Florida Power & Light Company, 700 Universe Boulevard, Juno Beach, FL 33408

FPL

August 7, 2009

L-2009-185
10 CFR 52.3(b)(2)

Mr. Michael Johnson
Director, Office of New Reactors
U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C. 20555-0001

Re: Florida Power & Light Company
Proposed Turkey Point Units 6 & 7
Project No. 763
Supplemental Information – COL Application Part 2
Final Safety Analysis Report Sections 2.5.1 and 2.5.2

Reference: FPL Letter to NRC, L-2009-144 dated June 30, 2009, Application for Combined License for Turkey Point Units 6 and 7

In the referenced letter, Florida Power & Light Company (FPL) submitted an application for a combined license (COL) for Turkey Point Units 6 and 7 to be located in Miami-Dade County, FL.

In a meeting on July 28, 2009, NRC staff identified items that it stated were required to support the NRC sufficiency review of the Turkey Point Units 6 and 7 COL Application. These items included:

- NRC indicated that FPL should provide more detailed information on the geologic history and tectonics in the 200 mile radius of the site.
- NRC indicated that FPL should provide more detailed information on the development of Crustal Attenuation models for the Caribbean Region for use in Probabilistic Seismic Hazards Analysis (PSHA).

Attachment 1 contains additional information on the geologic history and tectonics in the 200 mile radius of the site. Attachment 2 provides additional information on the development of Crustal Attenuation models for the Caribbean Region for use in PSHA.

Conforming changes to the COL Application to reflect this additional information are not being proposed at this time, but will be included in the annual update.

D097
NRO

Designate as original
Donald Habib, PM
2-7-12

If you have any questions, or need additional information, please contact William Maher at 561-691-7490.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on August 7, 2009

Sincerely,

Martin W. Gettler

Martin Gettler
Vice President – New Nuclear Projects

Attachments (2)

cc:
Project Manager, AP1000 Projects Branch 1, USNRC DNRL/NRO

cc (w/o attachments):
Director, Division of New Reactor Licensing, USNRC
Regional Administrator, Region II, USNRC
Senior Resident Inspector, USNRC, Turkey Point Plant

Attachment 1

Turkey Point Units 6 & 7

Combined License Application

Supplemental Information

FSAR Chapter 2

<u>Geology, Stratigraphy, and Tectonics</u>

Supplemental FSAR Chapter 2 Information

Geology, Stratigraphy, and Tectonics

This attachment provides the NRC staff with requested clarification and supplemental information regarding geologic, stratigraphic and tectonic conditions within and beyond the Turkey Point site region, specifically:

- Supplemental information clarifying the level of presentation on the geology and tectonics of Cuba, including potentially active, northeast-striking faults on the island of Cuba;
- Supplemental information clarifying the level of presentation on the geology and structure associated with the transition from the western Florida Platform to the Gulf of Mexico; and
- Supplemental information clarifying the level of presentation on the geology and stratigraphy of the Bahama Platform.

A thorough literature search and review was performed in preparation of the Units 6 & 7 FSAR that focused on the geology, stratigraphy, and tectonics of the site region and beyond. All available information was reviewed and considered. Utilizing NRC Regulatory Guides 1.206 and 1.208, the Units 6 & 7 FSAR provides descriptions of the geology, stratigraphy, and tectonics in the site region (200-mile radius), site vicinity (25-mile radius), site area (5-mile radius), and site (0.6-mile radius), with the level of detail progressively increasing with proximity to the site.

Geology and Tectonics of Cuba

The Units 6 & 7 FSAR provides descriptions of the geologic units and tectonics of Cuba, which lies approximately 150 miles south of the Units 6 & 7 site. To document the scope of the literature search and review performed for Cuba, this attachment provides a list of references cited in the Units 6 & 7 FSAR that describe the geology, tectonics, and seismicity of Cuba. This list includes only those references cited in the Units 6 & 7 FSAR. Additional literature beyond that listed was also reviewed and considered. Due to the absence of both geologic hazards and stratigraphic relationships associated with the rock units mapped in Cuba with regard to those mapped at the Units 6 & 7 site, the geology of Cuba is not described in as much detail as that of the Florida Peninsula. FSAR Figure 2.5.1-201 and FSAR Subsections 2.5.1.1.2.2 and 2.5.2.4.4.3.2.5 describe the major rock units of northern Cuba, within the site region, which include:

- A volcanic arc terrane mainly comprised of Cretaceous volcanic rocks and older tholeiitic lavas;
- A northern ophiolite belt comprised of a thick mélange of Upper Jurassic through Lower Cretaceous rocks intermingled along the northern part of Cuba; and
- Passive continental margin sediments comprised of Jurassic through Cretaceous sedimentary sequences of neritic, slope, and basinal deposits. The oldest of these are Middle Jurassic evaporite deposits upon which a thick (4,000 to 6,000 feet)

sequence of carbonates and anhydrites is deposited, correlative with the standard stratigraphic section in Florida.

Multiple subsections throughout the Units 6 & 7 FSAR describe the tectonics of Cuba. For example, FSAR Subsections 2.5.1.1.3.1, 2.5.1.1.3.3.3, 2.5.2.4.4.3.2.1, and 2.5.2.4.4.3.2.5 describe faults within Cuba, including the northeast-striking strike-slip faults. FSAR Figure 2.5.2-220 shows these northeast-striking faults and other faults in Cuba. Only two of these, the Cardenas-Cochinos and Pinar faults, are located at least partially within the site region and, at their nearest points, are located approximately 160 and 197 miles from the Units 6 & 7 site, respectively. As described in FSAR Subsection 2.5.2.4.4.3.2.5, despite the recognition of several major crustal faults in Cuba, none has been adequately characterized for purposes of seismic hazard analysis for the Units 6 & 7 site. None has been characterized with a late Quaternary slip rate, or has unambiguous data to constrain timing or recurrence of large earthquakes. In addition, poorly located seismicity and a paucity of detailed geologic maps of Cuba make it difficult to assess potential activity, geometry, and segmentation of faults. Due to the absence of detailed, credible fault characterizations, and the evidence from geodetic data that all of Cuba is associated with low deformation rates compared to the plate boundary, Cuba and its direct offshore region is modeled as a single areal source in the Cuba and northern Caribbean seismic source characterization, as described in FSAR Subsection 2.5.2.4.4.3.3.

References Cited in the Units 6 & 7 FSAR Describing Geology, Tectonics, and Seismicity of Cuba

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Geology and Structure of the Transition Between the Western Florida Platform and the Gulf of Mexico

The Units 6 & 7 FSAR describes the geology and stratigraphy in the site region with a level of detail that progressively increases with proximity to the site. The transition between the western Florida Platform and the Gulf of Mexico at its nearest point is located approximately 50 miles beyond the site region, roughly 250 miles west of the site. Due to distance from the site and the lack of documented seismicity in this area, the Units 6 & 7 FSAR does not provide a more detailed discussion regarding the geology and structure of the transition between the western Florida Platform and the Gulf of Mexico.

Geology and Stratigraphy of the Bahama Platform

The Units 6 & 7 FSAR describes the geology and stratigraphy in the site region with a level of detail that progressively increases with proximity to the site. The Bahama Platform at its nearest point is located approximately 75 miles east of the site and extends southeastward beyond the site region. Due to distance from the site, the lack of documented seismic activity, and the absence of both geologic hazards and stratigraphic relationships associated with the rock units mapped in the Bahama Platform with regard to those mapped at the Units 6 & 7 site, the geology of the Bahamas is not described in as much detail as that of the Florida Peninsula.

Attachment 2

Turkey Point Units 6 & 7

Combined License Application

Supplemental Information

Development of Crustal Attenuation Models for the Caribbean Region for use in PSHA

Development of Crustal Attenuation Models for the Caribbean Region for Use in PSHA

Summary

This attachment provides details of the development of a suite of Caribbean region crustal ground motion attenuation relationships for use in the probabilistic seismic hazard analysis (PSHA) for the Florida Power & Light Company (FPL) Turkey Point Units 6 & 7 combined license (COL) application. The attenuation relationships developed are applicable for crustal seismic sources in the Caribbean region located south of the project site at distances between approximately 150 and 2,000 km and having maximum moment magnitudes as large as Mw~8.5+. The attenuation relationships were developed for Central and Eastern United States (CEUS) hard rock site conditions considering attenuation through crust representative of that between the Caribbean source and the site location for the seven structural frequencies used in the PSHA: PGA, 25, 10, 5, 2.5, 1.0 and 0.5 Hz. The developed ground motion attenuation models are based on the simulation of ground motions using a stochastic point source model and least-squares linear regressions. A sigma value based on a regional attenuation study for Puerto Rico is adopted for use in the PSHA.

Background

The original EPRI-SOG seismic source model used in the PSHA analysis for the Turkey Point Units 6 & 7 project does not include seismic sources in the Caribbean region located south of Florida. As part of the update of the EPRI-SOG source model, it was concluded – see FSAR subsection 2.5.2.4 – that Caribbean seismic sources, which are located at distances from Turkey Point Units 6 & 7 ranging from approximately 150 to 2,000 km, could significantly contribute to the total hazard at the site. This attachment presents the development of attenuation relationships (i.e., both regression models as a function of magnitude and distance and an assigned aleatory standard error "sigma") to be used with the Caribbean seismic sources in the PSHA for the Turkey Point Units 6 & 7 COL Application.

Although the Caribbean region is active seismically, the lack of a large dataset of empirical strong ground motion recordings, especially for larger magnitude earthquakes, has prevented the development of an empirical ground motion attenuation relationship for the region. Motazedian and Atkinson (2005) [MA2005] analyzed a dataset of approximately 300 earthquakes recorded by stations in Puerto Rico and developed a set of regional attenuation and source parameters. This dataset, however, only spans the magnitude range of 3 – 5.5 and, based on this relatively small upper magnitude value of 5.5, this dataset cannot be used directly to model ground motions for earthquakes with magnitudes as large as magnitude 8+. Given the regionally determined attenuation and source parameters, MA2005 simulated acceleration time histories and response spectra from earthquakes between magnitude 3.0 and 8.0 with distances between 2 and 500 km using a finite fault simulation technique with a dynamic corner frequency. Motazedian and Atkinson performed a regression on this simulated dataset to develop an attenuation model for the Puerto Rico region. This model is for generic soft rock or NEHRP C site conditions with an average shear wave velocity in the top 30 meters of between

360-760 m/s (Borcherdt, 1994) based on horizontal to vertical spectral ratios from the recorded dataset.

For the Units 6 & 7 COL Application PSHA, the attenuation relationship was developed to be applicable for magnitudes as large as Mw~8.5+ and distances as great as 2,000 km as needed for the Caribbean seismic sources. This upper magnitude value is not significantly larger than the simulation magnitude upper limit in the MA2005 dataset (i.e., magnitude 8.0); however, the extrapolation for distances from 500 km to 2,000 km is significantly beyond the distance range of the MA2005 dataset and gives ground motion values and ground motion spectra which are unconstrained and unacceptable for use in the PSHA.

The models of the attenuation relationship presented in this attachment are based on the regional attenuation and source parameters determined in the MA2005 study, as discussed in later sections of this attachment. Acceleration ground motion response spectra are developed using the program SMSIM (Boore, 2005). Both the Brune single corner source model with constant stress parameter scaling and magnitude dependent stress parameter scaling and the double corner source model (Atkinson and Boore, 1995) are used with the SMSIM program in developing spectral acceleration ground motions.

To account for parametric uncertainty in regionally defined parameters, distributions were defined about the central estimates of stress parameter and Q model presented in the MA2005 model. Considering the stress parameter value of 130 bars in the MA2005 model, a distribution of three stress parameter values was used in the current analysis: 65, 130, and 260 bars. This range is based on an assumed sigma of 0.7 Ln units (EPRI, 1993) with a base value of 130 bars from the MA2005 study. Considering the constant Qo term of 359 in the MA2005 model, a distribution of three Qo values was used in the current analysis: 241, 359, and 536. This range is based on an assumed sigma of 0.4 Ln units (Silva et al., 2003).

Finally, although a linear least-square regression was performed, the parametric uncertainty estimated from the regression (on the order of 0.4 natural log units and less) is assumed to under-represent the expected uncertainty in ground motions for this region where there is little or no strong ground motion data. For this reason an assumed sigma value, taken as the MA2005 aleatory sigma value of 0.28 in log base 10 units (0.645 in natural log units) is applied to all of the ground motion models at each of the seven frequencies.

As part of the development and review process of the suite of developed ground motion models, three presentations were made to the Technical Advisory Group (TAG) for Units 6 & 7. Based on these presentations and feedback from TAG members, modifications were made in an initial suite of attenuation models. Following the performance of a sensitivity study at the request of TAG members, an agreement by all TAG members on acceptability of the final crustal attenuation models (see Appendix A) for the Caribbean region for use in the PSHA was achieved. Following the SSHAC study level guidelines (NUREG CR-6372, 1997), development of the final attenuation models for the PSHA analysis for Caribbean crustal sources followed a SSHAC Study Level 2.

Ground Motion Simulations and Inputs Parameters

MA2005 collected and analyzed over 300 earthquakes recorded in and around the island of Puerto Rico. Based on their regression of the Fourier amplitude spectra from this dataset, MA2005 estimated the regional attenuation and source parameters listed in Table 1.

The simulation of ground motions using the program SMSIM (Boore, 2005) for the development of Caribbean ground motion models is based on the regional parameters from the MA2005 model and are listed in the third column in Table 1. The values listed in bold fonts are those values which are different than the MA2005 model (listed in column 2 of Table 1). As was presented in the previous section, a range in stress parameter values and Q models was used for the ground motion simulations. In addition, the site amplification factors from Chen and Atkinson (2002) for CEUS hard rock site conditions were used in place of the Puerto Rico soft rock (NEHRP C) site conditions. A kappa value of 0.006sec (EPRI, 1993) [appropriate for the CEUS Turkey Point site location] for the simulation runs was used in place of the MA2005 model kappa value of 0.03sec.

Table 1
Regional attenuation and source parameters
estimated for the simulation of ground motions.

Parameter	MA 2005 Values	Simulation Values
Stress Parameter	130 bars	**65 bars (Low Case)** 130 bars (Base Case) **260 bars (High Case)**
Geometrical Spreading	1/R for R<75km 1.0 for 75<R<100km 1/SQRT(R) for R>100km	1/R for R<75km 1.0 for 75<R<100km 1/SQRT(R) for R>100km
Quality Factor (Q) Model	359 $f^{0.59}$	**241 $f^{0.59}$ (Low Case)** 359 $f^{0.59}$ (Base Case) **536 $f^{0.59}$ (High Case)**
Path Duration	Atkinson and Boore (1995) Model with hinge points at 75 and 100 km	Atkinson and Boore (1995) Model with hinge points at 75 and 100 km
Site Amplifaction	Puerto Rico specific for soft rock site (NEHRP C) conditions based on H/V ratio	**Chen and Atkinson (2002) CEUS Hard Rock**
Kappa	0.03 sec	**0.006 sec (EPRI, 1993)**
Shear Wave Velocity (Vs) at the Source	3.6 km/sec	3.6 km/sec
Density	2.8 g/cm^3	2.8 g/cm^3

Note: The values listed in bold fonts are values which are different than the MA2005 model

Ground motions were computed for the seven frequencies of interest for the PSHA: PGA, 25, 10, 5, 2.5, 1, and 0.5 Hz. For each frequency, ground motions were simulated for magnitude values starting at 4.75 and increasing by a moment magnitude [Mw] step size of 0.25 units up to a maximum magnitude of 8.75 (i.e., a total of 17 magnitude values). The distance range was between 150 and 2,000 km with 17 values equally spaced in log-space (these distance values are listed in Table 2). These simulations generated a dataset of 289 ground motion values for a given frequency, stress parameter, and Q model.

To capture the uncertainty in source models, three different stochastic source scaling models were used in the simulations:

- Single Corner Constant Stress Parameter Scaling [1CC] (Boore, 2005)
- Single Corner Variable Stress Parameter Scaling [1CV] (Silva et al., 2003)
- Double Corner [2C] (Atkinson and Boore, 1995)

These three stochastic source models used in the SMSIM program represent an acceptable state-of-practice methodology for simulation of ground motions given a suite of regional attenuation and source parameters. The MA2005 model is based on an extended finite-fault stochastic source model with a dynamic corner frequency. At close fault distances (e.g., less than 100 km), the importance of a finite-fault simulation as opposed to a point source simulation could be significant. However, for the simulations and distances being modeled (i.e., 150 – 2,000 km), the finiteness of an extended fault would not be significant when compared to a point source.

Table 2
Equally spaced log-distance values used in the simulation of CEUS hard rock ground motions.

Distance (km)
150.0
176.4
207.4
243.8
286.6
337.0
396.2
465.9
547.7
644.0
757.1
890.2
1046.6
1230.6
1446.8
1701.1
2000.0

For the variable stress parameter scaling model, the magnitude dependent stress parameter scaling from Silva et al. (2003) was applied for the simulations. This magnitude-dependent stress parameter scaling is constant for magnitudes less than 5.5 and greater than 8.5. The reduction factors on the stress parameter from the Silva et al. (2003) reference are:

- Stress parameter for magnitudes less than 5.5 is equal to value for magnitude 5.5
- Stress parameter at magnitude 6.5 = 75% Stress parameter at magnitude 5.5
- Stress parameter at magnitude 7.5 = 75% Stress parameter at magnitude 6.5
- Stress parameter at magnitude 8.5 = 67.5% Stress parameter at magnitude 7.5
- Stress parameter for magnitudes greater than 8.5 is equal to value for magnitude 8.5

For the application to the range in magnitude values used, a linear interpolation of the reduction factor as a function of magnitude was estimated given the scaling noted above. These interpolated scale factors were then applied to the base stress parameter value of 130 bars to develop the variable stress parameters listed in Table 3 and used in the simulation analysis. Rounding differences on the order of 1 or 2 bars are not significant and the values listed in Table 3 are the specific values used in the analysis (Note that the same factor of 2 is applied for the Low and High stress parameter models.)

Table 3
Stress parameter values used in the simulation for the 1CC and 1CV cases

Magnitude	Low Stress Parameter	Base Stress Parameter	High Stress Parameter
4.75	65	130	260
5.00	65	130	260
5.25	65	130	260
5.50	65	130	260
5.75	61	122	244
6.00	57	114	228
6.25	53	106	212
6.50	49	98	196
6.75	46	91	182
7.00	43	85	170
7.25	40	79	158
7.50	37	73	146
7.75	35	69	138
8.00	33	65	130
8.25	31	61	122
8.50	29	57	114
8.75	29	57	114

Functional Regression Attenuation Model

Given the multiple sets of simulated data, a functional model was selected for the least-squares regression. The selected model is defined as:

$$Ln(Y) = C_1 + C_2{*}M + (C_3 + C_4{*}M){*}Ln(R+e^{C5}) + C_6{*}(M-M_1)^2 + (C_7 + C_8{*}M){*}R \quad (1)$$

(where Y is the ground motion value, M is magnitude, and R is distance)

This equation which was taken from the EPRI (2004) model for Class 1 cases, is not a linear equation because of the "e^{C5}" term. However, this term is a fictitious depth term and is used in ground motion attenuation models to saturate the ground motions for small distances. Since the closest distance being modeled is 150 km, this term will not have a significant impact and is set equal to 0. Application of the ground motion models for distances less than 150 km is not advised and can lead to misleading estimates of the ground motion. By setting this term equal to 0.0, the equation given above is linear.

$$Ln(Y) = C_1 + C_2*M + (C_3 + C_4*M)*Ln(R) + C_6*(M-6.0)^2 + (C_7 + C_8*M)*R \quad (2)$$

(where, M_1 is set to 6.0, as was done in EPRI (2004))

Results and Recommendations

Based on the preliminary analysis of the regression results, the range in stress parameter scaling (i.e., low, base and high stress parameter values) leads to a fairly uniform and frequency-independent scaling of the predicted attenuation models after the regression. Based on the observed distribution of ground motions from the three source models (i.e., 1CC, 1CV, and 2C) and three Q_o models used in the analysis, along with the requirement to capture the expected epistemic uncertainty in ground motion models, the three stress parameter cases (i.e., low, base and high) were combined for a given source model in the regression analysis. This reduces the number of 1CC and 1CV models from a total of 18 down to 6. The variation in the Q model was observed to be frequency dependent and, based on this observation, the ground motions from the different Q models were not combined for a given source model. This reduces the number of crustal ground motion models for the Caribbean region to a total of 9 models.

The regression ground motion models are plotted in Figure 1 for the seven frequencies of interest as a function of distance for a magnitude 7 earthquake. The thicker attenuation curves represent the final nine attenuation models while the thinner curves show the individual attenuation models which were developed during the analysis. In general, the nine models span a range in ground motions between factors of approximately 2 to greater than 10 at the largest distances. Based on this observed range in ground motions from the suite of models, it was concluded that no additional epistemic uncertainty would need to be considered in the PSHA if the complete suite of nine models were used.

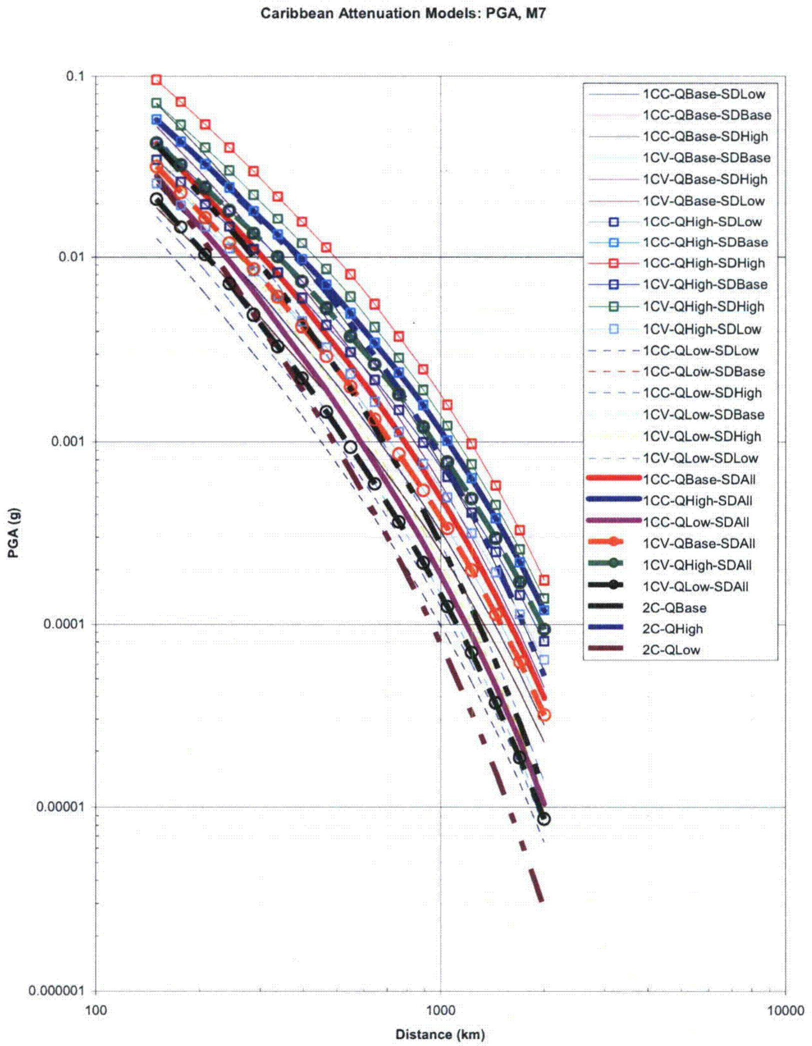

Figure 1a. Attenuation curves for M7 and PGA.

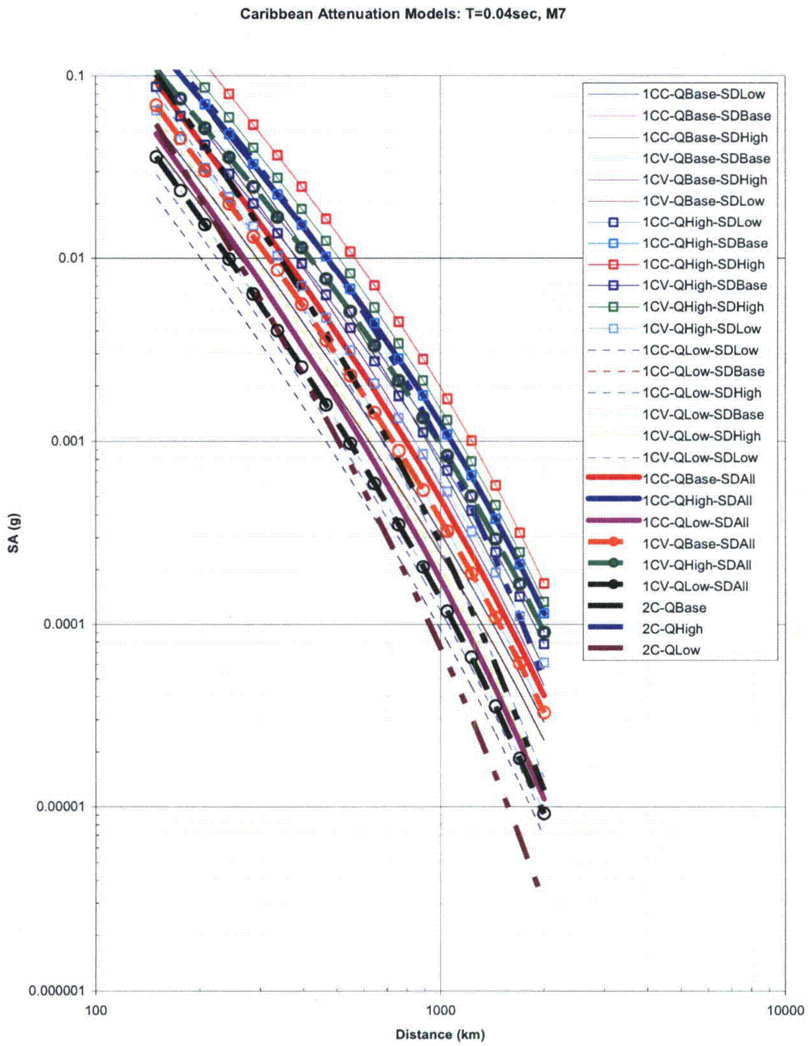

Figure 1b. Attenuation curves for M7 and 25 Hz/0.04sec.

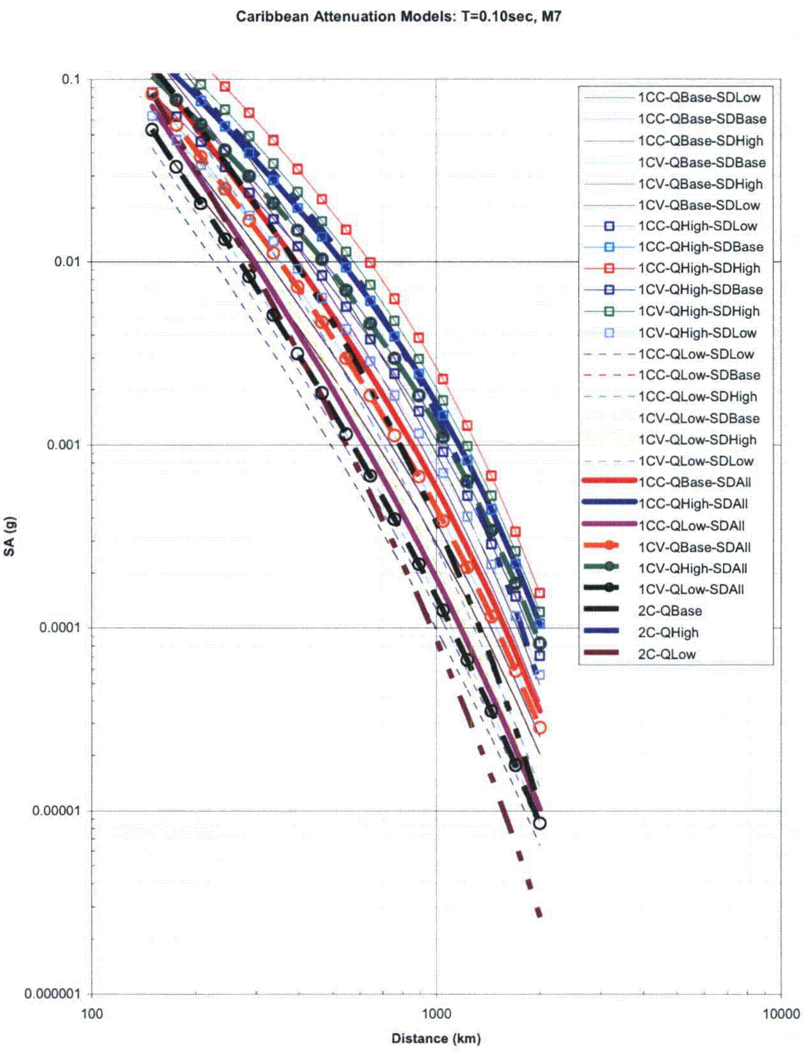

Figure 1c. Attenuation curves for M7 and 10 Hz/0.10sec.

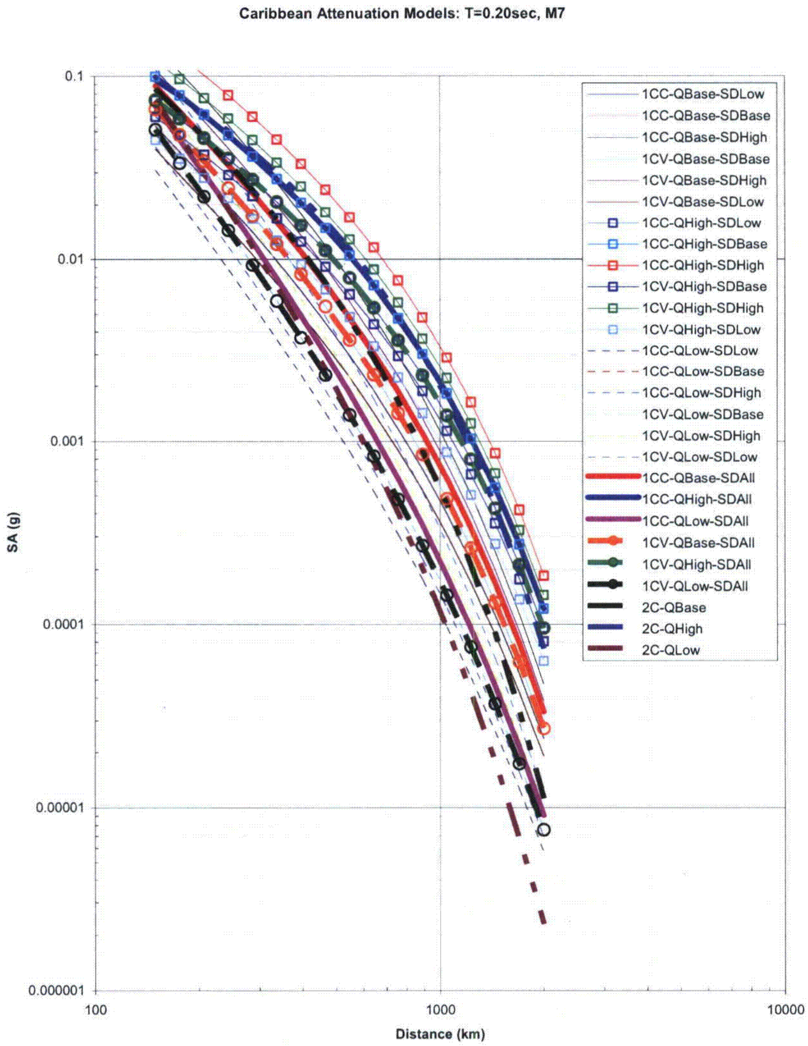

Figure 1d. Attenuation curves for M7 and 5 Hz/0.20sec.

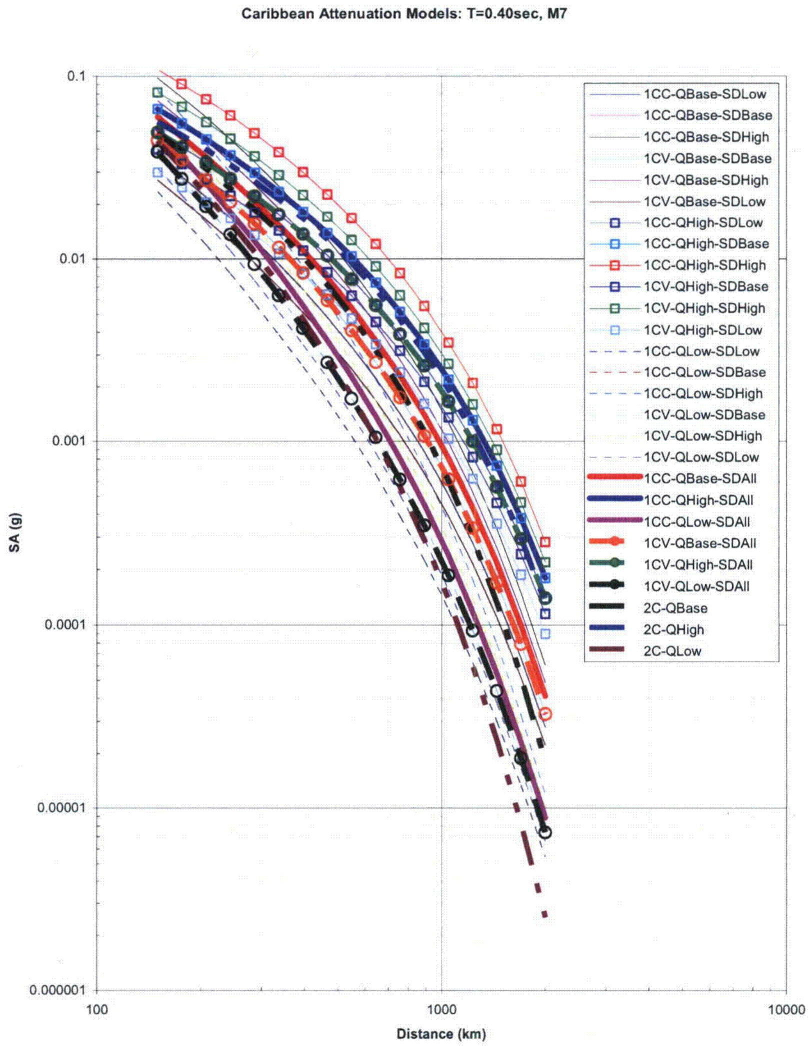

Figure 1e. Attenuation curves for M7 and 2.5 Hz/0.40sec.

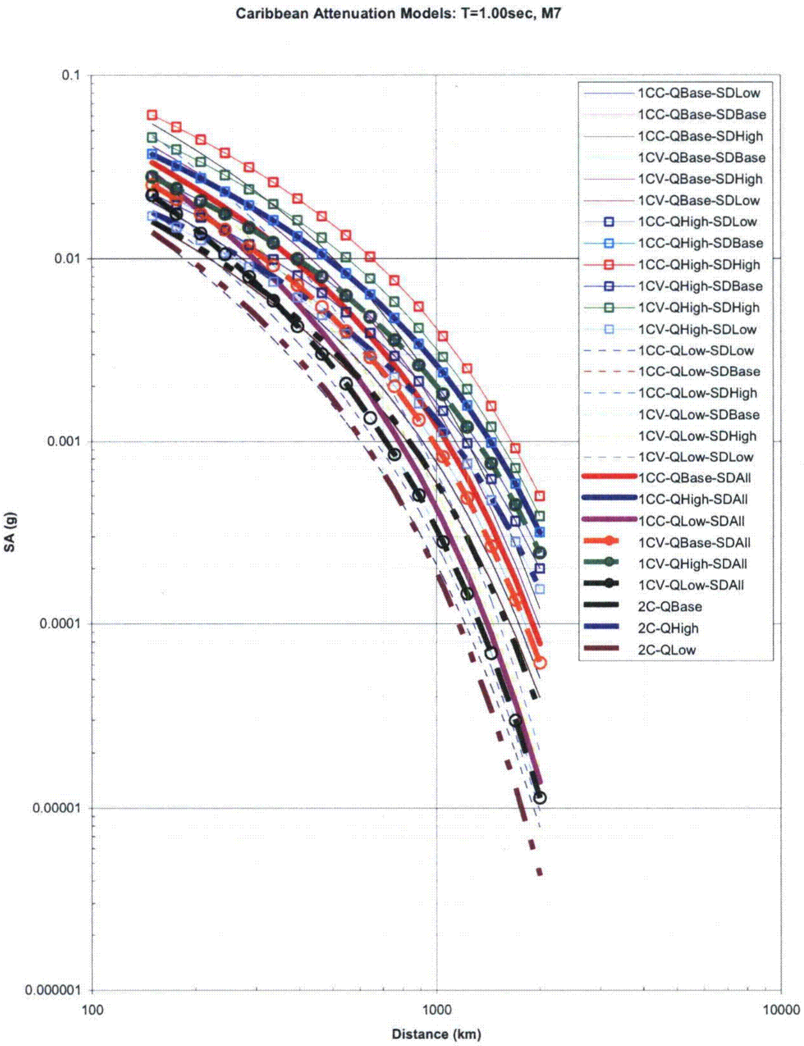

Figure 1f. Attenuation curves for M7 and 1 Hz/1.00sec.

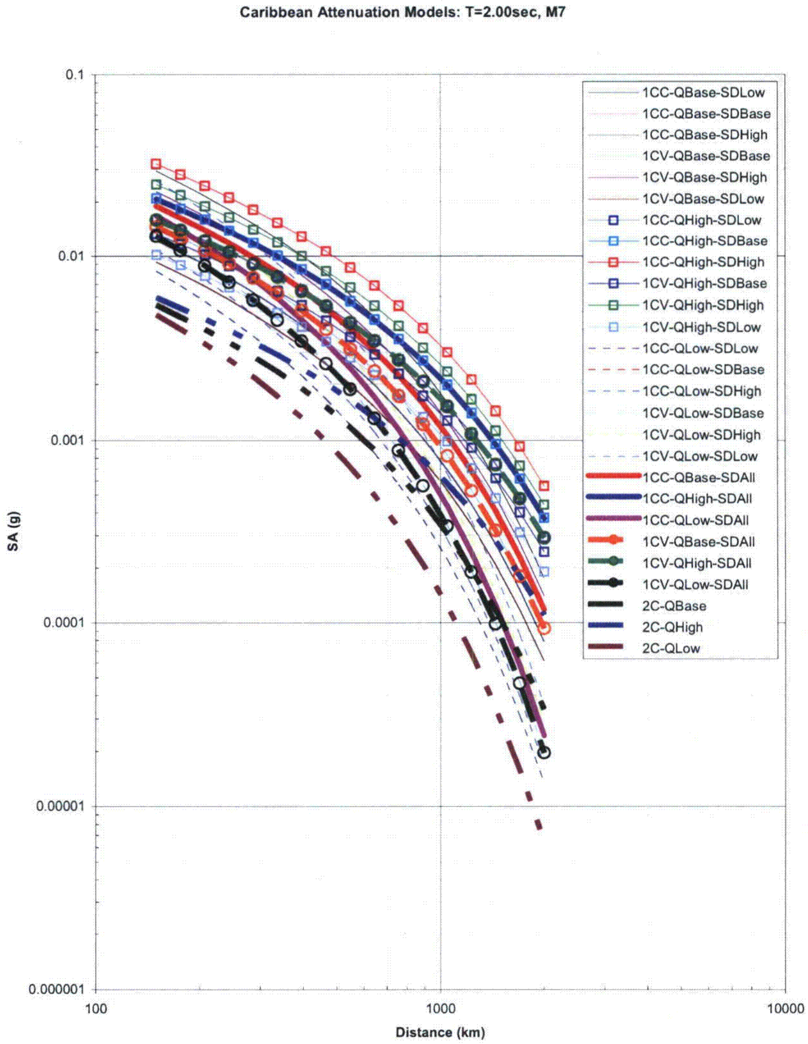

Figure 1g. Attenuation curves for M7 and 0.5 Hz/2.00sec.

The regression coefficients for the nine models are contained in the Appendix based on the functional form given in Equation 2. Although the ground motion models developed in the regression analysis have an associated uncertainty (i.e., on the order of 0.4 natural log units and less), the limited range in input parameters, especially the representation of three point values to represent a distribution of a given parameter, would suggest the conclusion that the regression uncertainty does not fully capture the expected uncertainty in ground motion models. For this reason, the aleatory sigma value of 0.28 in log10 units (0.645 in natural log units) from MA2005 was assigned to the models. This assignment is acceptable based on noted sigma values from other attenuation relationships (e.g., Abrahamson and Shedlock, 1997). This assigned aleatory sigma was applied at all seven frequencies, independent of magnitude and or distance.

Based on the selected suite of nine ground motion models and the similarities in source models and the non-uniform weighting methodology employed in the EPRI (2004) ground motion study, a non-uniform weighting scheme was developed. The single corner [1C] source model (both constant stress drop and variable stress cases) fall into Cluster 1 of the EPRI (2004) ground motion study for General Area seismic sources, while the double corner [2C] model falls into Cluster 2. The third Cluster in the EPRI (2004) study is based on hybrid empirical attenuation models, which have not been considered. The relative weights are listed as (see Figure 5-2 of EPRI, 2004):

Cluster 1	= 0.3512
Cluster 2	= 0.3985
Cluster 3	= 0.2503
Total	= 1.0

Based on these values, and specifically nearly equal weights between Cluster 1 and Cluster 2 the relative weights between the single corner source models and double corner source model were taken to be 50%/50%. Within the single corner source model case, the constant [1CC] and variable [1CV] stress parameter cases are also considered equally weighted 50%/50%. Finally, because of the large uncertainty in the regional anelastic attenuation, the relative weighting between the three Q low, base, and high models was assigned to be equal (i.e., 0.333, 0.334, 0.333). Combining these weights gives the weights for each of the nine models listed in Table 4.

These nine attenuation models were presented to TAG members at the final TAG meeting for review and acceptance. Two additional requests were made by TAG and a subsequent sensitivity analysis was performed to address these issues. The first request was to generate a double corner model using the source scaling from Western United States (WUS) earthquakes (Atkinson and Silva, 1997), and the second request was to use a Gulf Coast Q model (EPRI, 1993) in place of the MA2005 Q model. Although the comparisons between individual models used either a different source model (i.e., CEUS 2C source model or WUS 2C source model) or Q model (i.e., MA2005 Q model or Gulf Coast Q model), the overall distribution and resulting mean attenuation curves from all of the models are not significantly different (i.e., the results from the nine models are slightly larger) than the results using the nine models. Based on the results from this sensitivity study, the nine attenuation models were reviewed and accepted as applicable for the PSHA for Caribbean sources by TAG and as such have been used in the PSHA analysis for the Units 6 & 7 COL Application.

Table 4
Summary of attenuation tables listing regression coefficients and associated weights for each of nine models.

Attenuation Model	Appendix A Table of Coefficients	Model Weight
1CC, Q Base	Table A1	0.0834
1CC, Q High	Table A2	0.0833
1CC, Q Low	Table A3	0.0833
1CV, Q Base	Table A4	0.0834
1CV, Q High	Table A5	0.0833
1CV, Q Low	Table A6	0.0833
2C, Q Base	Table A7	0.1667
2C, Q High	Table A8	0.1667
2C, Q Low	Table A9	0.1666

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Appendix A - Regression coefficients for the nine models

Functional Ground Motion Model:

$$Ln(Y) = C_1 + C_2{*}M + (C_3 + C_4{*}M){*}Ln(R) + C_6{*}(M-6.0)^2 + (C_7 + C_8{*}M){*}R$$

(where R is in kilometers)

Model: Single Corner Constant Stress Parameter, Q base.

Table A1

Regression coefficients for the 1CC, Q Base model

Period(sec)	PGA	0.04s	0.10s	0.20s	0.40s	1.00s	2.00s
C1	-2.30600E-01	4.29876E+00	3.62516E-01	-5.71426E+00	-9.19084E+00	-1.06135E+01	-1.38416E+01
C2	8.80165E-01	7.98357E-01	1.24549E+00	1.71188E+00	1.78496E+00	1.63329E+00	1.94090E+00
C3	-2.03399E+00	-2.72903E+00	-1.87475E+00	-7.29569E-01	-2.44147E-01	-5.95026E-01	-7.16290E-01
C4	4.01763E-02	4.65873E-02	-4.54744E-02	-1.33066E-01	-1.26946E-01	-2.00984E-02	1.34957E-02
C6	-1.10473E-01	-1.02444E-01	-9.13379E-02	-8.35372E-02	-9.45177E-02	-1.94621E-01	-3.11072E-01
C7	-4.22385E-03	-3.81939E-03	-5.16025E-03	-6.29222E-03	-5.77508E-03	-3.46215E-03	-2.36535E-03
C8	4.14815E-04	4.28857E-04	5.53457E-04	6.23329E-04	4.89366E-04	1.73967E-04	7.01266E-05
Std. Error (Ln)[1]	0.368819	0.374473	0.394079	0.394229	0.378599	0.356484	0.330298

[1] Standard error values not used for aleatory uncertainty in PSHA. Value of σ_{lny} = 0.645 used (see main text).

Model: Single Corner Constant Stress Parameter, Q high.

Table A2

Regression coefficients for the 1CC, Q High model.

Period(sec)	PGA	0.04s	0.10s	0.20s	0.40s	1.00s	2.00s
C1	-1.43298E+00	1.73780E+00	-3.42259E+00	-6.32720E+00	-6.89259E+00	-9.46629E+00	-1.35318E+01
C2	9.24014E-01	9.97782E-01	1.38279E+00	1.41300E+00	1.22540E+00	1.40997E+00	1.87962E+00
C3	-1.71739E+00	-2.11797E+00	-1.08109E+00	-6.05819E-01	-7.18754E-01	-8.32851E-01	-7.75059E-01
C4	2.80727E-02	5.14554E-03	-7.09343E-02	-7.01397E-02	-1.14221E-02	2.63029E-02	2.54483E-02
C6	-9.00365E-02	-8.07435E-02	-7.02488E-02	-6.67675E-02	-8.99842E-02	-1.96376E-01	-3.10522E-01
C7	-3.25100E-03	-3.32367E-03	-4.58792E-03	-4.46433E-03	-3.25755E-03	-2.04212E-03	-1.57496E-03
C8	2.91582E-04	3.39688E-04	4.15554E-04	3.39786E-04	1.69033E-04	5.32811E-05	3.38375E-05
Std. Error (Ln)[1]	0.380326	0.392523	0.401984	0.392506	0.379988	0.358929	0.331514

[1] Standard error values not used for aleatory uncertainty in PSHA. Value of σ_{lny} = 0.645 used (see main text).

Model: Single Corner Constant Stress Parameter, Q low

Table A3

Regression coefficients for the 1CC, Q Low model

Period(sec)	PGA	0.04s	0.10s	0.20s	0.40s	1.00s	2.00s
C1	1.91935E+00	6.57272E+00	6.00713E+00	-2.57192E-01	-8.68467E+00	-1.34969E+01	-1.51898E+01
C2	6.72115E-01	4.58101E-01	7.05708E-01	1.35904E+00	2.10945E+00	2.22492E+00	2.19409E+00
C3	-2.57149E+00	-3.33658E+00	-3.09246E+00	-1.84607E+00	-3.26580E-01	1.25817E-02	-4.37048E-01
C4	8.72732E-02	1.19781E-01	6.22749E-02	-6.67062E-02	-1.98313E-01	-1.44592E-01	-3.92879E-02
C6	-1.35578E-01	-1.29313E-01	-1.18016E-01	-1.08294E-01	-1.10195E-01	-1.89386E-01	-3.06845E-01
C7	-5.22521E-03	-4.58425E-03	-5.29538E-03	-6.95395E-03	-8.25635E-03	-6.31424E-03	-3.99024E-03
C8	5.27876E-04	5.06495E-04	6.04659E-04	7.66483E-04	8.52876E-04	5.11070E-04	2.07700E-04
Std. Error (Ln)[1]	0.353141	0.356095	0.370952	0.385905	0.377982	0.353332	0.328141

[1] Standard error values not used for aleatory uncertainty in PSHA. Value of σ_{lny} = 0.645 used (see main text).

Model: Single Corner Variable Stress Parameter, Q base.

Table A4

Regression coefficients for the 1CV, Q Base model.

Period(sec)	PGA	0.04s	0.10s	0.20s	0.40s	1.00s	2.00s
C1	6.46351E-01	5.18119E+00	1.20451E+00	-4.89539E+00	-8.41396E+00	-9.85186E+00	-1.30628E+01
C2	7.12403E-01	6.29583E-01	1.08565E+00	1.55923E+00	1.64065E+00	1.48890E+00	1.79488E+00
C3	-2.04460E+00	-2.74004E+00	-1.87771E+00	-7.27859E-01	-2.34009E-01	-5.84387E-01	-7.16486E-01
C4	4.23239E-02	4.87807E-02	-4.50723E-02	-1.34084E-01	-1.29578E-01	-2.20711E-02	1.35750E-02
C6	-1.33274E-01	-1.25014E-01	-1.13495E-01	-1.05210E-01	-1.15571E-01	-2.16078E-01	-3.36759E-01
C7	-4.30606E-03	-3.90183E-03	-5.25216E-03	-6.38889E-03	-5.88004E-03	-3.54819E-03	-2.41617E-03
C8	4.31630E-04	4.45854E-04	5.72662E-04	6.43993E-04	5.11042E-04	1.90111E-04	7.93942E-05
Std. Error (Ln)[1]	0.37128	0.376611	0.395697	0.395743	0.381454	0.364251	0.342215

[1] Standard error values not used for aleatory uncertainty in PSHA. Value of σ_{lny} = 0.645 used (see main text).

Model: Single Corner Variable Stress Parameter, Q high

Table A5

Regression coefficients for the 1CV, Q High model

Period(sec)	PGA	0.04s	0.10s	0.20s	0.40s	1.00s	2.00s
C1	-5.19120E-01	2.63564E+00	-2.54967E+00	-5.46522E+00	-6.03184E+00	-8.59520E+00	-1.27037E+01
C2	7.50550E-01	8.27222E-01	1.21888E+00	1.25136E+00	1.06277E+00	1.24513E+00	1.72460E+00
C3	-1.73409E+00	-2.13099E+00	-1.08909E+00	-6.11782E-01	-7.24882E-01	-8.44497E-01	-7.85436E-01
C4	3.11429E-02	7.51238E-03	-6.98850E-02	-6.94977E-02	-1.04548E-02	2.85065E-02	2.73843E-02
C6	-1.11657E-01	-1.02049E-01	-9.11891E-02	-8.72129E-02	-1.10144E-01	-2.17775E-01	-3.36243E-01
C7	-3.30227E-03	-3.38026E-03	-4.64951E-03	-4.52534E-03	-3.31203E-03	-2.07439E-03	-1.59965E-03
C8	3.02306E-04	3.51519E-04	4.28714E-04	3.52552E-04	1.79688E-04	5.92123E-05	3.83155E-05
Std. Error (Ln)[1]	0.381997	0.393754	0.402841	0.393536	0.382479	0.366608	0.343272

[1] Standard error values not used for aleatory uncertainty in PSHA. Value of σ_{lny} = 0.645 used (see main text).

Model: Single Corner Variable Stress Parameter, Q low

Table A6

Regression coefficients for the 1CV, Q High model

Period(sec)	PGA	0.04s	0.10s	0.20s	0.40s	1.00s	2.00s
C1	2.77750E+00	7.44624E+00	6.85970E+00	5.75510E-01	-7.90981E+00	-1.28646E+01	-1.45696E+01
C2	5.06778E-01	2.88943E-01	5.41280E-01	1.20171E+00	1.96677E+00	2.10836E+00	2.07734E+00
C3	-2.57999E+00	-3.34742E+00	-3.09865E+00	-1.84781E+00	-3.16665E-01	5.02315E-02	-4.03622E-01
C4	8.92397E-02	1.22337E-01	6.37697E-02	-6.67045E-02	-2.01204E-01	-1.52341E-01	-4.54208E-02
C6	-1.60001E-01	-1.53540E-01	-1.41817E-01	-1.31590E-01	-1.32827E-01	-2.11469E-01	-3.32203E-01
C7	-5.34431E-03	-4.70165E-03	-5.41940E-03	-7.08370E-03	-8.40018E-03	-6.48893E-03	-4.12874E-03
C8	5.52052E-04	5.30232E-04	6.30010E-04	7.93760E-04	8.83429E-04	5.45399E-04	2.33237E-04
Std. Error (Ln)[1]	0.356846	0.359576	0.373857	0.388202	0.380878	0.360949	0.340186

[1] Standard error values not used for aleatory uncertainty in PSHA. Value of σ_{lny} = 0.645 used (see main text).

Model: Double Corner, Q base

Table A7

Regression coefficients for the 2C, Q Base model.

Period(sec)	PGA	0.04s	0.10s	0.20s	0.40s	1.00s	2.00s
C1	3.72811E+00	8.49077E+00	2.04648E+00	-4.36212E+00	-6.53863E+00	-8.93183E+00	-1.14216E+01
C2	3.62532E-01	2.80281E-01	9.29165E-01	1.29804E+00	1.16669E+00	1.20235E+00	1.37231E+00
C3	-2.63090E+00	-3.33352E+00	-2.02232E+00	-9.22639E-01	-8.61085E-01	-9.58224E-01	-8.63011E-01
C4	1.17439E-01	1.21552E-01	-3.84737E-03	-5.76716E-02	7.28201E-03	4.73354E-02	3.82344E-02
C6	-9.61466E-02	-9.13022E-02	-8.85030E-02	-9.63999E-02	-1.18739E-01	-1.16273E-01	-1.33446E-01
C7	-3.30674E-03	-3.02838E-03	-4.88201E-03	-5.58566E-03	-4.24819E-03	-2.68881E-03	-2.09044E-03
C8	2.05441E-04	2.33143E-04	3.86747E-04	3.73725E-04	1.58747E-04	3.23103E-05	2.58604E-05
Std. Error (Ln)[1]	0.077642	0.094942	0.169054	0.127204	0.049267	0.023579	0.078813

[1] Standard error values not used for aleatory uncertainty in PSHA. Value of σ_{lny} = 0.645 used (see main text).

Model: Double Corner, Q high

Table A8

Regression coefficients for the 2C, Q High model

Period(sec)	PGA	0.04s	0.10s	0.20s	0.40s	1.00s	2.00s
C1	1.20850E+00	3.85293E+00	-2.53345E+00	-4.51402E+00	-5.79354E+00	-8.88957E+00	-1.13305E+01
C2	4.96320E-01	6.22104E-01	1.05082E+00	9.54133E-01	9.44364E-01	1.17695E+00	1.34962E+00
C3	-2.04540E+00	-2.31197E+00	-1.08394E+00	-8.95616E-01	-1.01249E+00	-9.61513E-01	-8.70671E-01
C4	8.69941E-02	5.20951E-02	-2.55106E-02	1.36142E-02	5.27045E-02	5.18286E-02	4.13401E-02
C6	-8.58723E-02	-8.01707E-02	-7.86664E-02	-9.14501E-02	-1.18649E-01	-1.15192E-01	-1.31099E-01
C7	-3.02267E-03	-3.37961E-03	-4.65877E-03	-3.85147E-03	-2.70125E-03	-1.87583E-03	-1.48009E-03
C8	1.78738E-04	2.50685E-04	3.02755E-04	1.56949E-04	4.70685E-05	2.08105E-05	2.00235E-05
Std. Error (Ln)[1]	0.054298	0.109451	0.104154	0.042475	0.018439	0.022084	0.077194

[1] Standard error values not used for aleatory uncertainty in PSHA. Value of σ_{lny} = 0.645 used (see main text).

Model: Double Corner, Q low

Table A9

Regression coefficients for the 2C, Q Low model.

Period(sec)	PGA	0.04s	0.10s	0.20s	0.40s	1.00s	2.00s
C1	6.09985E+00	1.17504E+01	8.93229E+00	3.13919E-01	-7.28794E+00	-9.98786E+00	-1.19668E+01
C2	3.40409E-01	6.29906E-02	5.49866E-01	1.33462E+00	1.75821E+00	1.47681E+00	1.49053E+00
C3	-3.24124E+00	-4.16057E+00	-3.48716E+00	-1.88262E+00	-7.14571E-01	-7.55380E-01	-7.66507E-01
C4	1.29936E-01	1.71977E-01	7.21530E-02	-6.76985E-02	-1.12642E-01	-6.71478E-03	1.62271E-02
C6	-1.15036E-01	-1.11005E-01	-1.07426E-01	-1.12176E-01	-1.27873E-01	-1.20356E-01	-1.37312E-01
C7	-3.72272E-03	-3.01092E-03	-4.31708E-03	-6.17468E-03	-6.52226E-03	-4.30970E-03	-3.17507E-03
C8	2.87034E-04	2.63981E-04	4.13079E-04	5.52587E-04	4.77132E-04	1.51995E-04	7.28660E-05
Std. Error (Ln)[1]	0.113794	0.088303	0.18522	0.22628	0.169469	0.055671	0.080507

[1] Standard error values not used for aleatory uncertainty in PSHA. Value of σ_{lny} = 0.645 used (see main text).