performance Objectives for Earthquakes* (2018), https://bit.ly/2kxuIFc; S.T. Detweiler and A.M. Wein, eds., *The HayWired Earthquake Scenario—Engineering Implication,* Scientific Investigations Report 2017–5013, https://bit.ly/2Yx3OiK. The authors and reviewers of these studies include renowned engineers, experts with decades of professional experience designing and assessing buildings and developing the design standards on which building codes rely.

One of the most notable outcomes of the SAC steel study was a survey of damage to connections in real buildings. An analysis of the data shows that a large fraction of those connections fractured at levels of shaking in the Northridge earthquake that were much lower than design-level motion. K.A. Porter, *Assembly-Based Vulnerability of Buildings and Its Uses in Seismic Performance Evaluation and Risk-Management Decision-Making,* Doctoral Dissertation, Stanford University, Stanford, CA, and ProQuest Co., Ann Arbor, MI, pub. 99-95274, https://bit.ly/2mdXxa6. An important fact to remember here: new buildings are not designed to be earthquake proof. A small but nonzero fraction of them are expected to collapse when subjected to design-level motion—the orange color in Figure 3. It seems highly plausible that buildings that had been largely optimized to be just safe enough to pass code *without* brittle welds are too weak to resist collapse because they *do* contain a lot of brittle welds, when they are subjected to the earthquake for which they were designed. The various analyses mentioned above merely reinforce this intuition.

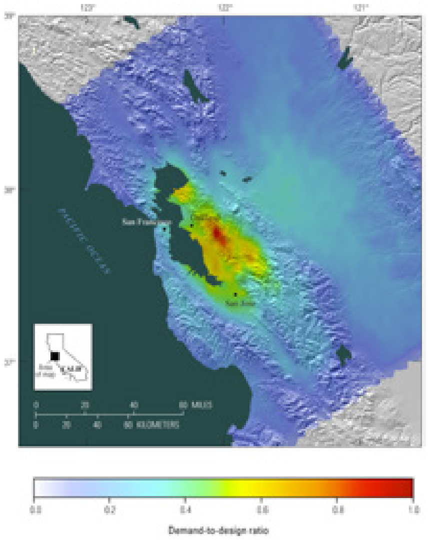

Figure 3. Map of the San Francisco Bay region, California, showing severity of shaking in the moment-magnitude-7.0 mainshock of the USGS's HayWired earthquake scenario, calculated for a 5-percent damped, 0.2-second spectral acceleration. Red color (a value of 1.0) corresponds to 50 percent stronger shaking than is used for design of new buildings. Orange or warmer colors (greater than 0.67 in the legend) exceed design-level shaking. The legend "demand to design ratio" refers to the ratio of the shaking in a given earthquake to a level of shaking that appears in a USGS map used in seismic design.

A Question of When, Not If

Substantial earthquakes are inevitable. In many places, they are arguably overdue. Most of the earthquakes considered in the previous examples occur on average every 150 to 300 years or so, and because there are so many of them, one of them is fairly likely to occur within decades and could occur any day. The San Francisco Bay area is more likely than not to experience a magnitude seven or greater earthquake in the next 30 years (Figure 4, page 38). California has a 93 percent chance of a magnitude seven or larger earthquake in the next 30 years, and greater than 99 percent probability of an earthquake at least the size of the 1994 Northridge earthquake. E.H. Field, *UCERF3: A New Earthquake Forecast for California's Complex Fault System (No. 2015-3009)* 4 (U.S. Geological Survey 2015). Any of these can produce design-level or stronger shaking. The higher the magnitude, the higher the likelihood that any given building will sustain such shaking.

Nor is California unique among the states in experiencing strong earthquakes. It is easy to find maps showing shaking in large, realistic scenario earthquakes published by the USGS (the nation's authority on earthquake hazards) and by the Building Seismic Safety Council (a group organized by the congressionally-chartered National Institute of Building Sciences, which develops much of the nation's seismic design provisions). Detailed maps and data cataloged in Figure 5 on page 38 indicate large earthquakes could affect virtually any metropolis west of Denver, plus Oklahoma, seven states of the central United States, South Carolina, and New England. Nor is that catalog exhaustive. Alaska experiences frequent strong earthquakes, and earthquakes could realistically shake New York City, Washington, DC, Hawaii, Puerto Rico, and other US locations with the kind of buildings discussed here. See Figure 6, page 38, for a simplified seismic hazard map of the United States. The USGS provides a free, authoritative, online tool for estimating how frequently any given US location will endure any given level of shaking. USGS, *Unified Hazard Tool* (2018), https://on.doi.gov/2qQmFE7. Although any given building may have

Figure 4. A USGS map of faults in the San Francisco Bay area capable of producing earthquakes of magnitude 6.7 or greater, along with the chance that each will do so within the coming 30 years. USGS *Earthquake Outlook for the San Francisco Bay Region, 2014-2043, Fact Sheet 2016-3020,* version 1.1, http://dx.doi.org/10.3133/fs20163020.

Figure 5. An authoritative map of ground shaking in realistic future earthquake scenarios. Each star indicates the epicenter of one such scenario. Warmer colors indicate stronger shaking in one of the maps. USGS, *2014 Building Seismic Safety Council (BSSC) Catalog,* https://earthquake.usgs.gov/scenarios/catalog.

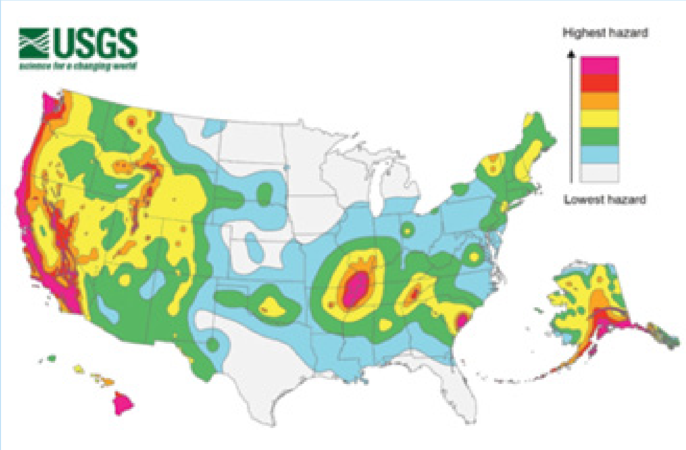

Figure 6. Simplified 2014 hazard map. Any place colored green or warmer can reasonably be considered to have at least moderate seismicity. USGS, https://earthquake.usgs.gov/hazards/hazmaps/conterminous/2014/images/HazardMap2014_lg.jpg.

only a small chance of experiencing design-level shaking in any given year, the chance that many buildings will experience design-level or greater higher shaking in an urban earthquake the next few decades is fairly high.

It Is Difficult to Be Unaware of the Problem

Structural engineers have publicized the problem to the general public. *The New York Times* included a long article on January 16, 1995, quoting prominent structural engineers and explicitly warning that steel-frame buildings could be seriously damaged or collapse in earthquakes. Seth Mydans, *Los Angeles's Steel-Frame Buildings: Quake-Proof or Not?*, N.Y. Times, Jan. 16, 1995, https://nyti.ms/2K9jO0Q; see also Kathryn Wexler, *Northridge Quake's Costly Legacy*, Wash. Post, Jan. 18, 1996, https://wapo.st/2GChnTO; Greg Brouwer, *Cracked!*, L.A. Wkly., Sept. 1, 1999, https://bit.ly/2KgFwAk.

Why So Little Has Been Done

For several reasons, most of these buildings are still with us. The cost to remediate the problem is huge. In 2000, each beam-column connection cost approximately $25,000 to fix. A single building can contain hundreds of such connections, so the fix could cost more than $1 million per building. Secondly, building codes generally do not act retroactively. The hundreds of buildings in question complied with the code at the time they were built, so owners of existing buildings are not required to remediate these connections. Owners would have to voluntarily spend that $1 million to deal with an earthquake that may or may not occur during their ownership period. Neither the threat of liability nor any market force that values safer buildings has yet proven to be sufficient motive for that voluntary expense in the absence of legal requirement.

Another issue may be the appearance of low probability. Some of the authors of the studies alluded to here write about the risk in 2,500-year shaking (approximately 50 percent greater than design-level shaking). Such a rare event may seem safe to ignore. But that sense of safety vanishes when one takes a societal viewpoint of risk: the risk to one building may be low, but a single large earthquake on any of the many long, active faults in California can affect millions of buildings, and there are many such faults. The sum of a lot of small chances can be great.

A third issue is probably a combination of natural inclination, constraints of the engineering profession, and self-interest. Structural engineers of the authors' acquaintance do not like to sound alarmist, and many depend for their living on being able to design lighter, less-expensive buildings that nonetheless comply with the building codes—engineers sometimes refer to that process as value engineering. Structural engineers work primarily at the direction of the owner, who is bound to make his new building meet only the requirements of the building code, and who (with few exceptions) has no explicit legal obligation to strengthen an existing building. To voluntarily expend millions of dollars strengthening an existing building can place the owner at a financial disadvantage relative to his neighbors. The engineer who urges such an expense runs a substantial risk of losing a client. And after all, the risk of any given occupant dying in a high-rise collapse is low, much lower than other leading causes of death in the United States.

FEMA doesn't fix the problem because FEMA doesn't own the problem, at least until a disaster occurs. Although it supported the study that quantified the problem, FEMA's mission does not yet include mandating costly building retrofits. Structural engineers have strong reasons not to press for a solution.

Because few others in authority even know that the problem exists, it has not yet been seriously addressed. But the problem of thousands of older steel buildings with brittle welds is not going away. High-rise buildings may in a sense be designed for a life of 50 years, but they are likely to stand for centuries and to be there when, not if, a strong earthquake occurs nearby.

A few cities are dealing with these buildings. Some have enacted new ordinances akin to previous mandatory retrofit requirements for unreinforced masonry bearing wall buildings, tilt-up concrete, soft-story woodframe, and others. Shortly after the 1994 Northridge earthquake, the City of Los Angeles recognized that "the damage to these welded steel moment frame buildings could expose occupants of these buildings to a potential life-safety risk in future earthquakes, and the City of Los Angeles must protect its population and property and enforce the Building Code so as to provide effective protection to all its citizens." Los Angeles, Cal., Ordinance 170406, https://bit.ly/2LSM7E6. The city required inspection within 180 days of 280 nonresidential steel-frame buildings in a strong-shaken part of the city and required repair of damaged welded moment connections. Id.

Twenty-four years after the Northridge earthquake and 29 years after the Loma Prieta earthquake, a group of experts led by the Applied Technology Council advised the City of San Francisco to develop inspection, evaluation, and repair provisions for older steel-frame buildings. Applied Technology Council, *Tall Buildings Safety Strategy* (2018), http://onesanfrancisco.org/esip.

In 2018, the California legislature passed a bill that would have required local jurisdictions to create an inventory of potentially hazardous older steel-frame buildings (among other unacceptably hazardous building types). But Governor Brown vetoed the bill for funding and schedule reasons, as opposed to objections regarding the hazardous nature of the buildings.

The Boeing 737 MAX as a Cautionary Tale

What will happen when one of these buildings collapses? The history of the Boeing 737 MAX might provide a clue. The Boeing 737 MAX is a narrow-body aircraft series designed and produced by Boeing Commercial Airplanes as the fourth generation of the Boeing 737. It entered service in May 2017. Two fatal crashes of 737 MAX 8 aircraft in October 2018 and March 2019 killed a total of 346 passengers and crew, after which regulatory authorities around the world grounded the aircraft series until further notice, leaving the 391 remaining delivered aircraft suddenly inoperable and, for the foreseeable future, worthless. Lawsuits came quickly from families of crash victims and others. Sinéad Baker, *Boeing 737 Max: List of Lawsuits and Investigations Boeing, FAA Face*, Business Insider (2019), https://bit.ly/2OFiVTc.

The parallel to pre-Northridge welded steel moment-frame building seems obvious: if only one of these readily identifiable buildings collapses for predictable reasons in an inevitable earthquake, the rest of the buildings could quickly change from assets to severe liabilities to their owners, investors, designers, tenants, local, state, and federal officials, taxing authorities, people who trade with displaced occupants, or otherwise indirectly rely on them. The liability differences between buildings and aircraft might not be great.

Potential for Legal Liability: Both Criminal and Civil

Under tort law, foreseeability must be proven by a preponderance of the evidence demonstrating that a party's action or inaction could reasonably result in the injury at issue in the case. In most cases, the decision about whether an action or inaction was negligent is considered a question of fact to be determined by a trial jury of six to 12 ordinary citizens. Normally, the plaintiff must be able to show that the injury was reasonably predictable to a person of ordinary intelligence and prudence. But people and organizations who hold themselves out as experts are held to a higher standard of what they should have foreseen. Landlords and all those who invite others to visit or occupy premises, including employers and tenants, have long been held to a standard that requires them to not only warn of known hazards, but also to fix the hazard. As the Association of Bay Area Governments points out, "[d]evelopers may be liable for earthquake-related damages and injuries under theories of implied warranty or strict liability. Designing a building to meet code standards does not act as a shield to liability. However, not meeting earthquake-related codes will surely result

By delaying remediation efforts, owners are externalizing their risk on tenants, future owners, and the people who live, work, walk by, or visit nearby buildings onto which these buildings could collapse.

in being judged negligent." Ass'n of Bay Area Gov'ts, *Summary Information, Business Liability for Earthquake Hazards & Losses* (2004).

By delaying remediation efforts, owners are externalizing their risk on tenants, future owners, and the people who live, work, walk by, or visit nearby buildings onto which these buildings could collapse. By delaying remediation, owners and all others potentially responsible for inviting, authorizing, or requiring potential victims to occupy or to be exposed to the hazards created by these unsafe structures are inviting liability. They may even face criminal charges in the event of serious injury or death arguably resulting from failure to repair a known hazard. Such was the case in 2006 when the private owner of the Ka Loko Dam in Kauai, Hawaii, was indicted for common law murder for his actions and failure to act before that reservoir breached, killing seven people. The owner was not alleged to have the criminal intent usually required to support a murder charge, but his actions were considered sufficiently reckless as to provide the requisite intent to support an indictment for murder. In 2013, he was permitted to plead guilty to a lesser charge of reckless endangerment, after paying substantial compensation to the victims' families. Tim Sakahara, *James Pflueger Enters Plea Deal in Fatal Dam Break*, Hawaii News Now, July 18, 2013, https://bit.ly/2GEbOnA.

The Ka Loko case is not an anomaly. There has been widespread media attention focusing on an increasing level of criminal prosecutions in situations as diverse as selling contaminated peanuts, violating mine safety laws, and most recently operating an allegedly unsafe limousine in a situation where 20 people died. Luis Ferré-Sadurni, *After Limo Crash that Killed 20, a Call for More Regulation*, N. Y. Times, Oct. 14, 2018, https://nyti.ms/2Om6tau.

Architects, engineers, developers, government officials, and all others involved in decisions about whether to repair a known life-safety hazard should know that legal liability may involve a jury of ordinary people evaluating their legal culpability for failure to take foreseeable natural hazards into account when making a decision that later resulted in harm or death. As has already been shown, engineers, local, state, and federal officials have been aware of the problem for decades. With extensive coverage in the local, national, print, and electronic press, building owners by now can be reasonably expected to know that earthquakes pose an unexpectedly high life-safety threat to these buildings.

Fundamentally, government exists to prevent us from harming each other. When businesses, employers, engineers, and architects combine with government and collectively fail in their duty to provide safe places for people to live and work, the people who are harmed may well seek to share their misery with everyone who contributed to their misfortune. Decision-makers who ignore the very real threat of unsafe buildings may be called upon to answer for their actions or inaction. For more information about civil and criminal liability related to natural hazards, see Edward Thomas, *Natural Hazard Disaster Risk Reduction as an Element of Resilience: Considerations about Insurance and Litigation* (2019), https://bit.ly/2kxpzgo.

Conclusion

Much of what has been said here applies to a few other well-known and common building types. Considering older steel-frame buildings, multiple highly reputable studies show that large but not-exceedingly-rare earthquakes can realistically cause several such buildings to collapse. Engineers, FEMA, and local officials in some cities have been aware of and concerned about the problem since at least 1994. Building owners and the general public have been exposed to coverage in the popular press explaining how the 1994 Northridge earthquake heavily damaged older steel-frame buildings, showing them to be far more dangerous than their designers had thought, and that future large earthquakes pose a particular life-safety threat to these buildings. Such earthquakes are coming, quite possibly within the next few decades, whether we do anything about it or not. We have already lost more than 20 years of advanced warning.

Shall we continue to ignore the problem, in the hope that it doesn't really exist or that somebody else will solve it? Even skeptical engineers find it realistic that a single large earthquake could cause several of these buildings to collapse. The collapse of only one or two could kill thousands of people and cause public confidence in these buildings to evaporate. Like the crash of two Boeing 737 MAX aircraft, the remaining stock would flip from financial assets into severe liabilities for a vast web of stakeholders. To fix these buildings will be very expensive. But if we do not do so before the earthquake, just wait until the bill comes due for not fixing them. That bill could arrive tomorrow and, one way or another, most of us will be stuck with part of the tab. ■

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