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Seismic Safety: when are we safe enough?

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Abstract

Owners want seismically safe buildings. While not usually interested in the details, they are content when told that their design professionals are following the latest standards of practice and are using the largest expected earthquake for the site. It gives them the reassurance, regardless of whether they understand all the details or the probabilities, that in the worse case, everyone will at least be "safe". Unfortunately, lost in the process is the performance expectation embodied in the code, its relationship to the defined largest expected earthquake, and an agreement about what constitutes "safe". This lack of clarity has lead to confusion in dealing with the recently increase hazard levels introduced in the latest codes. The 2% in 50 year maximum considered earthquake, recently added to achieve an equal hazard level across all regions, does not fit into the current code procedures because it results in designs that are too stringent. Other parts of the codes and standards need to be modified and made consistent with the needs of the community. Our efforts toward seismic safety will be "safe enough" when our performance expectations are clearly stated and the hazard level defined in a manner that supports a seismic safety program which is based in understanding and balanced with the other social, economic, and political needs of the community.

Introduction

Earthquake Engineers, Design Professionals, and Public Officials have a common fundamental goal related to the quality of the built environment in regions with seismic hazards: Public Safety. This goal is to prevent serious injury or death that would result from an earthquake. Even in the swirl of activity that surrounds Performance Based Engineering that allows us to consider and design for a family of earthquake levels and performance expectations, public safety remains the minimum expectation. Unfortunately, the definition of public safety is not a simple black and white statement. It demands definition in terms of how much and what type of damage is acceptable, how large of an earthquake is expected to occur, and how much risk the public is willing to accept.

Acceptable Damage

There is no clear evidence of when engineers started worrying about earthquakes. It is fair to speculate, though, that it likely happened soon after the first building was destroyed by strong ground shaking. Observations in Europe suggest that the surviving cathedrals of the Middle Ages, located in high seismic regions, purposely contained seismic resistant design features. Presumably, these were developed after strong earthquakes repeatedly caused unacceptable levels of damage. There is also evidence to suggest that seismic resistance was purposely designed into brick buildings in California in the middle 1800s based on the type of damage that occurred in the 1857 Hayward earthquake. This pattern continues today with engineers refining their codes and standards after each earthquake to eliminate damage that is considered unacceptable. While the process is correct, it is rarely clear whether these efforts intend to achieve a common minimum goal.

While earthquake engineers always appear to be focusing on life safety as the minimum level of performance, they rarely agree on what that means. To some, life safety means that it is acceptable for a building to be damaged to the point of nearly collapsing. Experience has shown that people can generally survive most earthquake damage that does not physically crush them. To others, life safety implies that the occupants will not be injured during the earthquake, that they will be able to exit afterward without assistance, and that the building will be repairable. This requires a building that is only moderately damaged, has not experienced significant permanent drift, and the interior, non-structural elements are not blocking the egress routes. At the other extreme, some believe that life safety extends to include minimizing damage and assuring that the essential facilities remain operational. Hospitals should be able to care for their critically ill, and those injured in the earthquake, in fully operational facilities. Police and Fire support facilities should also be undamaged so that they can continue to carry out their safety related functions. This operational level of performance also assumes that landslides, liquefaction, lateral spreading, and/or faulting does not cause adverse effects.

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It appears that most current seismic design codes and standards, written to achieve basic life safety, interpret their goal in the broadest sense. These provisions included strength and detailing requirements that strive to eliminate the potential for serious structural damage altogether, and include provisions for anchoring and bracing non-structural elements. These modern codes also include more stringent requirements for certain classes of occupancy (the essential buildings) that are designated to remain operational after the maximum expected earthquake. This interpretation of life safety works well for new buildings in high seismic regions where the cost to achieve a high level of seismic safety is nominal compared to the cost of the project. It does not work well when suggested for regions that have not experienced recent damaging earthquakes, nor when it is applied to existing buildings where a minimal upgrade to "code" for a standard building can cost up to half the value of the building, and more than the full value of the building for an essential facility.

The need for special provisions for existing buildings has spawned a new series of guidelines. The latest evaluation guideline, FEMA 310 (FEMA 1998), and rehabilitation guideline, FEMA 273 (FEMA 1997), recognize the need for explicitly stating the performance expectations related to their provisions and offer a range of performance levels for evaluation and rehabilitation. The format used is consistent with the Performance Based Engineering principals currently gaining popularity, such as those contained in Vision 2000 (SEAOC 1995). They include procedures for achieving performance levels related to basic life safety, immediate occupancy, and operational ability. These documents are currently in the process of being converted to code language so they can be approved as standards. Their availability has permitted numerous rehabilitation projects to proceed to less than code levels while permitting reasonable expectations to be met and overall community seismic safety to improve.

Achieving seismic safety depends, in part, on a clear statement of what constitutes acceptable levels of damage. This is only possible when there is a clear definition of the performance expectations, and where there is the development of Performance Based Engineering Standards, which allow structures to be designed to predictable levels of performance. The family of performance levels needs to independently address life safety, functionality, and provisions that can be incorporated to minimize the cost of repairing the damage. We are just now beginning to approach this ability.

Maximum Considered Earthquake

The 1906 San Francisco Earthquake served as a good test of how well buildings could resist strong ground shaking. Because of the extraordinary fault rupture length and the size of the affected zone, it is commonly believed to be the largest expected earthquake for Northern California. From observations on which structures did well and which did not, engineers began to speculate on how to quantify the effect strong shaking had on buildings. Eventually, they selected acceleration as the key to understanding. Newton's second law, F=MA, lead to the notion that the weight of the building, it's strength, and the maximum acceleration that occurred during the ground shaking, held the keys to a successful design. This lead to the notion that the size of future earthquakes should be defined in terms of the expected acceleration levels, a fundamental concept that remains at the foundation of most analysis techniques used to quantify the effects earthquakes. It is interesting to note that buildings that remained standing performed in a life safe and repairable manner in 1906.

At first, since so little was known about the scientific basis of strong ground shaking, fairly simple procedures were developed to define the largest expected earthquake. With the development of weak and strong motion instrumentation, and as a result of decades of seismological research, the simple techniques yielded to scientifically based procedures for determining the largest expected earthquakes. In the sixties and seventies, these events were defined by the collaborative efforts of a few recognized experts. Today, these largest expected earthquakes are referred to as deterministic earthquakes.

As strong ground motion records became available, and the demand for scientifically defendable estimates grew, probabilistic seismic analysis was introduced to properly define the size of the largest expected event. This probabilistic approach allowed a wide variety of seismic sources to be included along with a proper characterization of uncertainty. It also permitted the systematic definition of design earthquakes that were smaller than the largest expected. These proved to be useful in better understanding the risk inherent in existing and vulnerable buildings. These probabilistic earthquake estimates brought with them the need for determining an acceptable level of hazard.

It was determined by the probabilistic technique that an earthquake the size of the 1906 San Francisco earthquake had a 10% probability of exceedence in 50 years (10/50). Since the 1906 earthquake was already recognized as the largest expected (deterministic) earthquake for the area, this probability of exceedence level soon became recognized as the acceptable hazard level. The 10/50 earthquake was introduced into various design codes and standards beginning in the

1970s as the largest expected, and it remains in many today. The continuing developments in seismology, especially in the low seismic regions, gave way to a recognition that there were significant variations in hazard curves across the regions of seismicity, and that the universal use of a 10/50 earthquake was not appropriate.

It appears that the driving reason behind this conclusion was the significant difference in the size of the probabilistic earthquake when compared to the deterministic earthquake. In addition, many experts believed that the absolute value of the probability of exceedence for the 10/50 earthquake was too high, relative to the consequence of failure, if exceeded. The two-decade long debate that ensued demanded a larger event for use in the lower regions of seismicity. At the same time, the development of seismic codes and standards had become a national effort in the United States. This national focus demanded an equal hazard level for all areas of the United States. Interestingly enough, it became apparent that the Central Valley areas of California had a similar set of hazard curves as other areas of low seismicity in other parts of the country. And, in California, the design codes had set an artificial minimum design value that was two to three times higher than the 10/50 year earthquake would require. In the late eighties, an earthquake hazard level equal to 2% in 50 years began to achieve acceptance in areas of lower seismicity, because it provided a better balance between the deterministic expectations and the probability level appeared to be more appropriate. At the same time, it became obvious that the 2/50 year level was close to the acceptable limits already set for California's areas of lower seismicity.

Setting a level of acceptable hazard is a consensus process; there is no one answer. The most recent effort was a joint effort of engineers and scientists from the United States Geologic Survey (USGS) and the Building Seismic Safety Council (BSSC). Their efforts resulted in the adoption of the 2% in 50-year hazard level for both the new building design provisions (NEHPR 1997), and for the previously mentioned FEMA rehabilitation guidelines. Once converted for use in design, this earthquake level is recognized as the "maximum considered earthquake" (MCE), and as such, can be referred to as the maximum expected earthquake. Undoubtedly, this hazard level was found acceptable to different people for different reasons. Its credibility rests in the application of accurate scientific research, consideration of the uncertainty in the data and process, and the consensus achieved on the acceptable hazard level selected.

Public Acceptance of Risk

Regardless of the good intentions of the earthquake engineering community, public tolerance for earthquake damage is highly variable, and dependent on the overall political and social environment. At times, especially after damaging events, the public shows no tolerance for excessive damage, injuries, or deaths related to earthquakes, regardless of the cost to mitigate. At the other extreme, which is not uncommon when no recent earthquakes have occurred, the cost of seismic safety is judged to be so high that the public will tolerate what appears to be a very high risk. The multi-billion dollar California Bridge retrofit program appears to be at one extreme, while the lack of mandatory seismic requirements in most moderate and low seismic regions, and in developing countries, appears to be at other. While it has occurred for decades, it is not appropriate to exclude the publics acceptance of risk from a discussion of seismic safety, especially when we are attempting to determine when the we are "safe enough." At the same time, we should not expect to be able to sufficiently generalize the varying needs of the public at large in a single design code.

There is a growing trend in public and private circles to use risk analysis and risk characterization to make better decisions related to the hazards that affect human health and welfare. The Committee on Risk Characterization of the National Research Council (NRC 1996) recently examined the use of risk analysis in decision making. The committee noted that it often failed to achieve its objective and suggested a proper procedure to improve it usefulness and maximize the benefits. They observed that in most cases, a technical analysis of the risks inherent in a hazard is developed, summarized, and delivered to the decision makers without any prior consultation. The style of technical analysis is often developed based on the available science and summarized from the prospective of the analyst. They report that, in many cases, this style of risk analysis fails to prove beneficial for two reasons. First, it is often misunderstood, which results in an unwise decision. Second, the technical information that is delivered is often not useful to the decision-maker because it does not specifically address the issues being faced.

The committee suggests that a process, which combines analysis and deliberation, is needed to achieve sound and acceptable decisions. They believe that the risk characterization should be a decision-driven activity that is directed toward informed choices and solving the actual problems that exist. The risk situation must be defined based on a broad understanding of the relevant losses, harms, and consequences as they relate to the needs of the interested parties. The risk characterization should treat uncertainties, seek to explain the meaning of the analytical findings, and improve the ability of those affected to participate in the risk decision process. To be successful, the process must be interactive, iterative, and involve broad representation. They argue that analysis alone, no matter how thorough, does not address the decision-relavent questions, leading to long delays, and jeopardizing the quality of understanding and the acceptability of the final decisions.

It appears that within the context of seismic safety, the technical analysis-only process has generally been followed. The results are presented in terms of meeting the code or not, for earthquakes of probabilities that have no particular relationship to the issues at hand. While the public and private decision-makers are trying to balance the need to invest in seismic safety with the other demands for the private and community resources, we are not clearly giving them the information needed for a thoughtful decision. They most often ask what the probability of failure is in terms of the development of a life safety concern, the loss of function, or the cost of repairs. Since our process has grown out of the design professions and the probabilistic hazard analysis procedures, without significant contribution from the decision-makers, it does not talk in those terms. The result is a lack of consensus among the experts on what constitutes proper seismic safety, and little enduring public policy which will lead to an acceptable level of seismic safety.

Because the public has not been engaged in the development of the seismic safety standards in a meaningful way, we have no idea whether we are in fact "safe enough," even though we have the beginnings of Performance Based Engineering and equal hazard levels throughout the all seismic regions.

Conclusion

Seismic Safety; when are we safe enough? At this point, we are perhaps half way to answering the question. We, as earthquake engineers and building officials, have worked from a reactive foundation, developing consensus amongst ourselves but without broader and significant input from the community. It appears that we will only be able to claim to have achieved seismic safety, to the point of being "safe enough", when we have accomplished the following:

1. We have added to our codes and standards a clear statement, understandable by the public, of our performance expectations, and how they relate to public safety, functionality, and minimizing the cost of repairs.

2. We continue to agree on a definition of the largest earthquake that we need to consider so that we can continue to say we are designing for the largest expected earthquake.

3. We have sufficiently educated the public on seismic safety, and assisted them in making policy decisions that properly balance seismic safety with all the other social, economic, and political issues unique to each jurisdiction, and lead to proper public policy.

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