Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts

Main Report

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Recommendations for PSHA: Guidance on Uncertainty and Use of Experts

ABSTRACT

Probabilistic Seismic Hazard Analysis (PSHA) is a methodology that estimates the likelihood that various levels of earthquake-caused ground motion will be exceeded at a given location in a given future time period. Due to large uncertainties in all the geosciences data and in their modeling, multiple model interpretations are often possible. This leads to disagreement among experts, which in the past has led to disagreement on the selection of ground motion for design at a given site.

In order to review the present state-of-the-art and improve on the overall stability of the PSHA process, the U.S. Nuclear Regulatory Commission (NRC), the U.S. Department of Energy (DOE), and the Electric Power Research Institute (EPRI) co-sponsored a project to provide methodological guidance on how to perform a PSHA.

The project has been carried out by a seven-member Senior Seismic Hazard Analysis Committee (SSHAC) supported by a large number other experts.

The SSHAC reviewed past studies, including the Lawrence Livermore National Laboratory and the EPRI landmark PSHA studies of the 1980's and examined ways to improve on the present state-of-the-art.

The Committee's most important conclusion is that differences in PSHA results are due to procedural rather than technical differences. Thus, in addition to providing a detailed documentation on state-of-the-art elements of a PSHA, this report provides a series of procedural recommendations.

The role of experts is analyzed in detail. Two entities are formally defined—the Technical Integrator (TI) and the Technical Facilitator Integrator (TFI)—to account for the various levels of complexity in the technical issues and different levels of efforts needed in a given study.
SPONSOR’S PERSPECTIVE

Probabilistic Seismic Hazard Analysis (PSHA) has become an increasingly important tool for aiding design and decision making at all levels in both the private sector and government. The level of sophistication applied to PSHA has increased dramatically over the past 27 years since the technique was first introduced in the literature. As more and more people and groups implemented and used PSHA in different forms, it became clear to the sponsors of the Senior Seismic Hazard Analysis Committee (SSHAC) report that the time had arrived to establish more uniform and up-to-date guidelines for future PSHA studies.

The need for such guidelines is threefold:

1. As the situation stands today, it is often the case that multiple PSHA studies are available for the same geographic region. However, due to differences in implementation, results of these studies often differ by substantial amounts for the same physical location. Further, because of the amount of technical information and complex combination of techniques utilized, it is not always simple to determine the source of these differences and which answer should be used.

2. Potential sponsors of a PSHA study are faced with the difficulty of determining the appropriate level of a proposed PSHA to ensure stable results that meet the sponsor’s needs.

3. The cost to perform a PSHA study can be quite large. The sponsors of this report expected that a suitable set of guidelines could be developed to assist the potential user in choosing the appropriate level of analysis consistent with the overall goals and resources available. Given the need to conserve resources, issuing such guidelines to optimize future PSHA studies in accordance with the sponsor’s need takes on added importance.

Overall, the sponsors saw a need for more stability in the PSHA process, both for nuclear and non-nuclear applications, in dealing with future needs for using PSHA to establish seismic hazard levels throughout the United States.

Comparative evaluations have shown that the differences between PSHA studies are often not technical, but due to the information gathering and assembly process used in the study. The integration of the different types of information required in a PSHA (geologic, seismotectonic, probability and statistics, information theory, and decision making) presents significant inter-disciplinary challenges and requires a project structure and process that assure proper integration. The skills required to be a good integrator and evaluator are not necessarily the same skills needed to be a good scientist. Our observation is that although many PSHA practitioners are trained experts in one or more fields, the PSHA divergence issue can partly be explained by a lack of integration and evaluation skills so important to the PSHA product. We believe this is true at all levels of PSHA, and these skill requirements may be most acute at the simpler levels of seismic hazard analysis not associated with critical facility assessments where typically the PSHA analysts must complete their work.

This report addresses the integration and evaluation issues that should be considered and focuses on the process of integration required in a PSHA. The SSHAC’s investigations have led to the conclusion that technical facilitation and integration is a necessary component for the proper implementation of a PSHA in some instances. In most of these cases, it is anticipated that following the approaches outlined in the report will bring about more consistent interpretations that are supported by the data or bulk of scientific thought. However, if an outlier interpretation persists, it is our firm belief—in agreement with the SSHAC—that the approaches outlined will allow for essential downweighting of that interpretation. This is
preferable to the stiff adherence to an equal weighting scheme, which can result in the final seismic hazard being driven by a single outlier input.

The issues that are raised and discussed in the SSHAC report, especially but not exclusively the process issues, apply in varying degrees to any PSHA project, and should be at least considered by sponsors and analysts before undertaking a PSHA. While the primary focus of SSHAC was on siting critical facilities, it is believed that all PSHA projects should attempt to achieve several primary objectives: 1) proper and full incorporation of uncertainties, 2) inclusion of the range of diverse technical interpretations that are supported by available data, 3) consideration of site-specific knowledge and data sets, 4) complete documentation of the process and results, 5) clear responsibility for the conduct of the study, and 6) proper peer review. Regardless of the level of the study, the goal in the various approaches is the same: to provide a representation of the informed scientific community's view of the important components and issues and, finally, the seismic hazard.

For these reasons, the sponsors believe that the SSHAC report is complete in terms of outlining the process a principal investigator should follow to complete a PSHA. Indeed, the report provides for technical flexibility where such flexibility is needed and, at the same time, encourages standardization of technical approaches and procedures as much as is feasible.

The future utility of PSHA in decision making depends to a large degree on our ability to implement the process in a meaningful and cost-effective way. Development of the SSHAC guidelines was planned with this goal in mind.
EXECUTIVE SUMMARY

Probabilistic seismic hazard analysis (PSHA) is a methodology that estimates the likelihood that various levels of earthquake-caused ground motions will be exceeded at a given location in a given future time period. The results of such an analysis are expressed as estimated probabilities per year or estimated annual frequencies. The objective of this project has been to provide methodological guidance on how to perform a PSHA. The project, co-sponsored by the U.S. Nuclear Regulatory Commission, the U.S. Department of Energy, and the Electric Power Research Institute, has been carried out by a seven-member Senior Seismic Hazard Analysis Committee (SSHAC), supported by a large number of other experts working under the Committee’s guidance, who are named in the following “Acknowledgments” section.

The members of the Senior Seismic Hazard Analysis Committee (SSHAC) are:

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The scope of the SSHAC guidance is intended to cover both site-specific and regional applications of PSHA (more broadly, applications in both low-seismicity and high-seismicity regions) in both the eastern U.S. and western U.S. Although the sponsors’ primary objective is guidance for applications at nuclear power plants and other critical facilities, the methodological guidance applies in whole or in part, on a case-by-case basis, to a broad range of applications.

The SSHAC guidance involves both technical guidance and procedural guidance, with a strong emphasis on the latter for reasons explained below. Therefore, the audience for the report includes not only analysts who will implement the methodology and earth scientists whose expertise will support the analysts, but also PSHA project sponsors—those decision-makers in organizations such as private firms or government agencies who have a need for PSHA information and are in a position to sponsor a PSHA study.

Note that our guidance is not intended to be “the only” or “the standard” methodology for PSHA to the exclusion of other approaches; there are other valid ways to perform a PSHA study. Likewise, our formulation should not be viewed as an attempt to “standardize” PSHA in the sense of freezing the science and technology that underlies a competent PSHA, thereby stifling innovation. Rather, our guidance is intended to represent SSHAC’s opinion on the best current thinking on performing a valid PSHA.
The most important and fundamental fact that must be understood about a PSHA is that the objective of estimating annual frequencies of exceedance of earthquake-caused ground motions can be attained only with significant uncertainty. Despite much recent research, major gaps exist in our understanding of the mechanisms that cause earthquakes and of the processes that govern how an earthquake’s energy propagates from its origin beneath the earth’s surface to various points near and far on the surface. The limited information that does exist can be—and often is—legitimately interpreted quite differently by different experts, and these differences of interpretation translate into important uncertainties in the numerical results from a PSHA.

The existence of these differences of interpretation translates into an operational challenge for the PSHA analyst who is faced with (1) how to use these different interpretations properly, and (2) how to incorporate the diversity of expert judgments into an analytical result that appropriately captures the current state-of-knowledge of the expert community, including its uncertainty.

The SSHAC studied a large number of past PSHAs, including two landmark studies from the late 1980s known as the “Lawrence Livermore (LLNL)” study and the “Electric Power Research Institute (EPRI)” study, both of which broke important new methodological ground in attempting to characterize earthquake-caused ground motion in the broad region of the U.S. east of the Rocky Mountains. Most important, the mean seismic hazard curves presented in the reports for most sites in the eastern U.S. differed significantly. However, the median hazard results did not differ by nearly as much. We now understand that differences in both the inputs and the procedures by which the two studies dealt with the inputs were among the key reasons for the differences in the mean curves. At the time this was not understood, and the differences between the mean curves caused not only considerable consternation, but launched several efforts to understand what might underlie the differences and attempts to update the older work.

Ultimately, the inability to understand all of the differences between the LLNL and EPRI hazard results—and the concomitant need for an improved methodology going beyond the late-1980s state-of-the-art—led directly to the formation of the SSHAC to perform this project. However, although the Committee studied both the LLNL and EPRI projects carefully to obtain methodological insights (both positive and negative), it did not undertake a forensic-type review to identify past “errors.” Rather, it attempted to draw more broadly upon the entire body of PSHA literature and experience, including of course the LLNL and EPRI projects along with many others, to formulate the guidance herein.

In the course of our review, we concluded that many of the major potential pitfalls in executing a successful PSHA are procedural rather than technical in character. One of the most difficult challenges for the PSHA analyst is properly representing the wide diversity of expert judgments about the technical issues in PSHA in an acceptable analytical result, including addressing the large uncertainties. This conclusion, in turn, explains our heavy emphasis on procedural guidance.

This also explains why we believe that how a PSHA is structured is as critical to its success as the technical aspects—perhaps more critical because the procedural pitfalls can sometimes be harder to avoid and harder to uncover in an independent review than the pitfalls in the technical aspects. Finally, this also explains why one of the key audiences for this report is the project sponsor, who needs to understand the procedural/structural aspects in order to initiate and support the desired PSHA project appropriately.

This Executive Summary will conclude with a brief overview of what the SSHAC believes are its most important findings, conclusions, and recommendations in the procedural area. Because we recognize that several very important pieces of technical guidance concerning the earth-sciences aspects of PSHA will not be discussed in this Executive Summary, the SSHAC requests that readers turn to the full report to review the technical guidance. The key procedural points follow:
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1) SSHAC identifies and describes several different roles for experts based on its conclusion that confusion about the various roles is a common source of difficulty in executing the aspect of PSHA involving the use of experts. The roles for which SSHAC provides the most extensive guidance include the expert as proponent of a specific technical position, as an evaluator of the various positions in the technical community, and as a technical integrator (see the next paragraph).

2) SSHAC identifies four different types of consensus, and then concludes that one key source of difficulty is failure to recognize that 1) there is not likely to be “consensus” (as the word is commonly understood) among the various experts and 2) no single interpretation concerning a complex earth-sciences issue is the “correct” one. Rather, SSHAC believes that the following should be sought in a properly executed PSHA project for a given difficult technical issue: (1) a representation of the legitimate range of technically supportable interpretations among the entire informed technical community, and (2) the relative importance or credibility that should be given to the differing hypotheses across that range. As SSHAC has framed the methodology, this information is what the PSHA practitioner is charged to seek out, and seeking it out and evaluating it is what SSHAC defines as technical integration.

3) SSHAC identifies a hierarchy of complexity for technical issues, consisting of four levels (representing increasing levels of participation by technical experts in the development of the desired results), and then concentrates much of its guidance on the most complex level (level 4) in which a panel of experts is formally constituted and the panel’s interpretations of the technical information relevant to the issues are formally elicited. To deal with such complex issues, SSHAC defines an entity that it calls the Technical Facilitator/Integrator (TFI), which is differentiated from a similar entity for dealing with issues at the other three less-complex levels, which SSHAC calls the Technical Integrator (TI). Much of SSHAC’s procedural guidance involves how the TI and TFI functions should be structured and implemented. (Both the TI and TFI are envisioned as roles that may be filled by one person or, in the TFI case, perhaps by a small team).

4) The role of technical integration is common to the TI and TFI roles. What is special about the TFI role, in SSHAC’s formulation, is the facilitation aspect, when an issue is judged to be complex enough that the views of a panel of several experts must be elicited. SSHAC’s guidance dwells on that aspect extensively, in part because SSHAC believes that this is where some of the most difficult procedural pitfalls are encountered. In fact, the main report identifies a number of problems that have arisen in past PSHAs and discusses how the TFI function explicitly overcomes each of them.

5) For most technical issues that arise in a typical PSHA, the issue’s complexity does not warrant a panel of experts and hence the establishment of a TI role. Technical integration for these issues can be accomplished—indeed, is usually best accomplished—by a TI. In fact, SSHAC has structured its recommended methodology so that even the most complex issues can be dealt with using the less expensive TI mode, although with some sacrifice in the confidence obtained in the results on both the technical and the procedural sides.

6) One special element of the TFI process is SSHAC’s guidance on sequentially using the panel of experts in different roles. Heavy emphasis is placed on assuring constructive give-and-take interactions among the panelists throughout the process. Each expert is first asked, based on his/her own knowledge (yet cognizant of the views of others as explored through the information-exchange process), to act as an evaluator; that is, to evaluate the range of technically legitimate viewpoints concerning the issue at hand. Then, each expert is asked to play the role of technical integrator, providing advice to the TFI on the appropriate representation of the composite position of the community as a whole.
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Contrasting the classical role of experts on a panel acting as individuals and providing inputs to a separate aggregation process, the TFI approach views the panel as a team, with the TFI as the team leader, working together to arrive at (i) a composite representation of the knowledge of the group, and then (ii) a composite representation of the knowledge of the technical community at large. (Neither of these representations necessarily reflects panel consensus—they may or may not, and their validity does not depend on whether a panel consensus is reached.)

The SSHAC guidance to the TFI emphasizes that a variety of techniques are available for achieving this composite representation. SSHAC recommends a blending of behavioral or judgmental methods with mathematical methods, and in the body of the report several techniques along these lines are described in detail. A key objective for the TFI is to develop an aggregate result that can be endorsed by the expert panel both technically and in terms of the process used.

7) The TFI's integrator role should be viewed not as that of a "super-expert" who has the final say on the weighting of the relative merits of either specific technical interpretations or the various experts' interpretations of them; rather, the TFI role should be seen as charged with characterizing both the commonality and the diversity in a set of panel estimates, each representing a weighted combination of different expert positions. SSHAC thus sees the TFI as performing an integration assisted by a group of experts who provide integration advice.

8) Thus, the TFI as facilitator structures interaction among the experts to create conditions under which the TFI's job as integrator will be simplified (e.g., either a consensus representation is formed or it is appropriate to weight equally the experts' evaluations of the knowledge of the technical community at large). In the rare case in which such simple integration is not appropriate, additional guidance is provided. In the main report, guidance is presented on two possible approaches involving (i) explicit quantitative but unequal weights (when it becomes obvious that using equal weighting misrepresents the community-as-a-whole); and (ii) "weighting" rather than "weighing", in cases when the experts themselves, acting as evaluators and integrators, find fixed numerical weights to be artificial, and when it is appropriate to represent the community's overall distribution in a less rigid way.

9) The SSHAC guidance gives special emphasis to the importance of an independent peer review. We distinguish between a participatory peer review and a late-stage peer review, and we also distinguish between a peer review of the process aspects and of the technical aspects for the more complex issues. We strongly recommend a participatory peer review, especially for the process aspects for the more complex issues. This paper details the pitfalls of an inadequate peer review.
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Although the intellectual responsibility for the report rests solely with the seven SSHAC members, the task could not have been accomplished without the diligent and very capable contributions of a large number of others who worked in a collaborative mode under the SSHAC Committee’s overall direction. These other experts, some of whom ghost-wrote entire subsections or appendices of the report, were:

**Don L. Bernreuter**, Lawrence Livermore National Laboratory

**Michael P. Bohn**, Sandia National Laboratories (DOE Project Manager; lead author for the Glossary)

**Auguste C. Boissonnade**, Lawrence Livermore National Laboratory

**Martin W. McCann**, Jack Benjamin & Associates Inc. (lead author for Chapter 7)

**Robin K. McGuire**, Risk Engineering Inc. (author of Appendix G)

**Richard W. Mensing**, Logicon-RDA (lead author for Chapter 6; author of Appendix D; contributor to Chapter 4 and Appendix A)

**Jean B. Savv**, Lawrence Livermore National Laboratory (NRC Project Manager)

**Gabriel R. Toro**, Risk Engineering Inc. (major contributor to Chapter 5; author of Appendices F and I; contributor to Chapter 4 and Appendices A and B)

The SSHAC project organized four different workshops that were attended by a large number of experts representing a variety of disciplines. The participants, who are all listed in the workshop descriptions (see Appendices A, B, C, and H), deserve our thanks for contributing so significantly to the project.

We would also like to thank Norman Abrahamson for contributing an excellent piece of guidance that we have taken the liberty to incorporate herein as Appendix E.

The National Academy of Sciences/National Research Council organized a special “Panel on Seismic Hazard Evaluation” under its Committee on Seismology with the charter to review our report. This review was supported by the U.S. Nuclear Regulatory Commission. The Panel’s review comments on our draft report of November 11, 1994 were especially helpful in focusing the SSHAC on key issues that needed extra attention. Besides the NAS/NRC Panel’s review, we had the benefit of informal review comments on the November draft from about a dozen other specialists and organizations for which we are very grateful. The comments of the NAS/NRC Review Panel, which were published separately by the National Academy Press, are included in this report as an Appendix to Volume I.

Finally, the logistical effort of pulling the report together, based on input from many different authors typing on many different word processors, was accomplished in an outstanding manner by Rosa I. Yamamoto of LLNL, whose skill and dedication the SSHAC gratefully acknowledges.