OPINION

Seismic Hazard vs. Seismic Risk

The world is full of uncertainties, ranging from climate change, financial markets, natural disasters, terror attacks, and personal health to the measurements of the most fundamental elements of all: time and space. Dealing with uncertainty is a given in life, and any decision is always made under a certain degree of uncertainty. Risk is one of the most important concepts for dealing with uncertainty in decision making. Another important concept associated with risk is hazard. Hazard is a natural or man-made phenomenon that has the potential to cause harm (*i.e.*, social or economic consequences). Hurricanes, earthquakes, tornadoes, and floods, for example, are natural hazards, whereas car crashes, chemical spills, train derailments, and terror attacks are man-made hazards. Risk, on the other hand, is the probability of harm if someone or something is exposed to a hazard. Similarly, *seismic hazard* and *seismic risk* are fundamentally different. Seismic hazard is a natural phenomenon such as ground shaking, fault rupture, or soil liquefaction that is generated by an earthquake, whereas seismic risk is the probability that humans will incur loss or damage to their built environment if they are exposed to a seismic hazard. In other words, seismic risk is an interaction between seismic hazard and vulnerability (humans or their built environment). In general, seismic risk can be expressed qualitatively as

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$$\text{Seismic Risk} = \text{Seismic Hazard} \times \text{Vulnerability} \qquad (1)$$

As shown in Equation 1, high seismic hazard does not necessarily mean high seismic risk and vice versa. There is no risk if there is no vulnerability, even though there is a high seismic hazard. Equation 1 also shows that engineering design or a policy for seismic hazard mitigation may differ from design and policy decisions related to seismic risk reduction. It may or may not be possible to mitigate seismic hazard, but it is always possible to reduce seismic risk, either by mitigating seismic hazard, reducing the vulnerability, or both.

As a natural phenomenon, seismic hazard is quantified by three parameters: level of severity (physical measurement), spatial measurement, and temporal measurement. For example, an **M** 7.5 earthquake with a mean recurrence interval of 500 years in the New Madrid Seismic Zone of the central United States, and a median peak ground acceleration (PGA) of 0.3 g with a mean return period of 100 years in San Francisco, are seismic hazards. Seismic hazard is assessed from instrumental, historical, and geological observations. In other words, seismic hazard is assessed from Earth sciences. Therefore, Earth scientists, seismologists in particular, play a key role in seismic hazard assessment.

Seismic risk quantification is very complicated and somewhat subjective because it not only depends on the desired physical measurement (*i.e.*, magnitude, ground motion, fatalities, or economic loss), but also on how the hazard and vulnerability interact in time and space. The hazard and vulnerability could interact at a specific site (site-specific risk) or over an area (aggregate risk). To estimate seismic risk, a model has to be assumed or introduced to describe how the hazard and vulnerability interact in time. Models including the Poisson, empirical, Brownian passage time, and time-predictable have been assumed for earthquake occurrences in time and used for seismic risk estimation. Different models result in different seismic risk estimations. The most commonly used model for seismic risk estimation is the Poisson model. Under the Poisson assumption, seismic risk, expressed in terms of a probability p of an earthquake exceeding a specified magnitude (M) over an exposure time t for a given vulnerability, can be estimated by

$$p = 1 - e^{-\frac{t}{\tau}}, \qquad (2)$$

where τ is the average recurrence interval or $1/\tau$ is the average frequency of an earthquake with magnitude M or greater. Equation 2 describes a quantitative relationship between seismic hazard (*i.e.*, an earthquake of magnitude M or larger with an average recurrence interval or frequency) and seismic risk

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(*i.e.*, a probability p that an earthquake of magnitude M or larger could occur during an exposure time t for a given vulnerability). Equation 2 has also been used to estimate flood, wind, and other risks. For example, 1 percent probability of exceedance in one year and 2 percent probability of exceedance in one year are considered for building design for flood and wind, respectively. These risks are calculated from Equation 2 for the 100-year flood and 50-year wind hazards, and an exposure time of one year, respectively. Similarly, 10, 5, and 2 percent probability of exceedance in 50 years have been considered for building design for earthquake resistance and are calculated from Equation 2 for the ground-motion hazards with return periods of 500, 1,000, and 2,500 years, respectively.

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Equation 2 is derived from the interactions between the hazard and vulnerability in time and space without consideration of the physical interaction between the hazard and vulnerability. The physical interaction is very complicated. For example, for certain buildings, there is a relationship between ground motion and damage levels (*i.e.*, fragility curve). And the damage level can also be related to a level of economic loss. Through the fragility curve (*i.e.*, the physical interaction relationship between the seismic hazard and vulnerability), seismic risk can also be expressed as a probability that a building could be slightly damaged, or a $20,000 loss could result in a certain number of years, such as 50 years. Thus, seismic risk is quantified by four parameters: *probability*, *level of severity* (*i.e.*, a physical or monetary measurement), *spatial* measurement, and *temporal* measurement.

Although the terms seismic hazard and seismic risk have often been used interchangeably, they are fundamentally different concepts. To reiterate, seismic hazard describes a natural phenomenon generated by an earthquake, whereas seismic risk describes the probability that humans will incur loss or damage to their built environment if they are exposed to a seismic hazard. It is critical for Earth scientists, seismologists in particular, to clearly define, quantify, and communicate seismic hazard because it is the basis for risk assessment and other applications. Seismic risk assessment is even more complicated and requires cooperative efforts among Earth scientists, engineers, and others.

Zhenming Wang
Kentucky Geological Survey
University of Kentucky
Lexington, Kentucky 40506 U.S.A.
zmwang@email.uky.edu