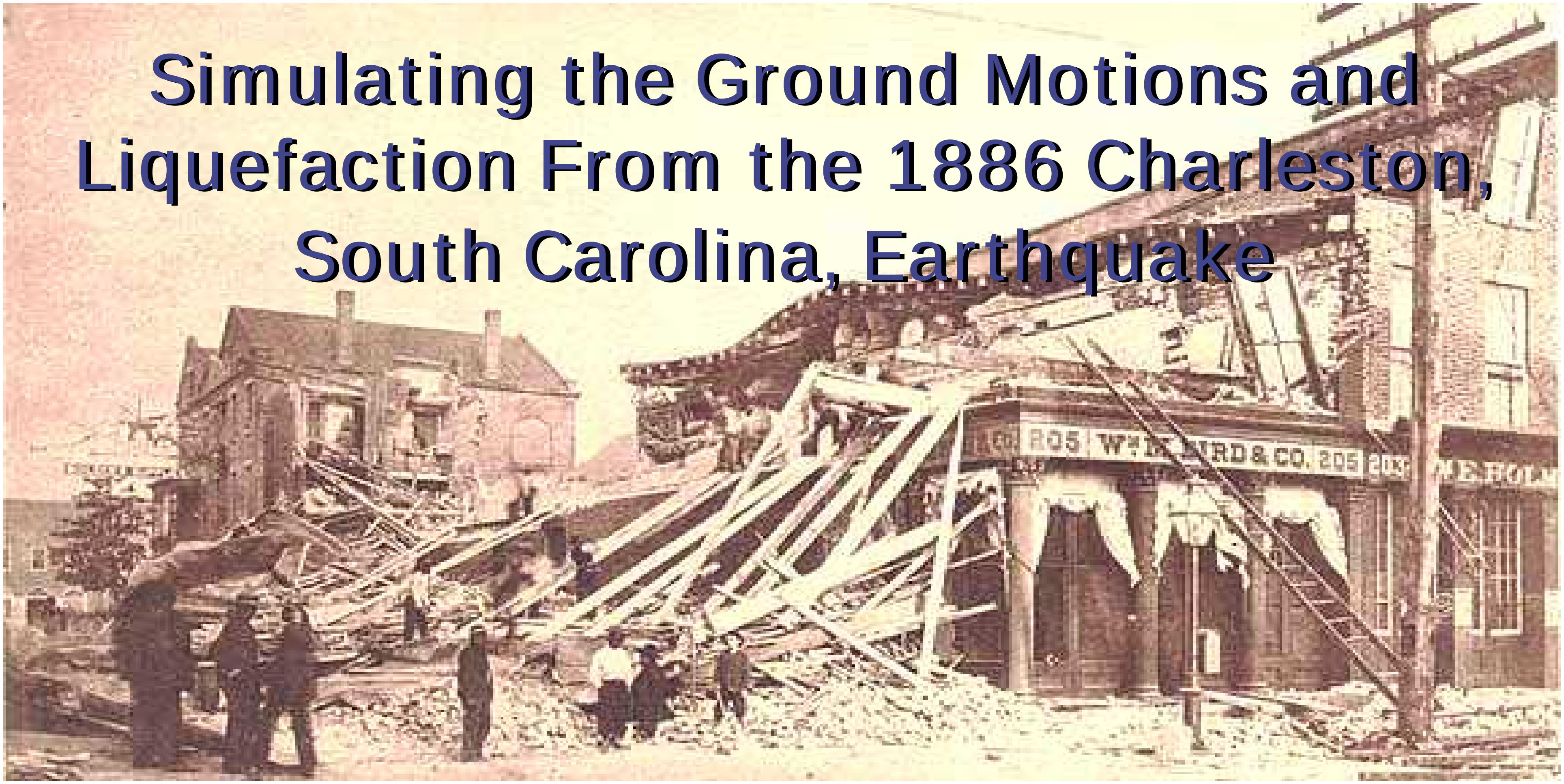
Simulating the Ground Motions and Liquefaction From the 1886 Charleston, South Carolina, Earthquake



IVAN WONG, URS Corporation, Oakland, CA

WALTER SILVA, Pacific Engineering & Analysis, El Cerrito, CA

TIM SIEGEL, S&ME, Inc., Knoxville, TN

NICK GREGOR, Pacific Engineering & Analysis, El Cerrito, CA

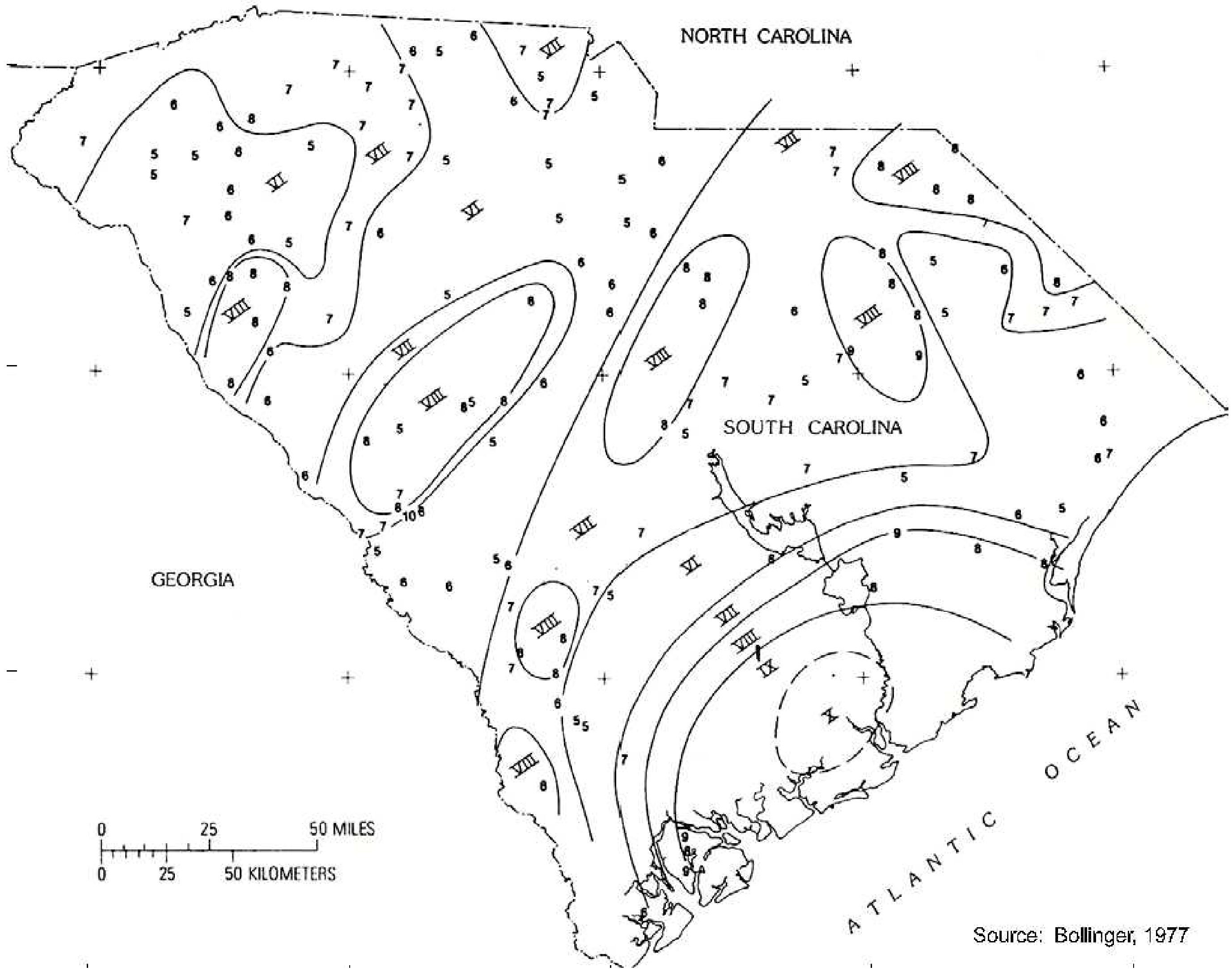
RICHARD LEE, Los Alamos National Laboratory, Los Alamos, NM

USGS National Hazard Maps – Central and Eastern U.S. – 8 May 2006

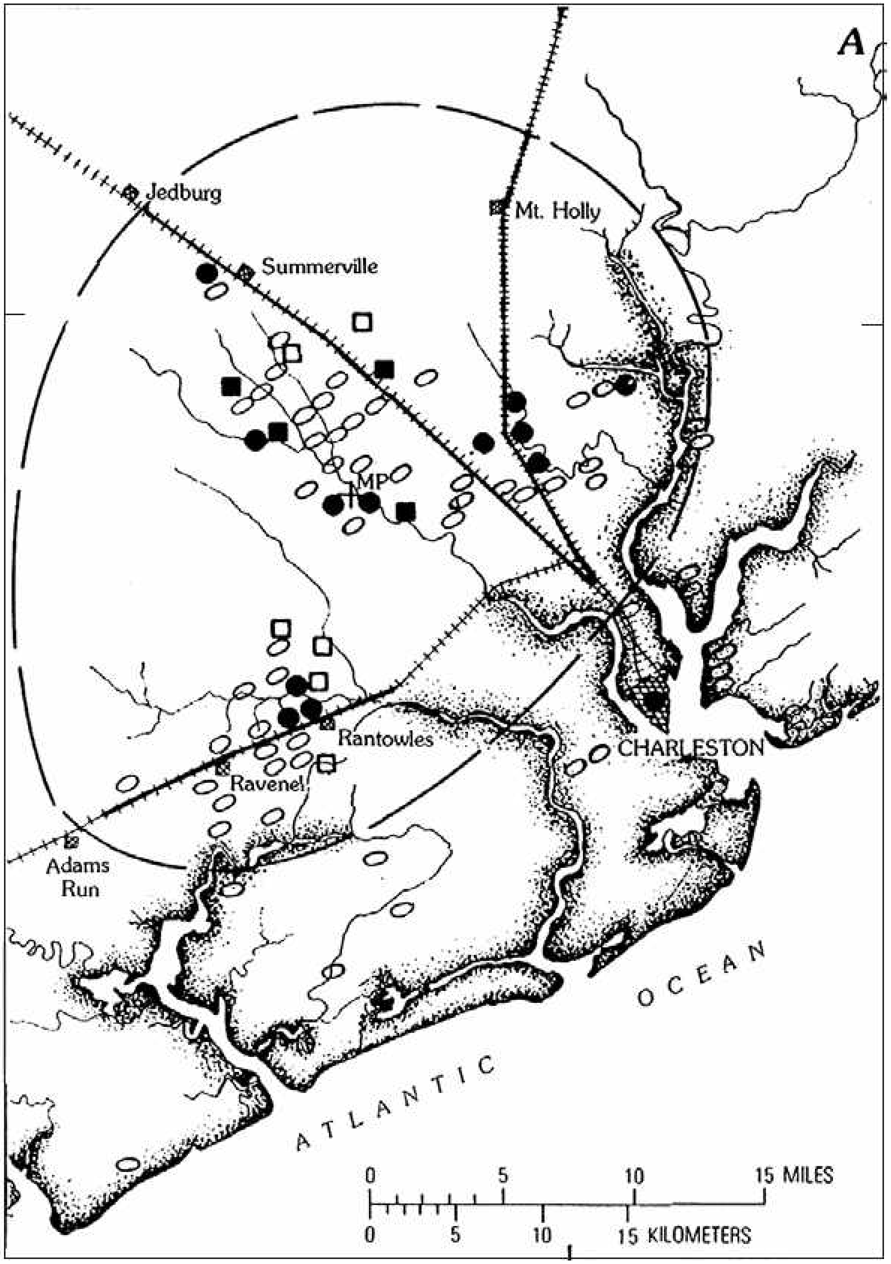
Purpose

As part of a comprehensive HAZUS evaluation of South Carolina, surficial ground motions and probability of liquefaction were estimated for a M 7.3 "1886 Charleston-like" earthquake using finite-fault and point-source stochastic numerical modeling and site response and liquefaction analyses.

Statewide Isoseismal Map of the 1886 Charleston Earthquake



Map of MM X Effects Near Charleston in 1886



Source: Bollinger, 1977

1886 Magnitudes

- Range of magnitudes from m_{bLg} 6.7 to M_W 7.5 to M_S 7.7
- We adopted M_W 7.3 from the USGS National Hazard Maps

Charleston Source

- We modeled the source as a NNE-trending, predominantly right-lateral, strike-slip fault that coincided with the location, strike, and dip of the Woodstock fault.
- The center of the fault was placed at the approximate center of the 1886 meizoseismal area as defined by the Modified Mercalli (MM) X intensity contour.
- To accommodate the uncertainty which exists in the appropriate rupture area for a given magnitude in the CEUS (Johnston, 1996), two rupture models were used.

Charleston Source (cont.)

- The models were taken to express the range in median static stress drops for large earthquakes.

- The first rupture area is based on the Wells and Coppersmith (1994) empirical relation principally from western U.S. (WUS) earthquakes which predict an area of about 2,000 km^2 for M 7.3.

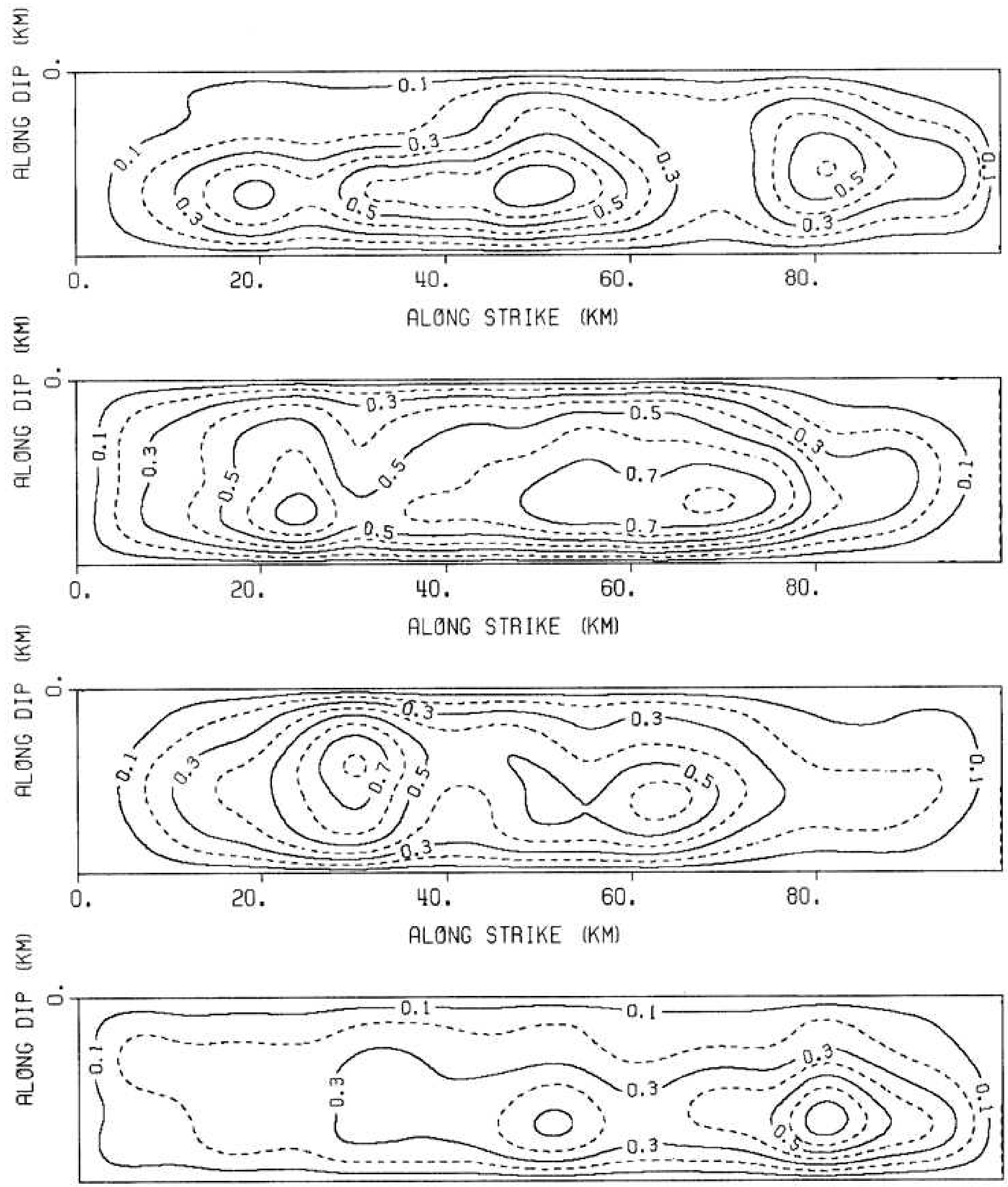
- To determine an appropriate rupture length, the rupture width was set at 20 km, based on the seismogenic crustal width inferred from contemporary seismicity.

Charleston Source (cont.)

- The resulting rupture length is 100 km. This rupture scenario reflects the assumption of WUS rupture areas for CEUS earthquakes and a constant static stress drop of 27 bars.

- For the other model, which assumes static stress drops are higher in the CEUS than the WUS, one of the preferred rupture models of Johnston (1996) is used. For M 7.3, the rupture length is 50 km and the width is 16 km, resulting in a static stress drop of 107 bars.

Example Suite of Four (Total of 30) Random Slip Models for the M 7.3 Charleston Earthquake Scenario



Attenuation Relationships

- Finite fault modeling was performed for the two 1886 rupture models: low and high stress drop.

- To accommodate epistemic uncertainty in CEUS source processes, three different implementations of the point-source model were used:

  – Single-corner frequency model with a constant stress drop

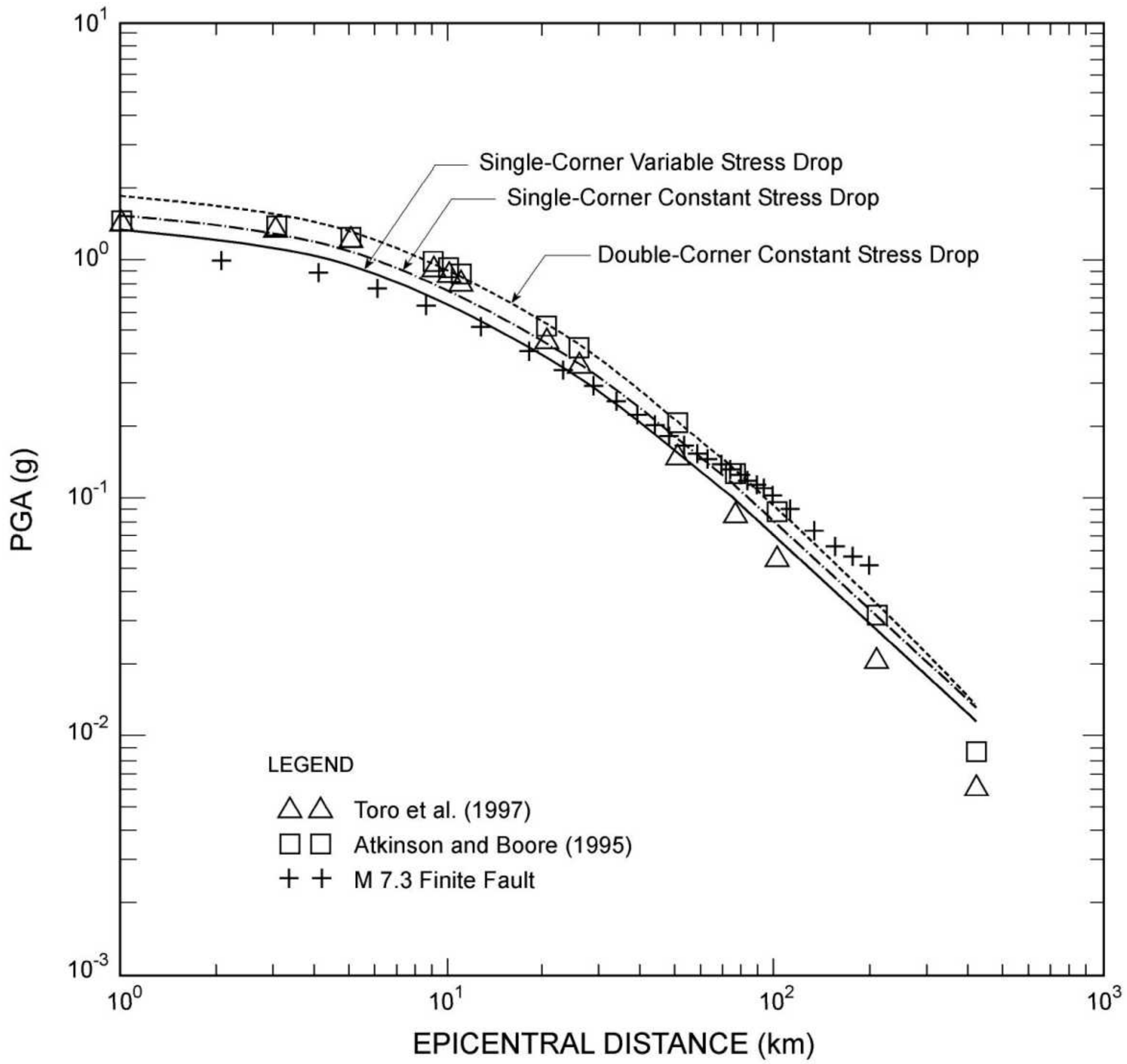
  – Single-corner frequency with a magnitude-dependent stress drop (Silva et al., 1997)

  – Double-corner frequency model of Atkinson and Boore (1995).

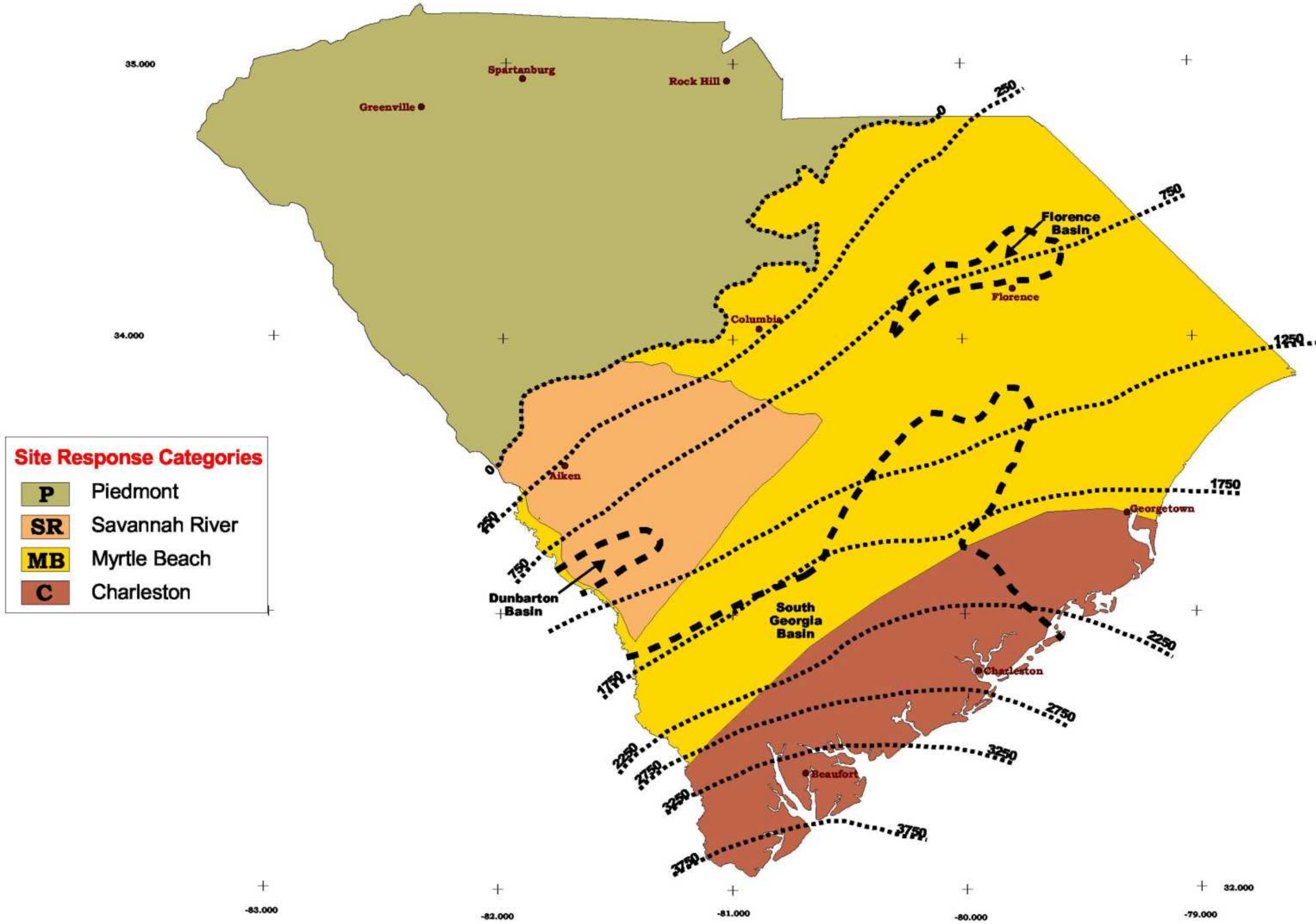
Attenuation Relationships (cont.)

- The single-corner frequency model was run with a constant stress drop for all magnitudes of 120 bars.
- Magnitude-dependent stress drops were varied from 160 bars for M 4.5 to 95 bars for M 7.5.
- In the double-corner model, there is no variation of stress drop with magnitude.
- The point-source model relative weights were adopted as: variable stress drop, 0.6; constant stress drop, 0.2; and double-corner, 0.2.

Comparison of Finite-Fault and Regionalized Point-Source Ground Motion Attenuation Models

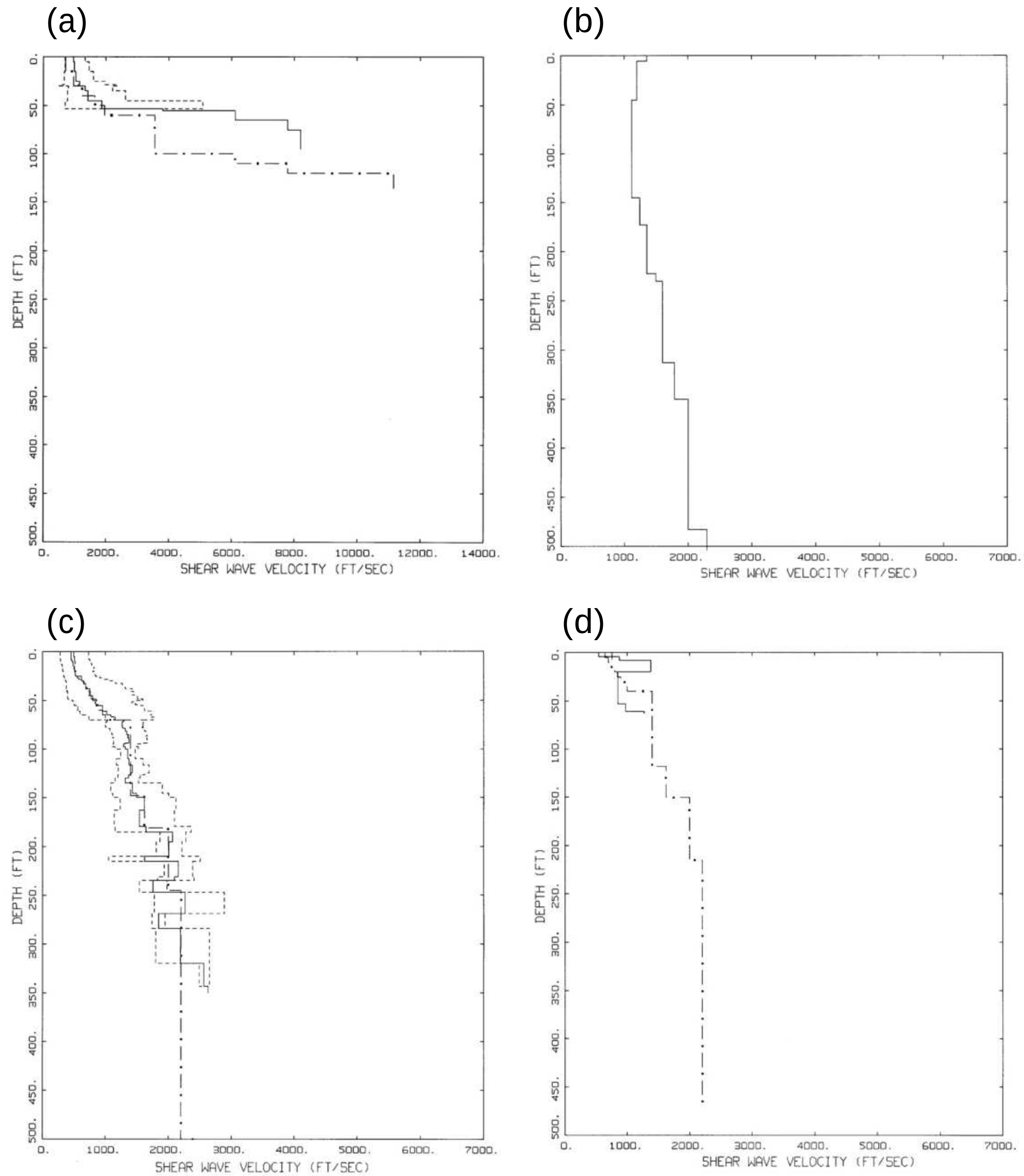


Site Response Categories and Depth to Pre-Cretaceous Rock

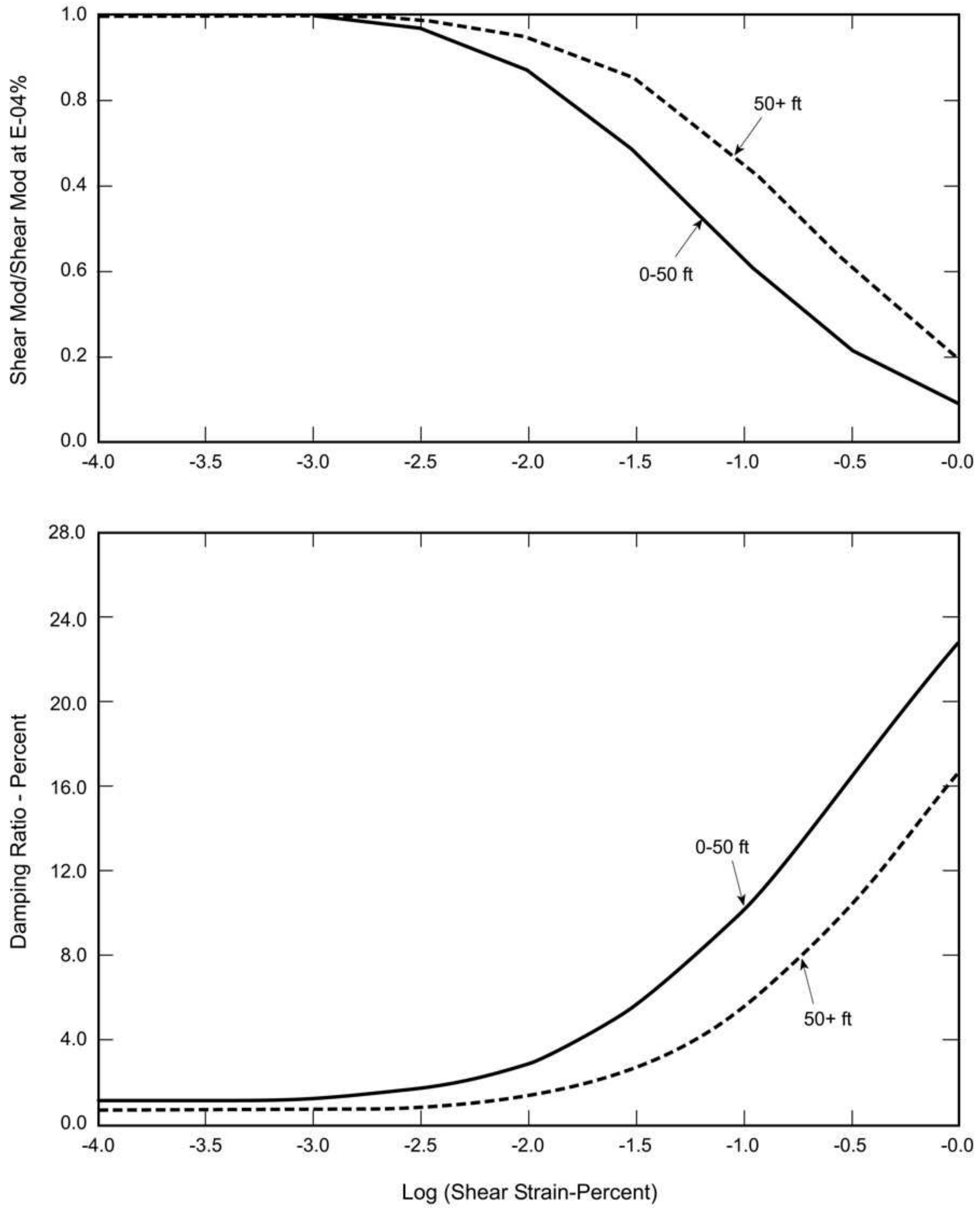


Base Case Shear-Wave Velocity Profiles for the Site Response Categories:

(a) Piedmont/Blue Ridge,
(b) Savannah River,
(c) Charleston, and
(d) Myrtle Beach



Generic Shear Modulus Reduction and Hysteretic Damping Curves Assigned to the Savannah River Category



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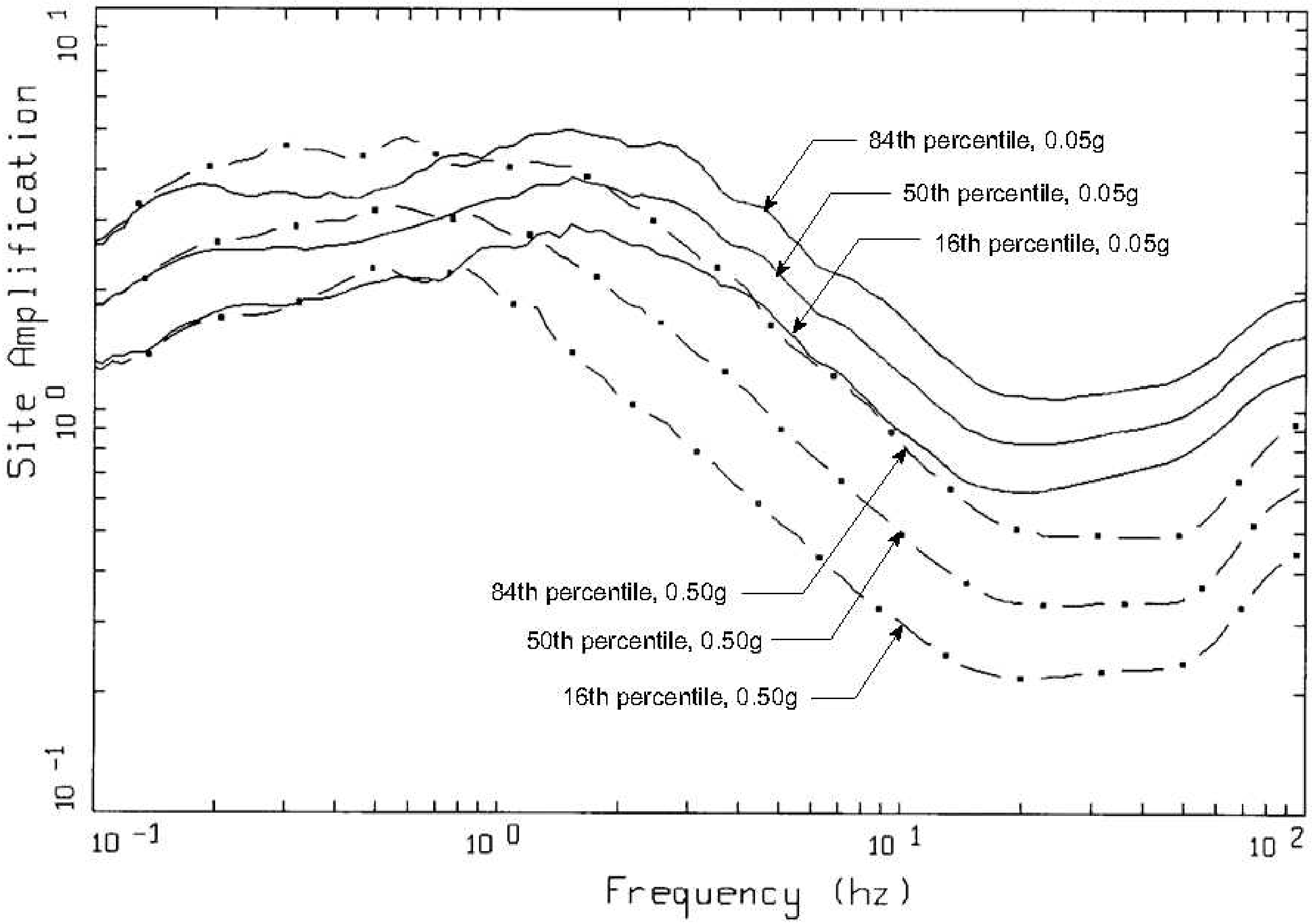
Comparison of Median and ± 1 σ Amplification Computed for the Charleston Site Response Category



Water Level Depth and Liquefiable Zone

- Available published information was used to divide the State into four regions with water levels of 0.0 to 0.6, 0.6 to 1.2 , 1.2 to 1.8, and 1.8+ m.
- Although soil is present in the Blue Ridge and Piedmont categories, they are considered to have a very low risk of liquefaction.
- We have neglected Holocene riverbank deposits above the Fall Line.

Liquefaction Analysis

- The probability for liquefaction was predicted based on factors of safety computed from average cyclic stress and shear-wave velocity (V_S)-based cyclic resistance ratios, clay content and saturation.

- Calculate the CRR from V_S (Andrus and Stokoe, 2000):

$$CRR = 0.022\,(K_C\,V_{S1}/100)^2 + 2.8\,[1/(V_{S1C} - K_C\,V_{S1}) - 1/V_{S1C}] \cdot MSF$$

- The cyclic stress ratio (CSR), is defined as:

$$CSR = \tau_{cyc}/\sigma_v'$$

Liquefaction Analysis (cont.)

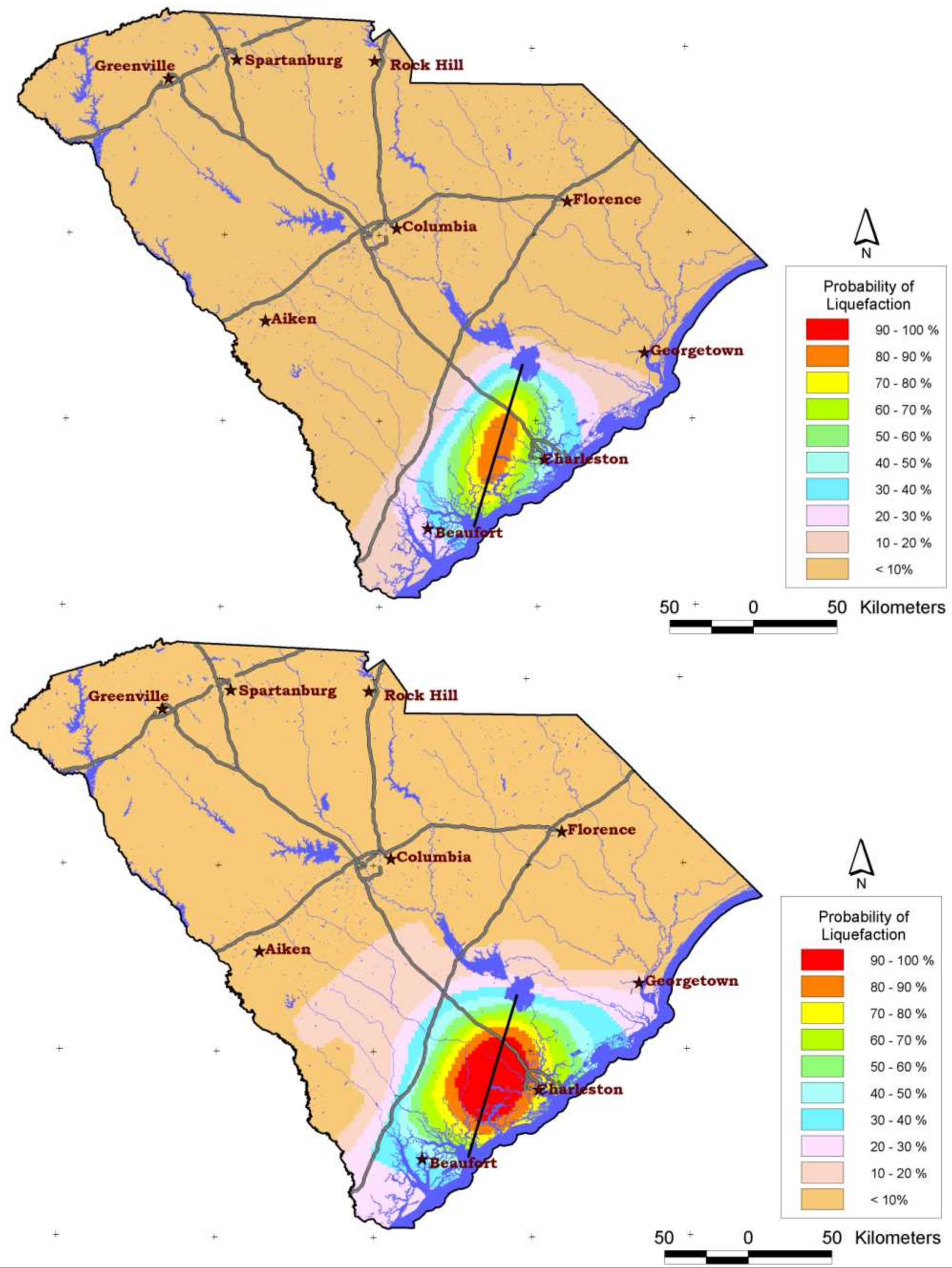
- Factor of safety is:

$$\frac{CRR}{CSR} = FS$$

- Probability of liquefaction:

$$P_L = 1/(1 + FS/0.8)^{3.5}$$

Comparison of Probabilities of Liquefaction for susceptible Soils Using Median Ground Motions from Low Stress Drop and High Stress Drop



Weighting of Attenuation Relationships

- The high-stress drop results clearly overestimate the extent of the 1886 liquefaction features. Thus a relative weight of 0.8 was selected for the low-stress drop rupture and a weight of 0.2 for the high-stress drop rupture scenario.

- Based on 0.8 weight for the finite fault modeling and 0.2 to the point-source models, the following weights were assigned:

  – Low-stress drop finite fault 0.64

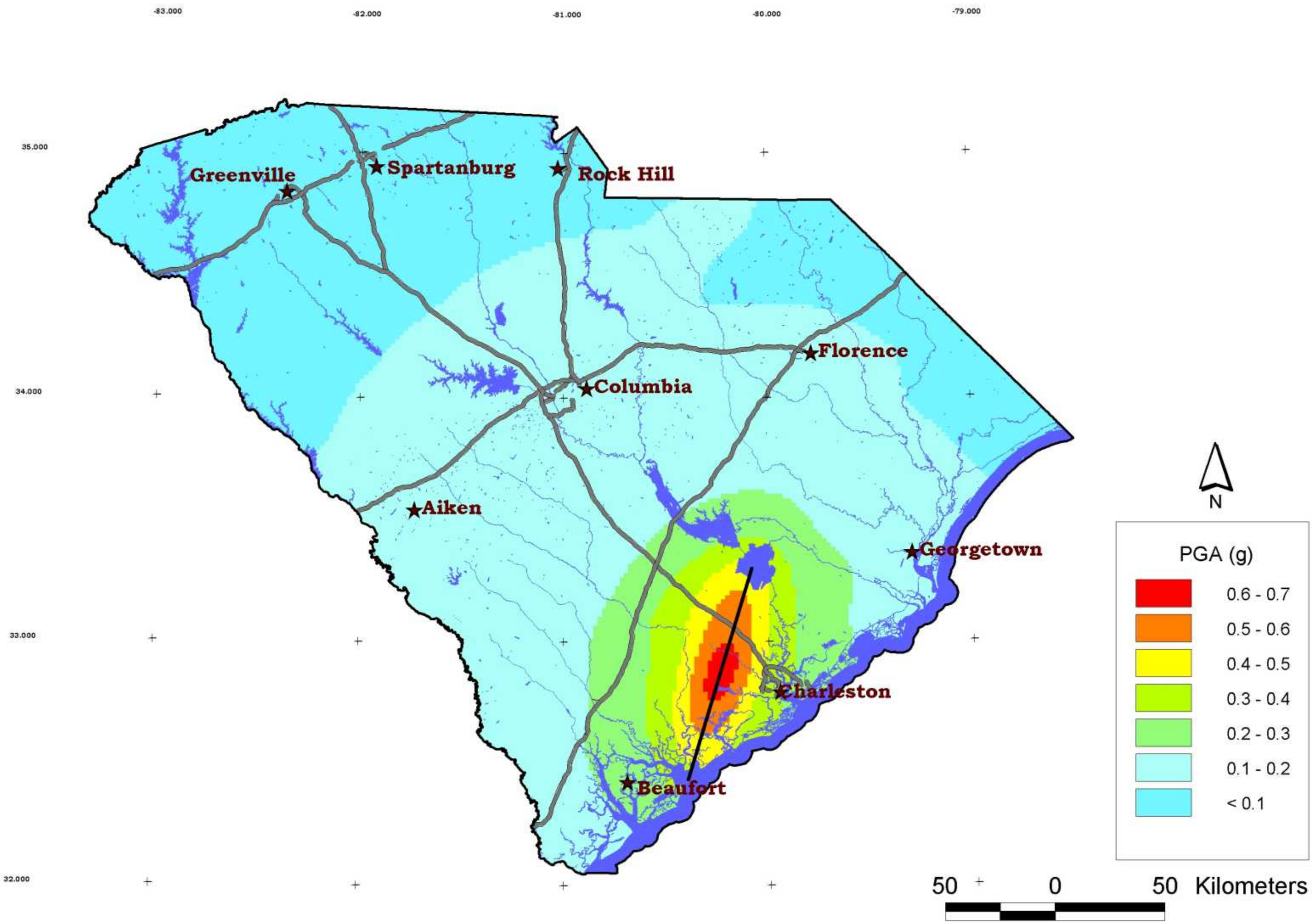
  – High-stress drop finite fault 0.16

  – Variable stress drop single-corner point-source 0.12

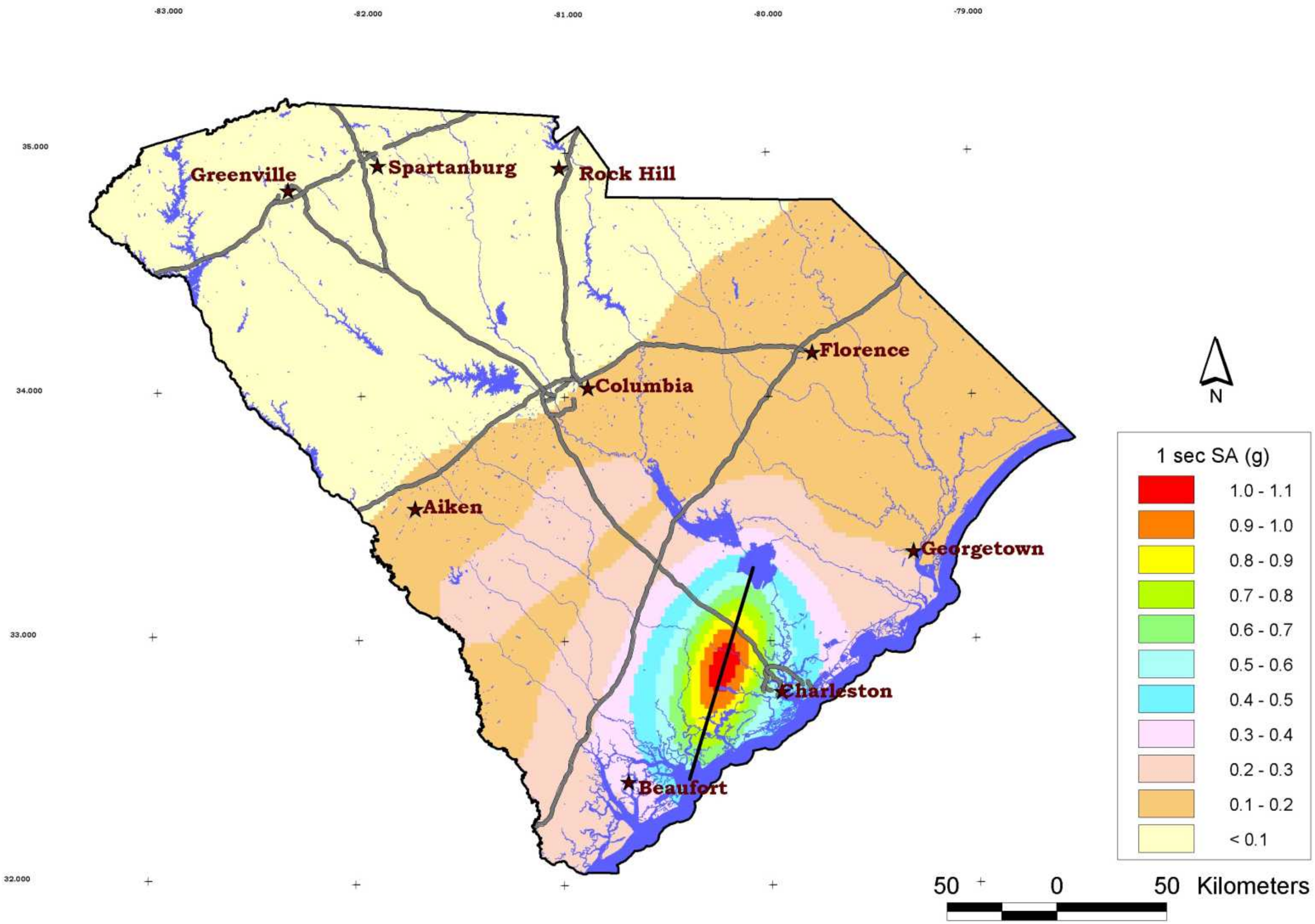
  – Constant stress drop single-corner point-source 0.04

  – Double-corner point-source 0.04

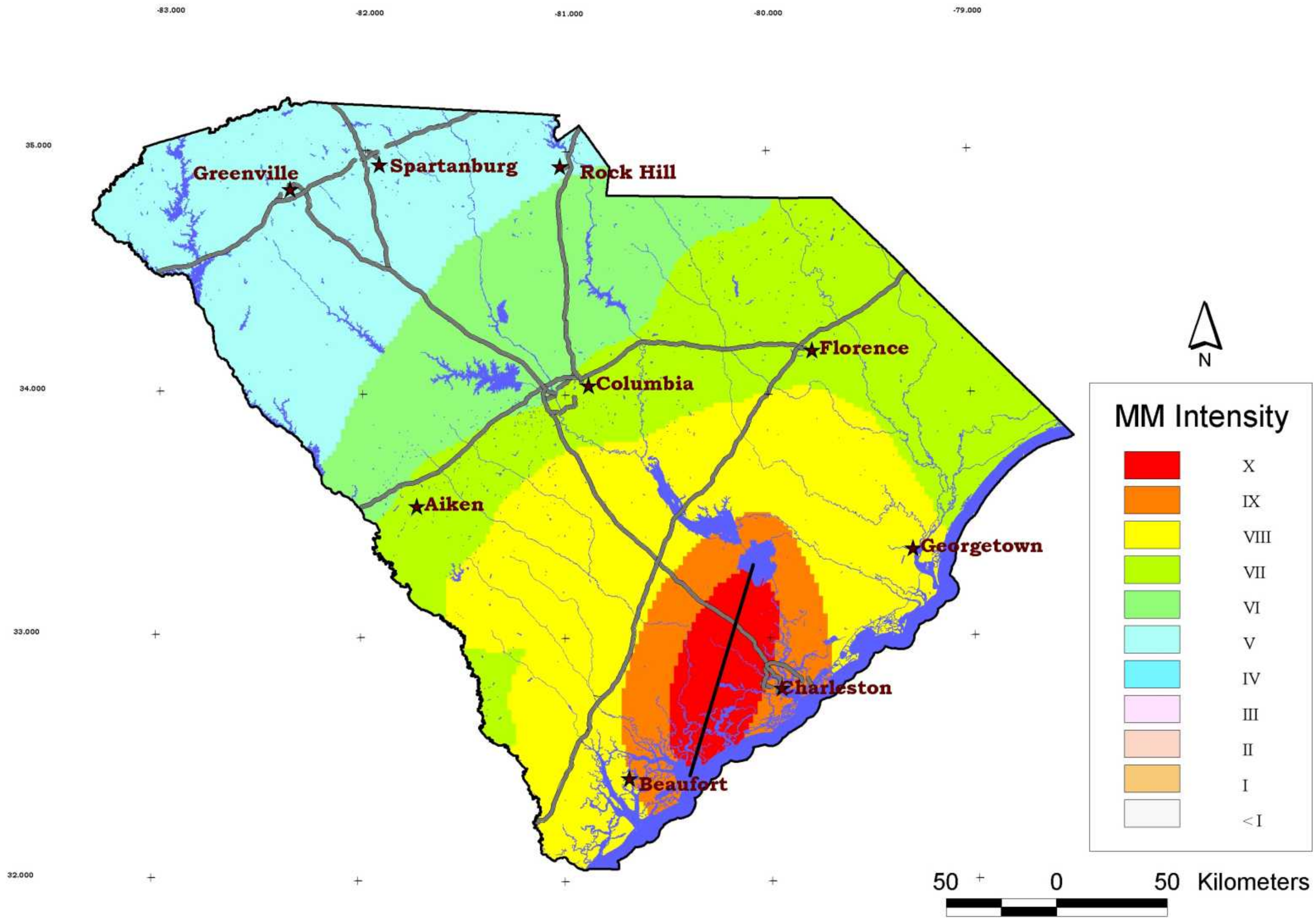
M 7.3 Charleston Earthquake Scenario Median Peak Horizontal Accelerations at the Ground Surface



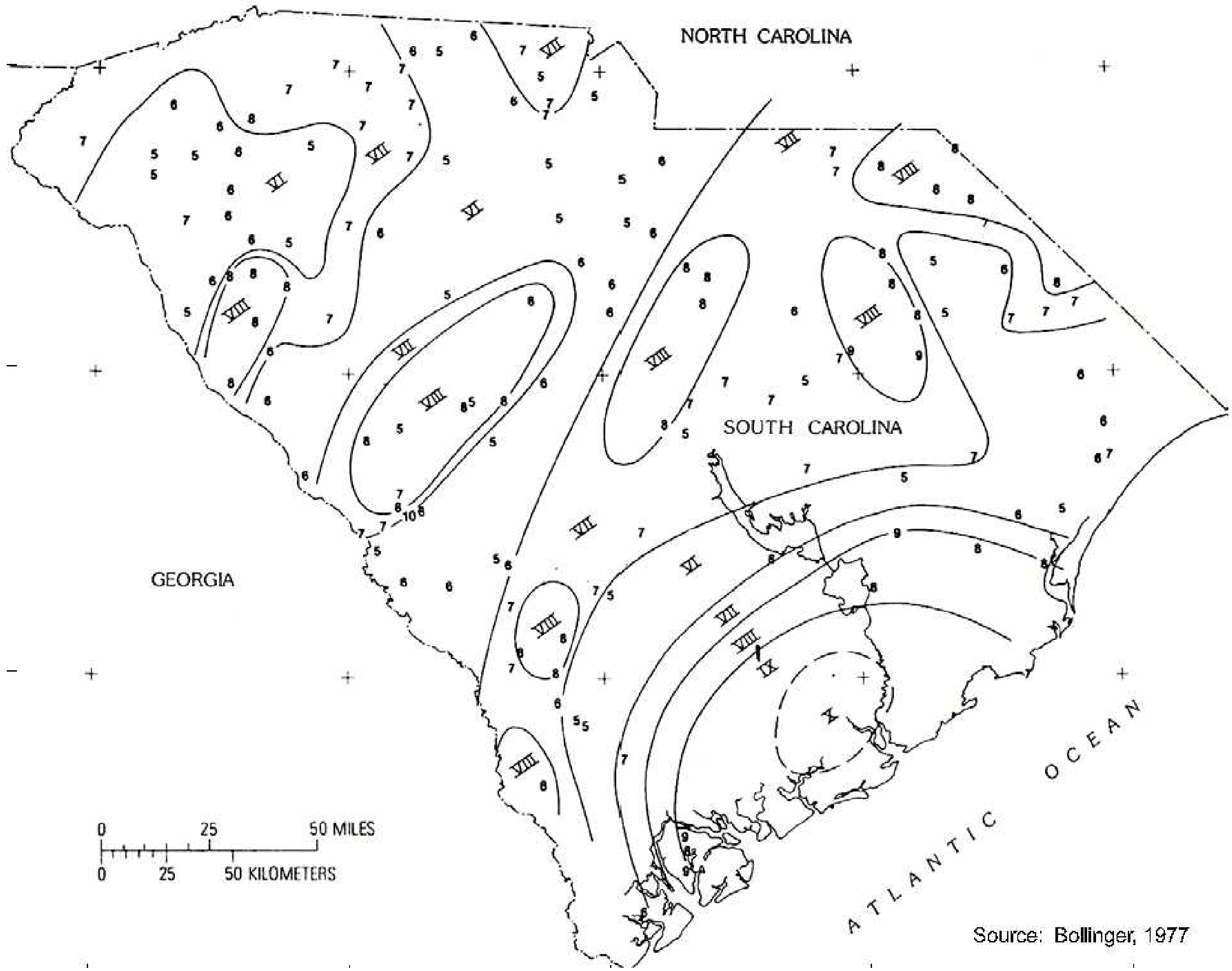
M 7.3 Charleston Earthquake Scenario Median 1.0 Sec Spectral Accelerations at the Ground Surface



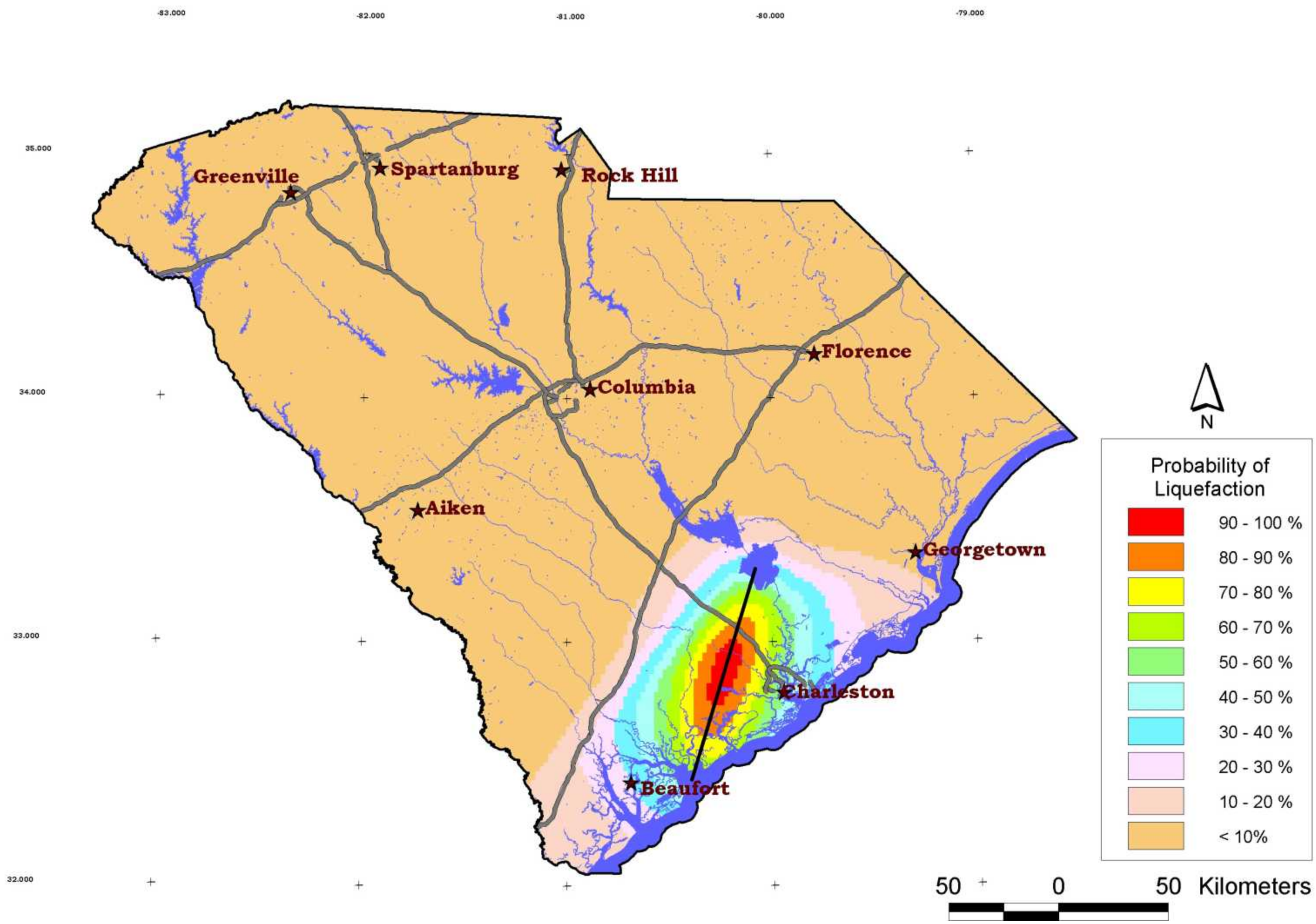
Computed Isoseismal Map Using Median Peak Ground Velocity for the M 7.3 Charleston Scenario Earthquake



Statewide Isoseismal Map of the 1886 Charleston Earthquake



Probability of Liquefaction for Susceptible Soils Using Median Ground Motions for the M 7.3 Charleston Scenario Earthquake



Summary

- We have modeled the ground motions and liquefaction from the 1886 M 7.3 Charleston earthquake assuming a 50- to 100-km-long strike-slip fault source coincident with the Woodstock fault.
- Although there has been considerable uncertainty regarding the source and size of the 1886 earthquake, our results based on the assumption of the Woodstock fault as the source and a M 7.3 (resulting in a generally low static stress drop) are in good agreement with observations.

Summary (cont.)

- It is surprising that the 1886 observations are better modeled using a WUS-based empirical rupture model than Johnston's (1996) preferred 50-km long rupture model. This model would suggest that the 1886 earthquake had rupture properties more consistent with expected WUS earthquakes assuming M 7.3.

- Although we have not simulated the effects of a low-angle fault (areal source), our simulations are consistent with and favor the Woodstock fault for the 1886 earthquake consistent with the earlier suggestions of Johnston (1996) and Marple and Talwani (2000).