U.S. Geological Survey Coastal Plain Amplification Virtual Workshop

Open-File Report 2022–1006

U.S. Department of the Interior
U.S. Geological Survey

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By Oliver S. Boyd, Thomas L. Pratt, Martin C. Chapman, Allison Shumway, Sanaz Rezaeian, Morgan P. Moschetti, and Mark D. Petersen

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Wave Speed	
kilometer per second (km/s)	0.6214	miles per second (mi/s)
kilometer per second (km/s)	3280.84	feet per second (ft/s)
meters per second (m/s)	3.281	feet per second (ft/s)
	Density	
gram per cubic centimeter (g/cm^3)	62.4220	pound per cubic foot (lb/ft^3)
	Pressure	
pascal (kg/s^2m)	0.000145	pound-force per square inch (lbf/in^2)
	Frequency	
hertz (Hz)	1	cycle per second

Abbreviations

CEUS-SSC	Central and Eastern United States - Seismic Source Characterization
CPA	coastal plain amplification
DASG	Darragh, Abrahamson, Silva, and Gregor (2018) Gulf Coast ground motion model
DNAG	Decade of North American Geology
GC19	Guo and Chapman (2019) model
GMM	ground motion models
H/V	horizontal-to-vertical spectral ratios
NGA-East	Next Generation Attenuation Relationships for the Eastern United States
NGA-West-2	Next Generation Attenuation Relationships for the Western United States, version 2
NSHM	National Seismic Hazard Model
PEER	Pacific Earthquake Engineering Research Center
PSA	peak spectral acceleration
PSHA	probabilistic seismic hazard analyses
SA	spectral accelerations
USGS	U.S. Geological Survey
WG	working group
g	the acceleration due to Earth's gravity, 9.8 meters per second squared
M	earthquake magnitude
Q	quality factor
R	source-to-site distance
T	period
V_{S30}	time-averaged shear-wave velocity within the upper 30 meters of the Earth's surface
V_S	shear (*S*)-wave velocity
V_P	primary (*P*)-wave velocity
z	sediment thickness
1-D	one dimensional
3-D	three dimensional

U.S. Geological Survey Coastal Plain Amplification Virtual Workshop

By Oliver S. Boyd,[1] Thomas L. Pratt,[1] Martin C. Chapman,[2] Allison Shumway,[1] Sanaz Rezaeian,[1] Morgan P. Moschetti,[1] and Mark D. Petersen[1]

Abstract

In early October of 2020, the U.S. Geological Survey (USGS) held a virtual workshop to discuss Gulf and Atlantic Coastal Plains site-response models. Earthquake researchers came together to assess (1) research related to proposed Coastal Plains amplification models and (2) USGS plans for implementing these models. Presentations spanned a broad range of topics from Atlantic and Gulf Coastal Plains geophysical properties including seismic velocity and attenuation, to ground motion amplification models and their impacts on seismic hazard. Interspersed with these presentations were discussions regarding the definition and extent of the Atlantic and Gulf Coastal Plains, potential complexities of wave propagation in the Atlantic and Gulf Coastal Plains, and problems that need to be overcome to implement various proposed site-response models. Based on feedback from this workshop, the USGS working group on Coastal Plain Amplification is considering applying published models that depend on sediment thickness. The working group is also exploring potential application of models that depend on the length of path traversed across the Coastal Plain, including the Gulf Coastal Plain ground-motion model adjustments from the Next Generation Attenuation Relationships for the Eastern United States.

Introduction

Earthquake ground motions on the Atlantic and Gulf Coastal Plains of the south-central and southeastern United States are unique relative to those of the western and interior United States. The Atlantic and Gulf Coastal Plains are characterized by a syn- and post-rift, Mesozoic and Cenozoic Eras, wedge of sediment that thickens to more than 10 kilometers (km) in the Gulf Coast and 4 km along the Atlantic Coast. The gradual thickening of low-velocity sediments over high-velocity basement rocks leads to an unusually strong frequency dependence in ground motions, which is not accounted for in the 2018 and earlier versions of the U.S. Geological Survey (USGS) National Seismic Hazard Model (NSHM).

On October 5 and 7, 2020, during four, 2-hour virtual sessions, 44 earthquake researchers came together to discuss (1) research related to proposed Atlantic and Gulf Coastal Plains amplification models in the 2023 update of the NSHM and (2) USGS plans for implementing these models.

Attendees listened to 13 presentations on research ranging from Atlantic and Gulf Coastal Plains geophysical properties including seismic velocity and attenuation, to ground motion amplification models and their impacts on seismic hazard. Interspersed with these presentations were discussions regarding the definition and extent of the Atlantic and Gulf Coastal Plains, potential complexities of wave propagation in the Atlantic and Gulf Coastal Plains, and problems that need to be overcome to implement various proposed site response models. Based on feedback from this workshop, the USGS working group (WG) on coastal plain amplification (CPA) is considering applying the models that depend on sediment thickness (Chapman and Guo, 2021; Pratt and Schleicher, 2021). The WG is also considering potential application of Next Generation Attenuation Relationships for the Eastern United States (NGA-East) that depend on path length within the Atlantic and Gulf Coastal Plains and other published models (Cramer, 2018; Graizer, 2018; Harmon and others, 2019b). For additional information, see the abstracts by Martin C. Chapman, Thomas L. Pratt, Roland LaForge, Youssef Hashash, Chris H. Cramer, and Vladimir Graizer, and related discussions. The NGA-East model would require significant modification of the codes used to calculate the USGS NSHM and may be considered for later versions of the NSHM that make greater use of path-dependent ground-motion variability.

There was broad support to continue interactions between the USGS WG and the greater earthquake engineering community. The WG plans to hold a follow-on workshop to hear from the community about how their research relevant to CPA have progressed and to provide an update on the efforts of the USGS to implement CPA models in the NSHM.

[1]U.S. Geological Survey.

[2]Virginia Polytechnic Institute and State University.

Workshop Goals

The goals of the 2020 USGS Coastal Plain Amplification Virtual Workshop were to

1. Develop a clear path forward as to the ways in which the USGS could incorporate Coastal Plain site response in future updates of the NSHM.
2. Present and get feedback on methods the USGS has considered for including Coastal Plain site response.
3. Hear from subject matter experts on their views and work related to site response on the Atlantic and Gulf Coastal Plains and potentially analogous Central and Eastern United States environments.
4. Decide whether reconvening the workshop to include other subject matter experts, gather additional feedback, and update the earthquake engineering community on our efforts would be beneficial.

Participants

Table 1 provides the names, emails, and affiliations for the 44 participants in the 2020 USGS Coastal Plain Amplification Virtual Workshop.

Table 1. U.S. Geological Survey Coastal Plain Amplification Virtual Workshop attendees, October 5 and 7, 2020. Meeting convened online.

[USGS, U.S. Geological Survey; LLC, limited liability company]

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Table 1. U.S. Geological Survey Coastal Plain Amplification Virtual Workshop attendees, October 5 and 7, 2020. Meeting convened online.—Continued

[USGS, U.S. Geological Survey; LLC, limited liability company]

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Ed Woolery	ewoolery@uky.edu	University of Kentucky

Agenda

Table 2 provides the agenda for the 2020 USGS Coastal Plain Amplification Virtual Workshop.

Table 2. U.S. Geological Survey Coastal Plain Amplification Virtual Workshop agenda, October 5 and 7, 2020. Meeting convened online.

[1-D, one dimensional; NGA-East, Next Generation Attenuation Relationships for the Eastern United States; CEUS-SSC, Central and Eastern United States-seismic source characterization]

Time	Session or presentation title	Session leader	Notes taken by
	Monday, October 5, 2020		
10:00 a.m.–10:10 a.m.	Workshop overview	Oliver Boyd	Martin C. Chapman
10:10 a.m.–10:20 a.m.	Participant introductions	Oliver Boyd	Martin C. Chapman
10:20 a.m.–10:40 a.m.	Proposed Model for the Implementation of Ground Motion Amplification on the Atlantic and Gulf Coastal Plains[1]	Oliver Boyd	Martin C. Chapman
10:40 a.m.–11:00 a.m.	Discussion		Martin C. Chapman
11:00 a.m.–11:25 a.m.	"Seismic Response of Thick Unconsolidated Sediments"	Charles A. Langston	Martin C. Chapman
11:25 a.m.–11:50 a.m.	"Deep Sediments Thickness Correction and Apparent Anelastic Attenuation in Applications to Ground Motion Modeling"	Vladimir Graizer	Martin C. Chapman
11:50 a.m.–12:15 p.m.	"Site Amplification Models for Central and Eastern North America"	Youssef Hashash	Martin C. Chapman
12:15 p.m.–1:00 p.m.	Lunch		
1:00 p.m.–1:30 p.m.	"Primary Site-Response Parameters and an Evaluation of Site-Response Proxies at Selected Sites in the Upper Mississippi Embayment"	Seth Carpenter	Thomas L. Pratt
1:30 p.m.–2:00 p.m.	"1-D Velocity Profiles of Atlantic Coastal Plain Sedimentary Strata from Receiver Functions"	Erin Cunningham	Thomas L. Pratt
2:00 p.m.–2:30 p.m.	"Central and Eastern United States Attenuation Boundaries and Coastal Plain Crustal Seismic Attenuation Models"	Chris H. Cramer	Thomas L. Pratt
2:30 p.m.–3:00 p.m.	"Mapping Site Response in the U.S. Coastal Plain"	Charles Mueller	Thomas L. Pratt

Table 2. U.S. Geological Survey Coastal Plain Amplification Virtual Workshop agenda, October 5 and 7, 2020. Meeting convened online.—Continued

[1-D, one dimensional; NGA-East, Next Generation Attenuation Relationships for the Eastern United States; CEUS-SSC, Central and Eastern United States-seismic source characterization]

Time	Session or presentation title	Session leader	Notes taken by
	Wednesday, October 7, 2020		
10:00 a.m.–10:30 a.m.	“Atlantic Coastal Plain Amplification and Velocity Studies”	Thomas L. Pratt	Allison Shumway
10:30 a.m.–11:00 a.m.	“A Response Spectral Ratio Model to Account for Amplification and Attenuation Effects in the Atlantic and Gulf Coastal Plain”	Martin C. Chapman	Allison Shumway
11:00 a.m.–11:30 a.m.	“Effects of NGA-East Ground Motion Models’ Gulf Coast Corrections on Hazard Curves and Uniform Hazard Spectra, as applied to the CEUS-SSC Source Model”	Roland LaForge	Allison Shumway
11:30 a.m.–12:00 p.m.	“Sediment Thickness Along the Atlantic and Gulf Coastal Plains”	Oliver Boyd	Allison Shumway
12:15 p.m.–1:00 p.m.	Lunch		
1:00 p.m.–1:30 p.m.	“A Ground Motion Database to Support Evaluation of Atlantic Coastal Plain Amplification Factors for use in Seismic Hazard Assessments”	Morgan P. Moschetti	Sanaz Rezaeian
1:30 p.m.–2:00 p.m.	“Implementation of the Guo & Chapman (2019) Coastal Plain Amplification Model”	Peter M. Powers	Sanaz Rezaeian
2:00 p.m.–2:30 p.m.	Discussion		Sanaz Rezaeian
2:30 p.m.–3:00 p.m.	Next Steps		Sanaz Rezaeian

[1]There is no abstract associated with this introductory session, and it is not included in the total number of presentations.

Abstracts

“Seismic Response of Thick Unconsolidated Sediments”

By Charles A. Langston (University of Memphis)

Seismic wave propagation for Earth structures that contain thick sections of near-surface, laterally continuous, unconsolidated sediment does not necessarily conform to the standard source-path-receiver convolutional model that is often assumed in earthquake shaking hazards assessments, particularly for earthquake sources within the region covered by the sediments. In theory, earthquakes that occur within the Mississippi embayment or Gulf of Mexico/Atlantic Coastal Plains may excite large, relatively high frequency surface waves in addition to large *S* waves that can contribute to strong ground shaking. Excitation of these surface waves may be quite high in amplitude if faulting extends into the sediments. In practice, there have been no large earthquakes recorded in these regions to test this assertion although there are hints that this occurs from shallow, low magnitude seismicity. In addition to the velocity structure of the sediments and impedance contrast at the sediment-basement interface, the anelastic attenuation structure will also be an important factor in controlling the frequency dependence of amplification, excitation, and propagation of both *S* and surface waves. Conversely, the velocity, attenuation, and nonlinear wave propagation characteristics of thick sediments can be studied experimentally using surface waves from earthquakes, explosions, high amplitude controlled sources and surface waves of the ambient noise field. A short review of past work in the Mississippi embayment, use of horizontal-to-vertical ambient noise, teleseismic receiver functions, explosion sources, controlled sources, and earthquake waveform modeling will be presented. Proposals for future instrumentation facilities and field experiments will also be suggested to address the problem of sediment seismic response.

“Deep Sediments Thickness Correction and Apparent Anelastic Attenuation in Applications to Ground Motion Modeling”

By Vladimir Graizer (U.S. Nuclear Regulatory Commission)

The deep sediments typically found in basins can significantly amplify ground motions. I implemented a deep sediment thickness effect in ground motion models (GMM) for the 5 percent-damped spectral accelerations (SA) based on the depth to the shear-wave velocity horizon of 2.5 kilometers per second (km/s) ($Z_{2.5}$) for the Graizer (2018) GMM. In most cases, the actual basin depth under the seismic station is not known and is usually substituted in GMM by the *Z*-term: depth to the shear-wave velocity horizon of 1.0 km/s ($Z_{1.0}$), 1.5 km/s ($Z_{1.5}$), or 2.5 km/s ($Z_{2.5}$). I do not recommend using the term “basin effect” in application to current GMM, instead the term “deep sediments effect” is a more appropriate. This can help avoid confusion and misunderstanding when comparing to a basin effect in seismology because (1) none of the *Z*-terms represent actual basin depths, (2) the basin-edge effect is not considered, and (3) the actual shape of the basin is not considered.

Anelastic attenuation of SA is another issue that needs to be clarified. Apparent attenuation of SA quality factor, Q_{SA}, is different from the classical seismological *Q* determined from Fourier spectra of *S*, *Lg*, or coda waves. From a physical point of view, the Q_{SA} quality factor represents the diminution of amplitude in the 5 percent-damped response spectral amplitudes at a certain frequency not necessarily associated with one wave. The seismological *Q*-factor represents the fraction of energy lost per cycle in a specific wave.

“Site Amplification Models for Central and Eastern North America”

By Youssef Hashash (University of Illinois at Urbana-Champaign), Okan Ilhan (University of Illinois at Urbana-Champaign), Halil Uysal (University of Illinois at Urbana-Champaign), Jonathan P. Stewart (University of California at Los Angeles), Ellen M. Rathje (University of Texas), and Sissy Nikolaou (Williams Sale Partnership Limited—WSP)

Site amplification factors are used to compute a ground motion intensity measure of interest at a surface condition through adjustment of the ground motion intensity measure at the reference condition. Central and Eastern North America, which is known as a stable continental region, but with significant seismic hazard, lacks region-specific site amplification functions due to a dearth of ground motion recordings for empirical characterization of site amplification. As part of NGA-East geotechnical working group, we performed a large-scale parametric study of over 1.7 million linear, equivalent-linear, and nonlinear, one dimensional (*1-D*) site response analyses to represent variability in site conditions in Central and Eastern North America (Harmon and others, 2019a, b). These simulations were used to propose a suite of conventional simulation-based site amplification functions, which were adapted in the development of semi-empirical linear (Stewart and others, 2020) and simulation-based nonlinear amplification (Hashash and others, 2020) models for National Seismic Hazard Maps applications (Petersen and others, 2020). Recently, this parametric study design is further updated (over 3.6 million linear, equivalent-linear, and nonlinear analyses), and an alternative modeling approach using artificial neural network deep learning techniques is adopted to better capture the simulated amplification dataset (Ilhan, 2020). These studies highlight the need to go beyond the time-averaged shear-wave velocity within the top 30 meters (m) of the Earth’s surface, V_{S30}, as an input proxy for site amplification and as a minimum, include site natural period to significantly enhance the fidelity of conventional and artificial neural network based ergodic site amplification models.

“Primary Site-Response Parameters and an Evaluation of Site-Response Proxies at Selected Sites in the Upper Mississippi Embayment”

By Seth Carpenter (Kentucky Geological Survey), Zhenming Wang (Kentucky Geological Survey), and Ed Woolery (University of Kentucky)

Numerous proxies have been proposed and used to account for site response, that is, modification of ground motion by near-surface, low-velocity materials in terms of spectral content, amplitude, and duration. Some proxies are based on portions of a site’s velocity profile, including the time-average shear-wave velocity from the surface to a particular depth or the depth to a particular velocity. Others are based on the surface geology or thickness of unlithified sediments over bedrock. Empirical and theoretical studies have shown that site response can be quantified by the fundamental (f_0) and peak site frequencies (f_{peak}) and the corresponding amplifications, A_0 and A_{peak} (Carpenter and others, 2020; Wang and Carpenter, 2021a, 2021b; Zhu and others, 2021). We estimated fundamental and peak weak-motion response parameters from empirical and theoretical *1-D* site-responses in the thick sediments (from 100 m to approximately 850 m below the land surface) of the upper Mississippi embayment at the two deep vertical seismic arrays and at eight other seismic stations where velocity profiles to bedrock are available. We then compared the fundamental and peak site frequencies and the corresponding amplifications with those proxies. Our results show that the fundamental site period and peak amplification do not simultaneously correlate with velocity- and thickness-based proxies. For example, although f_0 correlates strongly with depth to bedrock, A_0 does not. Further, there is no correlation between f_{peak}, A_{peak}, and sediment thickness. Likewise, the average *S*-wave velocity in the upper 30 m does not correlate with f_0. Our results suggest that a single proxy cannot capture site response, and reliably predicting linear site response relies on site-specific characterizations. We also found that f_0 and A_0 can be estimated by single-station weak-motion *S*-wave horizontal-to-vertical spectral ratios (H/V) to within 8 percent and 18 percent on average, respectively. Thus, H/V may provide useful approximations of linear site responses in the embayment.

"*1-D* Velocity Profiles of Atlantic Coastal Plain Sedimentary Strata from Receiver Functions"

By Erin Cunningham (University of Memphis)

The thickness and seismic velocities of sedimentary sequences strongly affect their response during earthquakes and can prolong and amplify ground motions. We characterize the shallow structure of Atlantic Coastal Plain sediments using a passive-seismic approach based on high-frequency *P*-to-*S* receiver functions. Using sediment *S*-wave reverberations and *P*-to-*S* phase arrival times measured directly from the receiver functions, we invert for average *S*- and *P*-wave velocity (V_S, V_P) profiles of the Atlantic Coastal Plain sedimentary strata. We find that V_S increases with depth following a power-law relationship, whereas the increase of V_P with depth is more difficult to constrain using converted wave methods. Finally, we use the variation of measured *S*-reverberation amplitudes with depth to validate these velocity profiles.

"Central and Eastern United States Attenuation Boundaries and Coastal Plain Crustal Seismic Attenuation Models"

By Chris H. Cramer (University of Memphis)

Studies of seismic crustal attenuation in the Central and Eastern United States have mainly identified two different attenuation regions: mid-continental and Gulf Coast. The boundaries between regions have generally been defined using criteria other than seismic attenuation observations due to limited observations of crustal quality factor (*Q*). The USArray (IRIS Transportable Array, 2003) provided sufficient station coverage and data to define the actual boundaries of the Gulf Coast crustal attenuation region. We have shown that the Gulf Coast region does not include the upper Mississippi embayment, northern and central Alabama, Georgia, most of Florida, and does not extend under the Atlantic Coastal Plain, but does extend into western Mississippi, southern Arkansas, east Texas, and parts of Oklahoma.

There are also suggestions of higher attenuation under basins and rifts northwest of the Gulf Coast region. Gulf Coast regional crustal *Q* has been observed between 0.1 and 10 hertz (Hz) as Q_o at 1 Hz = 259 +24/−22 and the power of frequency (estimated time of arrival) = 0.715 ± 0.013. Intensity observations from historical earthquake magnitude (*M*) 7 and recent *M*5 earthquakes are consistent with our crustal *Q* boundary observations, which provides greater support for our model compared to other recent crustal attenuation models. The ground motions generated by the August 9, 2020, *M*5.1 earthquake in Sparta, North Carolina, indicate an Atlantic Coastal Plain crustal *Q* that is similar to the mid-continental *Q*. The eastern United States attenuation anisotropy observed in the 2011 *M*5.7 earthquake in Mineral, Virginia, is also observed in the 2020 Sparta, North Carolina earthquake, but with the added observation of lower attenuation to the east toward the Atlantic Coastal Plain.

"Mapping Site Response in the United States Coastal Plain"

By Charles Mueller (USGS)

A method for estimating and mapping seismic site response over a region is applied to the United States Atlantic and Gulf Coastal Plains. The geologic structures that control the site response are relatively simple in the study area, where 0–15 km of poorly consolidated Cretaceous Period and younger sediments overlie bedrock. At each site on a grid, a spectrum of Fourier-spectral site amplification factors is computed, using power-law V_S-depth and shear-wave quality factor (Q_S) depth models tied to surface geology and depth to bedrock, and applying a quarter-wavelength procedure that accounts for both amplification and attenuation. These factors are applied with a stochastic methodology to simulate linear site response for peak ground acceleration and 1 Hz, 5 Hz, and 10 Hz spectral response. Results are presented as maps of site response factors for selected earthquake magnitudes and distances. Patterns show complex tradeoffs between surface geology and depth to bedrock. Peak ground acceleration for small source distances is amplified by factors of 2–3 near landward edges of the Atlantic and Gulf Coastal Plains, and amplifications are reduced by factors up to 2 in the lower Mississippi River valley. Peak ground acceleration for large source distances is amplified everywhere, up to factors of 2–3 across broad areas of the Mississippi embayment and Atlantic Coastal Plain.

Response for 1 Hz, 5 Hz, and 10 Hz is generally amplified at sites with young sediments or shallow bedrock. High-frequency motions are reduced in the lower Mississippi River valley; up to factors of 5 at the delta where sediments are thickest. Efforts to model nonlinear site response were hampered by difficulties in modeling sediment modulus and damping effects.

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"Atlantic Coastal Plain Amplification and Velocity Studies"

By Thomas L. Pratt (USGS)

We examine the effect that the Atlantic Coastal Plain strata have on ground motions in the eastern and southeastern United States. At 217 sites on Atlantic Coastal Plain strata with thicknesses up to nearly 4,000 m, we compute spectral ratios relative to the average of 4 bedrock sites west or northwest of the strata. Results show prominent resonance peaks that define the largest amplifications at specific thicknesses for each frequency (Pratt and Schleicher, 2021). As frequencies increase, the resonance peaks migrate to thinner Atlantic Coastal Plain strata and increase in amplitude. We develop simple equations to define the approximate shape of the amplifications versus Atlantic Coastal Plain thickness. Comparison with other corrections based on sediment thickness show similarities on thin Atlantic Coastal Plain strata but divergence on thicker sediment.

We also test the reliability of H/V spectral ratios using ambient noise and earthquake arrivals to estimate the fundamental resonance peak of the Atlantic Coastal Plain strata, compared to spectral ratios relative to bedrock. We find that H/V ratios accurately define the frequency of the fundamental resonance peaks but consistently underestimate the amplitudes. Correcting the H/V ratios by multiplication with the vertical to horizontal spectral ratio of bedrock sites to partially correct for the source *P*-wave to *S*-wave amplitude ratio brings the H/V ratios more in line with bedrock spectral ratios. After this correction, the bedrock spectral ratios are about a factor of 1.5 greater than the H/V ratios, although scatter is wide in the data. We also find that H/V ratios using ambient noise are remarkably consistent during one-half hour time windows throughout a day, and in one-half hour time windows each day throughout nearly a month. These latter observations indicate that H/V ratios using ambient noise are an effective method for identifying the frequencies of the fundamental resonance peaks, although the amplitudes again show considerable scatter.

Finally, we are using joint inversions of dispersion curves and H/V ratios to invert for the velocity structure of the Atlantic Coastal Plain strata along the arrays of the Eastern North American Margin experiment (Lynner and others, 2019; Magnani and others, 2014). The inversion is done using a genetic algorithm that evaluates initial random models, chooses components from the best models, and evaluates this as a new generation of models by comparison with the dispersion curves and H/V ratios. After 150 generations, each consisting of 250 models (37,500 models total), we choose the average of the best 750 models (best 2 percent) as our result. Results clearly show the Atlantic Coastal Plain strata having velocities of less than 300 meters per second (m/s) at the surface to nearly 1,000 m/s in the deepest parts of the Atlantic Coastal Plain, below which velocities rapidly increase to more than 2,500 m/s.

"A Response Spectral Ratio Model to Account for Amplification and Attenuation Effects in the Atlantic and Gulf Coastal Plains"

By Martin C. Chapman (Virginia Polytechnic Institute and State University) and Zhen Guo (Virginia Polytechnic Institute and State University)

The Atlantic and Gulf Coastal Plains in the southern and southeastern United States contain extensive Cretaceous Period and Cenozoic Era sedimentary sequences of variable thickness. We investigated the difference in site response in the Atlantic and Gulf Coastal Plains relative to sites outside that region using Fourier spectral ratios from 17 regional earthquakes occurring during 2010–18 recorded by the EARTHSCOPE transportable array (IRIS Transportable Array, 2003) and other stations. We used mean coda and *Lg* spectra for sites outside the Coastal Plain as a reference. We found that Coastal Plain sites experience amplification of low-frequency ground motions and attenuation at high-frequencies relative to average site conditions outside the Coastal Plain (Guo and Chapman, 2019). The spectral ratios at high frequencies gave estimates of the difference between kappa, a measure of ground motion attenuation, at Coastal Plain sites and the reference condition. Differential kappa values determined from the coda are correlated with the thickness of the sediment section and agree with previous estimates determined from *Lg* waves. Averaged estimates of kappa reach about 120 milliseconds (ms) at Gulf Coast stations overlying ~12 km of sediments. Relations between *Lg* spectral ratio amplitudes versus sediment thickness in successive frequency bins exhibit consistent patterns, which were modeled using piecewise linear functions at frequencies ranging from 0.1 to 2.8 Hz. For sediment thickness greater than about 0.5 km, the spectral amplitude ratio at frequencies higher than approximately 3 Hz is controlled by the value of kappa. The peak frequency and maximum relative amplification at frequencies less than about 1.0 Hz depend on sediment thickness. At 0.1 Hz, the mean Fourier amplitude ratio (Coastal Plain/reference) is about 2.7 for sediment of 12 km thickness.

The model for the Fourier amplitude ratio was used develop a corresponding peak spectral acceleration (PSA) response spectral ratio model, by direct time-domain simulations via the stochastic model. The PSA ratio model for the Coastal Plain region is referenced to a site condition defined as the mean response for site locations outside the Coastal Plain. The model is strongly dependent on sediment thickness. The model can be used to predict PSA response at sites in the Atlantic or Gulf Coastal Plain with a known thickness of Coastal Plain sediment, given a ground motion prediction model for conditions outside the Coastal Plain region of the Central and Eastern United States. Results will be presented in terms of residual plots using PSA observations from 17 earthquakes and the NGA-East median ground motion prediction model developed specifically for the USGS.

"Effects of NGA-East Ground Motion Models' Gulf Coast Corrections on Hazard Curves and Uniform Hazard Spectra, as Applied to the Central and Eastern United States–Seismic Source Characterization (CEUS-SSC) Source Model"

By Roland LaForge (LaForge GeoConsulting)

The Central and Eastern United States Seismic Source Characterization (CEUS-SSC) source model was developed over the period 2008–11 by the Nuclear Regulatory Commission (Electric Power Research Institute, 2012), to provide a regional seismic source model for use in probabilistic seismic hazard analyses (PSHA) for nuclear facilities in the eastern United States. Key components of any PSHA are the ground motion models, which translate a magnitude and distance into a horizontal ground motion. The NGA-East Ground Motion project, completed and published by the Pacific Earthquake Research Center in 2018 (Goulet and others, 2018), comprises the most recent and comprehensive set of ground motion models for the eastern United States and southeastern Canada. Computer code has been developed that applies the NGA-East ground motion models to the CEUS-SSC source model.

The issue of reduced ground motions for ray paths within, and traversing, the Gulf Coast region was of particular concern and focus on the NGA-East project. Details are contained in the "Next Generation Attenuation" report (Goulet and others, 2018), but to summarize, two independent groups derived corrections to non-Gulf Coast ray paths based on simulations and the sparse available observations. The correction is based on the fraction of total distance the ray path spends in the Gulf Coast zone. Weights are applied to the two groups corrections, and two geographic definitions of the Gulf Coast zone. To inform the goals of this workshop, several source-site paths traversing the Gulf Coast regions will be executed in the PSHA code, with and without the correction, to show the effect of the NGA-East correction scheme on hazard curves and uniform hazard spectra.

"Sediment Thickness Along the Atlantic and Gulf Coastal Plains"

By Oliver S. Boyd (USGS) and Sarah Mills (Colorado School of Mines)

Earthquake ground motions along the Atlantic and Gulf Coastal Plains show significant frequency-dependent deviations relative to other areas in the Central and Eastern United States (Guo and Chapman, 2019; Pratt and Schleicher, 2021). Ground motions have been shown to be strongly correlated with sediment thickness, where sediment is generally defined as being of Cretaceous Period or younger age. Studies have found that greater sediment thickness leads to higher attenuation and lower ground motion amplitudes at short periods, but higher ground motion amplitudes at longer periods (Guo and Chapman, 2019; Pratt and Schleicher, 2021). With the recent implementation of basin depths for select areas in seismic hazard analyses for the western United States, a USGS working group has been formed to consider whether a sediment thickness model can be constructed for the Atlantic and Gulf Coastal Plains and successfully implemented in Central and Eastern United States seismic hazard analyses. In this presentation, we will detail the many existing sediment thickness datasets that have been gathered by our working group to date and the construction of a composite sediment thickness model for the Atlantic and Gulf Coastal Plains. Most of the data are available as printed maps covering one or more States. Several datasets consist of digitized shapefiles covering larger areas. Contours and sediment thickness values from wells on the printed maps are rectified and digitized. They are combined with the previously available digitized datasets (Mills and others, 2020), and values are averaged where multiple datasets overlap. Smooth transitions are applied to minimize artifacts from the edges of datasets, for example, at State boundaries. The standard deviation of differences between datasets, where overlap occurs, averages about 100 m, providing some estimate of uncertainty. When comparing thicknesses from the composite surface to those produced from a rough digitization of similar surfaces applied in the work of Guo and Chapman (2019) and Thomas L. Pratt (U.S. Geological Survey, written commun., 2020), we find close one-to-one agreement, although values from Pratt's original analysis on the Atlantic Coastal Plain tended to be on the shallow side for larger sediment thickness values. Pratt's sediment thickness values for his analysis have since been updated with the new composite surface (Pratt and Schleicher, 2021).

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"A Ground Motion Database to Support Evaluation of Atlantic Coastal Plain Amplification Factors for use in Seismic Hazard Assessments"

By Morgan P. Moschetti (USGS), Eric Thompson (USGS), Dan McNamara (USGS), and David Churchwell (USGS)

We have compiled an initial ground motion dataset of earthquakes greater than *M*4 since 2010 near the Atlantic Coastal Plain to evaluate the Atlantic Coastal Plain amplification models being proposed for incorporation into USGS seismic hazard models. The NGA-East ground motion database (Goulet and others, 2021), which is the most widely accepted dataset for earthquake ground motions in the Central and Eastern United States, contains few observations from the Atlantic Coastal Plain, and its most recent records correspond to events in 2011. Since 2010 broadband seismic stations of the USArray Transportable Array (IRIS Transportable Array, 2003) were installed across the Central and Eastern United States, and data from numerous temporary seismic networks have become available (see https://www.fdsn.org for more information). More than 100 earthquakes greater than *M*4 have occurred in the Central and Eastern United States since that time. Many of these events are potentially induced earthquakes in Oklahoma, Kansas, Texas, and Arkansas, but about 30 events have occurred within about 500 km of the Atlantic and Gulf Coastal Plains. We applied automated ground motion processing to the seismic data from these events to produce a ground motion dataset for the region. The processing workflow used the GMProcess software (Hearne and others, 2019), developed internally and publicly available, which has been applied to earthquake sequences in Alaska, Hawaii, southern California, and the Pacific Northwest to produce Fourier and response spectral amplitudes. The ground motion processing method has been verified with records in the NGA-East and Next Generation Attenuation relationships for the Western United States-2 (NGA-West-2) ground motion databases. Incorporation of additional site metadata (for example, sediment thicknesses) permits evaluation of the amplification functions proposed for use with existing ground motion models (for example, NGA-East) used in the National Seismic Hazard Model.

"Implementation of the Guo & Chapman (2019) Coastal Plain Amplification Model"

By Peter M. Powers (USGS) and Jason M. Altekruse (USGS)

We present implementation details and hazard implications of the Guo & Chapman (2019) Atlantic and Gulf Coastal Plain site amplification and attenuation model. The model, derived from spectral ratios, provides adjustments to median hard-rock site condition ground motions as a function of sediment thickness at a site, the earthquake magnitude and hypocentral distance, and response spectral period. When computing hazard, we apply the adjustments to median ground motions derived from the GMM used in the Central and Eastern United States for the 2018 update of the NSHM. We compare CPA-adjusted ground motions to ground motions modified using the 2018 NSHM Central and Eastern United States site effects model, which is a function of V_{S30}, at a variety of sites throughout the southeastern United States. Further work would be beneficial (and we welcome discussion) on possible adjustments to Central and Eastern United States GMM aleatory variability models and on comparisons to NGA-East Gulf Coastal Plain site effects models. These latter models define CPA site effects as a function of the source-to-site path length in the Gulf Coastal Plain as opposed to sediment thickness at a site.

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Workshop Notes

Monday, October 5, 2020, 10 a.m. to 12:15 p.m. MST

(notes by Martin C. Chapman)

10:00 a.m. Workshop Overview

Oliver S. Boyd, USGS

Oliver S. Boyd stated the purpose and goals of the workshop and discussed the agenda.

The goal is to address the question of how wave propagation effects in the Coastal Plain region of the Eastern and Central United States can be incorporated into future (possibly 2023) USGS National Seismic Hazard Maps. Specific items to be addressed are as follows:

1. The path forward to incorporate Coastal Plain response in the 2023 maps,
2. feedback on proposed models, and
3. discussion on whether future workshops are needed.

Allison Shumway provided an introduction for the attendees on using the various functions of Microsoft Teams for the virtual workshop.

Mark D. Petersen thanked the attendees and explained that the USGS has been working on improving the modeling of the effect of geologic structure on earthquake ground motions in the Atlantic and Gulf Coastal Plains for some time. Mark D. Petersen emphasized that one of the workshop goals is to determine whether the work done to date is mature enough to include in the next update of the National Seismic Hazard Model.

10:10 a.m. Participant Introductions

Oliver S. Boyd led an introduction of workshop attendees, where each attendee had the opportunity to relate affiliation, position, and scientific interest.

10:20 a.m. "Proposed Models for the Implementation of Ground Motion Amplification on the Atlantic and Gulf Coastal Plains" by Oliver S. Boyd

Oliver S. Boyd briefly summarized the current models the CPA WG is considering. This includes the models by Pratt and Schleicher (2021), Chapman and Guo (2021), and the Pacific Earthquake Engineering Research Center (Goulet and others, 2018) and unpublished work by Charles Mueller (U.S. Geological Survey, written commun., 2019). He noted that the USGS has developed an Atlantic and Gulf Coastal Plain sediment thickness database and map, which is not yet published. Oliver S. Boyd proposed to the group the idea of giving equal weight to all the current models. He noted that one of the issues to be addressed involves adjustment to these models for variations in V_{S30} using National Earthquake Hazard Reduction Program or other recently developed site amplification factors.

10:40 a.m. Group Discussion

Walter Mooney asked about the definition of sediment. Charles Mueller and Oliver S. Boyd responded by saying that the Atlantic and Gulf Coastal Plain sediments are those units (mostly of Cretaceous Period and younger age) lying above the post-rift unconformity. Eric Thompson had questions about larger magnitude events than those in the existing dataset, the importance of surface waves, and the possibility of nonlinear response in the Coastal Plain sediments. Walter Mooney pointed out that the practice of using V_{S30} for site response definition is quite old and incomplete and may not be particularly useful in the Central and Eastern United States. Shahram Pezeshk asked about the purpose of the mapping effort regarding regional versus site-specific hazard assessment.

5-minute break

11:00 a.m.–12:15 p.m. 25-Minute Participant Presentations on Relevant Research

11:00 a.m. “Seismic Response of Thick Unconsolidated Sediments” by Charles A. Langston

Charles A. Langston pointed out that the standard source-path-site convolutional approach often used for earthquake hazard assessment can break down in cases were a fault ruptures into a sedimentary structure, such as the Mississippi embayment or Atlantic and Gulf Coastal Plain. Such an event can generate large surface waves, and the database does not contain examples of this potential event. He emphasized the importance of using full wavefield simulations to quantify ground shaking hazard. He also stressed the important datasets needed to accomplish the modeling, including velocity well logs, seismic reflection data to constrain sediment thickness, and average velocity measurements of the sediment section and the resonant frequencies. Methods include receiver functions and phase modeling of micro-earthquakes. He advocated the use of controlled experiments to better improve our understanding of wave propagation in the Mississippi embayment and Coastal Plain. He finds that Q for S and P waves is approximately 100 and 200, respectively, in the Mississippi embayment, from surface-wave analysis. Also, the upper Mississippi embayment acts to trap surface waves, increasing amplitude and duration.

Discussion

Gail Atkinson asked Charles A. Langston if Q is dependent on frequency in the sediments. He replied that wave propagation codes typically assume frequency independence but noted that Q is at least depth dependent. He indicated that reconciling the frequency dependence of Q in wave propagation codes is an important problem.

11:25 a.m. “Deep Sediments Thickness Correction and Apparent Anelastic Attenuation in Applications to Ground Motion Modeling” by Vladimir Graizer

Vladimir Graizer discussed the use of $Z_{1.0}$, $Z_{1.5}$, and $Z_{2.0}$. These are the depths in a sedimentary basin to shear-wave velocities of 1.0 km/s, 1.5 km/s, and 2.0 km/s, respectively. He recommends the term “deep sediment effect” rather than the term “basin effect” in the context of estimating response in GMM due to sedimentary structures because none of the Z terms represents depth to the bottom of the basin. Basin edge and basin shape effects are not considered. He noted that the V_{S30} scaling term in GMM often already incorporates implicit basin amplification effects to some degree. He also pointed out the difference between what he refers to as Q_{SA} (quality factor derived from engineering SA response spectra) and the traditional seismological quality factor Q, which is often derived from the Fourier amplitude spectrum of ground motion.

11:50 a.m. “Site Amplification Models for Central and Eastern North America” by Youssef M.A. Hashash, Okan Ilhan, Halil Uysal, Jonathan P. Stewart, Ellen M. Rathje, and Sissy Nikolaou

Youssef Hashash reviewed the parametric study of more than 1.7 million linear, equivalent-linear, and nonlinear *1-D* site response analyses to quantify variability of site response in the Central and Eastern United States. This led to the development of linear and nonlinear amplification models for the latest USGS National Seismic Hazard Maps. Recently, that work has been updated using artificial neural network deep learning techniques. These studies highlight the need to go beyond V_{S30} as a proxy for site amplification. The study underscores the importance of site period. Models for site response in terms of both linear and nonlinear Fourier amplitude spectra have been developed.

Discussion

Emel Seyhan asked about consistency of the recent results and site terms previously developed for the NGA-East project by the authors. Art Frankel asked about the preferred method for determining site period, in other words, direct measurement via H/V or taking values from the regional database the USGS is developing. Youssef Hashash proposed using H/V measurements. Art Frankel noted that H/V does not work well in the Portland, Oregon area, as well as in some other areas.

Steve Jaumé suggested that the Charleston, South Carolina area would be a good test site for the methodology. He also noted that H/V spectra in the Charleston area do not show just one peak at the fundamental site period.

12:15 p.m.–1:00 p.m. Lunch

Monday, October 5, 2020, 1 p.m. to 3 p.m. MST

(notes by Thomas L. Pratt)

The afternoon session consisted of four back-to-back talks with limited discussion after each talk.

1:00 p.m. "Primary Site-Response Parameters and an Evaluation of Site-Response Proxies at Selected Sites in the Upper Mississippi Embayment" by Seth Carpenter

Seth Carpenter presented results from site-response studies in southwest Kentucky (the Jackson Purchase) where they looked at various proxies for V_{S30} when estimating site response. They made the point that V_{S30} is inadequate to characterize site response by showing several profiles, both modeled and real, showing that similar V_{S30} values can come from much different velocity structures that produce much different site responses. The main issue is that V_{S30} does not account for deeper interfaces that can cause strong resonances. They presented results from two deep borehole sites (VSAP—Vertical Seismic Array Paducah; and CUSSO—Central U.S. Seismic Observatory) in the upper Mississippi embayment where they had seismometers both at the surface and at depth. One dimensional (*1-D*) models of site response reproduced the observed site response well, which is consistent with the flat layers of the upper embayment showing little influence from three dimensional (*3-D*) effects. Maps of fundamental frequency and amplification in the Jackson Purchase were shown to have little correlation with each other; fundamental frequency correlates well with depth, but amplification and peak frequency do not. There was also little correlation between V_{S30} and amplification. They conclude that fundamental frequency and amplitude match *1-D* models well, and the impedance ratios in the models work well. Estimating the amplitude of the fundamental peak using H/V overestimates the amplitude compared to full resonance models made from the borehole data, but dividing the H/V amplification by a factor of 1.5 brings the H/V into a better match with the models. They summarized that V_{S30} does not work well for estimating site response in the Mississippi embayment and that there is no single proxy that works well.

Discussion

Chris H. Cramer said that they are getting similar results, but they still prefer *3-D* models.

A question was asked as to whether *Q* is higher in the Mississippi embayment than we suspect. Several people suggested that indeed it seems higher than is generally assumed, with values closer to 100 than to 50.

1:30 p.m. "*1-D* Velocity Profiles of Atlantic Coastal Plain Sedimentary Strata from Receiver Functions" by Erin Cunningham

Erin Cunningham described her work on using receiver function analyses to estimate sediment thickness and velocity in the Atlantic Coastal Plain east and south of the Appalachians, which was described in her 2020 Bulletin of the Seismological Society of America paper (Cunningham and Lekic, 2020). They assume *1-D* velocity structure and used receiver functions to recover the impedance contrast and resonances within the sediments. In particular, the autocorrelation of the receiver function works well to estimate the frequency and amplitude of the primary reverberations, both for *S* waves and *P* waves. She then showed maps of fundamental frequency at USArray sites and the estimated reflection coefficient at the base of the sediments. She also computed a velocity versus depth function under the assumption of flat layers, with average velocity to a particular depth being constant and differences to bedrock being the result of successively deeper layers.

Discussion

Erin clarified that the velocities she was deriving are the velocity at each depth, not the average velocity to that depth. She was asked if she had information about the velocity of basement rocks beneath the Atlantic Coastal Plain sediments and answered that she did not.

There was extra time here, and the participants conducted a discussion of the role of duration in hazard estimates, and especially its influence on Fourier spectra versus response spectra. Other topics included how to account for duration in response spectra (an open question), whether there were any duration models for Atlantic Coastal Plain strata (none that people were aware of), and whether there was information about duration in the Atlantic Coastal Plain strata versus in bedrock (none that people could think of). These topics were largely unresolved other than to conclude that they are topics that warrant being investigated.

2:00 p.m. “Central and Eastern United States Attenuation Boundaries and Coastal Plain Crustal Seismic Attenuation Models” by Chris H. Cramer

Chris H. Cramer gave a presentation on the crustal boundaries in the Gulf Coast region, which was largely a summary of his 2018 Bulletin of the Seismological Society of America paper (Cramer, 2018). He also added some observations of ground motions from the recent *M*5.1 Sparta, North Carolina, earthquake. For the boundary work, he used the vertical component of USArray data to look at the 5 Hz versus 1 Hz boundaries west of Alabama based on attenuation (the inverse of the quality factor, *Q*). He presented several regressions of *Q* in different areas in the form of $Q = Q_o f^n$, where Q_o is the quality factor at 1 Hz, *f* is shaking frequency, and *n* is an exponent that controls how quickly *Q* increases with frequency. He concluded that the Gulf Coast region has higher attenuation in an area smaller than was previously thought. The high-attenuation region is confined largely to the Gulf Coast of Texas, Louisiana, and Mississippi. Alabama, Georgia, and Florida do not have reduced amplitudes because they lie outside of the high-attenuation area. There is a change at the approximate Georgia-Florida border, however, with *Q* being higher in Florida. The pattern he sees from analysis of USArray data are consistent with intensity observations from the 1886 Charleston, South Carolina, earthquake, which showed a rapid decrease in intensities at the edge of the Gulf Coast region. There is also a boundary in southern Oklahoma, with higher *Q* north of this boundary.

He presented a focal mechanism for the Sparta, North Carolina earthquake, with a focal plane that is consistent with the small fault scarp at the surface. Depth seems to be very shallow, with a stress drop of about 22 mega Pascals (MPa) that seems similar to other earthquakes in the Central and Eastern United States investigated by Cramer such as induced earthquakes in Oklahoma. There is a strong azimuthal variation in ground motions from the earthquake, with higher attenuation to the northwest than in other directions, although the ground motions are least attenuated to the northeast along strike of the Appalachians. *Q* seems to be lower than in Atkinson and Boore (2014).

Discussion

There was a question about whether Cramer is measuring crustal *Q*, or *Q* within the thick sediments of the Gulf Coast region. He feels it is mostly *Q* in the rocks underneath the sediments, but others pointed out that the thick sediment must be affecting amplitudes at the surface, and thus estimates of *Q*.

This led to an extensive discussion about why the bedrock geology would change in the Gulf Coast area, with Chris H. Cramer pointing out that there is a major boundary (Ouachita Mountains) at the north side of the high-attenuation area.

2:30 p.m. “Mapping Site Response in the U.S. Coastal Plain” by Charles Mueller

Charles Mueller gave a presentation on his work in estimating site response in the Atlantic and Gulf Coastal Plain. He put extensive work into digitizing maps of the sediment thickness, mostly from the Decade of North American Geology (DNAG) volumes from 1980–90 (Klitgord and others, 1988; Olsson and others, 1988; Salvador, 1991). He tried to produce simple models of ground motion amplification with a map of sediment thickness, *S*-wave velocity, and *Q* for the region and using the SMSIM (Fortran Programs for Simulating Ground Motions from Earthquakes—Boore, 2000) point-source simulation code. He defined the base of the sediments as the post-rift unconformity, assuming sediments were deposited on uniform basement rocks. Power law V_S versus depth and *Q* versus depth were assumed for the Coastal Plain. He also incorporated geologic maps of the surface units (Schruben and others, 1994).

He used a Thompson-Haskell matrix method and the quarter-wavelength method to estimate site response throughout the Atlantic and Gulf Coastal Plain region, concluding that the quarter-wavelength method is preferred because it had less influence from higher-mode resonance peaks. He then computed site responses, showing a suite of models with some areas of amplification and others of deamplification. The results were not compared to recordings of ground motions, so they are strictly model-based results.

Discussion

Someone pointed out that sensitivity tests would be useful to determine what parameters have the largest influence on ground motions. Mueller has not done these.

A lengthy discussion broke out about how these site response results could be used in the national maps. It was suggested to use soil response codes to calculate nonlinear effects.

The question was asked as to whether newer maps of Atlantic Coastal Plain thickness compiled by Oliver S. Boyd differ significantly from the older values in the Charles Mueller maps. Oliver S. Boyd responded that they are quite similar in most areas, but some limited areas do show large differences in thickness.

It was asked whether the differences between the different site response models in Mueller's work would be an indication of the uncertainty. The answer is yes. The question was then posed as to how to extrapolate points regionally, but this was not resolved.

Meeting adjourned after this discussion at 3 p.m. MST.

Wednesday, October 7, 2020, 10 a.m. to 12 p.m. MST

(notes by Allison Shumway)

Oliver S. Boyd gave a quick introduction about the agenda for the day and provided some reminders about muting audio during presentations and turning off video to save bandwidth.

10:00 a.m. "Atlantic Coastal Plain Amplification and Velocity Studies" by Thomas L. Pratt

Thomas L. Pratt measured teleseisms and regional earthquakes (shorter time windows) from four arrays: Eastern North America seismic experiment (Lynner and others, 2019; Magnani and others, 2014), Southeastern Suture of the Appalachian Margin Experiment (SESAME; Fischer and others, 2010), EarthScope Temporary Array (IRIS Transportable Array, 2003), and Washington DC seismic array (Pratt and others, 2017) to calculate sediment-to-bedrock spectral ratios. Bedrock sites had a flat response whereas sites on the Atlantic Coastal Plain showed a prominent resonance peak, f_o and low amplification at values greater than 5 Hz. As sediments get thicker, the resonant peak decreases in amplitude and frequency. Teleseisms work well for looking at the spectral ratios, even without a lot of frequency content (die out at 6–7 Hz).

He showed plots of f_o versus thickness, amplification of resonance peak versus thickness, and amplification of resonance peak versus frequency. At 0.8 Hz and above, there is a need for site-specific studies, as amplifications attenuate. Scatter is large at higher frequencies (for which the thicknesses are not known as well) and may be due to near-surface layers varying spatially.

He showed that the Atlantic Coastal Plain is different in North Carolina and Virginia when compared to Georgia and Florida.

He characterized observations with equations: for $h<h_o$, for $h_o>h<2h_o$, and for $h>2h_o$ and compares with Harmon and others (2019b) corrections. Correction curves do well out to several hundred meters thickness, then start missing resonance peaks. Comparisons with sediment-to-bedrock spectral ratios show that H/V spectral ratios tend to be about three quarters amplitude of bedrock spectral ratios.

H/V with ambient noise—He can identify resonance peaks using ambient noise, probably because they are dominated by a *1-D* velocity substructure, but it takes averaging over several windows to avoid weird peaks from noise.

Conclusions were as follows (1) low frequencies (<0.8 Hz) can be characterized well as amplitude versus thickness, (2) above ~0.8 Hz, site-specific studies need to be done (amplifications are not predictable in a regional sense), (3) H/V using ambient noise or earthquakes identify resonance frequency well, amplitude of H/V is about 0.75 times that of sediment-to-bedrock spectral ratios, (4) H/V can be partially corrected using vertical to horizontal spectral ratios from bedrock site(s), (5) future work is planned in Charleston (SUGAR—Suwanee Suture and Georgia Rift basin—experiment, velocity inversions) and 200 station embayment nodal array from bedrock to bedrock across the Mississippi embayment.

Velocity inversions using Eastern North America seismic experiment dataset is a work in progress—joint inversion of dispersion and H/V curves.

Inflection point moves to lower frequencies with increase in sediment thickness.

A total of 37,500 randomized models are considered in the genetic algorithm that is used to solve for the best-fitting velocity profile.

He shows an Atlantic Coastal Plain shear-wave velocity profile, which is a work in progress. The surface has a velocity of 300 m/s and bedrock is 1,000 m/s. Within the sedimentary wedge, there are 300–600 m and 600–1,000 m layers, but these results need refinement.

Planned future work: additional velocity inversions (Charleston, SUGAR experiment) and embayment nodal array (about 200 stations spanning 250 km of Mississippi embayment).

Discussion

Emel Seyhan asked if Thomas L. Pratt observed any basin edge effects and if he investigated studies to determine depth to bedrock. Thomas L. Pratt did not see any obvious basin edge effects but does not think the resolution is good enough (receivers spread too far apart; 2–4 km) to be able to see any. He also stated that he would not expect any basin edge effect because there is only about a 2 to 3-degree slope to the basin surface, so really a *1-D* (not *3-D*) environment. Thomas L. Pratt would take resonant frequency and invert with a velocity function to get depth to bedrock (he is doing the opposite now using contour maps).

Chris H. Cramer asked about providing variability or standard deviation for fits to curves. Thomas L. Pratt says plots have them and he has been trying to track them. Chris H. Cramer says we need them for PSHA.

Jonathan P. Stewart asked about relationship between V_{S30} and depth at sites and whether V_{S30} scaling captures effects at low frequencies. Thomas L. Pratt says we know V_{S30} at about 1 percent of these sites, so we do not know. He does not see a correlation, but we do not know without velocity measurements. These are almost flat sediments (no *3-D* effects)—*1-D* models fit well (Steve Jaumé and Chris H. Cramer agree).

10:30 a.m. "A Response Spectral Ratio Model to Account for Amplification and Attenuation Effects in the Atlantic and Gulf Coastal Plain" by Martin Chapman

Martin C. Chapman started out showing three of his papers that provide background for this work (Chapman and Conn, 2016; Guo and Chapman, 2019; Chapman and Guo, 2021). They want to quantify the response of the Atlantic and Gulf Coastal Plains sites relative to reference sites. They use a traditional spectral ratio approach for coda and *Lg* waves. The reference condition is not a rock site, but an average response of stations located outside the Atlantic and Gulf Coastal Plains region. The motivation is the need to develop correction factors for Atlantic and Gulf Coastal Plains sites that can be applied to existing GMM for Central and Eastern North America.

This study has two elements: (1) determine models for the ratios of Fourier amplitude spectra for stations inside the Atlantic and Gulf Coastal Plains with respect to the average Fourier amplitude spectrum of stations outside the Atlantic and Gulf Coastal Plains and (2) use the Fourier amplitude spectral ratio model to develop a model for PSA spectral ratios as functions of earthquake magnitude (*M*), source-to-site distance (R), and sediment thickness that can be used as correction factors for existing GMMs for response at sites outside the Atlantic and Gulf Coastal Plains.

There were 17 earthquakes used in study, mostly induced seismicity events in Oklahoma and a few tectonic events (2011 Mineral, Virginia, and earthquakes in South Carolina, Eastern Tennessee Seismic Zone, Kentucky, and Delaware). Comparison of coda and *Lg* waves recorded in the Atlantic and Gulf Coastal Plains and at a reference site show amplification at low frequencies and attenuation at high frequencies.

For an example of the Fourier amplitude spectra ratio model, they look at coda and *Lg* waves recorded in the Atlantic and Gulf Coastal Plains and at a reference site (Iowa). The coda spectral ratio represents the response of the Atlantic and Gulf Coastal Plains site relative to the reference site condition. They also consider a kappa model for inside and outside Atlantic and Gulf Coastal Plains. They take the ratio of two stations within Atlantic and Gulf Coastal Plains and find that kappa increases with sediment thickness.

At low frequencies, the coda spectral ratios at large lapse time contain surface wave energy and may not be a good estimate of the relative site response for the higher amplitude parts of the seismograms that are associated with the *Lg* phase. They showed *Lg* spectral ratio versus sediment thickness. At 0.1 Hz, ratios increase to 2.5 km thickness, and continue to increase to 12 km thickness. At 0.5 Hz, spectral ratio decreases with increasing thickness above the transition thickness, which becomes obvious above 1 Hz—deamplification at higher frequencies with increasing thickness. At high frequency (>2.68 Hz), the spectral ratio reflects deamplification due to a delta kappa term that is a function of sediment thickness. He summarized by saying that with increasing thickness, amps go up then turn over at higher frequencies. There are good amps at low frequencies, then attenuate at high frequencies.

He then moved on to discussing how to go from Fourier to PSA by using a stochastic method of ground motion time series simulation to develop synthetic acceleration time series. To do this, a range of earthquake magnitude, distances, and sediment thickness is needed. He went on to show PSA response spectrum for the Atlantic and Gulf Coastal Plains divided by PSA spectra for reference rock condition assuming a stochastic phase model and *Lg* duration model (same slope as Herrmann, 1985). The PSA response spectra ratios were calculated for thousands of magnitudes, distances, and thickness. The residuals are relative to the reference calculated GMM, which we used for exploring the effectiveness of the PSA spectral ratio model and is the weighted mean NGA-East model developed specifically for the USGS (V_{S30} = 3,000 m/s) with the Stewart and others (2017) linear site amp factor for V_{S30} = 760 m/s added.

Conclusions: The PSA spectral ratio model can correct the existing dataset for Atlantic and Gulf Coastal Plains stations to be in good agreement (on average) with predictions of the NGA-East model developed specifically for the USGS (on average) for stations outside the Atlantic and Gulf Coastal Plains using the Stewart and others (2017) V_{S30} = 760 m/s amplification corrections. If you do not use the Stewart and others (2017) correction factors at high frequencies, you get a small, positive bias in the residuals. The existing dataset is limited to *M*5.8 for testing the model, and the model is for linear response only.

Discussion

Vladimir Graizer asked if he understood correctly that Martin C. Chapman did not calculate PSAs directly but converted from Fourier. Martin C. Chapman responded that they went from Fourier to response spectral values by doing stochastic simulations. Vladimir Graizer asked if they ever checked if they could get the same result directly from PSAs and calculate PSA ratios without stochastic. Martin C. Chapman said he did not check this.

Oliver S. Boyd moved us on to Roland LaForge.

11:00 a.m. "Effects of NGA-East Ground Motion Models' Gulf Coast Corrections on Hazard Curves and Uniform Hazard Spectra, as applied to the CEUS-SSC Source Model" by Roland LaForge

NGA-East developed Gulf Coast corrections as part of the project. Two groups came up with correction factors. DASG (Darragh, Abrahamson, Silva, and Gregor) Gulf Coast ground motion model (Darragh and others, 2018) uses a theoretical-based approach based on the point source stochastic model, constraining the point-source parameters by data inversion from the Gulf Coastal Plain. They ran ground motion simulations for a wide range of *M* (4.5–8.5) and Joiner-Boore source-to-site distance (1–1,000 km) for both regions and computed PSA ratios. Their model is frequency dependent. The Pacific Earthquake Engineering Research Center (PEER) Gulf Coast model (Hollenback and others, 2018) used an empirically based Fourier amplitude spectrum functional form, which was recalibrated with the Gulf Coastal Plain data through a residual analysis procedure. It is not frequency dependent. NGA-East also defines two gulf zone geographic models (large and small).

Roland LaForge implemented the NGA-East GMM with (and without) the Gulf Coast correction factors into his code for the Nuclear Regulatory Commission to run hazard using the CEUS-SSC source model (very complex model with large logic trees).

He looked at hazard results for the city of New Orleans, Louisiana, to see how hazard compared when using the Gulf Coast corrections or not using the corrections. Corrections were determined by horizontal distance of ray paths in the Gulf zones. For the weighted reduction model, DASG was given a weight of 0.33 and PEER a weight of 0.67. The large Gulf zone geometry was given a weight of 0.6 and the small Gulf zone geometry was given a weight of 0.4. No site response was included (hard rock sites are assumed). Tracing ray path is complicated as the path can go in and out of the gulf zones more than once.

Roland LaForge presented hazard results for short return periods (475, 975, and 2,475 years) and long return periods (10,000; 50,000; and 100,000 years). He showed results for DASG, PEER, and then the weighted reduction model. He then showed a bunch of tables comparing the corrected and uncorrected results.

This analysis gives a rough estimate of how the Gulf Coastal Plain ground motion reductions, as implemented in NGA-East and applied to the CEUS-SSC model, affect uniform hazard response spectra for a large range of return periods from the USGS (short) to the Nuclear Regulatory Commission (long). Maximum reductions in long return period/ Nuclear Regulatory Commission hazard spectra are on the order of 0.05 the acceleration of gravity (g) at 1–2 Hz. Maximum reductions in short return period/USGS hazard spectra are <0.02 g at 1–2 Hz. Both reductions are on the order of 30 percent. No site response was included—how would this affect the results? This analysis should be useful in comparing any future Gulf Coastal Plain reduction algorithms to those in the NGA-East.

Discussion

Oliver S. Boyd asked about reductions in ground motions being higher at lower frequency. Roland LaForge responded that the absolute reduction is very small because the ground motions at very long periods are very, very small. The percent reduction looks very big, but you are comparing two very small numbers and getting those percentages. You are not really concerned with the lower frequency, there is more concern with the higher frequency where the reductions are 30 percent.

Oliver S. Boyd mentioned that we have a few minutes and asked if there any additional questions for Thomas L. Pratt or Martin C. Chapman?

Additional questions for Thomas L. Pratt or Martin C. Chapman:

Steve Jaumé asked Thomas L. Pratt if deep Coastal Plain sites had effects of local geology (for example, Charleston, South Carolina), but noticed in some of the spectral ratios that in some cases the amplification at higher frequency was as large or larger than the amplification at the fundamental frequency. Thomas L. Pratt said he noticed some sites out in the Coastal Plain with unusually large amplifications, but not a whole lot. There might be something odd about the spectral ratios at those sites, maybe a noise burst.

Thomas L. Pratt commented on the correlation of V_{S30} and Coastal Plain sediment thickness. Washington and Charleston have similar V_{S30} measurements. However, Washington has little to no sediment thickness, whereas Charleston has up to 1,000 km so he would not be surprised if there was little or no correlation.

Chris H. Cramer notes that Martin C. Chapman pointed out in his presentation that he is assuming that the crustal attenuation (source and path effects) is the same everywhere. So, when applying his corrections, you must be aware of the fact that you do not want to mix crustal variations in Q with his model because to some degree it is already incorporated in the site effect.

Art Frankel asked Thomas L. Pratt that now that he has these V_S profiles from the inversion, is he planning to do *1-D* simulations to see if he could predict the observed amplification? Thomas L. Pratt says he has thought about this but not sure if it is worthwhile because you would be taking the dispersion curves and H/V and inverting them for the velocity profile so if you turn around and do a forward model you should get the same result back that you started with, so I would assume you would get the same H/V curve. Art Frankel says, for both Thomas L. Pratt and Martin C. Chapman's work, it would be good if we could model these things to get a deeper understanding so we could expand these to different areas that we might not have observations. Thomas L. Pratt says he is getting a velocity versus depth profile for different Atlantic Coastal Plain sites, and he is under the assumption that these could roughly be applied across the Atlantic Coastal Plain as the structure seems to be uniform in the sense that you get fairly uniform response throughout the region.

Charles A. Langston asked Thomas L. Pratt about H/V and when Thomas L. Pratt talked about the inversion of the velocity structure you then fit the H/V as well. Charles A. Langston did not understand what that meant. Did Thomas L. Pratt make a synthetic H/V curve and how did he do that? Thomas L. Pratt responded that he took a velocity model and then forward modeled the surface waves running through the velocity profile and then calculated an H/V and dispersion curve from that forward model and compared the misfit with the observed data. Thomas L. Pratt and Charles A. Langston will talk more about this offline.

Art Frankel asked Thomas L. Pratt about using teleseisms versus regional events and seeing differences due to differences in the angles of incidence. Thomas L. Pratt said he did not see a systematic difference. Sometimes one site would be consistently lower than the others and another site would be consistently higher, but there is no consistent pattern. The events seemed to be merged because the *1-D* resonance overpowers everything else. If there were *3-D* effects, Thomas L. Pratt would expect to see more differences.

11:30 a.m. "Sediment Thickness along the Atlantic and Gulf Coastal Plains" by Oliver Boyd

Oliver S. Boyd presented what he and Sarah Mills did to put together a sediment thickness surface along the Atlantic and Gulf Coastal Plains. They used Guo and Chapman (2019) and Pratt and Schleicher (2021) sites in their analysis. These studies rely on the same underlying datasets for sediment thickness as what Oliver S. Boyd uses, but some of their sites have different thickness values. Charles Mueller also had thickness values (from digitizing DNAG maps). Sarah Mills (student intern from Colorado School of Mines) obtained and digitized datasets—contour maps from six publications. Oliver S. Boyd would like to include Maryland, Delaware, and the DNAG maps for the Atlantic and Gulf Coast. Data also were available online (well data). Sarah Mills georeferenced the wells onto the contour maps and then digitized them all. Some of the maps had overlapping data (up to four models in the same location); therefore, epistemic uncertainty could be assessed. The average standard deviation is about 100 m. Multiple models were given equal weight. They came up with a composite surface and compared with Guo and Chapman (2019) and Pratt and Schleicher (2021) and got a one-to-one agreement, mostly. There are larger differences with Mueller values, which may be due to fewer DNAG values available in certain areas. They need to digitize more DNAG maps.

Six contour maps and four well datasets are georeferenced and digitized and they obtained two hydrogeologic models and a North Carolina well database. These sources of data are combined with Mueller's DNAG data to produce a composite surface of the elevation of the basement at the top of the post-rift unconformity (pre-Cretaceous Period). When multiple datasets overlap, the average standard deviation is 100 m with deviations over 500 m in limited areas. The resulting composite surface is consistent with Guo and Chapman (2019) and preliminary analysis of Pratt and Schleicher (2021) in which they roughly estimate these values from contour maps, which is not surprising as Oliver S. Boyd and Sarah Mills are using nearly the same datasets. Planned additional work: the surface needs to be extended into west Texas, digitizing more of the DNAG contours would improve the model, and the model needs to be published.

Discussion

Thomas L. Pratt confirmed that he did re-run his analysis based on these thicknesses versus the original dataset of thicknesses he used.

Vladimir Graizer asked Thomas L. Pratt about the V_{S30} values used for reference sites. Thomas L. Pratt said his reference sites are bedrock sites just inside the Atlantic Coastal Plain, but we do not need to know the shear-wave velocity because all we are doing is taking a spectral ratio. But the shear-wave velocities Thomas L. Pratt has seen are ~3,500 m/s, coming from Martin C. Chapman's work in the central Virginia seismic zone that calculated a velocity model to locate earthquakes. So, most are probably 3,000–3,500 m/s, but Thomas L. Pratt did not calculate shear-wave velocities.

Chris H. Cramer asked Oliver S. Boyd about the hydrological model between North Carolina and New York. Oliver S. Boyd responded that this is a digitized model that shows surfaces of aquifers down to basement (Pope and others, 2016). Chris H. Cramer asked for reference to this digitized model. Oliver S. Boyd will send.

Emel Seyhan asked about extending Oliver S. Boyd's study from sediment thickness to fundamental period/site period. This could be input to empirical GMMs. Thomas L. Pratt showed a good correlation between fundamental period and amplification in the Atlantic Coastal Plain. Thomas L. Pratt has an equation for that in the Atlantic Coastal Plain (Schleicher and Pratt, 2021), give him a thickness, and he can tell you the fundamental period.

Art Frankel commented on what Jonathan P. Stewart said about V_{S30}, stating that we already have these V_{S30} factors in the hazard maps so then it becomes very important to know what the difference in the V_{S30} value is between the reference site and these sedimentary Atlantic and Gulf Coastal Plains sites. We need to be careful that we have our refence sites consistent here and we are comparing equal V_{S30} sites in the Atlantic and Gulf Coastal Plains versus outside the Atlantic and Gulf Coastal Plains; we want that difference to be correct. Ray Weldon had a similar concern that Gulf sites versus East Coast sites could have systematic differences between the V_{S30} which feeds into what Art Frankel was talking about.

Martin C. Chapman looked at different values for the site amplification factors for the stations outside of the Atlantic and Gulf Coastal Plains to see what effect that has. It mainly affects the bias on the mean residuals, but he has not looked at the site conditions at those stations to see what they are. They probably run from hard rock to soft rock, so we are somewhere in the average value range. Martin C. Chapman points out that at Houston, Texas, the sediment is about 12 km thick, and, at some point, that sediment is hard rock down there at 12 km. So, we have a velocity gradient, and putting a reference condition on it might not be possible. Thomas L. Pratt said what he was doing with the spectral ratios was to try and isolate the Atlantic Coastal Plain, so whatever velocity structure is in the bedrock, that is under the Coastal Plain.

12:00 p.m.–1:00 p.m. Lunch

Wednesday, October 7, 1 p.m. to 3 p.m. MST

(notes by Sanaz Rezaeian)

1:00 p.m. "A Ground Motion Database to Support Evaluation of Atlantic Coastal Plain Amplification Factors for Use in Seismic Hazard Assessments" by Morgan P. Moschetti

Morgan P. Moschetti presented plans to make a database for evaluation of Atlantic Coastal Plain amplification factors. GMProcess: new code/software being used in our office for automated signal processing, on github, software data release by Hearne and others (2019). Processing uses the same workflow as was used for NGA-East and NGA-West-2 projects. Significant efforts were made to read different data formats, pick signal/noise windows, and ensure useable signal. Software provides reports. Code is verified using data from NGA-West-2 and NGA-East projects. Same code has been used in many other ongoing projects such as Oklahoma induced earthquakes, Alaska in-slab, Hawaii caldera collapse, Ridgecrest. Atlantic Coastal Plain data: showed preliminary data (processed examples shown) from NGA-East database and a channel network map with recordings between 2010–20. For events greater than *M*4, 32 events, <500 km → 1,200 records. Very few records for <100 km, max *M*5.75. Mostly focused on future plans: compile the database for testing Atlantic Coastal Plain, calculate ground motion residuals using Atlantic Coastal Plain adjusted NGA-East model, and evaluate amplification/ deamplification. They suspect bias between NGA-East and Martin C. Chapman reference rock sites. They will investigate trends with distance, magnitude, V_{S30}, and sediment thickness, and will come up with recommendations.

Discussion

There was a question on induced events and their ground motion bias due to their shallow focal depths. They may not want to include all earthquakes in GMProcess in order to not bias the results.

Emel Seyhan asked if this would be added to NGA-East database? Morgan P. Moschetti replied that it would not be, instead it will be a stand-alone database.

Dan McNamara expressed concerned about the NGA-East review process and suggested to look at those data again. Eric Thompson mentioned that currently there was no plan to review NGA-East. Chris H. Cramer responded that he was included in making the initial database and said they did extensive review of processing and recommended not clipping the Saguenay strong motion data.

There was some discussion on looking at the bias of Atlantic Coastal Plain data versus the current NSHM Central and Eastern United States amplification model.

1:30 p.m. "Implementation of the Guo & Chapman (2019) Coastal Plain Amplification Model" by Peter M. Powers

Peter M. Powers presented the preliminary implementation of the Guo and Chapman (2019) model (GC19; preliminary model was provided to the USGS). He discussed the following. (1) sediment thickness and webservice—data comes from Oliver S. Boyd for both Gulf and Atlantic Coasts. This can be accessed from a web-service (https://earthquake.usgs.gov/ws/nshmp/data/gulf) as a part of the NSHMP Non-NSHM Services. Given latitude and longitude one can get sediment thickness. (2) GC19 implementation: function of period (T), magnitude (*M*), source-to-site distance (R), and sediment thickness (z). A preliminary implementation can be found on the Response Spectrum Plotter tool of USGS (https://earthquake.usgs.gov/nshmp/gmm/spectra), but it ignores V_{S30}. The tool temporarily uses $Z_{2.5}$ for z input. For deterministic response spectra, the model reduces SA at short period but increases SA at long period (>1 s). (3) Hazard curves were shown for example sites for three cases to illustrate the differences between hard rock, a site outside the Atlantic and Gulf Coastal Plains with estimated non-rock V_{S30}, and an Atlantic and Gulf Coastal Plains site: results for New Madrid, Missouri show that GC19 is similar to Central and Eastern United States. Site effects modeled at long period (5 s), are lower at 1 s, and cross over at 0.2 s. Results really depend on the return period. For probabilistic response spectra, in general, GC19 reduces SA more than the current Central and Eastern United States amplification at short period, but SA is almost the same for longer periods. Similar results were shown for other locations such as Miami, Florida, where GC19 reduces SA at short period but increases at long period. (4) Planned next steps: implement other models (for example, the unpublished results of Charles Mueller), look at aleatory variability, and address handling path properties for NGA-East.

Discussion

Oliver S. Boyd asked about GC19 raising the ground motion for long period, and what happens if or when the Gulf Coast correction of NGA-East would be applied. The answer is not clear, but it seems to be period dependent.

Shahram Pezeshk stated that, in the comparisons, be careful with nonlinear effects and how GC19 behaves because it might be making a lot of difference.

Shahram Pezeshk and Chris H. Cramer: Many of the NGA-East seed models excluded the Gulf Coast (for example, Pezeshk and others, 2018) if the models were made for the Gulf Coast it would make a difference. Therefore, Shahram Pezeshk thinks that the USGS should look at these models (Cramer, 2018; Pezeshk and others, 2021).

Mark D. Petersen asked if aleatory uncertainty should be modified because it could make a big difference, so we may want to reduce it.

Roland LaForge asked that, because NGA-East Gulf Coast models are distance dependent (path dependent), how do you see this being implemented in the future? Peter M. Powers commented on the difficulties of implementation of path-dependent models and potential solutions for implementing site-specific information, which is not very clear right now, but it is important that we think about it. Art Frankel mentioned that there are other site-specific parameters (for example, *Q*) that we should be very careful with, so that we do not mess with short period ground motions (important for building codes) estimation while not gaining too much improvement for long period.

2:20 p.m.–2:59 p.m. Discussion

Discussions started after Peter M. Power's presentation (see above).

Oliver S. Boyd presented a few slides summarizing the issues for discussion that came up during the two days of workshop:

- Definition of sediments—Chris H. Cramer clarified that usually there is broad range, Vladimir mentioned the usefulness of $Z_{2.5}$, and no participants voiced a differing definition.
- Relatively high *Q* of sediments in embayment—Chris H. Cramer: high *Q* is prevalent, and do not see low Q_S in their geologic based modeling. Thomas L. Pratt: too much scatter but concluded that data are more consistent with *Q* values of 100–200 rather than 25–50. Martin C. Chapman: saw *Q* for *P*-waves around 100 above the Chesapeake Bay Impact Crater. Charles Mueller: provided some data and mentioned the work of Pujol and others (2002)—*Q* of 20 to 40 in the upper 60 m of the Mississippi embayment. Art Frankel suggested that Martin C. Chapman's work shows frequency dependence where we normally assume frequency independent kappa. He asks if we can do better. Shahram Pezeshk also commented.

- Duration model in conversion of Fourier to response spectra—Martin C. Chapman has done some work using stochastic simulations and has pushed it to the frequency limit (>0.1 Hz), we really need to model using full waveform simulations going forward.
- Applicability to large magnitude (*M*)—Emel Seyhan: look at different distance parameters for larger magnitudes. Eric Thompson has done some work on this but has no further plans. Chris H. Cramer: this will only be helpful for close distances and there will be issues with nonlinearity anyway (saw a lot of deamplification due to site modeling). Concerns came up about reducing the short period ground motions too much (Art Frankel suggested more site-specific studies for short period motions). Steven Jaumé also suggested to be conservative with high-frequency motions until more site-specific studies are available in urban areas. Chris H. Cramer: he thought that ground motions observed in the Christchurch, New Zealand earthquake showed some surprises and that one could go back and review those observations, since Christchurch is a somewhat analogous setting to Atlantic and Gulf Coastal Plains geology.
- Other models to consider—Chris H. Cramer and Shahram Pezeshk mentioned their models (not published), also Harmon and others (2019b) study.
- Engineering and application considerations (for example V_{S30}-based)—how to deal with Pratt and Schleicher (2021) and Chapman and Guo (2021) models? Chris H. Cramer: we do not see large variations (150 to 2,000 m/s is needed for building codes) mostly about 300 m/s so the models would only apply to a narrow range of V_{S30}. Chris H. Cramer: none of the models would be applicable in Florida. Martin C. Chapman: apply only to relevant V_{S30} maps, in the meantime we should see how much information we can gather about V_{S30} in the region and the applicability range of the models in terms of V_{S30} (Eric Thompson provided this link as a partial response: https://earthquake.usgs.gov/data/vs30/us/). Morgan P. Moschetti and Peter M. Powers: maybe we can take an approach similar to what we did with basin depth application in the Western United States (a lot of challenges).
- For site-specific analysis: other parameters could be considered in addition to V_{S30}, and Youssef Hashash has some recommendations in his presentation.
- New terms/parameters needed (natural period, sediment thickness, and others).

Jonathan P. Stewart chatted that he has a suggestion on a path forward. He added this to the chat window “At the time we generated the NGA-East GWG site models that are currently in use, we did not have access to Atlantic Coastal Plain depth maps as have been shown in this workshop. We looked for trends of residuals with respect to some older basin models (Grace Parker can speak to the details), which were inconclusive, but the maps of Atlantic Coastal Plain extent and depth should be used to recheck this. Trends that are identified could be modelled to capture Atlantic Coastal Plain-specific deviations from the general Central and Eastern North America model. This would provide a valuable check and would support the evaluation of phiS2S models specific to the Atlantic Coastal Plain.” In response, Youssef Hashash wrote “Per Jon's note, some of the work we have done can be extended to the Atlantic Coastal Plain depths and bring in natural period influence.”

Youssef Hashash put this note in the comments: “As I mentioned in my call, we have an update of Harmon's work that would be more suitable for the greater depths.”

2:59 p.m.–3:00 p.m. Next Steps

Oliver S. Boyd quickly summarized planned next steps for the Atlantic and Gulf Coastal Plain working group efforts. They plan to complete and publish the Atlantic and Gulf Coastal Plains sediment thickness model. They plan to compare observations from Morgan P. Moschetti and other’s ground motion database with the Guo and Chapman (2019) and Pratt and Schleicher (2021) site amplification models. The working group plans to compare these results with other published models, for example, Pezeshk and others (2018), Cramer (2018), Harmon and others (2019b) and NGA-East (Goulet and others, 2018). Lastly, they plan to determine logic tree weights for these various site amplification models. More sensitivity analyses would be useful, and the working group and larger earthquake engineering community are likely to benefit from an additional workshop, which was not discussed. Oliver S. Boyd and others will complete a workshop report detailing this meeting.

3:00 p.m. Meeting Adjourned

Conclusion

The U.S. Geological Survey National Seismic Hazard Modeling project is aiming to improve estimates of seismic hazard along the Atlantic and Gulf Coasts of the south-central and southeastern United States. They have formed a working group to address this problem and brought together the earthquake engineering community at a workshop to discuss current research and progress made toward implementing multiple Atlantic and Gulf Coastal Plains site amplification models.

Researchers showed that high frequency ground shaking can be highly attenuated, whereas low frequencies can be amplified and even exhibit resonance. The former can be seen whether site amplification is a function of the path length across the Atlantic and Gulf Coastal Plains or its thickness and is an indication of strong attenuation by the Atlantic and Gulf Coastal Plains sediments. In the latter, resonance was more apparent along the Atlantic Coastal Plain than in the Gulf Coastal Plain and is due to strong impedance contrasts from a relatively flat lying post-rift unconformity.

Several viable site amplification models are published and can be incorporated into future generations of seismic hazard models. Researchers presented a model of sediment thickness along the Atlantic and Gulf Coastal Plains and a database of central and eastern United States ground motions that complements the previous Next Generation Attenuation Relationships for the Eastern United States database. This information is being used to test these amplification models to better understand where and under what conditions these models do and do not work. Concurrently, sensitivity tests are ongoing so that the U.S. Geological Survey may better appreciate these potentially significant changes to their hazard models.

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