Chapter 13

The Continued Utility of Probabilistic Seismic-Hazard Assessment

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ABSTRACT
Probabilistic seismic-hazard assessment (PSHA) has been a standard input to the engineering, planning, and insurance industries for over four decades. The purpose of this chapter is to provide an overview of how PSHA is performing in the modern world. PSHA has been, after all, the focus of considerable criticism in the literature in recent years, particularly after the occurrence of major devastating earthquakes in many parts of the world. In this chapter, I discuss the advantages and limitations of PSHA in light of the recent criticisms, and then discuss the new developments that are contributing to PSHA, or are expected to do so in the future.

13.1 INTRODUCTION
The method of probabilistic seismic-hazard assessment (PSHA) has now been a standard input to engineering, planning, and insurance applications for several decades. The PSHA method defined by Allin Cornell in the late 1960s (Cornell, 1968) uses the location, recurrence behavior, and predicted ground motions of earthquake sources to estimate the frequency or probability of exceedance for a suite of ground-motion levels (Figure 13.1). Between 2002 and 2014, a great deal of debate has occurred in the literature regarding the validity of the PSHA (e.g., Castanos and Lomnitz, 2002; Stein et al., 2011; Stirling, 2012; Wyss et al., 2012; Kossobokov and Nekrasova, 2012; Panza et al., 2014). Many of the more recent criticisms claim that PSH models have been inadequate in anticipating the accelerations due to recent devastating earthquakes (e.g., $M_w$ 9, March 11, 2011, Tohoku, Japan, and $M_w$, February 22, Christchurch, New Zealand earthquakes). The purpose of this chapter is to review the present utility of PSHA from the perspective of...
someone who has led the development of PSH models at national, regional, and site-specific scales over much of the last 20 years, and who regularly provides timely PSH solutions to end users.

13.2 THE LOGIC OF PSHA

PSHA is based on Cornell’s fundamental logic that hazard at a site is based on the location, recurrence behavior, and predicted ground motions of earthquakes surrounding the site (Figure 13.1). PSH models use estimates of earthquake recurrence derived from seismicity catalogs, active fault data, and from geodetic strain rates derived from global positioning system (GPS) data to develop source models (Steps 1 and 2 in Figure 13.1). Ground-motion prediction equations (GMPEs; Step 3) are developed from strong motion data sets. The fundamental output of PSHA is the hazard curve (Step 4), which gives the expected frequency or probability of exceedance for a suite of earthquake shaking levels (e.g., peak ground acceleration (PGA), spectral acceleration, and peak ground velocity). Many details are associated with the

FIGURE 13.1 The four steps of probabilistic seismic hazard analysis (PSHA).
The continued utility of probabilistic seismic hazard analysis (PSHA) is specifically applied at a site, such as the types of earthquake sources, particulars of the recurrence behavior, effect of distance on ground motions, and the ground conditions. However, the same logical method (Figure 13.1) is the foundation of all PSHAs.

PSHA has for a long time served to provide input ground motions for the design of engineered structures, which requires estimates of hazard that are relevant to the lifespan of the structure. For example, building design typically considers return periods of 500 or 2,500 years, which are, respectively, equivalent to a 10 percent and 2 percent probability of exceedance in 50 years. In contrast, nuclear facilities and major hydroelectric developments typically use hazard estimates with 10,000-year return periods or longer. Hazard estimates for these three return periods typically show large quantifiable differences across regions such as the western USA, Europe, Japan, and New Zealand, reflecting the long-term, tectonically driven differences in the expected future activity of earthquake sources across the regions. These differences are intuitively obvious, given that one would expect sites close to major plate boundary faults to experience more earthquakes in the long-term than sites further away. This is well illustrated by national PSH maps (e.g., New Zealand and USA; Figure 13.2(a) and (b)), and indeed, global maps (e.g., Global Seismic-Hazard Analysis Program (GSHAP), the predecessor of the Global Earthquake Model (GEM; globalquakemodel.org; Figure 13.2(c))), which show high hazard along the main plate boundary areas (areas of highest concentration of active faults and seismicity), and lower hazard away from the plate boundaries. This is useful information for engineering in particular, being the basis for development of design standards such as the New Zealand Loadings Standard NZS1170.5 (Standards New Zealand, 2004).

Response spectra (e.g., Figure 13.3) can be rapidly developed from a PSH model to provide seismic design loadings for a range of return periods and spectral periods. Spectral shapes differ according to the different mixes of earthquake magnitudes and distances surrounding the site of interest, which provides meaningful input to design loadings, including the selection of design earthquake scenarios and associated time histories. Spectra for given return periods (referred to as a uniform hazard spectra) can be disaggregated to identify the most likely (or most unlikely) earthquake scenarios for the site or region in question (Figure 13.4), and these scenarios are often used to select realistic time histories for input to seismic loading analysis, and for territorial authorities and others to plan for future earthquake hazards.

Many modern PSH models incorporate comprehensive epistemic (model or knowledge) uncertainties into every component of the model to account for all possible surprise events. The most recent version (version 3) of the Unified California Earthquake Rupture Forecast (UCERF) models, for instance (scec.usc.edu/scecpedia/UCERF3.0), allows virtually every possible
FIGURE 13.2 PSH maps produced from the (a) New Zealand national seismic hazard model; (b) US national seismic hazard model; and (c) Global Seismic Hazard Analysis Program (GSHAP) model. Each map shows the peak ground accelerations (PGAs) expected for a 500-year return period on soft rock sites. Map sources are Stirling et al. (2012), Petersen et al. (2008), and Giardini et al. (1999), respectively.
combination of rupture geometry on the California fault sources, and uses seismological and geodetic data to define a range of distributed (background) seismicity rates.

Prior to PSHA, seismic-hazard assessment was based on deterministic methods, in which the location and predicted ground motions of the most important earthquake sources were the basis for hazard estimation (i.e., no recurrence information considered). Although conceptually simple and useful, deterministic methods can also lead to the overestimation of the hazard in the case of a source of extremely long recurrence interval being used to define the

**FIGURE 13.2** cont’d

**FIGURE 13.3** Examples of response spectra for return periods of 150, 475, 1,000, and 2,500 years, for shallow soil site conditions. The spectra are plotted as accelerations for a given spectral period, in which the PGA is plotted at 0.03 s due to the inability to plot 0.0 s in the log scale. These spectra are for Wellington city, New Zealand, and are derived from the 2002 and 2010 versions of the national seismic hazard model for New Zealand (Stirling et al., 2002, 2012).
hazard at the site, or underestimation of hazard by ignoring local sources with relatively short recurrence intervals for moderate earthquakes that may still produce damaging ground motions at a site. By disaggregating the hazard curve, a realistic deterministic scenario can be selected for use in scenario-based studies and analysis.

13.3 NATURE OF RECENT CRITICISMS OF PSHA

Many of the recent criticisms of PSHA imply that specific PSH models failed to anticipate the level of acceleration in recent, devastating earthquakes such as the Tohoku and Christchurch earthquakes (e.g., Stein et al., 2011). Although it is indeed the case that the PSH models did not provide any indication that the events were going to occur in the year 2011, criticisms of this nature have been made without full appreciation of the construction and intended use of PSH models. In short, people always want to see high levels of hazard on maps where the subsequent major earthquakes and associated strong ground motions occur, and when they do not they conclude that the models must be wrong. The reason for these apparent discrepancies is that the recurrence intervals or rates of occurrence of the causative earthquakes are fundamentally important drivers of the hazard estimates.

FIGURE 13.4 Example of a disaggregation for the city of Christchurch derived from the New Zealand national seismic-hazard model (Stirling et al., 2012). Despite the model being produced prior to the 2010–2012 Christchurch earthquake sequence, the disaggregation plot identifies two relevant classes of earthquakes that dominate the hazard of the city: earthquakes of $M_w$ 5–6.0 at distances of <10 km to the city and $M_w$ 6.0–7.5 at distances of 10–50 km. These classes of earthquakes encompass all the major earthquakes of the Canterbury earthquake sequence. PGA, peak ground acceleration.
As an example, the Christchurch earthquake produced rock PGAs of about 1g in an area of formerly low seismicity where the New Zealand PSH model (Stirling et al., 2012) showed 500-year PGA motions of about 0.3g. As I have mentioned, the 500-year return period is one of the most frequently used portrayals of PSH, but in low seismicity areas, the 500-year motions will almost invariably underestimate the motions produced by rare, damaging earthquakes if they occur there.

The ways of extracting strong motion information from a PSH model to adequately represent such rare events are threefold: First, the hazard can be calculated for return periods that are appropriately long (e.g., ≥2,500 years) so as to produce higher levels of hazard. Important facilities such as hospitals usually consider a 2,500-year, return period hazard; Second, scenario (deterministic) hazard estimates can be provided by considering the motions that would be produced by specific local sources near a site, irrespective of the recurrence interval of the sources; Third, time-dependent or “time-varying” hazard models can be developed to produce high PSH if adequate knowledge of enhanced earthquake probabilities exists. In the absence of such time-varying information (the typical case), the PSH model will typically be based on a Poissonian probability model (time-independent earthquake rate or probability). The obvious limitations in the above are the choice of return period (people will often consider long return periods too conservative), choice of scenario earthquakes (people will be dubious of hazard estimates that are based on poorly defined sources of long/unknown recurrence interval), and data quantity/quality/uncertainty issues in time-varying hazard modeling. These limitations necessitate very careful recommendations being made in the PSHA process, and full documentation of the associated model caveats.

If a PSH model can be augmented with time-varying (forecasting) components, then the model can provide hazard estimates relevant to time periods of days to decades (e.g., Gerstenberger et al., in press). These models require two types of data: (1) a detailed knowledge of the earthquake history and prehistory of well-studied faults, so the earthquake recurrence interval and elapsed time since the last earthquake faults can be determined and (2) high-quality earthquake catalogs that allow temporal and spatial characteristics of earthquake occurrence to be deciphered and modeled with time-varying rate or probability models (e.g., Rhoades et al., 2010; Kossobokov, 2014; Schorlemmer and Gerstenberger, 2014; Wu, 2014; Zechar et al., 2014). In all efforts to establish such time-varying models, the resulting models are generally associated with large epistemic uncertainty and aleatory (random) variability. Furthermore, no one model is presently capable of providing a prospective short-term forecast of a large earthquake sequence that suddenly occurs (as was the case for the Canterbury earthquake sequence). Not surprisingly, the ability to provide actual earthquake forecasts for end-user application and policy is in the early stages of
development. To attain reliable earthquake forecasts, there needs to be some significant advances in relevant scientific research and monitoring/detection.

Legitimate criticisms can be leveled at elements of the PSHA inputs for regions relevant to the recent major earthquakes mentioned above. In the case of the Tohoku earthquake, the magnitude of the earthquake was considerably greater than the maximum magnitude of the Japanese PSH model, which was retrospectively seen as a clear deficiency in the model. However, in the Christchurch, New Zealand earthquake, the causative fault was unknown prior to the earthquake, due to the long recurrence interval and resulting lack of topographic expression and seismicity along the fault. Without a prior knowledge of a fault source, it was impossible to estimate where the strongest near-field ground motions would occur. PGAs $>2g$ were produced at some strong motion stations at soft soil sites around Christchurch during the earthquake, due to the city being close to the fault source, and a likely combination of near-fault effects such as high stress drop and hanging wall effects.

In the national seismic-hazard model for New Zealand (Stirling et al., 2012), the Christchurch earthquake was to an extent accounted for by the distributed seismicity model. Distributed seismicity models are typically made up of a set of sources at grid points that have activity rates defined on the basis of the spatial distribution of seismicity. They are designed to model the seismicity expected to occur away from the known fault sources in the area, and if correctly parameterized, will account for earthquakes on unknown sources. In the case of the New Zealand seismic-hazard model, the earthquake magnitudes, recurrence intervals, and ground motions were to an extent accounted for in the national seismic-hazard model in three ways.

- In the Christchurch area, the maximum magnitude of $M_w 7.2$ was defined in the distributed seismicity model several years prior to the occurrence of the $M_w 7.1$, September 4, 2010, Darfield earthquake, the main shock of the Canterbury sequence.
- The recurrence interval for Darfield-sized earthquakes estimated from this distributed seismicity model is of the order of 11,000 years (Stirling et al., 2012), which is of an order similar to the emerging recurrence estimates for the Greendale Fault derived from paleoseismology (uncertain recurrence estimate of 16,000 years; Quigley et al., 2010; Figure 13.5).
- The ground motions were to an extent accounted for in prior national seismic-hazard models, as illustrated by the response spectra in Figure 13.6. The New Zealand Loadings Standard (NZS1170) spectrum for the 2,500-year return period is not dissimilar to (i.e., depending on spectral period) the recorded motions for the Christchurch earthquake from strong motion stations around Christchurch (Figure 13.6). While the NZS1170...
spectra are based on a previous version of the national seismic-hazard model (Stirling et al., 2002), the estimated hazard for Christchurch did not change greatly in the later model (Stirling et al., 2012). Comparison of national seismic-hazard models at 2,500-year (and longer) return periods to the Christchurch earthquake is reasonable, given the likely long recurrence interval of the causative fault source, which had no evidence of prior ruptures in the epicentral area.

**FIGURE 13.5** Simplified trace of the Greendale fault and the distributed seismicity grid cells of the New Zealand national seismic-hazard model in the immediate vicinity. The accompanying magnitude–frequency distribution shows the combined earthquake rates for these cells (cumulative number of events ≥$M$; magnitude range in the figure is limited to the magnitudes normally associated with damaging ground motions), and the 1/16,000-year rate estimate for the Greendale fault from paleoseismic data. *Figure reproduced from Stirling et al. (2012).*
13.4 ADVANCES IN PSH INPUTS

The PSH models are only as good as the input data and methods of source parameterization, ground-motion estimation, and probability estimation. However, as long as the associated uncertainties and limitations are fully expressed in the model commentary, and appropriate advice provided, the models can still be useful. The use of deterministic models and appropriate parameterization of distributed seismicity models are two examples of solutions used to compensate for known or suspected deficiencies in PSH models.

Improvements to the performance of PSH models require improvements to PSHA inputs and components. It is therefore worthwhile to review some of the major advances in PSHA inputs and components being made at present, and identify issues and priorities for future research focus.

13.4.1 Ground-Motion Prediction

The aleatory variability in ground-motion prediction remains a large issue, despite major efforts to develop new GMPEs. The next generation attenuation (NGA) project (peer.berkeley.edu/nga) has involved some of the world’s key GMPE developers producing a suite of GMPEs from the same quality-assured, strong motion data set. The models have incorporated more input parameters in an effort to improve ground-motion prediction, particularly with respect to source geometry. However, the aleatory variability, generally measured as the standard deviation of a log-normal distribution of ground motions, does not appear to have been reduced from those of earlier models.
(e.g., Watson-Lamprey, 2013). This may mean that the new parameters are not important as predictor variables, or they are important, but their impact on the GMPEs is being counteracted by the capturing of a more complete range of aleatory variability in the recently acquired strong motion data.

### 13.4.2 Monitoring

Efforts to improve the recording of input data by seismic and GPS networks are of fundamental importance to PSHA. Seismic networks (e.g., Geonet.org.nz) are making large improvements to the detection threshold of earthquakes (the minimum magnitude for a complete record of earthquakes), and the ability to observe temporal and spatial changes in seismicity. GPS is being increasingly used to provide input to source models (e.g., distributed seismicity models and subduction interface models). The generally short temporal coverage of GPS data is compensated for by a large spatial coverage, and as such, it can be a complement to other source models. This is illustrated in Figure 13.7 where I use GPS-based strain rates to develop a magnitude—frequency distribution for the plains surrounding Christchurch New Zealand (the Canterbury Plains). GPS results show that the order of 2-millimeters per year deformation rate is unaccounted for by the known active faults across the plains, and is presumably accommodated by earthquakes on unknown fault sources beneath the plains. The use of the GPS-derived 2-millimeters per year deformation rate to develop distributed seismicity rates for these sources produce seismicity rates that are a factor of two higher than the rates estimated from the observed seismicity prior to the Canterbury earthquake sequence.

Lastly, remote sensing techniques such as synthetic aperture interferometry are seeing improvements in applicability and resolution over time, and these will allow greater ability to detect the coseismic deformation field from earthquakes (e.g., Taubenböeck et al., 2014).

### 13.4.3 Active Faults: Detection and Characterization

Active fault data are the only PSHA input data set that is able to extend the earthquake record back in time to prehistory (Meghraoui and Atakan, 2014). Great improvements in the ability to detect and characterize active faults for input to PSHA have been seen in the last 10 years. Fault mapping has improved significantly through accumulated experience and the availability of new tools (e.g., LIDAR). Greater ability to map the surface geometry of faults and distributions of displacement has led to the improved characterization of fault sources in PSH models. The use of different disciplines and data sets together for fault characterization, particularly with respect to mapping fault ruptures in three dimensions, has yielded a great deal of understanding of rupture complexity and detail. Furthermore, increased age constraints on paleoearthquakes have made it
possible to establish conditional probabilities and associated uncertainties for future earthquakes on specific faults.

13.4.4 Supercomputing to Consider all Possibilities

PSH models are increasingly drawing on diverse data sets and methods, and using high-end computing resources. The Californian UCERF3 model

**FIGURE 13.7**  Magnitude–frequency distributions developed from GPS-measured 2 millimeters per year across the Canterbury Plains, New Zealand, for the entire plains (extent of yellow arrow); the 50-km-wide corridor across the full width of plains (Area 1 + Area 2), and for the 50 × 50-km Area 2. Also shown is the equivalent distribution derived for Area 2 from the distributed seismicity model of the New Zealand national seismic hazard model (Stirling et al., 2012). The city of Christchurch lies at the northeastern end of the boundary between Area 1 and Area 2.
incorporates hundreds of thousands of logic tree branches in its comprehensive source model, and the use of supercomputers allows the model to be run through the four steps of PSHA (Figure 13.1). Furthermore, physics-based, seismic-hazard modeling efforts such as CyberShake (SCEC.org), use supercomputers to run multiple realizations of earthquake scenarios from multiple sources, with shaking at the site computed directly from source, path, and site effects for each earthquake. The millions of calculations required would not be possible without access to major computing resources, and this was not possible as recently as a decade ago. Today, plausible scenarios such as the linking of fault sources to produce extended ruptures, and the range of uncertainties in magnitude—frequency statistics for the myriad of sources are able to be considered without the limitation of CPU demand. Already, exciting scientific results have emerged from the UCERF3 modeling efforts, such as the finding that the seismicity on faults cannot be modeled by the Gutenberg—Richter relationship, as this produces a poor fit to the paleoseismic data in California (Edward Field personal communication, 2013).

13.4.5 Forums for Scientific Debate

Some recent efforts have focused on providing scientific forums to openly debate some of the criticisms leveled at PSHA and the associated input. The American Geophysical Union and Seismological Society of America have held “Earthquake Debates” sessions on several occasions over the last 5 years. Furthermore, the Powell Center for Analysis and Synthesis (www.powell.usgs.gov) has recently supported a series of workshops that have brought together PSHA experts and critics from around the world to address issues associated with maximum magnitude estimation, testability of PSHA, and development of global, seismic-source models face to face (nexus.globalquakemodel.org/Powell). These meetings have been very positive, as people have been working together on common ground rather than talking past each other in the literature.

13.5 FUTURE NEEDS

13.5.1 Correct Use of PSH Models

I have indicated that many of the criticisms of PSHA in the recent literature have been without full appreciation of the drivers of PSH models, and how the models should best be used. Comparing PSH estimates at short return periods to the motions produced by rare, damaging earthquakes (e.g., our earlier Christchurch earthquake example) is inappropriate in the context of PSH model evaluation. Appreciation of the recurrence behavior of the relevant earthquake sources in a region is an essential part of the PSH process, resulting in the selection of appropriate return periods and/or scenario earthquakes to quantify the hazard.
13.5.2 Earthquake Forecasting during Seismic Quiescence

The frequently expressed desire to enhance PSH models to enable them to be used for short-term forecasting presents a major scientific challenge. As is, PSHA is inappropriate for short-term forecasting for the simple fact that it uses the past as a proxy for the future. In other words, spatial differences in the level of seismic hazard are a direct consequence of the past distribution of historical seismicity, GPS strain, and active faults. Although this reflects the long-term distribution of hazard, it does not identify where and when major earthquakes will next occur, especially in low seismicity areas. What is missing is the ability to achieve forecasting without the forecasts being entirely based on the presence of existing earthquake sequences, and the spatial density and longer term activity of sources. For instance, none of the various forecasting models (e.g., Short Term Earthquake Probability (STEP), Epidemic Type Aftershock Sequence (ETAS) and Every Earthquake a Precursor According to Scale (EEPAS)) could have provided advanced warning of the Canterbury earthquake sequence of 2010–2012, as the area had essentially no seismicity in the preceding decades. In order to achieve short-term forecasting, future research efforts need to be focused on improving the ability to monitor and detect microseismicity and crustal deformation, and identification of reliable earthquake precursors not currently known or observed.

In the New Zealand context, efforts are now in place to advance the national seismic-hazard model through the incorporation of short-term forecasting models. The Canterbury earthquake sequence initiated this work through an immediate need to provide hazard estimates for rebuilding Christchurch. The resulting hazard estimates are an ensemble of time-varying and time-independent earthquake probability models (e.g., Gerstenberger et al., in press). The ensemble PSH model shows that the resulting hazard will be well above that calculated prior to the Canterbury earthquake sequence (Stirling et al., 2012) for some decades to come.

13.5.3 Reduction in Aleatory Uncertainty in Ground-Motion Prediction

The aleatory uncertainty in ground-motion estimation is very large (the standard deviations in GMPEs are typically about 0.5 in natural log units of ground motion), and does not seem to have been reduced in the complex GMPEs available today. In other words, a very large range in the potential ground motions still exists that could be produced at a single site due to earthquakes of the same magnitude and distance. In contrast, the differences between GMPEs (epistemic uncertainties) do appear to have been reduced in recent years, at least within the NGA project.
13.5.4 Testability of PSHA

Finally, efforts need to be supported in the objective testing of PSH models, as to date PSH models have largely been developed in the absence of any form of verification (e.g., Panza et al., 2014). The Collaboratory for the Study of Earthquake Predictability (http://www.cseptesting.org/ and Schorlemmer and Gerstenberger, 2014) has been developing testing strategies and methods for a wide variety of applications, and collaborative work has also been focused on developing ground motion-based tests of the New Zealand and US national seismic-hazard models.

The Global Earthquake Model (GEM), a worldwide seismic hazard and loss modeling initiative, is including testing and evaluation as an integral part of the overall model development. This work is mainly focused on the evaluation of components of the PSH model, such as GMPEs. The Yucca Mountain seismic-hazard modeling project developed innovative approaches to consider all viable constraints on ground motions for long return periods for nuclear waste repository storage, prior to the cancellation of the project in 2008 (Hanks et al., 2013). The need to verify the hazard estimates for return periods of $10^4$–$10^6$ years advanced the use of geomorphic criteria to test the hazard estimates. The rationale is that “fragile geologic features” (Figure 13.8) provide evidence for nonexceedance of ground motions for long return periods, and prior to the cancellation of the Yucca Mountain project appeared to be showing new constraints on PSH models at long return periods.

![Figure 13.8](image)

**FIGURE 13.8** Example of an ancient fragile geologic feature at Yucca Mountain, Nevada, that has been studied to obtain constraints on past ground motions for return periods equivalent to the age of the feature ($10^4$–$10^5$ years). The cowboy hat at the base of the feature gives an indication of scale.
return periods (e.g., Anderson et al., 2011). Specifically, ancient fragile geologic features observed at Yucca Mountain were inconsistent with extremely strong ground-motion estimates produced for the very long return periods considered for repository design. The Yucca Mountain project therefore revealed the extent to which PSH estimates become driven by the “tails” of statistical distributions, namely, the log-normal distribution of predicted ground motions from GMPEs. Had the Yucca Mountain project continued, fragile geologic features would have played a major part in reducing the design ground-motion estimates for repository design. Similar observations have been made elsewhere in the USA and in New Zealand (e.g., Stirling and Anooshehpoor, 2006; Anderson et al., 2011), and fragile geologic features are now recognized as the only viable criteria for constraining ground-motion estimates for long return periods (Anderson and Biasi, 2014; Stirling et al., 2014).

13.5.5 Complex PSHA on Normal Computers

If the future of PSHA is in the development of complex PSH models such as UCERF3, and in the development of physics-based PSH models, the reliance of these models on supercomputer resources will be a significant barrier to their widespread utility. Significant efforts will therefore need to be focused on making these models usable on standard computers, or uptake will be extremely limited in everyday PSHA for end-user applications.

13.6 CONCLUSIONS

PSHA is a simple, logical method that bases future earthquake hazard on the location, rate, and predicted shaking intensities of past earthquakes. The PSHA method provides useful solutions for end users, mainly as input to engineering design. As such it is here to stay until another alternative method is available that is shown to do better than PSHA. Work focused on the pursuit of such models should be supported by the funding institutions, whether they be governmental or private industry. Furthermore, input to PSHA must continue to be improved, which requires that all the current developments described above continue to be supported. Finally, recent experience has taught me that the critics of PSHA can make considerable contributions to doing things better when they are brought together with the PSHA scientists to participate in forums such as the Powell Center for Analysis and Synthesis. In recent forums, we found that scientists who had been very critical of PSHA in the literature were able to be understood and appreciated by the PSHA scientists in the face-to-face Powell setting. In turn, the responsibilities and practical needs of PSH scientists to provide timely solutions to end users were better appreciated by the critics. Forums like these must continue to be supported.
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