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**NORTH ANNA EARLY SITE PERMIT APPLICATION
REFERENCE INFORMATION**

The NRC North Anna ESP application project manager, Mr. Michael L. Scott, recently requested a copy of Reference No. 116 listed in the Site Safety Analysis Report, Section 2.5 of the North Anna Early Site Permit application. That reference, *CEUS Ground Motion Project, Model Development and Results, Technical Update 1008910 published August 2003 by EPRI*, is enclosed.

Please advise if you require any additional information.

Very truly yours,

Marvin L. Smith

Marvin L. Smith
Project Manager
Early Site Permit Project

Enclosure: As stated

c: Michael L. Scott, Project Manager
New, Research and Test Reactors Program
Office of Nuclear Reactor Regulation

D074

CEUS Ground Motion Project

Model Development and Results

1008910

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Technical Update, August 2003

EPRI Project Manager

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ABSTRACT

Three utilities are currently pursuing Early Site Permits (ESPs) for siting possible new nuclear power plant facilities in the central and eastern United States (CEUS). The geological, seismological, and engineering characteristics of a site and its environs must be investigated in sufficient scope and detail to permit an adequate evaluation of the proposed site and to provide sufficient information to support evaluations performed to arrive at estimates of the Safe Shutdown Earthquake (SSE) ground motion. 10 CFR Part 100.23 emphasizes that uncertainties are inherent in such estimates and these uncertainties must be addressed through an appropriate analysis, such as a probabilistic seismic hazard analysis (PSHA). Strong ground motion attenuation is a large contributor to uncertainty in PSHA.

The purpose of this project is to perform an evaluation of strong ground motion attenuation for hard rock site conditions in the CEUS. The objective of the evaluation is to estimate the uncertainty in ground motion that represents "the composite distribution of the informed technical community." To support this evaluation, a panel of ground motion experts was convened to provide input on ground motion models and data and to support the evaluation of candidate models by the Technical Integrators (TIs). The TIs developed a probabilistic model for the CEUS based on available CEUS ground motion models and which includes a representation of the composite distribution of the informed technical community.

The purpose of this report is to describe the development of the ground motion model and its results.

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1 INTRODUCTION

Three utilities are currently pursuing Early Site Permits (ESP) for siting possible new nuclear power plant facilities in the central and eastern United States (CEUS). 10 CFR Part 100.23, "Geologic and Seismic Siting Criteria", sets forth the principal geologic and seismic considerations that guide the NRC in its evaluation of the suitability of a proposed site and of the adequacy of the design bases established in consideration of the geologic and seismic characteristics of the proposed site. The geological, seismological, and engineering characteristics of a site and its environs must be investigated in sufficient scope and detail to permit an adequate evaluation of the proposed site and to provide sufficient information to support evaluations performed to arrive at estimates of the Safe Shutdown Earthquake (SSE) ground motion. 10 CFR Part 100.23 emphasizes that uncertainties are inherent in such estimates and these uncertainties must be addressed through an appropriate analysis, such as a probabilistic seismic hazard analysis (PSHA) or suitable sensitivity analyses.

One of the data elements to be considered is strong ground motion attenuation. The EPRI CEUS seismic hazard study [1] found the ground motion element to be the largest contributor to uncertainty in PSHA. During the 15 years since the EPRI study was completed, substantial work has been done to improve the understanding and engineering estimation of earthquake ground motions in the CEUS. Thus updating the ground motion input for ESP work is important.

This report is the second technical update published for this project. The first [2] was provided to describe the project plan. The purpose of this report is to provide basic information on the development of the model and the model results. This information is appropriate for use in PSHA evaluations for ESP applications. A final report is planned that will meet the guidance related to project documentation in the SSHAC report [3]. The remaining portions of this section provide an introduction to the project and the other sections of the report.

1.1 Project Description

For purposes of performing PSHAs in the CEUS, a SSHAC Level 3 analysis was performed to develop the ground motion input. The analysis was conducted using the guidance provided in the SSHAC report [3]. In a Level 3 analysis a Technical Integrator (TI) is responsible for the development of the composite distribution on ground motion based on evaluations of available information, including interactions with ground motion experts.

The CEUS Ground Motion Project Plan [2] provides information on how this project was carried out. The project included a series of three workshops during which ground motion experts, including proponents of available models, made presentations and discussed the features of the available models and the basis for model evaluation. The TI for the project evaluated the arguments for available models and conducted an evaluation to develop the composite distribution on ground motion.

The participants in the Level 3 analysis included:

1. Technical Integrator (TI) - the role of the TI is to be an evaluator of available ground motion models and to develop a probability distribution on ground motion amplitudes (e.g., peak ground acceleration, spectral acceleration) in terms of earthquake magnitude and distance for hard rock sites in the CEUS that represents "the composite distribution of the informed technical community" [3]. The TI has technical responsibility for evaluations that are performed and ownership of the results of the Level 3 analysis. A team of three experts and PSHA analysts performed the TI role for the project: Martin W. McCann, Jr., James E. Marrone and Robert R. Youngs.
2. Ground Motion Expert Panel (EP) - the role of the EP is twofold: 1) provide input to the TI on available ground motion models and data for the CEUS and to discuss in project workshops features of these models as well as issues associated with modeling ground motion in PSHA calculations for sites in the CEUS, and 2) provide input and guidance to the TI with regard to a process for evaluating available ground motion models and the development of a distribution on ground motion for use in CEUS PSHAs. The EP consists of 6 members: Gail M. Atkinson, Kenneth W. Campbell, Richard C. Lee, Walter J. Silva, Paul G. Somerville and Gabriel. R. Toro.
3. Peer Review Panel (PRP) - the primary role of the PRP is to provide review and oversight of the implementation of the Level 3 elicitation and evaluation process. The PRP consists of 2 members: C. Allin Cornell and J. Carl Stepp.
4. Technical and Administrative Support Staff - project staff members will be responsible for data collection activities, conducting technical analyses to support the Level 3 evaluation, project documentation, and administrative support.

The following tasks were carried out in the project:

- Identify and select the members of the EP and PRP
- Gather information on available ground motion models, data, etc.
- Conduct ground motion model and PSHA sensitivity calculations to support the TI's evaluation
- Conduct a series of ground motion workshops
- Carryout workshop logistical activities (planning, meeting documentation, etc.)
- Perform technical integration evaluations and develop a composite distribution on ground motion
- Project Quality and Documentation (in-progress)

1.2 Ground Motion Model Development

Section 2 of this document provides a summary description of the approach developed and implemented by the Technical Integrator (TI) team in developing a representation of central and eastern United States (CEUS) earthquake ground motion and its uncertainty. The model is appropriate for use in PSHAs for hard rock sites. Features of the new CEUS model include:

1. Models for the Mid-continent and Gulf regions [4] of the CEUS.

2. Evaluation of the epistemic uncertainty in the median ground motion, including an assessment of the model consistency with available ground motion data in the CEUS, and consideration of the primary sources of epistemic uncertainty in estimating ground motions,
3. Assessment of the aleatory variability in ground motions and the epistemic uncertainty in the estimate of this element of the model, and
4. Adjustments for modeling earthquake sources as point events as opposed to extended fault ruptures.

The model was developed by the project TI, which was supported by a panel of ground motion experts and a peer review team.

Appendix A presents plots of distance adjustment models. Appendix B shows plots of the additional aleatory standard deviation for the variability in ground motions due to randomness in rupture orientation and epicentral location.

1.3 Ground Motion Model Results

Section 3 of this document describes the model results. The equations and their coefficients are provided for both the Mid-continent and Gulf region models. Appendix C provides plots of median ground motion model results while Appendix D provides plots of results from the aleatory variability model.

2
GROUND MOTION MODEL DEVELOPMENT

This section describes the development of the models for the Mid-Continent region and the adjustments to this model for the Gulf Coast region. The ground motion representation is comprised of the following four elements:

- Median ground motion
- Aleatory variability about the median;
- Epistemic uncertainty in the median, and
- Epistemic uncertainty in the aleatory variability

2.1 Background and Motivation for the Evaluation Approach

The focus of the CEUS ground motion project was to use existing CEUS ground motion models as building blocks to construct the four elements of a ground motion model, as defined above. As a result, 13 ground motion models were identified as being appropriate for estimating earthquake ground motions on hard rock sites in the CEUS as shown in Table 2-1.

Table 2-1
Summary of CEUS Ground Motion Models

No.	Model	Type
1	Abrahamson & Silva [5]	Hybrid
2	Atkinson & Boore [6][1]	Spectral, Double-Corner
3	Atkinson [7] & Sadigh et al. [8]	Hybrid
4	Campbell [9]	Hybrid
5	Hwang & Huo [10]	Spectral, Single-Corner
6	Silva et al. [11] – SC-CS	Spectral, Single-Corner
7	Silva et al. [11] – SC-CS-S	Spectral, Single-Corner
8	Silva et al. [11] – SC-VS	Spectral, Single-Corner
9	Silva et al. [11] DC	Spectral, Double-Corner
10	Silva et al. [11] DC-S	Spectral, Double-Corner
11	Somerville et al. [12]	Finite Source/Greens Function
12	Toro et al. [13]	Spectral, Single-Corner
13	USGS [14][1]	Spectral, Single-Corner

[1]Model refit for Joyner-Boore distance (R_{JB})

The common approach for modeling epistemic uncertainty in ground motions in PSHAs is to assign weights to individual members of the set of applicable ground motion models. The weighted set of alternative models is then used to represent the epistemic uncertainty in ground motion modeling. However, each of the individual models has an associated degree of epistemic uncertainty, generally not explicitly quantified. As illustrated in Figure 2-1, when quantified empirically, the epistemic uncertainty in a given model may be comparable to or larger than the range in median estimates for the set of models. This would suggest that each of the individual models should be represented by several discrete alternatives to represent the model's epistemic uncertainties. For the following reasons, the TI team did not consider this the optimum approach:

- Most available models do not have a quantified representation of epistemic uncertainty.
- There is a large degree of dependency between many of the models to the extent that some of them might be considered an expression of epistemic uncertainty for a single model. This complicates the process of assigning weights to the individual models.

An alternative is to group the models into appropriate subsets. Each subset can be represented by a median relationship and the epistemic uncertainty in that median. The subsets, in turn can be assigned relative weights based on some of the criteria discussed at the workshops and in the Expert Survey. The set of weighted medians for each subset together with the epistemic uncertainty in each median provides an estimate of the epistemic uncertainty in median ground motions.

A question for this approach is how to define the various subsets. The TI team explored a number of alternative groupings or clustering approaches. These alternatives were discussed at each of the project workshops. At the highest level, three classes of models were defined: spectral models (with 9 members), hybrid models (3 members), and finite source/Green's function modeling (1 member). A first attempt to weight these three groups using criteria such as "consistent with seismological principals," "consistent with recorded CEUS data," and "consistent with observed trends in ground motion data" did not produce a satisfactory result. Further, it was recognized there is a wide variety in the details of the approach used for the individual models within the two classes with multiple members. To address this, the TI team further subdivided the model classes according to details of their implementation (the seismologic building blocks of the models and the steps carried out as part of their development). The result was a set of approximately 24 possible model subclasses. The available 13 ground motion models fell into only nine of these subclasses, with any one subclass having at most 2 models. At this point, we were nearly back to the case of individual models. Attempting to apply the weighting criteria to the model subclasses proved to be no more satisfactory than for the three main classes.

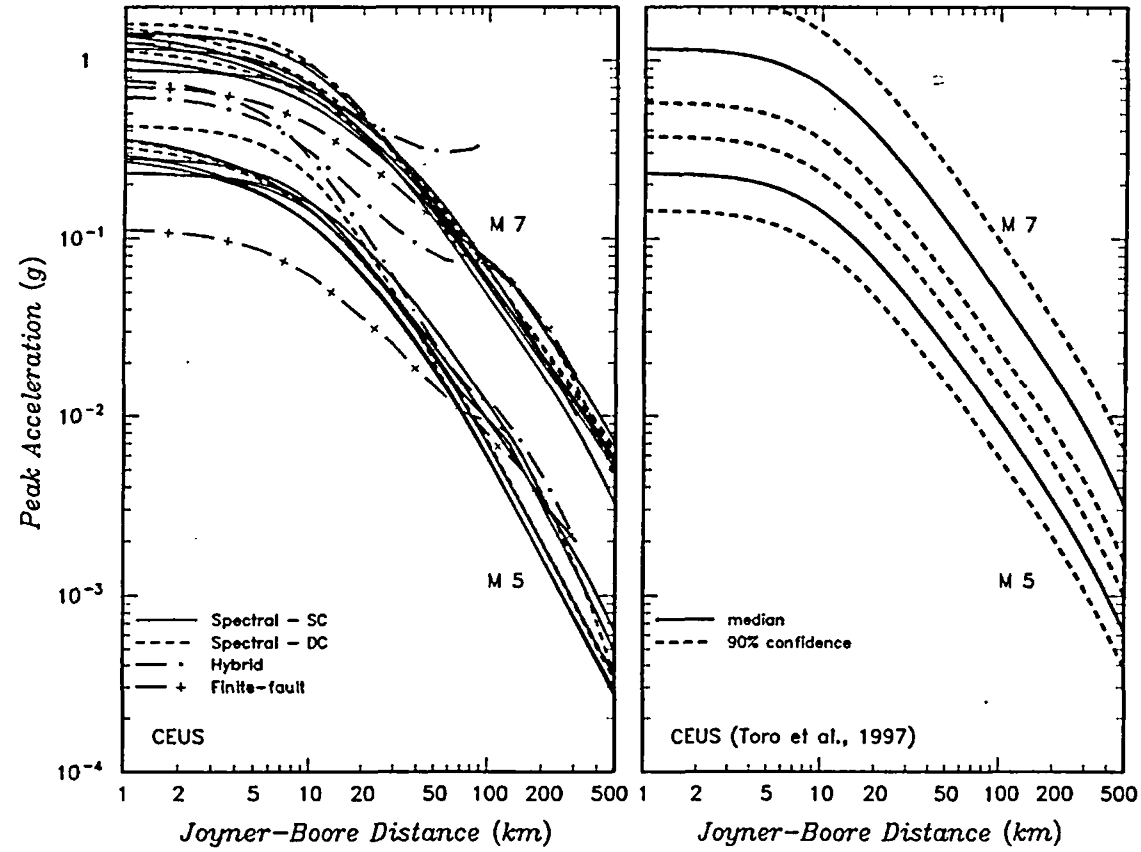

Figure 2-1
Comparison of the Range of 13 CEUS PGA Models (left) and the Epistemic Uncertainty (empirically based) In One Model (right)

The TI team also considered an alternative approach to grouping the 13 ground motion models based on outcome. Ideally, if the ground motions predicted by the individual relationships fell into clearly distinct clusters, then models that produced a similar result could be grouped together and the different clusters weighted. However, as shown in Figure 2-1, there is a large degree of overlap in the ground motion predictions of the models, making a separation purely on the basis of differences in the absolute level of predicted ground motions somewhat problematical. There are, however, distinct differences in certain fundamentals of ground motion models and the pattern of their predicted ground motions. These fundamentals arise from the differences in how the various models characterized the seismic source and model wave propagation.

After examining the alternative approaches and discussion with the expert panel, it was concluded that a clustering approach based on ground motion model classes was preferred. This approach followed fundamental seismological approaches for estimating strong ground motions and reflects the current state-of-knowledge and practice with respect to estimating ground motions for events considered in a PSHA.

2.2 Ground Motion Model Clusters

Table 2-2 shows the four model clusters that were identified and the members of each cluster. In this evaluation the spectral model class was divided into two sub-classes; single-corner and double-corner spectral models. The fourth cluster has only one member. Due to limitations of this model (and therefore the cluster), its intended applicability is only for events of $\mathbf{M} \geq 6$, and its incorporation in the CEUS model is limited to specific seismic source categories. This is discussed later.

Table 2-2
Grouping of CEUS Attenuation Models

Cluster No.	Wave Propagation	Models
1	Spectral, Single Corner	Hwang & Huo [10]
		Silva et al. [11] – SC-CS
		Silva et al. [11] – SC-CS-S
		Silva et al. [11] – SC-VS[1]
		Toro et al. [13]
		USGS [14][2]
2	Spectral, Double Corner	*Atkinson & Boore [6]*[1,2]
		Silva et al. [11] DC
		Silva et al. [11] DC-S
3	Hybrid	Abrahamson & Silva [5]
		Atkinson [7] & Sadigh et al. [8]
		Campbell [9])[1]
4	Finite Source/Greens Function	*Somerville et al.* [12] [1]

[1]Cluster representative functional form
[2]Model fit to reported simulations by TI and adjusted to R_{JB}

2.3 Representation of Median Ground Motions and Their Epistemic Uncertainty

The above grouping of the CEUS ground motion models forms the basis for developing a representation of the median ground motion and its epistemic uncertainty. This representation includes:

- variation in the median ground motion between clusters (model classes),
- variability within a cluster (i.e., variability of the cluster members about the cluster mean),
- uncertainty in the model class characterization of the seismic source and modeling of wave propagation, and
- standard error in fitting a functional form to the median ground motions for a cluster.

The framework for this representation is outlined in the logic tree shown in Figure 2-2. Each of the four clusters is considered to represent an approach to modeling CEUS ground motions that

leads to differences in the form of scaling of median ground motions with magnitude and distance.

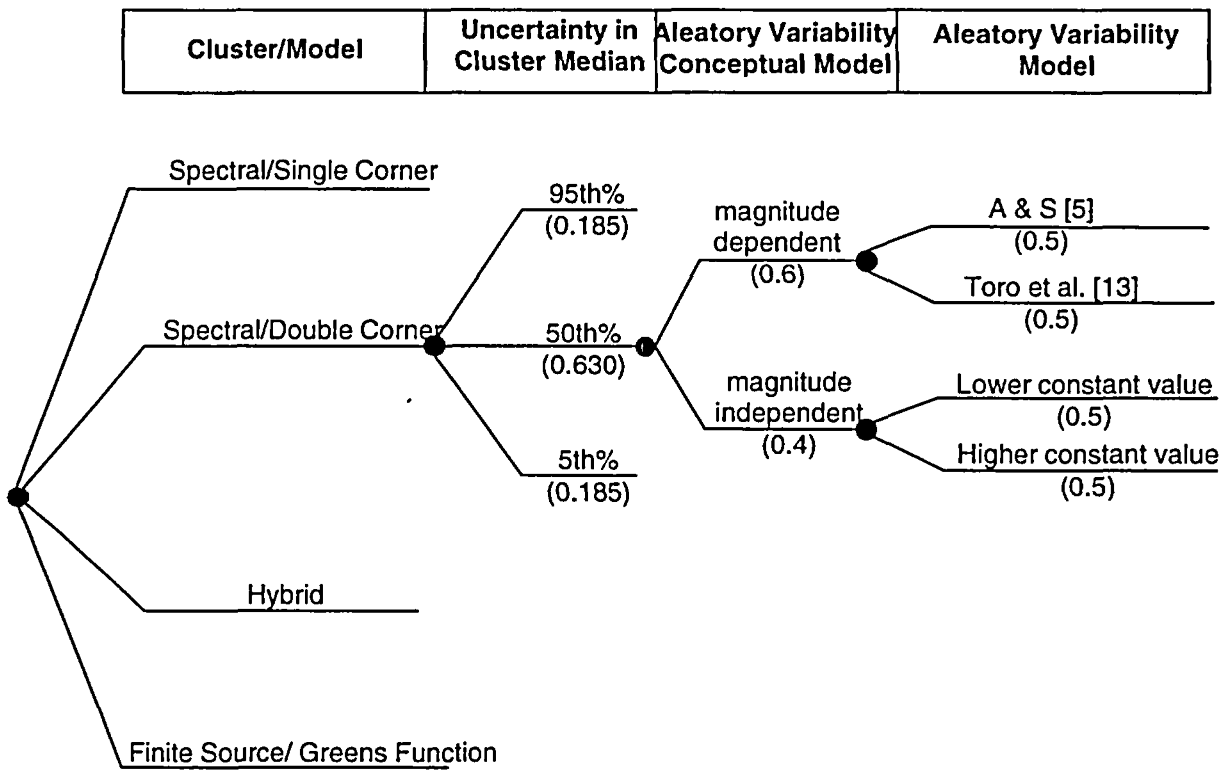

Figure 2-2
Logic Tree Illustrating the CEUS Ground Motion Model

In order to represent the influence of these conceptual differences on the epistemic uncertainty in median ground motions, each of the four model clusters is explicitly represented in the logic tree. The four model clusters are assigned weights based on the evaluation process and criteria discussed below.

Each model cluster is represented by a median model and a logarithmic standard deviation, that defines the epistemic uncertainty of the cluster median model. In practice this standard deviation can be used to construct a discrete set of alternative models, such as the three-point discrete model represented in Figure 2-2. For a given cluster, the standard deviation of the median is derived from:

- the variability among the models within the cluster, and
- consideration of sources of epistemic uncertainty in modeling the seismic source and/or path that have not been addressed by the models within the cluster.

The development of the median and the epistemic uncertainty are described in the following subsections.

2.3.1 Determining the Cluster Median

For each cluster (with the exception of cluster 4), the following steps were taken to determine the cluster median. For each cluster, the mean log ground motion (cluster mean) was determined for a range of magnitudes and distances ($5.0 < \mathbf{M} \leq 8.5$ and $1.0 < R_{JB} \leq 1{,}000$km). For each magnitude-distance pair, the cluster mean was calculated as a weighted average of the median estimates given by the cluster member models. The model weight was based on the variance between a model's predictions and the available ground motion database. This variance was computed as the sum of the squares of the mean deviation of the model predictions from the data and the standard error of estimation of the mean deviation. Model weights (normalized) were calculated in inverse proportion to this total variance. The resultant cluster mean values provided a dataset of **M** and R data for each cluster.

The median ground motion model for each ground motion measure for a cluster was then determined by fitting the functional form for the representative model for that cluster to the cluster mean dataset. The representative model for a cluster was selected on the basis of its goodness-of-fit to the CEUS data and its degree of development. This approach provides a 'best-fit' to the cluster mean as opposed to the approach of adjusting the representative model by a constant shift in log space. The next step in the process was to determine parameters for the median ground motion taking into account the epistemic uncertainty for a cluster. The epistemic uncertainty in the median is modeled by a three-point distribution corresponding to $\pm$ 1.645 standard deviations from the mean (see Fig. 2-2). The parameters of the upper and lower alternative estimates of the median were determined by scaling the cluster mean dataset for a ground motion measure by a factor corresponding to exp{$\pm$1.645 $_e$(m,r)} where $_e$(m,r) is the epistemic uncertainty for a cluster which is a function of magnitude and distance (discussed below). The functional relationship for the representative model was then fit to these scaled datasets to determine the alternative estimates of the median. This process was carried out for each cluster and each ground motion measure. The result for each ground motion measure is a set of 12 model coefficients (3 for each cluster).

2.3.2 Modeling Epistemic Uncertainty within Model Clusters

The epistemic uncertainty in the median ground motion within model clusters is considered to contain two primary components. These are:

- the variability among the model predictions within a cluster, and
- epistemic uncertainties in parameterizing the seismic source and wave propagation not represented by the models within the cluster.

An example of the latter is given by cluster 1. Most of the median models within that cluster are based on very similar estimates of median stress drop (stress parameter). Thus, the epistemic uncertainty in the median stress drop has not been captured by the range of median models within the cluster.

Table 2-3 summarizes each of these sources of epistemic uncertainty. The estimation of the total epistemic uncertainty based on the listed sources of uncertainty is cluster dependent.

Table 2-3
Types of Model Cluster Epistemic Uncertainty

Type	Description
Intra-Cluster Variability	The variation within a cluster represents alternative interpretations with respect to model parameters. (See example described above.)
Seismic Source Parameterization Uncertainty	Within any cluster, there is uncertainty associated with parameterization of the seismic source (e.g., median estimate of the stress parameter).
Wave Propagation/ Attenuation Uncertainty	This uncertainty is associated with modeling the regional attenuation of seismic waves in the CEUS. It is associated with crustal wave attenuation (Q model), crustal reflection effects, and strong motion duration for spectral models.

The intra-cluster variability is determined by an evaluation of the variation of the member models within a cluster, averaged over the applicable range of magnitudes and distances. This variability is determined for each ground motion measure. Figures 2-3, 2-4, and 2-5 show the standard deviation of the natural log of peak ground and spectral accelerations as a function of magnitude and distance resulting from the intra-cluster variability for Clusters 1, 2, and 3, respectively.

Seismic source parameterization uncertainty can be characterized in terms of the variability associated with the model stress parameter for the single corner spectral models. Information to estimate this source of uncertainty and its impact on earthquake ground motions includes the work by EPRI [4], Toro et al. [13], Campbell [9] and Silva [15]. In the EPRI report [4] the uncertainty in stress drop, which varies with magnitude, translates into a variability on ground motion that ranges from approximately 0.12 ($M<6$) to 0.40 ($M>6.5$). Campbell's [9] estimate of epistemic uncertainty in hybrid models includes source variability as derived from alternative WUS models. His estimates, which include a weak magnitude dependence, are less than approximately 0.30 (for distances less than 70 km), and vary with magnitude by about 0.05. Based on calculations performed by Silva [15] for alternative assumptions with regard to the median stress drop, estimates of the logarithmic standard deviation on ground motion vary from approximately 0.20 to 0.40, depending on frequency and magnitude. For this analysis, the TI computed the epistemic uncertainty in median ground motions for a single corner spectral model using the uncertainty in the median (mean log) stress parameter of the EPRI [4] data set. The EPRI [4] data set contains 19 earthquakes with a median stress parameter of 120 bars and a standard deviation of $\ln(\Delta\sigma)$ of 0.7. The corresponding standard deviation of the mean log is 0.16. Figure 2-6 shows the standard deviation of the natural log of peak or spectral acceleration obtained using a standard deviation of 0.16 in the median stress parameter. Direct quantitative assessments of source parameterization uncertainty are not presently available for the other three ground motion model clusters, although Campbell [9] has made some estimates of overall epistemic uncertainty in his hybrid model. Therefore, the TI has used the estimate of source parameterization uncertainty for the single corner model as an estimate of source parameterization uncertainty for the other three clusters.

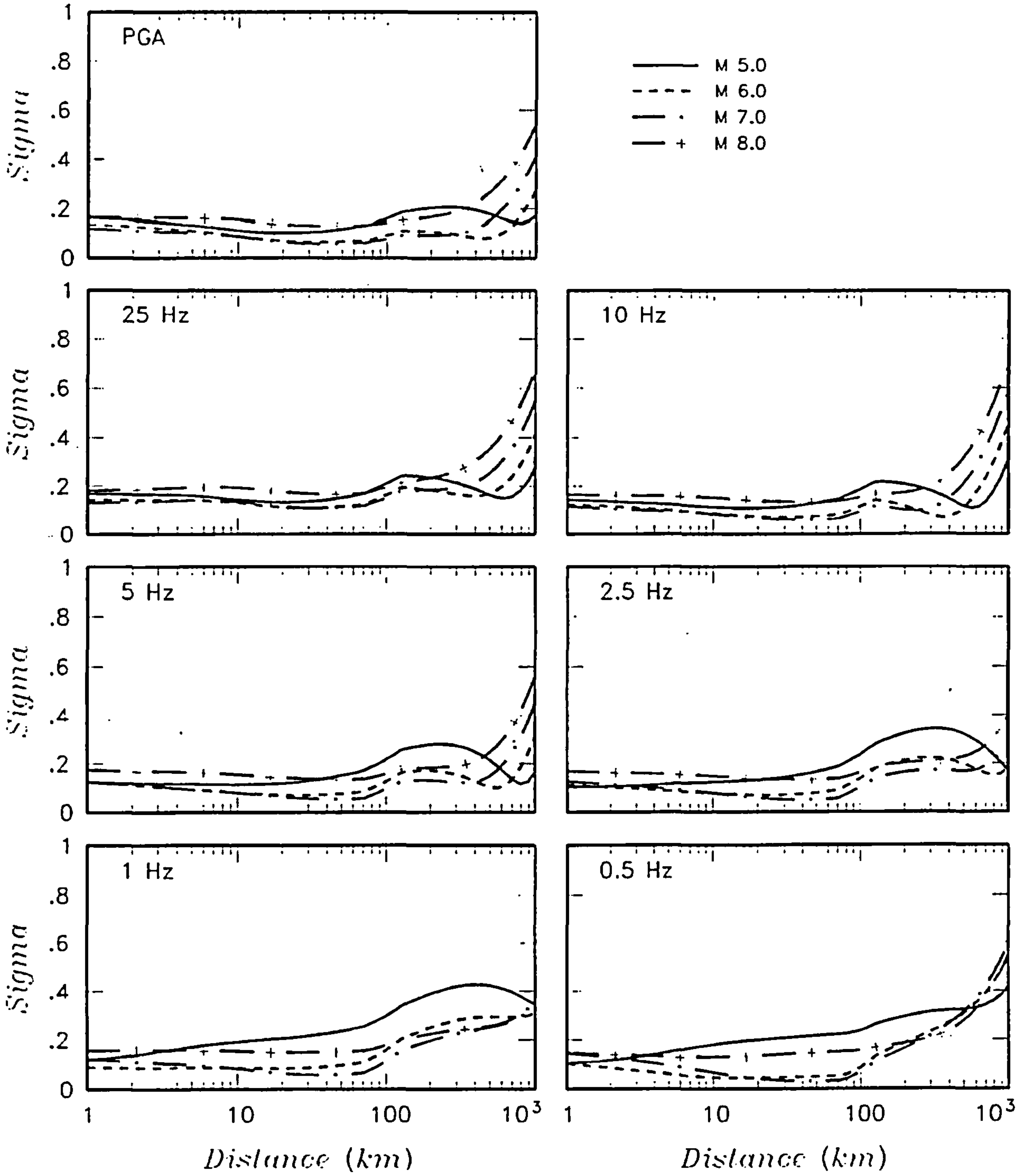

Figure 2-3
Intra-Cluster Variability for Cluster 1

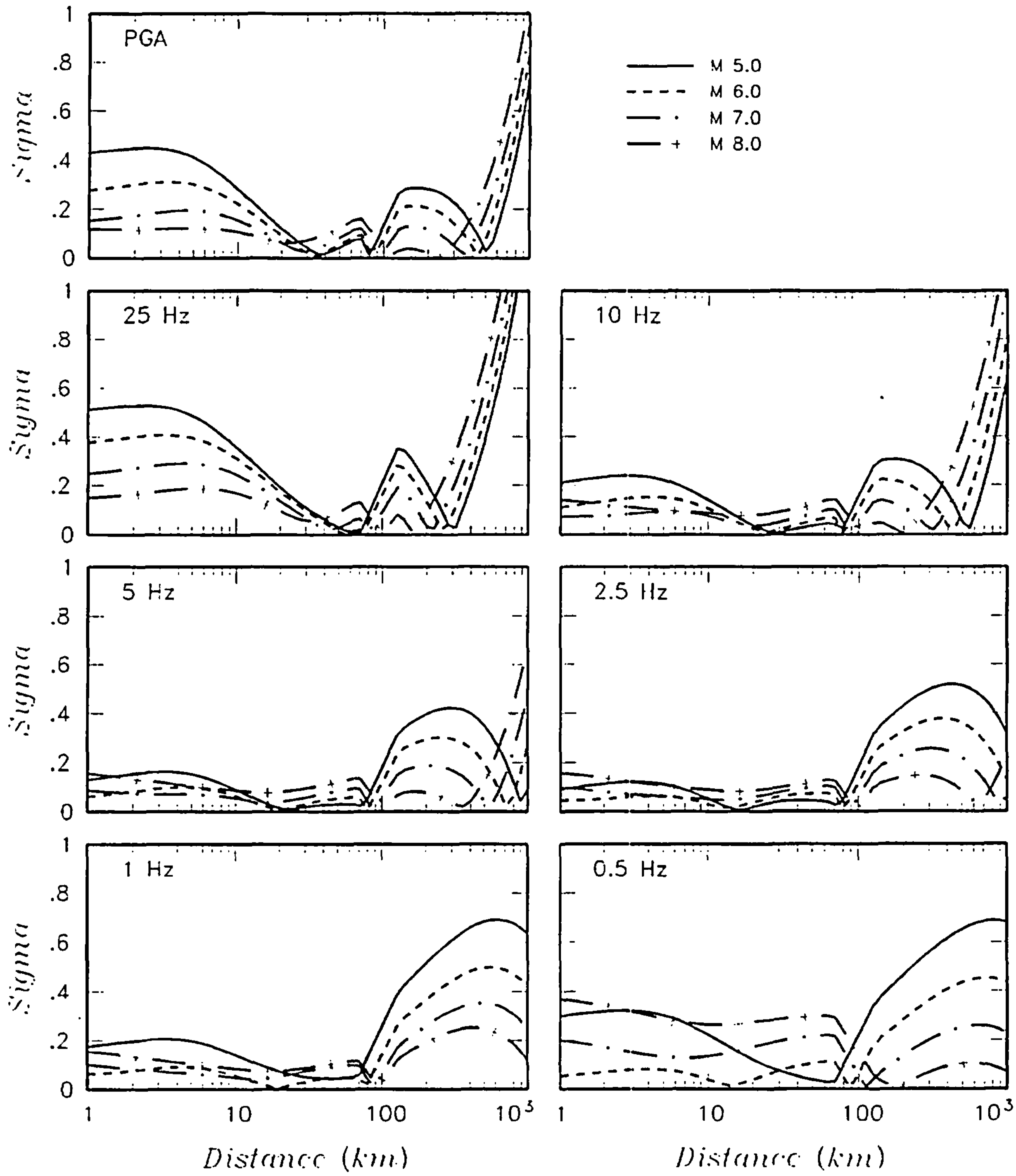

Figure 2-4
Intra-Cluster Variability for Cluster 2

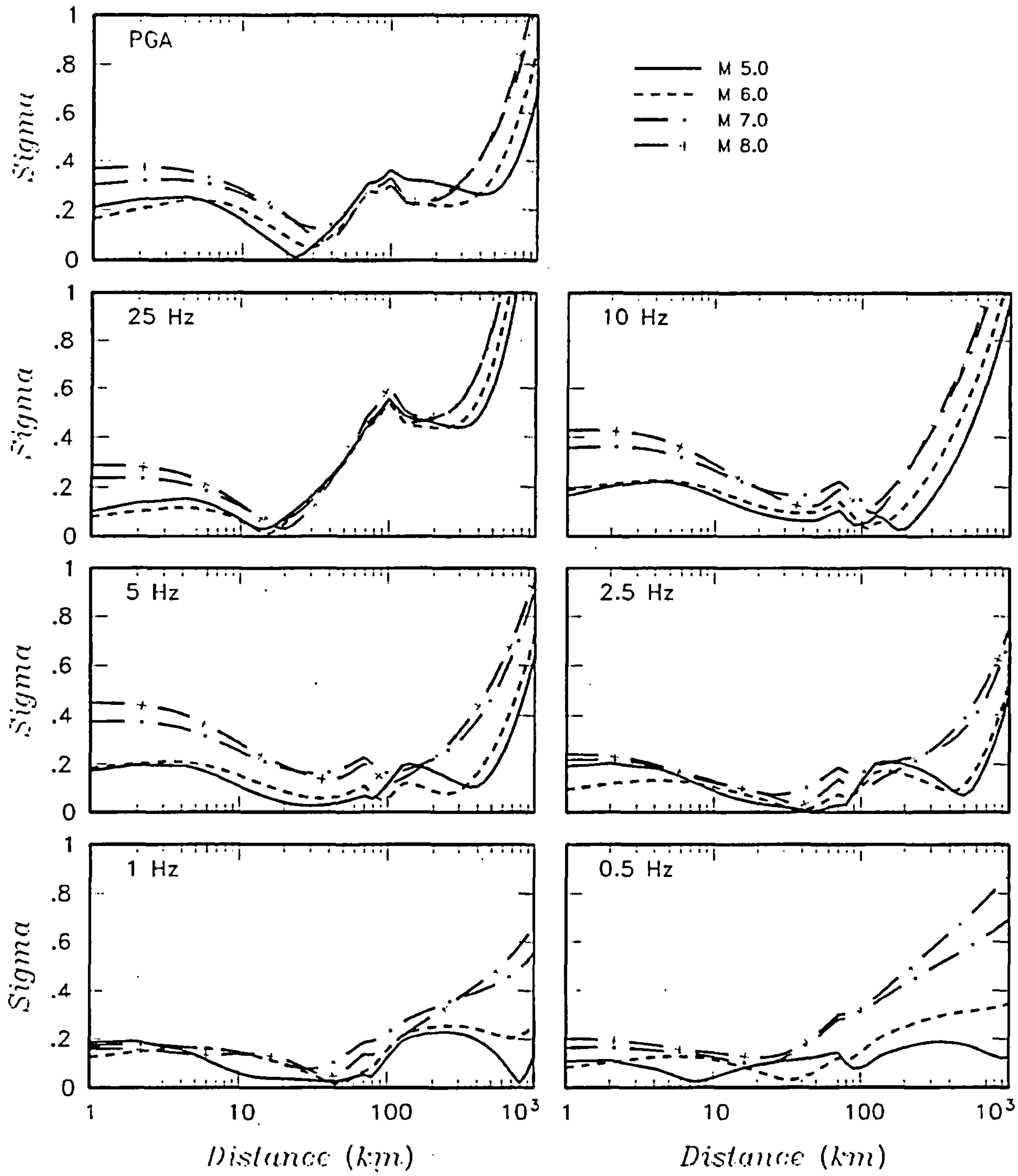

Figure 2-5
Intra-Cluster Variability for Cluster 3

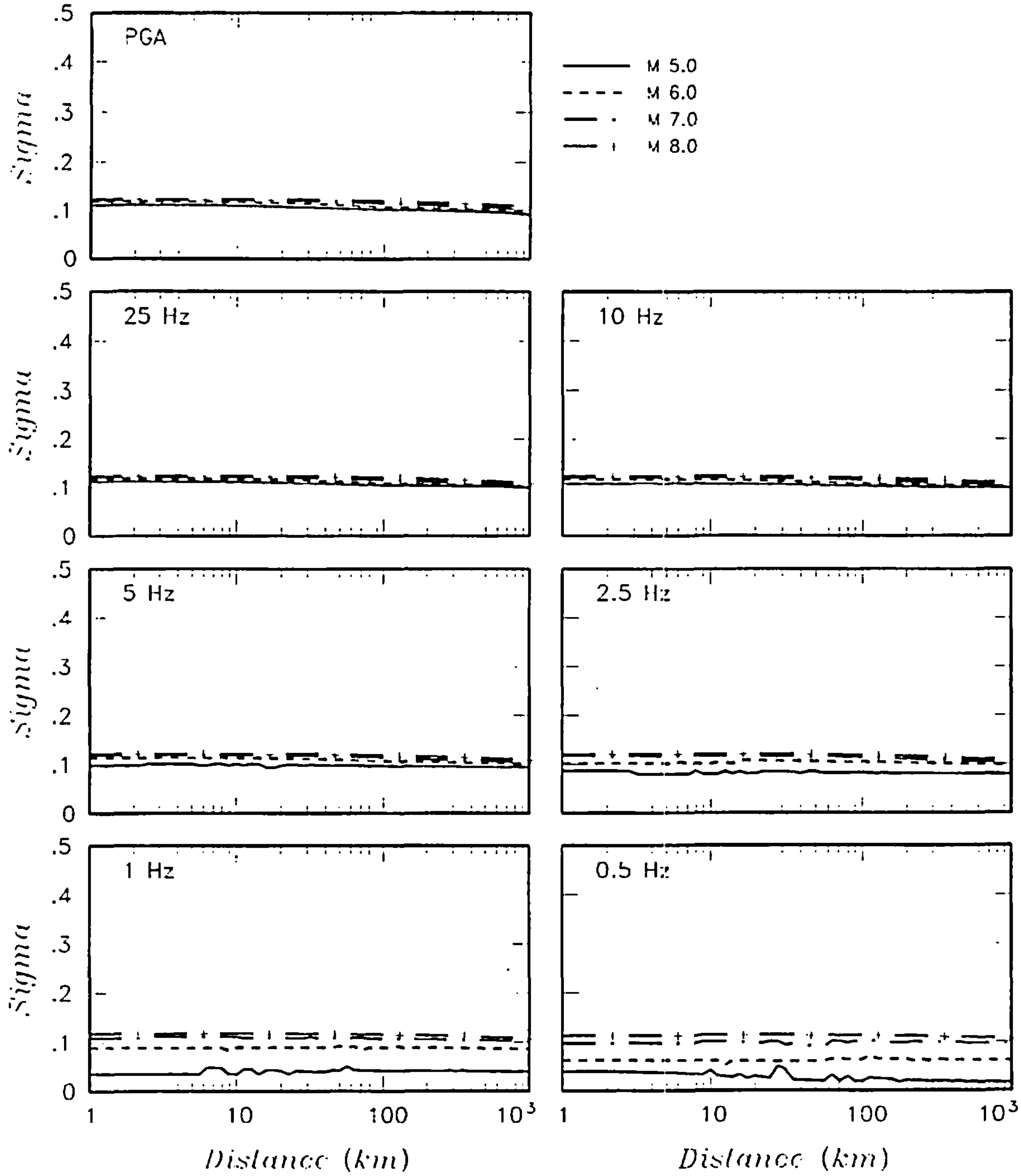

Figure 2-6
Epistemic Uncertainty in Ground Motion Due to Source Effects for the Single Corner Spectral Model

The path uncertainty is composed of uncertainty in the Q model, uncertainty in crustal wave propagation effects (e.g. crustal reflections), and uncertainty in variation of strong motion duration with distance. The TI evaluated the magnitude of this uncertainty by computing ground motions for a single corner spectral model using the range in path parameters employed by the spectral models (single and double corner) listed in Table 2-1. Figure 2-7 shows the resulting standard deviation of the natural log of peak or spectral acceleration as a function of magnitude and distance.

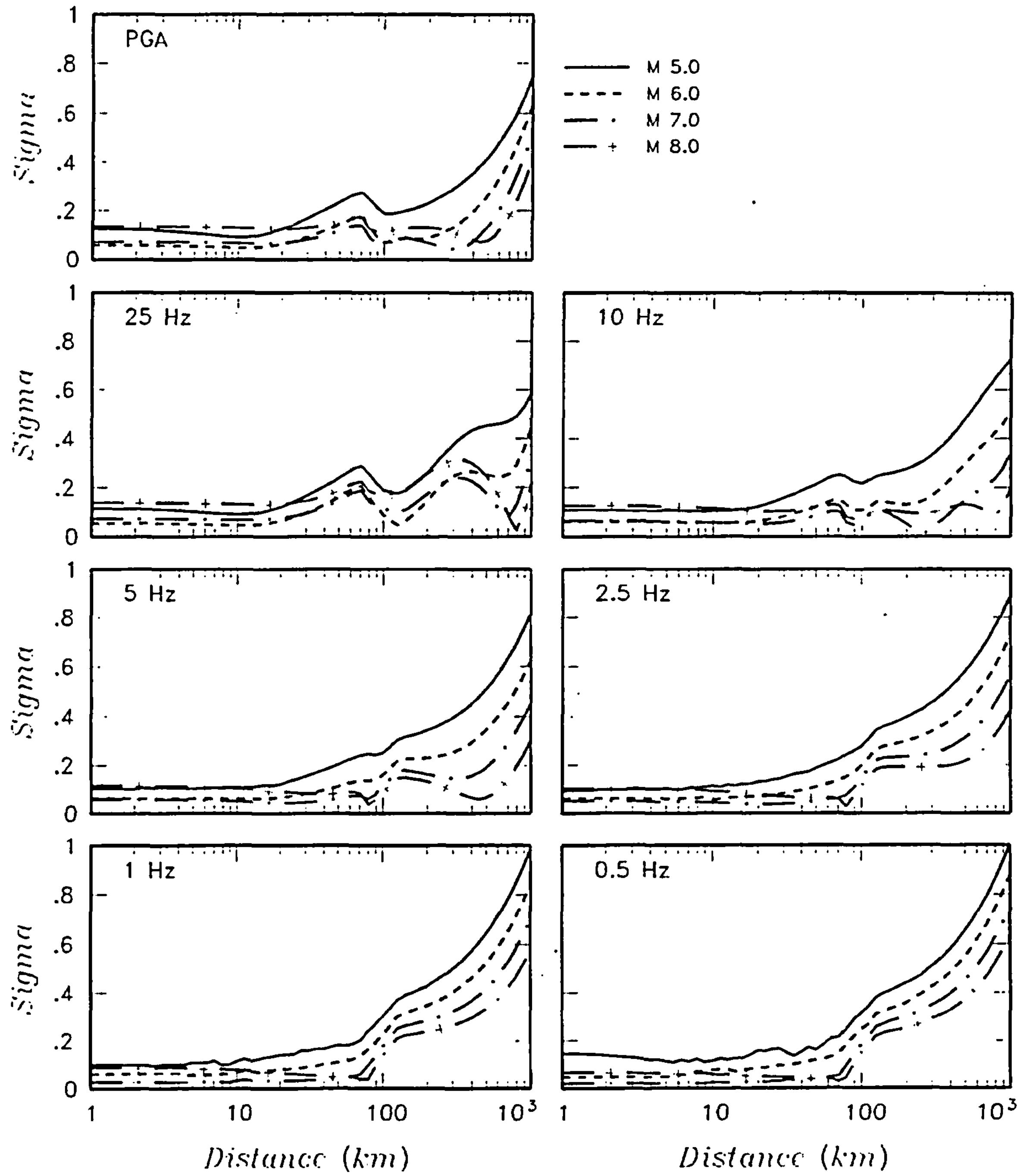

Figure 2-7
Epistemic Uncertainty in Ground Motion Due to Path Effects

The total epistemic uncertainty for each cluster was obtained by combining (sum of variances) the intra-cluster variability, source and/or path uncertainty, as appropriate, and the standard deviation of the fit to the cluster mean. The intra-cluster variability is shown on Figures 2-3, 2-4, and 2-5 for Clusters 1, 2, and 3, respectively. For Clusters 1, 2, and 3, only the uncertainty due to the source parameterization uncertainty (Figure 2-6) was included because the intra-cluster variability was judged to include path uncertainty for these clusters. For Cluster 4, both the source uncertainty (Figure 2-6) and the path uncertainty (Figure 2-7) were included in computing

the total epistemic uncertainty. The standard deviation of the fit to the cluster means for Clusters 1, 2, and 3 was in the range of 0.02 to 0.07. The total epistemic uncertainty for each cluster is shown in Figures 2-8 to 2-11. To support the fitting process, the individual M-R estimates of the epistemic uncertainty were smoothed over distance using a Gaussian smoothing window.

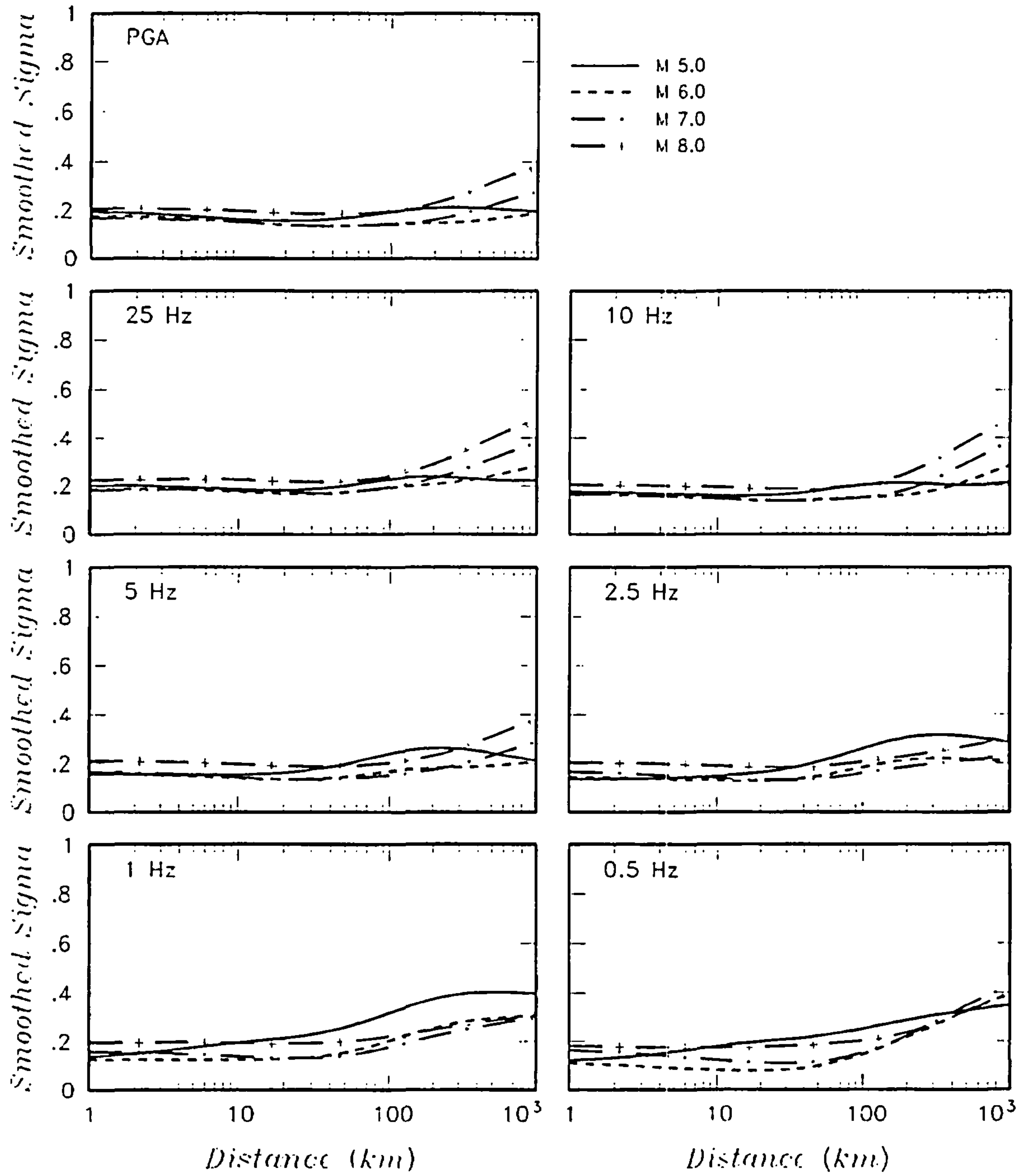

Figure 2-8
Total Epistemic Uncertainty for Cluster 1

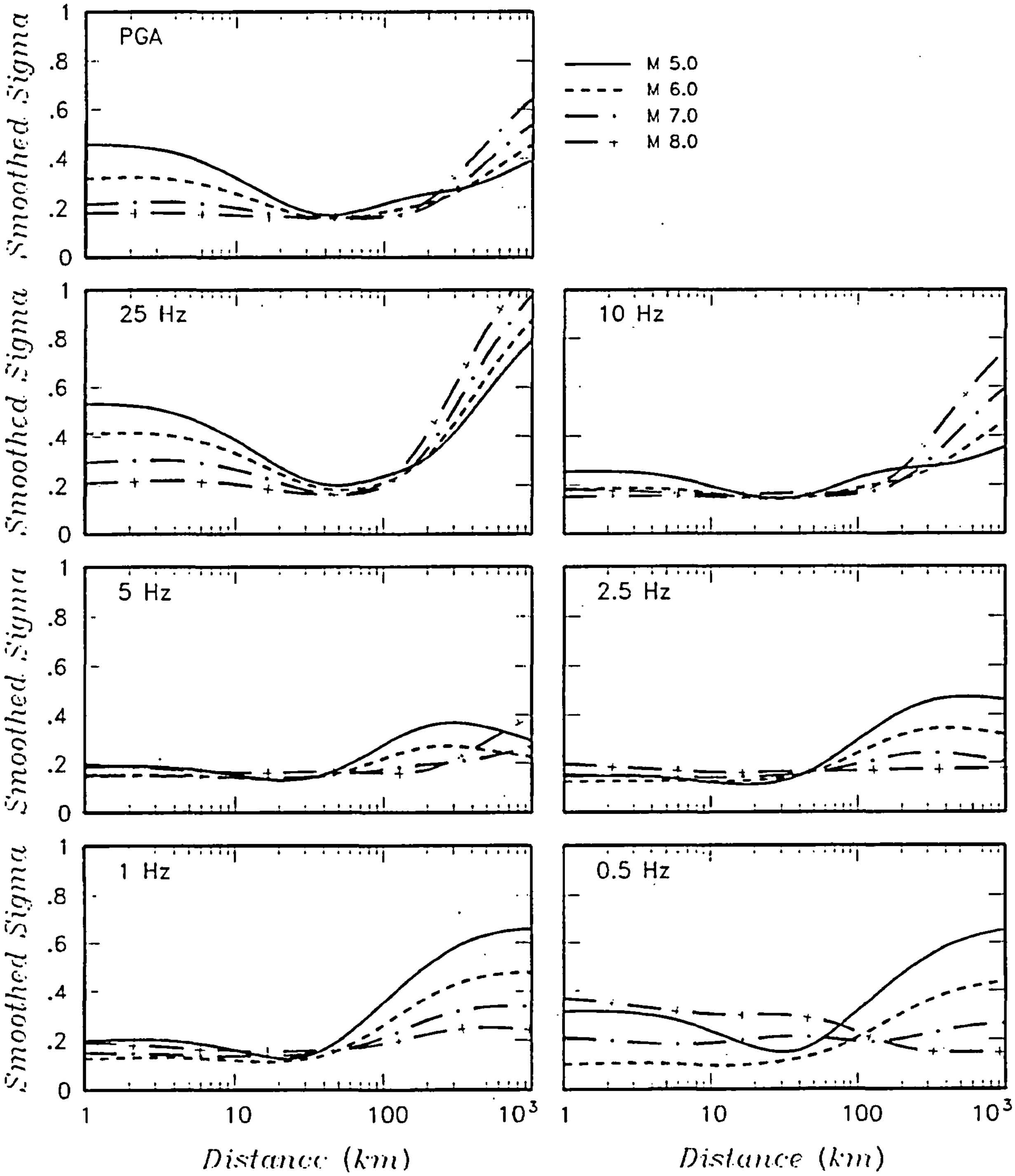

Figure 2-9
Total Epistemic Uncertainty for Cluster 2

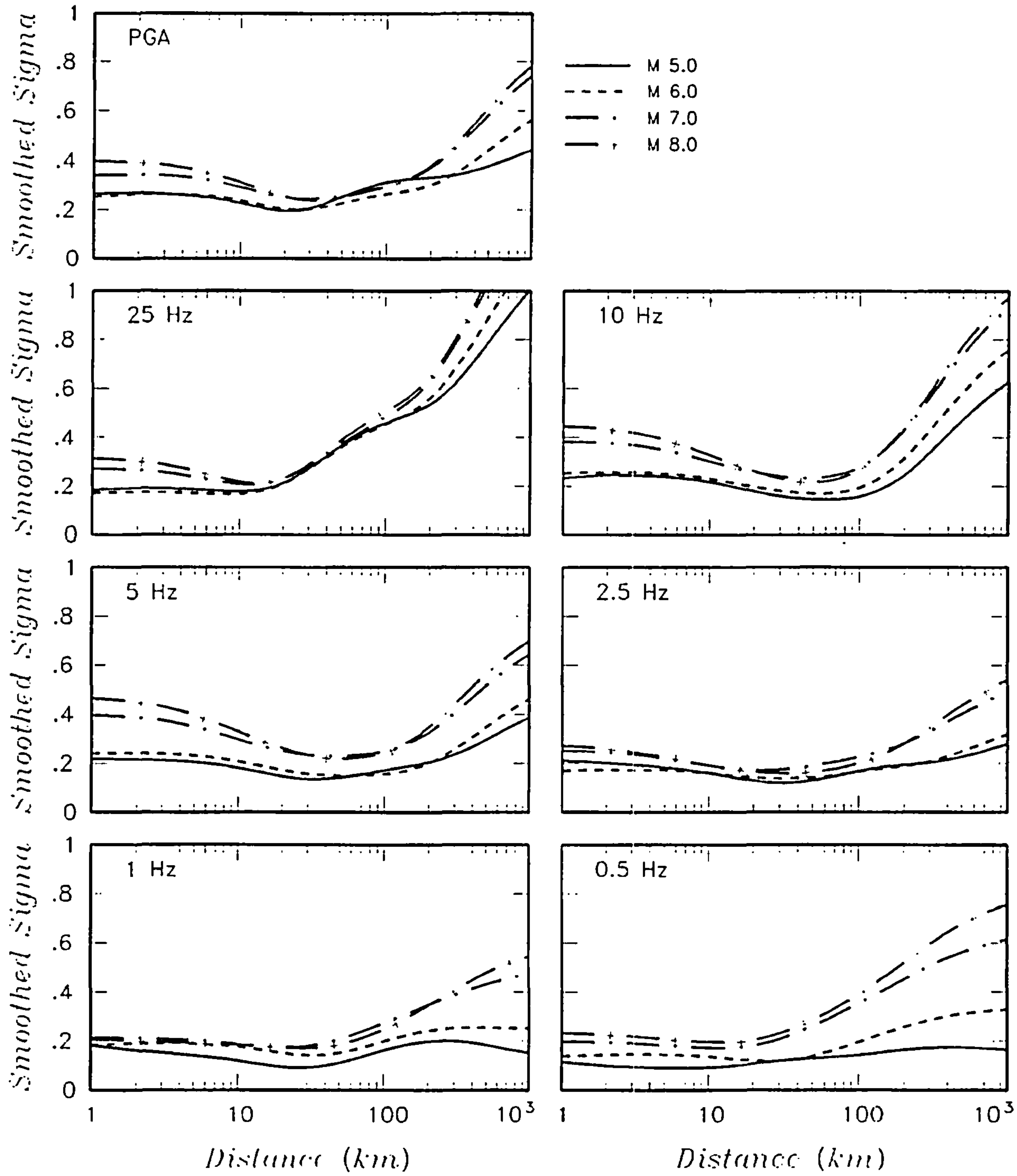

Figure 2-10
Total Epistemic Uncertainty for Cluster 3

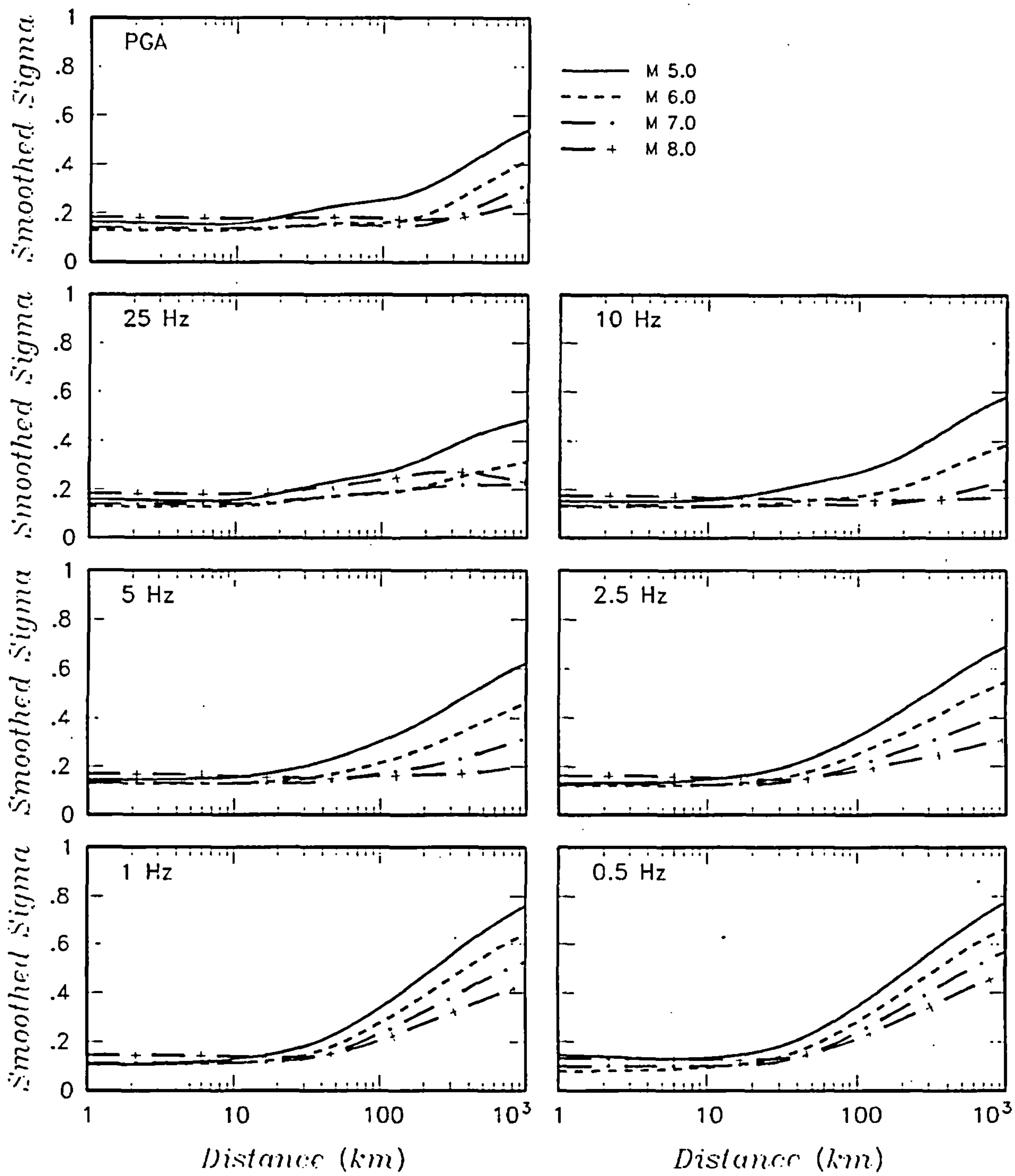

Figure 2-11
Total Epistemic Uncertainty for Cluster 4

2.3.3 Weighting of Model Clusters

To develop relative weights for the four model clusters, an evaluation criteria was used that considered:

- consistency of the cluster median with CEUS ground motion data, and
- the strength of the seismological principles used in the model development and the level of modeling of epistemic uncertainty in developing individual ground motion relationships.

To evaluate the consistency of each cluster with recorded CEUS data, the median model for each cluster as derived by the fitting process described above was used. For each cluster the mean and variance of the model deviations with respect to the data was determined. A relative cluster weight based on consistency with CEUS data was determined from the variance between a models predictions and the available ground motion database for frequencies of 1, 2.5, 5 and 10 Hz. This variance was computed as the sum of the mean deviation of the model predictions from the data and the standard error of estimation of the mean deviation. Cluster weights (normalized) were calculated in inverse proportion to this total variance. The resulting relative weights based on consistency with CEUS data for the four model clusters are listed in Table 2-4.

Table 2-4
Relative Weights for Consistency with CEUS Data

Cluster	Relative Weight
1	0.3639
2	0.5869
3	0.0135
4	0.0357

The second criterion is used to address the extent to which seismological principles were used to develop the models in a cluster and the degree to which the models explicitly model epistemic uncertainties. The motivation for considering treatment of epistemic uncertainty as part of a weighting function is that explicit treatment of uncertainty in developing a ground motion model leads to a more robust estimate of the median ground motions. Three levels were defined for this criterion: 1) no consideration of uncertainty, 2) modeling only parametric variability, and 3) explicit modeling of epistemic uncertainty.

Table 2-5 lists the relative scores assigned to different levels of these two criteria on a scale of 1 to 10. The highest score is assigned for the condition when the models in a cluster have made strong use of seismological principles and all models include explicit treatment of epistemic uncertainty. The lowest score is assigned to the case when there has been limited use of seismological principles and only parametric or no consideration of uncertainty. The relative scores for the other cases reflect several judgments. The first is that an explicit treatment of epistemic uncertainty, given a level of use of seismological principles is highly valued over no consideration. A second is the value associated with the implementation of seismological principles. For instance, in the upper right box, if there has been explicit consideration of epistemic uncertainties, but limited consideration of seismological principles, a low relative weight is assigned. In this case a score of 3 is assigned. The lower left box corresponds to the case in which a High rating is assigned for the use of seismological principles, but there has been no consideration of uncertainties. For this case a score of 4 is assigned.

Table 2-5
Seismological Principles/Uncertainty Evaluation Matrix

Consideration of Epistemic Uncertainty	Seismological Principles: High	Medium	Low
Explicit Modeling of Epistemic Uncertainty	10	8	3
Model only Parametric Variability	7	5	1
No Consideration of Uncertainty	4	3	1

Table 2-6 shows how the four model clusters are scored against the evaluation matrix in Table 2-5. The members of Cluster 1 are spectral models, the majority of which consider parametric variability. In addition, the Toro et al. model [13] explicitly models epistemic uncertainty. The member models in this cluster also represent alternative estimates of model parameters. For example, there is a range of estimates of the median stress parameter in this cluster. Alternative path representations are also included in the cluster. Spectral models are assigned a Medium rating for their consideration of seismological principles. A 0.60 relative weight is given for consideration of parametric variability and a 0.40 weight for explicit modeling of epistemic uncertainties. Cluster 2 is also based on spectral models and thus assigned a Medium rating for consideration of seismological principles. In this cluster two models consider parametric variability and the third does not. The alternative models in this cluster also represent alternative approaches to modeling path effects. Thus, relative weights of 0.8 and 0.2 are assigned for consideration of parametric variability and consideration of epistemic uncertainty. Cluster 3 consists of three hybrid models, one of which explicitly evaluated the epistemic uncertainties in this modeling approach. For this cluster, which was assigned a medium rating for consideration of seismological principles, a 0.50 relative weight was given for consideration of parametric variability and 0.50 weight for explicit modeling of epistemic uncertainty. Cluster 4 is assigned a High rating for consideration of seismological principles and a rating of 1.0 for evaluation of parametric variability. There is no explicit consideration of epistemic uncertainty in this cluster. Normalizing these relative scores produces the relative weights listed at the bottom of Table 2-6.

Table 2-6
Seismological Principles/Uncertainty Relative Weights

		Clusters: 1	2	3	4
	Seismological Principles	Medium	Medium	Medium	High
Uncertainty Index	No Consideration	0.00	0.00	0.00	0.00
	Only Parametric Variability	0.60	0.80	0.50	1.00
	Explicit Modeling of Epistemic Uncertainty	0.40	0.20	0.50	0.00
	Relative Score	6.2	5.6	6.5	7
	Final Weight	0.245	0.221	0.257	0.277

2.3.3.1 Final Combination and Assessment of Model Cluster Weights

The final step is to combine the two sets of relative weights (Consistency with Data and Seismological Principles and Uncertainty Evaluation). This requires an assessment of the relative importance of the two criteria in judging the merit of the ground motion estimates provided by each cluster. The application of seismological principles and the modeling of epistemic uncertainty are considered to be three times as important as the Consistency with Data. Consistency with the recorded data is assigned less importance because the data set is sparse and consists mostly of recordings from earthquakes smaller than the magnitude range of interest for hazard assessment. Using these importance factors produces the composite set of relative weights shown in the right-hand column of Table 2-7.

Table 2-7
Relative Weights for Model Clusters

	Importance Weights		
	0.25	0.75	
Cluster	**Consistency With Data**	**Seismological/ Uncertainty**	**Composite Weight**
1	0.3639	0.245	0.275
2	0.5869	0.221	0.312
3	0.0135	0.257	0.196
4	0.0357	0.277	0.217

2.4 Aleatory Variability

Figures 2-12 through 2-15 show the models for aleatory variability associated with the 13 ground motion models considered in this study. Also shown on these figures are the median estimates from NUREG/CR-6607 (the "TIP" expert elicitation) [16]. These models can be grouped into two conceptual models, one in which the aleatory variability is magnitude-dependent up to some specified magnitude (typically about **M** 7) and one in which aleatory variability is magnitude-independent over the magnitude range of interest to hazard assessment. Those models that invoke magnitude-dependence are either based on WUS aleatory models (perhaps increased somewhat for migration to the CEUS) or on arguments that the aleatory variability in stress drop is magnitude-dependent (e.g. Toro et al. [13]). The TIP result, which is a composite assessment of multiple experts, also shows a small magnitude-dependence.

The right-hand side of Figure 2-2 shows the logic structure for epistemic uncertainty model developed for aleatory variability. The first level considers the alternative conceptual models of magnitude-dependence and magnitude-independence. It is judged that, at present, the scientific community slightly favors magnitude-dependence and this conceptual model is assigned a weight of 0.6 versus 0.4 for magnitude-independence.

The next assessment is the selection of the aleatory variability parameters. For the magnitude-dependent case, two models are considered to appropriately represent the range of results. One is the model developed by Abrahamson and Silva [5], which is the WNA aleatory model of Abrahamson and Silva [17] increased to account for the uncertainty in translating to the CEUS. The second is the model developed by Toro et al. [13] specifically for the CEUS. The Toro et al. [13] model was updated to include the more recent assessment of modeling aleatory variability for the spectral models given in Silva et al. [11]. These two models are judged to be equally

credible. The assessments for Campbell [9] and Atkinson [7] represent purely WNA aleatory models. Based on observations that the variability in stress drop is somewhat higher in the CEUS than in WNA, it is judged that the Abrahamson and Silva [5] estimates are more appropriate for use than purely WNA aleatory variability.

For the magnitude-independent model, two levels of aleatory variability are represented. Looking at the comparisons shown on Figures 3-12 through 3-15, most constant model assessments cluster a value of about 0.6 for 10 Hz motions, increasing to about 0.7 for 1 Hz motions. These values are consistent with the median estimates from the TIP assessment. The standard error in $\sigma_{ln(SA)}$ for the TIP assessment was typically about 0.1. The values obtained by Hwang and Huo [10] fall below levels appropriate for WNA and may represent only parametric variability in the simulations. These low values are judges not to be appropriate. The highest values are those obtained by Silva et al. [11]. The other high level is that of the Frankel et al. model [14]. However, the basis for the Frankel et al. [14] aleatory values is not clear from their documentation. Two levels are therefore used to represent the uncertainty in the level of aleatory variability for the magnitude-independent case. The first level corresponds approximately to the average of the median values obtained by TIP and the estimates for Somerville et al. [12] and Atkinson and Boore [19]. At low frequencies, the estimates of Atkinson and Boore [19] decrease from the levels at higher frequencies, in contrast to nearly all other assessments. Thus their values are down-weighted in defining the level of constant aleatory variability. The second level corresponds to the estimates obtained by Silva et al. [11].

The aleatory variability models shown on Figures 2-12 through 2-15 are considered to represent aleatory variability at distances of 25 km or more from the source. In the model developed by EPRI [4] and Toro et al. [13] the aleatory variability increases at shorter distances to account for the effect of random source depth when using the Joyner-Boore distance measure. This effect was added to the other three models using the following procedure. Using the distribution for point source depth defined by Silva et al. [11] ground motions were simulated using a single corner source model holding all parameters fixed except point-source depth. Figure 2-16 shows the standard deviation in ground motions obtained from these simulations. These values were modeled as a distance-dependent path component to the total aleatory variability in a similar fashion to Toro et al. [13] This aleatory variability component was added to the variability estimates for the models based on Abrahamson and Silva [5] and TIP when used with Joyner-Boore distance measures (Clusters 1, 2, and 4). The aleatory variability estimates developed by Silva et al. [11] contain the effect of random source depth averaged over all distances. The aleatory variability due to random depth alone computed by the TI was averaged over the distances used by Silva et al. [11] and the result subtracted from their total sigma estimates. The distance-dependent component of aleatory variability was then added to these adjusted values to produce an aleatory variability model of similar form to the other three.

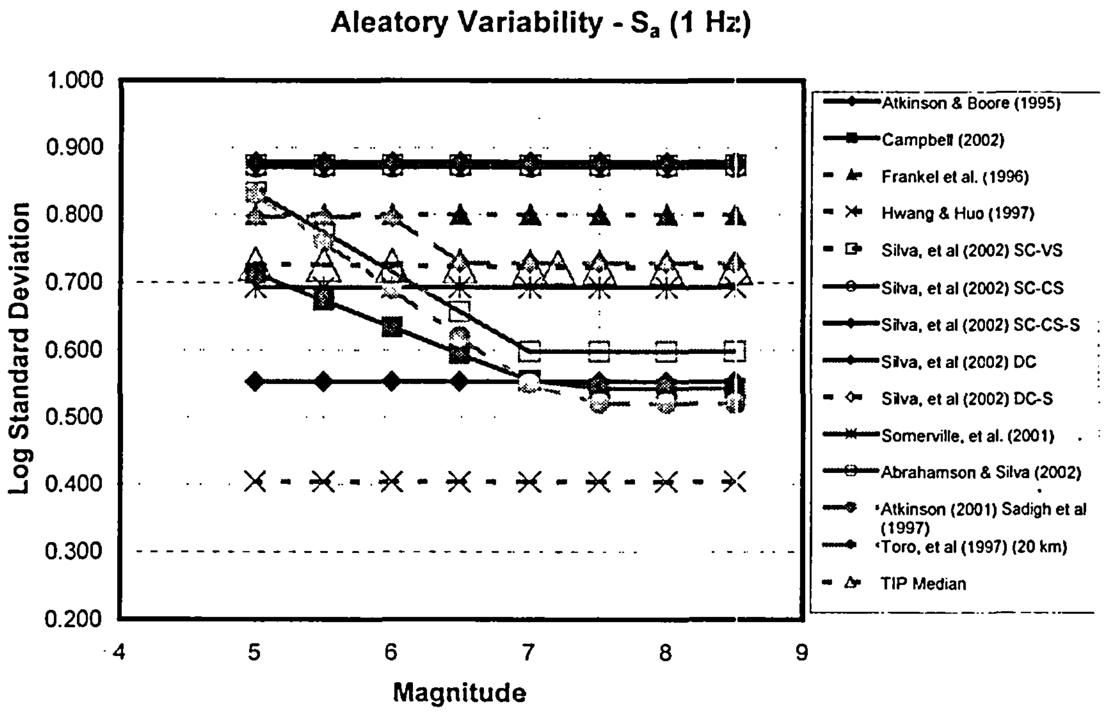

Figure 2-12
Aleatory Variability In 1-Hz Spectral Acceleration for CEUS Ground Motion Models

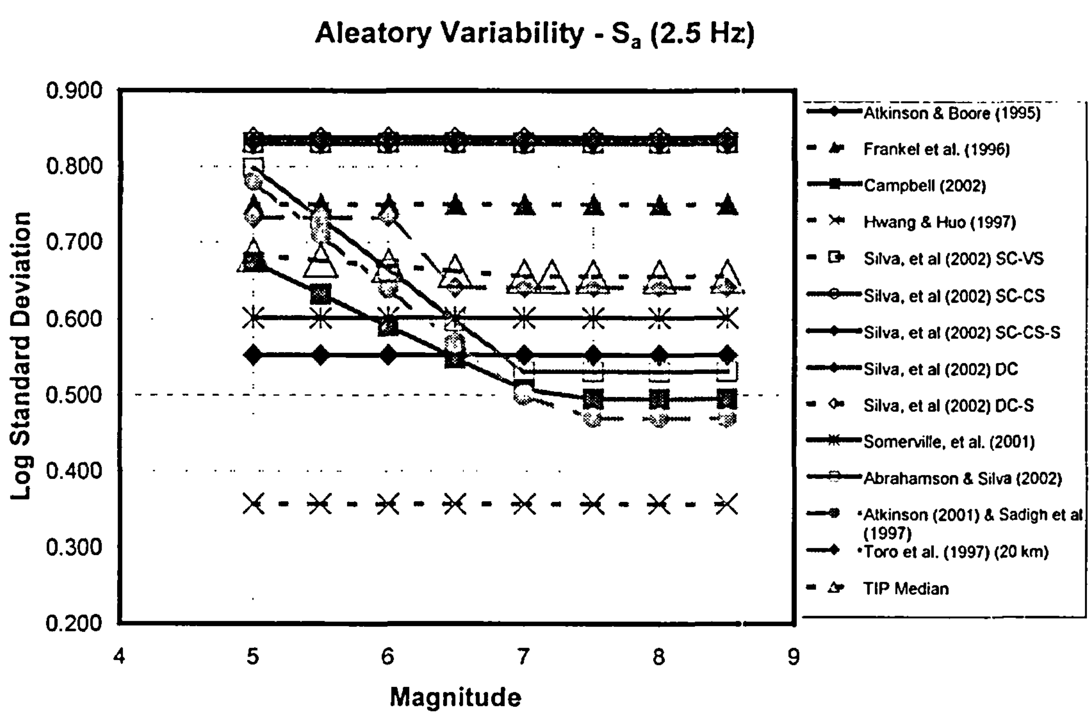

Figure 2-13
Aleatory Variability In 2.5-Hz Spectral Acceleration for CEUS Ground Motion Models

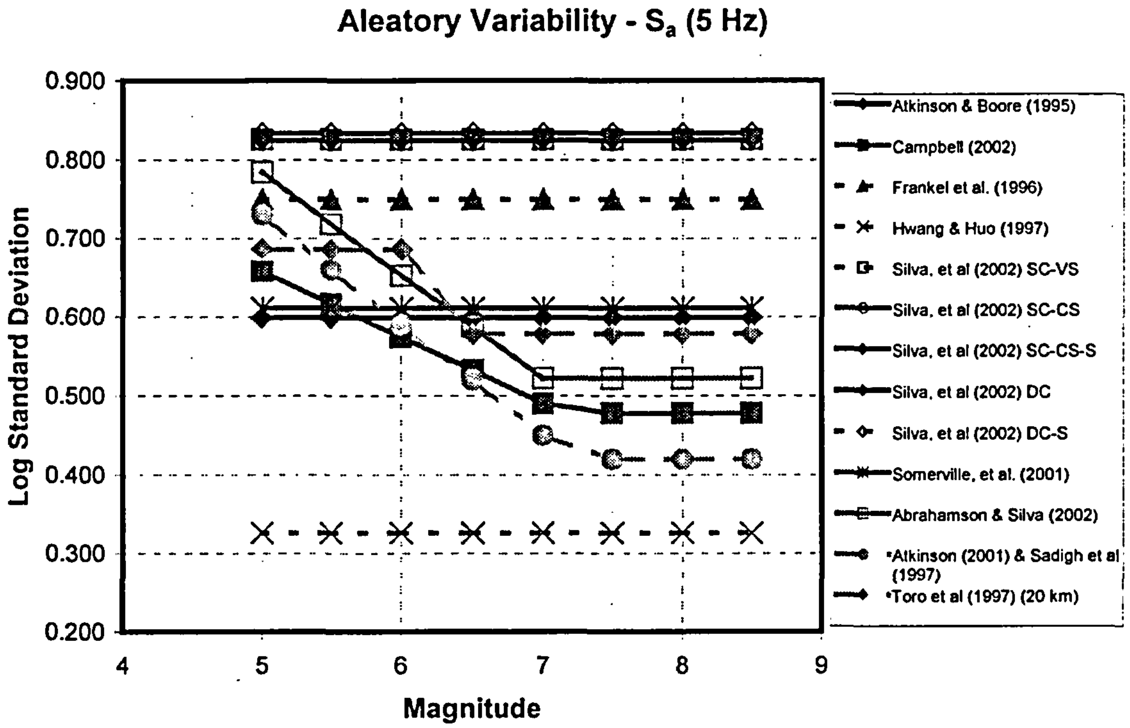

Figure 2-14
Aleatory Variability In 5-Hz Spectral Acceleration for CEUS Ground Motion Models

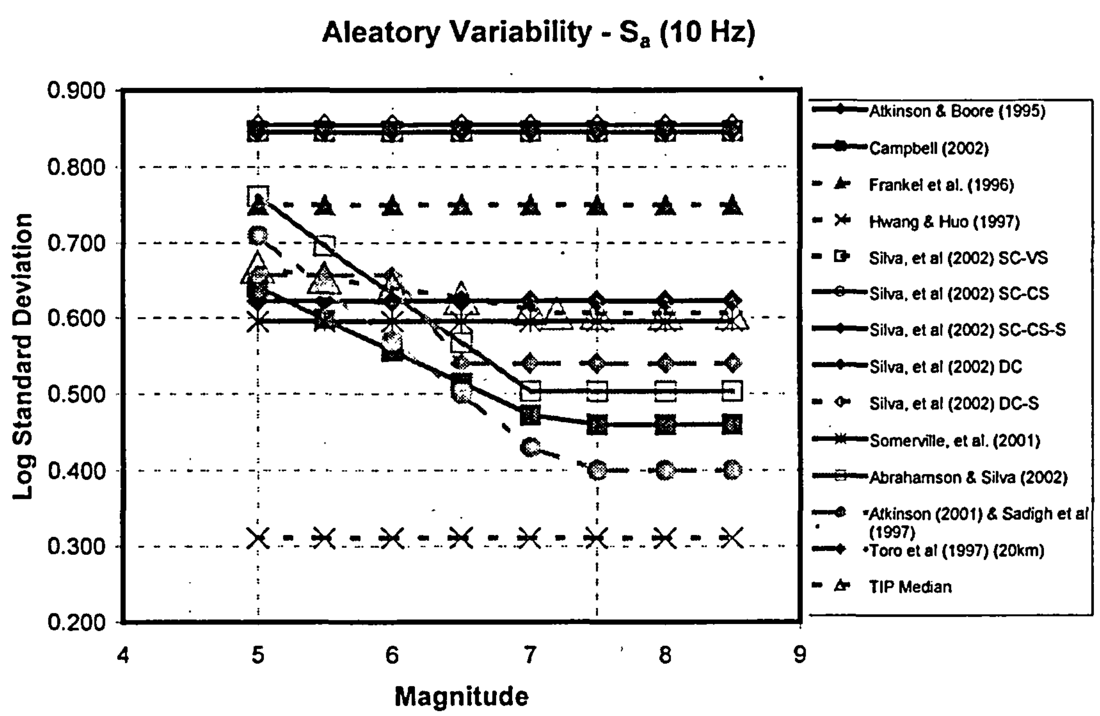

Figure 2-15
Aleatory Variability In 10-Hz Spectral Acceleration for CEUS Ground Motion Models

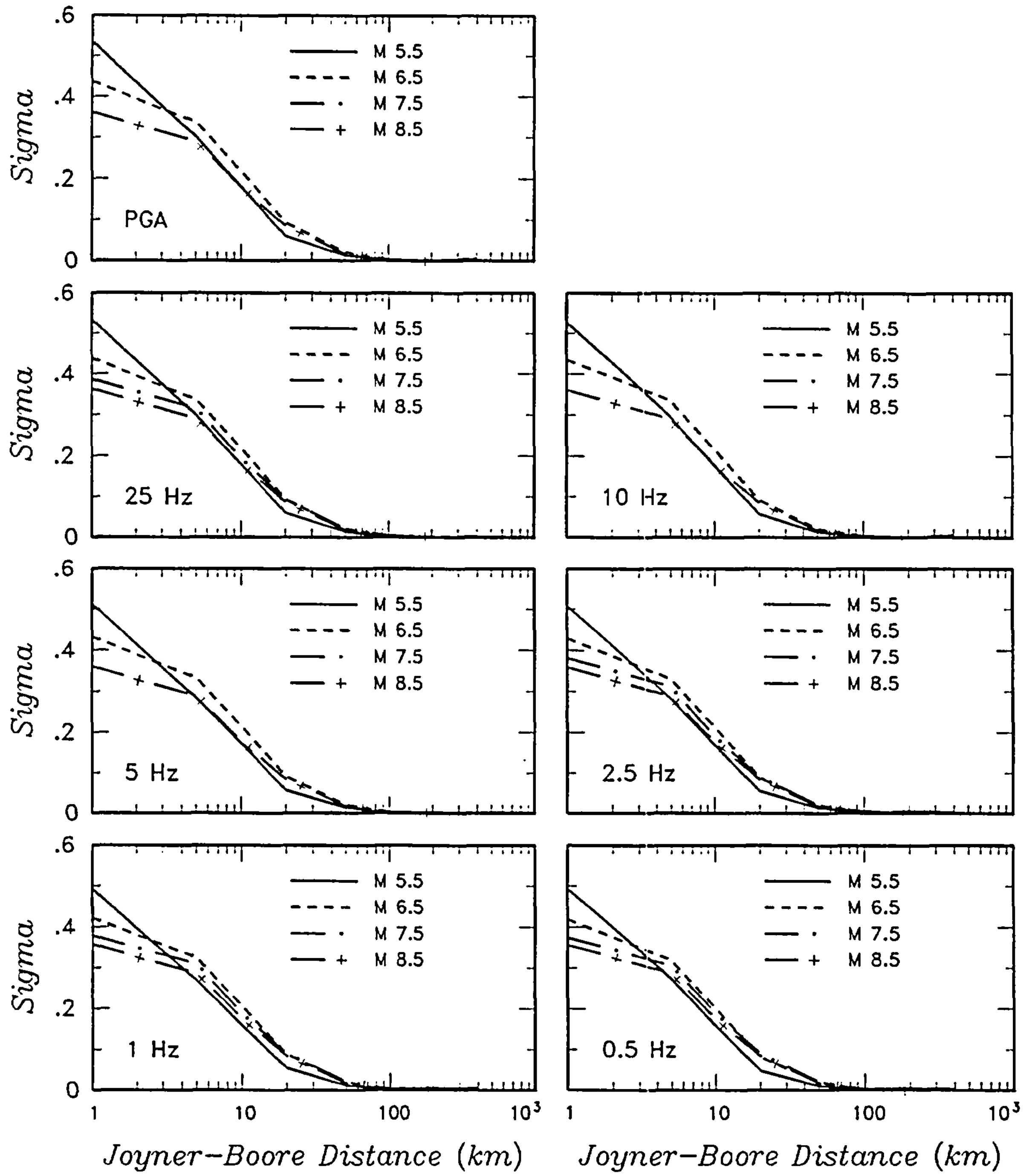

Figure 2-16
Aleatory Variability Resulting From Random Point-Source Depth

2.5 Adjustments to Median Models for Application to the Gulf Coast Region

The only model currently available for the Gulf Coast region is Toro et al. [13]. However, as part of this project Silva [15] has provided the results of a series of simulations that compute the ratio of spectral accelerations for hard rock sites in the Gulf Coast region over hard rock sites in

the Mid-continent for distances of 1 to 800 km. Figure 2-17 shows the resulting spectral ratios as a function of magnitude, distance, and frequency. These results were fit with a continuous functional form and used to scale the Mid-continent cluster mean for a cluster to provide a Gulf data set for each cluster. These cluster mean data for the Gulf region are then fit to determine the cluster median relationship for each cluster. The epistemic uncertainty in the cluster median for the Gulf was assumed to be equivalent to the epistemic uncertainty for the Mid-continent, plus an additional component of epistemic uncertainty associated with modeling path (wave propagation) effects. This is the same path component used for the Mid-continent. This additional uncertainty on the median ground motions is added to account for the more limited state-of-knowledge in estimating motions in the Gulf region.

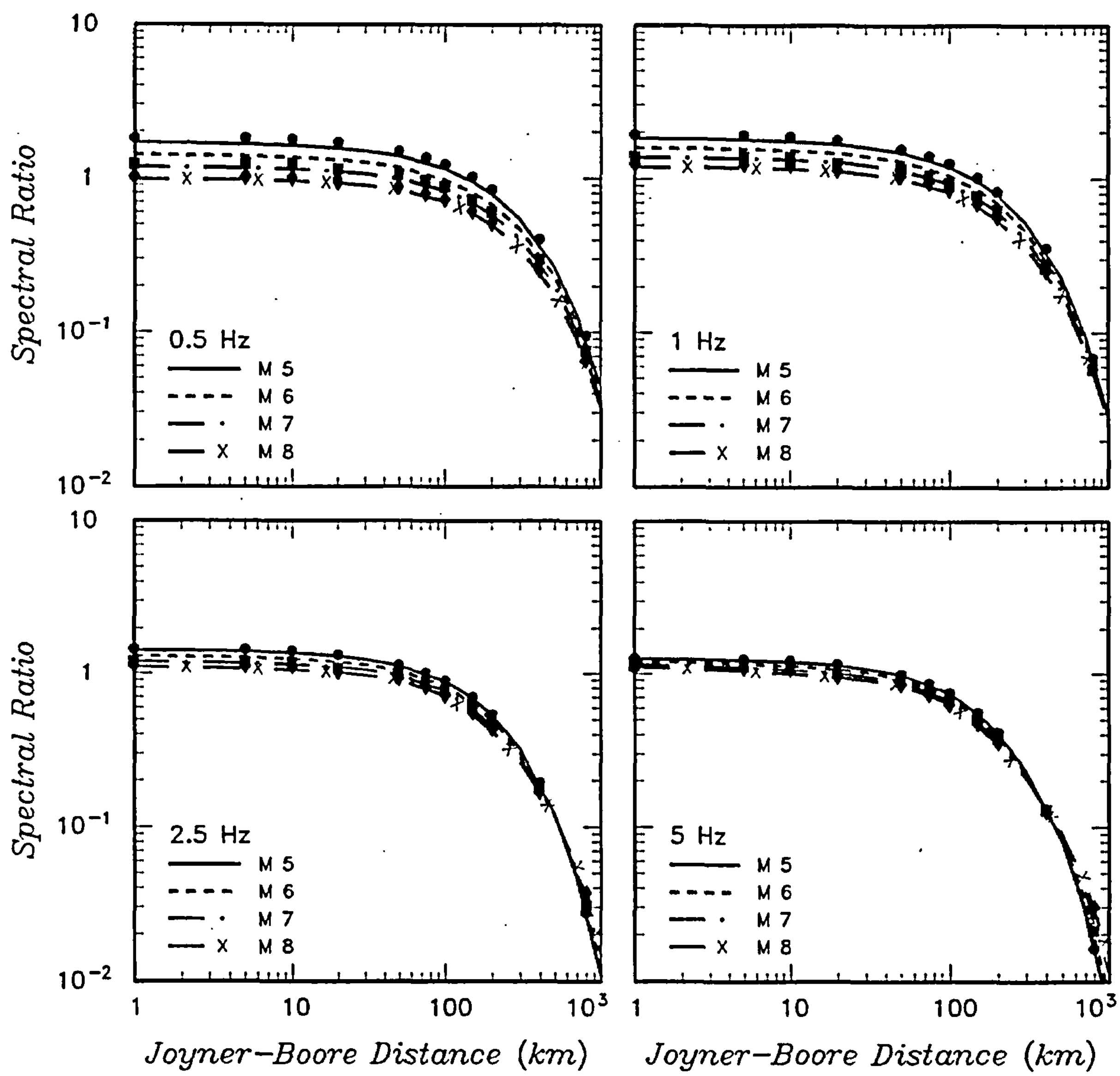

Figure 2-17
Ratio of Gulf to Mid-Continent Ground Motions

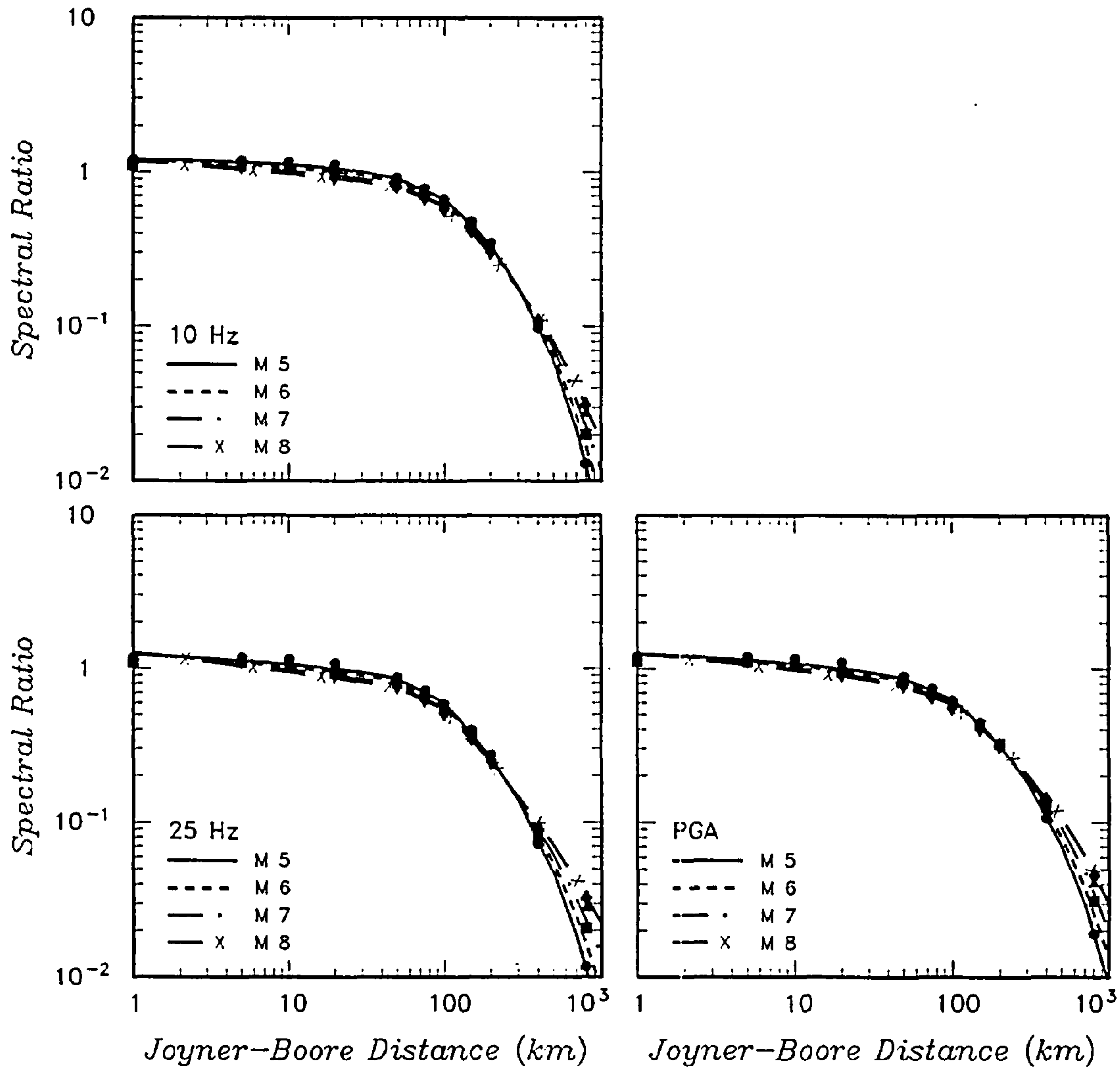

Figure 2-17
Ratio of Gulf to Mid-Continent Ground Motions (continued)

2.6 Adjustments for Point Source Applications in PSHAs

It is anticipated that the CEUS ground motion models may be used in PSHA applications in which earthquake occurrences are modeled as point sources. For these applications two adjustments are required:

1. conversion of the epicentral distance that is determined in the PSHA for a point source to either a Joyner-Boore distance measure or the closest distance to the fault as appropriate.

2. incorporation of an additional source of aleatory variability due to the randomness in the orientation of extended fault ruptures with respect to a site and randomness in earthquake depth when using a rupture distance model (i.e. Cluster 3).

For this study, point-source adjustment models are provided for the case where rupture orientation is assumed to be uniformly distributed in azimuth from 0 to 360 degrees and a mixture of strike-slip and reverse earthquakes. Other assumptions, such as preferred orientations for rupture, will require source-specific point source adjustment factors developed by the analyst or explicit modeling of finite ruptures. The point-source adjustments present here are determined for each model cluster and ground motion measure. To determine the distance and aleatory variability adjustments, simulations of extended fault ruptures were modeled with random depths and fault orientations. Two alternative cases were considered when modeling earthquake epicentral locations. The first case, referred to as "Random Epicenters," is based on the assumption that the epicenter of an earthquake is uniformly distributed along the length of the rupture. The case, referred to as "Centered Epicenters," is based on the assumption that the epicenter is centered on the earthquake rupture. These two options are provided so that a user may chose which assumption is more consistent with the seismic source interpretation.

The modeling process for a given cluster is as follows. For each epicentral distance and magnitude, simulations were performed for a strike-slip fault dipping at 90 degrees and a reverse fault dipping at 40 degrees (the average dip for reverse faults in intra-continental regions. For each simulated rupture, the appropriate distance measure was computed and the corresponding median ground motion obtained for each ground motion measure. The geometric mean (mean log) of these values is considered to be the expected median ground motion for that epicentral distance and magnitude. The cluster median ground motion model was then inverted to obtain the distance that produces this median ground motion measure. The result is a distance adjustment factor for each epicentral distance and magnitude for each ground motion measure. These adjustment factors were then fit with a functional form. Appendix A presents plots of the resulting distance adjustment models.

The variability in ground motions due to randomness in rupture orientation was modeled as follows. For each epicentral distance, the variability in the median ground motions over the set of simulated ruptures was used to compute a standard deviation in ground motion due to random rupture orientation and epicentral location. These values provide an additional aleatory variability component for each epicentral distance and magnitude for each ground motion measure. Appendix B shows plots of the resulting additional aleatory standard deviation. This additional aleatory variability is combined with the aleatory variability defined for an event assuming extended fault ruptures are modeled (addition of variances)

3
GROUND MOTION MODEL RESULTS

The following describes the ground motion attenuation model for sites located in the Mid-continent and Gulf regions[1] of the Central and Eastern U.S. The model includes the epistemic uncertainty in the median estimate of ground motions and in the aleatory variability.

3.1 Ground Motion Model

The ground motion attenuation model is defined by:

$$\ln(y) = f(m, r) + \ _{r}$$

where,

y = ground motion measure (e.g., peak ground acceleration, spectral acceleration)

f(m,r) = function describing the variation of the median ground motion as a function of m, earthquake magnitude (also, see below) and r, source-to-site distance (also, see below)

$_{r}$= standard normal random variable with zero mean and logarithmic standard deviation, $_{a}$, that quantifies the aleatory variability in ground motions.

3.1.1 Ground Motion Measures

Ground motion attenuation models are provided for the following ground motion measures; peak ground acceleration (PGA), and spectral acceleration (S_a) at frequencies of 0.50, 1.0, 2.5, 5.0, 10.0, and 25.0 Hz. All ground motions are defined in units of g.

3.1.2 Earthquake Magnitude Scale

The ground motion attenuation models are defined in terms of moment magnitude, M.

3.1.3 Source-Site Distance

Two source-to-site distance measures are used for the ground motion attenuation models. These are the Joyner-Boore distance and the closest distance to the fault rupture[2]. The use of these distance measures is defined in the following tables as applicable. The ground motion models and their associated distance measures are suitable for use in a probabilistic seismic hazard analysis (PSHA) in which the earthquake occurrences in a seismic source are modeled as extended fault ruptures.

[1] The mid-continent region is defined in Reference 3.

[2] Two distance measures are used because some ground motion models that are the basis for the attenuation relationships provided here are based on different distance measures.

It is anticipated these ground motion models will be used in a PSHA in which earthquake occurrences are modeled as point sources (extended rupture is not considered). This might be the case when the EPRI/SOG seismic sources are used. To accommodate this application of the models, modifications to the source-site distance measures and models for the additional aleatory variability are provided for the case of representation of earthquakes as epicenters with randomly oriented ruptures.

3.1.4 Site Conditions

The ground motion models are applicable to hard-rock conditions in the CEUS (V_s ~ 2.8 km/s).

3.1.5 Seismic Source Categories

Ground motion models are provided for 3 categories of seismic sources. These categories are listed in Table 3-1. The table also provides guidance for model selection with respect to the important range of earthquake magnitudes and source-site distances. For the seismic source categories listed in Table 1, it is assumed that earthquake occurrences in a seismic source are represented by extended rupture. If earthquake occurrences are modeled as point sources and not as extended ruptures, the seismic source categories in Table 1 still apply; however, distance and aleatory variability adjustments are required. These adjustments are described later.

Table 3-1
Guidance for Identifying Seismic Source Categories and Selecting Ground Motion Attenuation Models

Category	Magnitude Range[1]	Location with Respect to a Site (km)[2]	PSHA Source Type[3]
General Area Sources	5.0 < M ≤ 8.0	0 < R ≤ 200	Area Sources
Seismic Sources Capable of Generating Large Magnitude Events, Nearby	M > 6.5	R < 150	Fault Sources
Distant, Active Seismic Sources Capable of Generating Large Magnitude Events	M ≥ 7.0	R ≥ 150	Area Sources or Fault Sources

[1]The magnitude range defines the range of earthquakes that are the important contributors to the ground motion at a site.
[2]The distance range defines the range of distances of earthquake occurrences that are important contributors to ground motion at a site.
[3]Source type refers to the geographic representation of a seismic source in the PSHA. Fault source refers to modeling of fault structures as line sources or dipping planes.

3.2 Median Ground Motion

The epistemic uncertainty in the median ground motion attenuation is defined in terms of:

1. alternative forms of the functional relationship that define the variation of the median ground motion with respect to earthquake magnitude and distance, and
2. alternative estimates of the parameters for the functional relationship.

Table 3-2 lists the alternative ground motion attenuation model functional forms.

The suite of alternative median ground motion models (the complete set of functional relationships and model parameters) define the epistemic uncertainty in the estimate of the median ground motion. A probability weight is associated with each functional relationship-parameter value pair. The sum of these weights is one.

Table 3-2
Ground Motion Attenuation Model Functional Forms

No.	Symbol	Functional Form[1]
1	F1	$\ln(y) = C_1 + C_2 m + (C_3 + C_4 m) \times \ln(d_{JB} + e^{C_5}) + C_6 (m - m_1)^2$
2	F1a	$\ln(y) = C_1 + C_2 m + (C_3 + C_4 m) \times \ln(d_{JB} + e^{C_5}) + C_6 (m - m_1)^2 + (C_7 + C_8 m) d_{JB}$
3	F2	$\ln(y) = C_1 + C_2 m + C_3 m^2 + (C_4 + C_5 m) \times \min\{\ln(r), \ln(r_1)\} + (C_6 + C_7 m) \times \max\{\ln(r/r_2), 0\} + C_8 r$ $r = \sqrt{d_{JB}^2 + h^2}$ $\quad h = \exp(C_9 + C_{10} m)$
4	F3	$\ln(y) = C_1 + C_2 m + C_3 (m_1 - m)^2 + C_4 \ln[f_1(m, d_{CD})] + f_2(d_{CD}) + (C_9 + C_{10} m) d_{CD}$ $f_1(m, d_{CD}) = \sqrt{d_{CD}^2 + (C_5 e^{C_6 m})^2}$ $f_2(d_{CD}) = 0 \quad d_{CD} \le r_1$ $= C_7 \{\ln(d_{CD}) - \ln(r_1)\} \quad r_1 < d_{CD} \le r_2$ $= C_7 \{\ln(d_{CD}) - \ln(r_1)\} + C_8 \{\ln(d_{CD}) - \ln(r_2)\} \quad d_{CD} \ge r_2$
5	F4	$d_{JB} < r_1$ $\ln(y) = C_1 + C_2 (m - m_1) + C_3 \ln(d) + C_4 (m - m_1) \ln(d) + C_5 d_{JB} + C_7 (m_2 - m)^2$ $d_{JB} \ge r_1$ $\ln(y) = C_1 + C_2 (m - m_1) + C_3 \ln(d_1) + C_4 (m - m_1) \ln(d) + C_5 d_{JB} + C_6 (\ln(d) - \ln(d_1)) + C_7 (m_2 - m)^2$ $d = \sqrt{d_{JB}^2 + h^2}$ $d_1 = \sqrt{r_1^2 + h^2}$

[1]m = moment magnitude; d_{JB} = Joyner-Boore distance; d_{CD} = closest distance to the fault rupture

The median ground motion attenuation models for the Mid-continent and Gulf regions of the CEUS and for each seismic source category and ground motion measure are provided in Figures 3-1 to 3-4. The figures show the median for each source category and ground motion measure and the range of the model estimates for magnitudes 5 and 7.

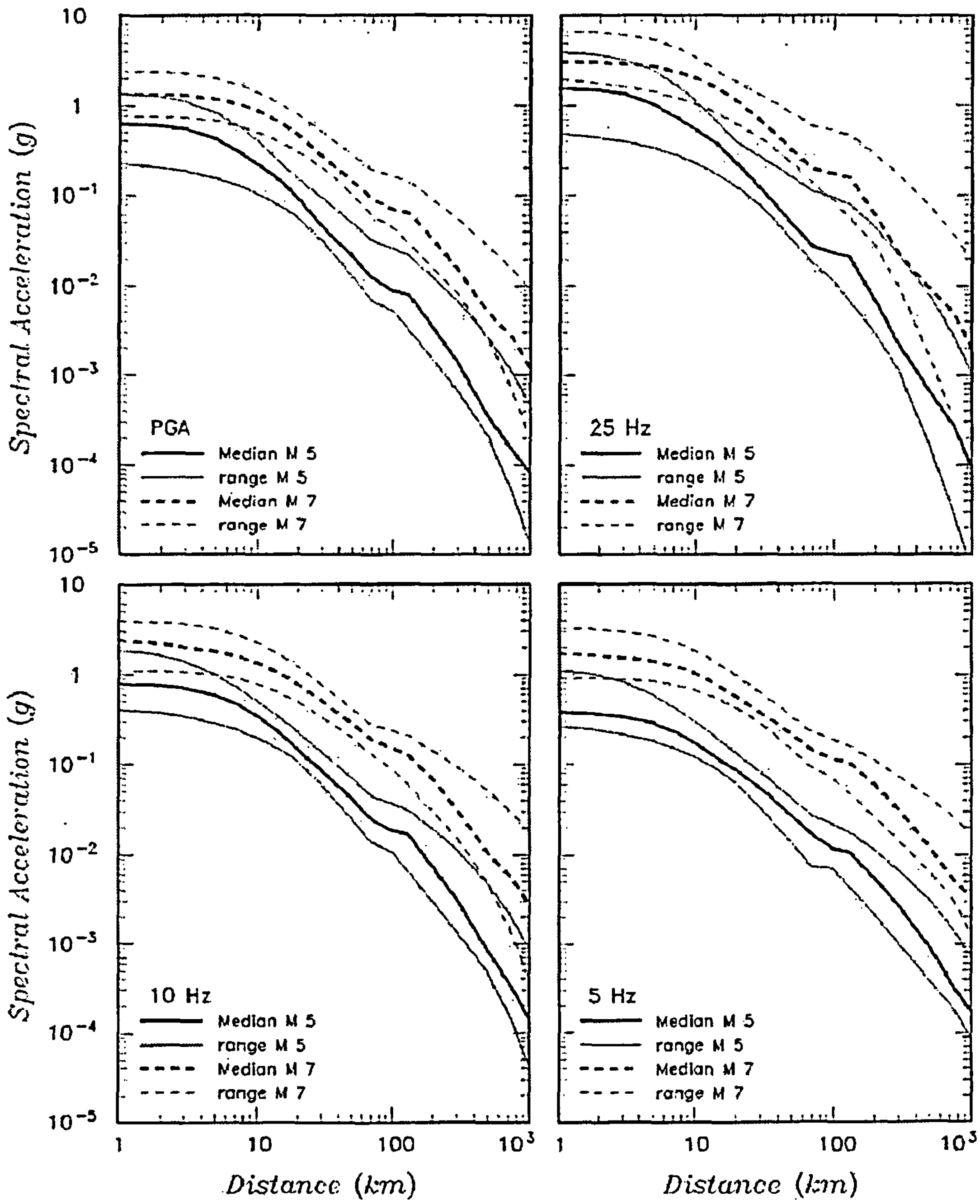

Figure 3-1
Ground Motion Models for General Area Sources in the Mid-Continent for Peak Ground Acceleration and Spectral Acceleration at 25, 10, 5, 2.5, 1.0 and 0.50 Hz. Each Figure Shows the Median and the Range of Ground Motion Estimates for Magnitudes 5 and 7

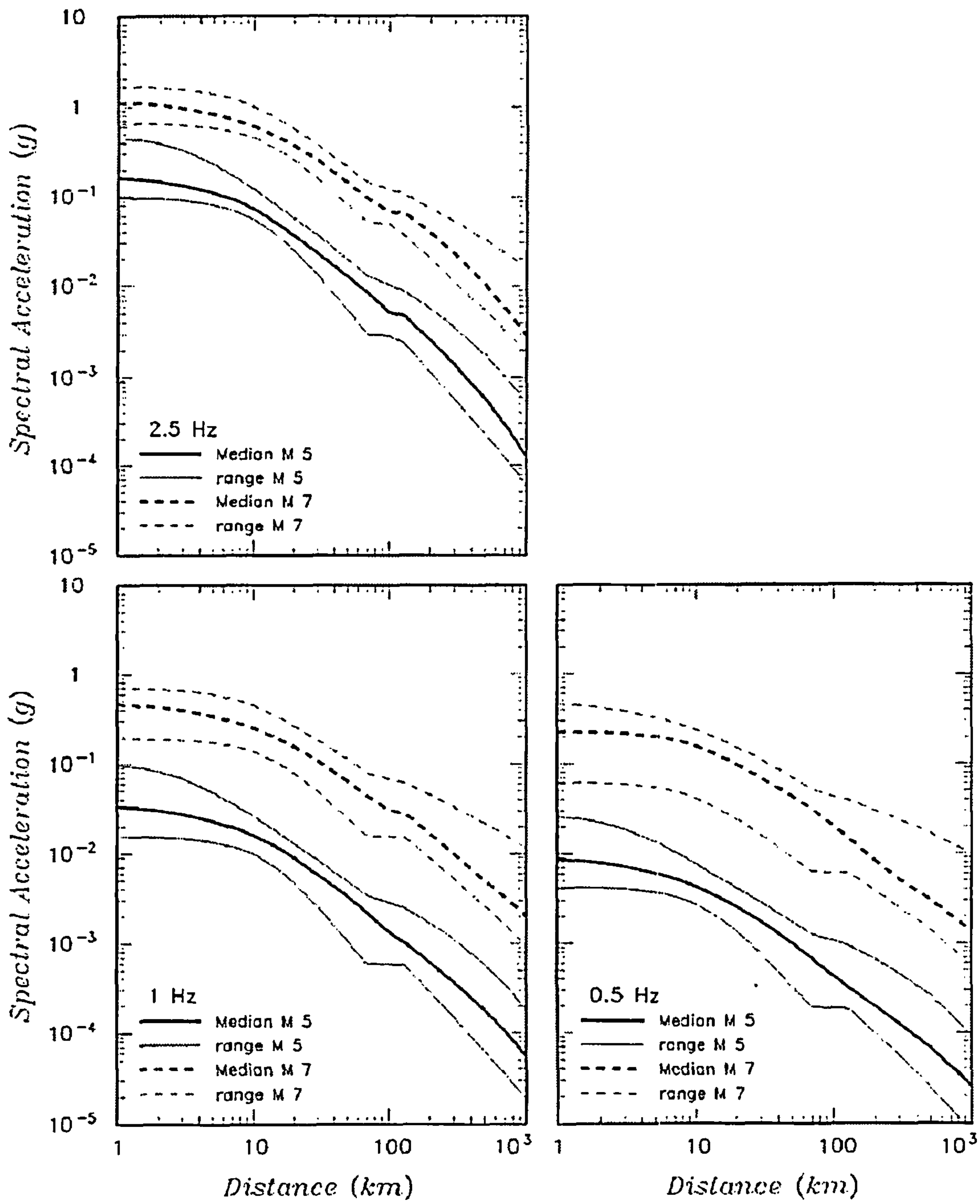

Figure 3-1
Ground Motion Models for General Area Sources in the Mid-Continent for Peak Ground Acceleration and Spectral Acceleration at 25, 10, 5, 2.5, 1.0 and 0.50 Hz. Each Figure Shows the Median and the Range of Ground Motion Estimates for Magnitudes 5 and 7 (continued)

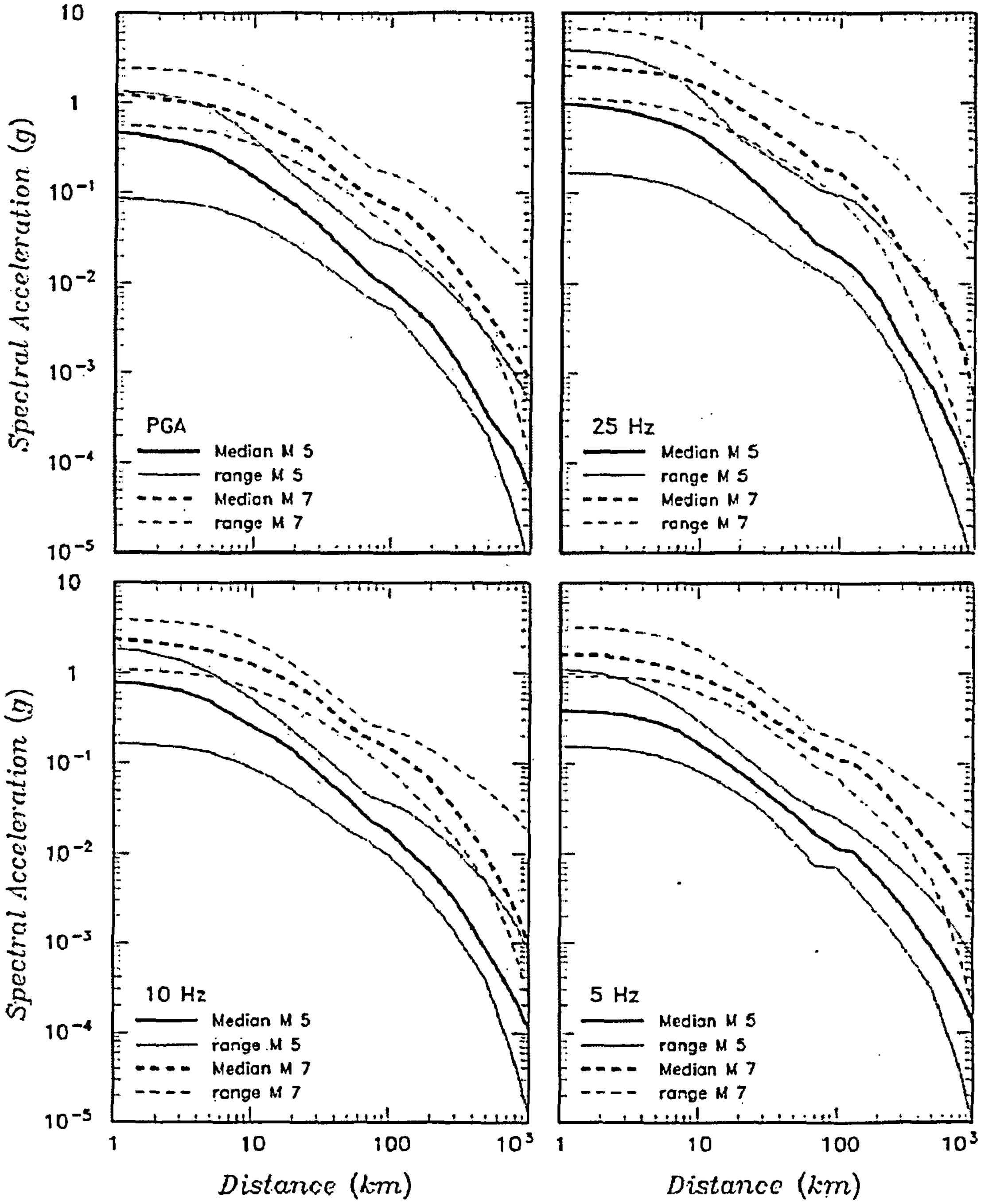

Figure 3-2
Ground Motion Models for Fault Sources and Large Magnitude/Distant Sources In the Mid-Continent for Peak Ground Acceleration and Spectral Acceleration at 25, 10, 5, 2.5, 1.0 and 0.50 Hz. Each Figure Shows the Median and the Range of Ground Motion Estimates for Magnitudes 5 and 7

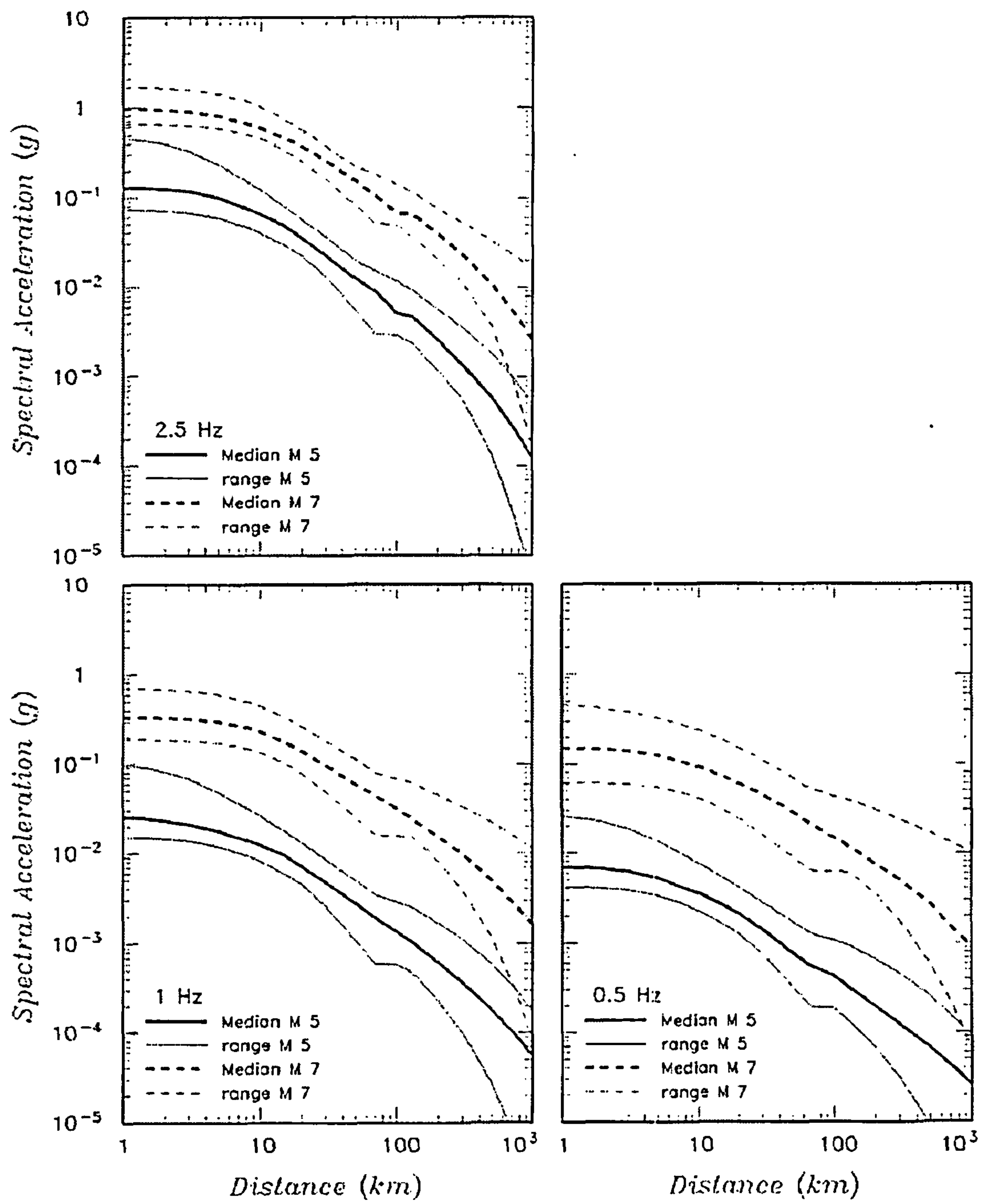

Figure 3-2
Ground Motion Models for Fault Sources and Large Magnitude/Distant Sources In the Mid-Continent for Peak Ground Acceleration and Spectral Acceleration at 25, 10, 5, 2.5, 1.0 and 0.50 Hz. Each Figure Shows the Median and the Range of Ground Motion Estimates for Magnitudes 5 and 7 (continued)

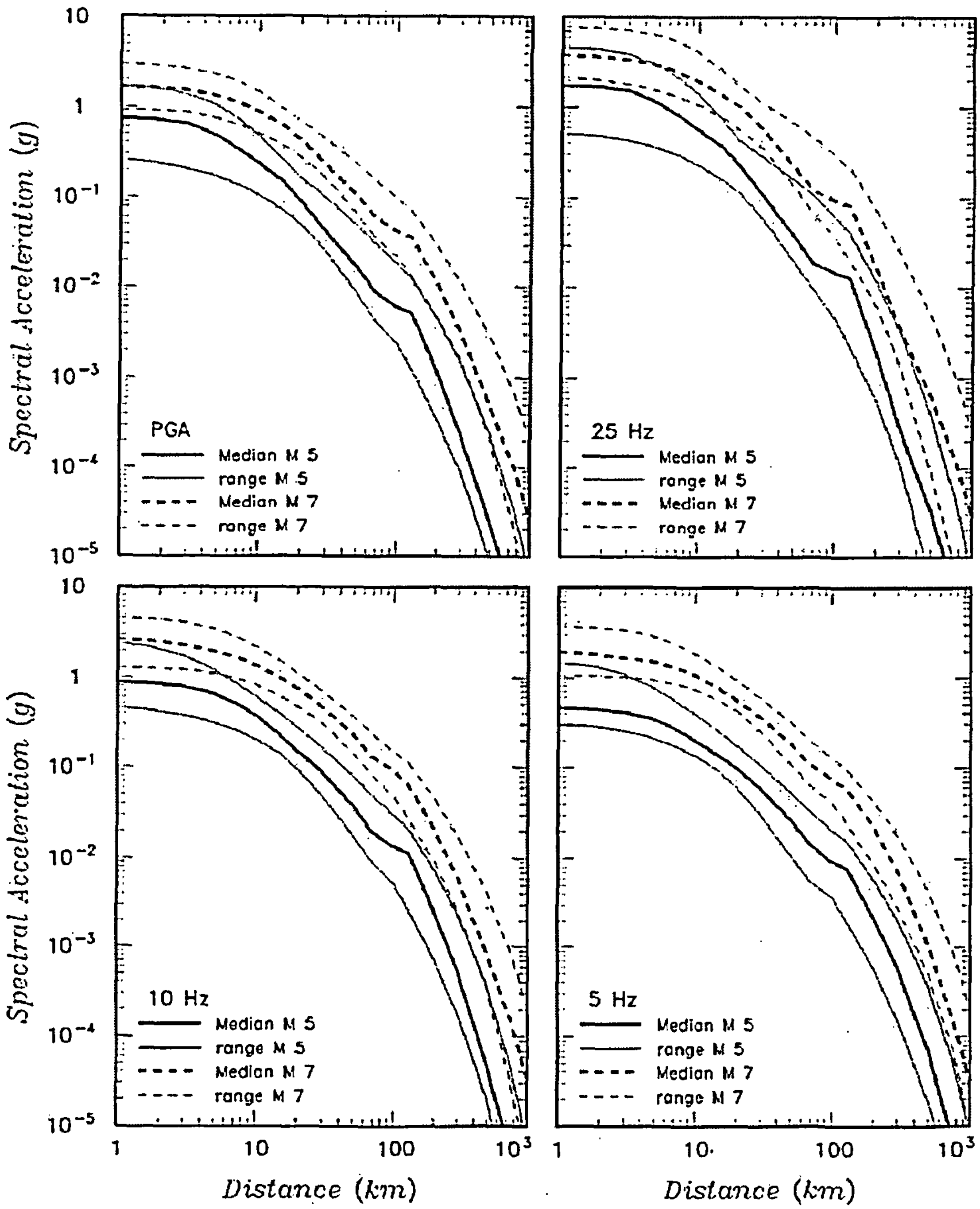

Figure 3-3
Ground Motion Models for General Area sources in the Gulf Region for Peak Ground Acceleration and Spectral Acceleration at 25, 10, 5, 2.5, 1.0 and 0.50 Hz. Each Figure Shows the Median and the Range of Ground Motion Estimates for Magnitudes 5 and 7

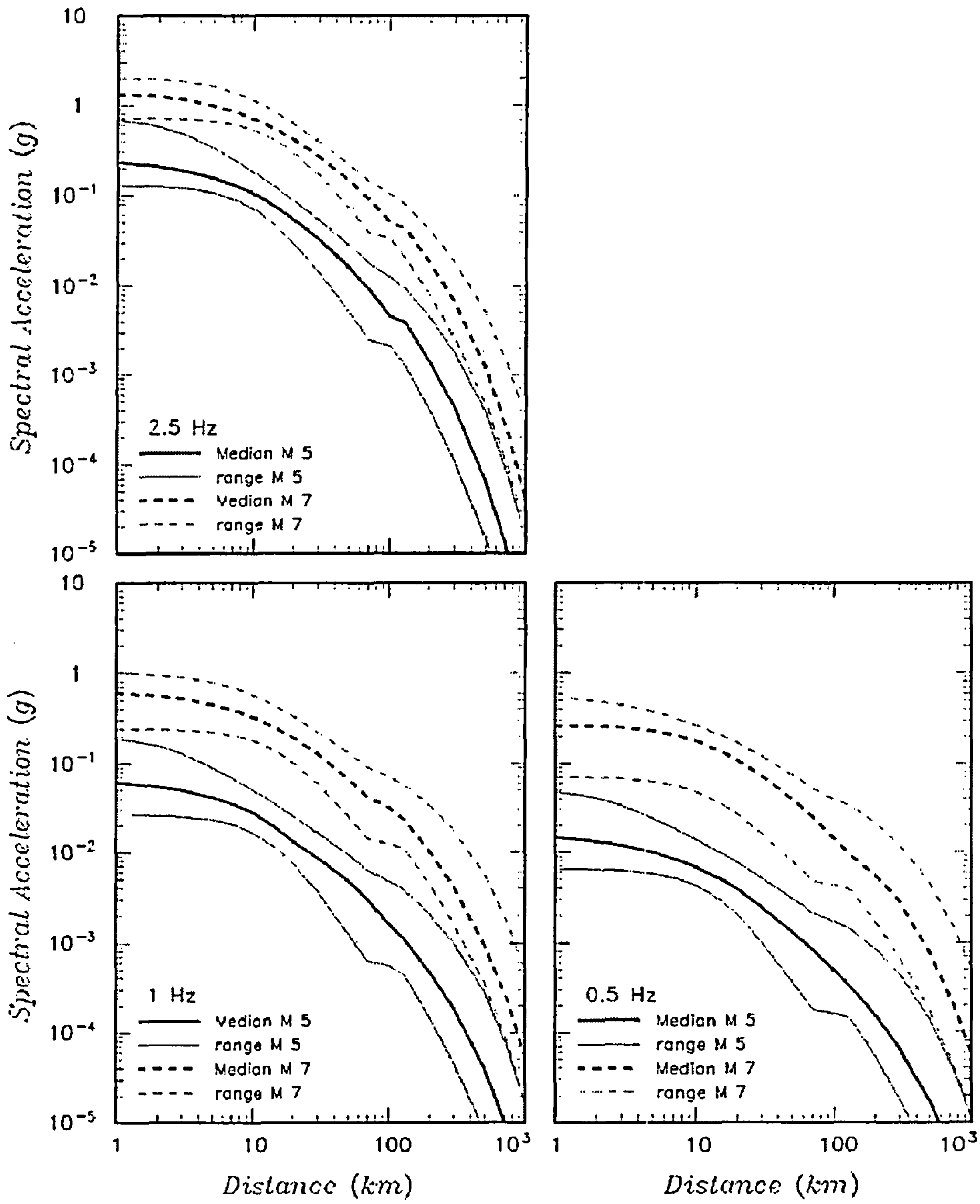

Figure 3-3
Ground Motion Models for General Area sources in the Gulf Region for Peak Ground Acceleration and Spectral Acceleration at 25, 10, 5, 2.5, 1.0 and 0.50 Hz. Each Figure Shows the Median and the Range of Ground Motion Estimates for Magnitudes 5 and 7 (continued)

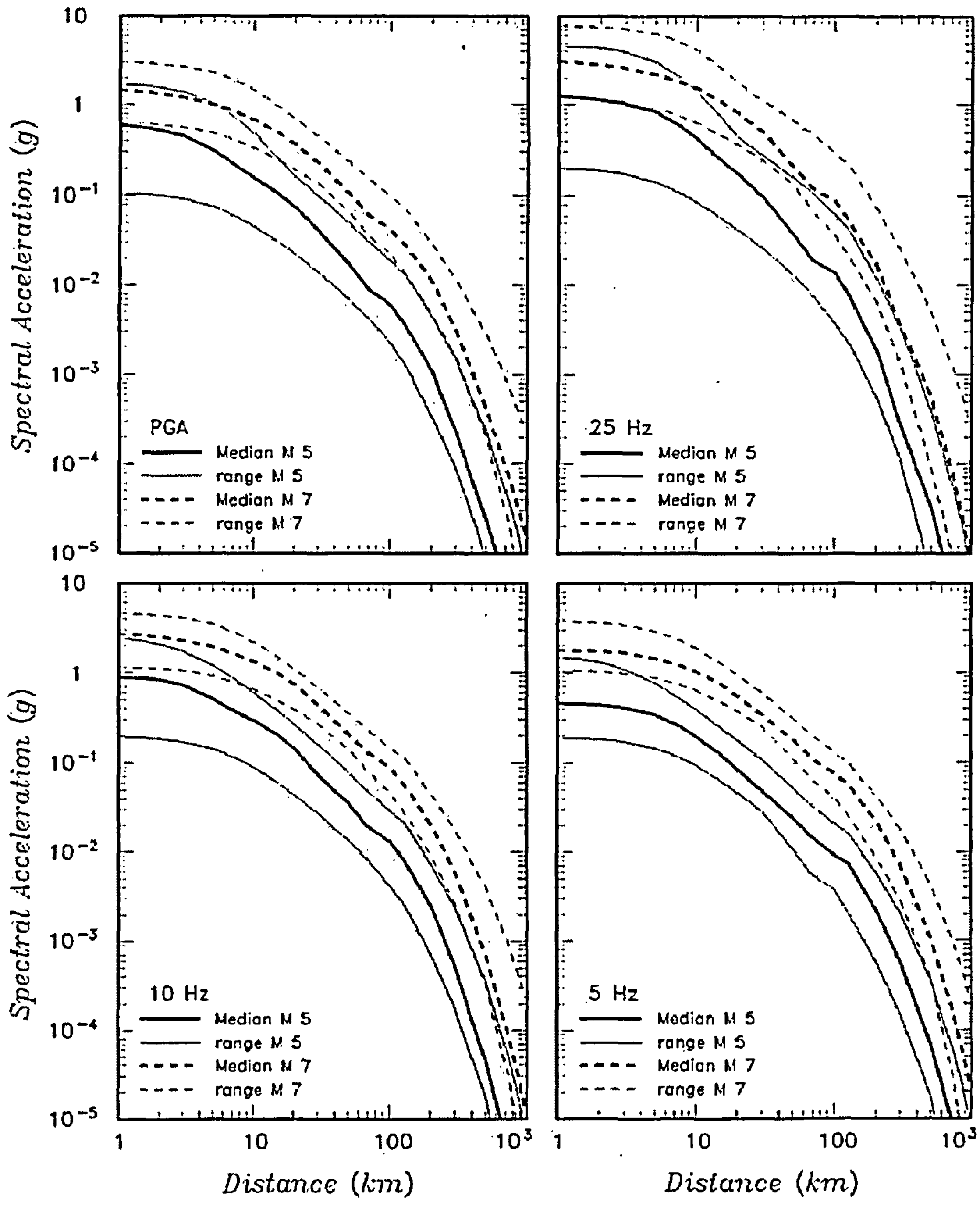

Figure 3-4
Ground Motion Models for Fault sources and Large Magnitude/Distant Sources in the Gulf Region for Peak Ground Acceleration and Spectral Acceleration at 25, 10, 5, 2.5, 1.0 and 0.50 Hz. Each Figure Shows the Median and the Range of Ground Motion Estimates for Magnitudes 5 and 7

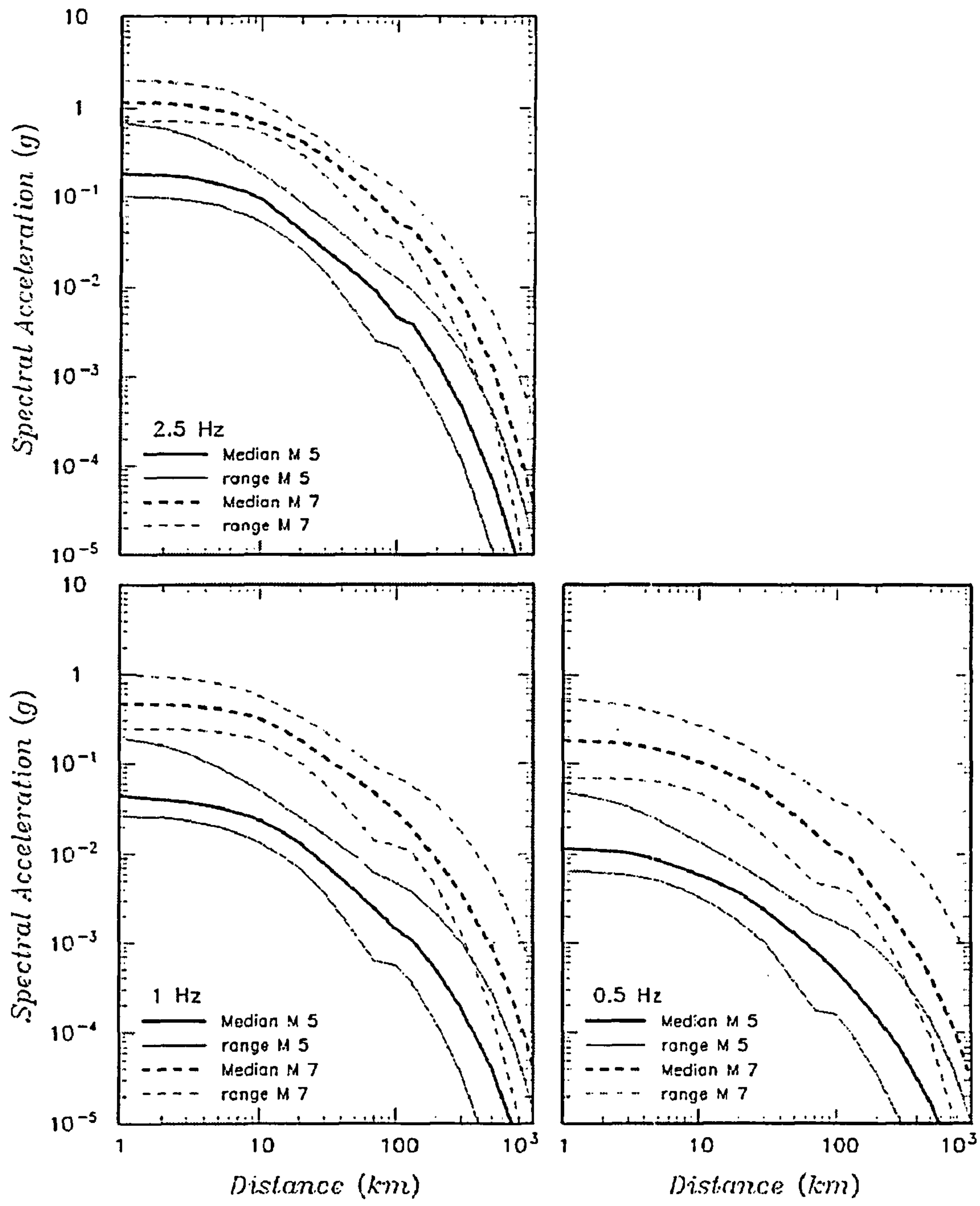

Figure 3-4
Ground Motion Models for Fault sources and Large Magnitude/Distant Sources in the Gulf Region for Peak Ground Acceleration and Spectral Acceleration at 25, 10, 5, 2.5, 1.0 and 0.50 Hz. Each Figure Shows the Median and the Range of Ground Motion Estimates for Magnitudes 5 and 7 (continued)

The median ground motion attenuation model parameters for the Mid-continent and Gulf regions of the CEUS and for each seismic source category and ground motion measure are provided in tables as follows:

Models	Ground Motion Measure	Table No.
Mid-Continent - Ground Motion Models w/Non-Rift Model	Peak Ground Acceleration	3-3
"	S_a(0.5 Hz)	3-4
"	S_a(1.0 Hz)	3-5
"	S_a(2.5 Hz)	3-6
"	S_a(5.0 Hz)	3-7
"	S_a(10.0 Hz)	3-8
"	S_a(25.0 Hz)	3-9
Mid-Continent - Rift Model Only [12]	Peak Ground Acceleration	3-10
"	S_a(0.5 Hz)	3-11
"	S_a(1.0 Hz)	3-12
"	S_a(2.5 Hz)	3-13
"	S_a(5.0 Hz)	3-14
"	S_a(10.0 Hz)	3-15
"	S_a(25.0 Hz)	3-16
Gulf - Ground Motion Models w/Non-Rift Model	Peak Ground Acceleration	3-17
"	S_a(0.5 Hz)	3-18
"	S_a(1.0 Hz)	3-19
"	S_a(2.5 Hz)	3-20
"	S_a(5.0 Hz)	3-21
"	S_a(10.0 Hz)	3-22
"	S_a(25.0 Hz)	3-23
Gulf - Rift Model Only [12]	Peak Ground Acceleration	3-24
"	S_a(0.5 Hz)	3-25
"	S_a(1.0 Hz)	3-26
"	S_a(2.5 Hz)	3-27
"	S_a(5.0 Hz)	3-28
"	S_a(10.0 Hz)	3-29
"	S_a(25.0 Hz)	3-30

Each table identifies the functional form for a model (as defined in Table 3-2) and the model parameters for the alternative estimates of the median ground motion. Appendix C provides plots of median ground motion model results for the Mid-Continent. As discussed later, a probability weight is associated with each alternative model.

Table 3-3
Mid-Continent - Model Parameters for Peak Ground Acceleration w/Non- Rift Model

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2, m_1	m_1/m_2
M1	F1	4.3940E+00	1.1600E-01	-3.1040E+00	1.9780E-01	2.9550E+00	-1.1070E-01							6.0
M2	F1	4.3260E+00	8.6300E-02	-3.0570E+00	2.0460E-01	2.8010E+00	-7.4460E-02							6.0
M3	F1	4.2470E+00	6.4230E-02	-3.0020E+00	2.0930E-01	2.6430E+00	-3.7470E-02							6.0
M4	F2	-2.3910E+00	1.4780E+00	-9.5300E-02	-2.6170E+00	1.7690E-01	-2.1290E+00	1.2150E-01	-3.3950E-03	1.9120E+00	5.6910E-02	70.0	130.0	
M5	F2	-1.5410E+00	1.2520E+00	-7.2560E-02	-2.4920E+00	1.5360E-01	-2.5170E+00	2.0250E-01	-3.0660E-03	1.1170E+00	1.6260E-01	70.0	130.0	
M6	F2	1.6660E-01	8.9280E-01	-4.7890E-02	-2.5580E+00	1.5680E-01	-2.8770E+00	2.7940E-01	-2.7340E-03	5.8780E-01	2.3130E-01	70.0	130.0	
M7	F3	-1.5510E+00	6.0540E-01	-4.8180E-02	-1.1680E+00	2.1700E-01	5.6550E-01	5.2850E-01	-7.3410E-01	-2.9760E-03	2.0620E-04	70.0	130.0	8.5
M8	F3	-8.4330E-01	5.5480E-01	-5.7910E-02	-1.1540E+00	2.5390E-01	5.1650E-01	6.3790E-01	-6.6230E-01	-4.2500E-03	4.3800E-04	70.0	130.0	8.5
M9	F3	-1.1580E-01	5.0490E-01	-6.8000E-02	-1.1450E+00	3.1470E-01	4.5930E-01	7.4730E-01	-5.8910E-01	-5.4970E-03	6.6710E-04	70.0	130.0	8.5
M10	F4	4.7100E-01	5.8720E-01	-7.6580E-01	9.7140E-02	-6.3800E-03	-3.0680E-01	-3.3570E-02			6.401	50.0	6.4	8.5
M11	F4	4.1800E-01	8.0800E-01	-7.2800E-01	6.5100E-02	-6.0100E-03	-3.0100E-01	0.0000E+00			6.000	50.0	6.4	8.5
M12	F4	3.9660E-01	1.0240E+00	-6.9870E-01	3.4040E-02	-5.6460E-03	-2.9270E-01	3.3560E-02			5.752	50.0	6.4	8.5

Table 3-4
Mid-Continent - Model Parameters for S_a(0.50 Hz) w/Non- Rift Model

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2, m_1	m_1/m_2
M1	F1	-7.3230E+00	1.5130E+00	-2.2740E+00	1.2090E-01	2.8430E+00	-3.7770E-01							6.0
M2	F1	-8.5400E+00	1.6070E+00	-1.9460E+00	9.7280E-02	2.6000E+00	-3.4530E-01							6.0
M3	F1	-9.6080E+00	1.6890E+00	-1.6440E+00	7.5900E-02	2.3170E+00	-3.1370E-01							6.0
M4	F2	-1.0310E+01	2.9310E+00	-2.1130E-01	-3.3820E+00	3.1830E-01	-2.3310E+00	1.9230E-01	-4.2910E-04	3.1460E+00	-1.2390E-01	70.0	130.0	
M5	F2	-1.4420E+01	3.1870E+00	-1.6130E-01	-1.7420E+00	9.0270E-02	-1.2900E+00	6.0160E-02	-5.6700E-04	1.0630E+00	1.6440E-01	70.0	130.0	
M6	F2	-1.3430E+01	2.5500E+00	-8.5690E-02	-1.0930E+00	-5.4750E-04	-7.7610E-02	-9.7320E-02	-6.8700E-04	2.8740E-01	2.6410E-01	70.0	130.0	
M7	F3	-2.3910E+00	5.0250E-01	-2.1720E-01	-1.0640E+00	4.0370E-01	4.5730E-01	1.6970E-01	-6.7690E-02	-1.2440E-04	-1.2030E-05	70.0	130.0	8.5
M8	F3	-2.6630E+00	5.5200E-01	-2.2680E-01	-9.7410E-01	2.0410E-01	5.4630E-01	3.6740E-01	-1.4660E-01	-2.3270E-03	2.9570E-04	70.0	130.0	8.5
M9	F3	-2.8650E+00	6.0270E-01	-2.3650E-01	-9.0440E-01	1.0700E-01	6.3470E-01	6.0210E-01	-2.4980E-01	-4.4940E-03	6.0080E-04	70.0	130.0	8.5
M10	F4	-7.7000E-01	6.3450E-01	-8.3930E-01	1.0290E-01	-3.2040E-03	-9.5260E-01	-1.5970E-01			6.568	50.0	6.4	8.5
M11	F4	-9.3200E-01	8.0800E-01	-7.5400E-01	6.5100E-02	-3.1800E-03	-7.0200E-01	-1.4000E-01			6.000	50.0	6.4	8.5
M12	F4	-1.0650E+00	9.7450E-01	-6.7630E-01	2.8630E-02	-3.1600E-03	-4.5030E-01	-1.2030E-01			5.500	50.0	6.4	8.5

Table 3-5
Mid-Continent - Model Parameters for S_a(1.0 Hz) w/ Non-Rift Model

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2, m_1	m_1/m_2
M1	F1	-3.4320E+00	1.0030E+00	2.5410E+00	1.5770E-01	2.7530E+00	-3.1340E-01							6.0
M2	F1	-4.1220E+00	1.0750E+00	2.2370E+00	1.2700E-01	2.6710E+00	-2.6610E-01							6.0
M3	F1	-4.1970E+00	1.0890E+00	2.1020E+00	1.1620E-01	2.6750E+00	-2.3350E-01							6.0
M4	F2	-7.7620E+00	2.3950E+00	-1.3820E-01	-2.9780E+00	2.1180E-01	-2.3470E+00	1.6420E-01	-3.9520E-04	2.4640E+00	1.9150E-02	70.0	130.0	
M5	F2	-1.1460E+01	2.6110E+00	-1.1230E-01	-1.6000E+00	5.9040E-02	-1.4920E+00	8.8120E-02	-8.9860E-04	1.1770E+00	1.5600E-01	70.0	130.0	
M6	F2	-1.1610E+01	2.3710E+00	-8.2740E-02	-1.0530E+00	6.4170E-03	-5.4340E-01	-1.3110E-03	-1.3700E-03	5.1220E-01	2.1580E-01	70.0	130.0	
M7	F3	-2.0360E+00	5.4180E-01	-1.7570E-01	-1.0680E+00	3.1250E-01	4.9290E-01	1.9100E-01	-7.1740E-02	-8.9210E-04	7.8110E-05	70.0	130.0	8.5
M8	F3	-1.3090E+00	4.7380E-01	-2.0000E-01	-1.0350E+00	2.1650E-01	5.3280E-01	4.0590E-01	-1.7230E-01	-2.5920E-03	3.1660E-04	70.0	130.0	8.5
M9	F3	-5.2190E-01	4.0330E-01	-2.2490E-01	-1.0130E+00	1.6010E-01	5.6550E-01	6.4120E-01	-2.8760E-01	-4.2850E-03	5.5580E-04	70.0	130.0	8.5
M10	F4	-4.0650E-02	6.3290E-01	-8.1480E-01	1.0700E-01	-4.0090E-03	-8.8850E-01	-1.1780E-01			6.533	50.0	6.4	8.5
M11	F4	-1.3900E-01	8.0800E-01	-7.3900E-01	6.5100E-02	-3.9800E-03	-6.5900E-01	-1.0200E-01			6.000	50.0	6.4	8.5
M12	F4	-2.0690E-01	9.7580E-01	-6.7130E-01	2.4620E-02	-3.9560E-03	-4.2810E-01	-8.6200E-02			5.564	50.0	6.4	8.5

Table 3-6
Mid-Continent - Model Parameters for S_a(2.5 Hz) w/ Non-Rift Model

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2, m_1	m_1/m_2
M1	F1	9.4170E-01	4.9000E-01	-2.7320E+00	1.7500E-01	2.7870E+00	-1.8610E-01							6.0
M2	F1	4.8150E-01	5.4150E-01	-2.5270E+00	1.5540E-01	2.7030E+00	-1.4680E-01							6.0
M3	F1	4.2120E-01	5.5370E-01	-2.4170E+00	1.4640E-01	2.6670E+00	-1.1180E-01							6.0
M4	F2	-5.7580E+00	2.2270E+00	-1.3680E-01	-2.7870E+00	1.9560E-01	-2.1940E+00	1.4830E-01	-1.0550E-03	2.0260E+00	6.6510E-02	70.0	130.0	
M5	F2	-8.3740E+00	2.4060E+00	-1.1760E-01	-1.7650E+00	7.5560E-02	-1.6660E+00	9.9900E-02	-1.4240E-03	1.1500E+00	1.6430E-01	70.0	130.0	
M6	F2	-9.2170E+00	2.3390E+00	-9.5060E-02	-1.1430E+00	5.1230E-03	-1.0910E+00	4.4740E-02	-1.7780E-03	5.0480E-01	2.3320E-01	70.0	130.0	
M7	F3	-1.2860E+00	5.5510E-01	-1.1740E-01	-1.1220E+00	2.5950E-01	5.2880E-01	3.6470E-01	-2.5460E-01	-1.8170E-03	1.4590E-04	70.0	130.0	8.5
M8	F3	-6.3360E-01	5.0710E-01	-1.3060E-01	-1.1250E+00	2.6260E-01	5.1130E-01	4.9790E-01	-2.6090E-01	-3.0120E-03	3.4580E-04	70.0	130.0	8.5
M9	F3	3.6040E-02	4.5640E-01	-1.4410E-01	-1.1280E+00	2.7040E-01	4.9060E-01	6.2890E-01	-2.6750E-01	-4.2230E-03	5.4880E-04	70.0	130.0	8.5
M10	F4	9.3410E-01	6.1070E-01	-7.9510E-01	1.1040E-01	-5.4340E-03	-5.8730E-01	-7.2070E-02			6.596	50.0	6.4	8.5
M11	F4	8.5100E-01	8.0800E-01	-7.2800E-01	6.5100E-02	-5.3800E-03	-4.2300E-01	-5.1800E-02			6.000	50.0	6.4	8.5
M12	F4	8.1190E-01	9.9620E-01	-6.7270E-01	2.1560E-02	-5.3340E-03	-2.5600E-01	-3.1530E-02			5.589	50.0	6.4	8.5

Table 3-7
Mid-Continent - Model Parameters for S_a(5.0 Hz) w/ Non-Rift Model

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2 m_1	m_1/ m_2
M1	F1	3.0100E+00	2.9620E-01	-2.8430E+00	1.7800E-01	2.8600E+00	-1.3270E-01							6.0
M2	F1	2.7180E+00	3.0930E-01	-2.7160E+00	1.7200E-01	2.7340E+00	-9.4700E-02							6.0
M3	F1	2.4340E+00	3.2410E-01	-2.5880E+00	1.6550E-01	2.6000E+00	-5.6730E-02							6.0
M4	F2	-3.6250E+00	1.9050E+00	-1.2610E-01	-2.7790E+00	2.0300E-01	-1.5120E+00	5.3850E-02	-2.1030E-03	1.9870E+00	6.0680E-02	70.0	130.0	
M5	F2	-5.2530E+00	1.9110E+00	-9.5670E-02	-1.8900E+00	8.8560E-02	-1.7710E+00	1.1030E-01	-2.1860E-03	1.1300E+00	1.6780E-01	70.0	130.0	
M6	F2	-5.5950E+00	1.7030E+00	-5.8740E-02	-1.2460E+00	5.0680E-03	-2.0010E+00	1.6260E-01	-2.2600E-03	3.8730E-01	2.6100E-01	70.0	130.0	
M7	F3	-1.3820E+00	5.9960E-01	-6.0130E-02	-1.1160E+00	1.8560E-01	5.9320E-01	3.9770E-01	-5.4180E-01	-2.4260E-03	1.8790E-04	70.0	130.0	8.5
M8	F3	-4.9610E-01	5.5510E-01	-8.1040E-02	-1.1660E+00	2.8910E-01	5.0310E-01	5.6420E-01	-4.1830E-01	-3.6150E-03	3.8450E-04	70.0	130.0	8.5
M9	F3	3.3330E-01	5.1280E-01	-1.0110E-01	-1.2050E+00	4.3100E-01	4.1760E-01	7.0060E-01	-2.7680E-01	-4.8200E-03	5.8390E-04	70.0	130.0	8.5
M10	F4	1.0680E+00	5.8250E-01	-7.8640E-01	1.1210E-01	-6.1380E-03	-3.9020E-01	-2.6940E-02			6.590	50.0	6.4	8.5
M11	F4	9.7800E-01	8.0800E-01	-7.2800E-01	6.5100E-02	-6.0100E-03	-3.0100E-01	0.0000E+00			6.000	50.0	6.4	8.5
M12	F4	9.4350E-01	1.0240E+00	-6.8440E-01	1.9950E-02	-5.8930E-03	-2.0780E-01	2.6930E-02			5.668	50.0	6.4	8.5

Table 3-8
Mid-Continent - Model Parameters for S_a(10.0 Hz) w/ Non-Rift Model

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2 m_1	m_1/ m_2
M1	F1	4.8730E+00	1.8500E-01	-3.0330E+00	1.8050E-01	3.0450E+00	-1.0660E-01							6.0
M2	F1	4.4970E+00	1.6400E-01	-2.9410E+00	1.8600E-01	2.8470E+00	-7.5060E-02							6.0
M3	F1	4.1150E+00	1.5690E-01	-2.8440E+00	1.9410E-01	2.6370E+00	-4.3530E-02							6.0
M4	F2	-3.2650E+00	1.7580E+00	-1.0460E-01	-2.3530E+00	1.4310E-01	-1.4600E+00	6.6850E-03	-3.1510E-03	1.5780E+00	1.1540E-01	70.0	130.0	
M5	F2	-2.9850E+00	1.5450E+00	-7.6380E-02	-2.0330E+00	9.9190E-02	-2.0720E+00	1.2850E-01	-2.8790E-03	1.0530E+00	1.8380E-01	70.0	130.0	
M6	F2	-2.0980E+00	1.2400E+00	-4.7510E-02	-1.8560E+00	7.5930E-02	-2.6630E+00	2.4730E-01	-2.6060E-03	6.8830E-01	2.2840E-01	70.0	130.0	
M7	F3	-1.7220E+00	6.3390E-01	-2.3970E-02	-1.0700E+00	1.3970E-01	6.2230E-01	2.7320E-01	-9.0500E-01	-2.8470E-03	2.2210E-04	70.0	130.0	8.5
M8	F3	-4.8480E-01	5.6200E-01	-5.0110E-02	-1.1490E+00	2.6630E-01	5.1310E-01	5.9070E-01	-6.5090E-01	-4.2240E-03	4.2670E-04	70.0	130.0	8.5
M9	F3	6.4580E-01	4.9490E-01	-7.4200E-02	-1.2100E+00	4.3870E-01	4.2180E-01	8.7070E-01	-3.7490E-01	-5.6390E-03	6.3640E-04	70.0	130.0	8.5
M10	F4	1.1680E+00	5.5650E-01	-7.6950E-01	1.0520E-01	-6.1970E-03	-3.4340E-01	-3.8320E-02			6.449	50.0	6.4	8.5
M11	F4	1.0710E+00	8.0800E-01	-7.2800E-01	6.5100E-02	-6.0100E-03	-3.0100E-01	0.0000E+00			6.000	50.0	6.4	8.5
M12	F4	1.0190E+00	1.0530E+00	-6.9880E-01	2.6330E-02	-5.8320E-03	-2.5500E-01	3.8320E-02			5.776	50.0	6.4	8.5

Table 3-9
Mid-Continent - Model Parameters for S_a(25.0 Hz) w/ Non-Rift Model

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2, m_1	m_1/m_2
M1	F1	5.7840E+00	1.0600E-01	-3.1790E+00	1.8960E-01	3.0670E+00	-9.5980E-02							6.0
M2	F1	5.6820E+00	7.0260E-02	-3.1350E+00	2.0170E-01	2.9240E+00	-6.7690E-02							6.0
M3	F1	5.5570E+00	4.5260E-02	-3.0820E+00	2.1140E-01	2.7750E+00	-3.8950E-02							6.0
M4	F2	-4.7040E+00	1.9630E+00	-8.5880E-02	-1.6650E+00	1.4990E-02	-3.1130E+00	1.0530E-01	-2.9140E-03	1.1470E+00	1.9400E-01	70.0	130.0	
M5	F2	-1.1480E+00	1.3890E+00	-7.8810E-02	-2.3760E+00	1.3130E-01	-3.1710E+00	1.9910E-01	-2.7920E-03	1.1460E+00	1.5770E-01	70.0	130.0	
M6	F2	1.6540E+00	9.4990E-01	-6.7330E-02	-2.8600E+00	2.0100E-01	-3.2440E+00	2.9560E-01	-2.6570E-03	9.8100E-01	1.6100E-01	70.0	130.0	
M7	F3	3.1420E-02	5.7480E-01	-4.7220E-02	-1.3180E+00	4.4920E-01	4.6500E-01	6.2580E-01	1.0850E+00	-4.1230E-03	2.1670E-04	70.0	130.0	8.5
M8	F3	-3.1550E-01	5.6900E-01	-4.6770E-02	-1.0790E+00	2.0390E-01	5.4730E-01	5.9070E-01	-8.8070E-01	-5.1320E-03	4.4300E-04	70.0	130.0	8.5
M9	F3	-3.8730E-01	5.5200E-01	-4.8470E-02	-8.9010E-01	9.3290E-02	6.2540E-01	6.4650E-01	-7.4130E-01	-6.1330E-03	6.7650E-04	70.0	130.0	8.5
M10	F4	1.2690E+00	5.7790E-01	-7.9390E-01	8.5320E-02	-5.9670E-03	-3.7670E-01	-4.2720E-02			6.514	50.0	6.4	8.5
M11	F4	1.0990E+00	8.0800E-01	-7.2800E-01	6.5100E-02	-6.0100E-03	-3.0100E-01	0.0000E+00			6.000	50.0	6.4	8.5
M12	F4	9.4810E-01	1.0340E+00	-6.6720E-01	4.5610E-02	-6.0560E-03	-2.2440E-01	4.2730E-02			5.533	50.0	6.4	8.5

Table 3-10
Mid-Continent - Model Parameters for Peak Ground Acceleration – Rift Model Only

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2 m_1	m_1/ m_2
M10	F4	3.0590E-01	5.8100E-01	-7.2050E-01	1.1870E-01	-5.3530E-03	-4.8200E-01	-3.3570E-02			6.508	50.0	6.4	8.5
M11	F4	2.3900E-01	8.0500E-01	-6.7900E-01	8.6100E-02	-4.9800E-03	-4.7700E-01	0.0000E+00			6.000	50.0	6.4	8.5
M12	F4	2.0530E-01	1.0220E+00	-6.4630E-01	5.4750E-02	-4.6130E-03	-4.6980E-01	3.3560E-02			5.661	50.0	6.4	8.5

Table 3-11
Mid-Continent - Model Parameters for S_a(0.50 Hz) – Rift Model Only

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2 m_1	m_1/ m_2
M10	F4	-9.6540E-01	6.2890E-01	-8.1450E-01	1.2440E-01	-2.2340E-03	-1.1970E+00	-1.5970E-01			6.612	50.0	6.4	8.5
M11	F4	-1.1320E+00	8.0500E-01	-7.2800E-01	8.6100E-02	-2.2100E-03	-9.4600E-01	-1.4000E-01			6.000	50.0	6.4	8.5
M12	F4	-1.2710E+00	9.7360E-01	-6.4880E-01	4.9250E-02	-2.1900E-03	-6.9450E-01	-1.2030E-01			5.447	50.0	6.4	8.5

Table 3-12
Mid-Continent - Model Parameters for S_a(1.0 Hz) – Rift Model Only

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2 m_1	m_1/ m_2
M10	F4	-2.0310E-01	6.2690E-01	-7.7320E-01	1.2850E-01	-3.6490E-03	-9.8450E-01	-1.1780E-01			6.595	50.0	6.4	8.5
M11	F4	-3.0700E-01	8.0500E-01	-6.9600E-01	8.6100E-02	-3.6200E-03	-7.5500E-01	-1.0200E-01			6.000	50.0	6.4	8.5
M12	F4	-3.8110E-01	9.7480E-01	-6.2660E-01	4.5260E-02	-3.5940E-03	-5.2450E-01	-8.6190E-02			5.497	50.0	6.4	8.5

Table 3-13
Mid-Continent - Model Parameters for S_a(2.5 Hz) – Rift Model Only

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2 m_1	m_1/ m_2
M10	F4	7.1650E-01	6.0340E-01	-7.3410E-01	1.3220E-01	-4.7350E-03	-7.2100E-01	-7.2070E-02			6.716	50.0	6.4	8.5
M11	F4	6.2200E-01	8.0500E-01	-6.6400E-01	8.6100E-02	-4.6800E-03	-5.5700E-01	-5.1800E-02			6.000	50.0	6.4	8.5
M12	F4	5.7320E-01	9.9520E-01	-6.0600E-01	4.2180E-02	-4.6320E-03	-3.9080E-01	-3.1530E-02			5.484	50.0	6.4	8.5

Table 3-14
Mid-Continent - Model Parameters for S_a(5.0 Hz) – Rift Model Only

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2 m_1	m_1/ m_2
M10	F4	8.9730E-01	5.7510E-01	-7.4130E-01	1.3390E-01	-5.1100E-03	-5.6560E-01	-2.6940E-02			6.714	50.0	6.4	8.5
M11	F4	7.9300E-01	8.0500E-01	-6.7900E-01	8.6100E-02	-4.9800E-03	-4.7700E-01	0.0000E+00			6.000	50.0	6.4	8.5
M12	F4	7.4580E-01	1.0230E+00	-6.3190E-01	4.0640E-02	-4.8600E-03	-3.8490E-01	2.6930E-02			5.566	50.0	6.4	8.5

Table 3-15
Mid-Continent - Model Parameters for S_a(10.0 Hz) – Rift Model Only

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2, m_1	m_1/ m_2
M10	F4	1.0010E+00	5.4970E-01	-7.2470E-01	1.2690E-01	-5.1700E-03	-5.1850E-01	-3.8320E-02			6.569	50.0	6.4	8.5
M11	F4	8.8800E-01	8.0500E-01	-6.7900E-01	8.6100E-02	-4.9800E-03	-4.7700E-01	0.0000E+00			6.000	50.0	6.4	8.5
M12	F4	8.2250E-01	1.0510E+00	-6.4610E-01	4.7070E-02	-4.7990E-03	-4.3220E-01	3.8330E-02			5.679	50.0	6.4	8.5

Table 3-16
Mid-Continent - Model Parameters for S_a(25.0 Hz) – Rift Model Only

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2, m_1	m_1/ m_2
M10	F4	1.1050E+00	5.7180E-01	-7.4720E-01	1.0690E-01	-4.9390E-03	-5.5240E-01	-4.2730E-02			6.599	50.0	6.4	8.5
M11	F4	9.2600E-01	8.0500E-01	-6.7900E-01	8.6100E-02	-4.9800E-03	-4.7700E-01	0.0000E+00			6.000	50.0	6.4	8.5
M12	F4	7.6740E-01	1.0340E+00	-6.1610E-01	6.6150E-02	-5.0240E-03	-4.0080E-01	4.2730E-02			5.448	50.0	6.4	8.5

Table 3-17
Gulf - Model Parameters for Peak Ground Acceleration w/ Non-Rift Model

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2, m_1	m_1/m_2
M1	F1a	5.8640E+00	8.4660E-02	-3.4750E+00	2.0430E-01	3.0090E+00	-1.3190E-01	-6.8910E-03	5.0910E-04					6.0
M2	F1a	5.2820E+00	1.4820E-01	-3.1860E+00	1.7300E-01	2.9130E+00	-7.4840E-02	-6.8090E-03	5.4140E-04					6.0
M3	F1a	4.8520E+00	1.9510E-01	-2.9290E+00	1.4530E-01	2.8190E+00	-1.7770E-02	-6.6410E-03	5.6290E-04					6.0
M4	F2	-2.3520E+00	1.6950E+00	-1.1380E-01	-2.8450E+00	1.7480E-01	-4.4780E+00	3.4860E-01	-5.5810E-03	1.9490E+00	4.8680E-02	70.0	130.0	
M5	F2	-1.1580E+00	1.2840E+00	-6.9720E-02	-2.5280E+00	1.2380E-01	-4.4960E+00	3.7580E-01	-5.1740E-03	1.2250E+00	1.4840E-01	70.0	130.0	
M6	F2	7.2340E-01	7.4130E-01	-2.0250E-02	-2.3210E+00	8.7520E-02	-4.4970E+00	4.0060E-01	-4.7660E-03	6.1830E-01	2.3200E-01	70.0	130.0	
M7	F3	-1.4180E-01	4.1530E-01	-7.3380E-02	-1.2150E+00	2.8820E-01	4.9160E-01	1.2690E-01	-9.3530E-01	-9.5630E-03	8.2790E-04	70.0	130.0	8.5
M8	F3	-1.2680E-01	4.4190E-01	-6.1860E-02	-1.1640E+00	3.1510E-01	4.4780E-01	1.4170E-01	-7.5890E-01	-9.9160E-03	9.2660E-04	70.0	130.0	8.5
M9	F3	-8.6080E-02	4.7570E-01	-5.0240E-02	-1.1310E+00	3.7810E-01	3.9260E-01	1.8000E-01	-5.9230E-01	-1.0180E-02	1.0140E-03	70.0	130.0	8.5
M10	F4	6.3270E-01	3.9080E-01	-8.1710E-01	1.4330E-01	-9.3610E-03	-7.3470E-01	-5.0040E-02			5.241	50.0	6.4	8.5
M11	F4	5.1070E-01	7.0700E-01	-7.5940E-01	9.8180E-02	-8.8310E-03	-7.2390E-01	2.6040E-06			4.704	50.0	6.4	8.5
M12	F4	4.3560E-01	1.0130E+00	-7.1450E-01	5.5140E-02	-8.3120E-03	-7.0940E-01	5.0040E-02			4.360	50.0	6.4	8.5

Table 3-18
Gulf - Model Parameters for S_a(0.50 Hz) w/Non-Rift Model

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2, m_1	m_1/m_2
M1	F1a	-4.1020E+00	1.1660E+00	-2.8460E+00	1.8030E-01	2.9580E+00	-3.8840E-01	-3.1750E-03	-5.7830E-05					6.0
M2	F1a	-7.1630E+00	1.4120E+00	-1.9630E+00	1.0430E-01	2.5420E+00	-3.4530E-01	-3.8390E-03	3.1450E-05					6.0
M3	F1a	-9.1760E+00	1.5620E+00	-1.2860E+00	4.7490E-02	2.0390E+00	-3.0200E-01	-4.0420E-03	7.4970E-05					6.0
M4	F2	-6.4810E+00	2.5470E+00	-2.1380E-01	-4.1360E+00	3.9080E-01	-2.6310E+00	1.9200E-01	-3.6780E-03	3.2040E+00	-1.0140E-01	70.0	130.0	
M5	F2	-1.3210E+01	3.0590E+00	-1.6010E-01	-1.7070E+00	7.7390E-02	-1.5260E+00	8.7390E-02	-3.9320E-03	9.2650E-01	1.9260E-01	70.0	130.0	
M6	F2	-1.1690E+01	2.2630E+00	-8.2780E-02	-1.0530E+00	7.9440E-03	-1.8790E-01	-5.1460E-02	-4.1590E-03	3.6050E-01	2.3780E-01	70.0	130.0	
M7	F3	-4.5410E-01	3.0470E-01	-2.4310E-01	-1.1590E+00	3.8770E-01	4.7590E-01	1.2580E-01	-1.2190E-01	-5.5230E-03	2.8520E-04	70.0	130.0	8.5
M8	F3	-1.3250E+00	3.8640E-01	-2.2600E-01	-9.7900E-01	1.9240E-01	5.5570E-01	3.4480E-01	-1.5740E-01	-6.2010E-03	3.6520E-04	70.0	130.0	8.5
M9	F3	-2.1100E+00	4.7010E-01	-2.0830E-01	-8.2520E-01	8.3830E-02	6.5250E-01	6.1040E-01	-2.2400E-01	-6 8570E-03	4.4550E-04	70.0	130.0	8.5
M10	F4	-3.3680E-01	3.6870E-01	-8.8800E-01	1.2670E-01	-6.6280E-03	-1.0970E+00	-1.7240E-01			6.834	50.0	6.4	8.5
M11	F4	-6.6050E-01	6.0620E-01	-7.5570E-01	7.5750E-02	-6.6180E-03	-7.2970E-01	-1.4000E-01			5.964	50.0	6.4	8.5
M12	F4	-9.3190E-01	8.3010E-01	-6.3720E-01	2.7400E-02	-6.6140E-03	-3.6050E-01	-1.0760E-01			5.175	50.0	6.4	8.5

Table 3-19
Gulf - Model Parameters for S_a(1.0 Hz) w/ Non-Rift Model

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2, m_1	m_1/m_2
M1	F1a	3.3500E-01	6.5000E-01	-3.1920E+00	2.1820E-01	2.9880E+00	-3.1590E-01	-3.5860E-03	-3.7470E-05					6.0
M2	F1a	-2.8520E+00	9.3290E-01	-2.2320E+00	1.2750E-01	2.6570E+00	-2.6380E-01	-4.5050E-03	7.2190E-05					6.0
M3	F1a	-5.1230E+00	1.1150E+00	-1.4680E+00	5.9880E-02	2.2190E+00	-2.1400E-01	-4.8950E-03	1.1280E-04					6.0
M4	F2	-7.0770E+00	2.5880E+00	-1.5180E-01	-3.0850E+00	1.8640E-01	-2.8920E+00	2.1160E-01	-4.1790E-03	2.2270E+00	7.8590E-02	70.0	130.0	
M5	F2	-1.0410E+01	2.5150E+00	-1.1100E-01	-1.5430E+00	4.5810E-02	-1.8120E+00	1.2450E-01	-4.6710E-03	1.0400E+00	1.7850E-01	70.0	130.0	
M6	F2	-1.0000E+01	2.0930E+00	-7.2640E-02	-9.4970E-01	2.0730E-05	-6.2060E-01	2.1870E-02	-5.1120E-03	4.5760E-01	2.1340E-01	70.0	130.0	
M7	F3	-1.1510E-01	3.7270E-01	-1.9930E-01	-1.1740E+00	3.3190E-01	4.9890E-01	1.5550E-01	-1.4620E-01	-6.9120E-03	4.0760E-04	70.0	130.0	8.5
M8	F3	-3.3650E-02	3.3680E-01	-1.9970E-01	-1.0350E+00	2.1030E-01	5.3640E-01	3.6330E-01	-1.8430E-01	-7.0440E-03	4.1270E-04	70.0	130.0	8.5
M9	F3	1.3330E-01	3.0410E-01	-2.0020E-01	-9.2320E-01	1.3400E-01	5.7250E-01	6.1360E-01	-2.4660E-01	-7.1170E-03	4.1190E-04	70.0	130.0	8.5
M10	F4	5.2230E-01	3.8420E-01	-8.5930E-01	1.3500E-01	-7.8460E-03	-1.0370E+00	-1.3090E-01			6.826	50.0	6.4	8.5
M11	F4	2.6760E-01	6.4050E-01	-7.3980E-01	7.6680E-02	-7.8310E-03	-6.9680E-01	-1.0200E-01			5.984	50.0	6.4	8.5
M12	F4	6.7240E-02	8.8170E-01	-6.3460E-01	2.1270E-02	-7.8230E-03	-3.5440E-01	-7.3080E-02			5.270	50.0	6.4	8.5

Table 3-20
Gulf - Model Parameters for S_a(2.5 Hz) w/ Non-Rift Model

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2, m_1	m_1/m_2
M1	F1a	4.4960E+00	1.7270E-01	-3.4460E+00	2.3970E-01	3.0400E+00	-1.9510E-01	-4.8820E-03	1.0100E-04					6.0
M2	F1a	1.4190E+00	4.7020E-01	-2.5400E+00	1.4860E-01	2.7620E+00	-1.4660E-01	-5.8730E-03	2.2040E-04					6.0
M3	F1a	-7.8080E-01	6.7140E-01	-1.8120E+00	7.7690E-02	2.4480E+00	-9.8050E-02	-6.4190E-03	2.8530E-04					6.0
M4	F2	-6.7390E+00	2.6510E+00	-1.4890E-01	-2.5900E+00	1.2100E-01	-3.3270E+00	2.6540E-01	-5.0480E-03	1.6160E+00	1.5930E-01	70.0	130.0	
M5	F2	-8.9480E+00	2.5420E+00	-1.0640E-01	-1.3300E+00	-1.4430E-02	-2.4550E+00	1.8270E-01	-5.3350E-03	6.5830E-01	2.6160E-01	70.0	130.0	
M6	F2	-8.7070E+00	2.1810E+00	-7.1610E-02	-7.5330E-01	-6.2390E-02	-1.5080E+00	8.9380E-02	-5.6170E-03	1.3860E-01	3.0170E-01	70.0	130.0	
M7	F3	2.1260E-01	4.1950E-01	-1.4040E-01	-1.2180E+00	3.0730E-01	5.1510E-01	2.3220E-01	-3.2580E-01	-8.5450E-03	5.6130E-04	70.0	130.0	8.5
M8	F3	2.4870E-01	3.9850E-01	-1.3170E-01	-1.1130E+00	2.7470E-01	4.9900E-01	3.4620E-01	-2.9310E-01	-8.4980E-03	5.6320E-04	70.0	130.0	8.5
M9	F3	3.3890E-01	3.8200E-01	-1.2320E-01	-1.0280E+00	2.6500E-01	4.7070E-01	4.8350E-01	-2.6940E-01	-8.3800E-03	5.5640E-04	70.0	130.0	8.5
M10	F4	1.3080E+00	3.7560E-01	-8.3410E-01	1.5060E-01	-9.6030E-03	-7.8640E-01	-8.5150E-02			6.879	50.0	6.4	8.5
M11	F4	1.0810E+00	6.7200E-01	-7.2680E-01	8.4840E-02	-9.5470E-03	-5.3900E-01	-5.1790E-02			5.924	50.0	6.4	8.5
M12	F4	9.3290E-01	9.4830E-01	-6.4060E-01	2.2920E-02	-9.5040E-03	-2.8770E-01	-1.8420E-02			5.265	50.0	6.4	8.5

Table 3-21
Gulf - Model Parameters for S_A(5.0 Hz) w/ Non-Rift Model

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2, m_1	m_1/m_2
M1	F1a	5.7060E+00	7.9300E-02	-3.4350E+00	2.2710E-01	3.0420E+00	-1.5080E-01	-6.1440E-03	2.5660E-04					6.0
M2	F1a	3.5320E+00	3.0790E-01	-2.7310E+00	1.5040E-01	2.8600E+00	-9.5050E-02	-7.0310E-03	3.9170E-04					6.0
M3	F1a	1.8950E+00	4.7370E-01	-2.1390E+00	8.7070E-02	2.6690E+00	-3.9350E-02	-7.6220E-03	4.8850E-04					6.0
M4	F2	-3.5790E+00	2.0500E+00	-1.4160E-01	-2.9020E+00	2.0720E-01	-3.3560E+00	2.5070E-01	-5.8690E-03	1.9960E+00	5.9910E-02	70.0	130.0	
M5	F2	-4.9990E+00	1.8950E+00	-9.4160E-02	-1.8060E+00	6.8890E-02	-3.0690E+00	2.3440E-01	-5.8560E-03	1.1060E+00	1.6780E-01	70.0	130.0	
M6	F2	-4.7890E+00	1.4800E+00	-3.9960E-02	-1.0370E+00	-2.8090E-02	-2.7440E+00	2.1260E-01	-5.8310E-03	3.4550E-01	2.5970E-01	70.0	130.0	
M7	F3	7.4370E-02	4.4760E-01	-8.7410E-02	-1.1920E+00	2.4490E-01	5.5290E-01	1.6480E-01	-6.3290E-01	-9.5030E-03	6.7860E-04	70.0	130.0	8.5
M8	F3	2.8580E-01	4.4100E-01	-8.3870E-02	-1.1450E+00	3.3450E-01	4.6620E-01	2.5980E-01	-4.7770E-01	-9.7450E-03	7.2960E-04	70.0	130.0	8.5
M9	F3	4.7790E-01	4.4980E-01	-7.9380E-02	-1.1170E+00	5.1990E-01	3.6230E-01	3.6310E-01	-3.1560E-01	-9.8450E-03	7.6090E-04	70.0	130.0	8.5
M10	F4	1.3290E+00	3.5220E-01	-8.2120E-01	1.5960E-01	-1.0270E-02	-6.6670E-01	-4.1290E-02			6.601	50.0	6.4	8.5
M11	F4	1.1140E+00	6.8710E-01	-7.2780E-01	9.0640E-02	-1.0090E-02	-5.3280E-01	-9.9470E-08			5.650	50.0	6.4	8.5
M12	F4	9.9870E-01	9.9970E-01	-6.6120E-01	2.6030E-02	-9.9320E-03	-3.9250E-01	4.1300E-02			5.139	50.0	6.4	8.5

Table 3-22
Gulf - Model Parameters for S_A(10.0 Hz) w/ Non-Rift Model

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2, m_1	m_1/m_2
M1	F1a	7.0890E+00	8.6250E-02	-3.5420E+00	2.0360E-01	3.1960E+00	-1.3380E-01	-6.9030E-03	4.2720E-04					6.0
M2	F1a	5.6910E+00	2.2540E-01	-3.0510E+00	1.5150E-01	3.0620E+00	-7.5060E-02	-7.5670E-03	5.5940E-04					6.0
M3	F1a	4.6380E+00	3.2710E-01	-2.6310E+00	1.0730E-01	2.9310E+00	-1.6290E-02	-8.0520E-03	6.6960E-04					6.0
M4	F2	-3.2860E+00	1.9480E+00	-1.2600E-01	-2.5790E+00	1.5750E-01	-3.7530E+00	2.2650E-01	-5.9610E-03	1.7390E+00	8.6970E-02	70.0	130.0	
M5	F2	-2.5780E+00	1.5190E+00	-7.3830E-02	-2.0310E+00	8.0940E-02	-3.9500E+00	2.9030E-01	-5.6790E-03	1.1850E+00	1.6170E-01	70.0	130.0	
M6	F2	-1.4270E+00	1.0020E+00	-1.7600E-02	-1.5470E+00	1.2530E-02	-4.1390E+00	3.5300E-01	-5.3970E-03	6.5390E-01	2.3340E-01	70.0	130.0	
M7	F3	-8.9850E-02	4.3200E-01	-5.6000E-02	-1.1260E+00	2.2880E-01	5.3420E-01	-1.1980E-01	-1.0730E+00	-9.6650E-03	7.8680E-04	70.0	130.0	8.5
M8	F3	3.0950E-01	4.3290E-01	-5.4680E-02	-1.1300E+00	3.4300E-01	4.4620E-01	8.1190E-02	-7.5070E-01	-1.0440E-02	9.0030E-04	70.0	130.0	8.5
M9	F3	6.7130E-01	4.4270E-01	-5.2400E-02	-1.1390E+00	5.3660E-01	3.5330E-01	2.7860E-01	-4.1980E-01	-1.1150E-02	1.0050E-03	70.0	130.0	8.5
M10	F4	1.3270E+00	3.3800E-01	-7.9620E-01	1.5260E-01	-9.7700E-03	-7.6490E-01	-5.6410E-02			5.790	50.0	6.4	8.5
M11	F4	1.1400E+00	6.9850E-01	-7.3150E-01	9.5550E-02	-9.5020E-03	-7.0250E-01	3.9760E-06			5.110	50.0	6.4	8.5
M12	F4	1.0270E+00	1.0440E+00	-6.8700E-01	4.1560E-02	-9.2500E-03	-6.3440E-01	5.6420E-02			4.770	50.0	6.4	8.5

Table 3-23
Gulf - Model Parameters for S_a(25.0 Hz) w/ Non-Rift Model

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2, m_1	m_1 / m_2
M1	F1a	9.0980E+00	8.0460E-02	-3.8890E+00	1.8610E-01	3.3510E+00	-1.2210E-01	-6.5840E-03	5.6460E-04					6.0
M2	F1a	8.2630E+00	1.2720E-01	-3.5600E+00	1.6390E-01	3.2590E+00	-6.7950E-02	-7.1730E-03	6.4640E-04					6.0
M3	F1a	7.5410E+00	1.6490E-01	-3.2520E+00	1.4350E-01	3.1620E+00	-1.3760E-02	-7.7200E-03	7.2390E-04					6.0
M4	F2	-4.9190E+00	2.3550E+00	-1.0500E-01	-1.8490E+00	-3.2140E-02	-5.7590E+00	3.2860E-01	-4.4880E-03	1.3570E+00	1.8400E-01	70.0	130.0	
M5	F2	-1.2760E+00	1.5950E+00	-7.4160E-02	-2.2830E+00	5.1480E-02	-5.7270E+00	3.9720E-01	-4.2920E-03	1.1380E+00	1.8980E-01	70.0	130.0	
M6	F2	1.9260E+00	9.2110E-01	-4.0520E-02	-2.5830E+00	1.0570E-01	-5.6990E+00	4.6670E-01	-4.0930E-03	8.5890E-01	2.1020E-01	70.0	130.0	
M7	F3	1.3610E+00	3.6750E-01	-6.9060E-02	-1.3300E+00	5.3490E-01	3.9860E-01	-1.0820E-01	-1.2700E+00	-1.0200E-02	8.3630E-04	70.0	130.0	8.5
M8	F3	5.6120E-01	4.2300E-01	-5.2740E-02	-1.0800E+00	2.8480E-01	4.5010E-01	-1.6220E-01	-1.0410E+00	-1.0900E-02	1.0100E-03	70.0	130.0	8.5
M9	F3	-4.1160E-02	4.7530E-01	-3.7040E-02	-8.7630E-01	1.4410E-01	5.0060E-01	-1.3290E-01	-8.7140E-01	-1.1570E-02	1.1860E-03	70.0	130.0	8.5
M10	F4	1.3240E+00	3.8800E-01	-8.2190E-01	1.2550E-01	-8.6010E-03	-1.0340E+00	-6.1110E-02			4.972	50.0	6.4	8.5
M11	F4	1.1010E+00	7.0890E-01	-7.3440E-01	9.7890E-02	-8.6670E-03	-9.2420E-01	9.2660E-06			4.355	50.0	6.4	8.5
M12	F4	9.0830E-01	1.0230E+00	-6.5500E-01	7.1620E-02	-8.7390E-03	-8.1220E-01	6.1120E-02			3.799	50.0	6.4	8.5

Table 3-24
Gulf - Model Parameters for Peak Ground Acceleration – Rift Model Only

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2 m_1	m_1/m_2
M10	F4	5.1470E-01	3.8320E-01	-7.8500E-01	1.6520E-01	-8.3460E-03	-9.0430E-01	-5.0030E-02			5.487	50.0	6.4	8.5
M11	F4	3.7640E-01	7.0530E-01	-7.2300E-01	1.1900E-01	-7.8140E-03	-8.9420E-01	5.4860E-06			4.841	50.0	6.4	8.5
M12	F4	2.8690E-01	1.0150E+00	-6.7410E-01	7.5290E-02	-7.2920E-03	-8.8090E-01	5.0050E-02			4.404	50.0	6.4	8.5

Table 3-25
Gulf - Model Parameters for S_a(0.50 Hz) – Rift Model Only

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2 m_1	m_1/m_2
M10	F4	-5.2990E-01	3.6160E-01	-8.6380E-01	1.4840E-01	-5.6580E-03	-1.3420E+00	-1.7240E-01			6.896	50.0	6.4	8.5
M11	F4	-8.5720E-01	6.0300E-01	-7.3060E-01	9.6770E-02	-5.6490E-03	-9.7330E-01	-1.4000E-01			5.980	50.0	6.4	8.5
M12	F4	-1.1350E+00	8.3030E-01	-6.1050E-01	4.7790E-02	-5.6440E-03	-6.0410E-01	-1.0760E-01			5.122	50.0	6.4	8.5

Table 3-26
Gulf - Model Parameters for S_a(1.0 Hz) – Rift Model Only

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2 m_1	m_1/m_2
M10	F4	3.6510E-01	3.7620E-01	-8.1910E-01	1.5690E-01	-7.4870E-03	-1.1330E+00	-1.3090E-01			6.929	50.0	6.4	8.5
M11	F4	1.0550E-01	6.3710E-01	-6.9840E-01	9.7760E-02	-7.4720E-03	-7.9220E-01	-1.0200E-01			6.015	50.0	6.4	8.5
M12	F4	-1.0200E-01	8.8160E-01	-5.9130E-01	4.1740E-02	-7.4620E-03	-4.5010E-01	-7.3080E-02			5.208	50.0	6.4	8.5

Table 3-27
Gulf - Model Parameters for S_a(2.5 Hz) – Rift Model Only

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2 m_1	m_1/m_2
M10	F4	1.1150E+00	3.6280E-01	-7.7940E-01	1.7350E-01	-8.9080E-03	-9.1890E-01	-8.5160E-02			7.148	50.0	6.4	8.5
M11	F4	8.7310E-01	6.6730E-01	-6.6860E-01	1.0620E-01	-8.8520E-03	-6.7110E-01	-5.1790E-02			6.038	50.0	6.4	8.5
M12	F4	7.1080E-01	9.4800E-01	-5.7850E-01	4.3450E-02	-8.8060E-03	-4.2060E-01	-1.8420E-02			5.227	50.0	6.4	8.5

Table 3-28
Gulf - Model Parameters for S_a(5.0 Hz) – Rift Model Only

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2 m_1	m_1/m_2
M10	F4	1.2000E+00	3.3760E-01	-7.8720E-01	1.8280E-01	-9.2520E-03	-8.3920E-01	-4.1310E-02			6.937	50.0	6.4	8.5
M11	F4	9.6330E-01	6.8200E-01	-6.8830E-01	1.1210E-01	-9.0730E-03	-7.0540E-01	3.8970E-07			5.816	50.0	6.4	8.5
M12	F4	8.2860E-01	9.9920E-01	-6.1640E-01	4.6620E-02	-8.9110E-03	-5.6640E-01	4.1300E-02			5.160	50.0	6.4	8.5

Table 3-29

Gulf - Model Parameters for S_a(10.0 Hz) – Rift Model Only

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2, m_1	m_1/m_2
M10	F4	1.2130E+00	3.2570E-01	-7.6600E-01	1.7540E-01	-8.7550E-03	-9.3520E-01	-5.6410E-02			6.129	50.0	6.4	8.5
M11	F4	1.0040E+00	6.9440E-01	-6.9560E-01	1.1680E-01	-8.4850E-03	-8.7340E-01	-4.1000E-07			5.297	50.0	6.4	8.5
M12	F4	8.7250E-01	1.0440E+00	-6.4610E-01	6.2000E-02	-8.2290E-03	-8.0670E-01	5.6420E-02			4.837	50.0	6.4	8.5

Table 3-30

Gulf - Model Parameters for Sa(25.0 Hz) – Rift Model Only

No.	Form	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}/h	r_1	r_2, m_1	m_1/m_2
M10	F4	1.2130E+00	3.8230E-01	-7.9030E-01	1.4710E-01	-7.5870E-03	-1.2040E+00	-6.1110E-02			5.198	50.0	6.4	8.5
M11	F4	9.7800E-01	7.0810E-01	-6.9970E-01	1.1850E-01	-7.6520E-03	-1.0940E+00	-3.3940E-06			4.498	50.0	6.4	8.5
M12	F4	7.7530E-01	1.0260E+00	-6.1760E-01	9.1440E-02	-7.7220E-03	-9.8240E-01	6.1110E-02			3.860	50.0	6.4	8.5

3.3 Aleatory Variability

The ground motion aleatory variability models have the following general form:

$$\sigma_{aleatory} = \sqrt{\sigma^2_{\text{source}} + \sigma^2_{\text{path}} + \sigma^2_{\text{modeling}}}$$

$$\sigma_{\text{source}} = S_1 \qquad \text{for } m < m_1$$

$$\sigma_{\text{source}} = S_2 \qquad \text{for } m > m_2$$

$$\sigma_{\text{source}} = S_1 + (S_2 - S_1) \times (m - m_1)/(m_2 - m_1) \qquad \text{for } m_1 \leq m \leq m_2$$

$$\sigma_{\text{path}} = S_3 \qquad \text{for } r < r_1$$

$$\sigma_{\text{path}} = S_4 \qquad \text{for } r > r_2$$

$$\sigma_{\text{path}} = S_3 + (S_4 - S_3) \times \ln(r/r_1)/\ln(r_2/r_1) \qquad \text{for } r_1 \leq r \leq r_2$$

$$\sigma_{\text{modeling}} = S_5$$

Note that the separation into "source," "path," and "modeling" components is only approximate. In some of the models presented below the "source" component includes path and modeling elements. The general form given above is used to cast all of the models into the same algebraic equation.

For each ground motion measure, four alternative aleatory variability models are defined, each with an associated probability weight. Tables 3-31 through 3-37 provide the parameters for the alternative models for each ground motion measure. The table also gives the probability weight assigned to each model. These models are applicable to seismic sources in the Mid-continent and the Gulf regions and when the ground motion attenuation models are used with seismic sources in which extended fault ruptures and Joyner-Boore or closest distance to the fault distance measures are used.

Note, in Tables 31 through 37 the value of *S3 should be set equal to S4 (no distance dependence)* when the aleatory model is combined with attenuation models based on functional model type F3 (Cluster 3 ground motion models).

Table 3-31
Aleatory Variability Model – Peak Ground Acceleration

		Aleatory Model Parameters								
No.	**Probability Weight**	**m_1**	**S_1**	**m_2**	**S_2**	**r_1**	**S_3**	**r_2**	**S_4**	**S_5**
1	0.30	5.0	0.7	7.0	0.42	5.0	0.40	25.0	0.0	0.10
2	0.30	5.5	0.50	8.0	0.38	6.0	0.54	23.0	0.20	0.48
3	0.20	5.0	0.64	7.0	0.64	5.0	0.40	25.0	0.0	0.0
4	0.20	5.0	0.66	7.0	0.66	5.0	0.40	25.0	0.0	0.48

Table 3-32
Aleatory Variability Model – S_a(0.5 Hz)

		Aleatory Model Parameters								
No.	**Probability Weight**	**m_1**	**S_1**	**m_2**	**S_2**	**r_1**	**S_3**	**r_2**	**S_4**	**S_5**
1	0.30	5.0	0.85	7.0	0.64	5.0	0.40	25.0	0.0	0.07
2	0.30	5.5	0.32	8.0	0.41	6.0	0.45	23.0	0.12	0.86
3	0.20	5.0	0.72	7.0	0.72	5.0	0.40	25.0	0.0	0.0
4	0.20	5.0	0.48	7.0	0.48	5.0	0.40	25.0	0.0	0.86

Table 3-33
Aleatory Variability Model – S_a(1.0 Hz)

No.	Probability Weight	Aleatory Model Parameters m_1	S_1	m_2	S_2	r_1	S_3	r_2	S_4	S_5
1	0.30	5.0	0.83	7.0	0.59	5.0	0.40	25.0	0.0	0.07
2	0.30	5.5	0.36	8.0	0.41	6.0	0.45	23.0	0.12	0.63
3	0.20	5.0	0.72	7.0	0.72	5.0	0.40	25.0	0.0	0
4	0.20	5.0	0.54	7.0	0.54	5.0	0.40	25.0	0.0	0.63

Table 3-34
Aleatory Variability Model – S_a(2.5 Hz)

No.	Probability Weight	Aleatory Model Parameters m_1	S_1	m_2	S_2	r_1	S_3	r_2	S_4	S_5
1	0.30	5.0	0.79	7.0	0.51	5.0	0.40	25.0	0.0	0.11
2	0.30	5.5	0.45	8.0	0.40	6.0	0.45	23.0	0.12	0.57
3	0.20	5.0	0.67	7.0	0.67	5.0	0.40	25.0	0.0	0.0
4	0.20	5.0	0.58	7.0	0.58	5.0	0.40	25.0	0.0	0.57

Table 3-35
Aleatory Variability Model – S_a(5 Hz)

No.	Probability Weight	Aleatory Model Parameters m_1	S_1	m_2	S_2	r_1	S_3	r_2	S_4	S_5
1	0.30	5.0	0.77	7.0	0.49	5.0	0.40	25.0	0.0	0.15
2	0.30	5.5	0.50	8.0	0.39	6.0	0.45	23.0	0.12	0.52
3	0.20	5.0	0.65	7.0	0.65	5.0	0.40	25.0	0.0	0.0
4	0.20	5.0	0.61	7.0	0.61	5.0	0.40	25.0	0.0	0.52

Table 3-36
Aleatory Variability Model – S_a(10 Hz)

No.	Probability Weight	Aleatory Model Parameters m_1	S_1	m_2	S_2	r_1	S_3	r_2	S_4	S_5
1	0.30	5.0	0.74	7.0	0.46	5.0	0.40	25.0	0.0	0.18
2	0.30	5.5	0.52	8.0	0.38	6.0	0.50	23.0	0.17	0.50
3	0.20	5.0	0.64	7.0	0.64	5.0	0.40	25.0	0.0	0.0
4	0.20	5.0	0.65	7.0	0.65	5.0	0.40	25.0	0.0	0.50

Table 3-37
Aleatory Variability Model – S_a(25 Hz)

No.	Probability Weight	Aleatory Model Parameters m_1	S_1	m_2	S_2	r_1	S_3	r_2	S_4	S_5
1	0.30	5.0	0.71	7.0	0.43	5.0	0.40	25.0	0.0	0.13
2	0.30	5.5	0.54	8.0	0.38	6.0	0.57	23.0	0.29	0.49
3	0.20	5.0	0.64	7.0	0.64	5.0	0.40	25.0	0.0	0.0
4	0.20	5.0	0.70	7.0	0.70	5.0	0.40	25.0	0.0	0.49

Appendix D shows the alternative aleatory variability models for each ground motion measure and ground motion model functional form (see Table 3-1). These models are applicable to seismic sources in the Mid-continent and the Gulf regions and to seismic

sources modeled as extended fault ruptures (e.g., for Joyner-Boore distance or the closest distance to the fault).

3.4 Point-Source Modeling of Earthquake Occurrences

If earthquake occurrences are modeled as points in a seismic source, two adjustments are required to use the ground motion attenuation models presented in this document. These are:

1. Distance Adjustment – a distance adjustment is required to convert the point source distance (epicentral distance) computed in the PSHA code to the appropriate Joyner-Boore or closest distance to the fault rupture to be used with the four functional forms defined in Table 2. This adjustment accounts for the expected difference between these distance measures. Tables 38 through 41 provide distance adjustment relationships to convert epicentral distance to Joyner–Boore or closest distance for extended ruptures randomly oriented about the epicenter location. Note there is a distance adjustment defined for each functional model type in Table 3-2.
2. Aleatory Variability Adjustment – For those cases where there is significant variability in the orientation of extended ruptures with respect to the point-source epicentral location of earthquakes, then one should include the additional aleatory variability in ground motions resulting from the variability in Joyner-Boore or closest distance for a given point source distance. Tables 42 through 45 provide relationships for each ground motion measure to determine the additional aleatory variability as a function of earthquake magnitude and distance for the case where earthquakes are modeled as epicentral locations and the extended ruptures are randomly oriented about the epicenter location. Note there is an aleatory variability adjustment defined for each functional model type in Table 3-2.

This additional aleatory variability must be combined with the aleatory variability determined for a given ground motion measure as defined in Tables 3-31 through 3-37. The total aleatory for point source models is determined by the following relationship:

$$\sigma_{\text{PointSourceTotalAleatory}} = \sqrt{\sigma^2_{\text{Extended Source Aleatory}} + \sigma^2_{\text{Additional Point Source Aleatory}}}$$

$_{\text{Extended Source Aleatory}}$ = Aleatory variability for earthquakes modeled as extended sources as defined in Tables 31 – 37.

$_{\text{Additional Point Source Aleatory}}$ = Additional aleatory variability for earthquakes modeled as point sources as defined in Table 3-42 – 3-45.

3.4.1 Distance Adjustment Models for Epicentral Distance

The distance adjustment models provide relationships to translate the epicentral distance computed by the PSHA software into the appropriate distance measure used by the four function forms defined in Table 3-2. A common functional form for the distance

adjustment was found to work for all models that use Joyner-Boore distance (attenuation forms F1, F2, and F4). This function form is:

$$r_{\text{Joyner-Boore}} = r_{\text{Epicentral}} \times \{1 - 1/\cosh(C_1 + C_2(\text{M} - 6) + C_3 \ln(r'))\}$$

$$r' = \sqrt{r_{\text{Epicentral}}^2 + h'^2}, \quad h' = \exp\{C_4 + C_5(\text{M} - 6)\}$$

For attenuation form F3, which uses closest distance to rupture, the above form is modified to include an additional term:

$$r_{\text{Closest Distance}} = \sqrt{\left[r_{\text{Epicentral}} \times \{1 - 1/\cosh(C_1 + C_2(\text{M} - 6) + C_3 \ln(r'))\}\right]^2 + CC^2}$$

$$r' = \sqrt{r_{\text{Epicentral}}^2 + h'^2}, \quad h' = \exp\{C_4 + C_5(\text{M} - 6)\}, \quad CC = \exp(C_6)$$

The coefficients for these models are provided below in Tables 3-38 through 3-41. Two sets of coefficients are provided for each attenuation form. One set, denoted "Random Epicenters," is based on the assumption that the epicenter of an earthquake is uniformly distributed along the length of the rupture. The second set, denoted "Centered Epicenters," is based on the assumption that the epicenter is centered on the earthquake rupture. These two options are provided so that the user may chose which assumption is more consistent with the seismic source interpretation.

Table 3-38
Distance Adjustment from Epicentral to Joyner-Boore Distance For Function Form F1

Frequency (Hz)	C_1	C_2	C_3	C_4	C_5
Centered Epicenters					
0.5	-0.4551E+00	-0.1394E+01	0.1003E+01	0.1235E+01	0.1421E+01
1.0	-0.4541E+00	-0.1394E+01	0.1003E+01	0.1237E+01	0.1424E+01
2.5	-0.4534E+00	-0.1394E+01	0.1003E+01	0.1237E+01	0.1426E+01
5.0	-0.4532E+00	-0.1394E+01	0.1003E+01	0.1238E+01	0.1427E+01
10.0	-0.4510E+00	-0.1394E+01	0.1003E+01	0:1240E+01	0.1433E+01
25.0	-0.4494E+00	-0.1394E+01	0.1002E+01	0.1240E+01	0.1437E+01
100.0 (PGA)	-0.4517E+00	-0.1394E+01	0.1003E+01	0.1239E+01	0.1431E+01
Random Epicenters					
0.5	-0.4098E+00	-0.1411E+01	0.9973E+00	0.1543E+01	0.1442E+01
1.0	-0.4060E+00	-0.1411E+01	0.9966E+00	0.1544E+01	0.1445E+01
2.5	-0.4066E+00	-0.1411E+01	0.9967E+00	0.1548E+01	0.1445E+01
5.0	-0.4086E+00	-0.1411E+01	0.9971E+00	0.1553E+01	0.1445E+01
10.0	-0.4006E+00	-0.1410E+01	0.9955E+00	0.1551E+01	0.1451E+01
25.0	-0.3976E+00	-0.1410E+01	0.9949E+00	0.1552E+01	0.1454E+01
100.0 (PGA)	-0.4013E+00	-0.1410E+01	0.9956E+00	0.1548E+01	0.1449E+01

Table 3-39
Distance Adjustment from Epicentral to Joyner-Boore Distance For Function Form F2

Frequency (Hz)	C_1	C_2	C_3	C_4	C_5
Centered Epicenters					
0.5	-0.9262E+00	-0.1518E+01	0.1113E+01	0.2229E+01	0.1097E+01
1.0	-0.9291E+00	-0.1517E+01	0.1113E+01	0.2239E+01	0.1096E+01
2.5	-0.9197E+00	-0.1513E+01	0.1111E+01	0.2231E+01	0.1101E+01
5.0	-0.9016E+00	-0.1507E+01	0.1106E+01	0.2211E+01	0.1109E+01
10.0	-0.8926E+00	-0.1504E+01	0.1104E+01	0.2204E+01	0.1117E+01
25.0	-0.8869E+00	-0.1504E+01	0.1103E+01	0.2189E+01	0.1114E+01
100.0 (PGA)	-0.8805E+00	-0.1501E+01	0.1101E+01	0.2181E+01	0.1117E+01
Random Epicenters					
0.5	-0.1167E+01	-0.1457E+01	0.1130E+01	0.2674E+01	0.9880E+00
1.0	-0.1158E+01	-0.1458E+01	0.1129E+01	0.2677E+01	0.9887E+00
2.5	-0.1127E+01	-0.1456E+01	0.1124E+01	0.2656E+01	0.9986E+00
5.0	-0.1092E+01	-0.1453E+01	0.1118E+01	0.2629E+01	0.1010E+01
10.0	-0.1033E+01	-0.1456E+01	0.1110E+01	0.2588E+01	0.1028E+01
25.0	-0.1034E+01	-0.1451E+01	0.1108E+01	0.2574E+01	0.1026E+01
100.0 (PGA)	-0.1031E+01	-0.1455E+01	0.1109E+01	0.2573E+01	0.1028E+01

Table 3-40
Distance Adjustment from Epicentral to Closest Distance to Rupture For Function Form F3

Frequency (Hz)	C_1	C_2	C_3	C_4	C_5	C_6
Centered Epicenters						
0.5	-0.6916E+00	-0.1452E+01	0.1056E+01	0.2281E+01	0.1113E+01	0.1699E+01
1.0	-0.6890E+00	-0.1451E+01	0.1055E+01	0.2278E+01	0.1109E+01	0.1696E+01
2.5	-0.7045E+00	-0.1452E+01	0.1058E+01	0.2303E+01	0.1099E+01	0.1700E+01
5.0	-0.7070E+00	-0.1451E+01	0.1059E+01	0.2311E+01	0.1096E+01	0.1703E+01
10.0	-0.7040E+00	-0.1450E+01	0.1058E+01	0.2306E+01	0.1097E+01	0.1702E+01
25.0	-0.6912E+00	-0.1446E+01	0.1055E+01	0.2287E+01	0.1104E+01	0.1696E+01
100.0 (PGA)	-0.6912E+00	-0.1446E+01	0.1055E+01	0.2287E+01	0.1104E+01	0.1696E+01
Random Epicenters						
0.5	-0.7868E+00	-0.1472E+01	0.1072E+01	0.2620E+01	0.1080E+01	0.1651E+01
1.0	-0.7800E+00	-0.1469E+01	0.1070E+01	0.2612E+01	0.1077E+01	0.1649E+01
2.5	-0.7879E+00	-0.1465E+01	0.1071E+01	0.2626E+01	0.1066E+01	0.1655E+01
5.0	-0.7729E+00	-0.1455E+01	0.1066E+01	0.2617E+01	0.1064E+01	0.1659E+01
10.0	-0.7409E+00	-0.1447E+01	0.1059E+01	0.2582E+01	0.1072E+01	0.1659E+01
25.0	-0.6974E+00	-0.1434E+01	0.1050E+01	0.2536E+01	0.1086E+01	0.1654E+01
100.0 (PGA)	-0.7715E+00	-0.1451E+01	0.1065E+01	0.2611E+01	0.1058E+01	0.1659E+01

Table 3-41
Distance Adjustment from Epicentral to Joyner-Boore Distance For Function Form F4

Frequency (Hz)	C_1	C_2	C_3	C_4	C_5
Centered Epicenters					
0.5	-0.5292E+00	-0.1396E+01	0.1017E+01	0.1671E+01	0.1231E+01
1.0	-0.5224E+00	-0.1393E+01	0.1015E+01	0.1657E+01	0.1236E+01
2.5	-0.5577E+00	-0.1402E+01	0.1024E+01	0.1709E+01	0.1210E+01
5.0	-0.5806E+00	-0.1408E+01	0.1029E+01	0.1744E+01	0.1193E+01
10.0	-0.5807E+00	-0.1408E+01	0.1029E+01	0.1744E+01	0.1193E+01
25.0	-0.5804E+00	-0.1408E+01	0.1029E+01	0.1745E+01	0.1193E+01
100.0 (PGA)	-0.5804E+00	-0.1408E+01	0.1029E+01	0.1745E+01	0.1192E+01
Random Epicenters					
0.5	-0.4553E+00	-0.1385E+01	0.1000E+01	0.1852E+01	0.1273E+01
1.0	-0.4360E+00	-0.1379E+01	0.9959E+00	0.1826E+01	0.1279E+01
2.5	-0.4800E+00	-0.1381E+01	0.1005E+01	0.1902E+01	0.1226E+01
5.0	-0.5122E+00	-0.1386E+01	0.1011E+01	0.1952E+01	0.1195E+01
10.0	-0.5125E+00	-0.1386E+01	0.1011E+01	0.1952E+01	0.1194E+01
25.0	-0.5123E+00	-0.1386E+01	0.1011E+01	0.1952E+01	0.1194E+01
100.0 (PGA)	-0.5127E+00	-0.1385E+01	0.1011E+01	0.1953E+01	0.1194E+01

3.4.2 Additional Point-Source Aleatory Variability for Epicentral Distance

The models described below provide an additional component of aleatory variability to account for the randomness of the earthquake rupture location about the epicenter. A common function form was found to work for all models. This function form is:

$$\sigma_{\text{AdditionalPointSource}} = \exp\{C_1 + C_2(\text{M}-6) + C_3(\text{M}-6)^2\} \times [1 - 1/\cosh(f_A)] \times \frac{1}{\cosh(f_B)}$$

$$f_A = \exp\{C_4 + C_5(\text{M}-6)\} + \exp\{C_6 + C_7(\text{M}-6)\} \times r_{\text{Epicentral}}$$

$$f_B = \exp\{C_8 + C_9(\text{M}-6)\} \times \ln(r'/h)$$

$$r' = \sqrt{r_{\text{Epicentral}}^2 + h^2}, \quad h = \exp\{C_{10} + C_{11}(\text{M}-6)\}$$

The coefficients for this model are provided below in Tables 3-42 through 3-45. Two sets of coefficients are provided for each attenuation form. One set, denoted "Random Epicenters," is based on the assumption that the epicenter of an earthquake is uniformly distributed along the length of the rupture. The second set, denoted "Centered Epicenters," is based on the assumption that the epicenter is centered on the earthquake rupture. These two options are provided so that the user may chose which assumption is more consistent with the seismic source interpretation. The appropriate additional point-source aleatory variability model should be paired with the corresponding distance adjustment model from Tables 3-38 through 3-41.

Table 3-42
Additional Aleatory Variability on Ground Motion Associated with Modeling Earthquakes as Epicenters For Function Form F1

Frequency (Hz)	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
Centered Epicenters											
0.5	-0.1741E+01	0.7986E+00	-0.6351E-01	-0.1339E+01	0.2116E+00	-0.7815E+00	-0.1027E+01	-0.1224E+00	0.3732E+00	0.1019E+01	0.1648E+01
1.0	-0.1711E+01	0.7967E+00	-0.6476E-01	-0.1378E+01	0.2278E+00	-0.7882E+00	-0.1043E+01	-0.1416E+00	0.3730E+00	0.1007E+01	0.1648E+01
2.5	-0.1658E+01	0.7936E+00	-0.6658E-01	-0.1383E+01	0.2278E+00	-0.7925E+00	-0.1048E+01	-0.1510E+00	0.3698E+00	0.9977E+00	0.1646E+01
5.0	-0.1636E+01	0.7970E+00	-0.6565E-01	-0.1310E+01	0.1873E+00	-0.8005E+00	-0.1052E+01	-0.1689E+00	0.3710E+00	0.9844E+00	0.1646E+01
10.0	-0.1620E+01	0.8029E+00	-0.6505E-01	-0.1302E+01	0.1731E+00	-0.8645E+00	-0.1050E+01	-0.1946E+00	0.3581E+00	0.9299E+00	0.1653E+01
25.0	-0.1623E+01	0.8100E+00	-0.6381E-01	-0.1293E+01	0.1623E+00	-0.8831E+00	-0.1046E+01	-0.2064E+00	0.3630E+00	0.9419E+00	0.1659E+01
100.0 (PGA)	-0.1577E+01	0.7921E+00	-0.6953E-01	-0.1368E+01	0.2120E+00	-0.8382E+00	-0.1049E+01	-0.1660E+00	0.3566E+00	0.9663E+00	0.1648E+01
Random Epicenters											
0.5	-0.1502E+01	0.5506E+00	-0.3874E-01	-0.8330E+00	-0.1935E-01	-0.1341E+01	-0.6375E+00	-0.1008E+00	0.3328E+00	0.1564E+01	0.1635E+01
1.0	-0.1604E+01	0.6415E+00	-0.5674E-01	-0.8626E+00	-0.1209E-01	-0.1177E+01	-0.7274E+00	-0.1472E+00	0.4290E+00	0.1722E+01	0.1635E+01
2.5	-0.1430E+01	0.5386E+00	-0.3777E-01	-0.7968E+00	-0.4394E-01	-0.1378E+01	-0.6413E+00	-0.1241E+00	0.3472E+00	0.1607E+01	0.1630E+01
5.0	-0.1399E+01	0.5586E+00	-0.4658E-01	-0.8270E+00	-0.2395E-01	-0.1371E+01	-0.6625E+00	-0.1347E+00	0.3469E+00	0.1595E+01	0.1628E+01
10.0	-0.1505E+01	0.6439E+00	-0.5982E-01	-0.8770E+00	-0.7960E-02	-0.1250E+01	-0.7413E+00	-0.1741E+00	0.4177E+00	0.1711E+01	0.1638E+01
25.0	-0.1492E+01	0.6576E+00	-0.6261E-01	-0.8870E+00	-0.8146E-02	-0.1277E+01	-0.7479E+00	-0.1958E+00	0.4116E+00	0.1684E+01	0.1647E+01
100.0 (PGA)	-0.1407E+01	0.5926E+00	-0.5345E-01	-0.8708E+00	-0.1605E-02	-0.1305E+01	-0.7161E+00	-0.1846E+00	0.3675E+00	0.1599E+01	0.1629E+01

Table 3-43
Additional Aleatory Variability on Ground Motion Associated with Modeling Earthquakes as Epicenters For Function Form F2

Frequency (Hz)	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
Centered Epicenters											
0.5	-0.1202E+01	0.1001E+01	-0.2372E+00	-0.1069E+02	0.4430E+01	-0.1762E+01	-0.7727E+00	0.1614E+00	0.6085E+00	0.1333E+01	0.1635E+01
1.0	-0.1586E+01	0.1154E+01	-0.2160E+00	-0.1076E+02	0.4417E+01	-0.1597E+01	-0.8200E+00	0.7865E-01	0.8274E+00	0.1606E+01	0.1640E+01
2.5	0.5135E+00	0.4877E-01	-0.1168E+00	-0.1070E+02	0.4409E+01	-0.2504E+01	-0.5014E+00	0.4871E+00	0.2847E+00	0.1020E+01	0.1641E+01
5.0	0.4241E+00	-0.1558E+00	-0.2706E-01	-0.1104E+02	0.4488E+01	-0.2446E+01	-0.4374E+00	0.4663E+00	0.2321E+00	0.1018E+01	0.1643E+01
10.0	0.8586E+00	-0.6059E+00	0.9655E-01	-0.1194E+02	0.4813E+01	-0.2496E+01	-0.3968E+00	0.4616E+00	0.9656E-01	0.7856E+00	0.1656E+01
25.0	0.5458E+00	-0.4894E+00	0.1181E+00	-0.1231E+02	0.4928E+01	-0.2240E+01	-0.4348E+00	0.3654E+00	0.4977E-01	0.7090E+00	0.1641E+01
100.0 (PGA)	0.5242E+00	-0.1310E+00	-0.2976E-01	-0.1095E+02	0.4454E+01	-0.2341E+01	-0.4919E+00	0.4057E+00	0.1937E+00	0.8905E+00	0.1639E+01
Random Epicenters											
0.5	0.3488E+00	-0.6677E+00	0.1250E+00	-0.9500E+01	0.3803E+01	-0.2468E+01	-0.2333E+00	0.3717E+00	0.1201E+00	0.1236E+01	0.1623E+01
1.0	-0.3501E+00	-0.1134E+00	0.4357E-01	-0.2771E+02	0.1275E+02	-0.2305E+01	-0.3035E+00	0.4214E+00	0.1588E+00	0.1790E+01	0.1396E+01
2.5	-0.1719E+00	-0.3229E+00	0.1109E+00	-0.2791E+02	0.1269E+02	-0.2358E+01	-0.2746E+00	0.4314E+00	0.3535E-01	0.1732E+01	0.1339E+01
5.0	-0.1464E+00	-0.3320E+00	0.1199E+00	-0.2798E+02	0.1269E+02	-0.2294E+01	-0.3142E+00	0.3248E+00	-0.1563E-01	0.1535E+01	0.1355E+01
10.0	-0.7696E-01	-0.4229E+00	0.1648E+00	-0.2946E+02	0.1326E+02	-0.2270E+01	-0.3395E+00	0.2772E+00	-0.1382E+00	0.1433E+01	0.1257E+01
25.0	0.5907E+00	-0.1068E+01	0.3221E+00	-0.2845E+02	0.1248E+02	-0.2338E+01	-0.2086E+00	0.2106E+00	-0.1151E+00	0.8669E+00	0.1653E+01
100.0 (PGA)	0.5855E+00	-0.7890E+00	0.1905E+00	-0.9864E+01	0.3825E+01	-0.2372E+01	-0.2792E+00	0.2418E+00	-0.1558E-01	0.9470E+00	0.1631E+01

Table 3-44

Additional Aleatory Variability on Ground Motion Associated with Modeling Earthquakes as Epicenters For Function Form F3

Frequency (Hz)	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
Centered Epicenters											
0.5	-0.1417E+01	0.1596E+00	0.4135E+00	0.1069E+01	-0.1246E+01	-0.2060E+01	-0.1217E+01	0.6214E+00	0.1992E+00	0.2230E+01	0.9989E+00
1.0	-0.8061E+00	0.3165E+00	0.1429E+00	0.3105E+00	-0.7465E+00	-0.3511E+01	-0.4371E+00	0.7568E+00	0.1483E+00	0.2310E+01	0.9991E+00
2.5	-0.7318E+00	0.3286E+00	0.1376E+00	0.2623E+00	-0.7334E+00	-0.3502E+01	-0.4353E+00	0.7318E+00	0.1535E+00	0.2295E+01	0.9994E+00
5.0	-0.6894E+00	0.3509E+00	0.1380E+00	0.2233E+00	-0.7425E+00	-0.3503E+01	-0.4471E+00	0.6582E+00	0.1515E+00	0.2217E+01	0.9999E+00
10.0	-0.1342E+01	0.5142E-01	0.3657E+00	0.1127E+01	-0.1165E+01	-0.1585E+01	-0.1258E+01	0.4044E+00	0.1297E+00	0.2047E+01	0.1000E+01
25.0	-0.1351E+01	0.1131E+01	0.1449E+01	0.1943E+01	-0.3160E+01	-0.2284E+01	-0.2669E+01	0.6302E+00	0.2595E+00	0.2151E+01	0.1002E+01
100.0 (PGA)	-0.7753E+00	0.3547E+00	0.1917E+00	0.3383E+00	-0.8140E+00	-0.3301E+01	-0.6024E+00	0.6504E+00	0.1580E+00	0.2205E+01	0.1000E+01
Random Epicenters											
0.5	-0.1028E+01	0.1833E+00	0.8666E-01	0.3635E+00	-0.6507E+00	-0.2894E+01	-0.5382E+00	0.4495E+00	0.3794E-01	0.2269E+01	0.1000E+01
1.0	-0.1098E+01	0.1607E+00	0.1234E+00	0.5374E+00	-0.7099E+00	-0.2584E+01	-0.6710E+00	0.4365E+00	0.4162E-01	0.2301E+01	0.1001E+01
2.5	-0.9248E+00	0.1756E+00	0.8843E-01	0.3690E+00	-0.6289E+00	-0.2859E+01	-0.5196E+00	0.4296E+00	0.2316E-01	0.2262E+01	0.1001E+01
5.0	-0.1043E+01	0.1394E+00	0.1295E+00	0.4668E+00	-0.6885E+00	-0.2405E+01	-0.7082E+00	0.3067E+00	0.1934E-02	0.2160E+01	0.1003E+01
10.0	-0.1192E+01	0.6772E-01	0.1633E+00	0.6987E+00	-0.7825E+00	-0.2034E+01	-0.8105E+00	0.2759E+00	-0.5055E-01	0.2217E+01	0.1007E+01
25.0	-0.1302E+01	-0.1183E-01	0.2101E+00	0.9169E+00	-0.8919E+00	-0.1566E+01	-0.1020E+01	0.1271E+00	-0.1129E+00	0.2067E+01	0.1025E+01
100.0 (PGA)	-0.1128E+01	0.7966E-01	0.1488E+00	0.6518E+00	-0.7498E+00	-0.2202E+01	-0.7362E+00	0.2954E+00	-0.4248E-01	0.2197E+01	0.1005E+01

Table 3-45

Additional Aleatory Variability on Ground Motion Associated with Modeling Earthquakes as Epicenters For Function Form F4

Frequency (Hz)	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
Centered Epicenters											
0.5	-0.1149E+01	0.3222E+00	0.1345E-02	-0.7230E+01	0.2753E+01	-0.1477E+01	-0.6411E+00	0.3008E-01	0.1028E+00	0.6472E+00	0.1637E+01
1.0	-0.1136E+01	0.2858E+00	0.1174E-01	-0.5588E+01	0.1936E+01	-0.1492E+01	-0.6258E+00	0.5529E-01	0.6871E-01	0.6603E+00	0.1639E+01
2.5	-0.3544E+00	-0.2998E+00	0.1293E+00	-0.8077E+01	0.3159E+01	-0.1734E+01	-0.5295E+00	0.1905E+00	-0.7156E-01	0.3629E+00	0.1636E+01
5.0	-0.1015E+01	0.4712E+00	-0.5350E-01	-0.6380E+01	0.2351E+01	-0.1364E+01	-0.7901E+00	-0.9400E-01	0.4889E-01	0.1010E+00	0.1635E+01
10.0	-0.3866E+00	-0.1192E+00	0.6865E-01	-0.1070E+02	0.4470E+01	-0.1670E+01	-0.5953E+00	0.1239E+00	-0.5744E-01	0.1857E+00	0.1635E+01
25.0	-0.9833E+00	0.2988E+00	-0.1421E-02	-0.6926E+01	0.2593E+01	-0.1438E+01	-0.6937E+00	-0.2966E-01	0.3643E-01	0.2892E+00	0.1635E+01
100.0 (PGA)	-0.3935E+00	-0.2678E+00	0.1246E+00	-0.1301E+02	0.5595E+01	-0.1710E+01	-0.5273E+00	0.1774E+00	-0.6106E-01	0.3578E+00	0.1635E+01
Random Epicenters											
0.5	-0.8868E+00	-0.1539E+00	0.1295E+00	-0.8115E+01	0.3079E+01	-0.1730E+01	-0.3783E+00	-0.1157E+00	-0.3331E-01	0.8132E+00	0.1658E+01
1.0	-0.2994E+00	-0.8069E+00	0.3097E+00	-0.1263E+02	0.5290E+01	-0.1935E+01	-0.2696E+00	0.1465E-01	-0.1862E+00	0.5793E+00	0.1710E+01
2.5	-0.3003E+00	-0.8104E+00	0.3145E+00	-0.1267E+02	0.5275E+01	-0.1835E+01	-0.3076E+00	-0.8809E-01	-0.2234E+00	0.2584E+00	0.1732E+01
5.0	0.2373E+00	-0.1368E+01	0.4654E+00	-0.2262E+02	0.1013E+02	-0.1999E+01	-0.2156E+00	0.3263E-01	-0.3355E+00	0.1533E+00	0.1655E+01
10.0	0.2050E+00	-0.1366E+01	0.4686E+00	-0.1955E+02	0.8573E+01	-0.2017E+01	-0.1962E+00	0.6155E-01	-0.3310E+00	0.2689E+00	0.1655E+01
25.0	0.3772E+00	-0.1506E+01	0.4995E+00	-0.2008E+02	0.8922E+01	-0.2045E+01	-0.1984E+00	0.7736E-01	-0.3523E+00	0.1671E+00	0.1655E+01
100.0 (PGA)	0.2129E+00	-0.1306E+01	0.4418E+00	-0.1786E+02	0.7822E+01	-0.1985E+01	-0.2338E+00	0.2347E-01	-0.3295E+00	0.1333E+00	0.1655E+01

3.5 Ground Motion Model Application

There are a number of considerations that must be addressed in the use of the ground motion attenuation model in PSHA applications. These considerations include the correlation of the models, the use of the alternative median ground motion models for different source types, and the combination of epistemic uncertainty associated with the median models and the aleatory variability. The application of the ground motion models as described in the logic trees apply to seismic sources in the Mid-continent and the Gulf regions.

3.5.1 Source Types

For General Area sources (see Table 3-1), ground motion models M1 through M9 in Tables 3-3 through 3-9 for seismic sources located in the Mid-Continent region and in Tables 3-17 through 3-23 for seismic sources located in the Gulf region are used. The probability weights for these models are determined according to the logic tree shown in Figure 3-5.

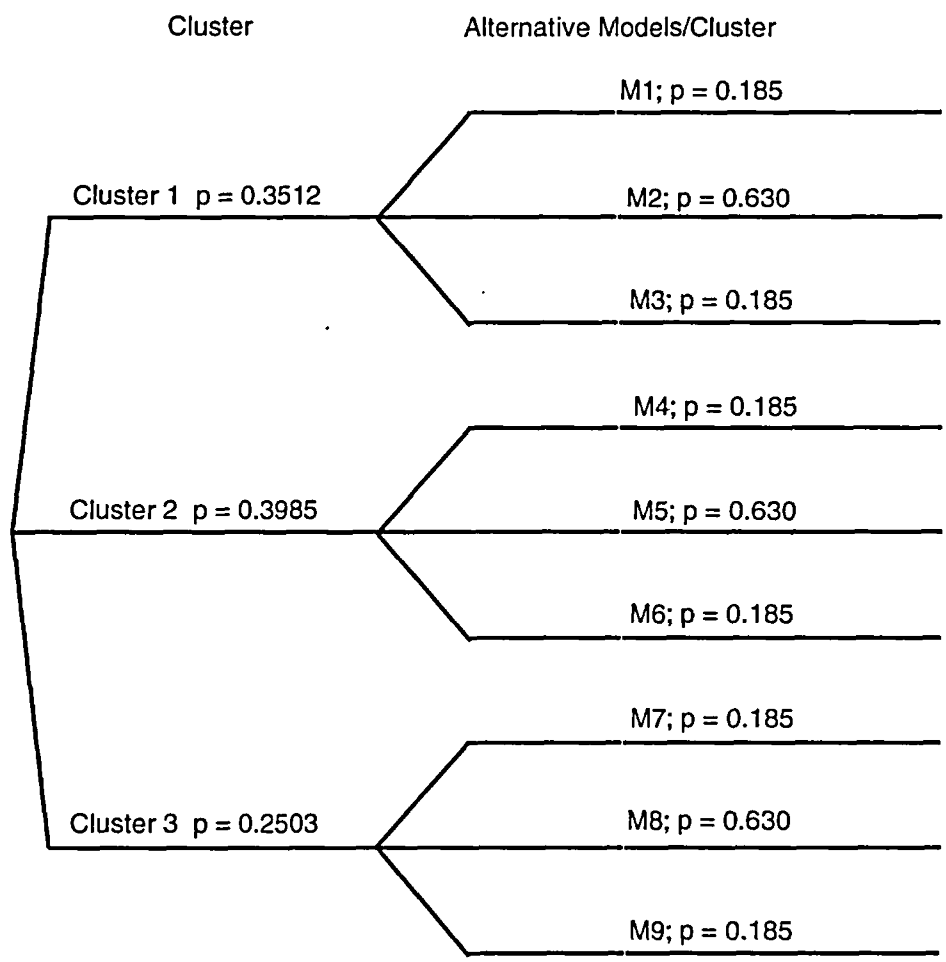

Figure 3-5
Logic Tree Illustrating the Calculation of Probability Weights for Ground Motion Models Used for General Area Sources

For a seismic source located in the Mid-continent that is either a Fault Source or a Distant source that is capable of generating large magnitude events, models M1 through M12 in Tables 3-3 through 3-9 for non-rifted sources are used. If a fault source located in the Mid-continent is rifted, models 10-12 in Tables 3-10 through 3-16 are used. For a seismic source located in the Gulf region that is either a Fault Source or a Distant Source that is capable of generating large magnitude events, models M1 through M12 in Tables 3-17 through 3-23 for non-rifted sources are used. If a fault source located in the Gulf region is rifted, models 10-12 in Tables 3-24 through 3-30 are used. The probability weights for these models are determined according to the logic tree shown in Figure 3-6.

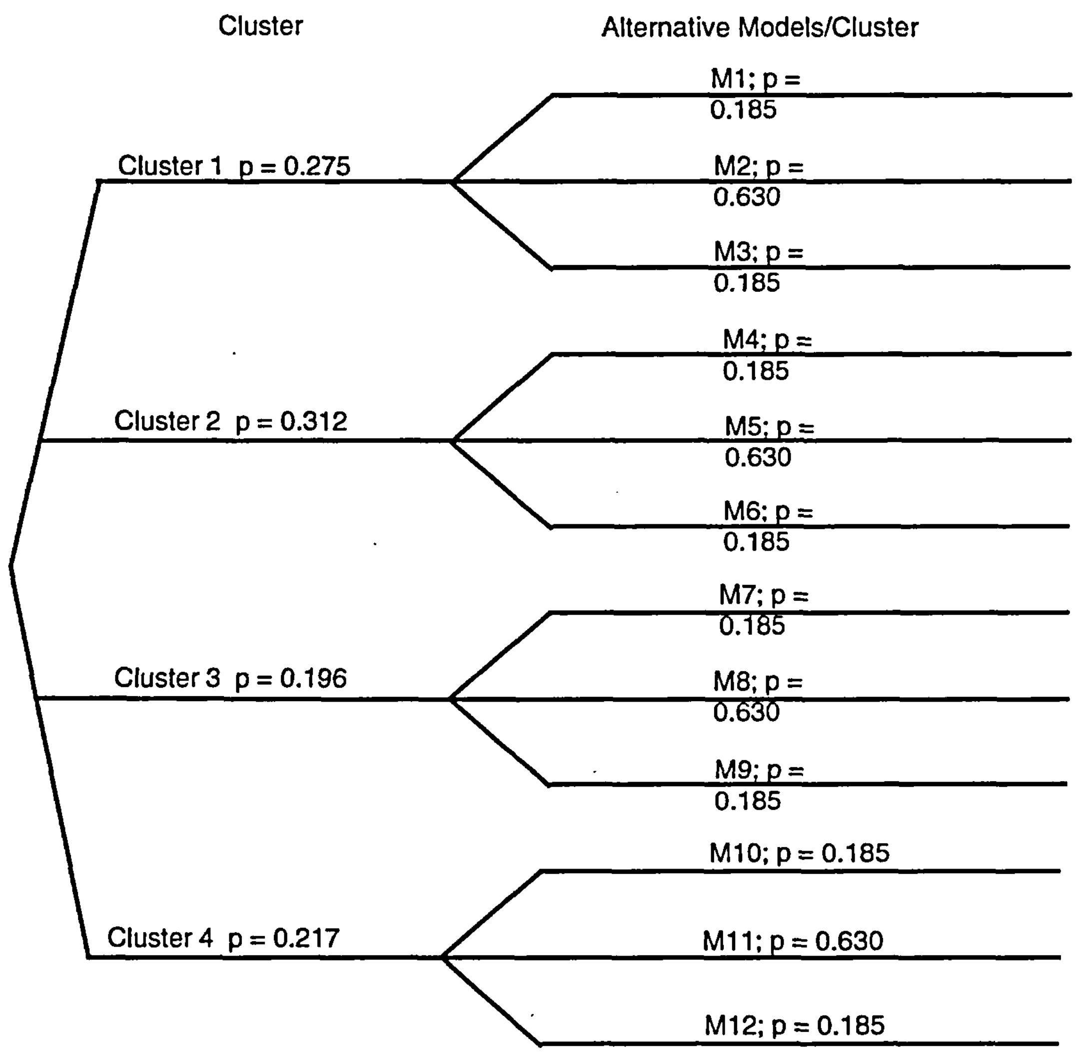

Figure 3-6
Logic Tree Illustrating the Calculation of Probability Weights for Ground Motion Models Used for Fault or Distant/Large Magnitude Event Sources

3.5.2 Combinations of Seismic Source Types

For cases where combinations of different seismic source types are considered (e.g., General Areas Sources and Fault Sources are simultaneously active), the logic tree in Figure 3-7 should be used.

3.5.3 Combining Median and Aleatory Variability Epistemic Uncertainty

Each median ground motion model is combined with the 4 alternative aleatory uncertainty models to produce a suite of alternative ground motion models. For the case in which ground motion models for the General Area Sources are used, the epistemic uncertainty in ground motion is defined by 9 estimates of the median ground motion, with an associated probability weight (for a given ground motion measure) and 4 aleatory variability models, for a total of 36 ground motion attenuation models that must be evaluated to quantify the epistemic uncertainty in ground motions. For the other source types there are 48 ground motion attenuation models. The combined probability weight associated with each of the ground motion attenuation models is defined by the product of the probability weights associated with a median ground motion model and an aleatory variability model. This is denoted by the following expression:

$$P(AM_k) = P(Median_i) * P(\ _{a,j})$$

where

$P(\,)$ = probability

AM_k = ground motion attenuation model k, which is defined by an estimate of the median ground motion attenuation, $f(m,r)_i$, and an estimate of the aleatory variability, $_a$

$P(Median_i)$ = probability weight associated with the i^{th} estimate of the median ground motion attenuation, $f(m,r)_i$

$P(\ _{aj})$ = probability weight associated with the j^{th} estimate of the aleatory variability, $_{a,j}$.

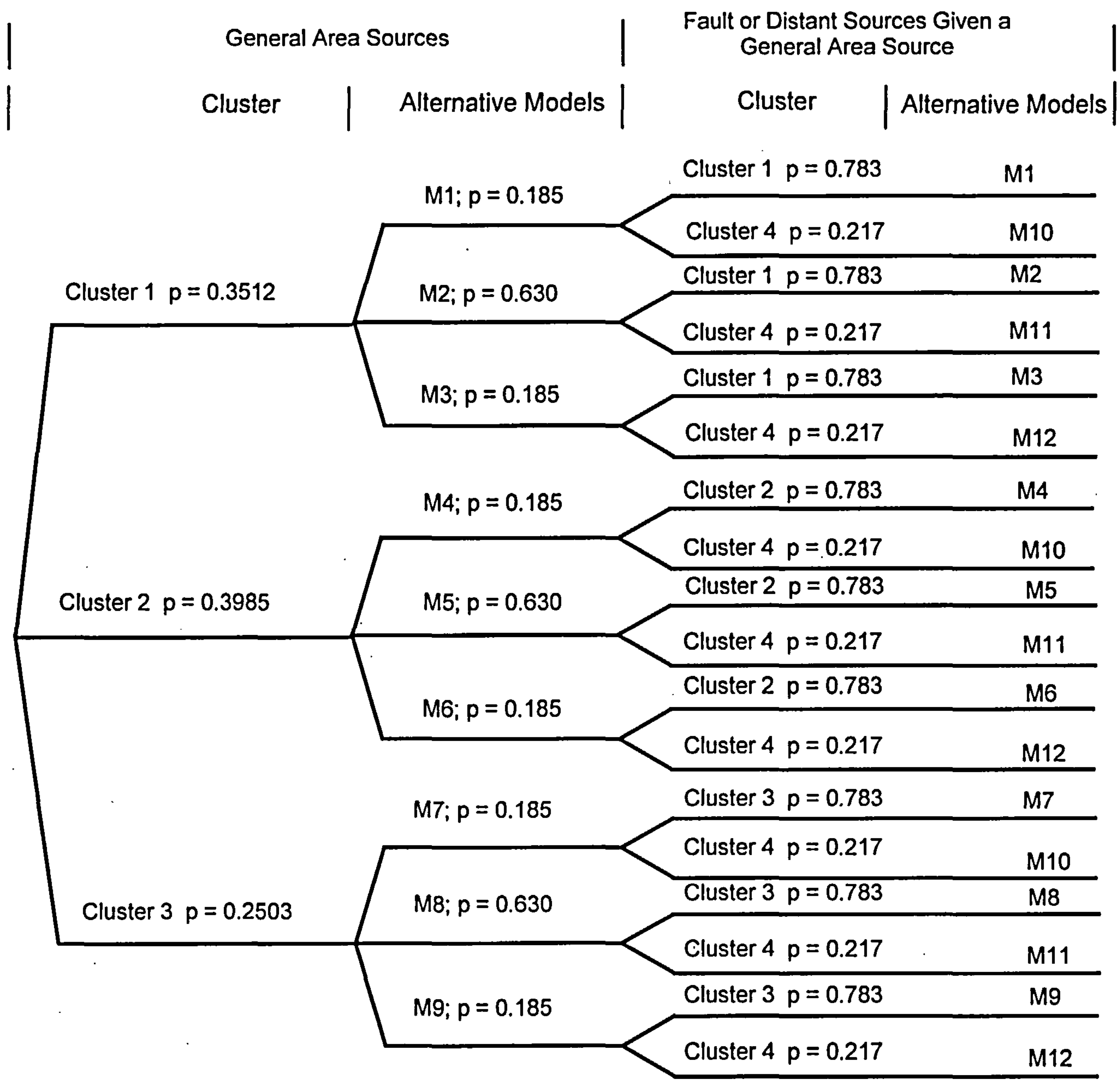

Figure 3-7
Logic Tree Logic Tree Illustrating the Calculation of Probability Weights Involving Multiple Seismic Source Types

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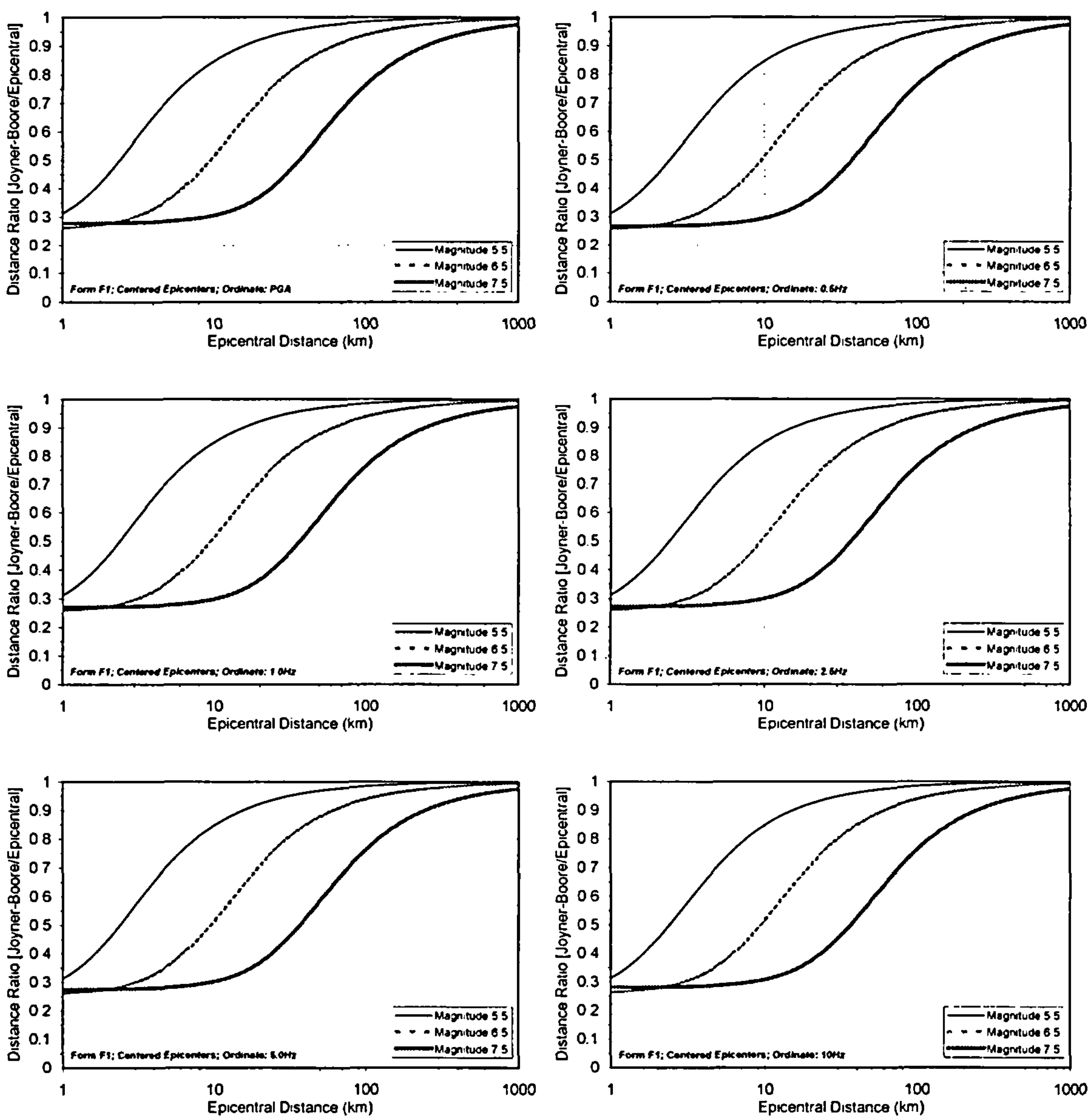
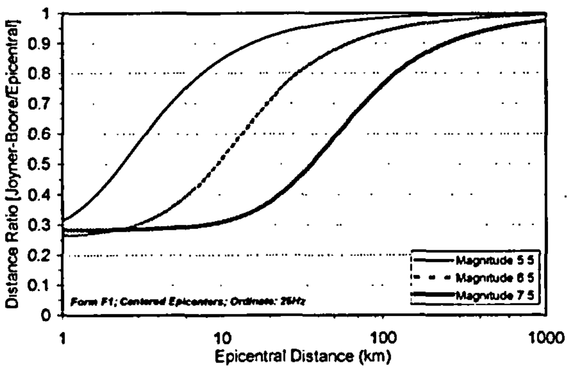
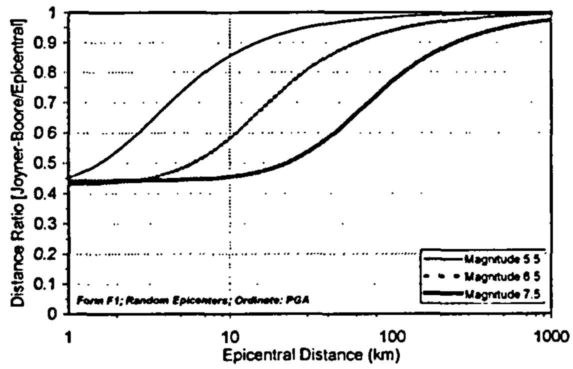
A

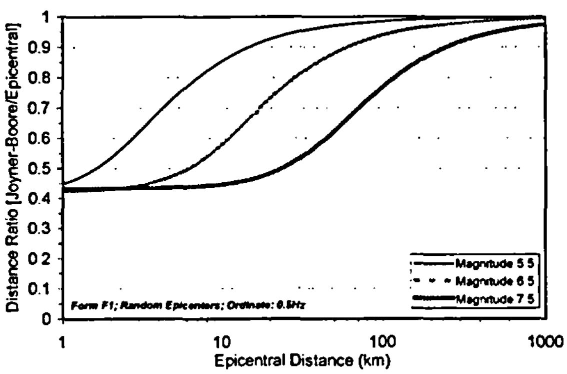
POINT-SOURCE DISTANCE ADJUSTMENT FACTORS

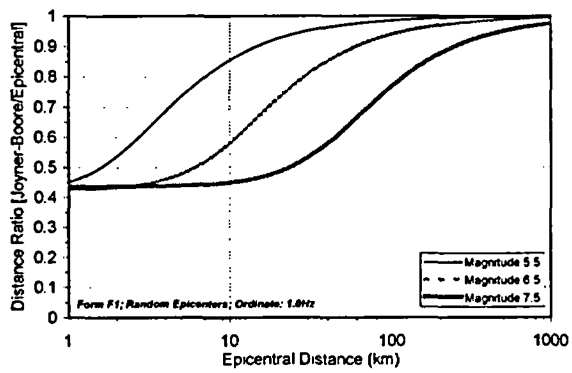
Figure A-1
Distance Adjustment: Epicentral to Joyner-Boore Distance F1

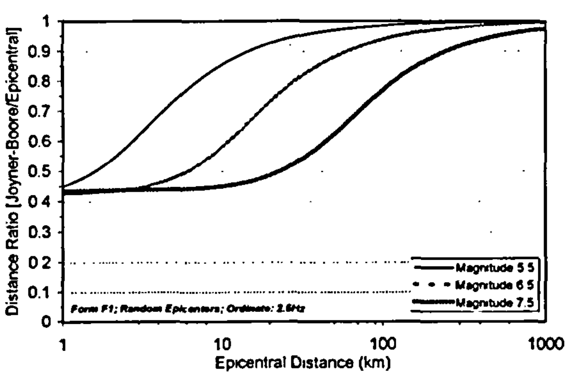


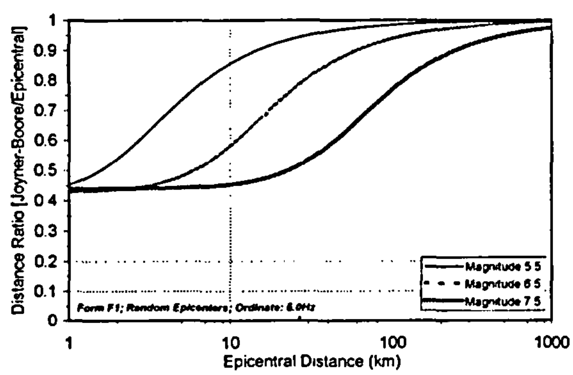

Distance Ratio [Joyner-Boore/Epicentral]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F1; Centered Epicenters; Ordinate: 25Hz

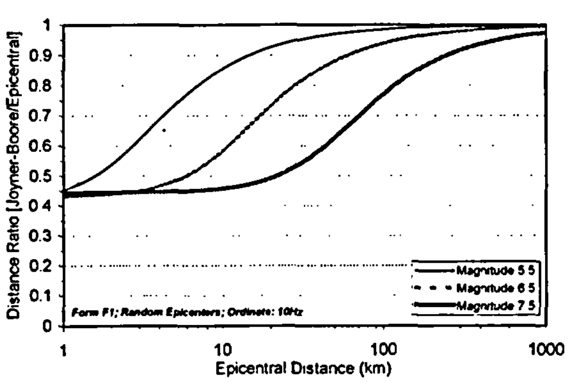

Distance Ratio [Joyner-Boore/Epicentral]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F1; Random Epicenters; Ordinate: PGA


Distance Ratio [Joyner-Boore/Epicentral]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F1; Random Epicenters; Ordinate: 0.5Hz


Distance Ratio [Joyner-Boore/Epicentral]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F1; Random Epicenters; Ordinate: 1.0Hz


Distance Ratio [Joyner-Boore/Epicentral]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F1; Random Epicenters; Ordinate: 2.5Hz


Distance Ratio [Joyner-Boore/Epicentral]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F1; Random Epicenters; Ordinate: 5.0Hz


Distance Ratio [Joyner-Boore/Epicentral]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F1; Random Epicenters; Ordinate: 10Hz

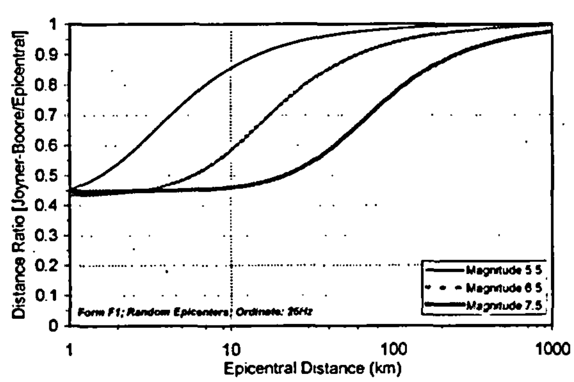
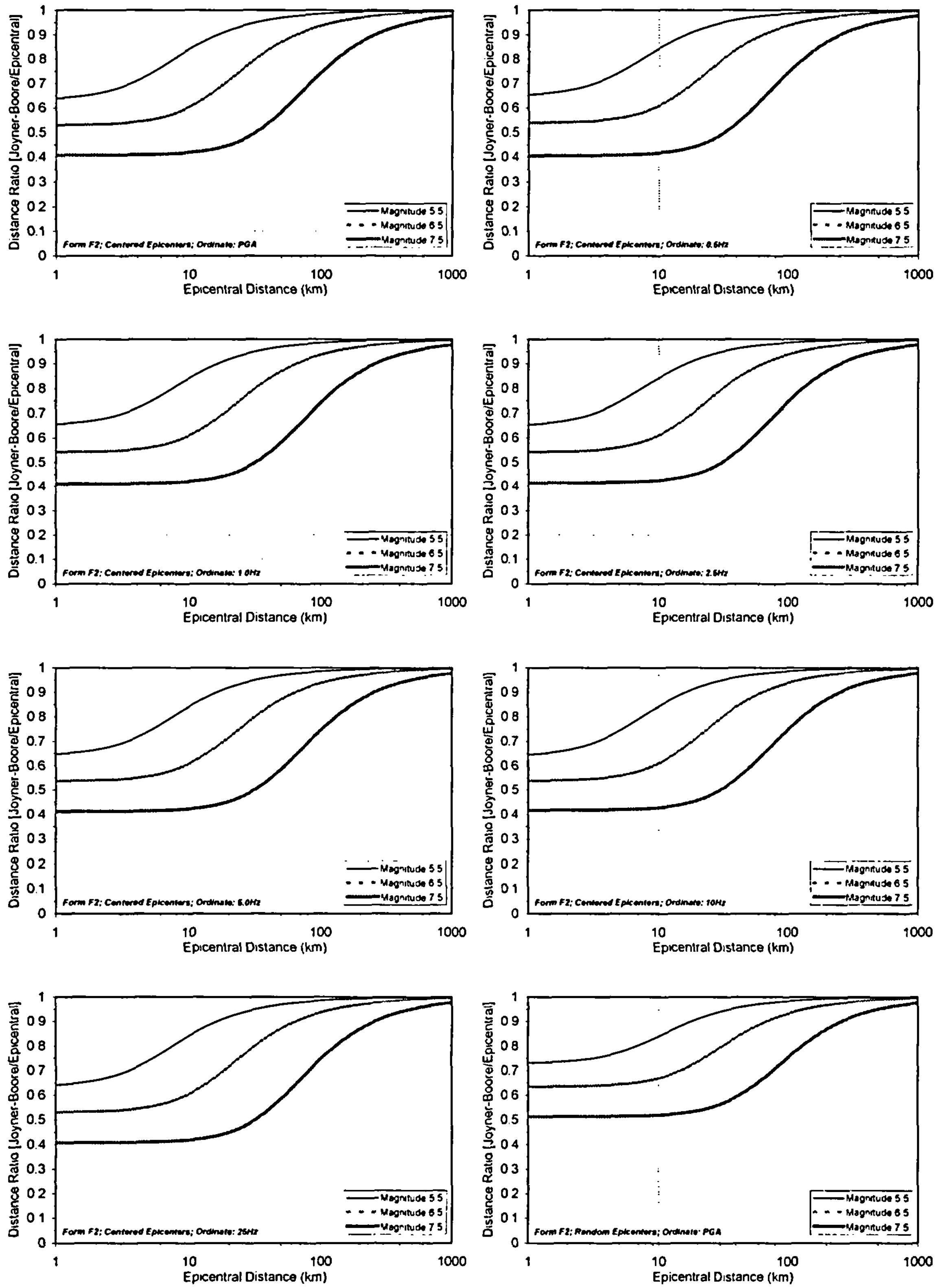
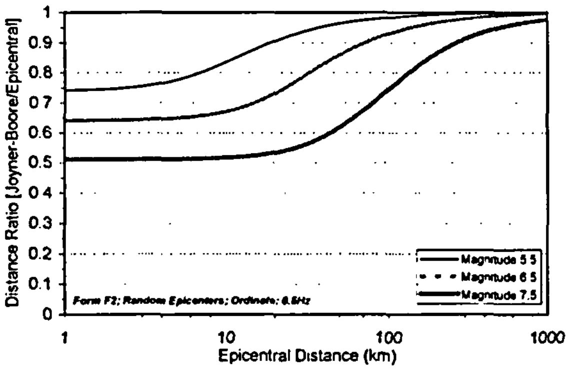
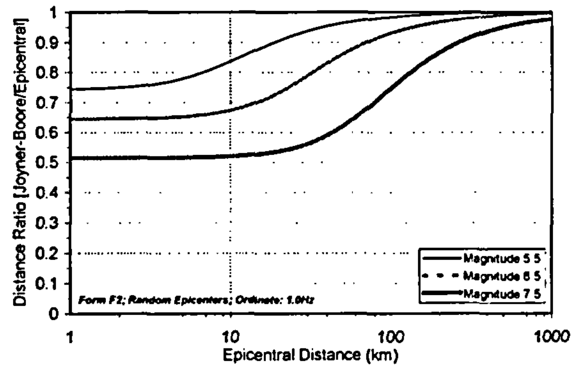
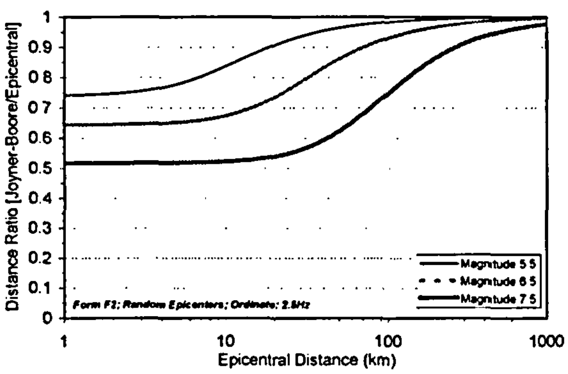

Distance Ratio [Joyner-Boore/Epicentral]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F1; Random Epicenters; Ordinate: 25Hz

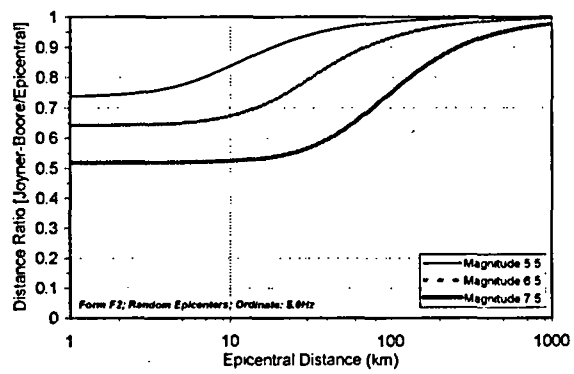
Figure A-2
Distance Adjustment: Epicentral to Joyner-Boore Distance F2

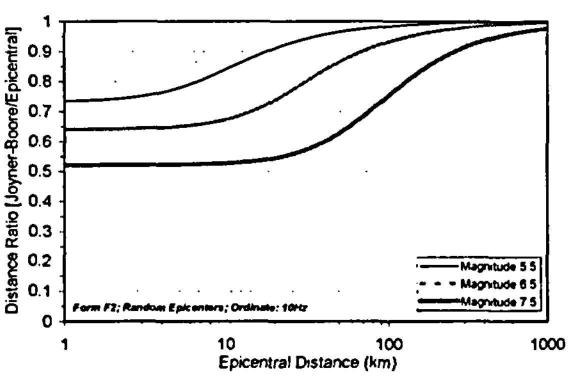



Distance Ratio [Joyner-Boore/Epicentral]
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F2; Random Epicenters; Ordinate: 0.5Hz


Distance Ratio [Joyner-Boore/Epicentral]
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F2; Random Epicenters; Ordinate: 1.0Hz


Distance Ratio [Joyner-Boore/Epicentral]
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F2; Random Epicenters; Ordinate: 2.5Hz


Distance Ratio [Joyner-Boore/Epicentral]
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F2; Random Epicenters; Ordinate: 5.0Hz


Distance Ratio [Joyner-Boore/Epicentral]
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F2; Random Epicenters; Ordinate: 10Hz

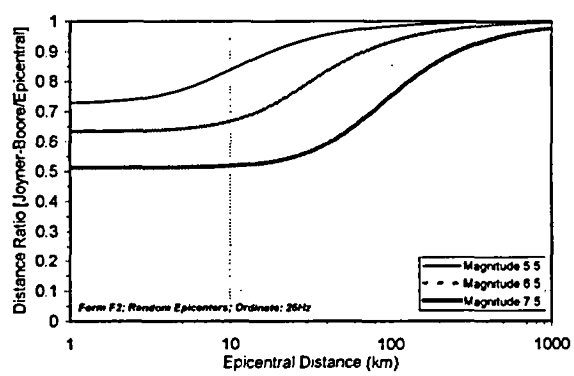
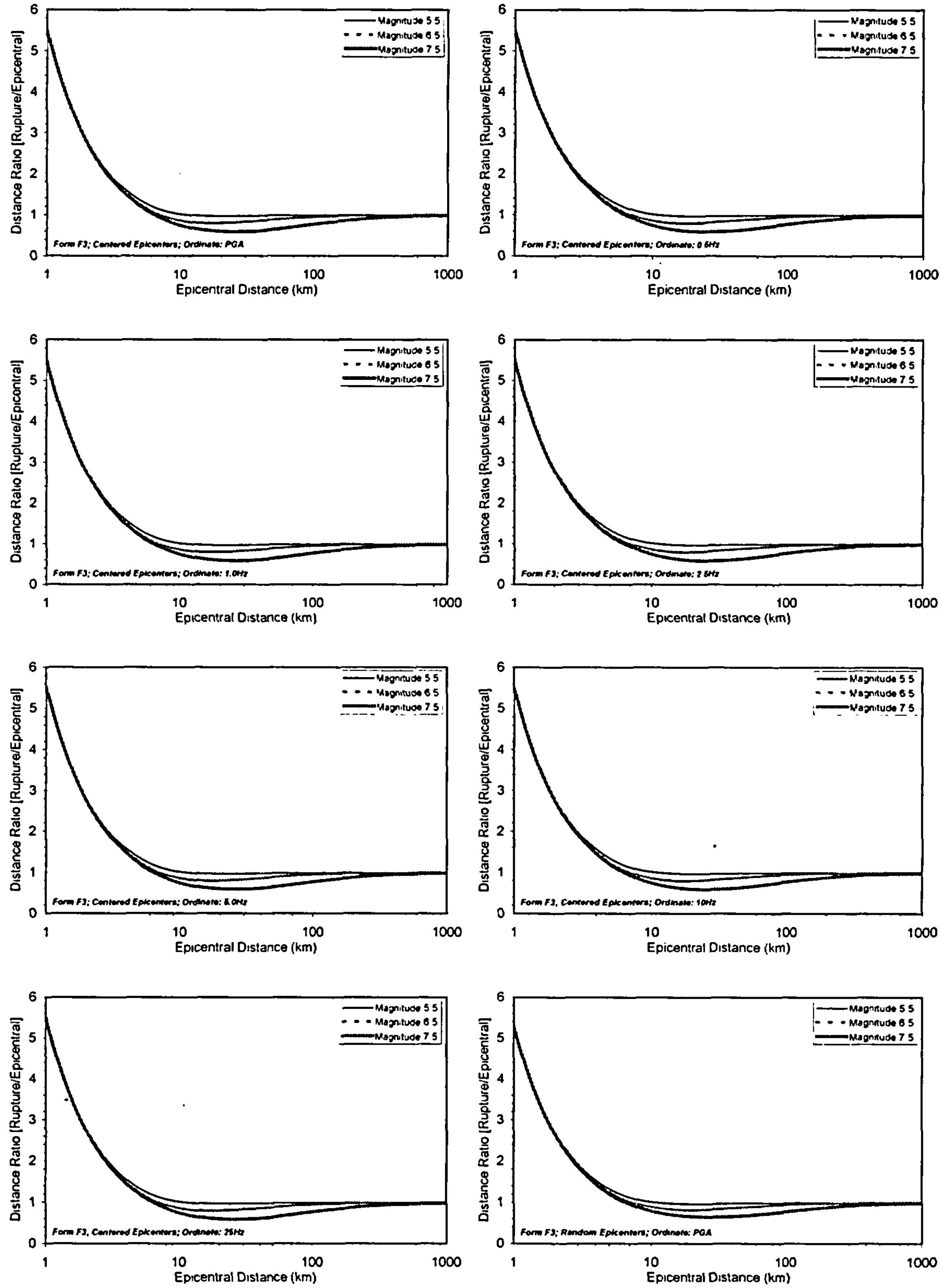
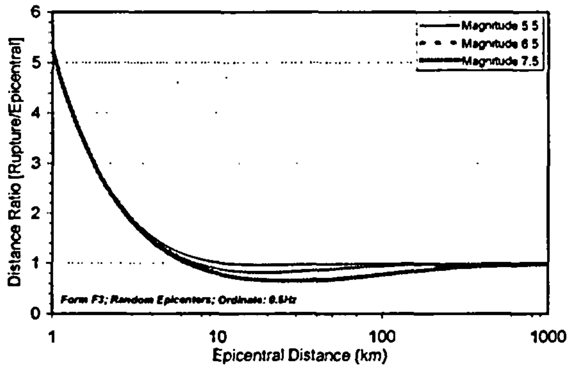
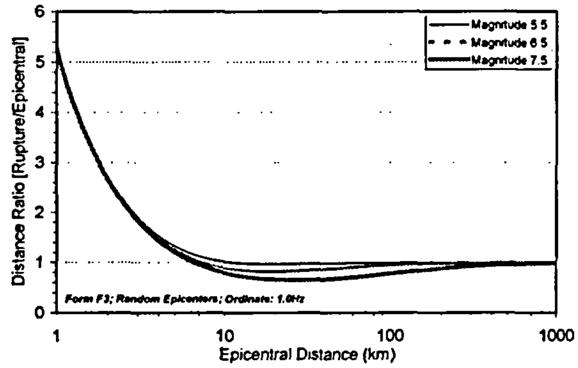

Distance Ratio [Joyner-Boore/Epicentral]
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F2; Random Epicenters; Ordinate: 25Hz

Figure A-3
Distance Adjustment: Epicentral to Joyner-Boore Distance F3

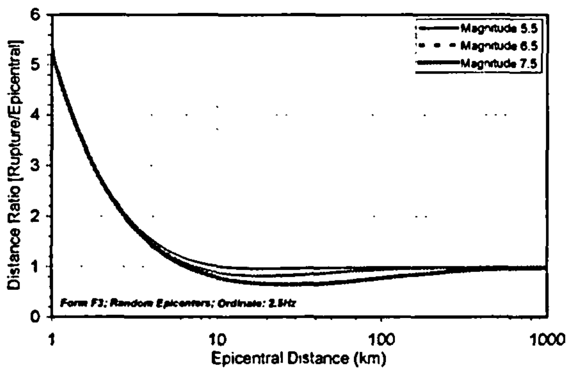




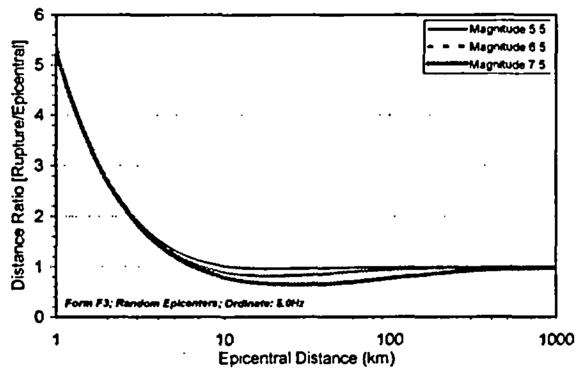
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F3; Random Epicenters; Ordinate: 0.5Hz
Distance Ratio [Rupture/Epicentral]
Epicentral Distance (km)



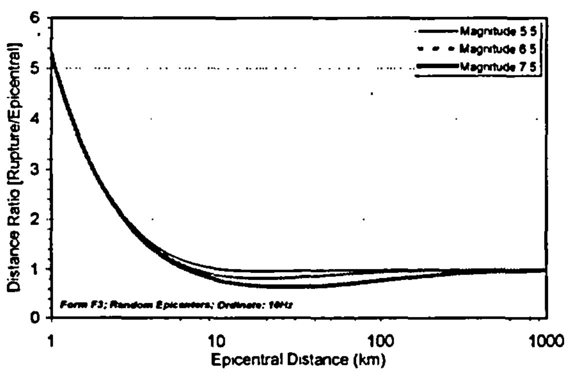
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F3; Random Epicenters; Ordinate: 1.0Hz
Distance Ratio [Rupture/Epicentral]
Epicentral Distance (km)



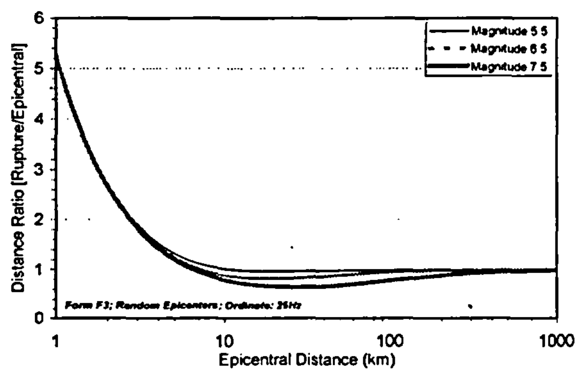
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F3; Random Epicenters; Ordinate: 2.5Hz
Distance Ratio [Rupture/Epicentral]
Epicentral Distance (km)



Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F3; Random Epicenters; Ordinate: 5.0Hz
Distance Ratio [Rupture/Epicentral]
Epicentral Distance (km)

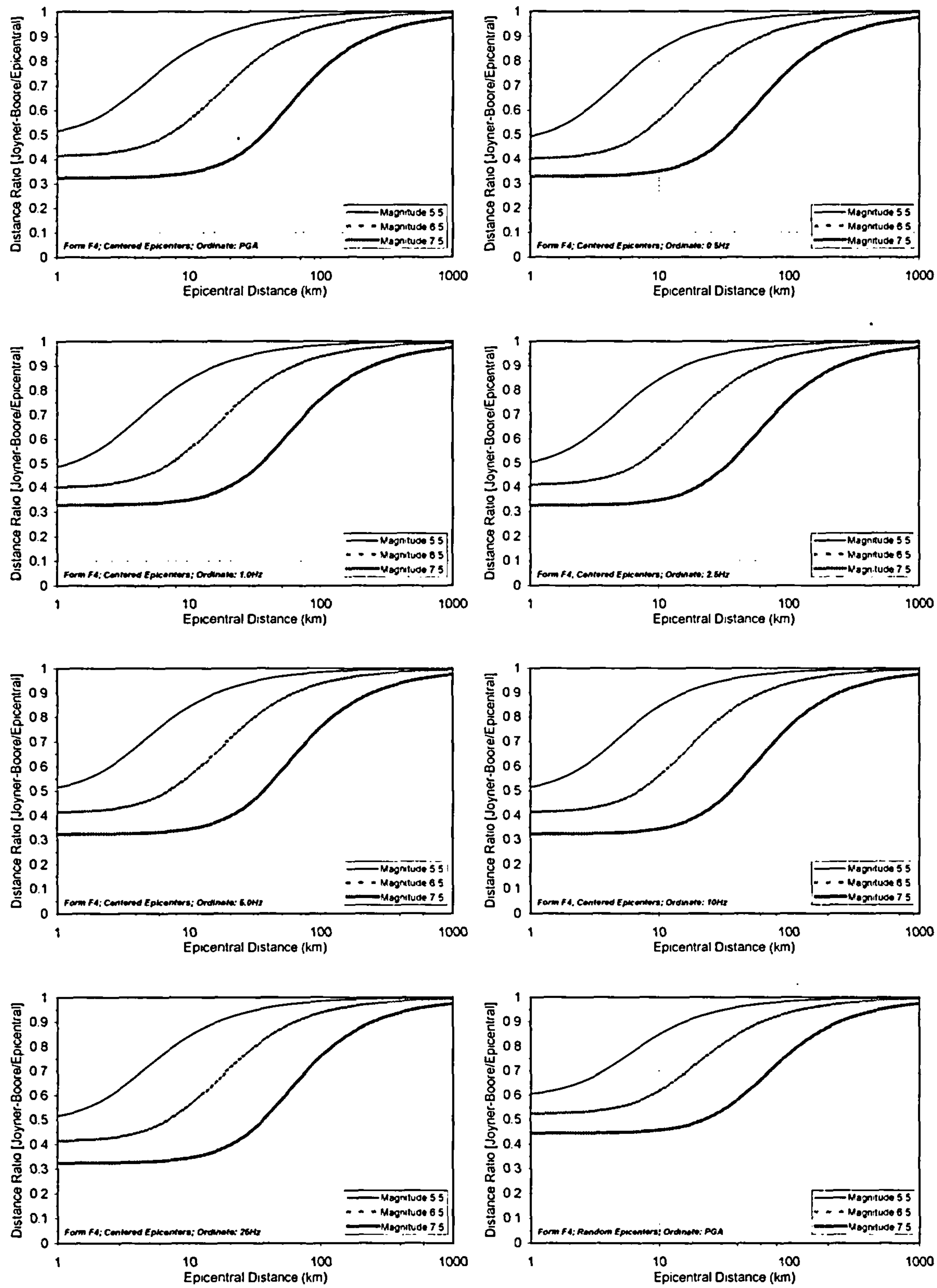


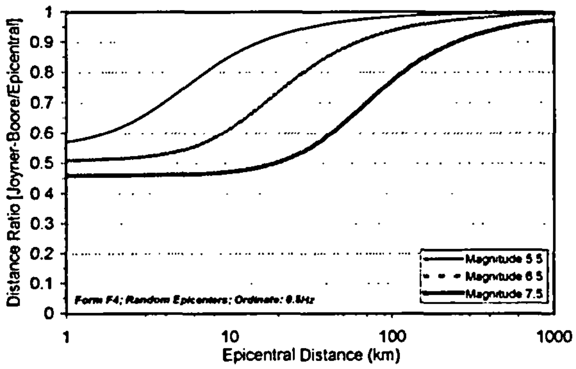
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F3; Random Epicenters; Ordinate: 10Hz
Distance Ratio [Rupture/Epicentral]
Epicentral Distance (km)

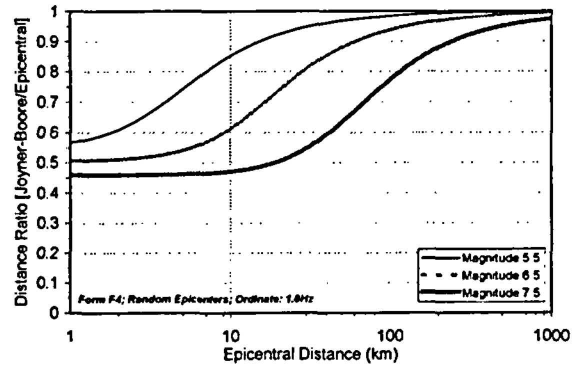


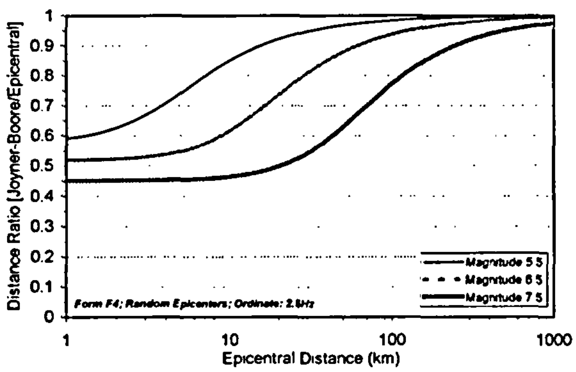
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F3; Random Epicenters; Ordinate: 25Hz
Distance Ratio [Rupture/Epicentral]
Epicentral Distance (km)

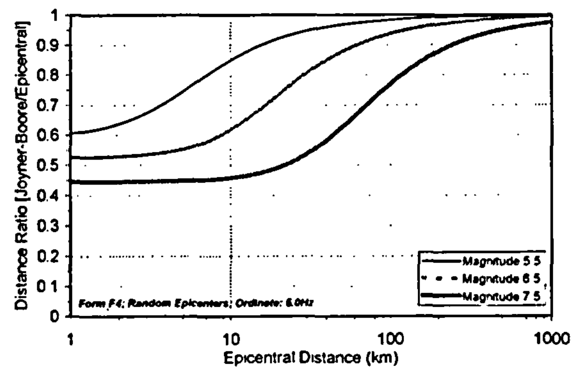
Figure A-4
Distance Adjustment: Epicentral to Joyner-Boore Distance F4

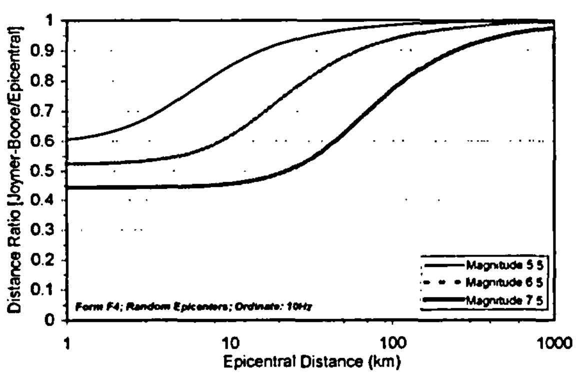


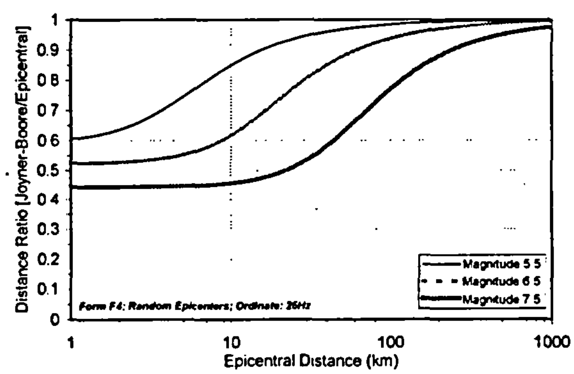

Distance Ratio [Joyner-Boore/Epicentral]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F4; Random Epicenters; Ordinate: 0.5Hz


Distance Ratio [Joyner-Boore/Epicentral]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F4; Random Epicenters; Ordinate: 1.0Hz


Distance Ratio [Joyner-Boore/Epicentral]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F4; Random Epicenters; Ordinate: 2.5Hz


Distance Ratio [Joyner-Boore/Epicentral]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F4; Random Epicenters; Ordinate: 5.0Hz

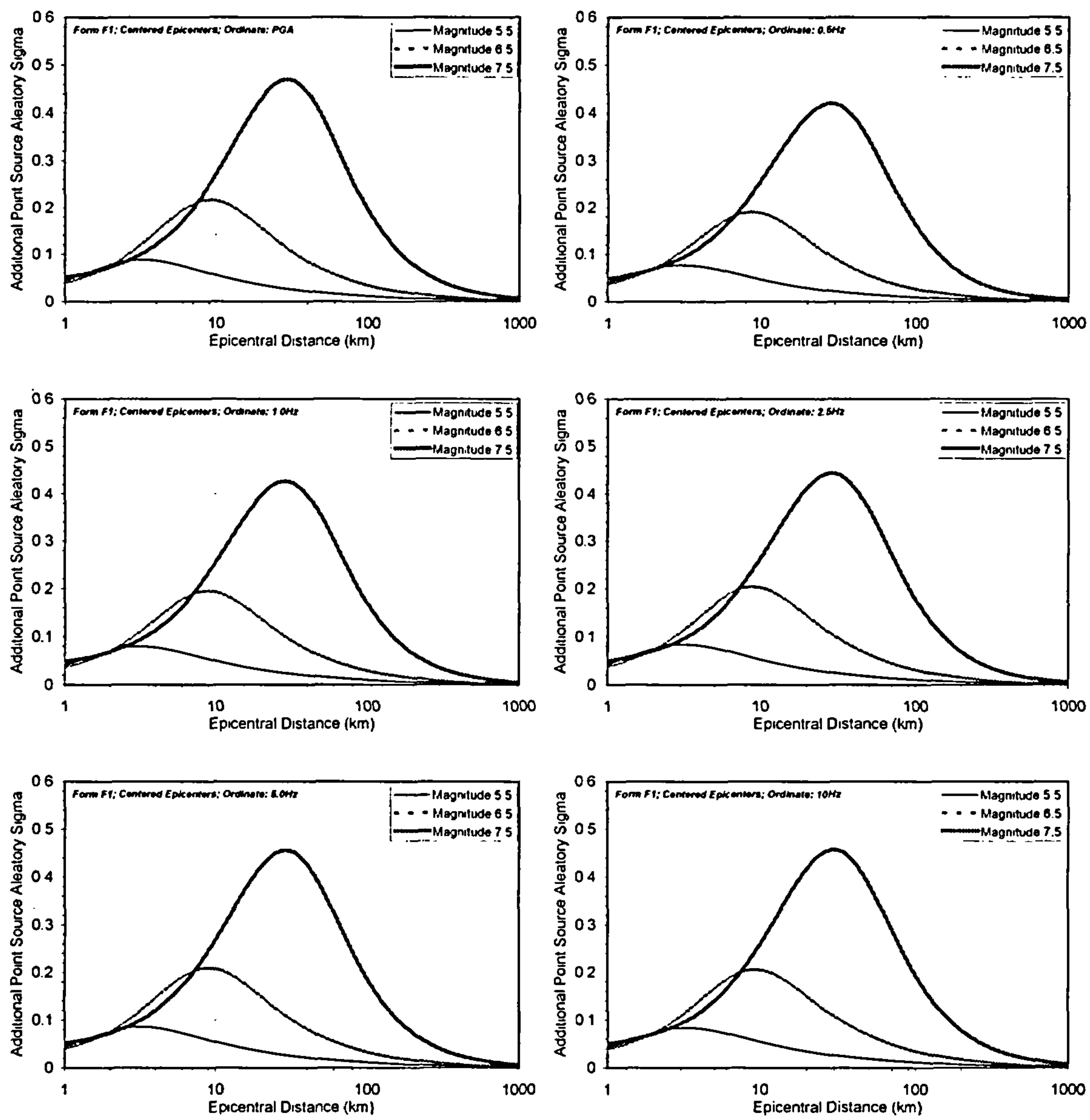

Distance Ratio [Joyner-Boore/Epicentral]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F4; Random Epicenters; Ordinate: 10Hz

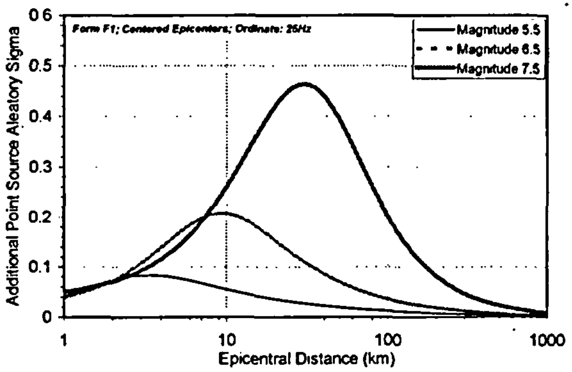

Distance Ratio [Joyner-Boore/Epicentral]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
Epicentral Distance (km)
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Form F4; Random Epicenters; Ordinate: 25Hz

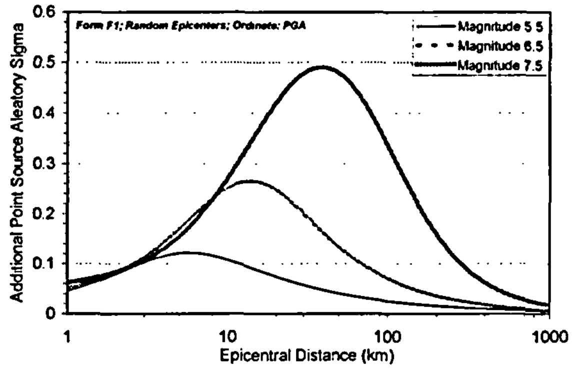
B

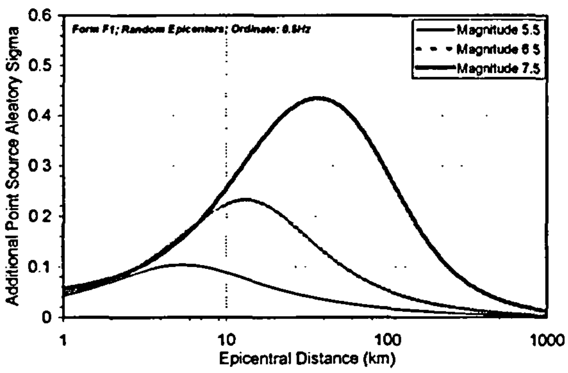
ADDITIONAL ALEATORY VARIABILITY FOR POINT-SOURCE APPLICATIONS

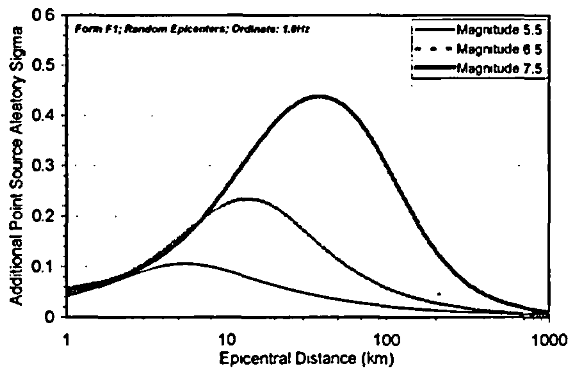
Figure B-1
Additional Point Source Aleatory Variability for Joyner-Boore Distance F1

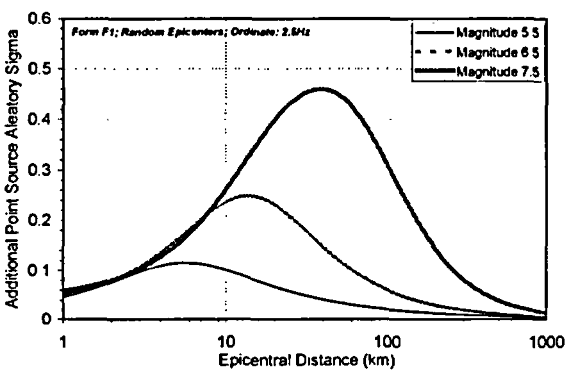


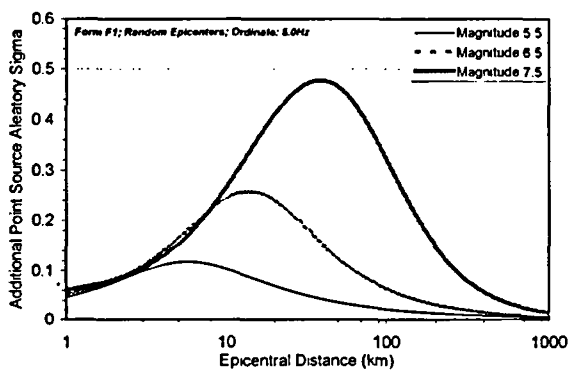

Form F1; Centered Epicenters; Ordinate: 25Hz
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)

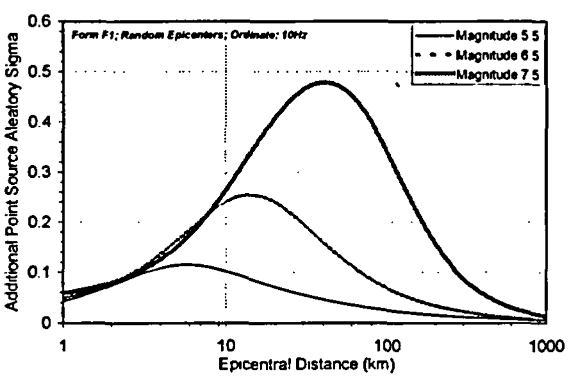

Form F1; Random Epicenters; Ordinate: PGA
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)


Form F1; Random Epicenters; Ordinate: 0.5Hz
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)


Form F1; Random Epicenters; Ordinate: 1.0Hz
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)


Form F1; Random Epicenters; Ordinate: 2.5Hz
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)


Form F1; Random Epicenters; Ordinate: 5.0Hz
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)


Form F1; Random Epicenters; Ordinate: 10Hz
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)

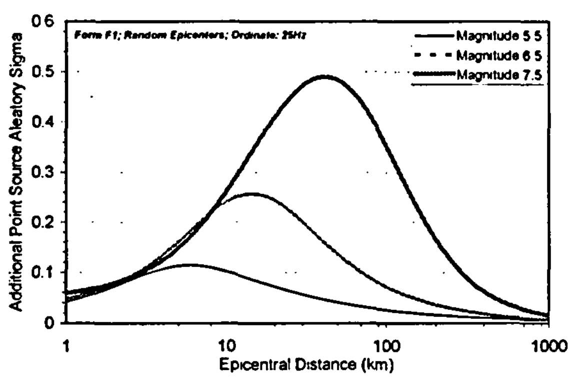
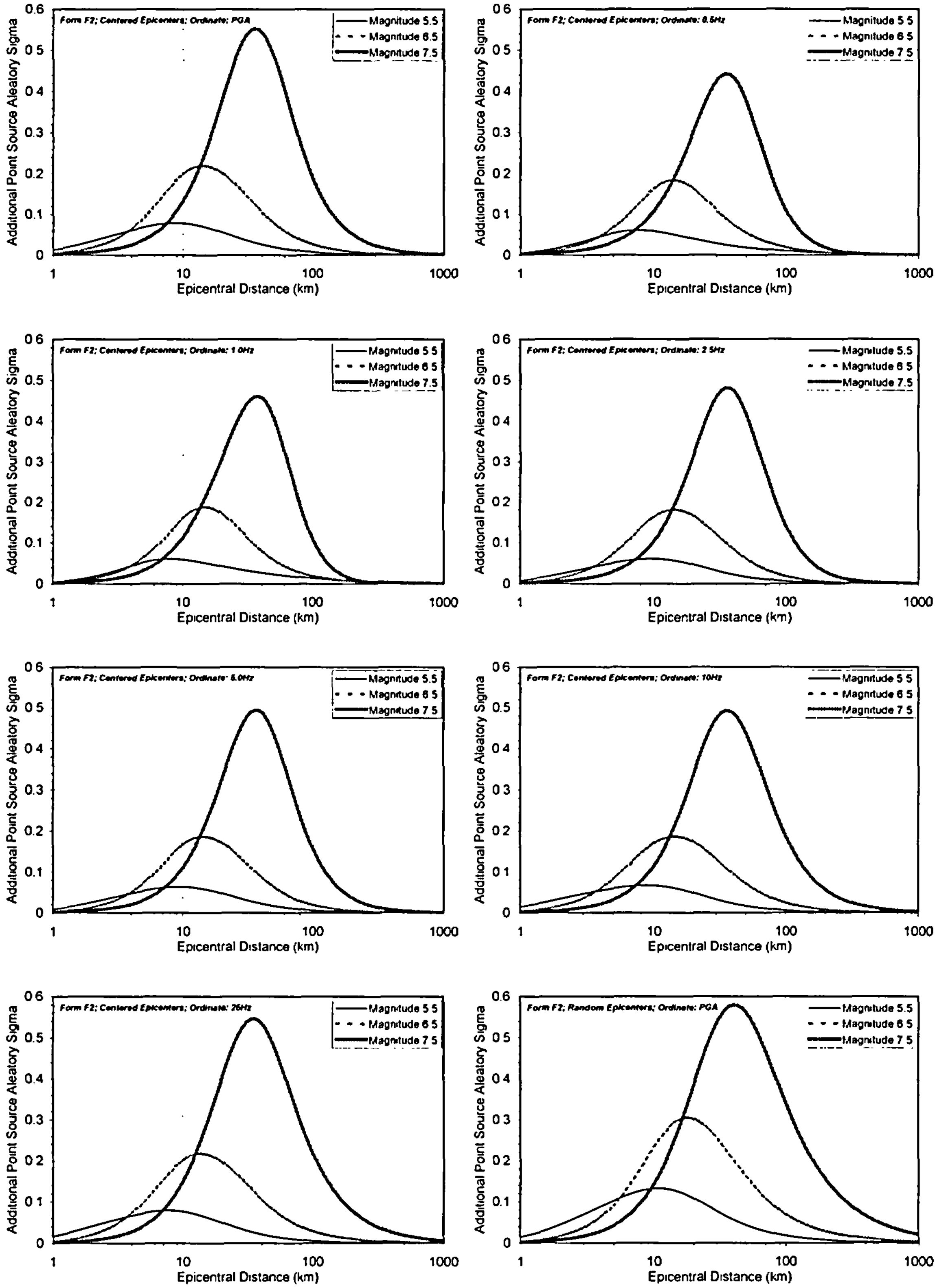
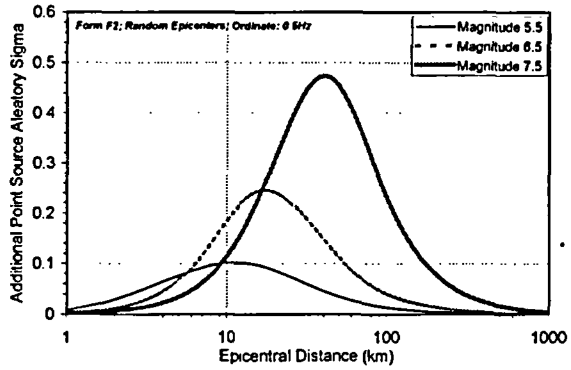
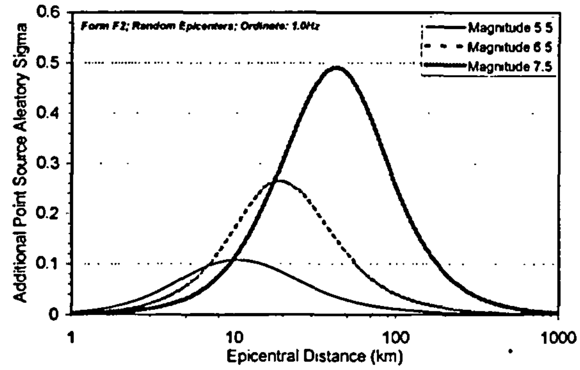
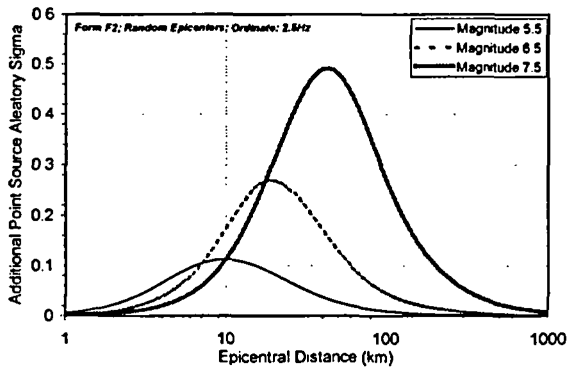

Form F1; Random Epicenters; Ordinate: 25Hz
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)

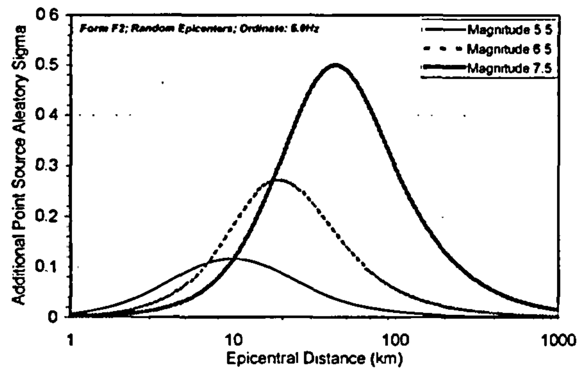
Figure B-2
Additional Point Source Aleatory Variability for Joyner-Boore Distance F2

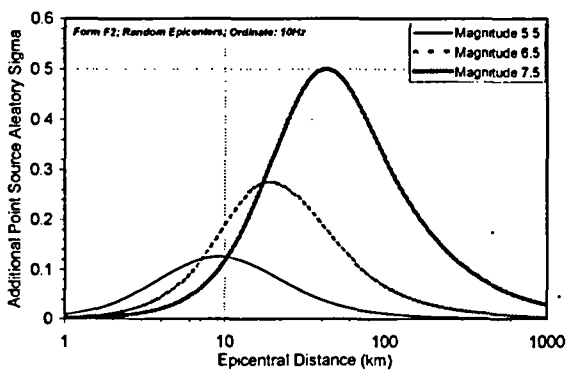



Form F2; Random Epicenters; Ordinate: 0.5Hz
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000


Form F2; Random Epicenters; Ordinate: 1.0Hz
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000


Form F2; Random Epicenters; Ordinate: 2.5Hz
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000


Form F2; Random Epicenters; Ordinate: 5.0Hz
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000


Form F2; Random Epicenters; Ordinate: 10Hz
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000

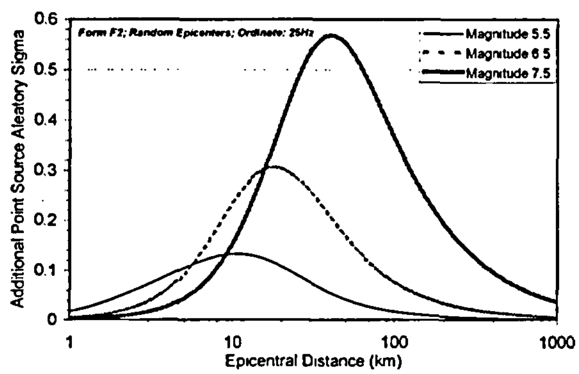
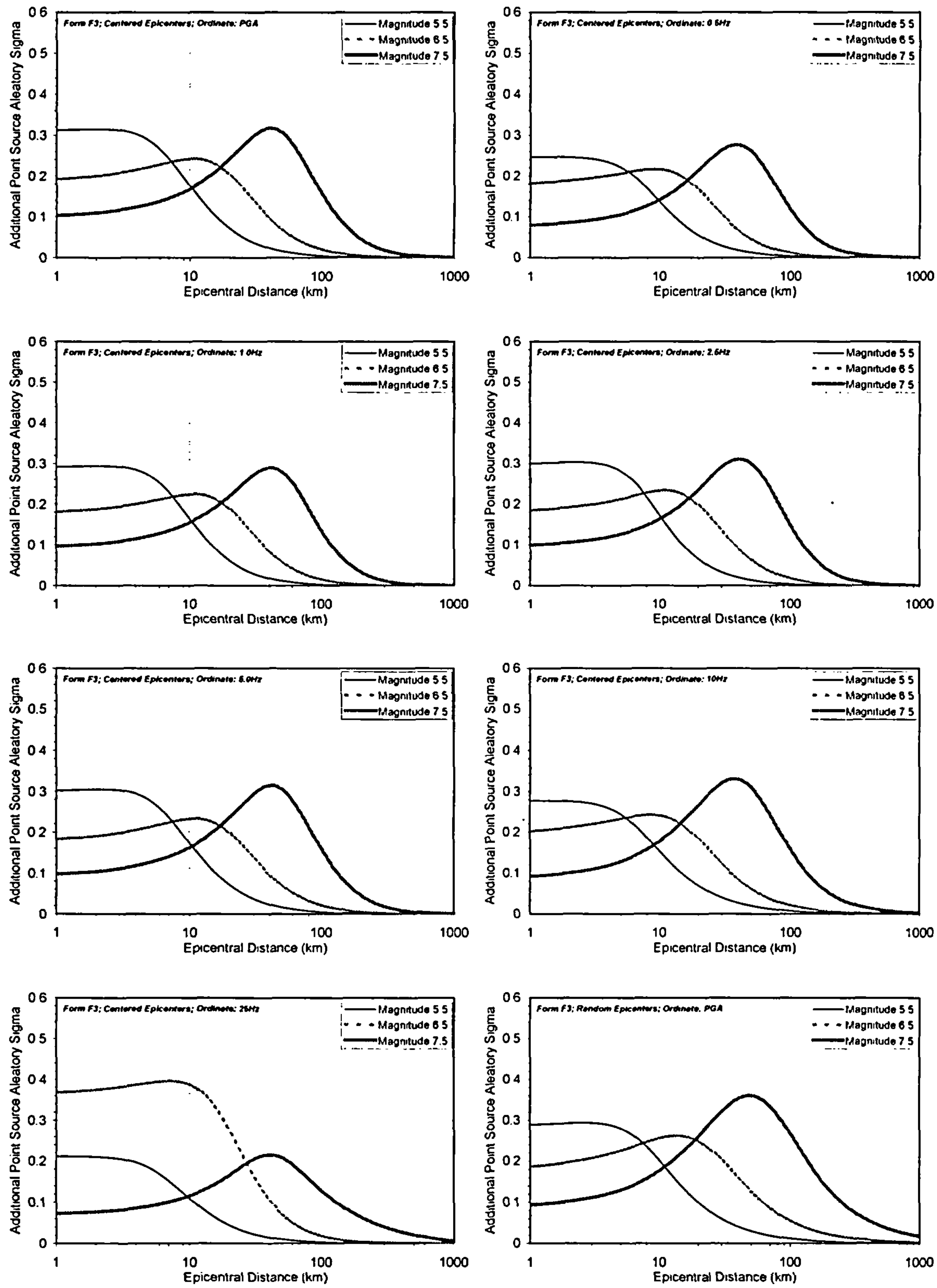
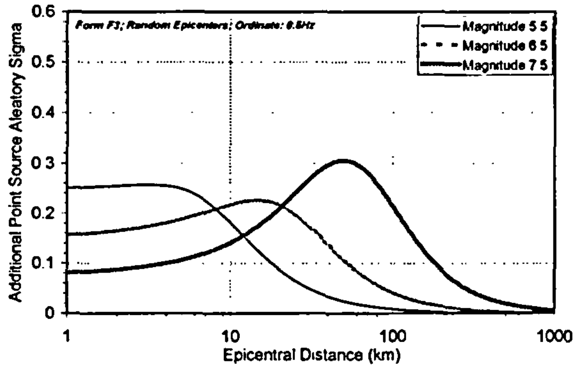
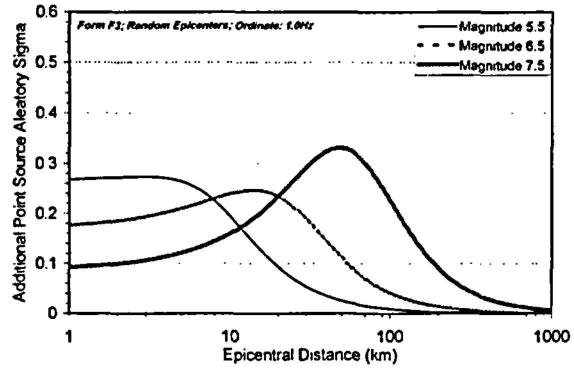
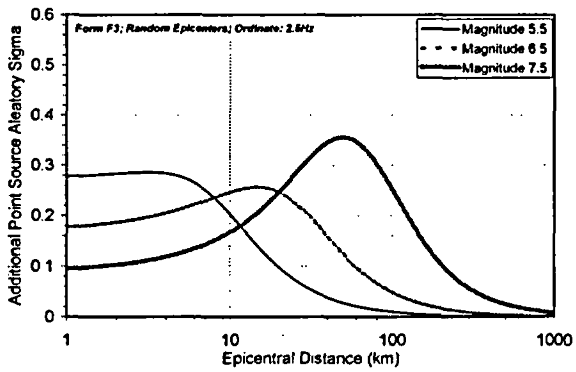

Form F2; Random Epicenters; Ordinate: 25Hz
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000

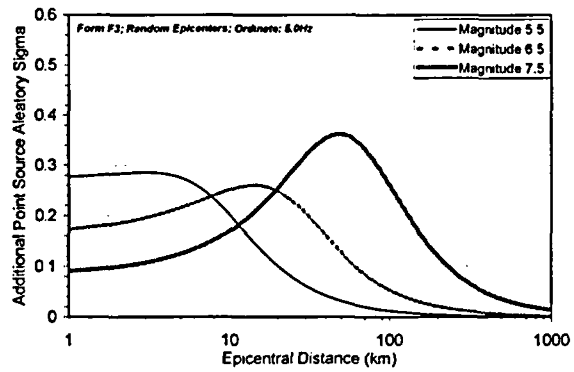
Figure B-3
Additional Point Source Aleatory Variability for Joyner-Boore Distance F3

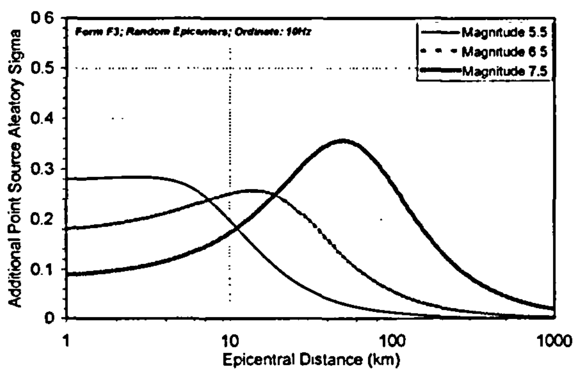



Form F3; Random Epicenters; Ordinate:
Magnitude 5 5
Magnitude 6 5
Magnitude 7 5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)


Form F3; Random Epicenters; Ordinate:
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)


Form F3; Random Epicenters; Ordinate:
Magnitude 5.5
Magnitude 6 5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)


Form F3; Random Epicenters; Ordinate:
Magnitude 5 5
Magnitude 6 5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)


Form F3; Random Epicenters; Ordinate:
Magnitude 5.5
Magnitude 6 5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)

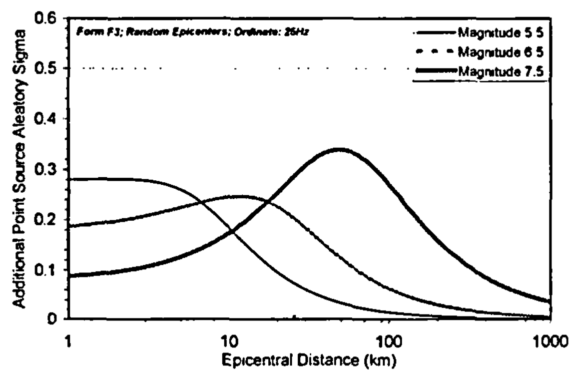
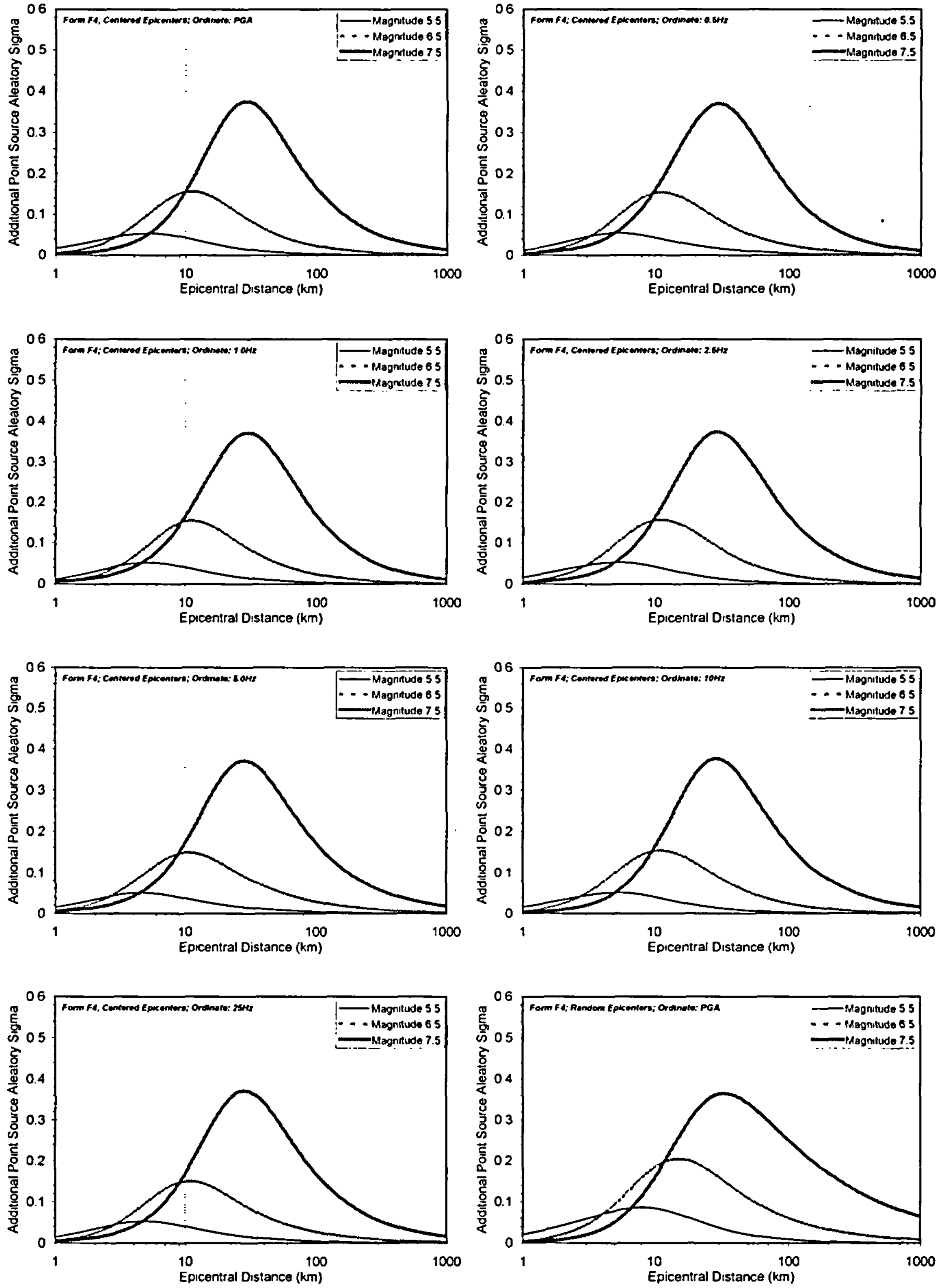
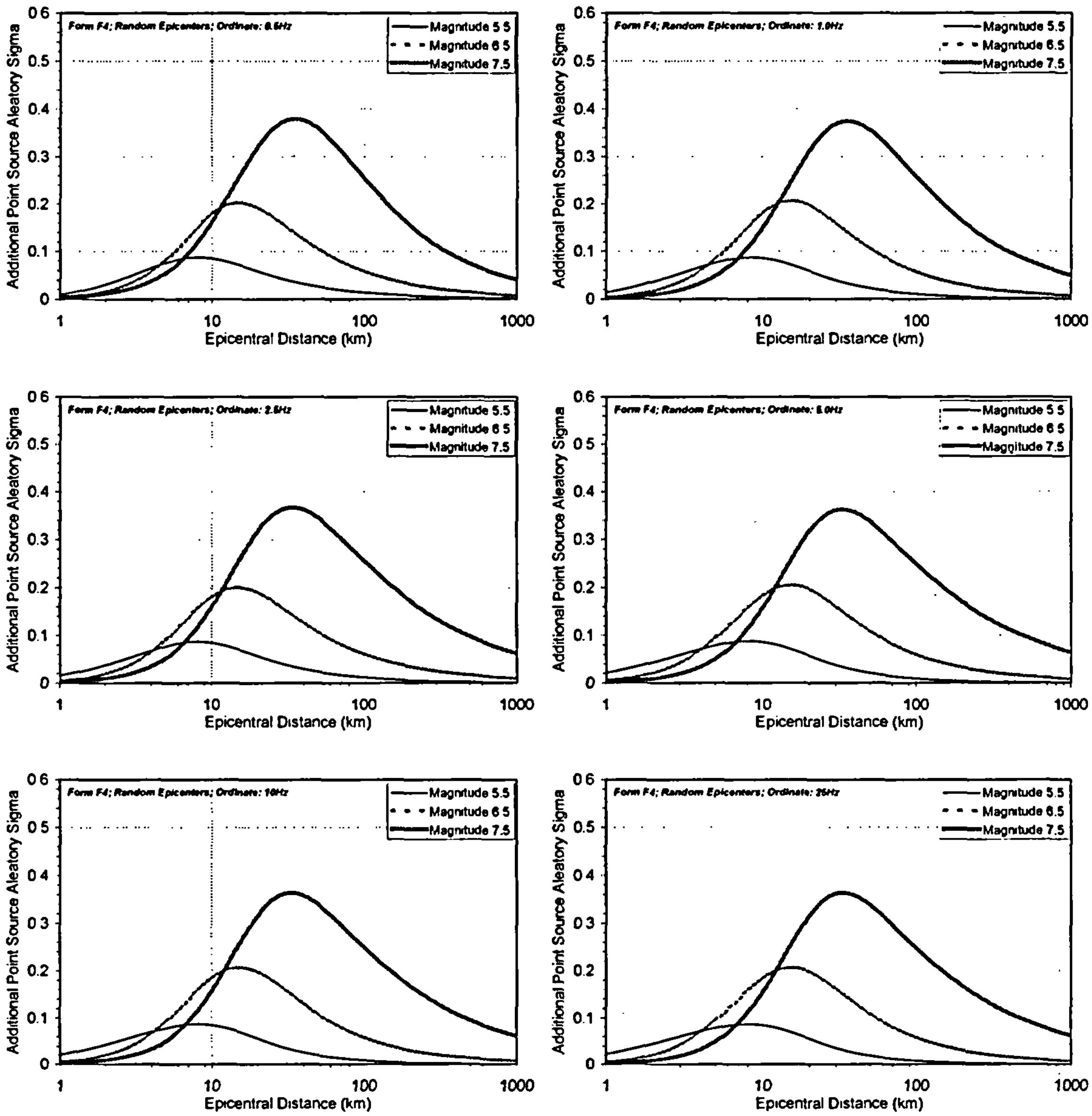

Form F3; Random Epicenters; Ordinate:
Magnitude 5 5
Magnitude 6 5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)

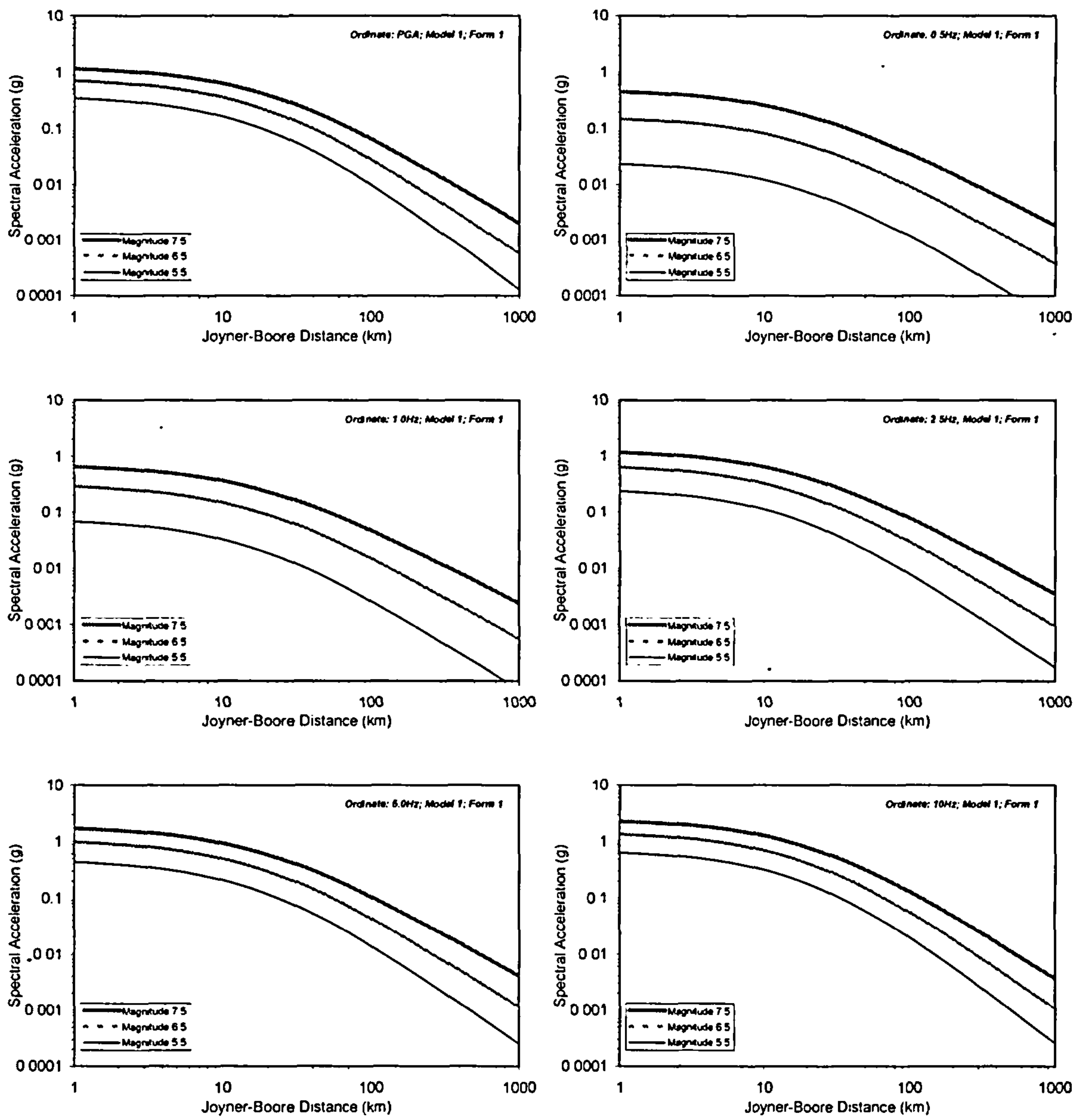
Figure B-4
Additional Point Source Aleatory Variability for Joyner-Boore Distance F4

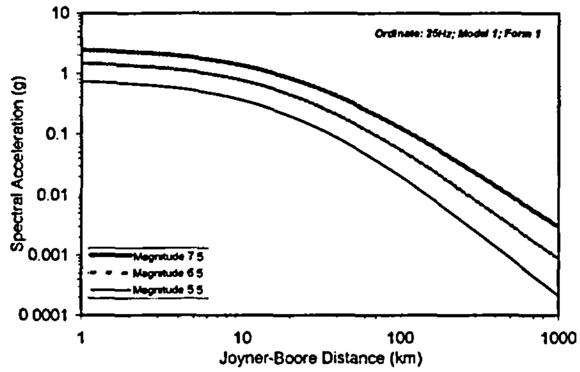


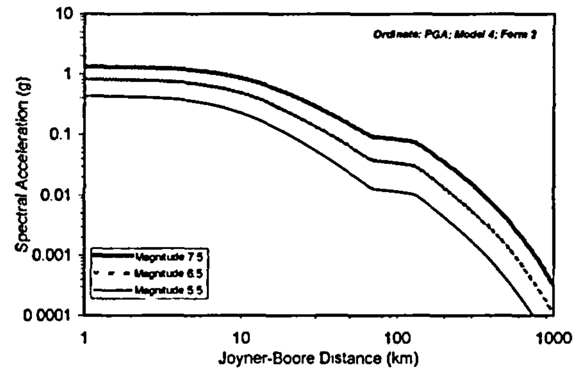

Form F4; Random Epicenters; Ordinate:
Form F4; Random Epicenters; Ordinate: 1.0Hz
Form F4; Random Epicenters; Ordinate: 2.5Hz
Form F4; Random Epicenters; Ordinate: 5.0Hz
Form F4; Random Epicenters; Ordinate: 10Hz
Form F4; Random Epicenters; Ordinate: 25Hz
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
Additional Point Source Aleatory Sigma
Epicentral Distance (km)
0
0.1
0.2
0.3
0.4
0.5
0.6
1
10
100
1000

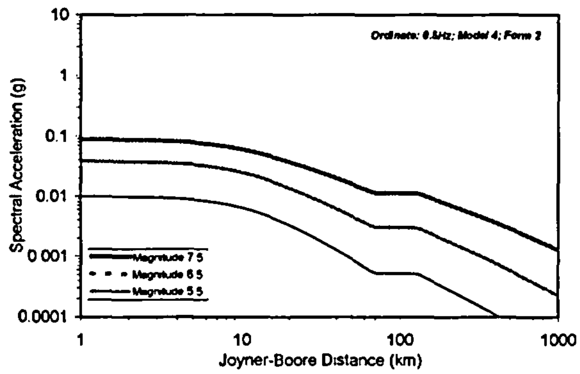
C
MEDIAN GROUND MOTION MODEL RESULTS

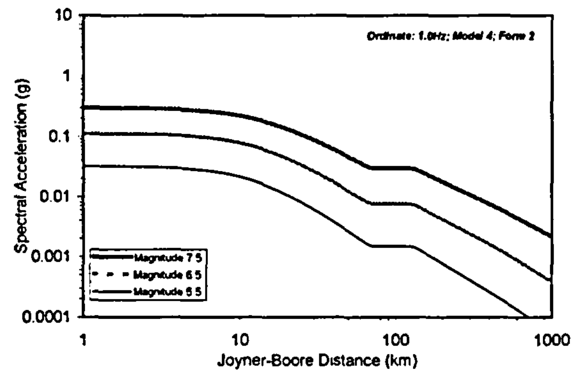
Figure C-1
Median Ground Motion for General Mid-Continent Area Sources: Cluster Lower Alternative Estimate Relations

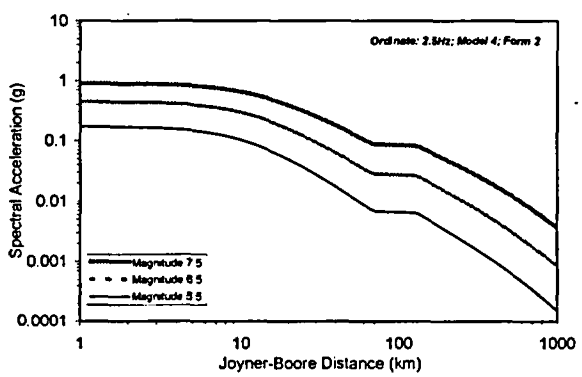


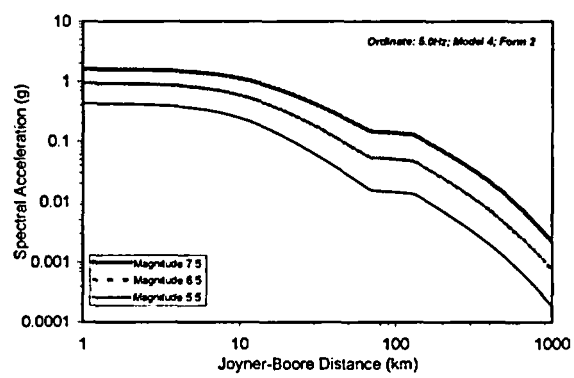

Ordinate: 25Hz; Model 1; Form 1
Spectral Acceleration (g)
Joyner-Boore Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

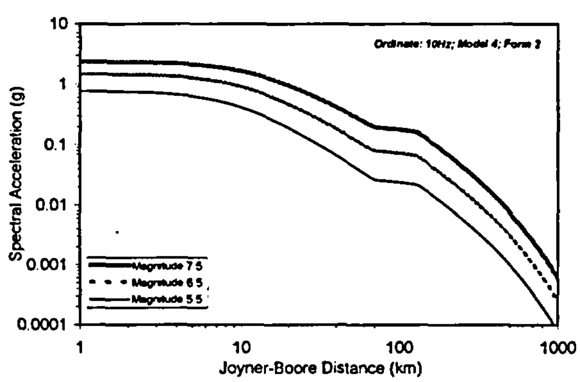

Ordinate: PGA; Model 4; Form 2
Spectral Acceleration (g)
Joyner-Boore Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

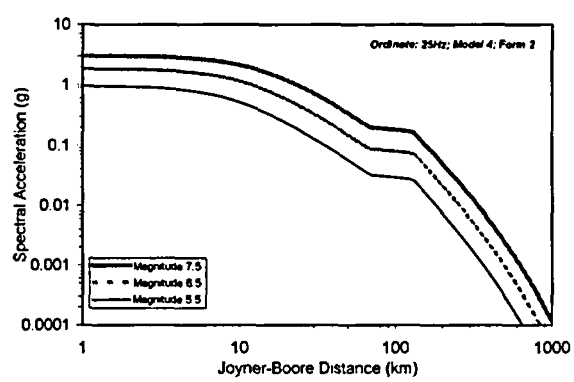

Ordinate: 0.5Hz; Model 4; Form 2
Spectral Acceleration (g)
Joyner-Boore Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

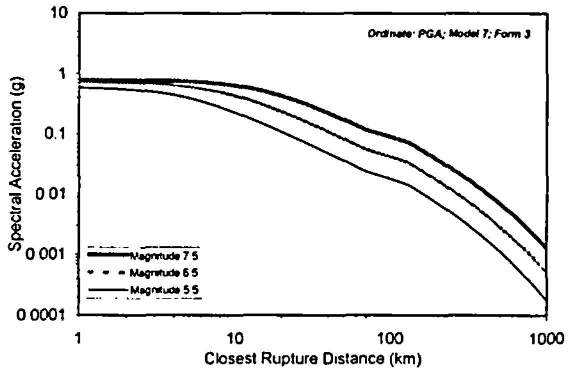

Ordinate: 1.0Hz; Model 4; Form 2
Spectral Acceleration (g)
Joyner-Boore Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

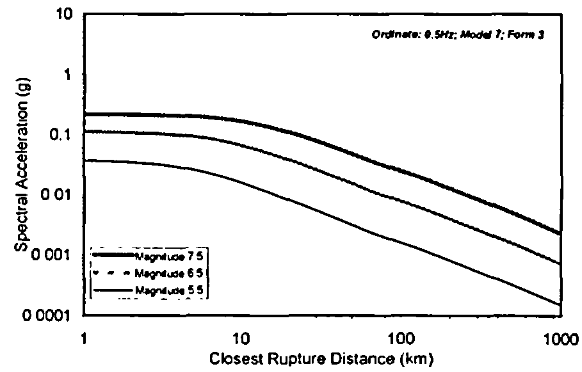

Ordinate: 2.5Hz; Model 4; Form 2
Spectral Acceleration (g)
Joyner-Boore Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

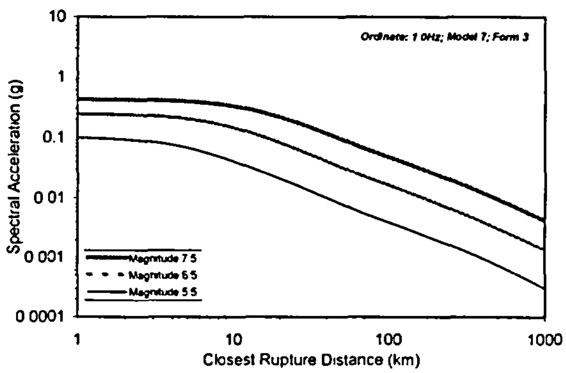

Ordinate: 5.0Hz; Model 4; Form 2
Spectral Acceleration (g)
Joyner-Boore Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

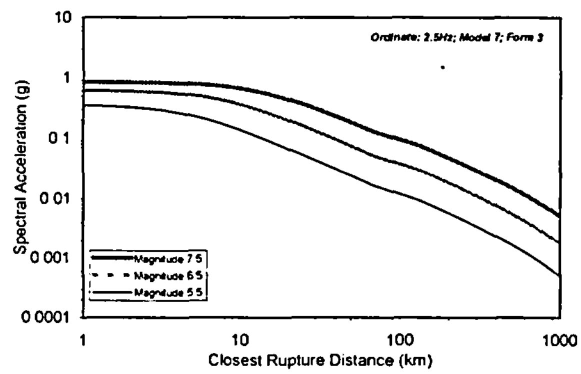

Ordinate: 10Hz; Model 4; Form 2
Spectral Acceleration (g)
Joyner-Boore Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

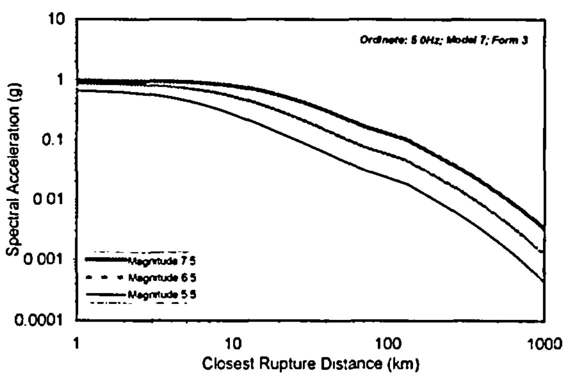

Ordinate: 25Hz; Model 4; Form 2
Spectral Acceleration (g)
Joyner-Boore Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

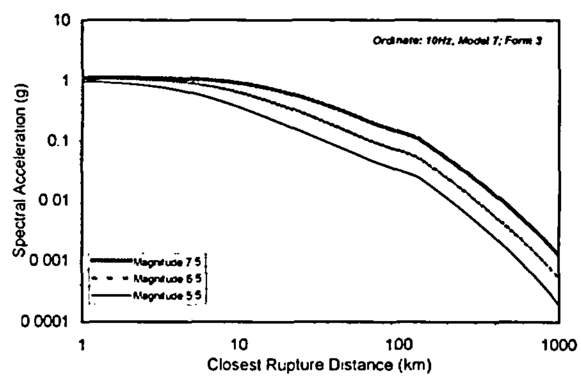

Ordinate: PGA; Model 7; Form 3
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
Spectral Acceleration (g)
Closest Rupture Distance (km)


Ordinate: 0.5Hz; Model 7; Form 3
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
Spectral Acceleration (g)
Closest Rupture Distance (km)


Ordinate: 1.0Hz; Model 7; Form 3
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
Spectral Acceleration (g)
Closest Rupture Distance (km)


Ordinate: 2.5Hz; Model 7; Form 3
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
Spectral Acceleration (g)
Closest Rupture Distance (km)


Ordinate: 5.0Hz; Model 7; Form 3
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
Spectral Acceleration (g)
Closest Rupture Distance (km)


Ordinate: 10Hz; Model 7; Form 3
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
Spectral Acceleration (g)
Closest Rupture Distance (km)

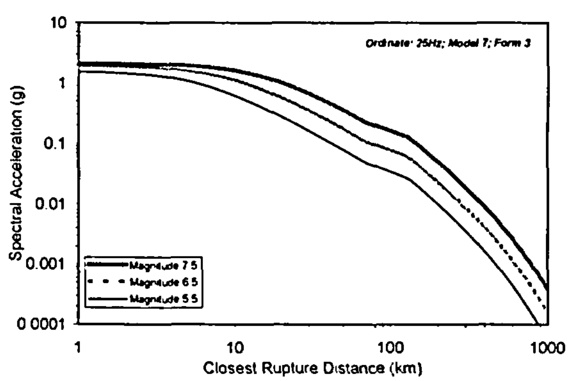
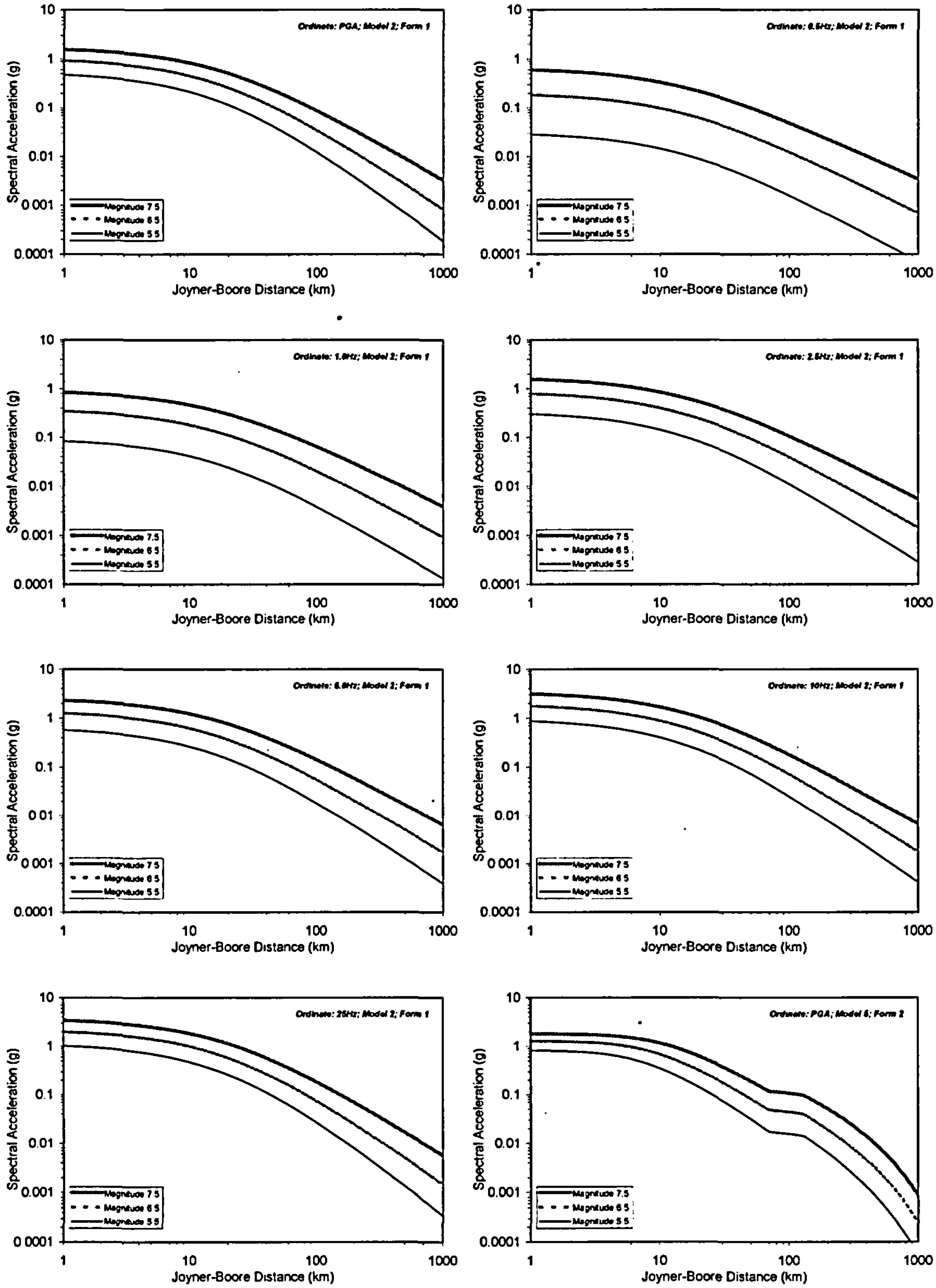
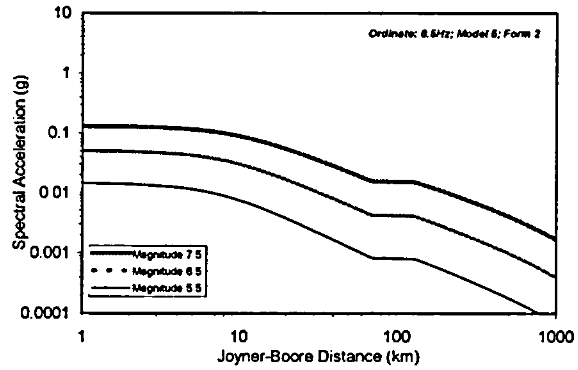
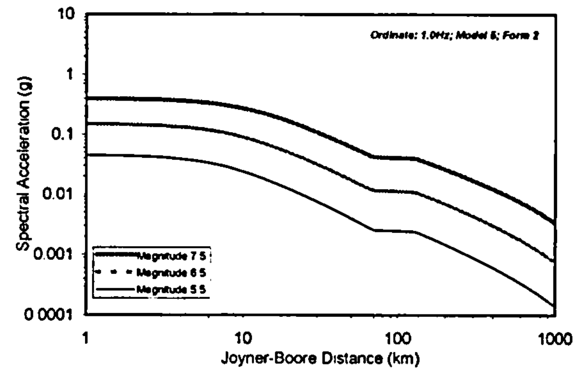
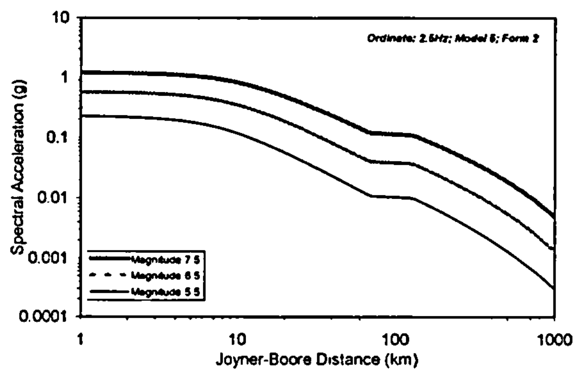

Ordinate: 25Hz; Model 7; Form 3
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
Spectral Acceleration (g)
Closest Rupture Distance (km)

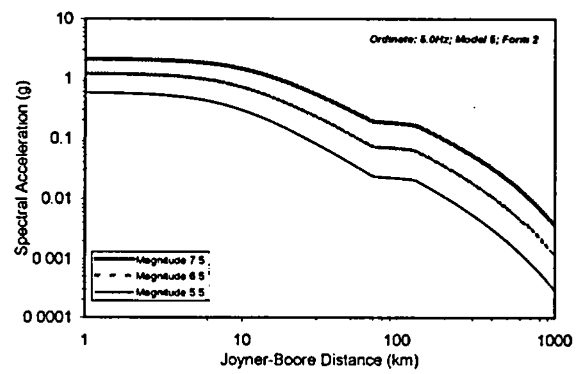
Figure C-2
Median Ground Motion for General Mid-Continent Area Sources: Cluster Middle Alternative Estimate Relations

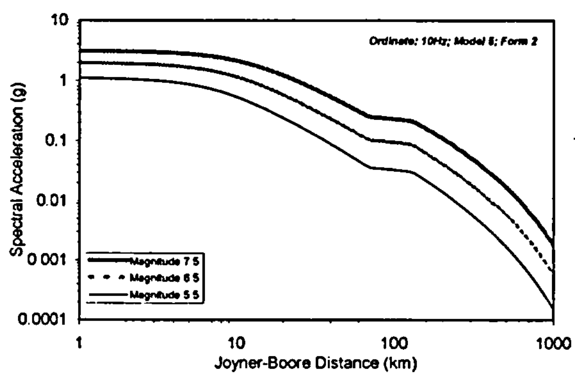


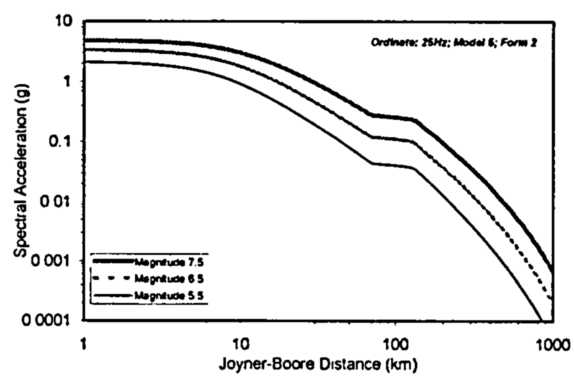

Ordinate: 0.5Hz; Model 5; Form 2
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
1
10
100
1000
Joyner-Boore Distance (km)

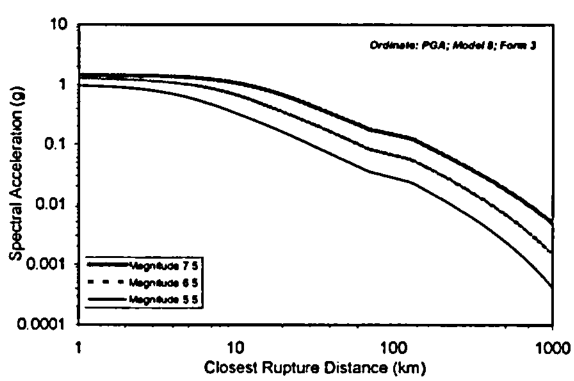

Ordinate: 1.0Hz; Model 5; Form 2
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
1
10
100
1000
Joyner-Boore Distance (km)

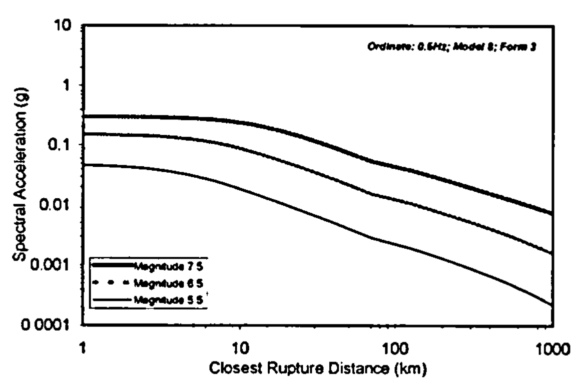

Ordinate: 2.5Hz; Model 5; Form 2
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
1
10
100
1000
Joyner-Boore Distance (km)

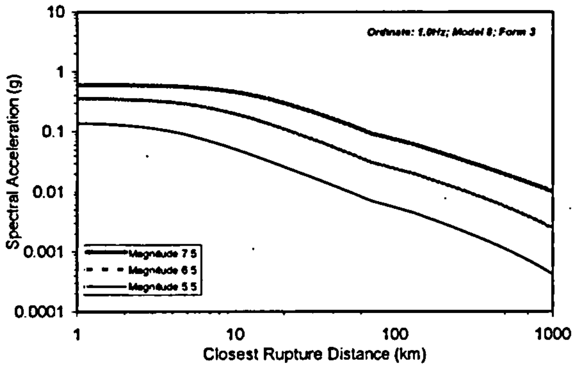

Ordinate: 5.0Hz; Model 5; Form 2
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
1
10
100
1000
Joyner-Boore Distance (km)

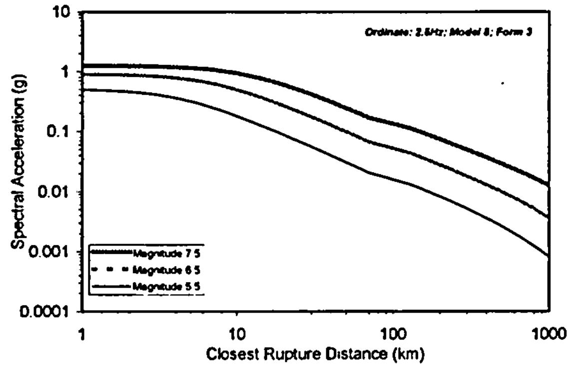

Ordinate: 10Hz; Model 5; Form 2
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
1
10
100
1000
Joyner-Boore Distance (km)

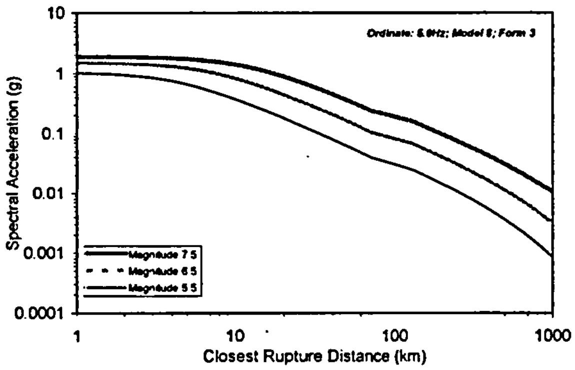

Ordinate: 25Hz; Model 5; Form 2
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
1
10
100
1000
Joyner-Boore Distance (km)

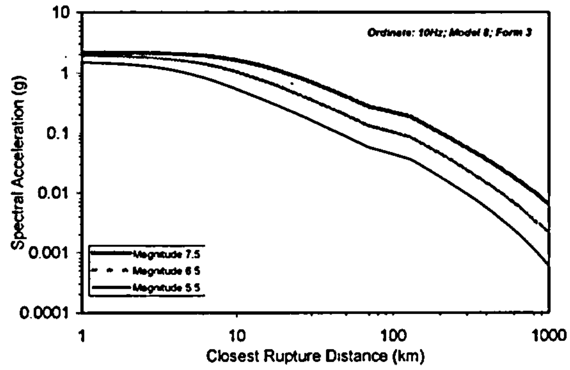

Ordinate: PGA; Model 8; Form 3
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
1
10
100
1000
Closest Rupture Distance (km)


Ordinate: 0.5Hz; Model 8; Form 3
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
1
10
100
1000
Closest Rupture Distance (km)


Ordinate: 1.0Hz; Model 8; Form 3
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Closest Rupture Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5


Ordinate: 2.5Hz; Model 8; Form 3
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Closest Rupture Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5


Ordinate: 5.0Hz; Model 8; Form 3
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Closest Rupture Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5


Ordinate: 10Hz; Model 8; Form 3
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Closest Rupture Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

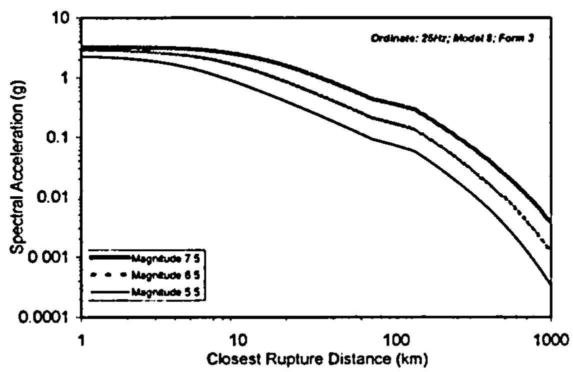
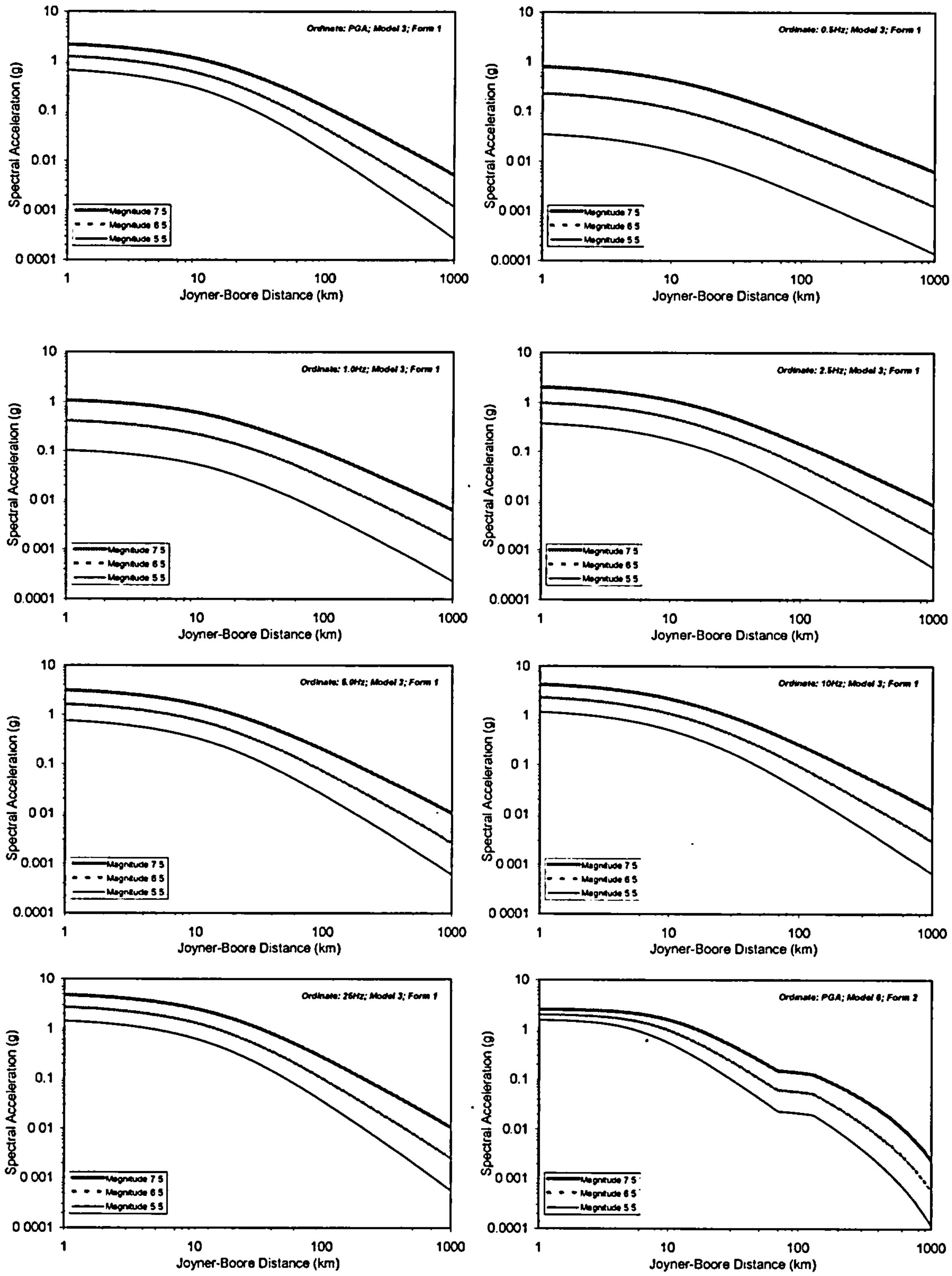
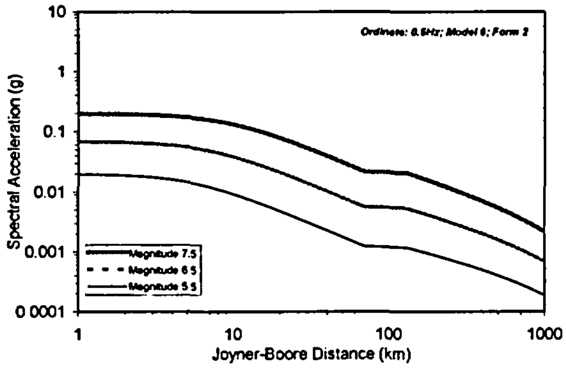
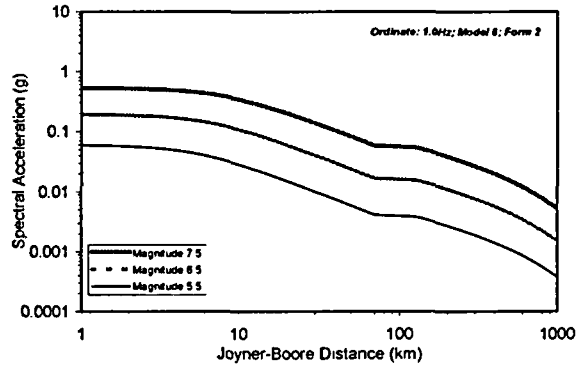
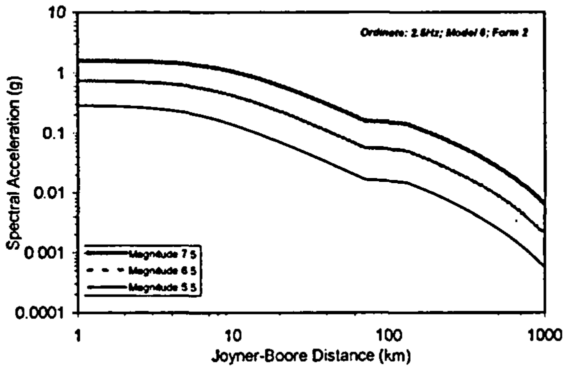

Ordinate: 25Hz; Model 8; Form 3
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Closest Rupture Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

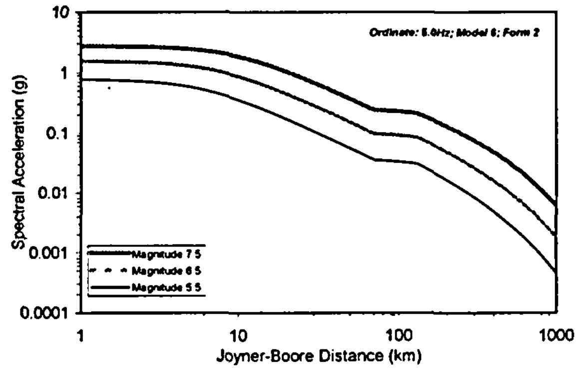
Figure C-3
Median Ground Motion for General Mid-Continent Area Sources: Cluster Upper Alternative Estimate Relations

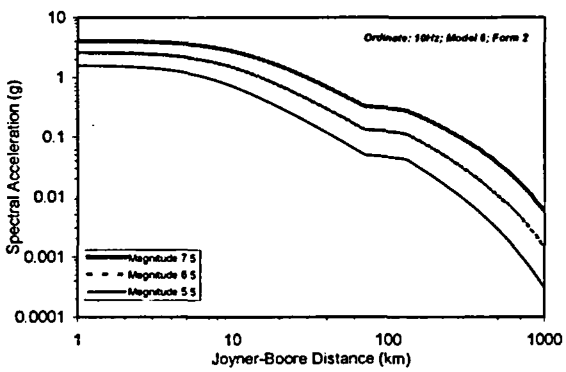


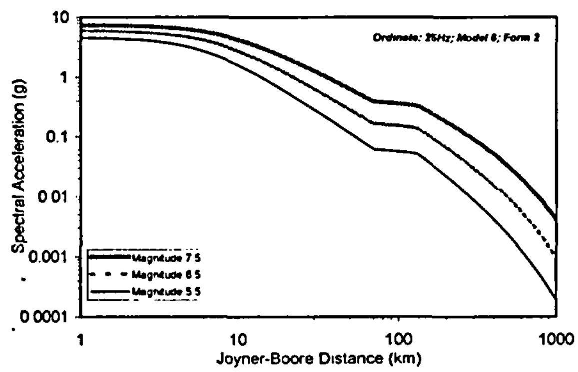

Ordinate: 0.5Hz; Model 6; Form 2
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Joyner-Boore Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

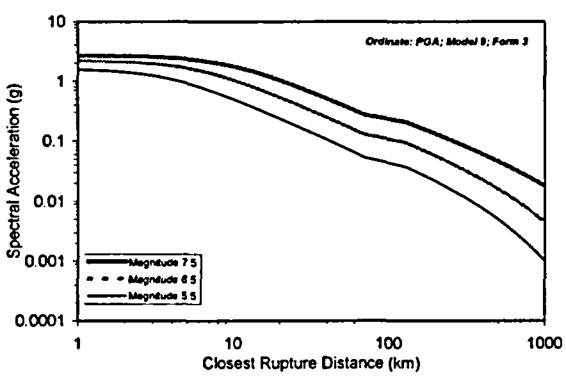

Ordinate: 1.0Hz; Model 6; Form 2
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Joyner-Boore Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

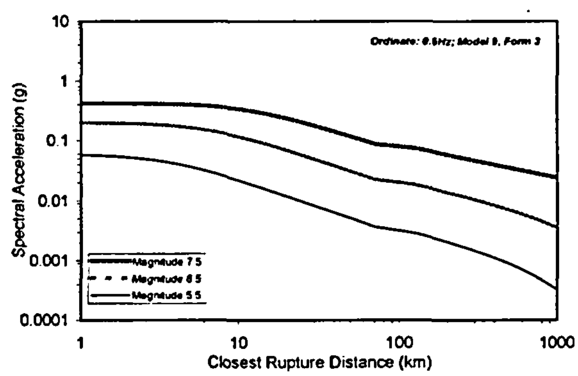

Ordinate: 2.5Hz; Model 6; Form 2
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Joyner-Boore Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

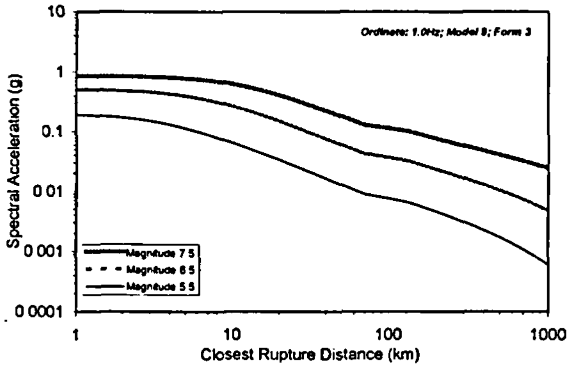

Ordinate: 5.0Hz; Model 6; Form 2
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Joyner-Boore Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

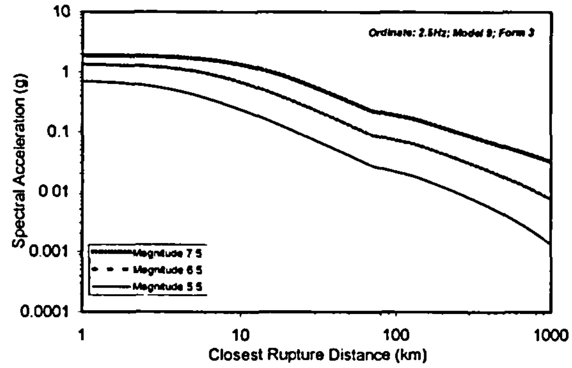

Ordinate: 10Hz; Model 6; Form 2
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Joyner-Boore Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

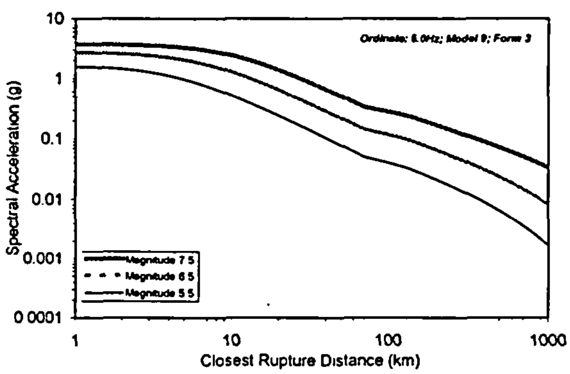

Ordinate: 25Hz; Model 6; Form 2
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Joyner-Boore Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

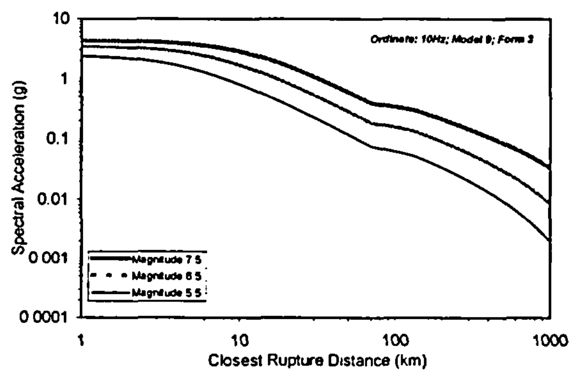

Ordinate: PGA; Model 9; Form 3
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Closest Rupture Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5


Ordinate: 0.5Hz; Model 9, Form 3
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Closest Rupture Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5


Ordinate: 1.0Hz; Model 9; Form 3
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Closest Rupture Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5


Ordinate: 2.5Hz; Model 9; Form 3
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Closest Rupture Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5


Ordinate: 5.0Hz; Model 9; Form 3
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Closest Rupture Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5


Ordinate: 10Hz; Model 9; Form 3
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Closest Rupture Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

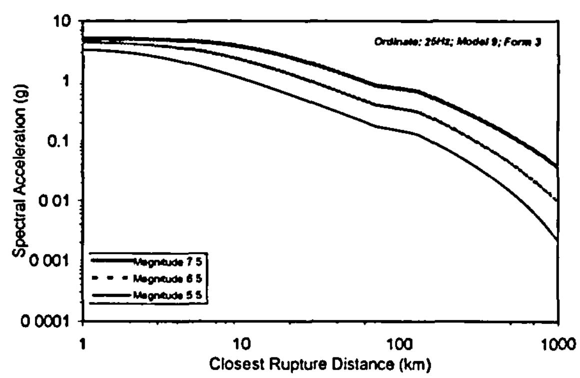
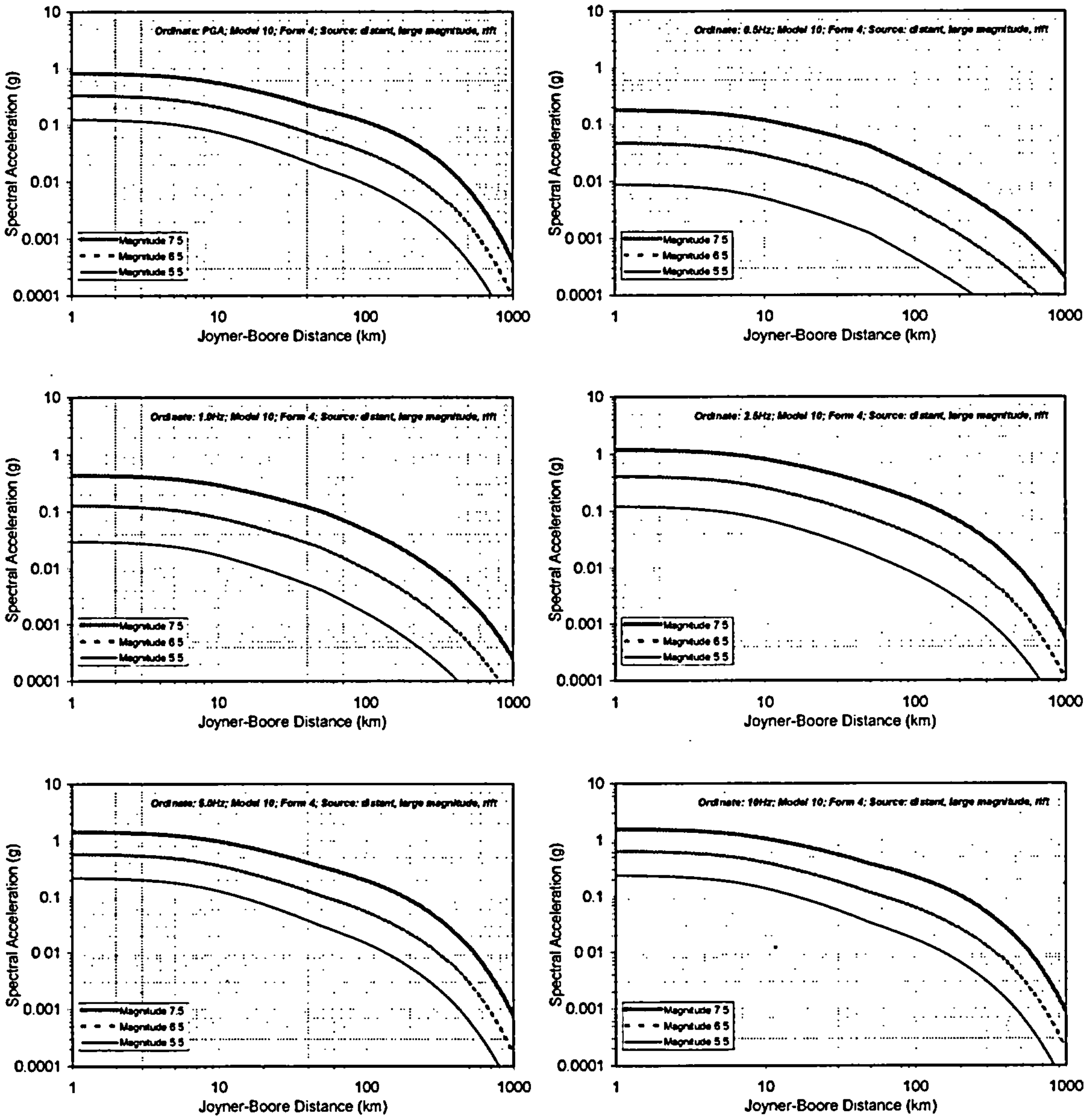

Ordinate: 25Hz; Model 9; Form 3
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Closest Rupture Distance (km)
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5

Figure C-4
Median Ground Motion: Distant, Large Magnitude Mid-Continent Rift Source Cluster 4 Lower Alternative Estimate Relations



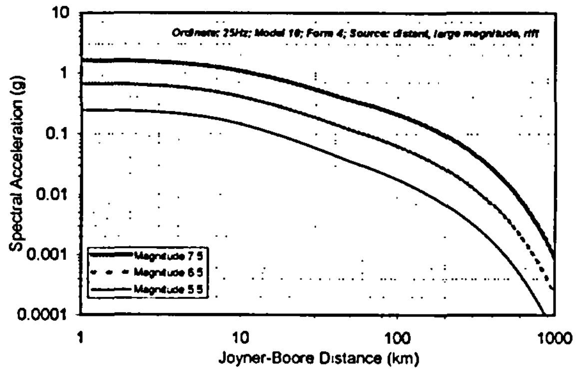
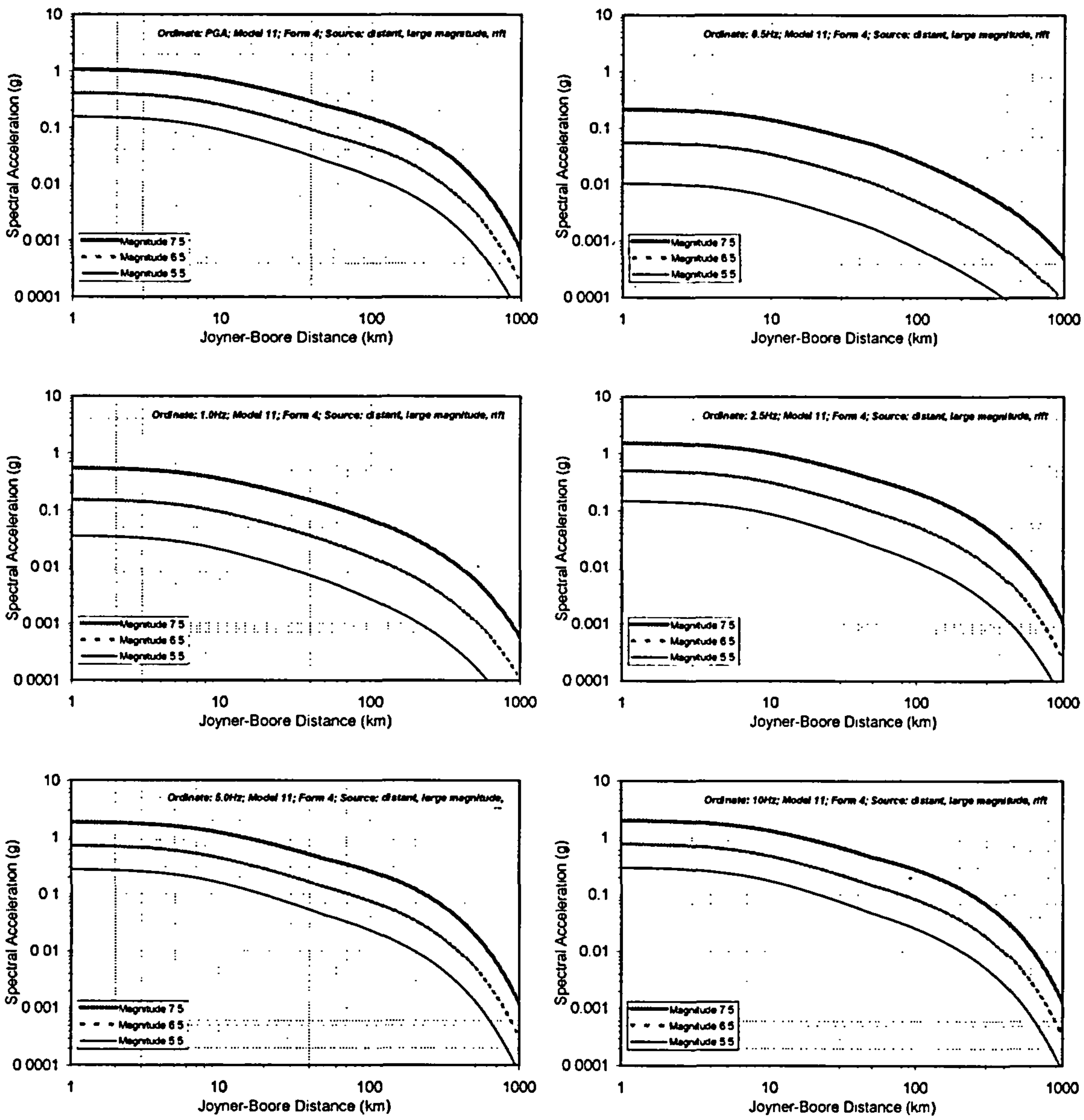


Figure C-5
Median Ground Motion: Distant, Large Magnitude Mid-Continent Rift Source Cluster 4 Middle Alternative Estimate Relations



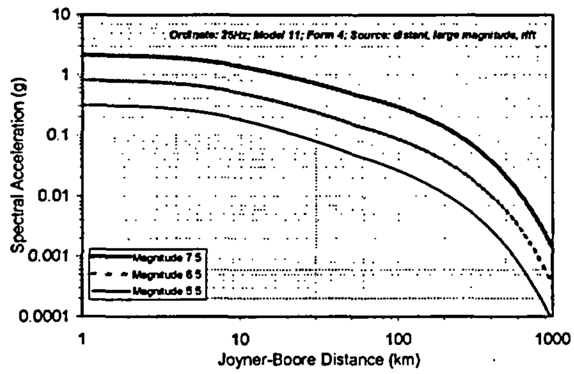
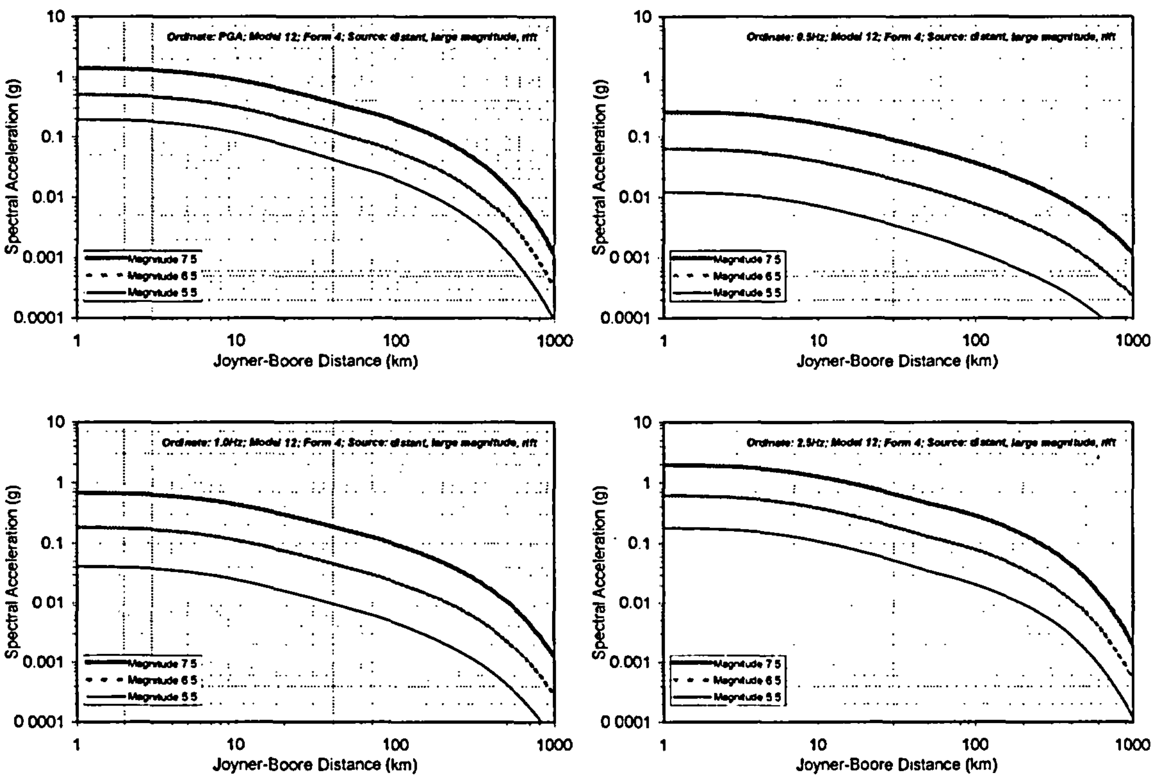
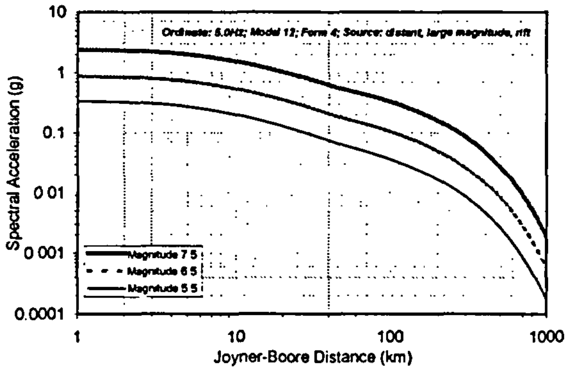
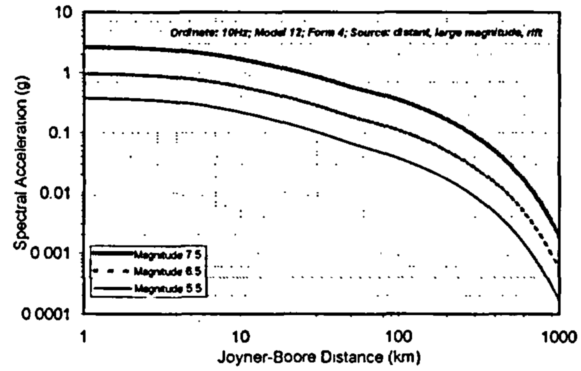
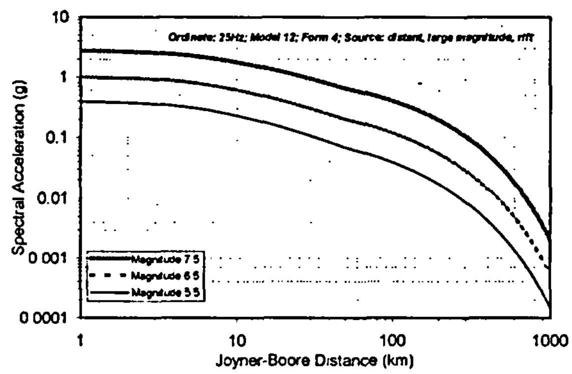


Figure C-6
Median Ground Motion: Distant, Large Magnitude Mid-Continent Rift Source Cluster 4 Upper Alternative Estimate Relations



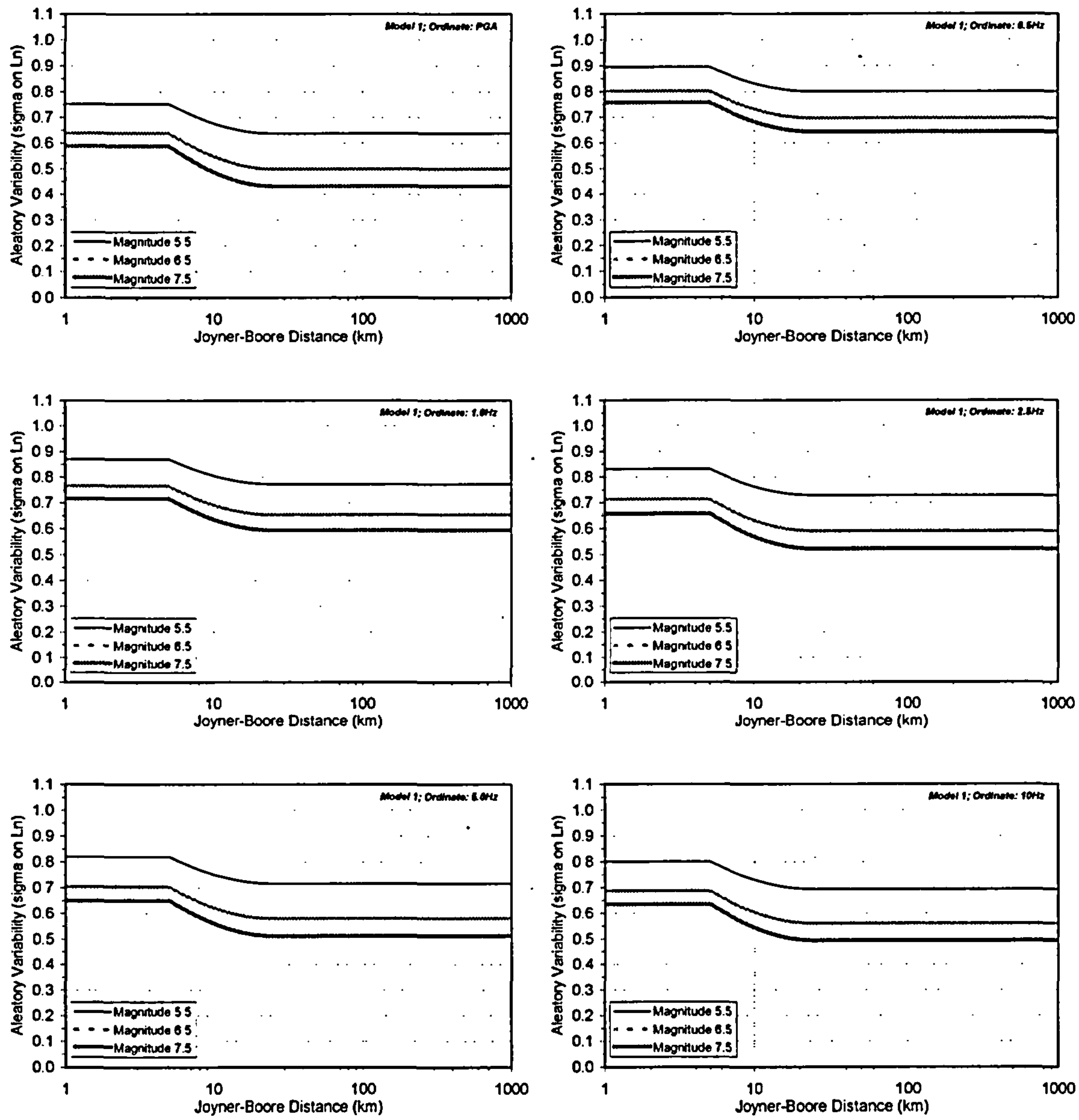

Ordinate: 5.0Hz; Model 12; Form 4; Source: distant, large magnitude, rift
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
1
10
100
1000
Joyner-Boore Distance (km)


Ordinate: 10Hz; Model 12; Form 4; Source: distant, large magnitude, rift
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
1
10
100
1000
Joyner-Boore Distance (km)


Ordinate: 25Hz; Model 12; Form 4; Source: distant, large magnitude, rift
Spectral Acceleration (g)
10
1
0.1
0.01
0.001
0.0001
Magnitude 7.5
Magnitude 6.5
Magnitude 5.5
1
10
100
1000
Joyner-Boore Distance (km)

D
ALEATORY VARIABILITY MODEL RESULTS

Figure D-1
Aleatory Variability Model 1, Joyner-Boore Distance



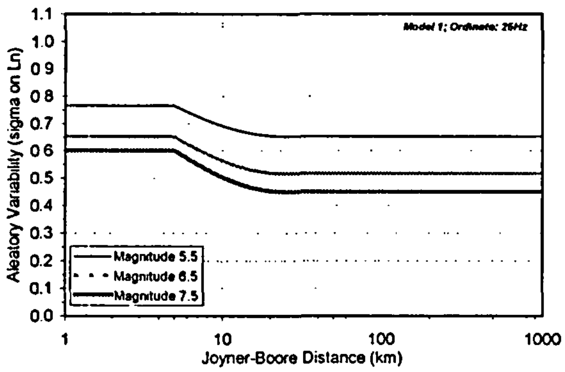

Model 1; Ordinate: 25Hz
Aleatory Variability (sigma on Ln)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Magnitude 5.5
Magnitude 6.5
Magnitude 7.5
1
10
100
1000
Joyner-Boore Distance (km)

Figure D-2
Aleatory Variability Model 2, Joyner-Boore Distance

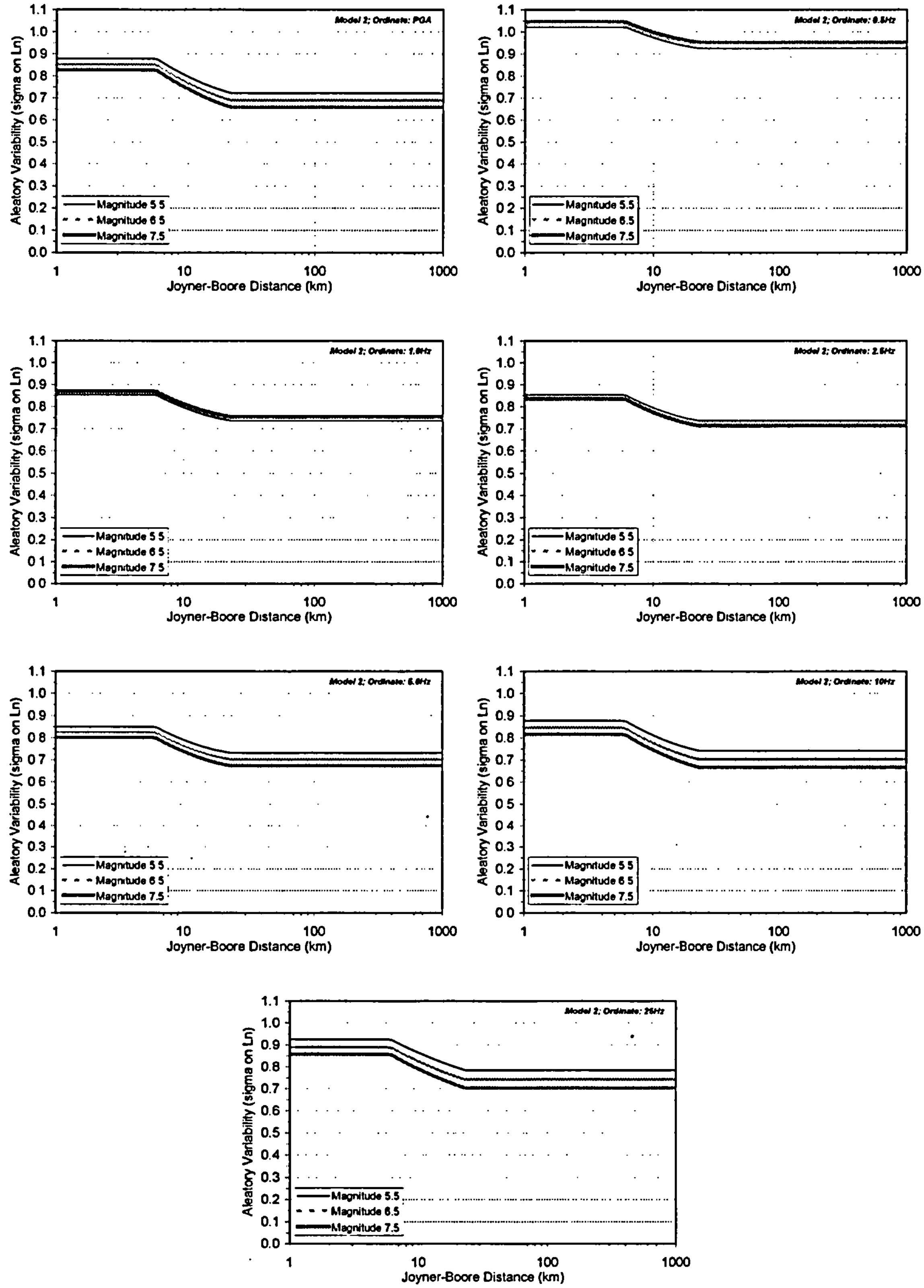


Figure D-3
Aleatory Variability Model 3, Joyner-Boore Distance

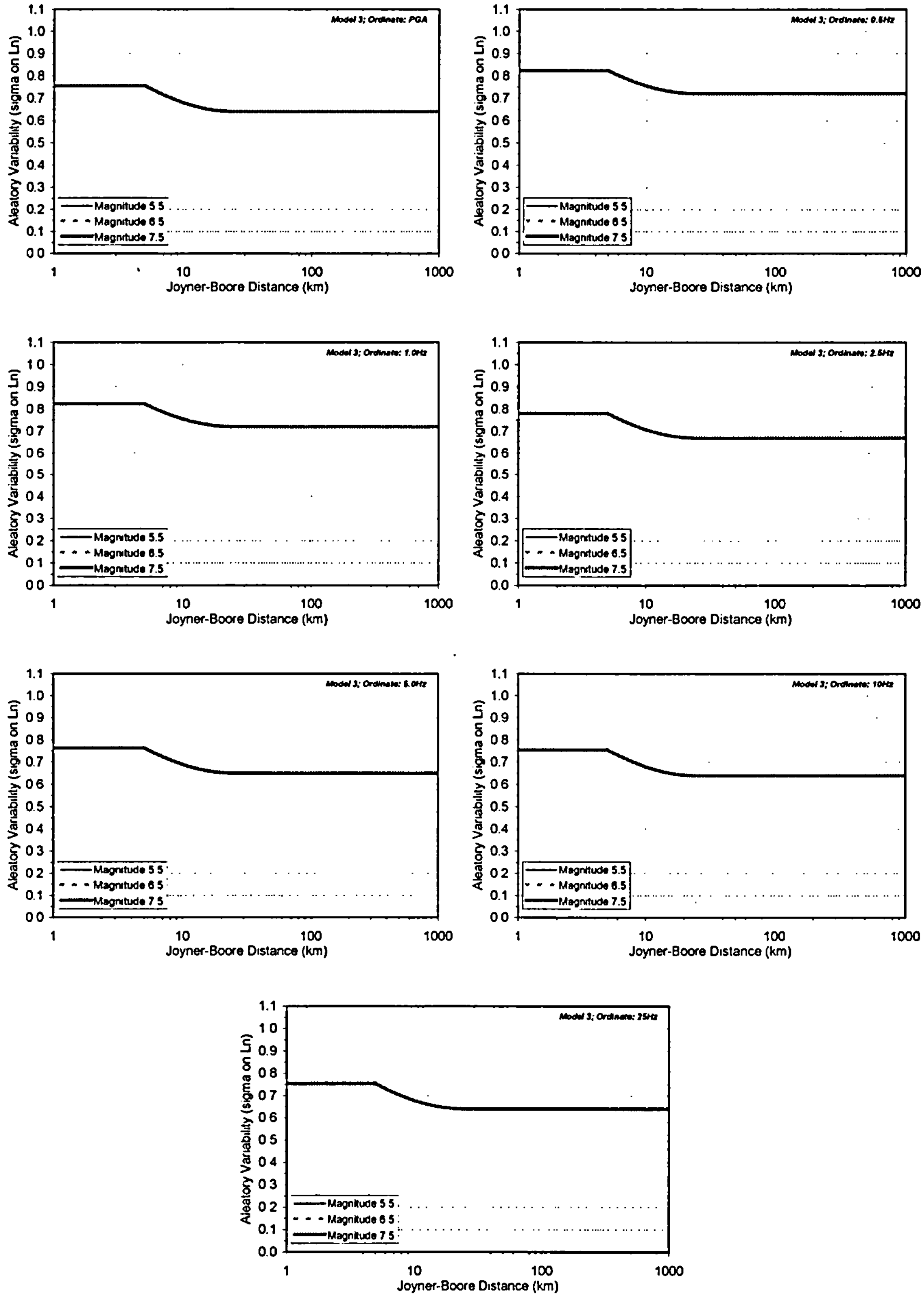


Figure D-4
Aleatory Variability Model 4, Joyner-Boore Distance

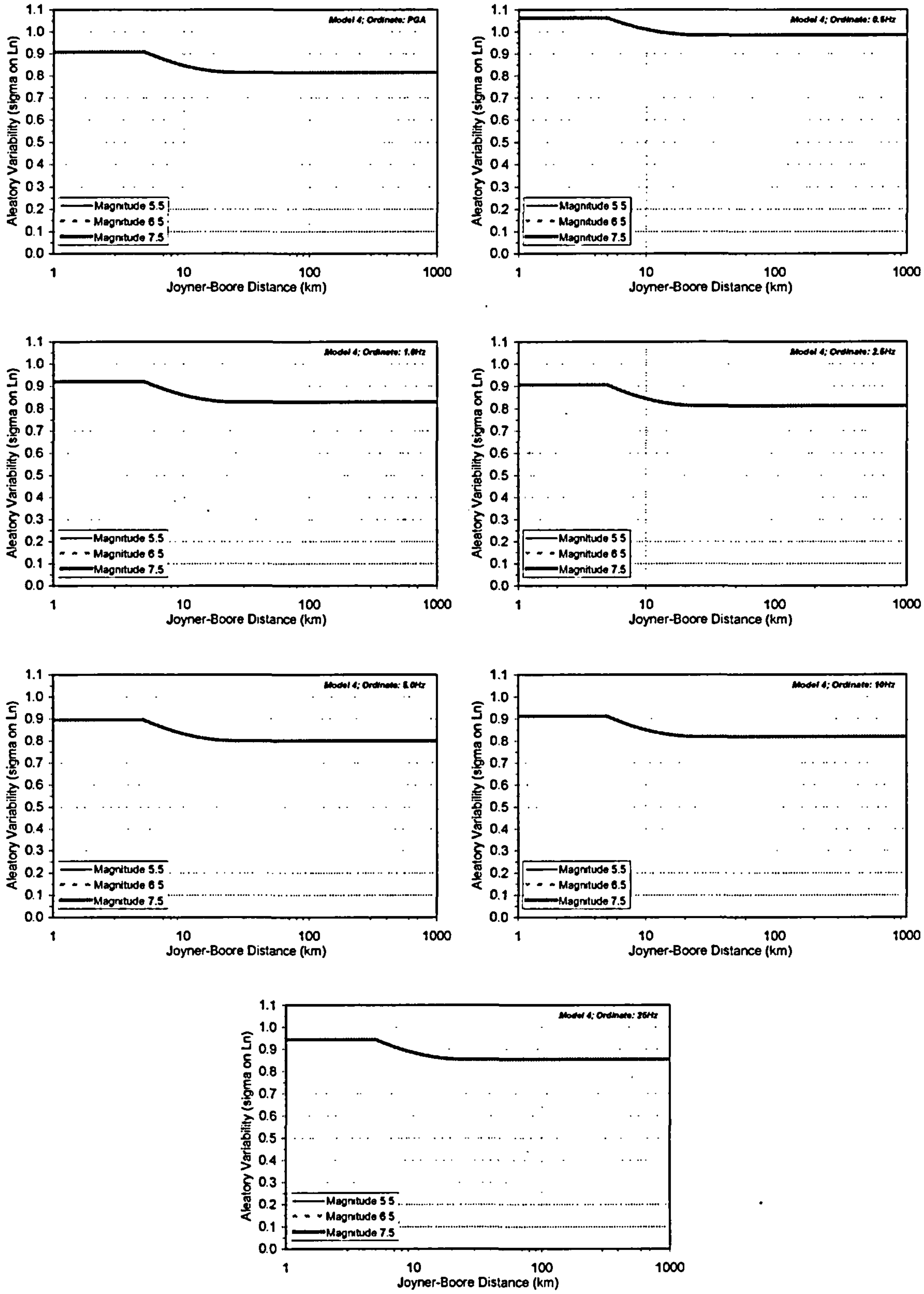


Figure D-5
Aleatory Variability Model 1, Closest Rupture Distance

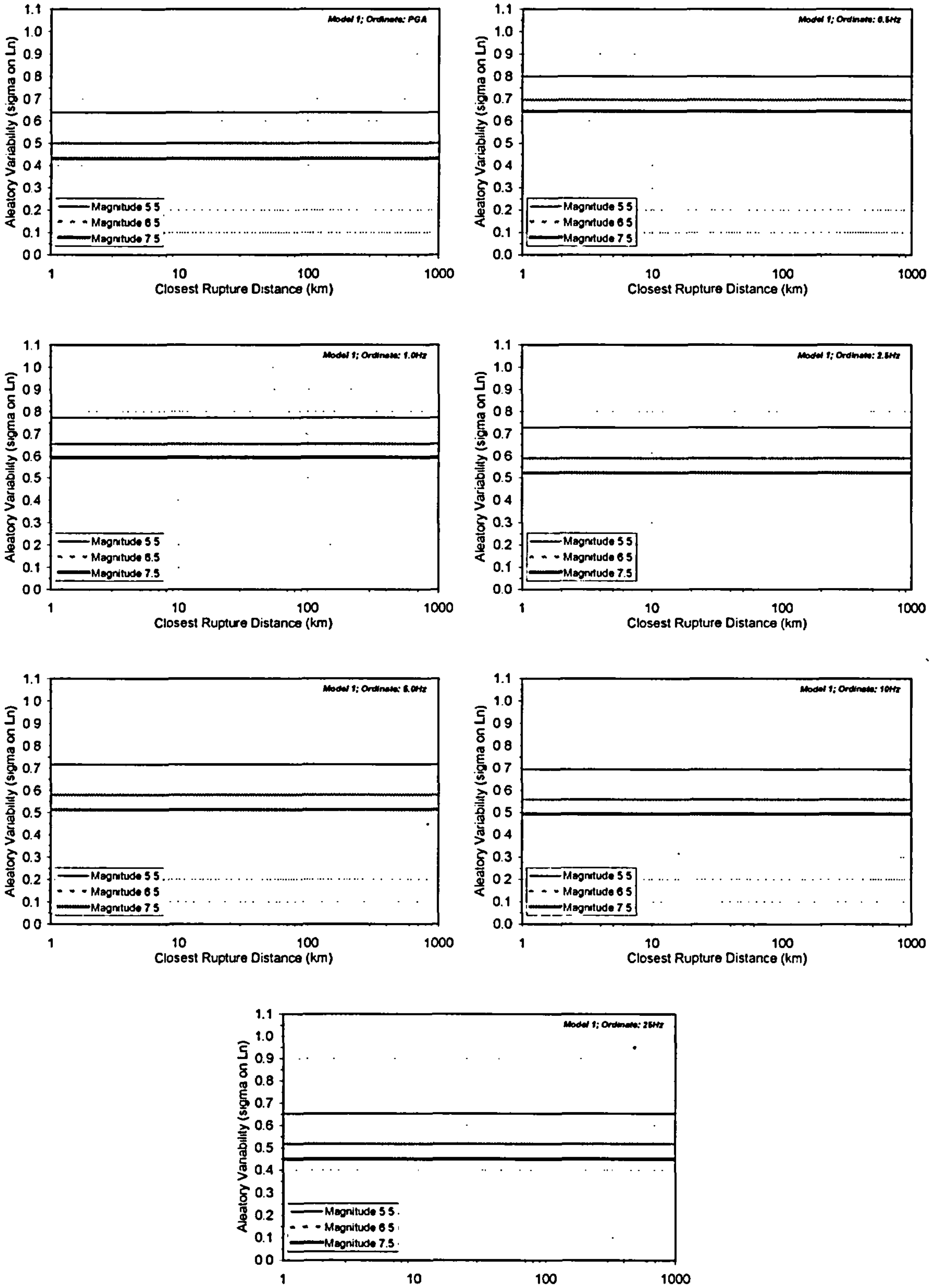


Figure D-6
Aleatory Variability Model 2, Closest Rupture Distance

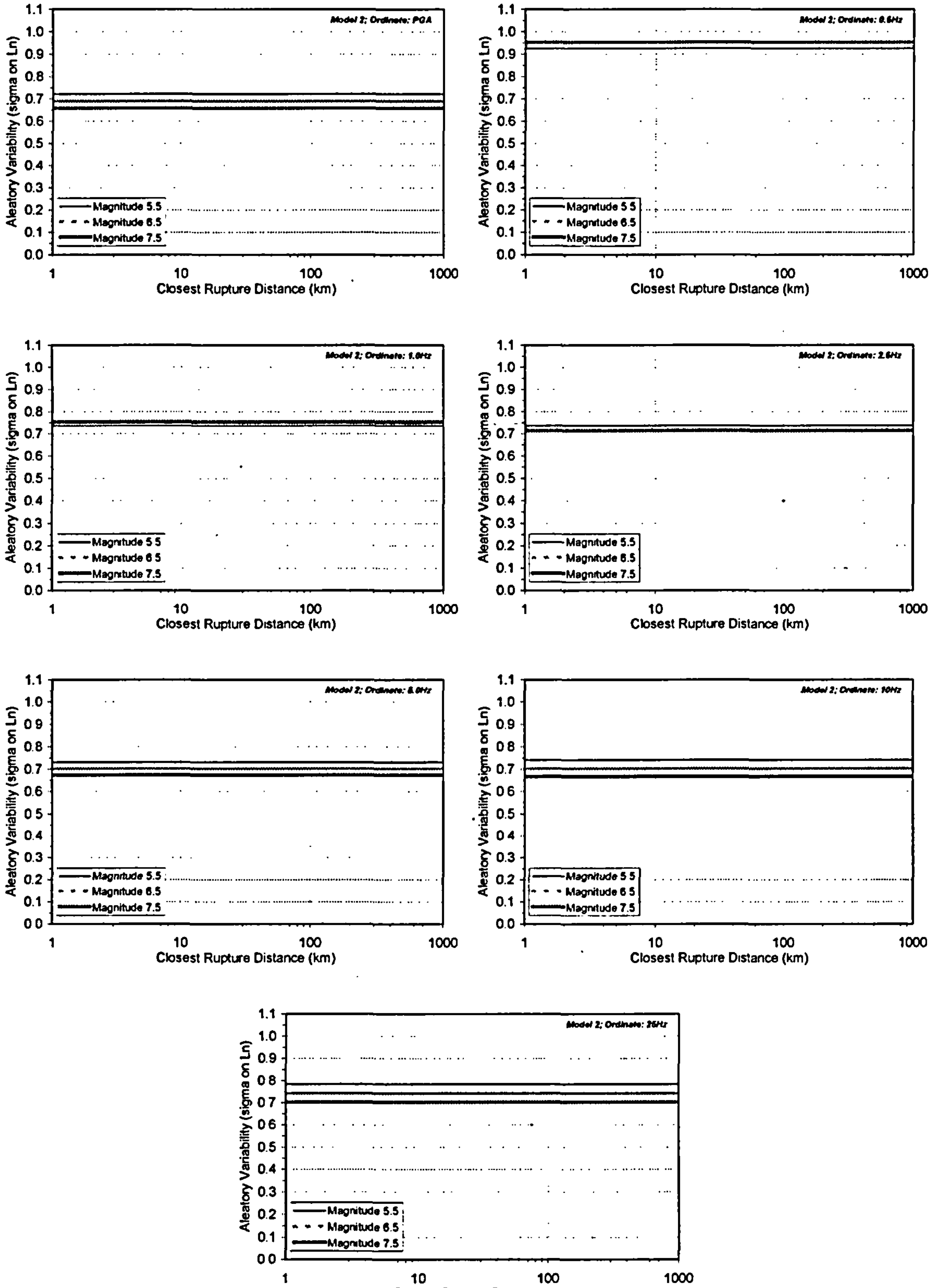


Figure D-7
Aleatory Variability Model 3, Closest Rupture Distance

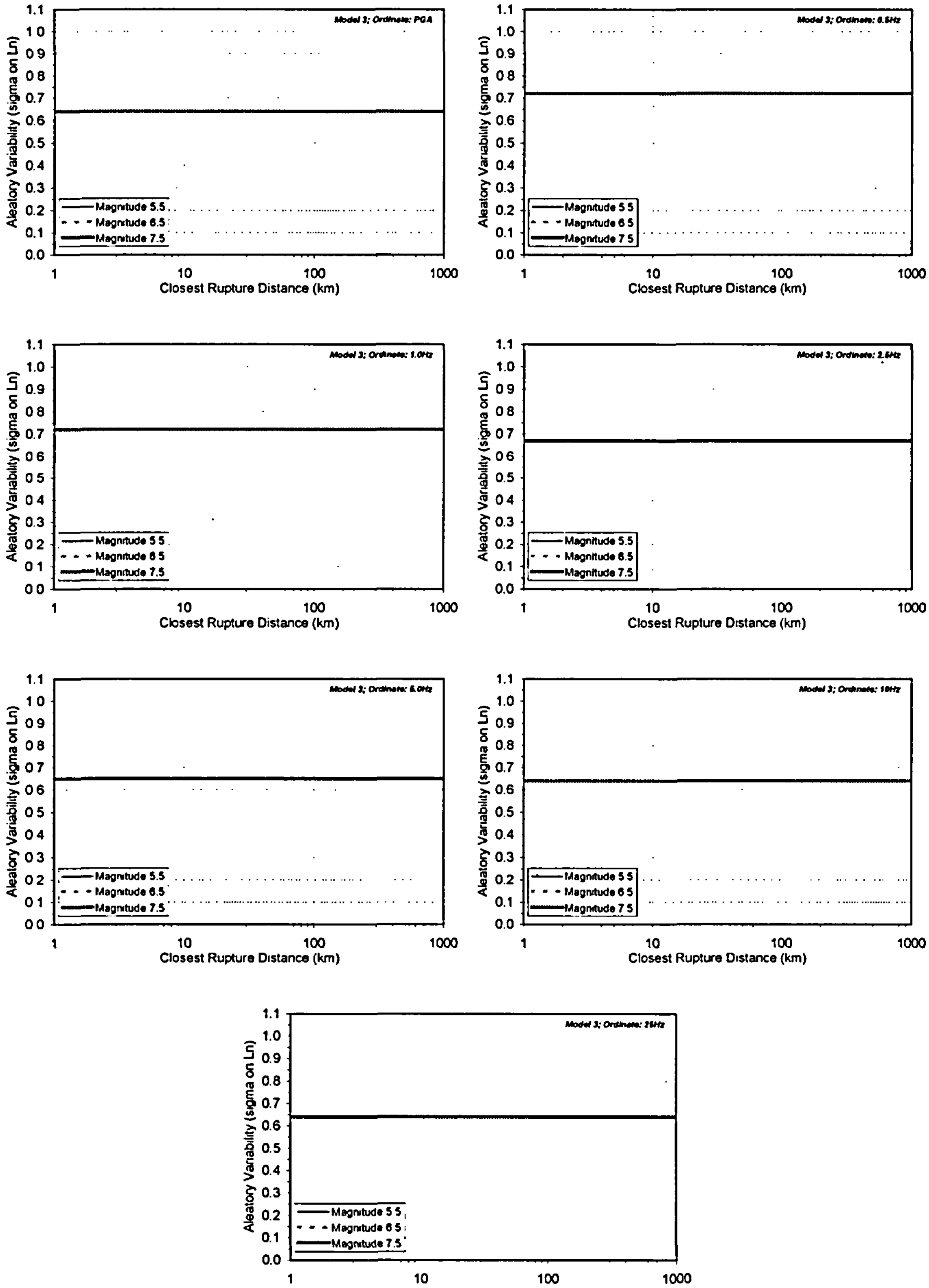
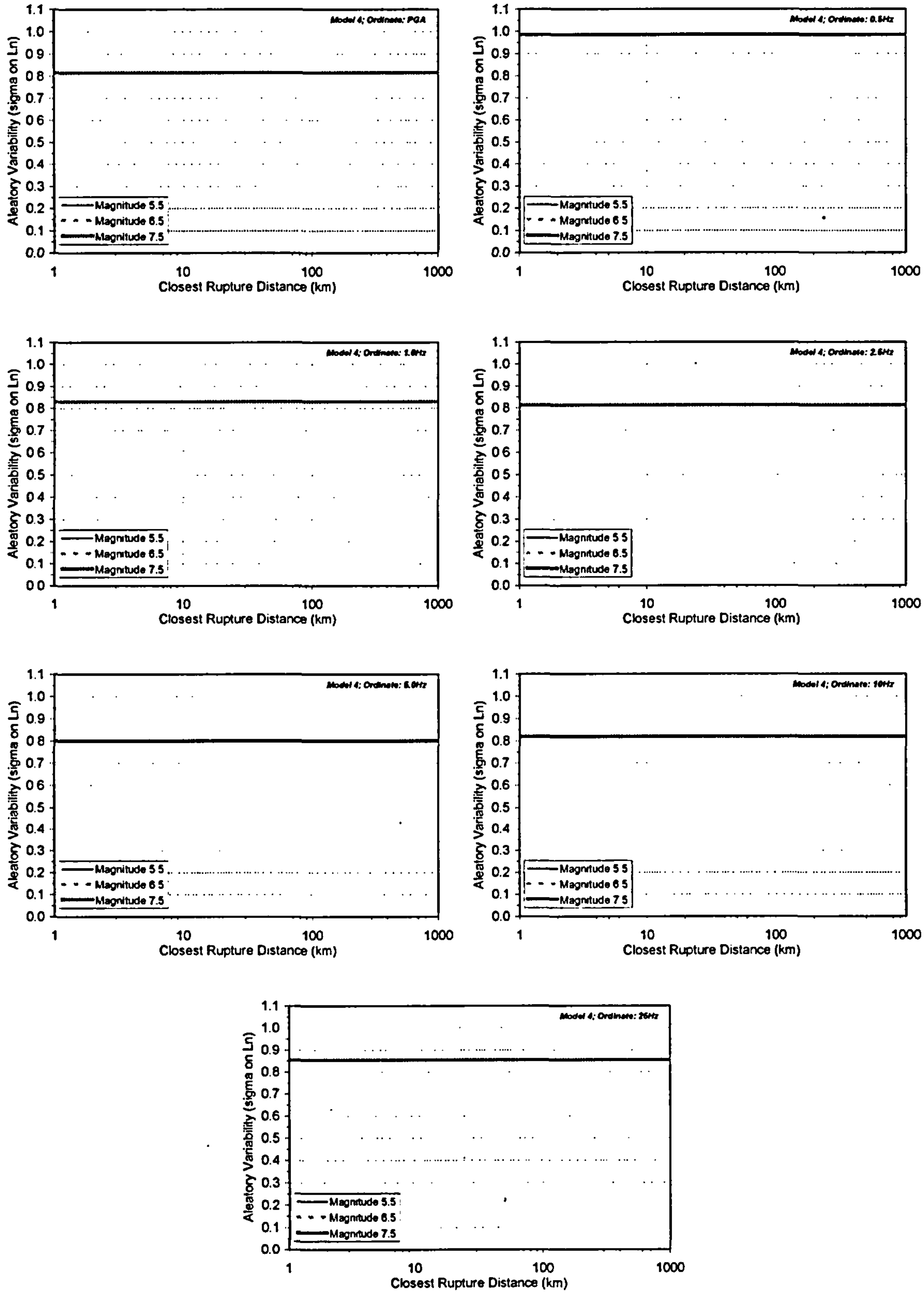


Figure D-8
Aleatory Variability Model 4, Closest Rupture Distance



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