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Opinion paper

Uncertainty about the uncertainty in seismic hazard analysis

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Abstract

In recent years, practitioners of probabilistic seismic hazard analysis have adopted the use of the terms aleatory and epistemic uncertainty. This new terminology has been criticised as a new weapon in the probabilist's arsenal, whereas, in fact, nothing has actually changed: These are merely new words for the existing concepts of randomness and uncertainty, whose usage has become confused and ambiguous. The debate regarding the relative merits and shortcomings of deterministic and probabilistic approaches will no doubt continue for many years. However, this debate could become more productive if clear definitions of concepts, such as uncertainty, are first established to avoid discussions at cross purposes.

Keywords: Seismic hazard assessment; Aleatory uncertainty; Epistemic uncertainty; Return period; Recurrence interval

1. Introduction

During the last decade, Ellis Krinitzsky has, amongst his many other contributions to engineering geology and geotechnical engineering, presented a series of publications in defence of a deterministic approach to seismic hazard assessment (DSHA). These papers are written in an engaging and lively prose that is a welcome change from so much of the scientific literature. The most recent salvo in his crusade against probabilistic seismic hazard assessment (PSHA) is true to form (Krinitzsky, 2002).

2. PSHA and DSHA

Since PSHA has been almost universally adopted as the method for determining design ground motions, Ellis Krinitzsky has played what I consider a useful role in challenging the precepts and applications of the probabilistic approach. He has often pointed out, e.g., the problems that result from smearing—to use his terminology—all earthquakes together in the hazard calculations, if representative accelerograms are ultimately required as the output. The resulting uniform hazard spectrum (UHS) will often represent a ground motion that could only be caused by the simultaneous occurrence of two earthquakes (Bommer et al., 2000).

Nonetheless, such shortcomings do not necessarily invalidate entirely the probabilistic approach: It may not be so helpful to throw the baby out with the bath water. Indeed, any rigid defence of PHSA or DSHA, particularly if accompanied by a dismissal of the alternative, is based on the premise that the two approaches constitute clearly established, uniquely defined and mutually exclusive methods for estimating the ground motions to be expected from future earthquakes. Examination of the methods actually used in current practice around the world strongly suggests that such a stark dichotomy does not really exist

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(Bommer, 2002). Indeed, several researchers and practitioners actually propose that deterministic and probabilistic elements in seismic hazard assessment be balanced according to the particular application in question (e.g., McGuire, 2001).

3. The need for a common language

The tension between the proponents of DSHA and PSHA may be healthy and possibly even beneficial, provided it takes the form of open and constructive debate. However, for this to be the case, there must first be complete clarity about the two methods. A starting point for this is the use of precise terminology, and I believe that the introduction of the terms epistemic and aleatory uncertainty is just an attempt to establish unambiguous names for what were previously known as simply uncertainty and randomness, terms that have come to be used interchangeably by many seismic hazard analysts. In broad and simple terms, the two types of uncertainty can be understood as the uncertainty we can measure, such as the scatter in strong-motion attenuation equations, which is aleatory, and the uncertainty that can only be judged, such as the value of the largest feasible earthquake magnitude, which is epistemic (not epistematic). The value of the concepts may also be debated, and our understanding of them may change with increasing knowledge: A legitimate school of thought will argue that all of the uncertainty in seismic hazard analysis is ultimately epistemic. Time will tell. In the meantime, the use of these "new" terms is already facilitating interesting discussions and analyses of the nature of the uncertainties (Anderson and Brune, 1999; Toro et al., 1997) even if these studies also illustrate that there is not yet a unique and universal definition of their meaning, which is needed.

If anyone claims that the use of the terms epistemic and aleatory uncertainty actually enables the overall uncertainty in seismic hazard assessment to be reduced, it is right that they be challenged. However, there is no intrinsic harm in trying to use unambiguous terminology, especially as so many terms are incorrectly used in seismic hazard studies (Abrahamson, 2000). A common example is the use of mean and median as if the terms had the same meaning; in log-space, the mean and median are equivalent. However, because in real engineering we always deal with absolute values of acceleration, it is the median and not the mean with which we are concerned. In his short article endorsing the views expressed by Krinitzsky, Paul (2002) also uses confused terminology in referring to "return periods much greater than the length of the records"; return periods of ground motions are not the same as recurrence intervals of earthquakes. Return period is perhaps a misleading term in itself because it overemphasises the units of time; it is nothing more than the reciprocal of the annual frequency of exceedance of the ground motion, whence it can quite easily be longer than the earthquake catalogue. Consider an earthquake with a recurrence interval of 100 years (and it should be noted that historical and geological insight can provide handles on the recurrence of larger events over periods longer than those covered by the instrumental catalogue) combined with the median plus two standard deviations of the chosen ground-motion parameter. This ground motion, for a given magnitude–distance couple, corresponds to the 97.7 percentile, which is approximately the 1-in-40 level; combined with the 1-in-100 year earthquake, a return period of 4000 years is comfortably achieved.

4. Seismic hazard analysis and engineering design

The selection of the most suitable approach for estimating earthquake ground motions should be made considering how the output of the hazard evaluation will actually be used. In this framework, it becomes easier to understand the attraction of DSHA to many practising engineers: In current practice, most engineering design is essentially deterministic. If the design loads are to be defined as a single level of ground motion corresponding to an annual frequency of exceedance (whose origin is often unclear), the potential benefits of PSHA become somewhat irrelevant. However, in civil engineering design, the concept of failure is not binary as Paul (2002) asserts because it is a term that only describes performance with respect to one criterion. Failure at the serviceability limit state is quite different from failure at the ultimate limit state, and as soon as both of these criteria are to be considered, the worst-case scenario ground motions that DSHA claims to provide become insufficient.

This is an exciting time to be involved in research into seismic hazard analysis, as the subject evolves, presenting new challenges and raising new questions. On the one hand, some probabilists are beginning to address inconsistencies in PSHA, such as the fact that the UHS is calculated assuming, incorrectly, that the probability associated with each spectral ordinate is independent, and the covariance amongst the scatter in different parameters is being incorporated into the calculations (Bazzurro and Cornell, 2002). On the other hand, projects that push PSHA to longer and longer return periods, such as the study for the Yucca Mountain nuclear waste repository in Nevada (Stepp et al., 2001) and the Pegasos project for nuclear power plants in Switzerland (Abrahamson et al., 2002), throw important issues into clearer light. One of these issues is the influence that can be exerted by the tails of the log-normal distribution of the scatter in strong-motion prediction equations (i.e., the aleatory uncertainty) and the need to truncate at maximum credible levels of motion, just as the users of both DSHA and PSHA are content to place a ceiling on the largest magnitude earthquake that could occur (Restrepo-Vélez and Bommer, 2003). In this sense, contrary to the proposal of Paul (2002), it is DSHA that is providing sanity checks for PSHA rather than the other way around. Or at least it could be doing so if current deterministic approaches actually did provide the "worst conceivable loads" as Paul (2002) claims: DSHA defines a maximum credible earthquake in terms of magnitude and location and then calculates the 50- or 84-percentile ground motion that this would generate at the site of interest. Examination of almost any ground-motion prediction equation shows that adding one standard deviation increases the amplitudes more than adding 0.5 units to the earthquake magnitude, a common approach for estimating the MCE from the largest historical earthquake. Because in any strong-motion data set we encounter ground motions with amplitudes at least two or three standard deviations above the median values from the prediction equations, adding one sigma to the median motions from the MCE cannot be considered to represent the worst-case scenario. However reluctant die-hard determinists are to acknowledge the fact, the use of the median plus one standard deviation reflects a choice based on probability, albeit implicitly.

5. Conclusion

The more we push the development of seismic hazard assessment and its application to earthquake engineering, the clearer it becomes that we cannot dispense completely with either probabilistic or deterministic elements: Both are needed. What is also needed is a state of practice, not with respect to the approach to adopt but with regard to the use of terminology and, particularly, the presentation of process and results. Krinitzsky (2002) is absolutely right to challenge seismic hazard analysts who do not disclose uncertainties and assumptions. Whilst DSHA may be inherently more transparent than PSHA, transparency is ultimately an issue of reporting and a determinist can as easily conceal and blur his or her reasoning, data and assumptions as can a probabilist. A checklist of items that all seismic hazard assessments should present would be useful to everyone, especially peer reviewers and end users.

The articles by Krinitzsky (2002) and Paul (2002) reflect, in my opinion, the state of confusion that currently exists with regard to seismic hazard assessment, and they do little to help clarify the situation. Being clear about the uncertainties in seismic hazard assessment will clearly not in itself make things more certain, but it will certainly make things clearer. And then the discussions on how to move seismic hazard assessment forward can focus on the core issues of obtaining more reliable estimates of ground motions and adapting these estimates to the evolving demands of earthquake engineering, and not on the semantics.

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