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CHAPTER 1
INTRODUCTION

1.1 Background and History

1.1.1 Context of the Study

This report describes the results of the Electric Power Research Institute (EPRI) (2004, 2006) Ground-Motion Model (GMM) Review Project. Consistent with present-day U.S. Nuclear Regulatory Commission (NRC) guidance for updating an existing accepted probabilistic seismic hazard analysis (PSHA) model, the project was carried out in two phases: first, to determine whether the EPRI (2004, 2006) GMM[1] should be updated, considering that new data have become available since that model was developed and advances had been made in seismological understanding of ground motions in the Central and Eastern United States (CEUS), and second, when it was determined that updating was needed, to then update the model. That update, which has now been completed, is intended for use by licensees of nuclear power plants (NPPs) located in the CEUS to develop responses to the Code of Federal Regulations (CFR) 50.54(f) Request for Information Regarding the Near-Term Task Force (NTTF) Review of Insights for the Fukushima Dai-Ichi Accident, Recommendation 2.1: Seismic. The NRC issued this Request for Information on March 12, 2012 (U.S. NRC, 2012a).

Recommendation 2.1 requires licensees and holders of construction permits under 10 CFR Part 50 to reevaluate the seismic hazard at their plant sites against present-day NRC seismic regulatory requirements and guidance. A central element of present-day NRC seismic regulatory requirements and guidance is a PSHA. Current NRC guidance accepts the recently completed CEUS Seismic Source Characterization (SSC) Model (EPRI/DOE/NRC, 2012), together with the EPRI (2004, 2006) GMM for the CEUS, as the starting-basis CEUS PSHA[2] model for performing site-specific PSHAs at nuclear plants located in the CEUS. The guidance addresses the expectation that with the passage of time after a model has been completed, new data will become available and advances in technology will occur that may necessitate updating or modifying the existing accepted model. During the approximately 10 years since the EPRI (2004, 2006) GMM was developed, significant additional ground-motion data have been obtained in the CEUS, and significant advances have been made in seismological understanding

[1] The EPRI (2004) GMM (EPRI, 2004), together with the updated sigma model (EPRI, 2006), is currently accepted for use in performing PSHAs at nuclear facility sites located in the CEUS. For brevity, we refer to the EPRI (2004) GMM updated with the EPRI (2006) sigma model as the "EPRI (2004, 2006) GMM."

[2] We refer to the combination of the CEUS SSC Model with the CEUS GMM as the "CEUS PSHA Model."

of ground-motion prediction. The results of this project update the EPRI (2004, 2006) GMM, taking into consideration both present-day data and advances in GMM development.

The EPRI (2004, 2006) GMM Review Project results support the EPRI Seismic Evaluation Guidance for use by licensees in order to ensure consistent evaluations and analyses for response to NTTF Recommendation 2.1 (EPRI, 2013b). The evaluation guidance includes a site-specific PSHA and the development of performance-based site-specific earthquake ground-motion spectra for each currently operating NPP, using present-day NRC seismic regulatory requirements and guidance. The Updated EPRI (2004, 2006) GMM described in this report completes the up-to-date CEUS PSHA Model for use by licensees to compute site-specific PSHA as required to develop their responses to NTTF Recommendation 2.1: Seismic.

1.1.2 Present-Day NRC Seismic Regulatory Requirements and Guidance

The NRC Geologic and Seismic Regulation 10 CFR 100.23 requires quantification of uncertainties in geologic and seismic data, as well as in scientific understanding of earthquake phenomena and ground-motion estimation in proposed seismic-design-basis ground motions. Accepted present-day technical procedures for satisfying the requirements of the regulation include a PSHA (U.S. NRC, 2007, 2012b). Accepted methodological guidance for developing seismic-source and ground-motion models[3] for performing a PSHA that satisfies the requirements of the regulation is described in the Senior Seismic Hazard Analysis Committee (SSHAC) Guidance, *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts* (Budnitz et al., 1997; also known as NUREG/CR-6372). The SSHAC Guidance describes four levels of study for developing a PSHA model (seismic-source model and ground-motion model), depending on the intended use for the model and other factors. A Level 3 or 4 study is required for developing a regional PSHA model that is accepted as an element of the NRC's seismic regulatory guidance for performing PSHAs at multiple nuclear facility sites located in a large geographic region such as the CEUS. A Level 3 or 4 study is also required for developing a site-specific PSHA model for sites where no accepted regional model exists. For a site-specific PSHA that uses an existing accepted regional PSHA model, a Level 2 study may be used for determining whether the existing accepted regional model should be updated for the specific intended use (U.S. NRC, 2012b).

The SSHAC Guidance established that, regardless of the study level, the fundamental goal of a SSHAC study is the same: to capture uncertainty in both current technical knowledge and currently available data and to properly represent the uncertainty in the PSHA. The SSHAC Guidance expresses this goal as follows:

> Regardless of the scale of the PSHA study, the goal remains the same: to represent the center, the body, and the range (CBR) of technical interpretations that the larger informed

[3] Performance of a PSHA requires an SSC model and a ground-motion characterization (GMC) model. The combination of the SSC and GMC models for the purpose of performing a PSHA is called the PSHA model. Because different subdisciplines of geology and seismology are required for development of SSC and GMC models, they are developed in independent SSHAC studies.

> technical community (ITC) would have if they were to conduct the study [Budnitz et al., 1997, p. 27].

Drawing upon approximately 10 years of experience gained using the SSHAC Guidance since it was published in 1997, the NRC developed *Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies* (NUREG-2117; U.S. NRC, 2012b). Emphasizing that the fundamental goal is unchanged, the Implementation Guidelines restate the fundamental goal of a SSHAC study in language that more clearly describes the principal activities of a SSHAC study—regardless of the study level—as evaluation and integration, as follows.

> The fundamental goal of a SSHAC process is to carry out properly and document completely the activities of evaluation and integration, defined as:
>
> *Evaluation:* The consideration of the complete set of data, models, and methods proposed by the larger technical community that are relevant to the hazard analysis.
>
> *Integration:* Representing the center, body, and range (CBR) of technically defensible interpretations (TDI) in light of the evaluation process (i.e., informed by the assessment of existing data, models, and methods).

In practical implementation of a SSHAC study, the TI Team evaluates each element of the hazard model considering the complete set of relevant data, models, and methods proposed by the larger technical community, and, informed by the evaluation, assesses the CBR of TDI. Elements of the hazard model are then integrated to properly capture the CBR of TDI in the integrated hazard model. This implementation process is independent of whether the purpose is to update an existing accepted SSC model or an existing accepted GMC model. A SSHAC Level 2 process is implemented consistent with recommendations in NUREG-2117, Chapter 6, for the purpose of performing the update of the EPRI (2004, 2006) GMM, as described in this report.

1.1.3 EPRI (2004) GMM and EPRI (2006) Update of Sigma Model—The EPRI (2004, 2006) GMM

Development of the EPRI (2004, 2006) GMM was motivated by extensive advances in seismological understanding in ground-motion prediction that began in 1988. After the NRC accepted the SSC Model developed in the EPRI-SOG[4] study (EPRI, 1989), EPRI performed a major CEUS ground-motion study targeted on developing a state-of-knowledge understanding of aleatory variability and epistemic uncertainty in proponent ground-motion-prediction equations (GMPEs). The CEUS GMM study was spurred by the EPRI-SOG study results, which showed uncertainty in ground-motion prediction to be the largest contributor to uncertainty in PSHA. Essentially all of the then-active GMPE experts participated in the study. The study resulted in the EPRI (1993a) GMM, which included an assessment of epistemic uncertainty in the median motions and an assessment of aleatory variability (sigma model). After the 1993 EPRI GMM

[4] Electric Power Research Institute – Seismicity Owners Group (EPRI-SOG) is the name given to the project that led to development of the EPRI-SOG SSC Model (EPRI, 1989); that model was accepted by the U.S. NRC in 1989 for use by licensees of nuclear plants located in the CEUS to respond to the "Charleston Earthquake Issue."

project was completed, a number of GMPE experts pursued individual research, which produced an equal number of GMPEs. These GMPEs and the 1993 EPRI GMM formed the range of GMPEs that were evaluated and integrated using a SSHAC Level 3 assessment process for development of the EPRI (2004) GMM, which captured the center, body, and range of then existing technically defensible interpretations. The EPRI (2006) sigma update to the EPRI (2004) GMM was based on experience from an ongoing study of GMPEs for the Western United States (WUS) known as the NGA-West 1 Project,[5] which was coordinated by the Pacific Earthquake Engineering Research (PEER) Center. This update was performed using a SSHAC Level 2 study. Later, the entire NGA-West study was published in a special theme issue of *Earthquake Spectra* (Power et al., 2008).

The EPRI (2004) GMM updated with the EPRI (2006) sigma component—the EPRI (2004, 2006) GMM—is the current accepted GMM for PSHA at sites located in the CEUS. Ten years have passed since the SSHAC Level 3 study for development of the model was begun in 2002, and eight years have passed since the SSHAC Level 2 study for updating the sigma component of the model was begun in 2005. Consistent with NRC guidelines and considering the fact that new data, models, and methods have become available during this time, it is necessary to evaluate the EPRI (2004, 2006) GMM using an updated database and, if needed, to update the model in order to provide a present-day technical basis for use by licensees in the development of responses to NTTF Recommendation 2.1.

An ongoing SSHAC Level 3 study known as the NGA-East Project has the goal of developing a new GMM for the CEUS, which is intended to replace the EPRI (2004, 2006) GMM. Currently, implementation of the NGA-East Project has progressed to the stage of compiling an updated database of ground-motion recordings. The evaluation and integration process for development of the replacement model will not be completed until at least 2015, which is beyond the date when licensees are required to respond to NTTF Recommendation 2.1. We have used the NGA-East database for this study, as described in detail in Chapter 6.

1.1.4 NRC Guidance for Updating Seismic Hazard Models

Based on experience gained from past implementation of the SSHAC Guidance, NUREG-2117 provides guidance and recommendations for (1) evaluating whether an existing accepted seismic hazard model should be updated and (2) updating the model, if needed. The recommendations address the expectation that with the passage of time, new data will become available, and advances in technology will occur that may necessitate updating an existing accepted model. With regard to selecting the appropriate SSHAC process level for an update study, NUREG-2117 identifies that a Level 2 process can be used. It is noted, however, that recommendations made in NUREG-2117 are not requirements and that the user may propose a process that will have a high likelihood of demonstrating regulatory requirements, considering the intended use of

[5] The "Next Generation of Ground-Motion Attenuation Models" (NGA) project is a multidisciplinary research program coordinated by the PEER Lifelines Program, in partnership with the U.S. Geological Survey (USGS) and the Southern California Earthquake Center (SCEC). The objective of the project is to develop new GMPEs and an integrated GMM for the CEUS. The project is organized and structured following a SSHAC Level 3 process.

the updated model. It is suggested in NUREG-2117 that the choice of the SSHAC study level be made in consultation with the regulator.

Considering the implementation guidance provided in NUREG-2117 and the intended use of the updated EPRI (2004, 2006) GMM for support of licensees' development of responses to the 50.54(f) Request for Information Regarding NTTF Recommendation 2.1: Seismic, a SSHAC Level 2 process with added Level 3 process activities was implemented. Details of the features of the selected study level are described in Chapters 2 and 3 of this report. Consistent with the suggestion in NUREG-2117 that the choice of the study level be made in consultation with the regulator, we implemented the step of obtaining PPRP review of the Project Plan and NRC review and acceptance of the proposed study level.

1.2 Purpose of the EPRI (2004, 2006) GMM Review Project

Given the guidance in the preceding paragraphs, the following approach was taken in this project. NUREG-2117 states that a SSHAC Level 2 process may be used for updating an accepted existing SSHAC Level 3 model considering present-day data for use in addressing a specific regulatory issue or a site-specific application. The objectives of the EPRI (2004, 2006) GMM Review Project were (1) to evaluate whether the EPRI (2004, 2004) GMM required updating in order for licensees to compute site-specific PSHA as required to develop their responses to NTTF Recommendation 2.1: Seismic, and (2) if it did, to update the model using an approach that is accepted by the NRC before proceeding with the calculation of ground-motion response spectra (GMRS) for existing NPP sites.

The EPRI (2004, 2006) GMM Review Project incorporated an up-to-date assessment of the EPRI (2004, 2006) GMM that has the following components:

- Assessment and incorporation of uncertainties.
- Structured and systematic evaluation of the range of diverse technical interpretations from the larger technical community.
- Up-to-date data, models, and methods.
- Proper documentation.
- Peer review.

A SSHAC Level 2 assessment process with enhancements was implemented for updating the EPRI (2004, 2006) GMM. The above approach led to a GMM that represents present-day data and knowledge for use by licensees to respond to the NRC Request for Information letter dated March 12, 2012 (U.S. NRC, 2012a).

1.3 Study Region

The project study region (Figure 1.3-1) represents the same region as the EPRI CEUS SSC Model. The project study region is divided into two subregions: the Midcontinent Region and Gulf Region. The Updated EPRI (2004, 2006) GMM is applicable to all sites within the project

study region. The western boundary is located approximately along the foothills of the Rocky Mountains at longitude 105°W. On the north, the study region extends a minimum of 322 km (200 mi.) beyond the U.S.-Canadian border. Only areas that lie within the continental crust are included. Areas that are not included are those outside the study region boundaries; this applies to the WUS, Mexico, Canada, and the Caribbean Plate boundary area.

1.4 Products of the Project

1.4.1 Project Plan

The project plan consists of a series of tasks designed to meet the project objectives (Chapter 2). The project plan was performed in two phases. Phase 1 consisted of Tasks 1 through 4, which involved reviewing the EPRI (2004, 2006) GMM in light of up-to-date data and seismological knowledge of ground-motion prediction in order to determine whether that model was appropriate for calculating GMRS at existing NPP sites without needing to be updated. The Phase 1 evaluations were presented to and reviewed by the Participatory Peer Review Panel (PPRP), Senior Technical Advisors, Sponsor, and NRC reviewers in Working Meeting 5 on August 14, 2012. PPRP Report #2 dated August 20, 2012, supported the decision to proceed with Phase 2. The decision to proceed with Phase 2 was documented in a letter from EPRI to the NRC dated August 24, 2012.

Phase 2 consisted of Tasks 5 through 12 (Chapter 2), which involved updating the EPRI (2004, 2006) GMM considering available present-day data and advances in seismological knowledge of ground-motion prediction. The project plan implements a SSHAC Level 2 process for the update assessment, as explained in Chapter 3. The project drew upon work accomplished to date by the NGA-East Project, which is being performed as a SSHAC Level 3 assessment process. The objective of the NGA-East Project is to develop a CEUS GMM intended for updating the GMM element of the NRC's seismic regulatory guidance at a date in the future.

1.4.2 Updated EPRI (2004, 2006) GMM

The Updated EPRI (2004, 2006) GMM was developed using the structural framework of the EPRI (2004) GMM for the Midcontinent Region and Gulf Region shown on Figure 1.3-1. The updated assessment was accomplished with the following major steps:

- Prepare an up-to-date database of ground-motion recordings for use in testing the available Central and Eastern North America (CENA) GMPEs, using as a starting point the ground-motion database assembled by the PEER NGA-East Project (see Chapter 6 and Section 7.2).
- Check the consistency of corrected data and adjust, if necessary.
- Identify GMPEs and assign GMPEs to clusters by reviewing the literature, conducting interviews, and holding a workshop with current ground-motion experts.
- Establish analytical and empirical approaches for adjusting recording site conditions using shear-wave-velocity measurements at strong-motion recording sites.

- Assess GMPE and cluster weights.
- Evaluate the epistemic uncertainty.
- Update the EPRI (2006) aleatory variability model.

Chapters 5 through 7 provide details regarding the evaluation and integration activities for development of the Updated EPRI (2004, 2006) GMM.

1.4.3 Hazard Input Document

A hazard input document (HID) was prepared to provide the documentation necessary for users to implement the Updated EPRI (2004, 2006) GMM in PSHA. The HID contains all the information required for future use of the model within a PSHA, but it does not include the technical basis or justification for the elements of the model. The purpose of the HID is to ensure that the expert assessments made by the Technical Integration (TI) Team are captured fully and accurately and delivered for use by the hazard analyst for a PSHA at a specific site. For the EPRI (2004, 2006) GMM Review Project, the HID was used by the hazard analyst to carry out hazard calculations at seven demonstration sites, as summarized in Chapter 8. Appendix G provides the HID for the Updated EPRI (2004, 2006) GMM.

1.4.4 Documentation of Literature Reviews and Expert Interviews

In order to demonstrate the structured and systematic evaluation of the range of diverse interpretations from the larger technical community, the TI Team conducted literature reviews and interviewed experts (Resource and Proponent Experts) some of whose work was either not published or was awaiting publication. Appendix B provides the documentation for literature reviews, including tables that document the reviews by the TI Team and demonstrate the structured and systematic approach used to evaluate the diverse interpretations from the larger technical community. Appendix C provides the documentation for the interviews conducted by the TI Team with Resource and Proponent Experts who are working on CEUS GMM. The TI Team obtained information from copies of papers under review or in press, as well as from updates pertinent to these experts' ongoing work. The questions that the TI Team prepared to facilitate the interview process are listed in Appendix C, along with the names of the interviewees.

1.4.5 Documentation of PPRP and Observer Comments

Documentation is an essential part of any SSHAC level assessment process, and feedback from the PPRP and from Observers from the NRC and the Defense Nuclear Facilities Safety Board (DNFSB) was an important part of the EPRI (2004, 2006) GMM Review Project, helping the TI Team to evaluate the range of diverse interpretations from the larger technical community. Appendix D documents the comments and recommendations received from the PPRP, the comments from the Observers, and the TI Team's responses to the comments.

1.4.6 Project Database

The purpose of compiling the project database was to organize and store those data and resources that had been carefully and thoroughly collected and described for the TI Team's use. Development of the project database began at the inception of the project to provide TI Team members with the current version of the NGA-East ground-motion database, the shear-wave-velocity database for seismic recording stations, and a current set of data, maps, and figures. The Database Manager established an FTP site for the TI Team and Project Manager to access the project database. Appendix A provides details regarding the project database.

1.4.7 Shear-Wave-Velocity Measurement at Seismic Recording Stations Database

Chapter 4 and the *EPRI (2004, 2006) Ground-Motion Model (GMM) Review Project: Shear Wave Velocity Measurements at Seismic Recording Stations* report (EPRI, 2013a) describe the investigation conducted by GEOVision and its subcontractor, The University of Texas (Austin), between May 15 and July 19, 2012, to develop S-wave velocity (V_S) models to a depth of 30 m (or more) and to estimate the average shear-wave velocity of the upper 30 m (V_{S30}) at 33 seismic recording stations located in the CEUS.

The U.S. Geological Survey (USGS) measured shear-wave velocity at 24 seismic recording stations during 2011 and 2012 (Kayen et al., 2013). The results of these measurements were provided to the EPRI (2004, 2006) GMM Review Project as part of the productive cooperation agreement arranged by the Project Manager. The measurements are based on surface-wave dispersion. A summary of results from each of the recording-site locations is provided in Chapter 4.

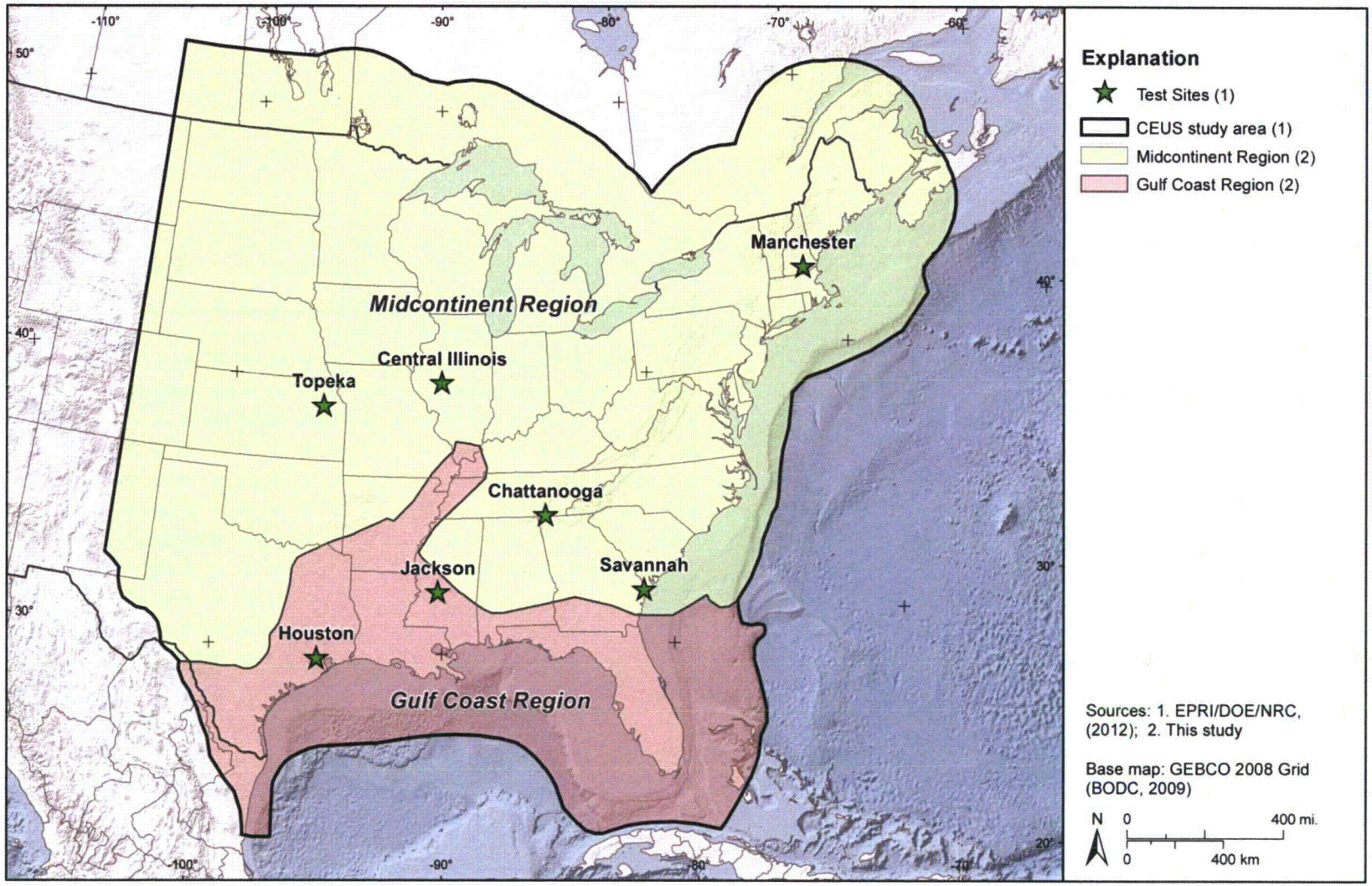

Figure 1.3-1
Map of project study region showing sub-regions for the Updated EPRI (2004, 2006) Ground-Motion Model and test site locations for seismic hazard calculations