Chapter 11

SOUTH CAROLINA GEOLOGY AND SEISMICITY

Final

SCDOT GEOTECHNICAL DESIGN MANUAL

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CHAPTER 11

SOUTH CAROLINA GEOLOGY AND SEISMICITY

11.1 INTRODUCTION

This Chapter describes South Carolina's basic geology and seismicity within the context of performing geotechnical engineering for the SCDOT. It is anticipated that the material contained in this Chapter will establish a technical framework by which basic geology and seismicity can be addressed. It is not intended to be an in-depth discussion of all the geologic formations and features found in South Carolina (SC) or a highly technical discussion of the state's seismicity. The designers are expected to have sufficient expertise in these technical areas and to have the foresight and resourcefulness to keep up with the latest advancements in these areas.

The State of South Carolina is located in the Southeastern United States and is bounded on the north by the State of North Carolina, on the west and the south by the State of Georgia, and on the east by the Atlantic Ocean. The State is located between Latitudes 32° 4' 30" N and 35° 12' 00" N and between Longitudes 78° 0' 30" W and 83° 20' 00" W. The State is roughly triangular in shape and measures approximately 260 miles East-West and approximately 200 miles North-South at the states widest points. The South Carolina coastline is approximately 187 miles long. South Carolina is ranked 40th in size with an approximate area of 30,111 square miles.

The geology of South Carolina is similar to that of the neighboring states of Georgia, North Carolina, and Virginia. These states have in the interior the Appalachian Mountains with an average elevation of 3,000 feet followed by the Appalachian Piedmont that typically ranges in elevation from 300 feet to 1000 feet. Continuing eastward from these highlands is a "Fall Line" which serves to transition into the Atlantic Coastal Plain. The Atlantic Coastal Plain gently slopes towards the Atlantic Ocean with few elevations higher than 300 feet.

The 1886 earthquake that occurred in the Coastal Plain near Charleston, South Carolina dominates the seismic history of the southeastern United States. It is the largest historic earthquake in the southeastern United States with an estimated moment magnitude, M_W, of 7.3. The damage area with a Modified Mercalli Intensity Scale of X, is an elliptical shape roughly 20 by 30 miles trending northeast between Charleston and Jedburg and including Summerville and roughly centered at Middleton Place. The intraplate epicenter of this earthquake and it's magnitude is not unique in the Central and Eastern United States (CEUS). Other intraplate earthquakes include those at Cape Ann, Massachusetts (1755) with a M_W of 5.9, and the New Madrid, Missouri (1811-1812) with M_W of at least 7.7.

The following sections describe the basic geology of South Carolina and the seismicity that will be used to perform geotechnical engineering designs and analyses. The topics discussed in these sections will be referenced throughout this Manual.

11.2 SOUTH CAROLINA GEOLOGY

South Carolina geology can be divided into three basic physiographic units: Blue Ridge Unit (Appalachian Mountains), Piedmont Unit, and the Coastal Plain Unit. The generalized locations of these physiographic units are shown in Figure 11-1.

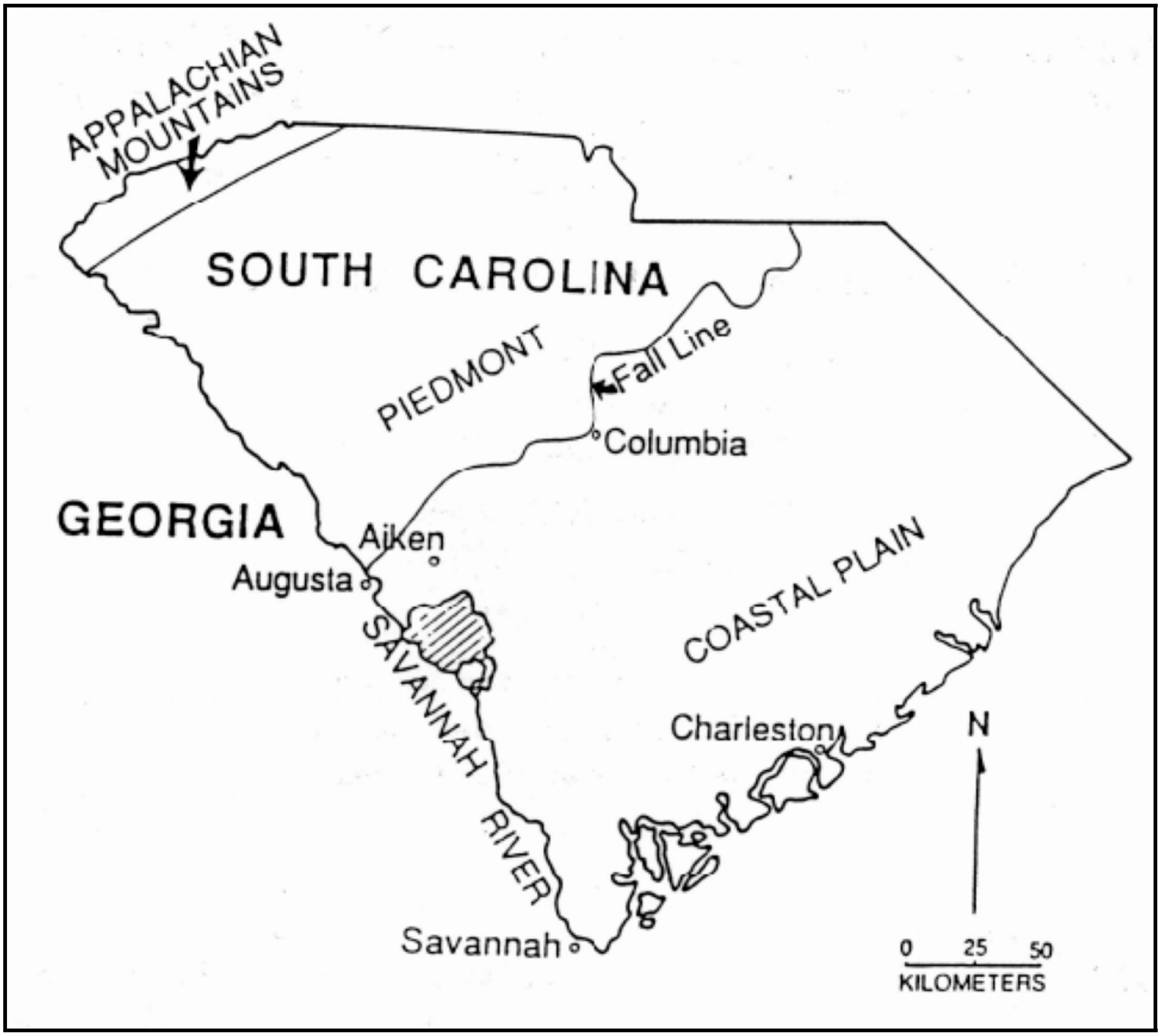


Figure 11-1, South Carolina Physiographic Units (Snipes et al., 1993)

The Blue Ridge Unit (Appalachian Mountains) covers approximately 2 percent of the state and it is located in the northwestern corner of the state. The Piedmont Unit comprises approximately one-third of the state with the Coastal Plain Unit covering the remaining two-thirds of the state. The geologic formations are typically aligned from the South-Southwest to the North-Northeast and parallel the South Carolina Atlantic coastline as shown in the generalized geologic map in Figure 11-2. The physiographic units in Figure 11-2 are broken down by the geologic time of the surface formations. South Carolina formations span in age from late Precambrian through the Quaternary period. The descriptions of events that have occurred over geologic time in South Carolina are shown in Figure 11-3.

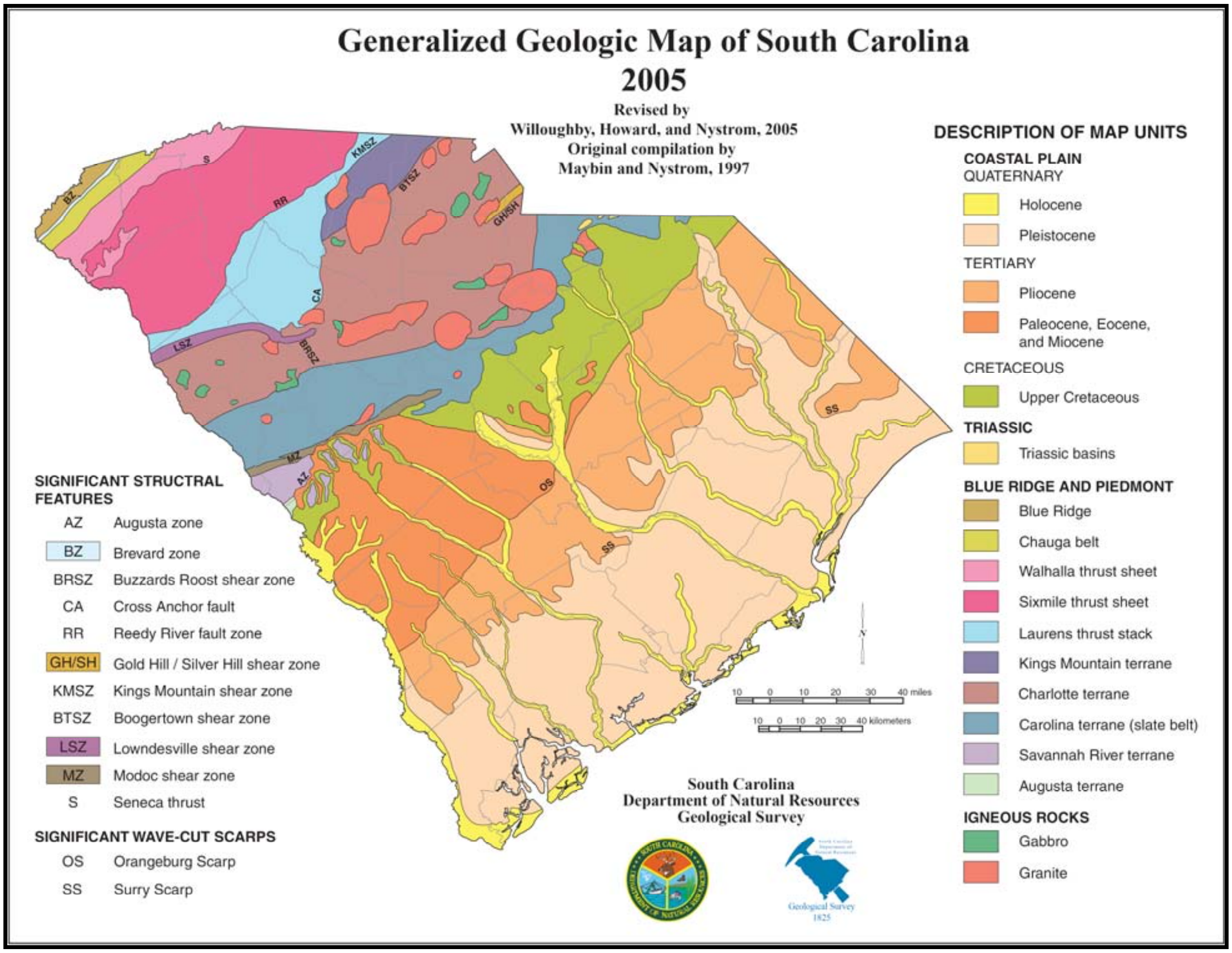


Figure 11-2, 2005 Generalized Geologic Map of South Carolina, (SCDNR)

A description of the geologic formations, age, and geologic features for the Blue Ridge, Piedmont, and Coastal Plain Physiographic Units are provided in the following sections.

Geologic Time Scale for South Carolina

(not scaled for geologic time or thickness of deposits)

EON	ERA	PERIOD	EPOCH	Geologic Events in South Carolina	MYA*
PHANEROZOIC	CENOZOIC	QUATERNARY	HOLOCENE	Barrier Islands formed; flood plains of major rivers established.	0.01
PHANEROZOIC	CENOZOIC	QUATERNARY	PLEISTOCENE	Surficial deposits cover the underlying Coastal Plain formations. Carolina Bays develop; scarps form due to sea level rise and fall.	1.6
PHANEROZOIC	CENOZOIC	TERTIARY – NEOGENE	PLIOCENE	Coastal Plain sediments reflect large-scale regressive cycles. Off-lap of the ocean and scouring responsible for the Orangeburg scarp.	5.3
PHANEROZOIC	CENOZOIC	TERTIARY – NEOGENE	MIOCENE	Uplift and erosion of Piedmont and mountains. Fluvial sediments spread over the Coastal Plain. Sandhill dunes deposited.	23
PHANEROZOIC	CENOZOIC	TERTIARY – PALEOGENE	OLIGOCENE	Deposition of carbonates predominate. Arches and embayments continue to influence deposition of Coastal Plain formations.	36.6
PHANEROZOIC	CENOZOIC	TERTIARY – PALEOGENE	EOCENE	Sand deposited in upper Coastal Plain; limestone deposited in middle and lower Coastal Plain. Fault activity.	53
PHANEROZOIC	CENOZOIC	TERTIARY – PALEOGENE	PALEOCENE	Fluvial, marginal marine and marine Coastal Plain sediments deposited.	65
PHANEROZOIC	MESOZOIC	CRETACEOUS		Development of the Cape Fear Arch and South Georgia Embayment influences deposition of Coastal Plain formations. Fault activity.	135
PHANEROZOIC	MESOZOIC	JURASSIC		Renewed sea floor spreading; intrusion of N-S and NW-SE trending diabase (basaltic) dikes. Great North American intrusive event.	205
PHANEROZOIC	MESOZOIC	TRIASSIC		Breakup of the supercontinent Pangea. Triassic rift-basins develop and fault activity.	250
PHANEROZOIC	PALEOZOIC	PERMIAN		Alleghanian Orogeny - closing of the Iapetus Ocean accompanied by continental collision and formation of the supercontinent Pangea. Rocks related to South Carolina are folded and thrusted; some rocks may have been metamorphosed.	290
PHANEROZOIC	PALEOZOIC	PENNSYLVANIAN	Emplacement of igneous intrusions	Time of uplift and erosion.	320
PHANEROZOIC	PALEOZOIC	MISSISSIPPIAN	Emplacement of igneous intrusions	Time of uplift and erosion.	355
PHANEROZOIC	PALEOZOIC	DEVONIAN	Emplacement of igneous intrusions	Arcadian Orogeny - rocks related to South Carolina may have been folded, faulted, and metamorphosed.	408
PHANEROZOIC	PALEOZOIC	SILURIAN	Emplacement of igneous intrusions	Laurentia and western South America/Africa shear apart as the Gondwanian supercontinent breakup begins.	438
PHANEROZOIC	PALEOZOIC	ORDOVICIAN	Emplacement of igneous intrusions	Taconic Orogeny - collision of Laurentia with western South America/Africa; Gondwanian supercontinent forms. Rocks related to South Carolina are folded, sheared/faulted, and metamorphosed.	510
PHANEROZOIC	PALEOZOIC	CAMBRIAN	Emplacement of igneous intrusions	Deposition of volcanic and sedimentary rocks found in the Slate belt.	570
PRECAMBRIAN	PROTEROZOIC EON			Opening of the Iapetus Ocean (750 to 700 million years ago) and continental rifting of Laurentia's (North America) eastern margin.	2,500
PRECAMBRIAN	ARCHEAN EON			Grenville Orogeny (1,100 million years ago) metamorphosed basement rocks and rocks related to the Blue Ridge. Oldest rock dated in South Carolina is 1,200 million years old.	3,800
					4,600
				Oldest known rock in U.S. - 3,600 million years old. Oldest known rock in world - 3,850 million years old. Formation of the Earth - 4,600 million years old.	

* Estimated age in millions of years.

MYA = million years ago

Based on the 1989 Global Stratigraphic Chart, International Union of Geological Sciences.

Figure 11-3, Geologic Time Scale for South Carolina (SCDNR)

11.3 BLUE RIDGE UNIT

The Blue Ridge Unit consists of mountains that are part of the Blue Ridge Mountains and is a southern continuation of the Appalachian Mountains. The Brevard Fault zone (depicted as the Brevard zone, BZ, in Figure 11-2) separates the Blue Ridge Unit from the Piedmont Unit. It consists of metamorphic and igneous rocks. The topography is rugged and mountainous and contains the highest elevations in the State of South Carolina with elevations ranging from 1,400 feet to 3,500 feet. Sassafras Mountain is the highest point in South Carolina with an elevation of 3,560 feet. The Appalachian Mountains were formed in the late Paleozoic era, about 342 million years ago (MYA). The basement rocks in the Blue Ridge Unit were formed in the late Precambrian time period (570 to 2,500 MYA). The oldest rock dated in South Carolina is 1,200 million years old.

The bedrock in this region is a complex crystalline formation that has been faulted and contorted by past tectonic movements. The rock has weathered to residual soils that form the mantle for the hillsides and hilltops. The typical residual soil profile in areas not disturbed by erosion or the activities of man consists of clayey soils near the surface where weathering is more advanced, underlain by sandy silts and silty sands. There may be colluvial (old land-slide) material on the slopes.

11.4 PIEDMONT UNIT

The Piedmont Unit is bounded on the west by the Blue Ridge Unit and on the east by the Coastal Plain Unit. The boundary between the Blue Ridge Unit and the Piedmont Unit is typically assumed to be the Brevard Fault zone (depicted as the Brevard zone, BZ, in Figure 11-2). The common boundary between the Piedmont Unit and the Coastal Plain Unit is the “Fall Line”. It is believed that the Piedmont is the remains of an ancient mountain chain that has been eroded with existing elevations ranging from 300 feet to 1,400 feet. The Piedmont is characterized by gently rolling topography, deeply weathered bedrock, and relatively few rock outcrops. It contains monadnocks that are isolated outcrops of bedrock (usually quartzite or granite) that are a result of the erosion of the mountains. The vertical stratigraphic sequence consists of 5 to 70 feet of weathered residual soils at the surface underlain by metamorphic and igneous basement rocks (granite, schist, and gneiss). The weathered soils (saprolites) are physically and chemically weathered rocks that can be soft/loose to very hard and dense, or friable and typically retain the structure of the parent rock. The geology of the Piedmont is complex with numerous rock types that were formed during the Paleozoic era (250 to 570 MYA).

The typical residual soil profile consists of clayey soils near the surface, where soil weathering is more advanced, underlain by sandy silts and silty sands. The boundary between soil and rock is not sharply defined. This transitional zone termed “partially weathered rock” (PWR) is normally found overlying the parent bedrock. Partially weathered rock is defined, for engineering purposes, as residual material with Standard Penetration Test resistances in excess of 100 blows/foot. The partially weathered rock is considered in geotechnical engineering as an Intermediate Geomaterial (IGM). Weathering is facilitated by fractures, joints, and by the presence of less resistant rock types. Consequently, the profile of the partially weathered rock and hard rock is quite irregular and erratic, even over short horizontal distances.

Also, it is not unusual to find lenses and boulders of hard rock and zones of partially weathered rock within the soil mantle, well above the general bedrock level.

11.5 "FALL LINE"

A "Fall Line" is an unconformity that marks the boundary between an upland region (bed rock) and a coastal plain region (sediment). In South Carolina the Piedmont Unit is separated from the Coastal Plain Unit by a "Fall Line" that begins near the Edgefield-Aiken County line and traverses to the northeast through Lancaster County. In addition to Columbia, SC many cities were built along the "Fall Line" as it runs up the east coast (Macon, Raleigh, Richmond, Washington D.C., and Philadelphia). The "Fall Line" generally follows the southeastern border of the Savannah River terrane formation and the Carolina terrane (slate belt) formation shown in Figure 11-2. Along the "Fall Line" between elevations 300 to 725, the Sandhills formations can be found which are the remnants of a prehistoric coastline. The Sandhills are unconnected bands of sand deposits that are remnants of coastal dunes that were formed during the Miocene epoch (5.3 to 23 MYA). The land to the southeast of the "Fall Line" is characterized by a gently downward sloping elevation (2 to 3 feet per mile) as it approaches the Atlantic coastline as shown in Figure 11-4. Several rivers such as the Pee Dee, Wateree, Lynches, Congaree, N. Fork Edisto, and S. Fork Edisto flow from the "Fall Line" towards the Atlantic coast as they cut through the Coastal Plain sediments.

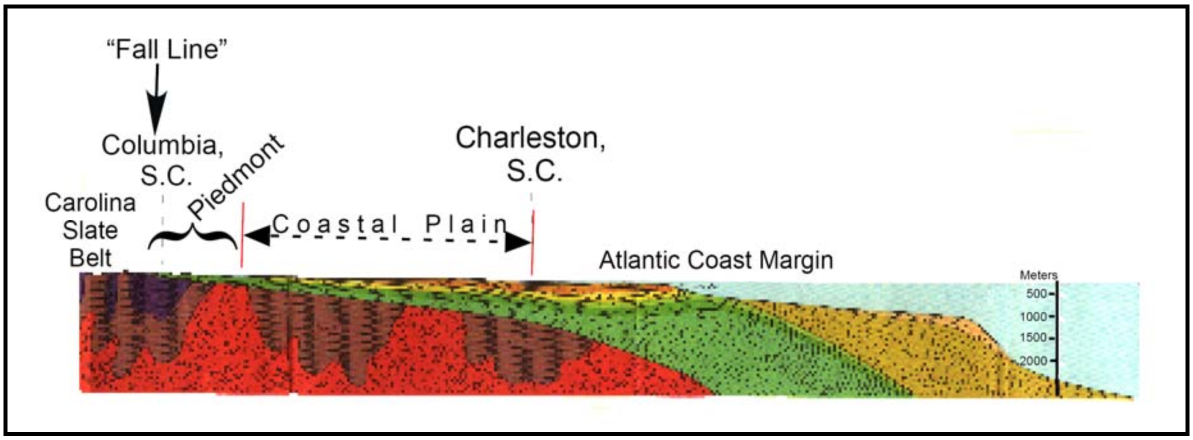


Figure 11-4, South Carolina "Fall Line"
(Odum et al., 2003)

11.6 COASTAL PLAIN UNIT

The Coastal Plain Unit is a compilation of wedge shaped formations that begin at the "Fall Line" and dip towards the Atlantic Ocean with ground surface elevations typically less than 300 feet. The Coastal Plain is underlain by Mesozoic/Paleozoic basement rock. This wedge of sediment is comprised of numerous geologic formations that range in age from late Cretaceous period to Recent. The sedimentary soils of these formations consist of unconsolidated sand, clay, gravel, marl, cemented sands, and limestone that were deposited over the basement rock. The marl and limestone are considered in geotechnical engineering as an IGM. The basement rock consists of granite, schist, and gneiss similar to the rocks of the Piedmont Unit. The thickness of the Coastal Plain sediments varies from zero at the "Fall Line" to more than 4,000 feet at the southern tip of South Carolina near Hilton Head Island. The thickness of the Coastal Plain sediments along the Atlantic coast varies from ~1300 feet at Myrtle Beach to ~4000 feet at

Hilton Head Island. The top of the basement beneath the Coastal Plain has been mapped during a SC Seismic Hazard Study that was prepared for SCDOT and the contours of the Coastal Plain sediment thickness in meters are shown in Figure 11-5.

The area is formed of older, generally well-consolidated layers of sands, silts, or clays that were deposited by marine or fluvial action during a period of retreating ocean shoreline. Predominantly, sediments lie in nearly horizontal layers; however, erosional episodes occurring between depositions of successive layers are often expressed by undulations in the contacts between the formations. Due to their age, sediments exposed at the ground surface are often heavily eroded. Ridges and hills are either capped by terrace gravels or wind-deposited sands. Younger alluvial soils may mask these sediments in swales or stream valleys.

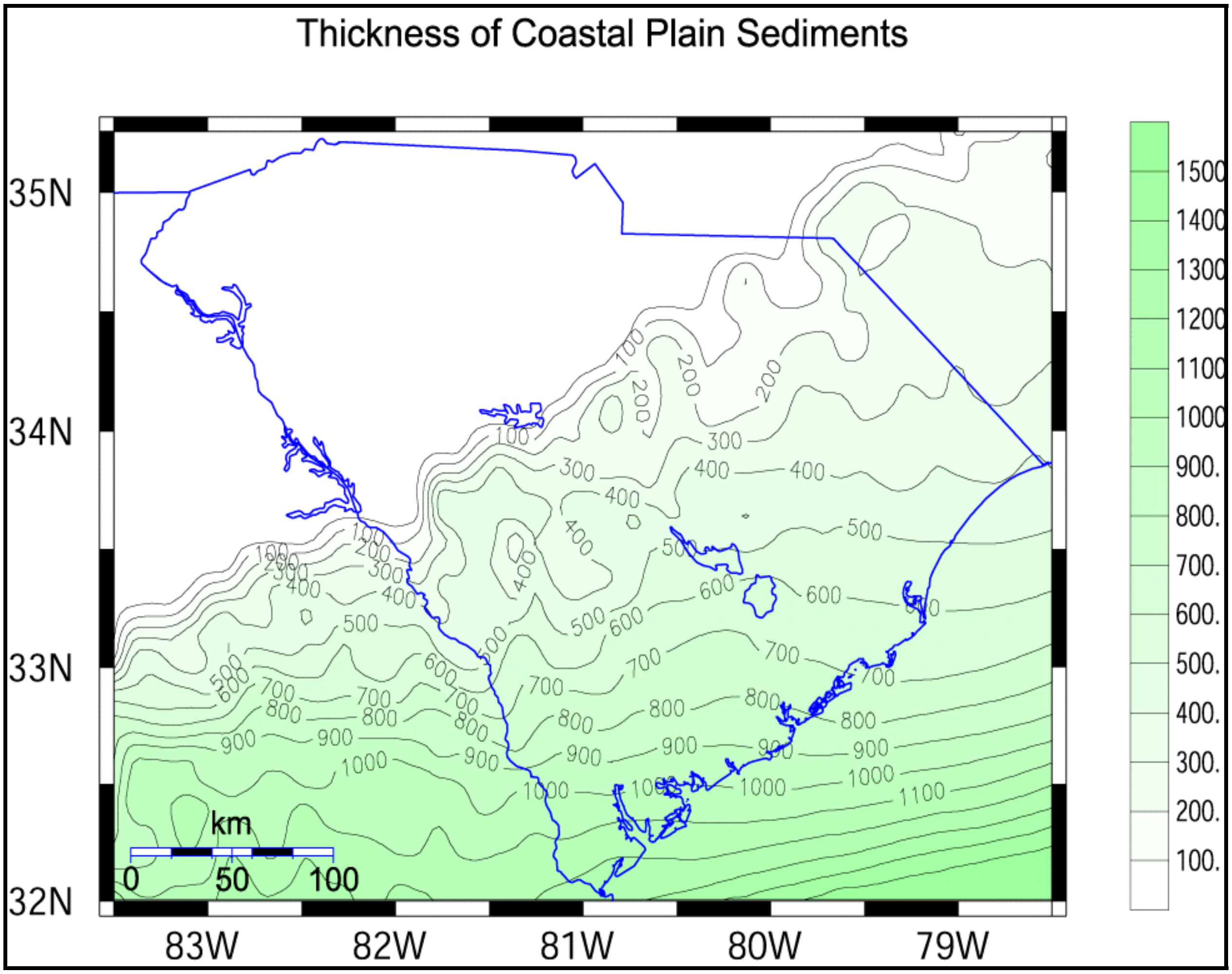


Figure 11-5, Contour Map of Coastal Plain Sediment Thickness, in meters (Chapman and Talwani, 2002)

This Coastal Plain Unit was formed during Quaternary, Tertiary, and late Cretaceous geologic periods. The Coastal Plain can be divided into the following three subunits:

- Upper Coastal Plain
- Middle Coastal Plain
- Lower Coastal Plain

The Lower Coastal Plain comprises approximately one-half of the entire Atlantic Coastal Plain of South Carolina. The Surry Scarp (-SS-) shown in Figure 11-2 separates the Lower Coastal Plain from the Middle Coastal Plain. The Surry Scarp is a seaward facing scarp with a toe elevation of 90 to 100 feet. The Middle Coastal Plain and the Upper Coastal Plain each compose approximately one fourth of the Coastal Plain area. The Orangeburg Scarp (-OS-) shown in Figure 11-2 separates the Middle Coastal Plain from the Upper Coastal Plain. The Orangeburg Scarp is also a seaward facing scarp with a toe elevation of 250 to 270 feet.

11.6.1 Lower Coastal Plain

The Lower Coastal Plain is typically identified as the area east of the Surry Scarp below elevation 100 feet. The vertical stratigraphic sequence overlying the basement rock consists of unconsolidated Cretaceous, Tertiary, and Quaternary sedimentary deposits. The surface deposits of the Lower Coastal Plain were formed during the Quaternary period that began approximately 1.6 MYA and extends to present day. The Quaternary period can be further subdivided into the Pleistocene epoch and the Holocene epoch. During the Pleistocene epoch (1.6 MYA to 10 thousand years ago) the surficial deposits that cover the underlying Coastal Plain formations were formed. This period specifically marks the formation of the Carolina Bays and scarps throughout the east coast due to sea level rise and fall. The Holocene epoch covers from 10 thousand years ago to present day. Barrier islands were formed and flood plains from major rivers were formed during the Holocene epoch. Preceding Quaternary period during the Eocene epoch (53 to 36.6 MYA) of the Tertiary period, limestone was deposited in the Lower Coastal Plain.

11.6.2 Middle Coastal Plain

The Middle Coastal Plain is typically identified as the area between the Orangeburg Scarp and the Surry Scarp and falls between elevation 100 feet and 270 feet. The vertical stratigraphic sequence overlying the basement rock consists of unconsolidated Cretaceous and Tertiary sedimentary deposits. The surface deposits of the Middle Coastal Plain were formed during the Pliocene epoch of the Tertiary period. During the Pliocene epoch (5.3 to 1.6 MYA) of the Tertiary period, the Orangeburg Scrap was formed as a result of scouring from the regressive cycles of the Ocean as it retreated. During the Eocene epoch (53 to 36.6 MYA) of the Tertiary period, limestone was deposited in the Middle Coastal Plain.

11.6.3 Upper Coastal Plain

The Upper Coastal Plain is typically identified as the area between the “Fall Line” and the Orangeburg Scarp and falls between elevations 270 feet and 300 feet. The Upper Coastal Plain was formed during the Tertiary and late Cretaceous periods. The Tertiary period began approximately 65 MYA and ended approximately 1.6 MYA. The Tertiary period can be further subdivided into the Pliocene epoch, Miocene epoch, Oligocene epoch, Eocene epoch, and Paleocene epoch. The Miocene epoch (23 to 5.3 MYA) is marked by the formation of the Sandhills dunes as a result of fluvial deposits over the Coastal Plain. During the early Tertiary period (65 to 23 MYA) fluvial deposits over the Coastal Plain consisted of marine sediments, limestone, and sand.

11.7 SOUTH CAROLINA SEISMICITY

11.7.1 Central and Eastern United States (CEUS) Seismicity

Even though seismically active areas in the United States are generally considered to be in California and Western United States, historical records indicate that there have been major earthquake events in Central and Eastern United States (CEUS) that have not only been of equal or greater magnitude but that have occurred over broader areas of the CEUS. The United States Geologic Survey (USGS) map shown in Figure 11-6 indicates earthquakes that have caused damage within the United States between 1750 and 1996. Of particular interest to South Carolina is the 1886 earthquake in Charleston, SC that has been estimated to have a M_W of at least 7.3. Also of interest to the northwestern end of South Carolina is the influence of New Madrid seismic zone, near New Madrid, Missouri, where historical records indicate that between 1811 and 1812 there were several large earthquakes with a M_W of at least 7.7.

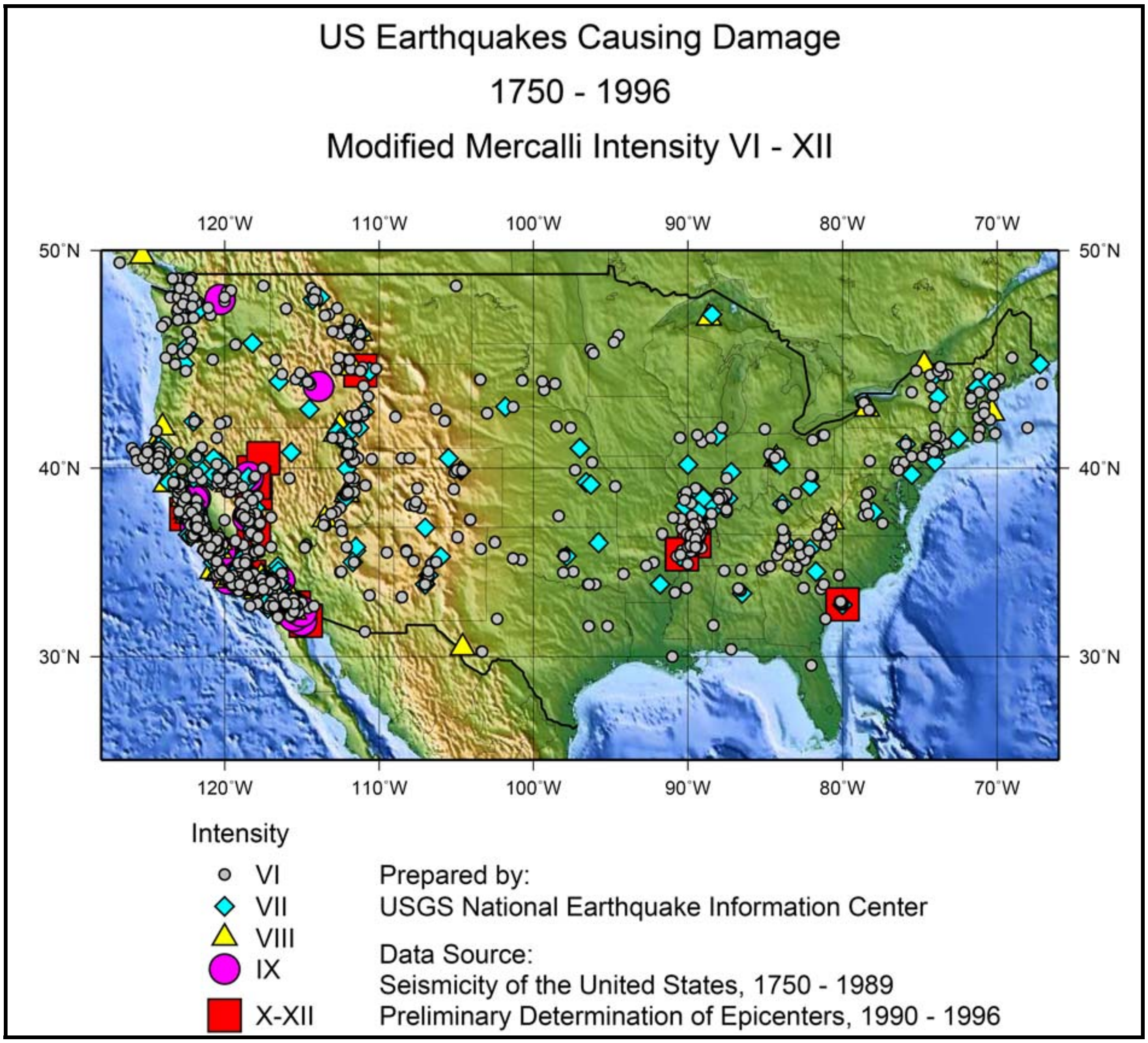


Figure 11-6, U.S. Earthquakes Causing Damage 1750 – 1996 (USGS)

11.7.2 <u>SC Earthquake Intensity</u>

The Modified Mercalli Intensity Scale (MMIS) is a qualitative measure of the strength of ground shaking at a particular site that is used in the United States. Each earthquake large enough to be felt will have a range of intensities. Typically the highest intensities are measured near the earthquake epicenter and lower intensities are measured farther away. The MMIS is used to distinguish the ground shaking at geographic locations as opposed to the moment magnitude scale that is used to compare the energy released by earthquakes. Roman numerals are used to identify the MMIS of ground shaking with respect to shaking and damage felt at a geographic location as shown in Table 11-1.

Table 11-1, Modified Mercalli Intensity Scale (MMIS)

INTENSITY	I	II – III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not Felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very Light	Light	Moderate	Moderate / Heavy	Heavy	Very Heavy

Figure 11-7 shows a map developed by the South Carolina Geological Survey with earthquake intensities, by county, based on the MMIS. The intensities shown on this map are the highest likely under the most adverse geologic conditions that would be produced by a combination of the August 31, 1886, Charleston, S.C. earthquake (M_W = 7.3) and the January 1, 1913, Union County, S.C., earthquake (M_W = 5.5). This map is for informational purposes only and is not intended as a design tool, but reflects the potential for damage based on earthquakes similar to the Union and Charleston earthquake events.

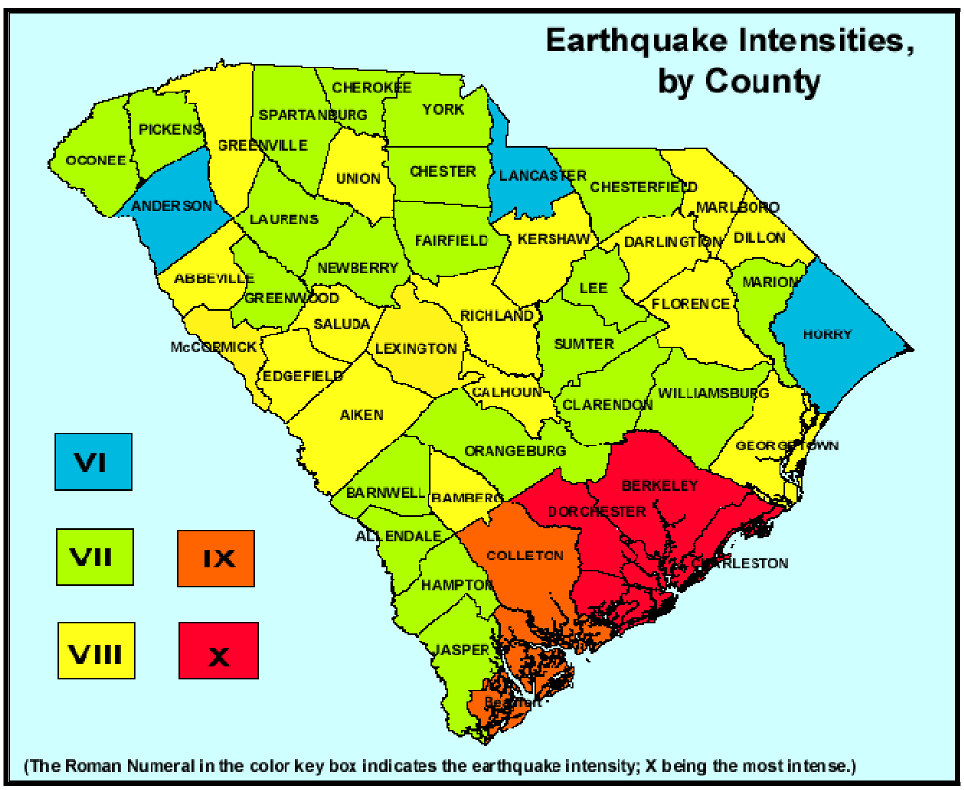


Figure 11-7, SC Earthquake Intensities By County (SCDNR)

11.8 SOUTH CAROLINA SEISMIC SOURCES

Sources of seismicity are not well defined in much of the Eastern United States. South Carolina seismic sources have therefore been defined based on seismic history in the Southeastern United States. The SC Seismic Hazard study (Chapman and Talwani, 2002) has identified two types of seismic sources: Non-Characteristic Earthquakes and Characteristic Earthquakes.

11.8.1 Non-Characteristic Earthquake Sources

Seismic histories were used to establish seismic area sources for analysis of non-characteristic background events. The study modified the Frankel et al., 1996 source area study to develop the seismic source areas shown in Figures 11-8 and 11-9.

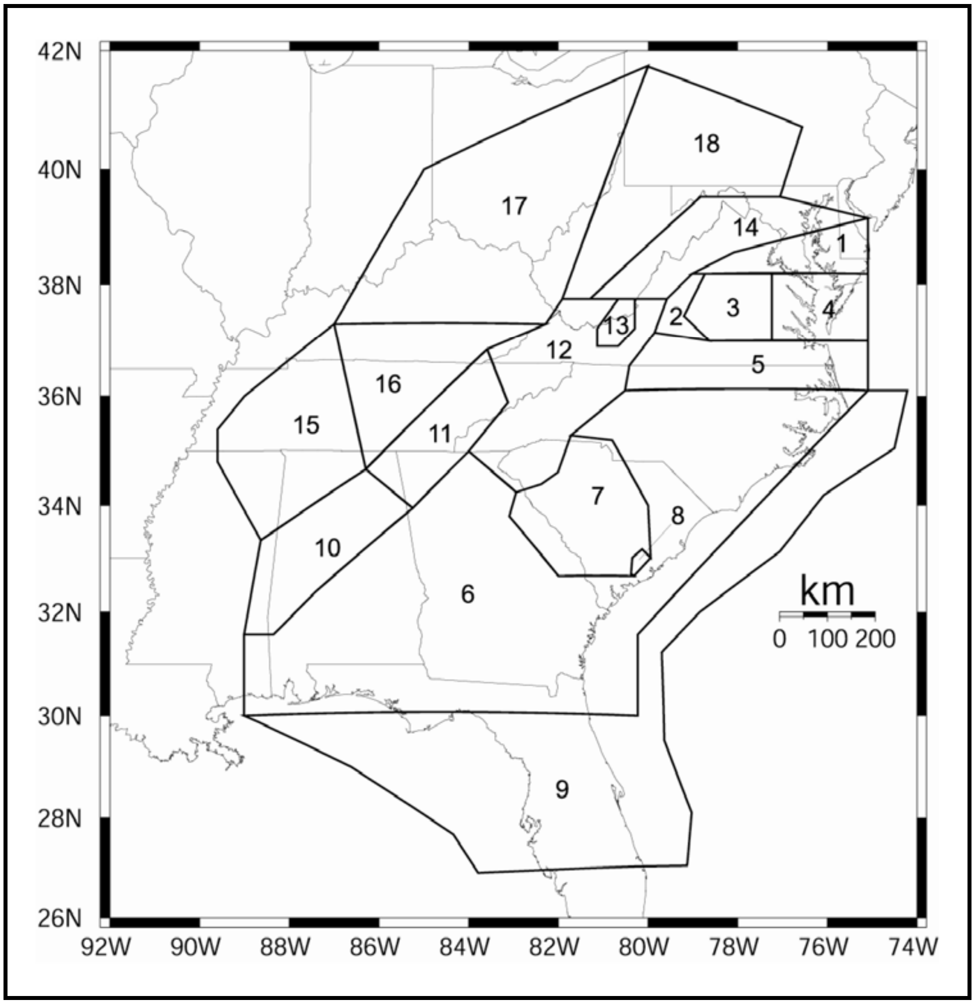


Figure 11-8, Source Areas for Non-Characteristic Earthquakes (Chapman and Talwani, 2002)

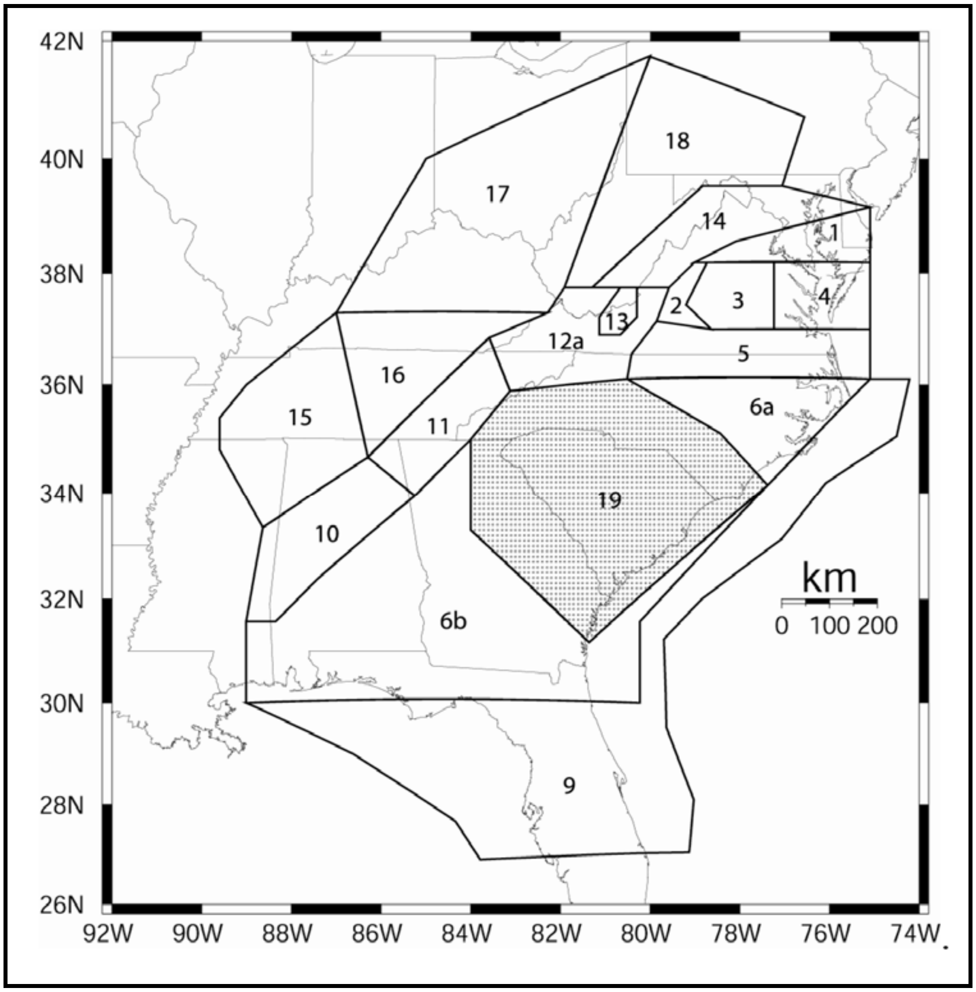


Figure 11-9, Alternative Source Areas for Non-Characteristic Earthquakes (Chapman and Talwani, 2002)

The source areas listed in Figures 11-8 and 11-9 are described in Table 11-2.

Table 11-2, Source Areas for Non-Characteristic Background Events (Chapman and Talwani, 2002)

Area No.	Description	Area (sq.miles)	Area No.	Description	Area (sq.miles)
1	Zone 1	8,133	**10**	Alabama	20,257
2	Zone 2	2,475	**11**	Eastern Tennessee	14,419
3	Central Virginia	7,713	**12**	Southern Appalachian	29,234
4	Zone 4	9,687	**12a**	Southern Appalachian N.	17,034
5	Zone 5	18,350	**13**	Giles County, VA	1,980
6	Piedmont and Coastal Plain	161,110	**14**	Central Appalachians	16,678
6a	Piedmont & CP NE	18,815	**15**	West Tennessee	29,667
6b	Piedmont & CP SW	95,854	**16**	Central Tennessee	20,630
7	SC Piedmont	22,248	**17**	Ohio – Kentucky	58,485
8	Middleton Place	455	**18**	West VA-Pennsylvania	34,049
9	Florida/Continental Margin	110,370	**19**	USGS Gridded Seis.-1996	---

Figure 11-10 shows additional historical seismic information obtained from the Virginia Tech catalog of seismicity in the Southeastern United States from 1600 to present that was used to model the non-characteristic background events in the source areas.

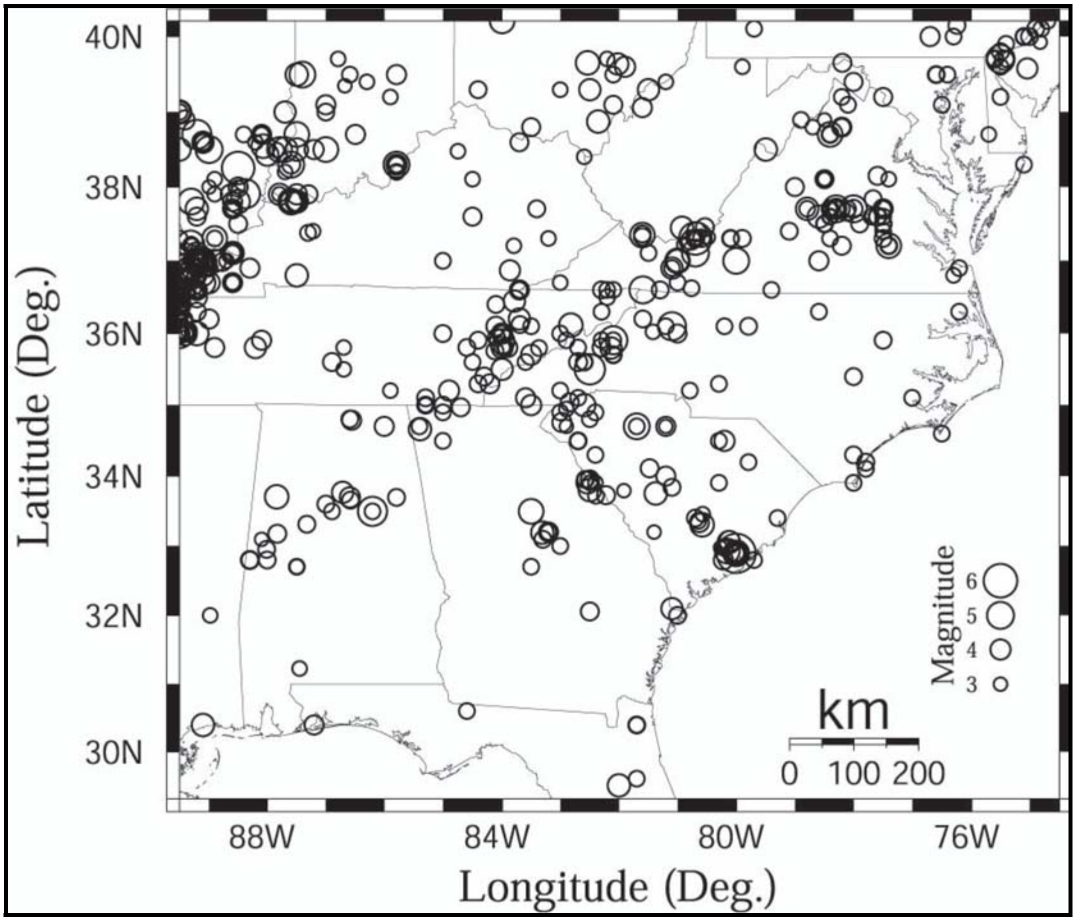


Figure 11-10, Southeastern U.S. Earthquakes (M_W > 3.0 from 1600 to Present) (Chapman and Talwani, 2002)

11.8.2 Characteristic Earthquake Sources

The single most severe earthquake that has occurred in South Carolina's human history occurred in Charleston, South Carolina, in 1886. It was one of the largest, earthquakes to affect the Eastern United States in historical times. The M_W of this earthquake has been estimated to range from 7.0 to 7.5. It is typically referred to have a M_W of 7.3. The faulting source that was responsible for the 1886 Charleston earthquake remains uncertain to date.

Large magnitude earthquake events with the potential to occur in coastal South Carolina are considered characteristic earthquakes. These earthquakes are modeled as a combination of fault sources and a seismic Area Source. The SC Seismic Hazard study used the 1886 Earthquake fault source, also known as the Middleton Place seismic zone, and the "Zone of River Anomalies" (ZRA) fault source. For the 1886 Earthquake fault source it assumed that rupture occurred on the NE trending "Woodstock" fault and on the NW trending "Ashley River" fault. The 1886 Earthquake fault source is modeled as three independent parallel faults.

Recent studies (Marple and Talwani, 1993, 2000) suggest that the “Woodstock” fault may be a part of larger NE trending fault system that extends to North Carolina and possibly Virginia, referred to in the literature as the “East Coast Fault System”. The ZRA fault source is the term used for the portion of the “East Coast Fault System” that is located within South Carolina. The ZRA fault system is modeled by a 145-mile long fault with a NE trend. The characteristic seismic Area Source is the same as is used in the 1996 National Seismic Hazard Maps. It models a network of individual faults no greater than 46 miles in length within the Lower Coastal Plain. The fault sources and area sources used to model the characteristic earthquake sources in the SC Seismic Hazard Study are shown in Figure 11-11.

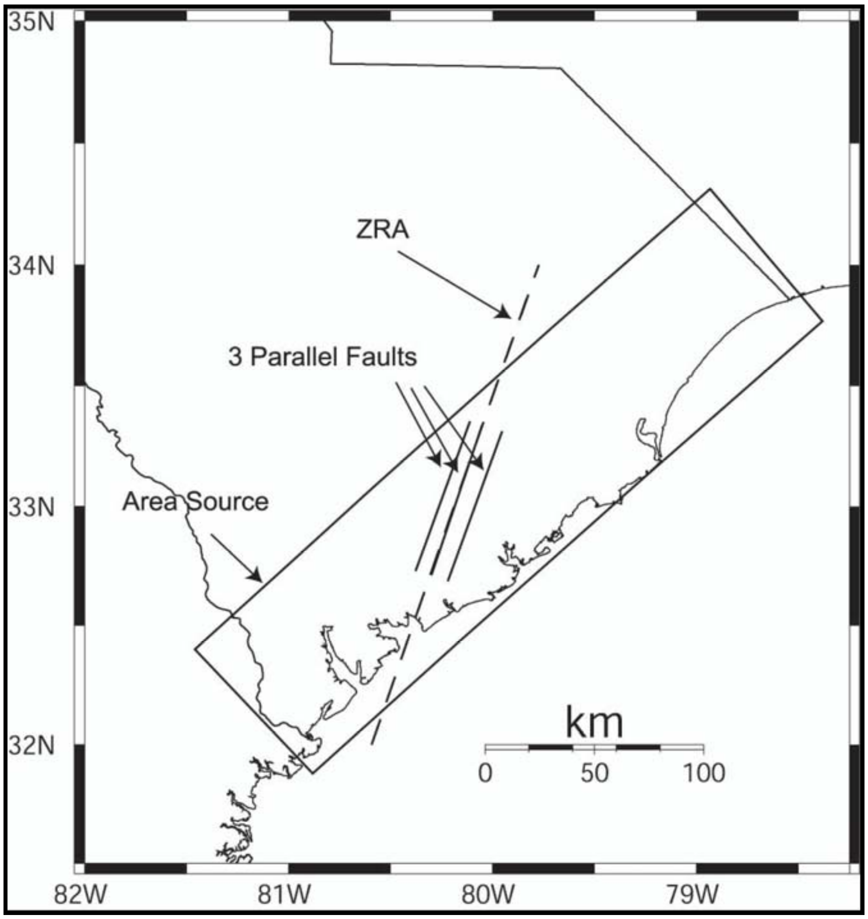


Figure 11-11, South Carolina Characteristic Earthquake Sources (Chapman and Talwani, 2002)

11.9 SOUTH CAROLINA EARTHQUAKE HAZARD

11.9.1 Design Earthquakes

The SCDOT uses a Functional Evaluation Earthquake (FEE) and a Safety Evaluation Earthquake (SEE) to design transportation infrastructure in South Carolina. The FEE represents a small ground motion that has a likely probability of occurrence within the life of the structure being designed. The SEE represents a large ground motion that has a relatively low probability of occurrence within the life of the structure. The two levels of earthquakes have been chosen for South Carolina because SEE spectral accelerations can be as much as three to four times higher than FEE spectral accelerations in the Eastern United States. In contrast, the California SEE spectral accelerations can be the same or as much as 1.8 times the FEE spectral accelerations. Because of the large variation between FEE and SEE design earthquake events it is necessary to perform geotechnical earthquake engineering analyses for each event and compare the resulting performance with the SCDOT Performance Limits established in Chapter 10. The design life for transportation infrastructure is typically assumed to be 75 years when evaluating the design earthquakes, regardless of the actual design life specified in Chapter 10. The likelihood of these events occurring is quantified by the design events probability of exceedance (P_E) within the design life of the structure. Descriptions of the design earthquakes used in South Carolina are provided in Table 11-3.

Table 11-3, SCDOT Design Earthquakes

Design Earthquake	Description
Functional **E**valuation **E**arthquake (**FEE**)	The ground shaking having a 15 percent probability of exceedance in 75 years (15%/75 year). This design earthquake is equal to the 10 percent probability of exceedance in 50 years (10%/50). The FEE PGA and PSA are used for the functional evaluation of transportation infrastructure.
Safety **E**valuation **E**arthquake (**SEE**)	The ground shaking having a 3 percent probability of exceedance in 75 years (3%/75 year). This design earthquake is equal to the 2 percent probability of exceedance in 50 years (2%/50). The SEE PGA and PSA are used for the safety evaluation of transportation infrastructure.

11.9.2 Probabilistic Earthquake Hazard Maps

A SC Earthquake Hazard study was completed for SCDOT In October 2006 (Chapman and Talwani, 2002 and Chapman, 2006). The study produced probabilistic seismic hazard maps that reflect the actual geological conditions in South Carolina. The seismic hazard maps are motion intensities for a specific probability of exceedance (P_E). The motions are defined in terms of pseudo-spectral accelerations (*PSA*) at frequencies of 0.5, 1.0, 2.0, 3.3, 5.0, 6.67, and 13.0 Hz, for a damping ratio of 0.05 (5%) and the peak horizontal ground acceleration (PHGA or PGA). These accelerations were developed for the geologically realistic site conditions as well as for the hypothetical hard-rock basement outcrop. The geologically realistic site condition is a hypothetical site condition that was developed by using a transfer function of a linear response. South Carolina has been divided into two zones as shown in Figure 11-12: Zone I – Physiographic Units Outside of the Coastal Plain and Zone II – Coastal Plain Physiographic Unit. The delineation between these two zones has been shown linearly in Figure 11-12 but in reality it should follow the “Fall Line.” Because of the distinct differences between these two physiographic units, a geologically realistic model has been developed for each zone.

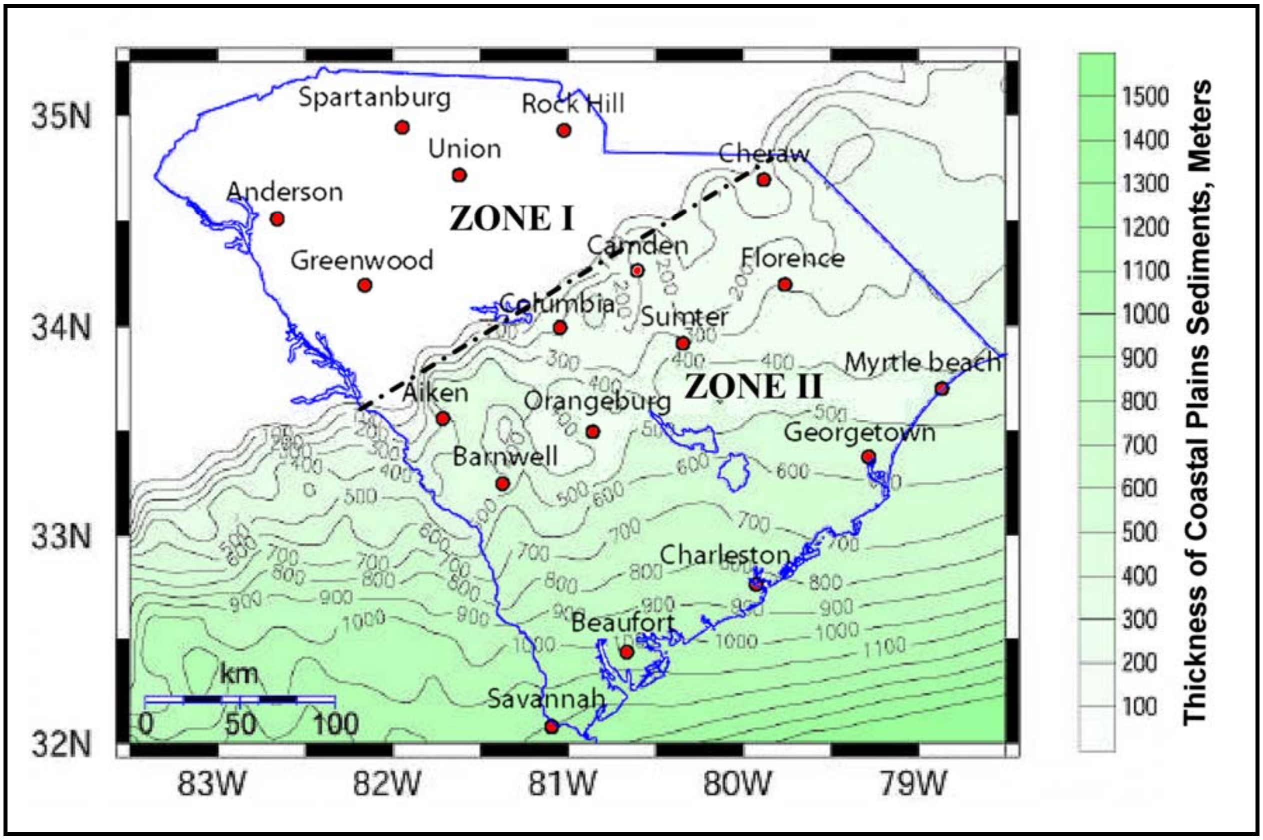


Figure 11-12, SCDOT Site Condition Selection Map (Modified Chapman and Talwani, 2002)

The Coastal Plain geologically realistic site condition consists of two layers, the shallowest layer consists of Coastal Plain sedimentary soil (Q=100) and weathered rock (Q=600), over a half-space of unweathered Mesozoic and Paleozoic sedimentary, and Metamorphic/Igneous rock, assuming vertical shear wave incidence. The soil properties for the Coastal Plain geologically realistic model are shown in Table 11-4.

The Piedmont geologically realistic site condition consists of one layer of weathered rock (Q=600) over a half-space of unweathered Mesozoic and Paleozoic sedimentary, and Metamorphic/Igneous rock, assuming vertical shear wave incidence. The soil properties for the Piedmont geologically realistic model are shown in Table 11-5.

Table 11-4, Coastal Plain Geologically Realistic Model

Soil Layer	Mass Density, ρ	Total Unit Weight, γ	Shear Wave Velocity, V_S
	kg/m^3	pcf	ft/sec
Layer 1 – Sedimentary Soils	2,000	125	2,300
Layer 2 – Weathered Rock	2,500	155	8,200
Half-Space – Basement Rock	2,600	165	11,200

Table 11-5, Geologically Realistic Model Outside of Coastal Plain

Soil Layer	Mass Density, ρ	Total Unit Weight, γ	Shear Wave Velocity, V_S
	kg/m^3	pcf	ft/sec
Layer 1 – Weathered Rock	2,500	155	8,200
Half-Space - Basement Rock	2,600	165	11,200

The transfer functions were computed using ¼ wavelength approximation of Boor and Joyner (1991). For more information on the development of the transfer function refer to Chapman and Talwani (2002).

The selection of the appropriate site condition is very important in the generation of probabilistic seismic hazard motions in the form of pseudo-spectral accelerations (*PSA*) and the peak horizontal ground acceleration (PHGA or PGA). The available site conditions for use in generating probabilistic seismic hazard motions are defined in Table 11-6. The selection of the appropriate site condition should be based on the results of the geotechnical site investigation, geologic maps, and any available geologic or geotechnical information from past projects in the area. Generally speaking the geologically realistic site condition should be used in the Coastal Plain. In areas outside of the Coastal Plain such as the Piedmont / Blue Ridge Physiographic Units and along the “Fall Line” should be evaluated carefully. The geotechnical investigation in these areas should be sufficiently detailed to determine depth to weathered rock having a shear wave velocity of approximately 8,000 to 8,200 ft/sec or to define the basement rock outcrop having a shear wave greater than 11,000 ft/sec.

Table 11-6, Site Conditions

<table>
<tr><th rowspan="2">South Carolina Zones</th><th colspan="2">Site Condition</th></tr>
<tr><th>Geologically Realistic</th><th>Hard-Rock Basement Outcrop</th></tr>
<tr><td>Zone I – Physiographic Units Outside of the Coastal Plain</td><td>Hypothetical outcrop of “Weathered Southeastern U.S. Piedmont Rock” that consist of 820 feet thick weathered formation of shear wave velocity, V_s = 8,000 ft/s overlying a hard-rock formation having shear wave velocity, V_s = 11,500 ft/s.</td><td rowspan="2">A hard-rock basement outcrop formation having shear wave velocity, V_s = 11,500 ft/s.</td></tr>
<tr><td>Zone II – Coastal Plain Physiographic Unit</td><td>Hypothetical outcrop of “Firm Coastal Plain Sediment” equivalent to the B-C Boundary having a shear wave velocity, V_s = 2,500 ft/s.</td></tr>
</table>

The seismic hazards computations use the seismic sources listed in Section 11.8, the design earthquake in Section 11.9.1, and the ground motions described in Section 11.9.4.

The PGA and PSA can be obtained for any location in South Carolina by specifying a Latitude and Longitude. The Latitude and Longitude of a project site may be obtained from the plans or by using an Interactive Internet search tool. Typical Latitude and Longitude for South Carolina cities are provided in Table 11-7 for reference.

Table 11-7, Latitude and Longitude for South Carolina Cities

SC City	Latitude	Longitude	SC City	Latitude	Longitude
Anderson, SC	34.50	82.72	Greenwood, SC	34.17	82.12
Beaufort, SC	32.48	80.72	Myrtle Beach, SC	33.68	78.93
Charleston, SC	32.90	80.03	Nth Myrtle B, SC	33.82	78.72
Columbia, SC	33.95	81.12	Orangeburg, SC	33.50	80.87
Florence, SC	34.18	79.72	Rock Hill, SC	34.98	80.97
Georgetown, SC	33.83	79.28	Spartanburg, SC	34.92	81.96
Greenville, SC	34.90	82.22	Sumter, SC	33.97	80.47

The site-specific hazard PGA and PSA are generated by the GDS for every project using Scenario_PC (2006) (Chapman, 2006). Scenario_PC generates seismic hazard data in a similar format as that generated by the USGS. The designer must obtain a SC Seismic Hazard request form and submit it to the GDS. A copy of the form is included in Appendix A. The SC Seismic Hazard request form requires that the designer provide the following information.

- SCDOT Project Name and Project Number
- Latitude and Longitude of Project Site
- Probability of Exceedance for Earthquake Design Event being analyzed
- Site Condition: Geologically Realistic or Hard-Rock Basement Outcrop

The geotechnical engineer is required to provide documentation for the selection of the Site Condition (Geologically Realistic or Hard-Rock Basement Outcrop) used.

A sample of the Seismic Hazard information generated by Scenario_PC (2006) for Columbia, SC is shown in Figure 11-13.

```
THE NAME OF THE DIRECTORY CONTAINING THIS FILE
 AND ALL ASSOCIATED OUTPUT FILES IS: Columbia


 3% PROBABILITY OF EXCEEDANCE (For 75 year Exposure)
      FOR GEOLOGICALLY REALISTIC SITE CONDITION


 RESULTS OF INTERPOLATION

     Site Location: 33.9500 N 81.1200 W
Nearest Grid Point: 34.0000 N 81.1250 W Distance From Site:   5.56 Km
Thickness of sediments, meters: 262.162

                    PSA and PGA as Percentage of g
  0.5Hz     1.0Hz     2.0Hz     3.3Hz     5Hz       6.7Hz     13Hz      PGA
 6.36404  18.97654  30.64109  40.70470  46.59745  45.10500  40.47712  19.61478
```

Figure 11-13, Scenario_PC (2006) Sample Output for Columbia, SC

In order to provide the designer with an overview of the South Carolina's probabilistic seismic hazard, probabilistic seismic hazard contour maps for the FEE and SEE design events for PGA, PSA for the short-period, S_s, (5 Hz = 0.2 seconds), and PSA for the long-period, S_1, (1 Hz = 1.0 second) have been included in this Chapter. The PGA and PSA values as a percentage of gravity (g) have been placed in contours and overlaid over a South Carolina map. FEE seismic hazard contour maps are provided for PGA, S_s, and S_1 in Figures 11-14, 11-15, and 11-16, respectively. SEE seismic hazard contour maps are provided for PGA, S_s, and S_1 in Figures 11-17 11-18, and 11-19, respectively. FEE and SEE peak ground accelerations (PGA) and pseudo-spectral accelerations (PSA) (generated by Scenario_PC 2006) for selected cities in South Carolina have been plotted at either the B-C boundary (geologically realistic) or hard rock basement outcrop in Figures 11-20 and 11-21. <u>The seismic hazard contour maps and the sampling of the PSA curves for various cities are provided for information only and must not be used for design of any structures in South Carolina.</u>

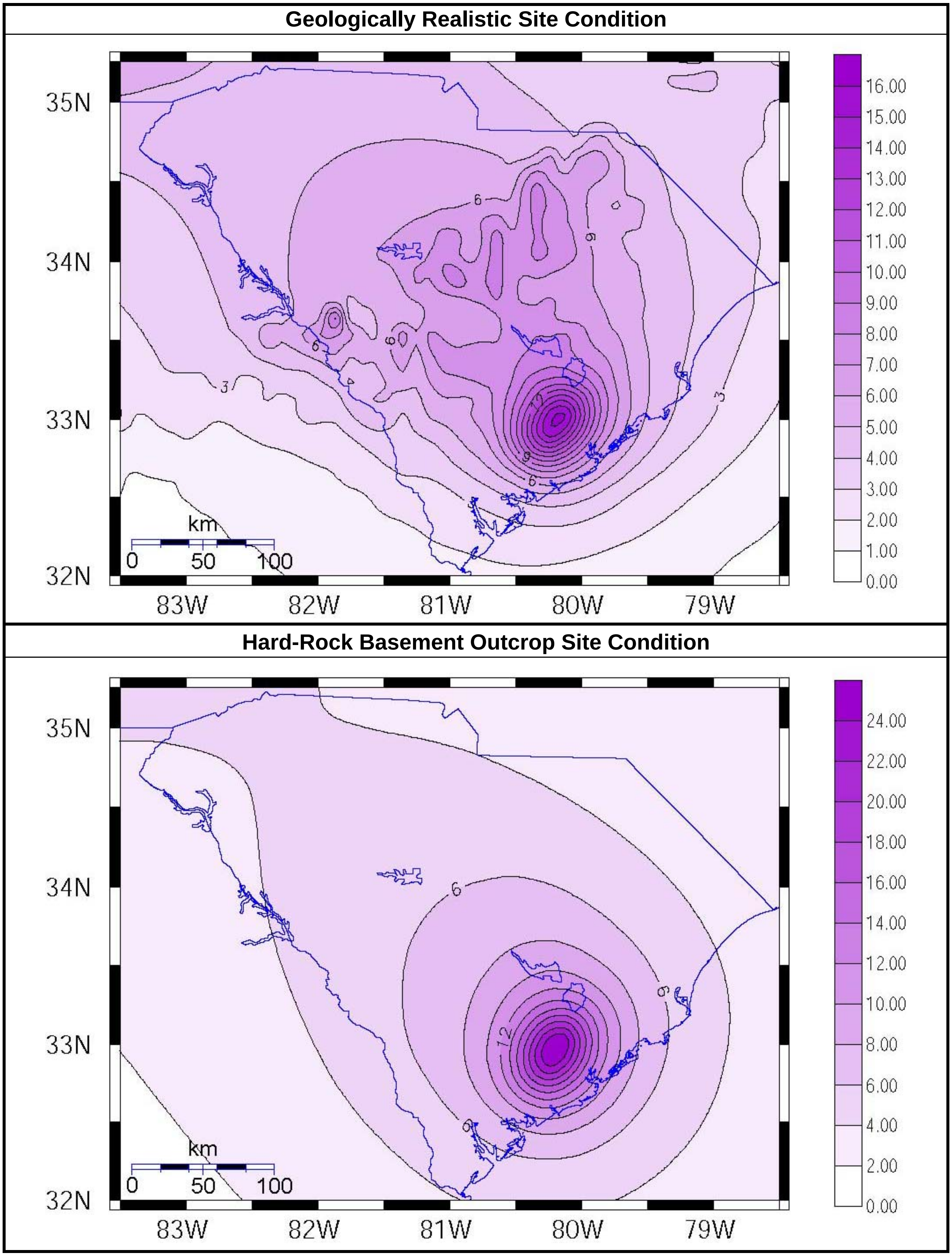
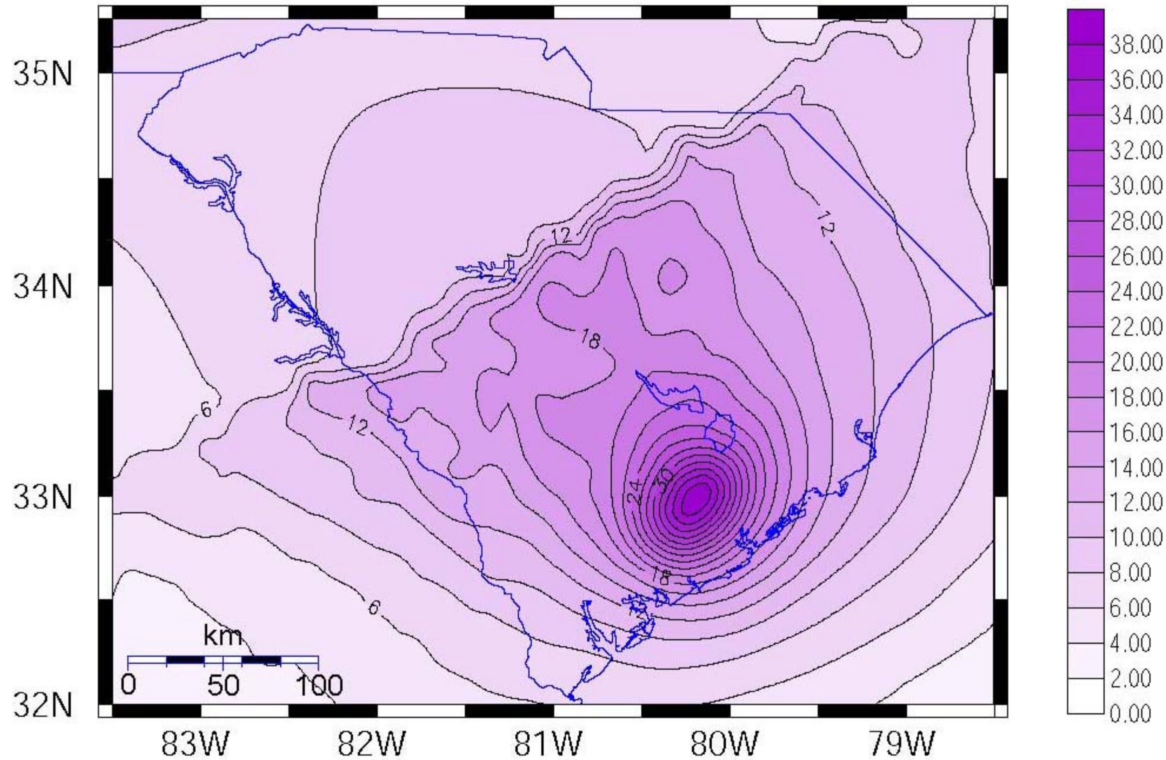


Figure 11-14, PGA (%g) - 15% P_E in 75 Years (10% P_E-50 Yr)
(Chapman and Talwani, 2002)

Geologically Realistic Site Condition



Hard-Rock Basement Outcrop Site Condition

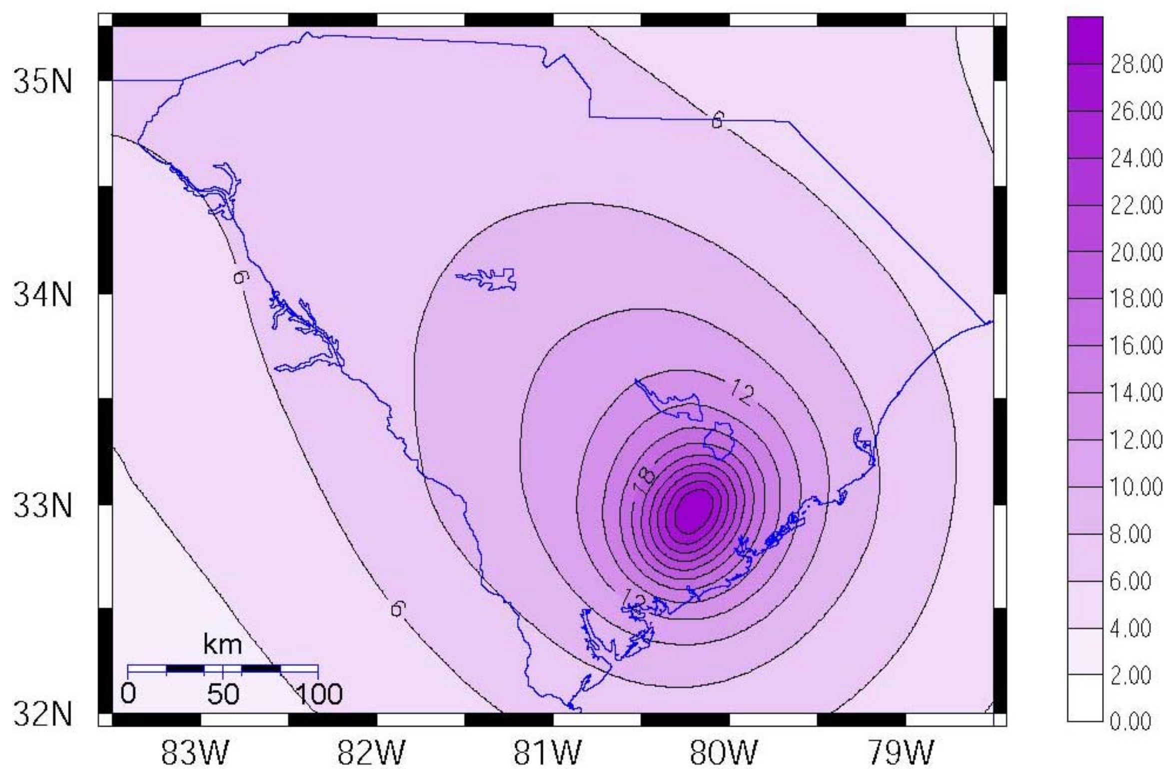
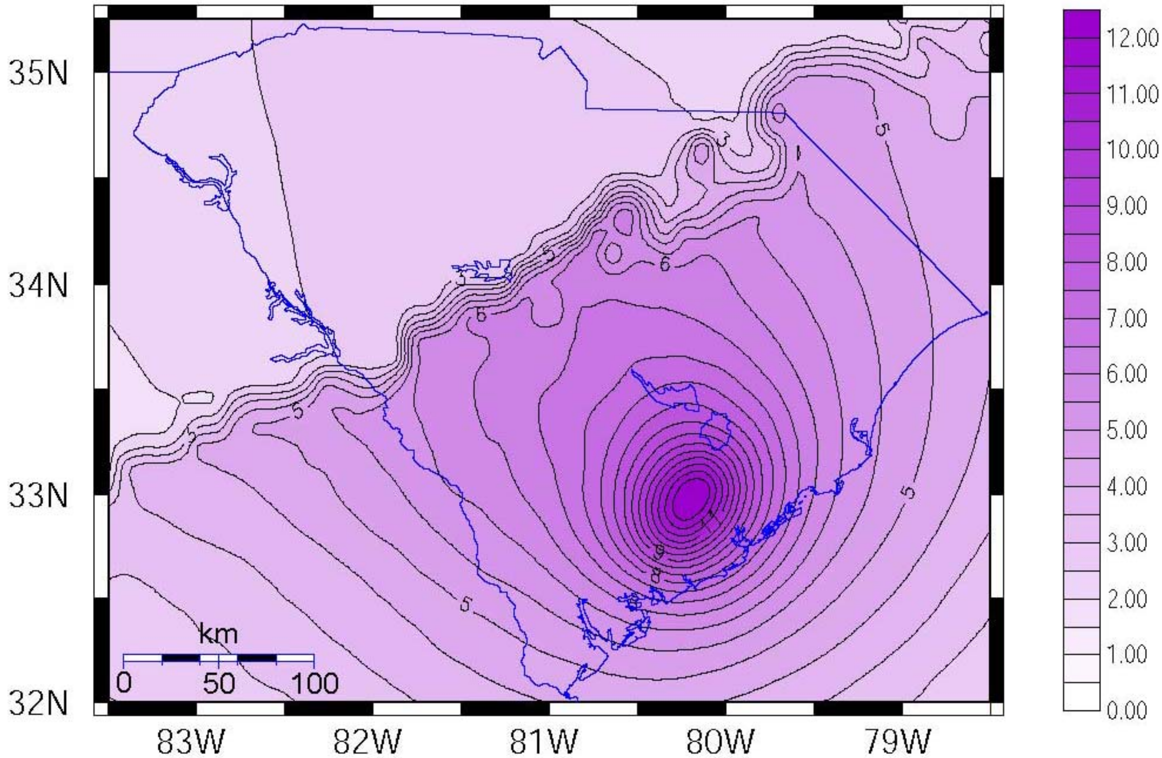


Figure 11-15, S_s Spectral Acceleration (%g) - 15% P_E in 75 Years (10% P_E-50 Yr) (Chapman and Talwani, 2002)

Geologically Realistic Site Condition



Hard-Rock Basement Outcrop Site Condition

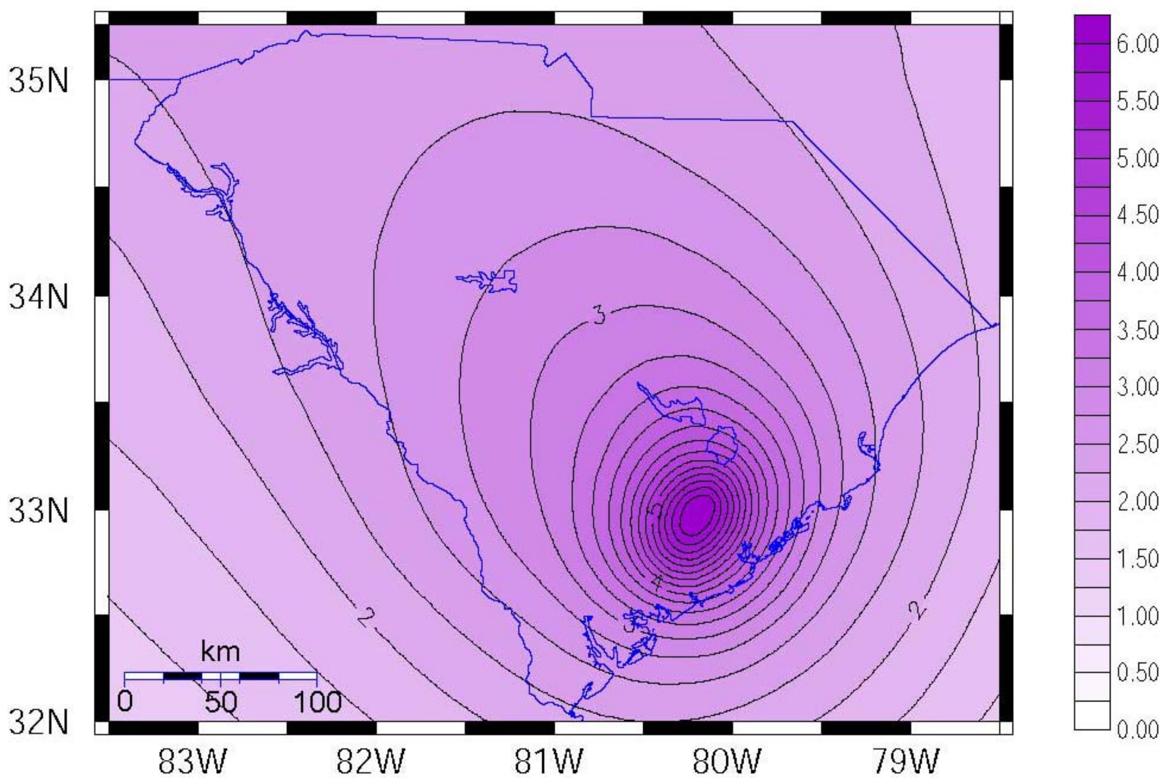
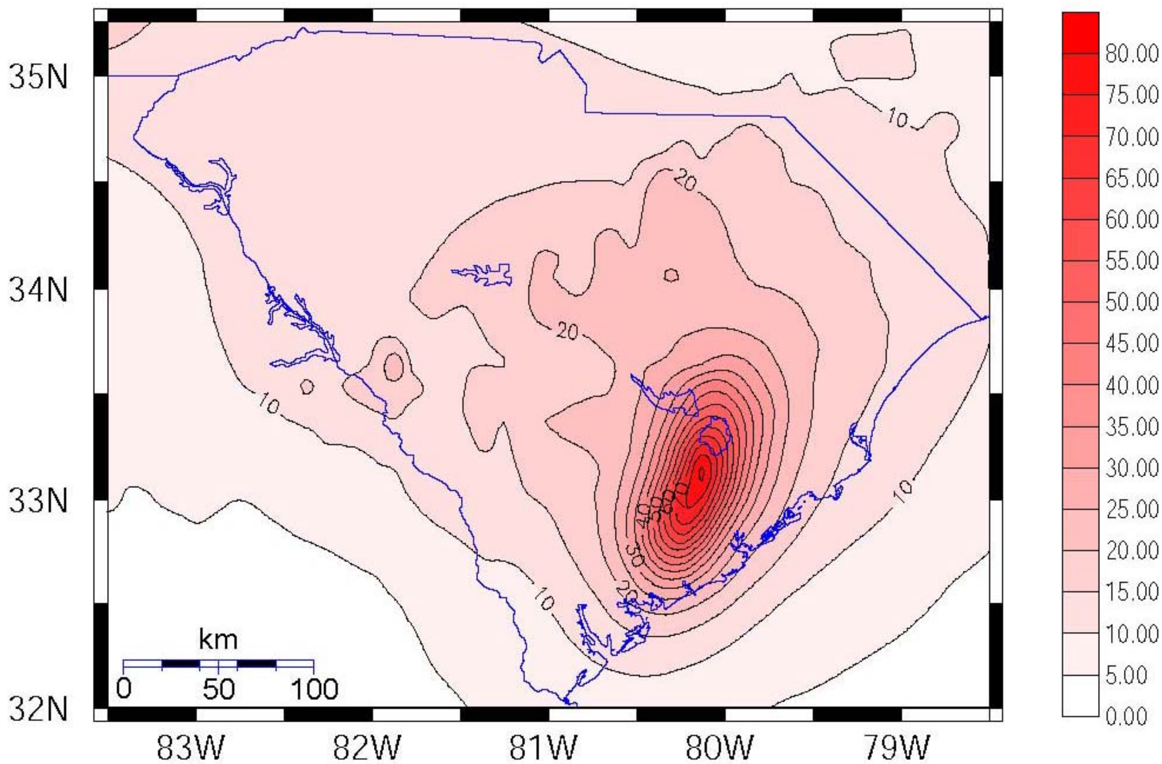


Figure 11-16, S_1 Spectral Acceleration (%g) - 15% P_E in 75 Years (10% P_E-50 Yr) (Chapman and Talwani, 2002)

Geologically Realistic Site Condition



Hard-Rock Basement Outcrop Site Condition

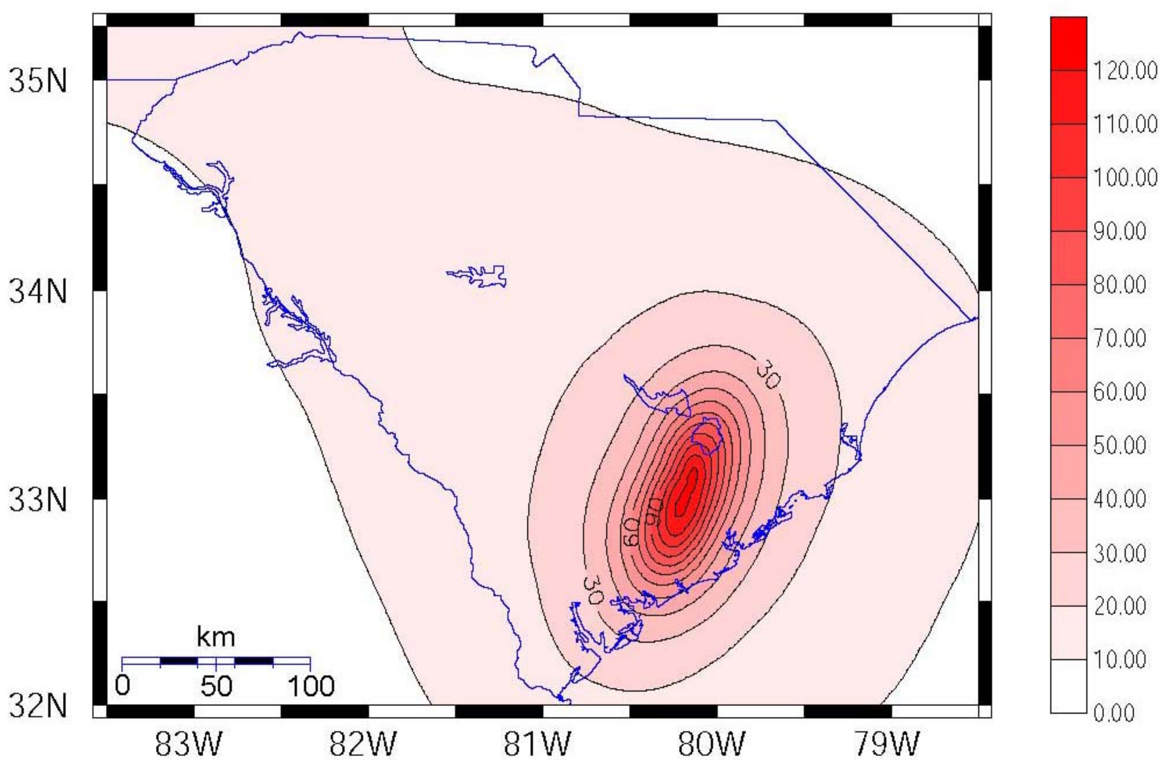
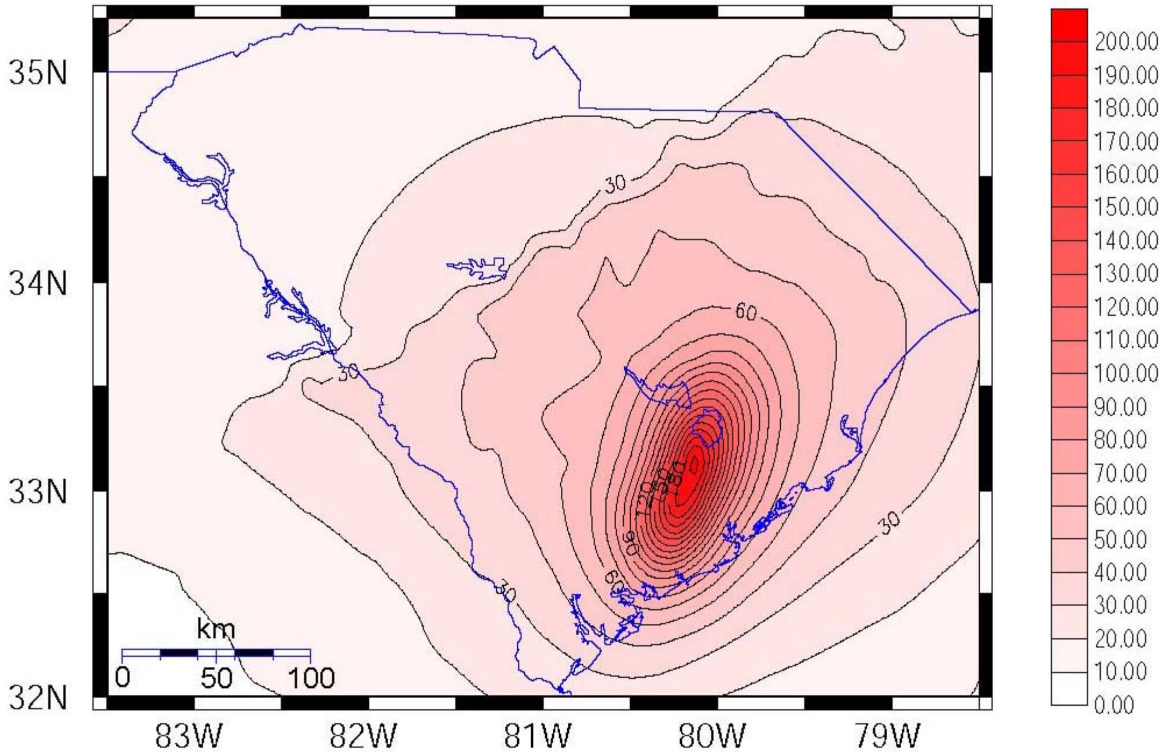


Figure 11-17, PGA (%g) - 3% P_E in 75 Years (2% P_E-50 Yr)
(Chapman and Talwani, 2002)

Geologically Realistic Site Condition



Hard-Rock Basement Outcrop Site Condition

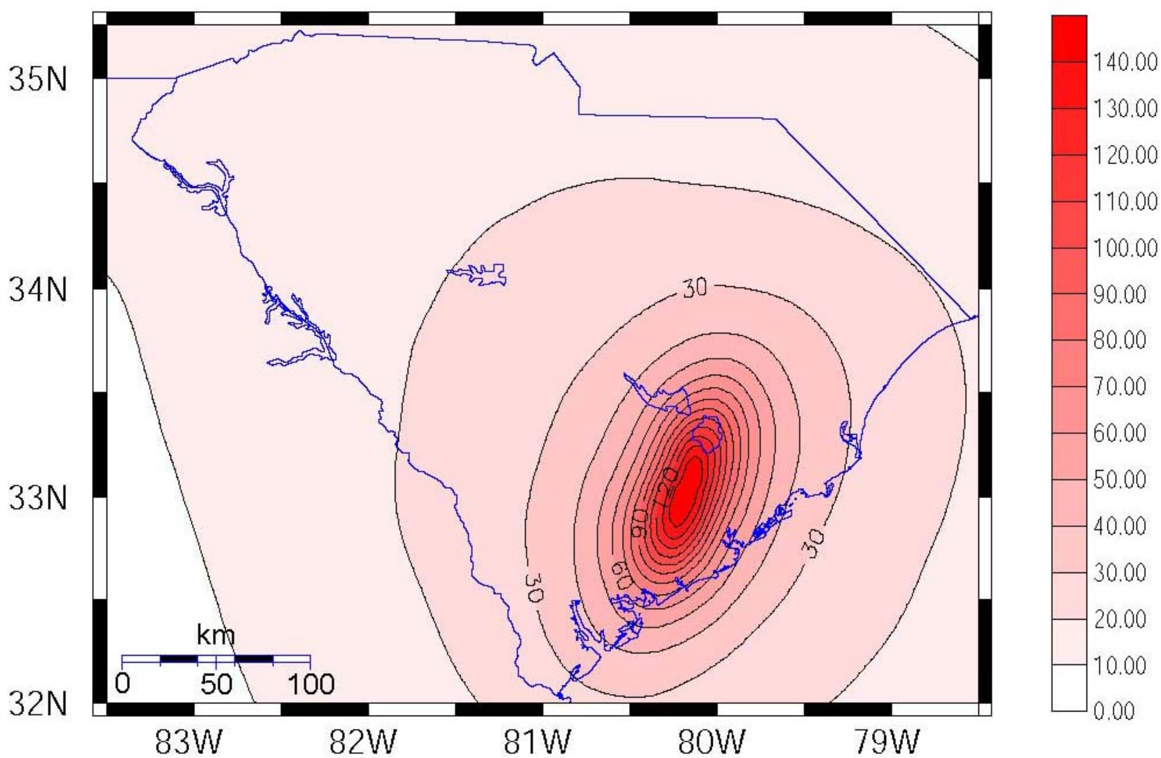
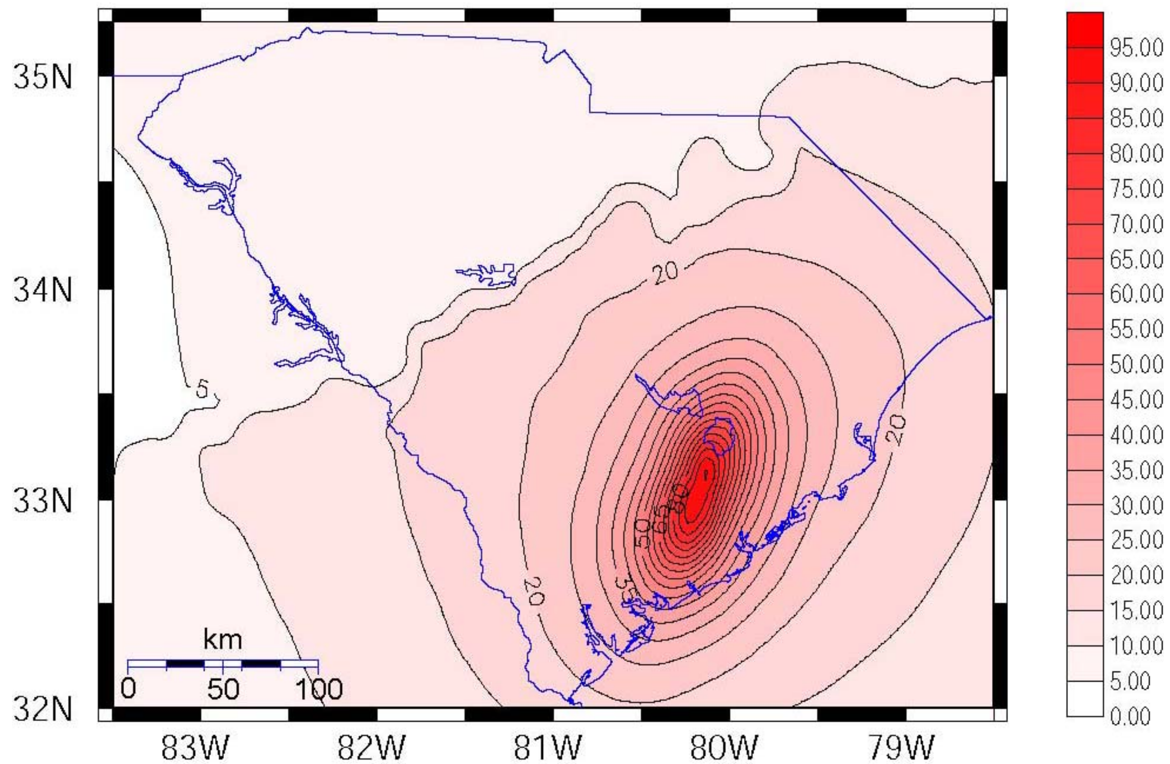


Figure 11-18, S_s Spectral Acceleration (%g) - 3% P_E in 75 Years (2% P_E-50 Yr) (Chapman and Talwani, 2002)

Geologically Realistic Site Condition



Hard-Rock Basement Outcrop Site Condition

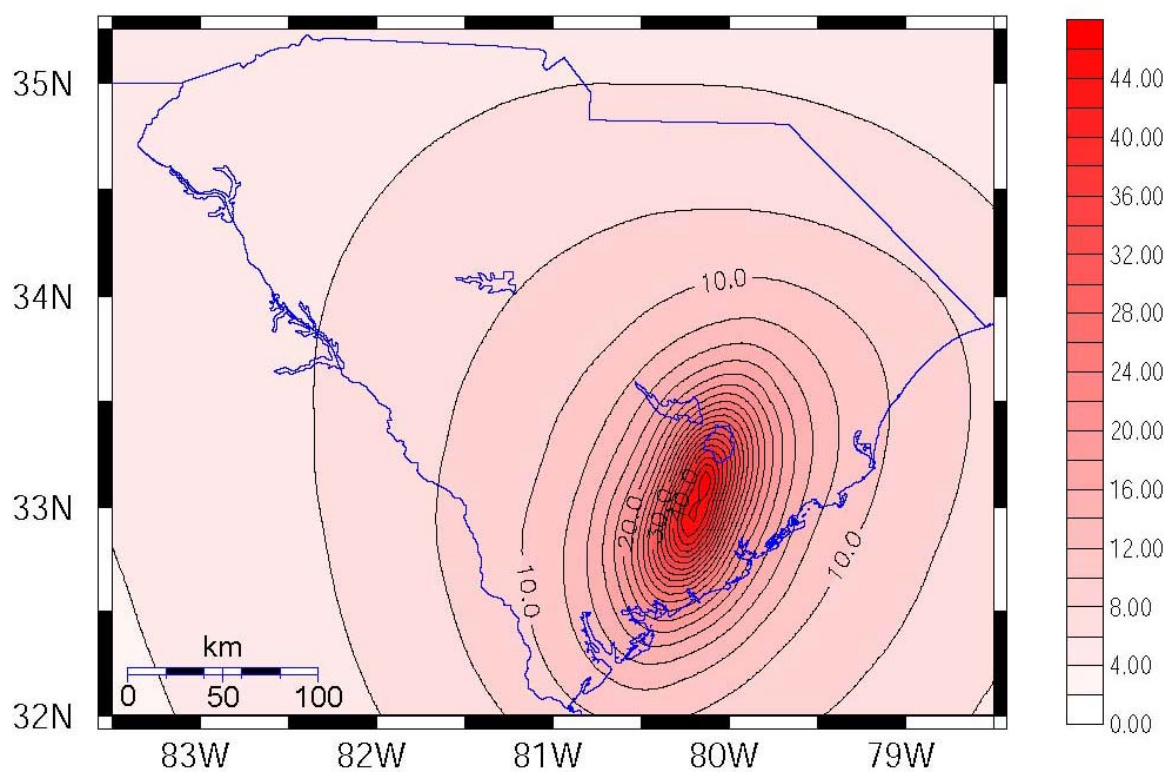


Figure 11-19, S_1 Spectral Acceleration (%g) - 3% P_E in 75 Years (2% P_E-50 Yr) (Chapman and Talwani, 2002)

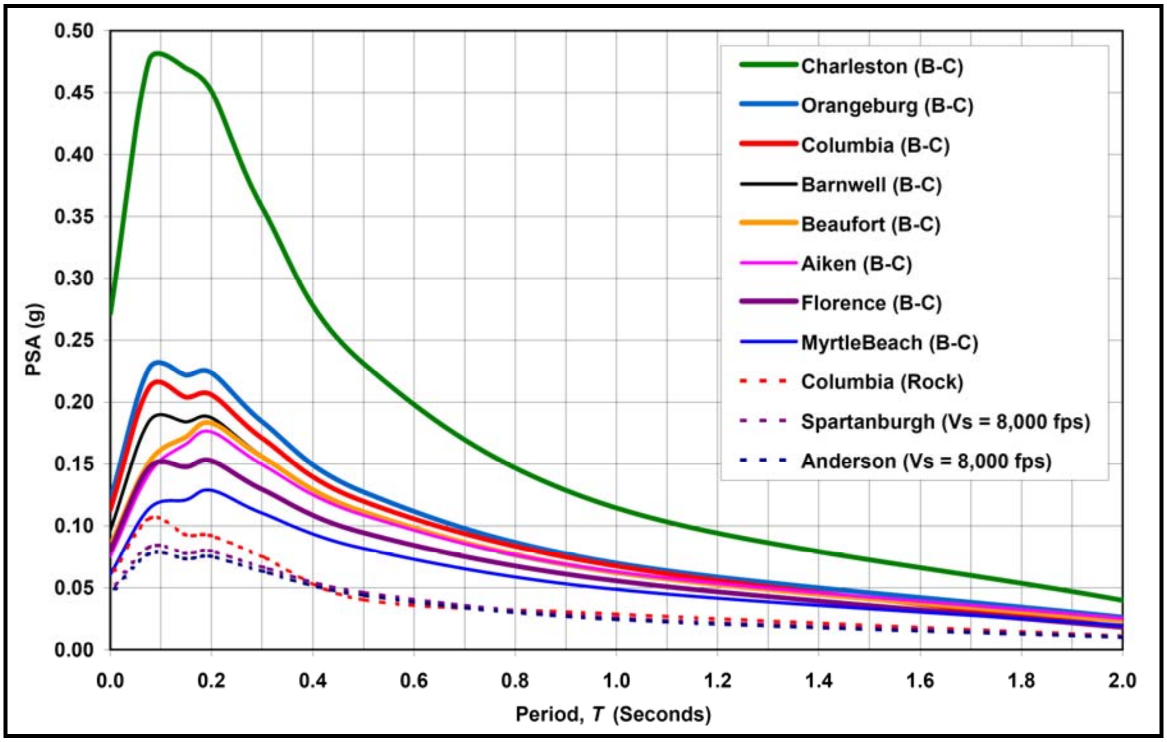


Figure 11-20, FEE PSA Curves for Selected South Carolina Cities

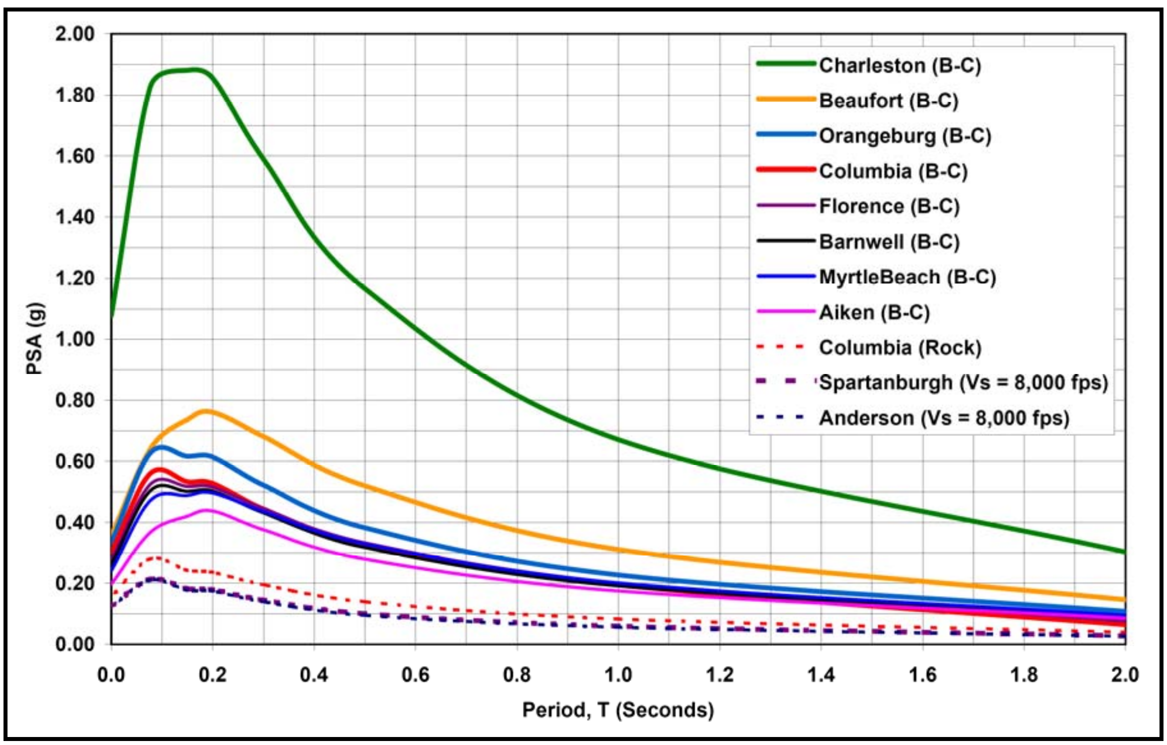


Figure 11-21, SEE PSA Curves for Selected South Carolina Cities

11.9.3 Earthquake Deaggregation Charts

The ground motion hazard from a probabilistic seismic hazard analysis can be deaggregated to determine the predominant earthquake moment magnitude (M_W) and distance (R) contributions from a hazard to guide in the selection of earthquake magnitude, site-to-source distance, and in development of appropriate time histories. The deagregation charts can be obtained by either of the following methods:

- SCDOT Scenario_PC (2006)
- USGS Interactive Earthquake Deaggregation 2002

The SCDOT Scenario_PC (2006) generates the interpolated results from the USGS Deaggregation 2002 data. A sample deaggregation output is provided in Figure 11-22 that was generated along with the SC Seismic Hazard results shown in Figure 11-13.

```
Interpolated results from USGS Deaggregation 2002
Freq. R(mean) km   mag(mean)   eps0(mean) R(modal) km  mag(modal)  eps0(modal)
PGA          58.6        6.31          .44        125.4        7.31         1.23
5 Hz         77.3        6.64          .68        125.1        7.30         1.05
1 Hz        113.1        7.06          .74        125.0        7.30          .81
```

Figure 11-22, Scenario_PC (2006) Deaggregation – Columbia, SC

Deaggregation of the seismic hazard can also be obtained from the USGS 2002 Interactive Deaggregation web site. The steps required to obtain USGS web site deaggregations are listed in Table 11-8. The project site Latitude and Longitude are obtained in the same manner as described in Section 11.9.2.

Table 11-8, USGS Interactive Deaggregation of Seismic Hazard

Step	Action
1	**Access** the USGS 2002 Interactive Deaggregations website to obtain the hazard deaggregation response for PGA and PSA frequencies. Website: http://eqint.cr.usgs.gov/deaggint/2002/index.php
2	**Complete the screen form (See Figure 11-23):** **Enter** "Site Name" **Enter** "Site Latitude and Longitude (*negative*) Coordinates" **Select** "Return period based on design earthquake": 10% PE 50 yrs = 15% PE 75 yrs (FEE) 2% PE 50 yrs = 3% PE 75 yrs (SEE) **Select** "SA Frequency": 5.0 Hz = 0.2 sec for Short-Period SA (S_S) 1.0 Hz = 1.0 sec for Long-Period SA (S_1) PGA **Select** Geographic Deaggregation – Optional (Fine Angle, Fine Distance) **Select** Stochastic Seismograms – Select None **Select** Generate Output
3	**Documents Generated:** Report - Hazard Matrix Data File (Figure 11-24) Deaggregation - Deaggregation Seismic Hazard Graph (Figure 11-25) Geographic Deaggregation – Optional (Figure 11-26)

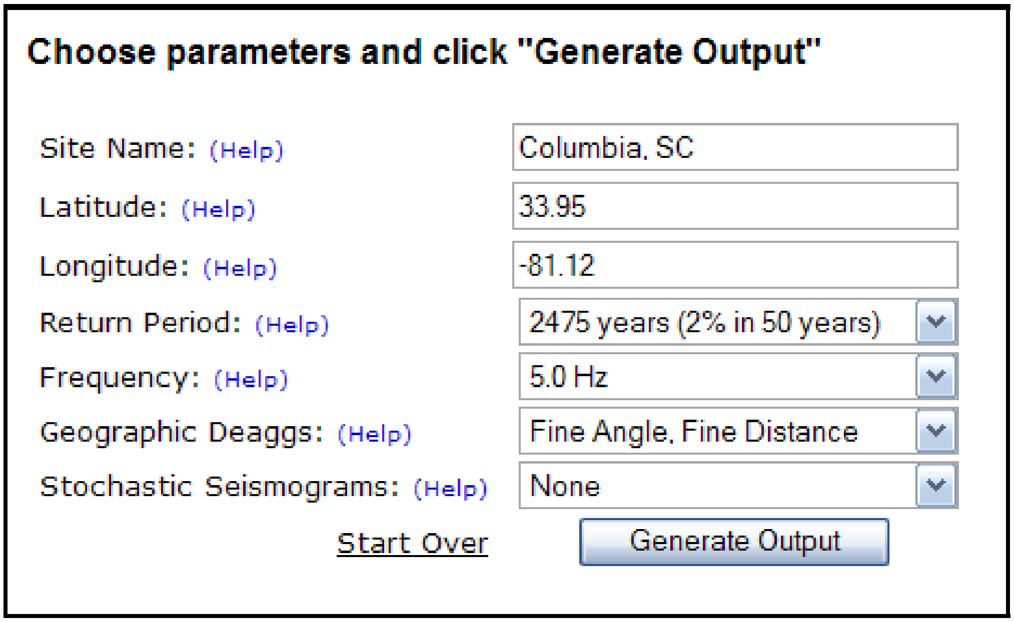


Figure 11-23, Interactive Deaggregation Input Screen (USGS 2002 Earthquake Deaggregations)

The Deaggregated Seismic Hazard Graph for the data entered in Figure 11-23 is shown in Figure 11-24. An abridged sample of the Hazard Matrix Data File is shown in Figure 11-25. The geographic deaggregation is shown in Figure 11-26.

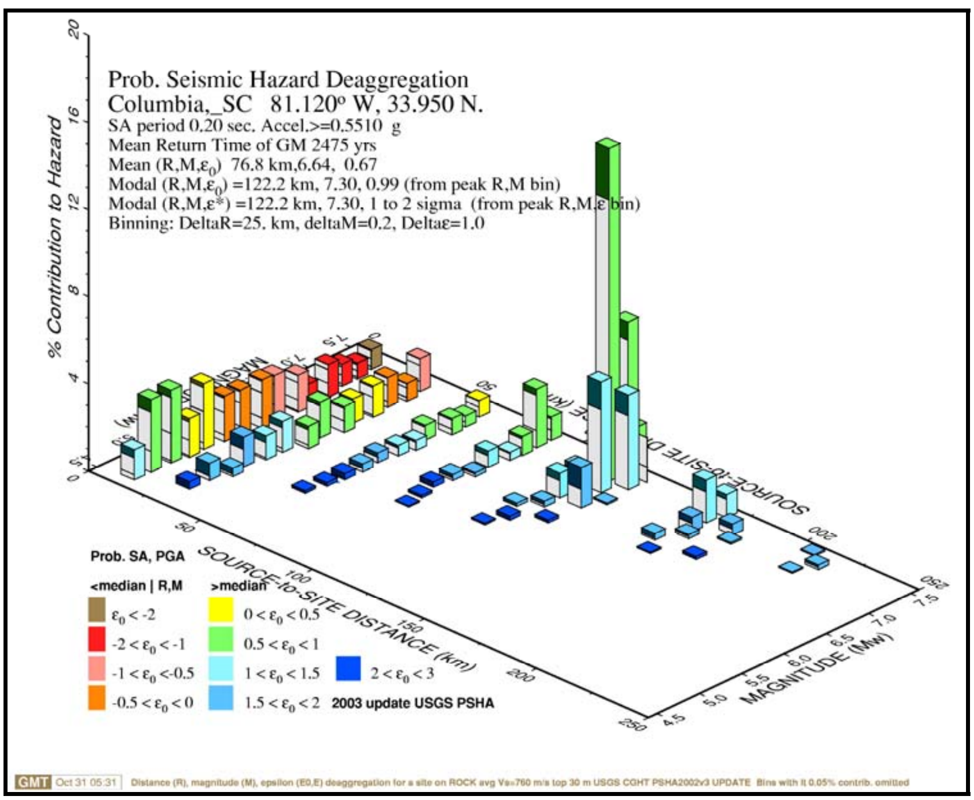


Figure 11-24, Columbia, SC Deaggregation SEE (3% P_E in 75 Years, 1Hz PSA) (USGS 2002 Earthquake Deaggregations)

```
*******************Central or Eastern U.S. Site ******************************
PSHA Deaggregation. %contributions. ROCK site: Columbia, _SC  long:  81.120 d W.,
                              lat: 33.950 N.
     USGS 2002-2003 update files and programs. Analysis on DaMoYr:31/10/2006
                Return period: 2475 yrs. 0.20 s. PSA =0.5510   g.
          #Pr[at least one eq with median motion>=PSA in 50 yrs]=0.00397
  DIST(km) MAG(Mw) ALL_EPS EPSILON>2  1<EPS<2 0<EPS<1 -1<EPS<0 -2<EPS<-1 EPS<-2
   181.3    7.18    0.080    0.042    0.039    0.000    0.000    0.000    0.000
   209.8    7.15    0.056    0.043    0.013    0.000    0.000    0.000    0.000
    12.8    7.39    0.915    0.001    0.061    0.354    0.361    0.131    0.007
    34.7    7.39    1.495    0.033    0.283    0.712    0.443    0.023    0.000
    60.8    7.39    0.753    0.042    0.268    0.434    0.009    0.000    0.000
    89.2    7.32    2.696    0.287    1.621    0.788    0.000    0.000    0.000
   122.2    7.30   15.286    2.376   11.030    1.879    0.000    0.000    0.000
   130.9    7.30    4.347    0.958    3.389    0.000    0.000    0.000    0.000

                  . . .  Additional output data omitted  . . .

   Summary statistics for above 0.2s PSA  deaggregation, R=distance, e=epsilon:
    Mean src-site R=   76.8 km; M= 6.64; eps0=   0.67. Mean calculated for all
                                  sources.
      Modal src-site R=  122.2 km; M= 7.30; eps0=   0.99 from peak (R,M) bin
               Gridded source distance metrics: Rseis Rrup and Rjb
    MODE R*= 122.2km; M*= 7.30; EPS.INTERVAL: 1 to 2 sigma  % CONTRIB.= 11.030

Principal sources (faults, subduction, random seismicity having >10% contribution)
Source Category:                            % contr.   R(km)    M   epsilon0 (mean
                                  values)
          Charleston Broad Zone             19.64   126.9   7.29    1.09
          Charleston Narrow Zone            24.38   125.0   7.29    1.06
          CEUS gridded seism.               55.98    38.2   6.12    0.36
               Individual fault hazard details if contrib.>1%:
*******************Central or Eastern U.S. Site ******************************
```

Figure 11-25, Abridged Seismic Hazard Matrix Data – Columbia, SC (USGS 2002 Earthquake Deaggregations)

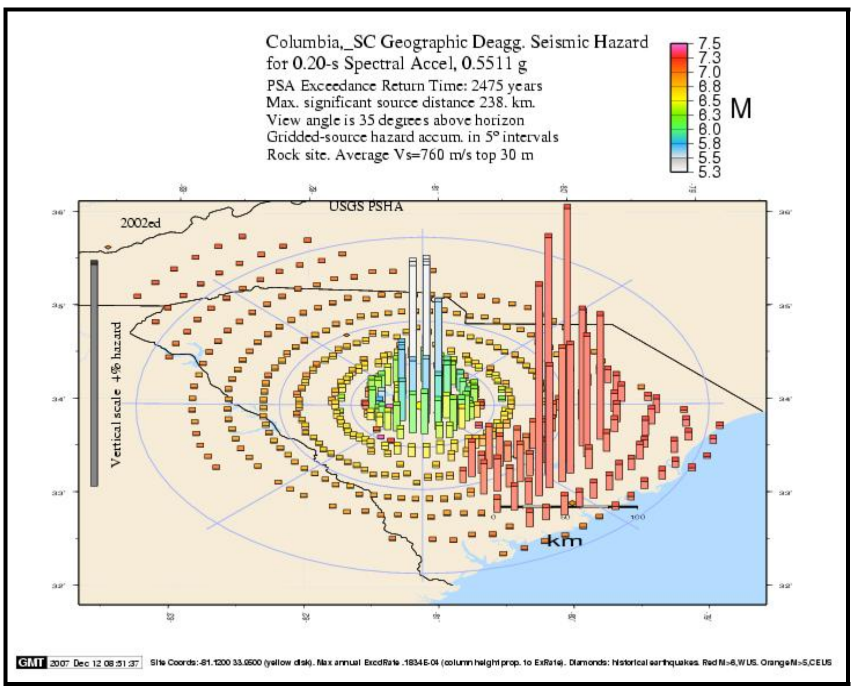


Figure 11-26, Geographic Deaggregation (Optional) (USGS 2002 Earthquake Deaggregations)

The earthquake deaggregations typically provide the source category, percent contribution of the source to the hazard, site-to-source distance (R), mean and modal moment magnitude (M), and epsilon (ε). Mean moment magnitudes (M_W) that cover several sources are typically not used since it is an overall average of earthquakes and does not appropriately reflect magnitude of the hazard contribution within a specific seismic source. Mean moment magnitude (M_W) values listed with respect to principal sources can be used. The epsilon (ε) parameter is as important to understanding a ground motion as is the moment magnitude (M_W) and the distance (R) values for the various sources. The epsilon (ε) parameter is a measure of how close the ground motion is to the mean value in terms of standard deviation (σ). The epsilon ε_o parameter is provided for ground motions having a fixed probability of exceedance (P_E). If a structure is designed for an earthquake with magnitude M_W that occurs a distance R from your site and the $\varepsilon_o = 0.0$, then the structure was designed to resist a median motion from this source. If the $\varepsilon_o = 1.0$, then the structure was designed to resist a motion one standard deviation ($+1\sigma$) greater than the median motion. Consequently, if the $\varepsilon_o = -1.0$, then the structure was designed to resist a motion one standard deviation (-1σ) less than the median motion. Predominance of a modal earthquake source is generally indicated if the epsilon (ε) is within ±1 standard deviation ($\pm1\sigma$).

For additional information on the interpretation of the deaggregation data, the designer should refer to the information provided at the USGS 2002 Interactive Deaggregation web site. The method chosen to deaggregate the South Carolina seismic hazard should be based on the intended use of the deagregation data. For example, the Scenario_PC (2006) deaggregations are sufficient to select the earthquake moment magnitude (M_W) and site-to-source distance (R) for liquefaction potential analyses and lateral spreading analyses. When performing a site-specific response analysis, the 2002 USGS Interactive Deaggregations are more detailed and informative and should therefore be used to obtain the earthquake moment magnitude (M_W) and site-to-source distance (R) used to generate the ground motion time histories. Further guidance in the method of obtaining and interpreting the earthquake deagregation data is provided in Chapter 12 and in Section 11.9.4, Ground Motions.

11.9.4 Ground Motions

Ground motions are required when a site-specific design response analysis and/or a site-specific seismic deformation analysis is being performed. These ground motions are developed from a site-specific ground shaking characterization that generates a time history. Time histories can be either recorded with seismographs or synthetically developed. Since the Charleston 1886 earthquake occurred, an earthquake with a magnitude of +7 has not occurred in South Carolina and therefore no seismograph records are available for strong motion earthquakes in South Carolina. SCDOT has chosen to generate synthetic project-specific time histories based on the SC Seismic Hazard study recently completed for SCDOT. The ground motion predictions used in the study are based on the results of recent work involving both empirical and theoretical modeling of Eastern North American strong ground motion. Even though the strong motion database for the East is small compared to the West, the available data indicate that high frequency ground motions attenuate more slowly in the East than in the West.

Synthetic ground motions can be developed using an attenuation model. The ground motions on hard rock produced from the SCDOT Seismic Hazard program Scenario_PC (2006) uses a stochastic model that uses weighted (w) attenuation relationships from 1987 Toro et al. (w=0.143), 1996 Frankel et al. (w=0.143), 1995 Atkinson and Boore (w=0.143), 2001 Somerville et al. (w=0.286), and 2002 Campbell (w=0.286) for the characteristic earthquake events with magnitudes ranging from 7.0 to 7.5. For the non-characteristic earthquake events with magnitudes less than 7.0, the following weighted prediction equations were used, 1977 Toro et al. (w=0.286), 1996 Frankel et al. (w=0.286), 1995 Atkinson and Boore (w=0.286), and 2002 Campbell (w=0.143).

The location of the ground motion is dependent on the Site Condition (Geologically Realistic or Hard-Rock Basement Outcrop) selected in Section 11.9.2. Table 11-9 provides the location where the ground motions are computed based on the Site Condition selected and Geologic Unit.

Table 11-9, Location of Ground Motion

Site Condition	**Geologic Unit** [1]	**Location of Ground Motion**
Geologically Realistic	Piedmont / Blue Ridge (Zone I)	Generated at a hypothetical outcrop of weathered rock (*Vs* = 8,200 ft/sec) equivalent to Site Class A (*Vs* > 5,000 ft/sec)
	Coastal Plain (Zone II)	Generated at a hypothetical outcrop of firm Coastal Plain sediment (V_s = 2,500 ft/sec) equivalent to the B – C Boundary
Hard-Rock Basement Outcrop	Piedmont / Blue Ridge (Zone I)	Generated at a hard-rock basement outcrop (V_s = 11,500 ft/sec) equivalent to Site Class A (*Vs* > 5,000 ft/sec)
	Coastal Plain (Zone II)	

[1] For geologic unit locations see Figure 11-1 and 11-3 and for Site Condition locations see Figure 11-12.

The time histories are generated based on project specific information using Scenario_PC (2006). The consultant must submit a SC Ground Motion request form to the GDS to obtain project specific time histories. The SC Ground Motion request form requires that the designer provide the following information.

- SCDOT Project Name and Project Number
- Latitude and Longitude of Project Site
- Probability of Exceedance for Earthquake Design Event being analyzed
- Site Condition: Geologically Realistic or Hard-Rock Basement Outcrop
- Sediment Thickness: If other than default thickness generated from Scenario_PC
- Scaling Method: Scaling of the time series to match Uniform Hazard, PGA, or PSA
- Moment magnitude (M_w) and epicenter site-to-source distance (R)

The sediment thickness may be changed from the default value if a site-specific geotechnical investigation indicates that the sediment thickness is different from the value generated in the Scenario_PC (2006) output.

The method of scaling the time series to match a Uniform Hazard Spectrum (UHS), PGA, or a PSA frequency is primarily dependent on the results of the earthquake deaggregation described in Section 11.9.3. When the uniform hazard is dominated by a well-defined modal earthquake event, the method of scaling the time series should be to match the UHS.

The Coastal Plain will typically be dominated by the 1886 Charleston earthquake seismic source as can be seen in Figure 11-27, Florence, SC Deaggregation FEE (USGS 2002). The earthquake deagregation chart in Figure 11-27 indicates that the FEE 1Hz PSA design earthquake would have a modal source site with a Moment Magnitude (M_w) of 7.30 with an epicenter site-to-source distance (R) of 87.1 km and an epsilon (ε_o) parameter of –0.85. The SEE 1Hz PSA design earthquake for Florence, SC in Figure 11-28 indicates a modal source site with a Moment Magnitude (M_w) of 7.30 with an epicenter site-to-source distance (R) of 36.2 km and an epsilon (ε_o) parameter of 0.01. As a result of the predominance of the 1886 Charleston Earthquake seismic source in the Coastal Plain geological unit, the time series generated for most project sites in the Coastal Plain should be scaled to match the UHS. By contrast, the FEE and SEE Anderson, SC Deaggregation (USGS 2002), shown in Figures 11-29 and 11-30, respectively, show several earthquakes that may be of significance to evaluating seismic hazards at the project site. Table 11-10 provides a summary of FEE 1Hz potential seismic sources that may be used for scaling the time series. All FEE 1Hz seismic sources appear to be equally predominant epsilons (ε) within ± 1 standard deviation ($\pm 1\sigma$).

Table 11-10, FEE 1Hz PSA Deaggregation Summary - Anderson, SC

Seismic Source Site	**% Contribution**	**R Distance, km**	**M_W**	**ε_O**
1886 Charleston Seismic Source	28.7	235	7.26	0.19
New Madrid (NMSZ)	12.5	640	7.72	0.82
CEUS	58.8	184	6.52	0.34
Total Contribution % =	100.0	---	---	---
Modal Source Site	---	282	7.30	0.09

Table 11-11 provides a summary of SEE 1Hz potential seismic sources that may be used for scaling the time series. The SEE 1Hz CEUS seismic source site appears to be predominate with an epsilons (ε) of 0.65.

Table 11-11, SEE 1Hz PSA Deaggregation Summary - Anderson, SC

Seismic Source Site	**% Contribution**	**R Distance, km**	**M_W**	**ε_O**
1886 Charleston Seismic Source	23.70	238	7.30	1.21
New Madrid (NMSZ)	6.9	644	7.77	1.77
CEUS	64.4	125	6.72	0.65
Total Contribution % =	100.0	---	---	---
Modal Source Site	---	282	7.30	1.17

Similar deaggregation data can be obtained for PGA or other PSA frequencies. Based on the type of structure being designed or seismic hazard being analyzed, there may be a need to develop more than one earthquake seismic source time series and have it matched to the PGA or a PSA frequency.

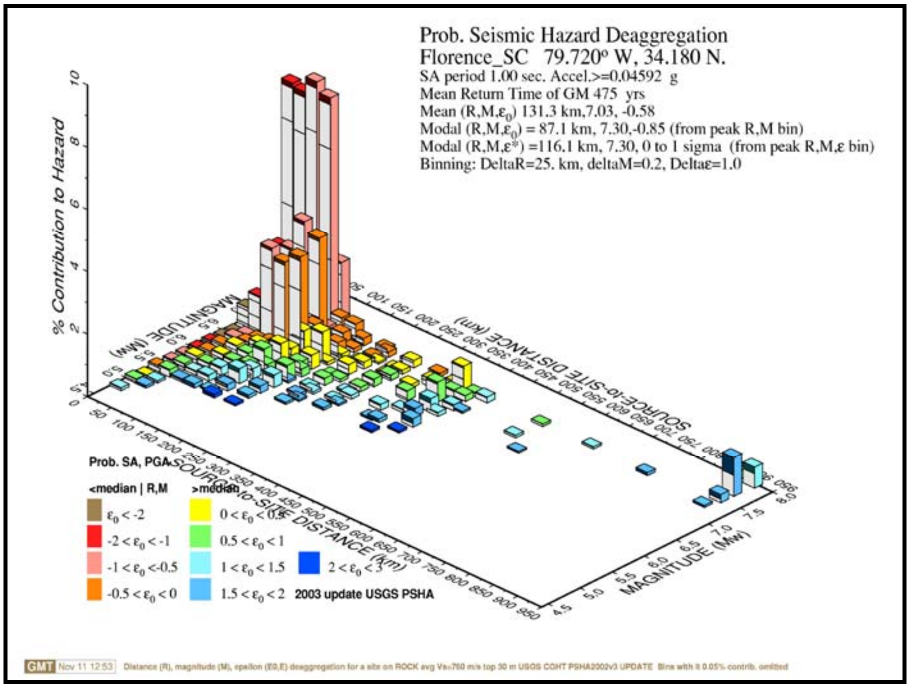


Figure 11-27, Florence, SC Deaggregation FEE (15% P_E in 75 Years, 1Hz PSA) (USGS 2002 Earthquake Deaggregations)

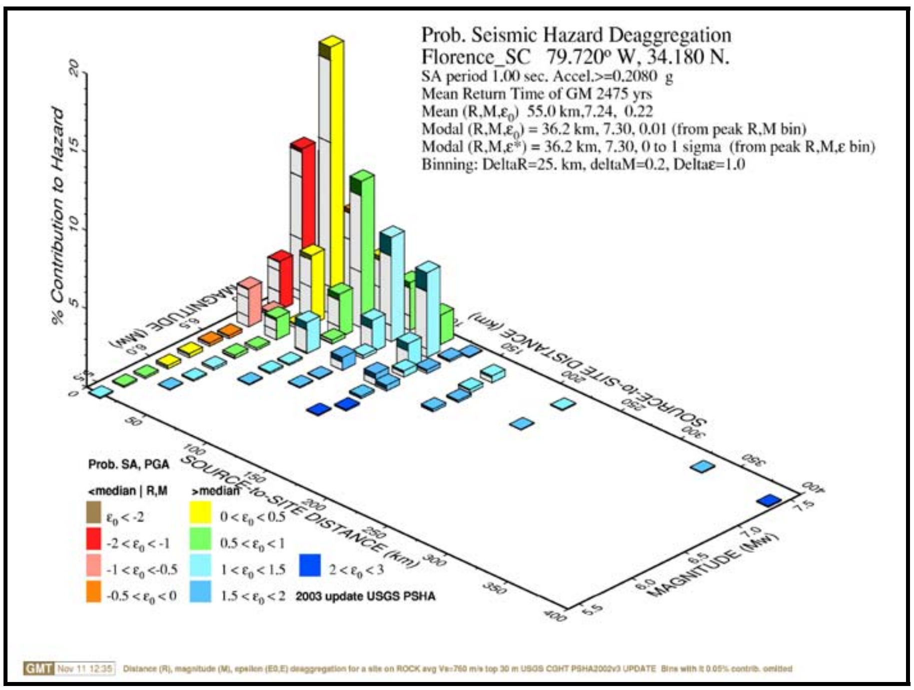


Figure 11-28, Florence, SC Deaggregation SEE (3% P_E in 75 Years, 1Hz PSA) (USGS 2002 Earthquake Deaggregations)

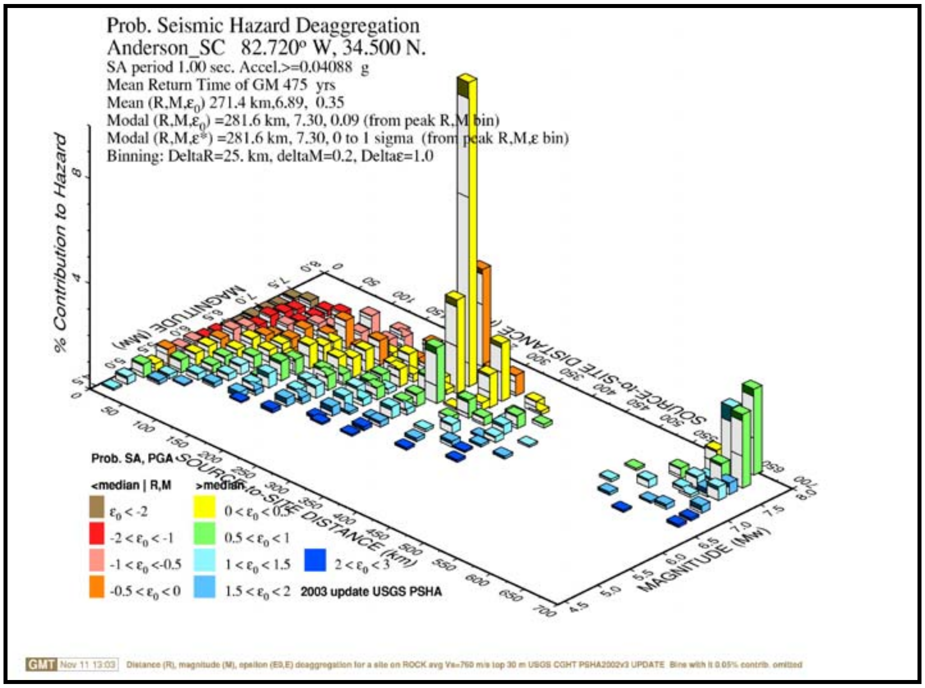


Figure 11-29, Anderson, SC Deaggregation FEE (15% P_E in 75 Years, 1Hz PSA) (USGS 2002 Earthquake Deaggregations)

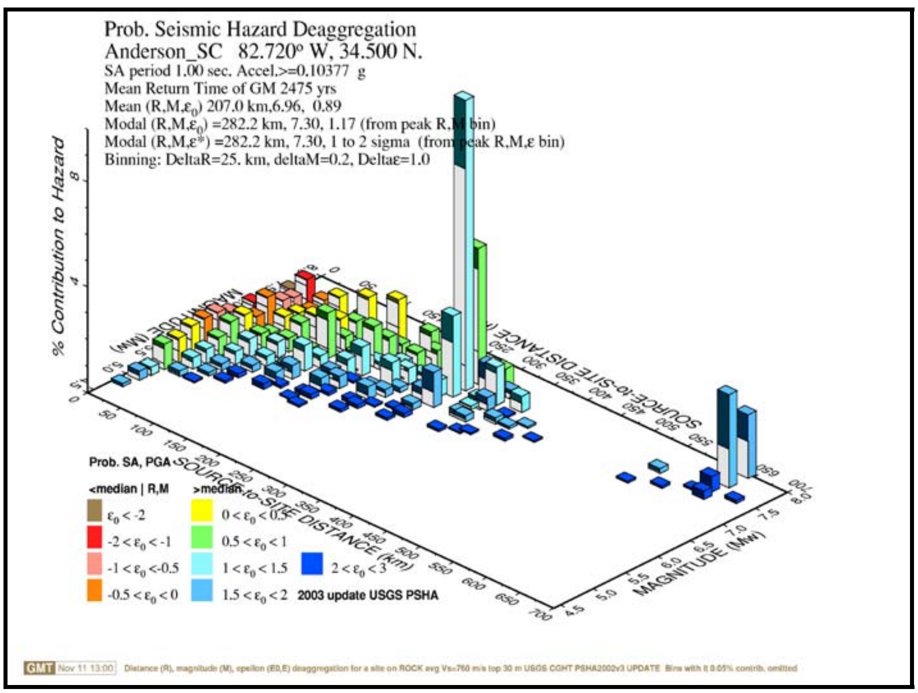


Figure 11-30, Anderson, SC Deaggregation SEE (3% P_E in 75 Years, 1Hz PSA) (USGS 2002 Earthquake Deaggregations)

11.10 REFERENCES

The geotechnical information contained in this Manual must be used in conjunction with the SCDOT *Seismic Design Specifications for Highway Bridges*, SCDOT *Bridge Design Manual*, and AASHTO LRFD Bridge Design Specifications. The Geotechnical Design Manual will take precedence over all references with respect to geotechnical engineering design.

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