Should Memphis Build for California's Earthquakes?

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State and local authorities in parts of the central U.S. that are at risk from earthquakes in the New Madrid Seismic Zone (NMSZ) are considering adopting a new building code that would increase the earthquake resistance of new buildings to levels similar to those in southern California.

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Here, we argue against this proposal on the dual grounds that the earthquake hazard has been overestimated, and that the costs of the proposed change are likely to far exceed the potential benefits. Instead, we recommend weighing the costs and benefits of alternative strategies that could yield reasonable seismic safety at significantly lower cost.

The new building code, IBC2000, is a national code developed under direction of the Federal Emergency Management Agency (FEMA), which includes regional provisions for seismic safety. Surprisingly, these have been proposed with almost no consideration of the costs and benefits. We estimate that building costs (about $2 billion annually in the Memphis area alone) could increase significantly, perhaps by 10% or more, depending on building type. This cost, in excess of $200 million, is more than 10 times FEMA's own estimate of the anticipated annualized earthquake loss of $17 million [*FEMA*, 2001]. Moreover, FEMA's estimates show that buildings in Memphis are 5 to 10 times less likely to be damaged than in San Francisco or Los Angeles. Hence, in our view, the new code should not be adopted unless justified by careful analysis.

Because most earthquake-related deaths result from the collapse of buildings—a principle often stated as "earthquakes don't kill people; buildings kill people"—the primary defense against earthquakes is designing structures that should not collapse. A community's choice of building codes reflects a complicated interplay among seismology, engineering, economics, and public policy. The goal is to assess the seismic hazard and chose a level of safety that makes economic sense, because such design raises construction costs and diverts resources from other uses. Ideally, building codes should not be too weak, permitting unsafe construction and undue risks; or too strong, imposing unneeded costs and promoting evasion. Deciding where to draw this line is a complex issue for which there is no unique answer. Although national codes offer overall insight, local jurisdictions are under no obligation to accept them, and can modify them to balance local hazards and costs.

California's building codes evolved over decades of damaging earthquakes. Although this process involved more trial and error than cost/benefit analysis, they are accepted because they seem to strike a sensible balance consistent with the public's experience. However, we doubt similar provisions would make sense or be accepted in the New Madrid seismic zone, where damaging earthquakes are rare.

New Madrid versus California

The differences between circumstances of the NMSZ and California are striking (Figure 1). NMSZ earthquakes of a given magnitude (M) are about 30 to 100 times less frequent than in southern California. This is because California's result from the approximately 46 mm/year motion within the boundary zone between the Pacific and North American plates, whereas New Madrid is within the interior of the North American plate, which is stable to better than 2 mm/yr [*Newman et al.*, 1999].

However, shaking from NMSZ earthquakes is thought to be comparable to that from California earthquakes one magnitude unit larger because midwest rock transmits seismic energy more efficiently. Because earthquakes of a given magnitude are about 10 times more frequent than those one magnitude unit larger, the shaking difference reduces the effect of the difference in earthquake rates by about a factor of 10. The precise net effect of these differences depends on the recurrence rate of large earthquakes and the resulting ground motion, neither of which is well known.

Thus, in any year, a building in southern California is much more likely to be seriously damaged by shaking than is one in the NMSZ. Over a thousand years, some locations in the NMSZ will experience such shaking once or twice, whereas many in California will experience such shaking many times. Hence, the risk of major damage to a typical building with a life of 50 years is much lower in the NMSZ, whereas that to a hypothetical structure with a 2500-year life might be comparable in the two areas.

In the past century, NMSZ earthquakes typically have been more of a nuisance than a catas-

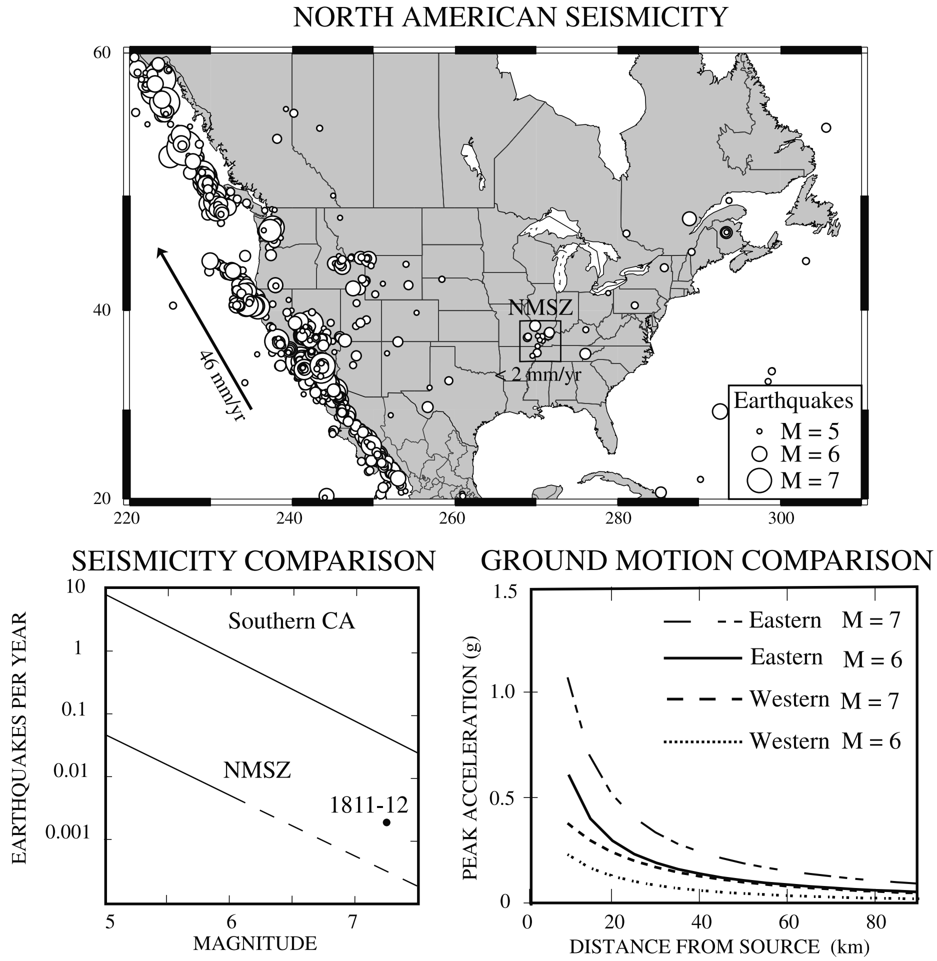

Fig. 1. Top: Seismicity (M 5 or greater since 1900) of the continental portion of the North American plate and adjacent areas. Seismicity and deformation are concentrated along the Pacific-North America plate boundary zone, reflecting the relative plate motion. The stable eastern portion of the continent, approximately east of 260°, is much less active, with seismicity concentrated in several areas, notably the New Madrid seismic zone. Bottom left: Comparison of the annual rates of earthquakes greater than a given magnitude for southern California and the NMSZ. Solid lines are computed from recorded seismicity, whereas dashed are extrapolated. Dot indicates paleoseismically inferred recurrence for the largest NMSZ earthquakes, assuming M 7.2. Bottom right: Predicted strong ground motion from earthquakes in the eastern and western U.S. For the models shown [Atkinson and Boore, 1995; Sadigh et al., 1997]*, shaking from an M 6 earthquake in the east is comparable to that for an M 7 earthquake in the west.*

trophe. Damaging earthquakes are rare; the most significant during this time—the 1968 (M 5.5) Illinois earthquake—caused some damage but no fatalities. However, repetition of large earthquakes like those that occurred in 1811 and 1812 would be very damaging and likely cause deaths. In 1811–1812, log cabins collapsed in the tiny town of New Madrid, Missouri, and minor damage occurred farther away in places including St. Louis, Louisville, and Nashville. Such reports can be used to infer the intensity, a descriptive measure of the effects of shaking, and thus estimate the earthquakes' magnitude and give insight into the effects of future ones. The most recent analysis infers that these earthquakes were low M 7 [*Hough et al.*, 2000], consistent with the results of *Nuttli* [1973], but significantly lower than those of *Johnston* [1996].

Estimating Earthquake Probability and Hazard

It is difficult to reliably assess the likelihood that such large earthquakes will recur soon. Paleoseismic studies find evidence for earthquakes that may have been comparable or smaller in 1450 ± 150 and 900 ± 100 AD [*Tuttle*, 2001], suggesting a recurrence interval of about 500 ± 100 years. Under this assumption, various estimates of the probability that a large earthquake will occur in the next 50 years can be made (Figure 2). The simplest model is a time-independent Poisson model, in which the probability that an earthquake will occur is 10% (50/500), regardless of how long it has been since the last earthquake in 1812. Although this assumption is used by the U.S. Geological Survey (USGS) for New Madrid [*USGS*, 2002], most earthquake probability studies in California and elsewhere use time-dependent models with some probability distribution describing the time between earthquakes [*Agnew et al.*, 1988; *Savage*, 1991].

In such models (Figure 2), the probability of the next large earthquake is small soon after one occurs, and then increases with time. For

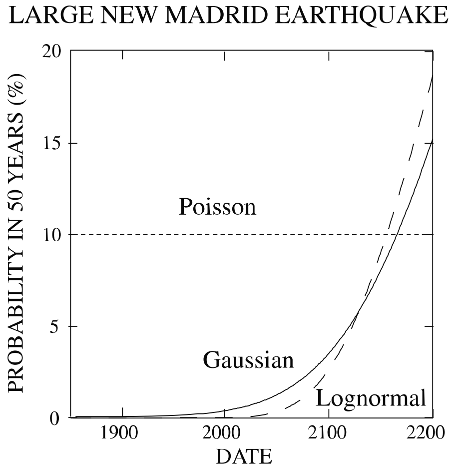

Fig. 2. Probabilities of a large New Madrid earthquake in the next 50 years as a function of time since 1812, for different models assuming a recurrence interval of 500 ± 100 yr.

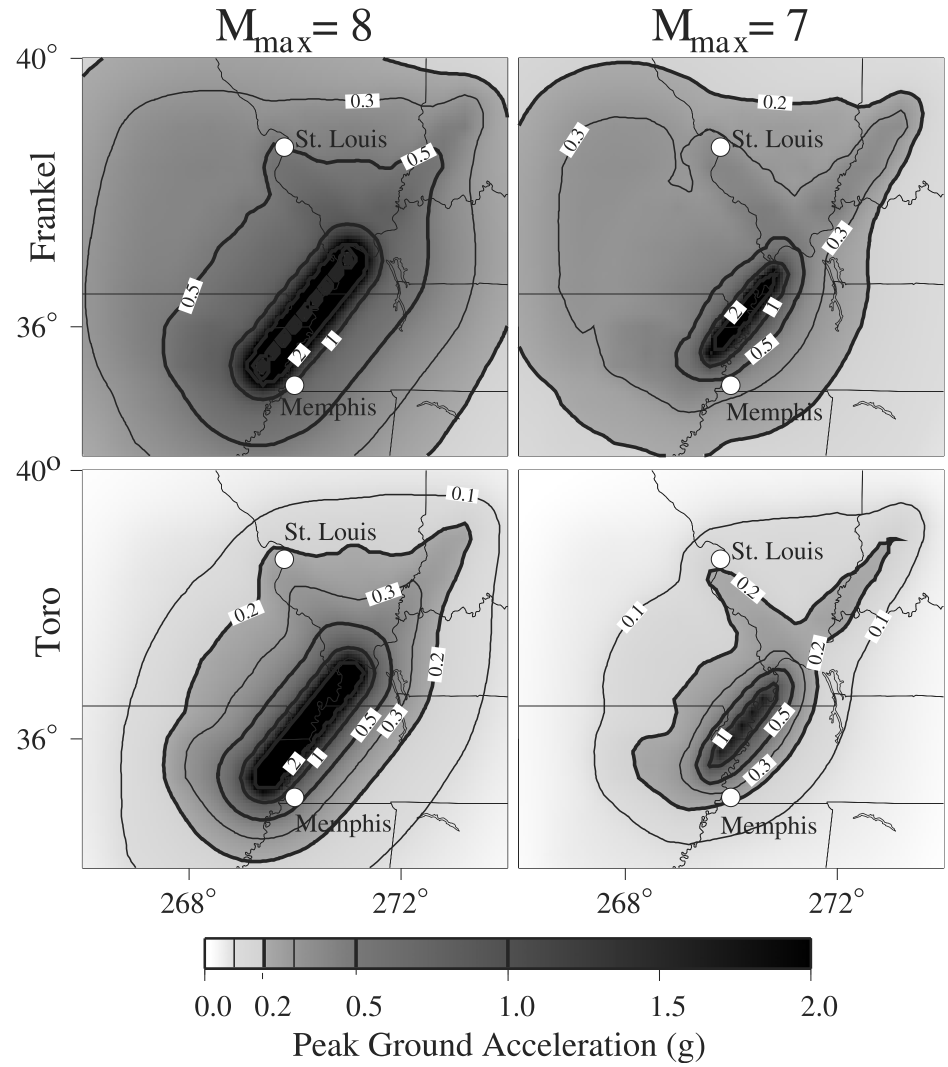

Fig. 3. Comparison of the predicted seismic hazard (peak ground acceleration expected at 2% probability in 50 years) from NMSZ earthquakes for alternative parameter choices. Columns show the effect of varying the magnitude of the largest earthquake every 500 years from 8 to 7, which primarily affects the predicted acceleration near the fault. Rows show how different ground motion models, which were averaged in the USGS maps, affect the predicted acceleration over a larger area. [Newman et al., 2001].

times since the previous earthquake of less than about two-thirds of the assumed recurrence interval, time-dependent models predict lower probabilities. Hence, at present, models using the commonly assumed Gaussian and log-normal distributions of recurrence times yield probabilities of 0.4% and 0.01%, respectively. The estimated probabilities differ either for other probability distributions, or other recurrence time estimates. For example, at Pallet Creek on the San Andreas, where paleoseismic data span ten earthquake cycles, different subsets of the data yield such different estimates that in 1989, the range of probabilities for a major earthquake before 2019 was estimated as about 7–51% [*Sieh et al.*, 1989]. Hence, at New Madrid, with only three earthquake dates, we favor not focusing unduly on specific numbers, and instead, following *Savage*'s [1991] nomenclature to quote the probability as low (<10%) rather than intermediate (10–90%) or high (>90%).

Similar difficulties beset efforts to estimate the hazard posed by large New Madrid earthquakes. The causes of the earthquakes are unclear, their magnitudes and recurrence intervals are difficult to reliably infer, and the resulting ground motion is essentially unconstrained, because there have been no large earthquakes since the invention of the seismometer around 1900. As a result, a wide range of hazard estimates can be made. The proposed building code is based on USGS hazard maps that predict the maximum shaking every 2500 years (2% probability in 50 years) [*Frankel et al.*, 1996]. These maps predict maximum shaking in parts of the NMSZ comparable to that for San Francisco or Los Angeles because of two key assumptions. One is that the 1811–1812 earthquakes were, and hence, the largest future earthquakes will be, M 8.0—larger than recent studies find. The second is that the resulting ground motion will significantly exceed that previously assumed.

Such predictions have considerable uncertainties, because they depend crucially on the assumed magnitude of the largest earthquake and resulting ground motion, both of which are poorly known. These uncertainties are illustrated (Figure 3) by comparison of maps showing the maximum predicted acceleration for different assumptions. As shown, the areas of significant hazard (0.2 g corresponds approximately to the onset of major damage to some buildings) differ significantly. The differences are even greater for longer-period ground motion, which poses the threat to tall buildings. These uncertainties will remain unresolved until the next major New Madrid earthquake.

An important contributor to these uncertainties is that predictions for longer time windows involve considering lower-probability earthquakes and shaking, so that both the estimated hazard and the uncertainties in the estimate increase. Hence, predictions of maximum shaking over 2500 years are both larger and more uncertain than those over the 500-year window (10% probability in 50 years) used previously in seismic hazard studies. In fact, the new building code does not use the 2500-year approach throughout California, because in some places, the predicted ground motions were so high as to require significant increases in the strength of construction over present codes [*BSSC*, 1997]. Moreover, comparison of reported damage in 1811–1812 to that predicted in future earthquakes by the USGS maps implies that these maps overestimate the seismic hazard. For example, reports from St. Louis were that the earthquakes' effects were "rousing people from sleep by the motion and the rattling of windows, doors, and furniture, to which was added a peculiar rumbling noise, resembling a number of carriages passing over a pavement... Some chimneys were thrown down and a few stone houses split."

Hough et al. [2000] interpret "split" as "cracked," and treat these reports as showing shaking of Modified Mercalli Intensity (MMI) VI-VII. However, the USGS maps predict peak ground motion of at least 0.3 g, which might be amplified by weak sediments. This would correspond to at least MMI VIII, defined for modern buildings as "Shaking severe, moderate to heavy damage; Damage slight in specially designed structures;

considerable in ordinary substantial buildings with partial collapse; great in poorly built structures." Hence, of the maps in Figure 3, the reported damage in St. Louis seems most consistent with the lower right map, which predicts about 40% of the shaking predicted by the USGS maps. It thus seems likely that the USGS maps also overpredict the hazard in Memphis, which is greater than in St. Louis, and elsewhere.

Economic and Public Policy Issues

Under the proposed IBC2000 code, buildings in areas like Memphis, which are unlikely to be seriously shaken during their useful life, would have to meet standards comparable to those for California, where buildings are likely to be shaken. Moreover, the new code requires that crucial buildings remain functional after an earthquake, rather than the traditional requirement that the building ensure life safety by not collapsing. Existing structures would be evaluated on the same basis, which could have adverse effects including preventing loans secured by these buildings and difficulties in securing insurance.

FEMA's estimate of the annualized earthquake loss in Memphis is about $17 million/year, which is probably too high, because it is based on the USGS hazard maps. The new code would reduce this loss by some fraction yet to be estimated. However, our initial estimate is that the code's cost for new construction would be far greater, over $200 million/year above that required by the seismic code adopted in 1994. Additional costs would be incurred by following FEMA's recommendation to retrofit existing critical buildings such as schools, hospitals, fire and police stations, and infrastructure including highways, bridges, utilities, and airport facilities. These costs can be 25–33% of the cost of a new building. For example, restoration of the Memphis Veterans Medical Center, including seismic retrofitting, costs $64 million; so expensive, that designers removed 9 floors of the existing 14-story tower; and making the cost nearly equal to that of a new building. The resulting economic impact, including reduced new construction, job losses, and reduced housing affordability, is likely to be significant.

A similar situation applies elsewhere in the NMSZ. For example, FEMA's estimate of the annualized earthquake loss for St. Louis is comparable, about $34 million/year. Another useful indicator is the annualized earthquake loss ratio, the ratio of annualized earthquake loss to the replacement cost of all buildings in the area. These values are 388 and 282 (times 10^{-6}) for Memphis and St. Louis, about one-fifth to one-tenth of those (3168 and 2300) for San Francisco and Los Angeles. On this basis, Memphis ranks 32nd in the nation among major cities, and St. Louis ranks 34th (just above Honolulu). Because these ratios are equivalent to the fractional risk of building damage, FEMA's estimate indicates that buildings in the NMSZ are 5 to 10 times less likely to be damaged during their lives than are buildings in California.

Hence, it seems unlikely that the proposed code would be justifiable on a cost/benefit basis. Another way to view the issue is to consider alternative uses of resources. For example, funds spent strengthening schools are not available to hire teachers, upgrading hospitals may require providing insurance to fewer uninsured patients (about $3,000/year each), and stronger bridges may result in hiring fewer police officers and firefighters (about $60,000/year each). A similar argument applies to saving lives: the proposed code might, over time, save a few lives per year, whereas the same sums invested in public health or safety measures (flu shots, defibrillators, highway upgrades, etc.) could save many more [*Wilson and Crouch*, 2001].

As a result, despite the natural tendency for communities in the area to quickly adopt FEMA's recommendations, doing so seems premature. Instead, we recommend a more sophisticated approach that carefully weighs the costs and benefits (together with associated uncertainties) of alternative strategies. The goal should be to develop one that makes economic sense and will be accepted by the public and business communities. For example, reasonable safety at lower cost might result from retaining codes like that recently adopted in Memphis. Another approach would be to use the methods of IBC2000, but plan for the ground motion expected over a shorter time—once in 500 years, as used in planning for floods and other natural disasters. Given the large sums at stake, the additional time spent getting things right would be well spent.

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