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Title: "Updating and Expanding Urban Seismic Hazard Maps and Public Outreach for Memphis and Shelby County, Tennessee"

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Summary

In 2004, Memphis urban seismic hazard maps were completed for a six-quadrangle area centered on Memphis and southern Shelby County (Cramer, et al., 2004, 2006, 2008). Both probabilistic and scenario seismic and liquefaction hazard maps were generated for the six quadrangle study area. These urban seismic hazard maps have been well received, particularly the liquefaction hazard maps, and used by consultants and public agencies to address seismic hazard mitigation in the Memphis area. Memphis has the highest seismic hazard and annualize expected loss ratio, and the second highest annualized loss in the central and eastern US (Petersen et al., 2008; FEMA, 2008). Additionally, the USGS national seismic hazard model has been updated since the first Memphis urban seismic hazard maps were completed in 2004 with significant changes in the New Madrid source model and attenuation relations (Petersen et al., 2008) that impact Memphis hazard.

Stevens (2007) updated and expanded the upper 100 m of the 3D geologic model for Shelby Co. and Csontos (2008) has improved the 3D geologic model for the Mississippi embayment sediments, including under Memphis and Shelby Co. As part of this 2012-2013 geologic update and expansion to all of Shelby County, Stevens (2007) has been further updated to cover all of Shelby County and 8 km or more into adjacent counties and states. Included in the geologic model is improved modeling of sharp changes due to faults and/or erosion of strata. Gomberg et al. (2003) previously fit smoothed surfaces through these sharp changes. We generated probabilistic and scenario ground-motion and liquefaction urban hazard maps for 12+ quadrangles covering Shelby Co. using this information and the Memphis urban hazard mapping approach (Cramer et al., 2004, 2006) updated for the 2008 USGS national seismic hazard model (Cramer, 2009, 2011).

The new urban hazard maps show high seismic and liquefaction hazard in Shelby County. The new detailed geology model shows similar seismic hazard in the original quadrangles compared to the 2004 urban hazard maps, and the newly added areas have similar hazard in the upland areas and lower hazard in the lowland areas of Shelby County. In the new geology based model, the seismic hazard is mainly controlled by variations in thickness of the 160-190 m/s alluvium/loess layer at the surface. We also compare in appropriate quadrangles the seismic hazard map results using both the Gomberg et al. (2003) smoothing technique and the detailed and updated Stevens (2007) model for impact on urban seismic hazard maps. The 2004 smoothing biases the alluvium/loess layer thickness toward uniformity in thickness and seismic hazard. Companion liquefaction hazard maps have been generated using the Memphis liquefaction hazard map approach of Cramer et al. (2008) and the liquefaction cumulative probability curves provided by Romaro-Hudock and Rix (2005). The liquefaction hazard maps indicate problems with the SPT geotechnical data and probability curves, although the CPT based liquefaction hazard maps seem more reasonable. Simplified seismic and liquefaction hazard maps based on a M7.7 scenario earthquake on the SW trend of seismicity of the New Madrid seismic zone are produced in this study. They show severe shaking hazard (> 0.25 g PGA) in the upland (loess) areas of Shelby County and a severe liquefaction hazard (> 60% of the area manifesting liquefaction at the surface) in the lowlands (river alluvial floodplain) areas.

Recommendations are made to further improve the Memphis seismic and liquefaction hazard maps.

The public and professional outreach component of the study focused on interaction via a technical working group (TWG) for guidance and a workshop for communication. The TWG met quarterly and held monthly conference calls to oversee and review the revised 3D geologic model and resulting hazard maps. It was formed in cooperation with the USGS from the past Memphis urban hazard mapping technical advisory group and other interested parties from government, business, and academic entities. A workshop was held March 13, 2013 at the University of Memphis to raise public, business, and professional awareness of Memphis area earthquake hazards, and to disseminate the urban hazard maps produced under this proposal. The one-day workshop focused on (1) dissemination of the updated Memphis urban hazard maps, (2) interaction with the professional, business, and public-sector user community concerning their needs, and (3) continuing hazard mapping and mitigation efforts for Memphis and west Tennessee.

Update of Memphis 3D Geologic Model
(work by Daniel Pryne, Justin Paul, and Roy Van Arsdale)

Introduction

This section provides an overview of how the Summer 2012 geologic modeling of Shelby County, Tennessee was completed for the Memphis Area Earthquake Hazards Mapping Project (MAEHMP). The document also presents commentary on the interpretations that influenced the model.

The Summer 2012 modeling project was designed to build upon the 2007 geologic model of Shelby County created by Krista Stevens. The methods and interpretations by Stevens provided guidelines for the summer 2012 project.

Stevens (2007) Database

The Stevens (2007) database was large and compiled from various sources. In total, the database contained 1940 boring log interpretations of the top elevation of the Memphis Sand, Upper Claiborne, and/or Upland Complex. Also recorded were the boring coordinates, original identification, and log source. Stevens collected around 400 logs from the Ground Water Institute (GWI) and local engineering firms, while the rest came from log databases built by former University of Memphis graduate students (Deen, 2006 and Martin, 2008). The vast majority of borehole logs were from within Shelby County, but some came from the surrounding counties of Tipton (TN), Fayette (TN), Desoto (MS), and Crittenden (AR).

At the beginning of Summer 2012, a few corrections needed to be made to the inherited Steven's (2007) database. Since the original 2006 study, it was discovered that some well locations were incorrect. A team from the Ground Water Institute (GWI) re-located the borings and recorded their correct coordinates within a master log database at their facility.

With the help of Dr. Brian Waldron and Sarah Girdner, the incorrectly located logs were identified, and the correct coordinates were recorded in the Stevens database.

Summer 2012 Database

Nearly all newly acquired boring logs used in the Summer 2012 project came from a single source. Drillers are required to send logs from all bore-holes drilled in Shelby County to Mr. Greg Parker's Water Quality Branch and Septic Tank Program office at the Shelby County Health Department (814 Jefferson Ave.). This made collecting logs from borings drilled in Shelby County simple, however, to collect logs outside Shelby County, engineering (Ensafe, Geotechnology Inc., Tri-State Testing Services) and governmental contacts (Army Corp of Engineers and TN Department of Environment and Conservation) were made. This summer project added 600 additional logs to the Stevens (2007) database, bringing the total number of logs for the current geologic model to 2535. Not only were more logs added, we were able to increase the data density in areas of Shelby County where data were lacking in the original model. We were also successful in adding data within a five-mile (eight-kilometer) radius of Shelby County to better constrain the updated Shelby County geologic model.

The 2012 database contains elevations for the tops of the Memphis Sand, Upper Claiborne, and Upland Complex, similar to Stevens (2007). Additionally, our database contains loess and alluvium thicknesses in Shelby County as well as Mississippi River alluvium thicknesses west of the bluff line. This database is thus a more complete geologic model of Shelby County that encompasses Tertiary and Quaternary strata.

Data Collection Procedures and Interpretations

Logs received first needed to be located. The logs were initially located by typing the address given in the boring file into Google Maps, and then more accurately located using the specific site maps with precise boring locations. Exact latitudes and longitudes of the boring locations were obtained by right clicking the location and using the "What's here?" function in Google Maps. The coordinates were recorded in Excel spreadsheets, organized by the year the boring was drilled, with the original identification of the boring file, source, and boring address.

After the logs were located, GIS software became the main tool used in data interpretation. The respective Excel spreadsheets, with coordinates and unique identification information, were imported into ArcMap 10 using the "add XY data" function. Shapefiles of boring locations were created for each individual spreadsheet. The first step in geologic interpretation was to extract surface elevations of the boring locations from a 3-meter USGS digital elevation model (DEM). This was done using the "extract values to point" function in ArcMap. Surface elevations were particularly important for identifying Holocene river alluvium.

Geologic picks were then interpreted using the lithologic descriptions of the logs and the acquired surface elevations. The depths to the top of the Upland Complex (Pliocene),

Upper Claiborne (Late Eocene), and Memphis Sand (Early Eocene) were recorded from each log when these data existed in the log, as were the alluvium and loess thicknesses where present.

The deepest/oldest unit picked in the Summer 2012 model is the top of the Memphis Sand. The Memphis Sand is characterized as a coarse white sand with intermittent clay beds. We were able to identify the top of the Memphis Sand in the logs with the key words "white sand" and "coarse sand." This marked a dramatic lithologic change from the predominately clay bearing overlying Upper Claiborne. However, sandy layers sometimes exist within the Upper Claiborne, thus making it locally difficult to differentiate the sandy portions of the Upper Claiborne and the Memphis Sand.

A clear lithologic change was observed between the top of the Upper Claiborne and the bottom of the Upland Complex. Seeing the terms "white clay," "fine sand," or "fat clay" in the logs below a 30+ foot section of red sand and gravel revealed the top of the Upper Claiborne. The Upland Complex is a red sand and gravel ancestral Ohio River terrace unit.

The upper contact of the Upland Complex in drainage divides was straight forward to identify and consists of brown silt (loess) overlying the Upland Complex. However, in the Holocene floodplains of the Wolf and Loosahatchie rivers mapped in this project it is locally difficult to differentiate between Pliocene Upland Complex gravel and Holocene gravel. By overlaying soils data downloaded from the Natural Resource Conservation Service (NRCS) on the DEM in ArcMap, it was possible to identify the Holocene floodplain as a silt and sandy low-lying area along the modern rivers. Differentiation of the Upland Complex and Holocene gravels was based on the color of the sand mixed with the gravel and the location of the log relative to the Holocene floodplain. The Upland Complex was identified by red sand and gravel, while the younger, reworked gravel contains brown sand. We interpret the gravel within the mapped Loosahatchie and Wolf river floodplains as Holocene alluvium, and not Upland Complex. Holocene alluvium was mapped where clays, silts, sands, and gravels overlie the Upper Claiborne in the Holocene floodplains; thus we believe that all the Upland Complex has been removed or reworked in the mapped Loosahatchie and Wolf river floodplains. Differentiating Pleistocene loess from Holocene floodplain silts was not possible in the small tributary valleys. The silt filled river valleys were grouped with loess because of their common silt compositions.

After all depths of geologic tops were converted to meters relative to sea level (elevation), the rest of the interpretations were made with ArcMap. Structure contour maps were created of the tops of the different stratigraphic units and thicknesses of alluvium and loess using the "kriging/cokriging" function in the "geostatistical wizard". Kriging generates a prediction surface from a scattered set of points (logs) with z-values (elevations/thickness). The kriging method creates an interpolated "raster" surface in which every cell in the raster has a predicted z-value and a standard error (uncertainty) of predictions (ESRI). The Geostatistical Wizard allows visualization of the semivariogram before the raster is created to identify trends and/or anisotropy in the data. The Geostatistical Wizard can then apply a first, second, or third order trend removal if a trend is indeed present in the data. For this project, both a default raster and a modified raster with a first order trend removal were

compared to obtain the desirable mean error closest to zero. Additionally, elevations and thickness values were posted at borehole log locations for visual validation of the raster surfaces

Fault/offset interpretations were made from the validated structure contour maps. Sharp elevation changes in geologic surfaces exist in Shelby County. Such elevation changes were the basis for identifying faults/offsets in the subsurface. Linearly-continuous 10+ meter elevation differences between adjacent logs constituted our basis for identifying faults/offsets. Interpreted fault/offset traces were marked on each computer generated map with black lines

Structure contour maps were also created for each fault/offset bounded block. Fault/offset blocks were created by "drawing polygons" that were bound by the interpreted faults/offsets and data coverage. The polygon graphics were then converted to respective fault/offset block shapefiles. Each fault/offset block, with its respective data distribution, was contoured using the same kriging methods described above.

Final Geology Products

The data for a fault/offset geologic model of Shelby County was submitted to Dr. Cramer in Excel spreadsheets. An instance of "-9999" in any spreadsheet cell means no data were available. In the fault/offset model, a master spreadsheet with top elevations was created for each geologic surface (Memphis Sand, Upper Claiborne, and Upland Complex). Each master spreadsheet was then organized by fault/offset blocks. Elevation data were extracted from a system of grid nodes with a spacing of 0.005 decimal degrees. Also provided in the faulted model spreadsheets are the uncertainties of elevations in meters at each grid node. The master spreadsheet contains borehole specific data including the depth in feet to each geologic unit, uncertainty in feet of each unit, and elevation in meters of each unit. The spreadsheet also contains thicknesses in meters of Loosahatchie, Mississippi, and Wolf River alluvium, and Pleistocene loess.

For the sediment layers below the Memphis sand, an Excel spreadsheet covering the MAEHMP and surrounding region was extracted from the Csontos (2008) Mississippi embayment database. This file of layer depth-to-top observations in deeper wells was provided to Dr. Cramer for improving the modeling of the deeper sediment layers over the 2004 Memphis geology model. No fault/offset modeling is possible for the layers below the Memphis Sand because the observations are too sparse.

A series of maps were also provided to Dr. Cramer. Structure contour maps of each geologic surface show our fault/offset interpretations with the fault/offset blocks labeled. Isopach maps depict the thicknesses of Loosahatchie, Mississippi, and Wolf River alluvium, and Pleistocene loess.

Geology Top-of-Layer Maps

Figure 1 presents the geologic units beneath Memphis down to the Paleozoic. Figures 2-10 present the top surface elevation contours (except Figure 2 which is layer thickness) for each layer of the Memphis 3D model. The first four layers (Figures 2-5) are the shallow geology layers down to the Memphis Sand and contain faults/offsets in the surface. The deeper four layers (Figures 6-9) are below the Memphis Sand and do not have faults/offsets due to the lack of observations. Figure 10 is the top of bedrock surface and has not been updated from the 2004 geology model because there are no new data for this surface near Memphis. Figure 11 shows a NW-SE cross-section for the top four layers of the model.

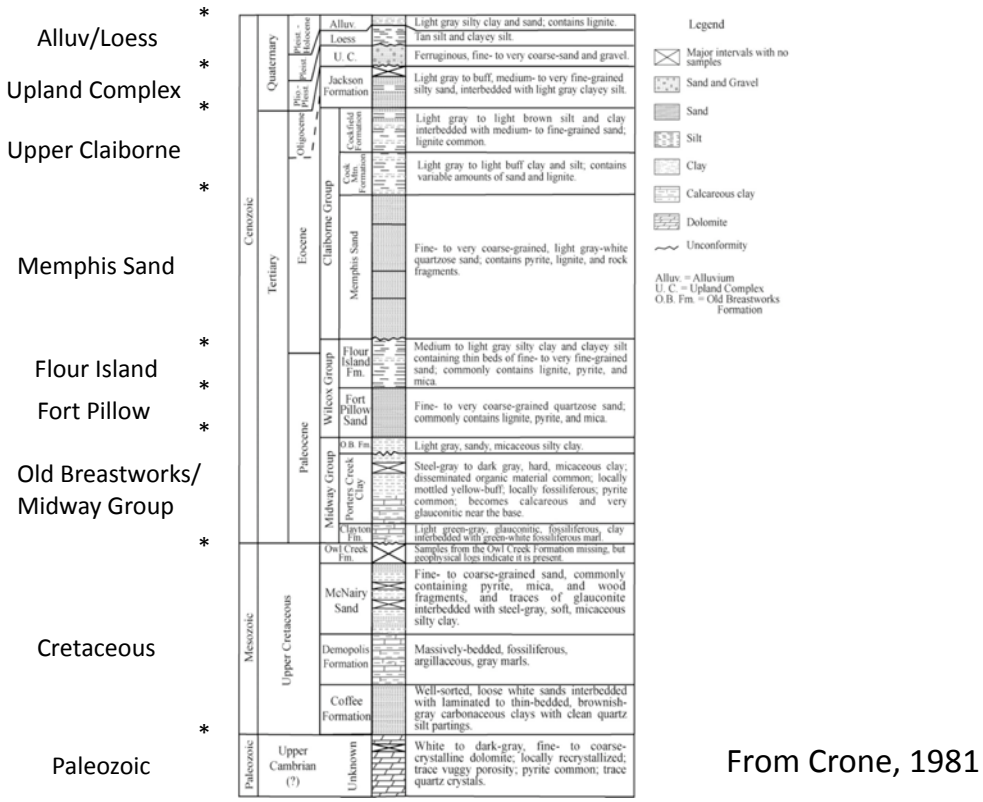


*Figure 1: Geologic units below Memphis from Crone, 1981 with tops of layers used in the Memphis 3D geology model indicated by the *s. Names of formations shown at left.*

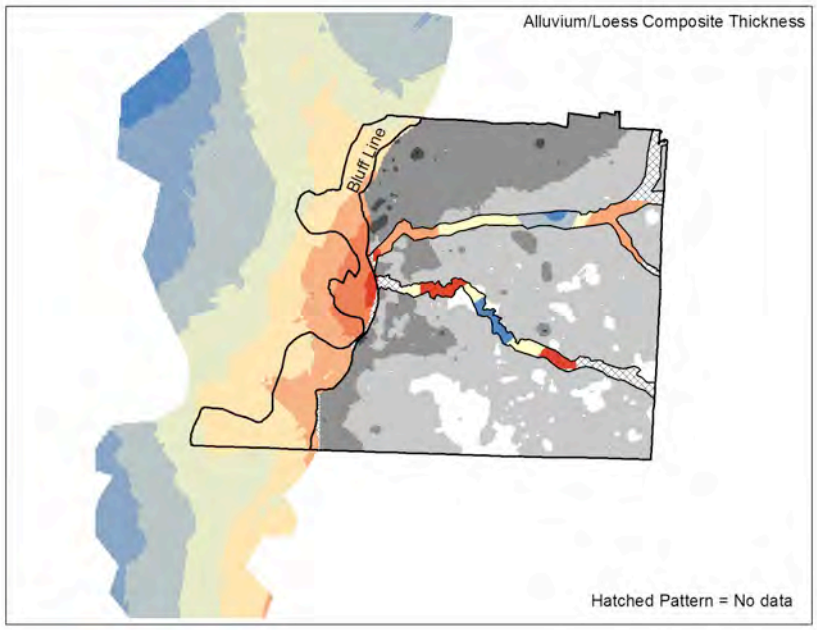


Figure 2: First layer thickness for alluvium (color contours) and loess (gray scale contours) in 5 m contour intervals (from red to blue and white to dark, respectively). See Figure 14 for a better representation of layer thickness within the MAEHMP study area. The outline of Shelby County, bluff line, and Loosahatchie (north) and Wolf (south) rivers are shown on the map.

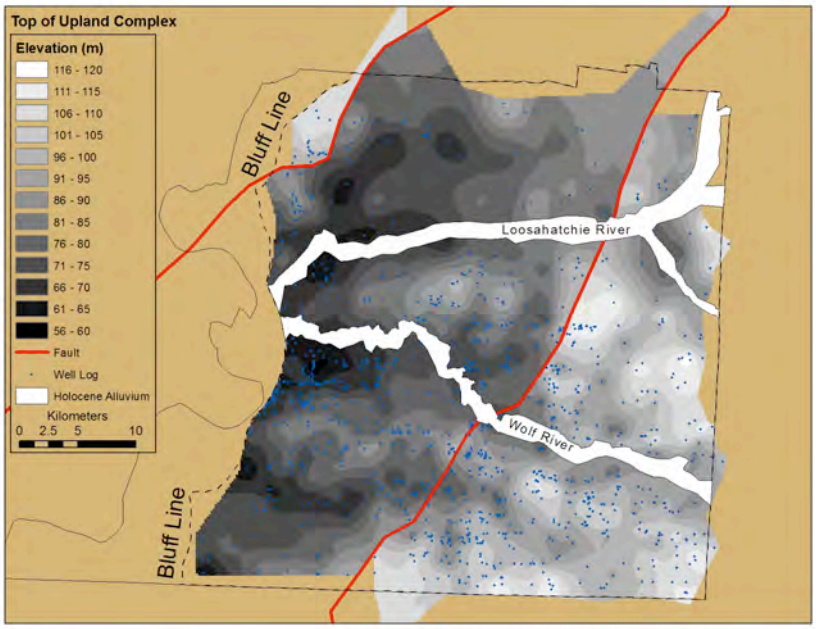


Figure 3: Top of Upland Complex elevation (m). The Upland complex does not extend west of the bluff line into the Mississippi floodplain (eroded away) and east of the eastern limit near the Shelby County line. The outline of Shelby County is shown on the map. Red lines are faults/offsets interpretations. Blue dots show borehole control.

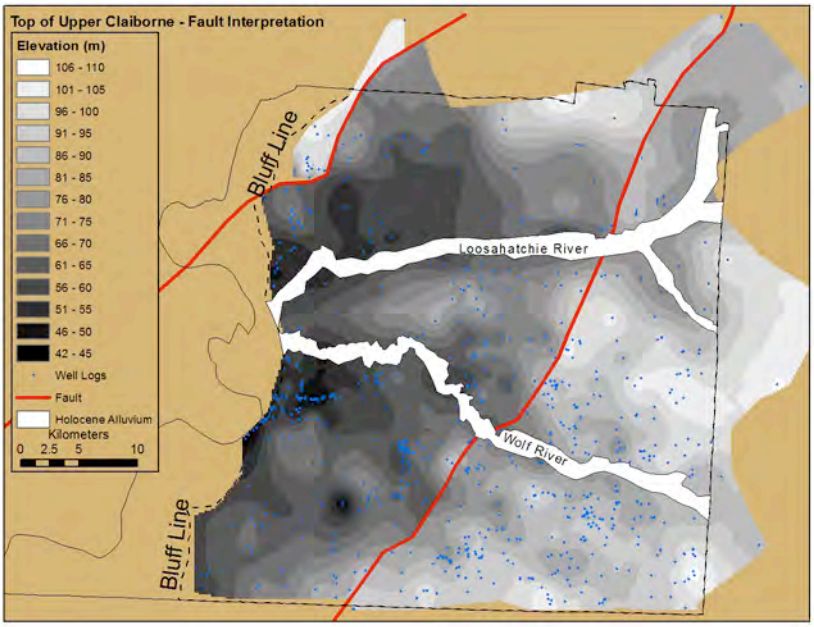


Figure 4a: Top of Upper Claiborne elevation (m) east of the bluff line. Red lines are faults/offsets interpretations. The outline of Shelby County is shown on the map. Blue dots show borehole control.

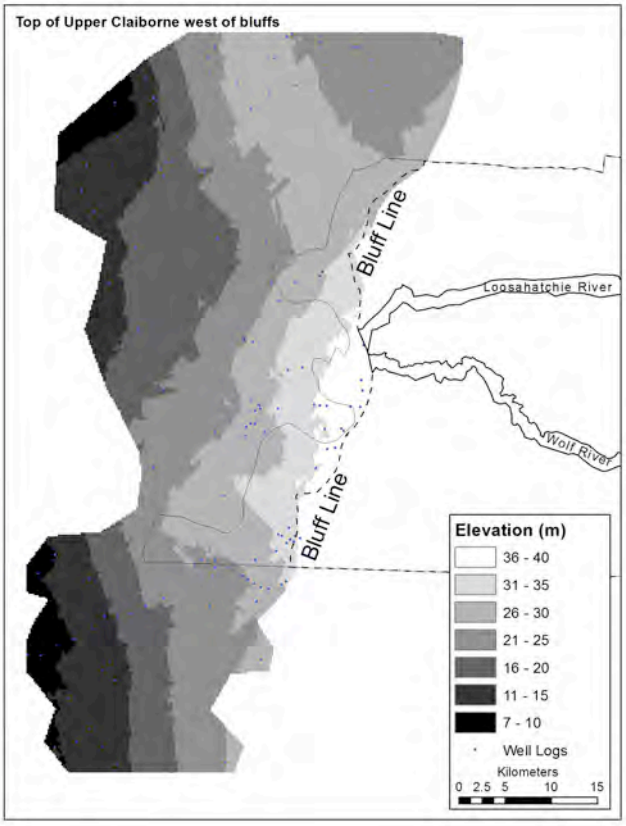


Figure 4b: Top of Upper Claiborne elevation (m) west of the bluff line. The outline of Shelby County is show on the map.

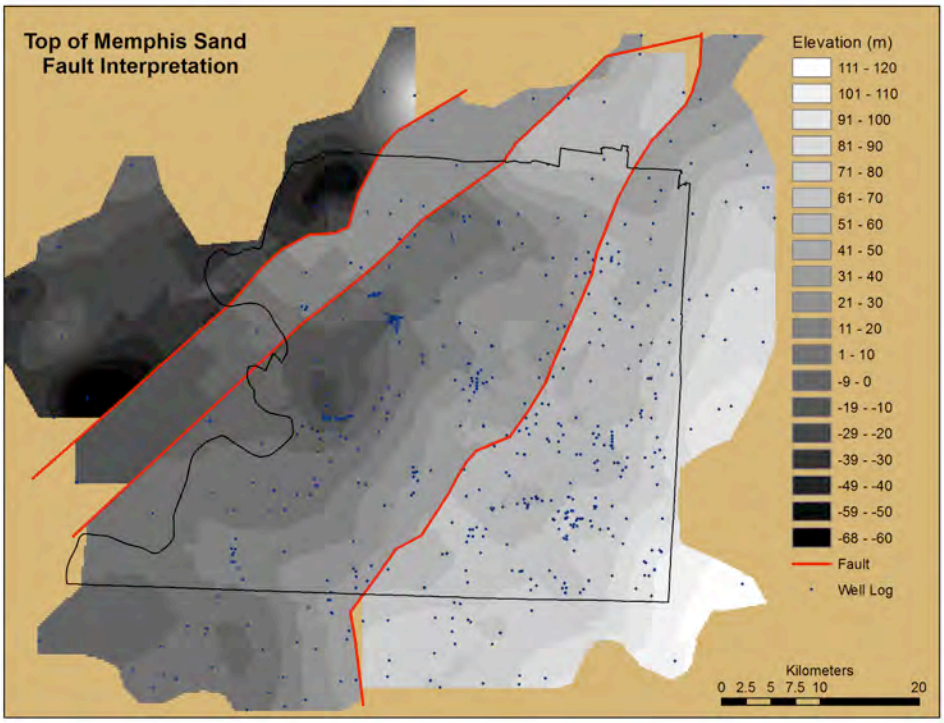


Figure 5: Top of Memphis Sand elevation (m). Red lines are faults/offsets interpretations. The outline of Shelby County is shown on the map. Blue dots show borehole control.

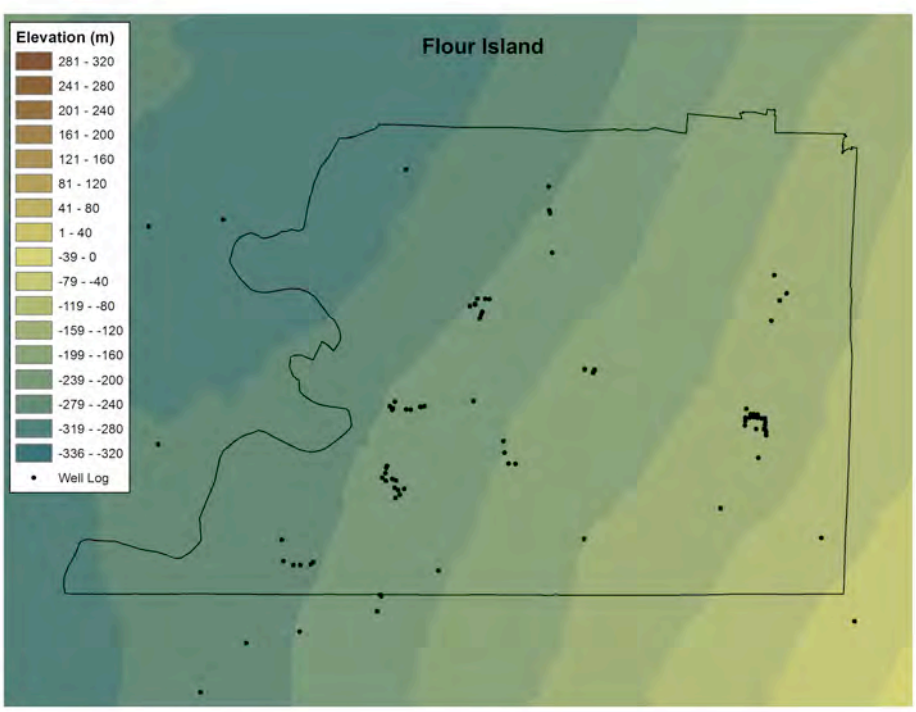


Figure 6: Top of Flour Island clay elevation (m). The outline of Shelby County is shown on the map. Black dots show borehole control.

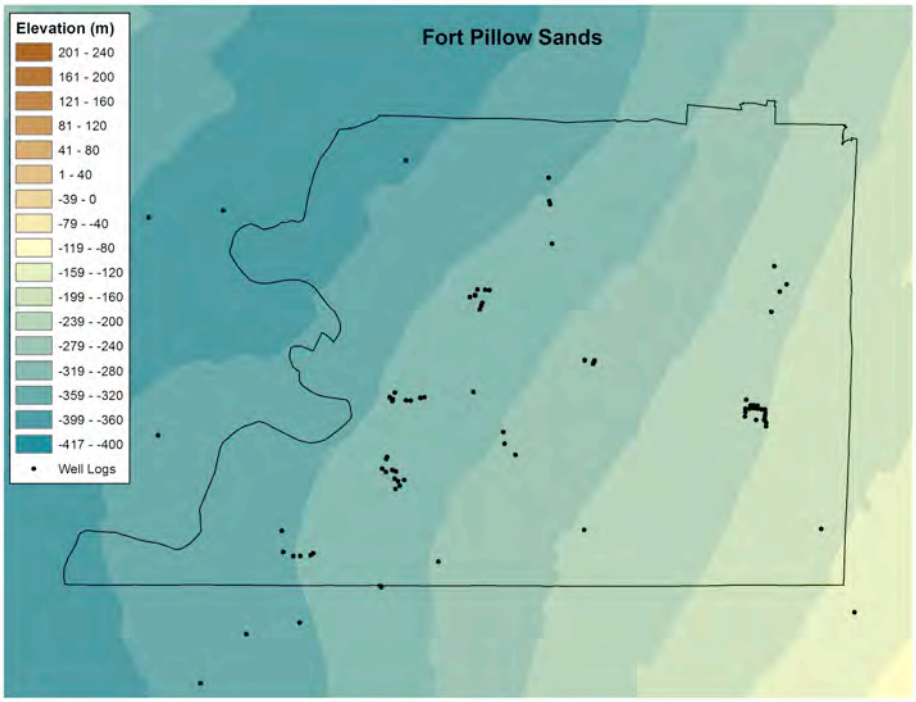


Figure 7: Top of Fort Pillow Sand elevation (m). The outline of Shelby County is shown on the map. Black dots show borehole control.

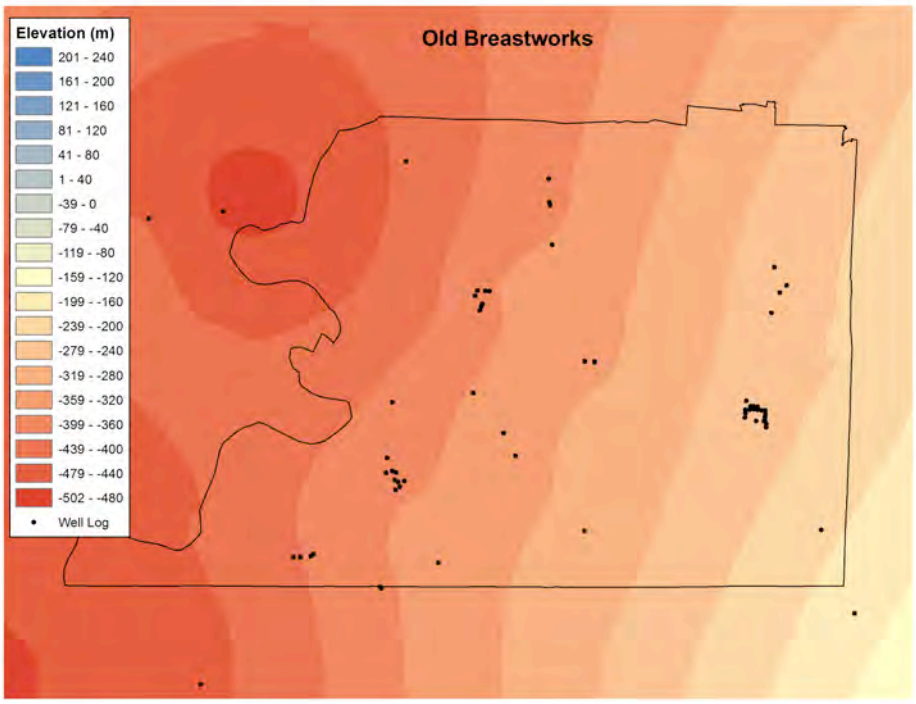


Figure 8: Top of Old Breastworks clay elevation (m). The outline of Shelby County is shown on the map. Black dots show borehole control.

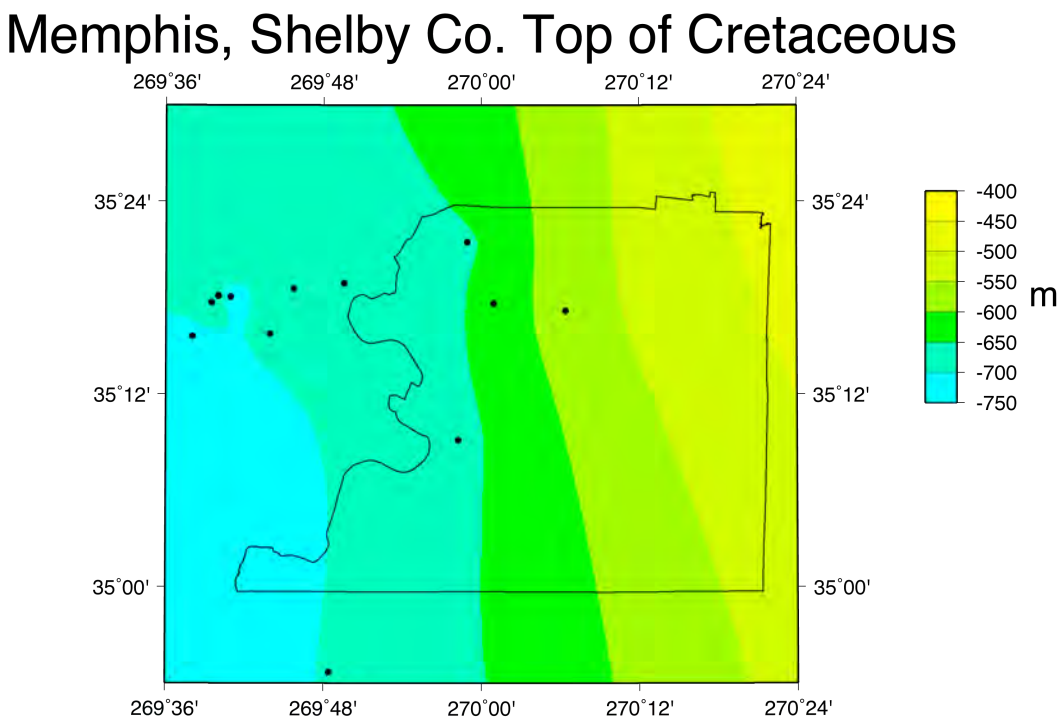


Figure 9: Top of Cretaceous (Owl Creek) elevation (m). The outline of Shelby County is shown on the map. Black dots show borehole control, which extends beyond the map boundaries.

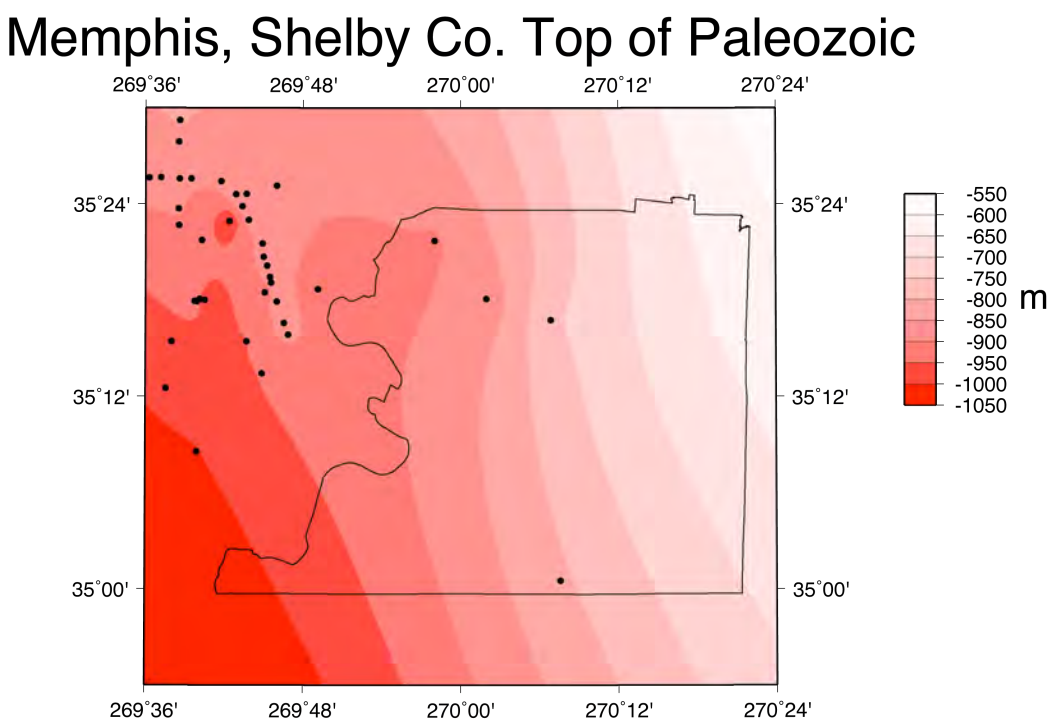


Figure 10: Top of the Paleozoic limestones elevation (m). The outline of Shelby County is shown on the map. Black dots show borehole control, which extends beyond the map boundaries.

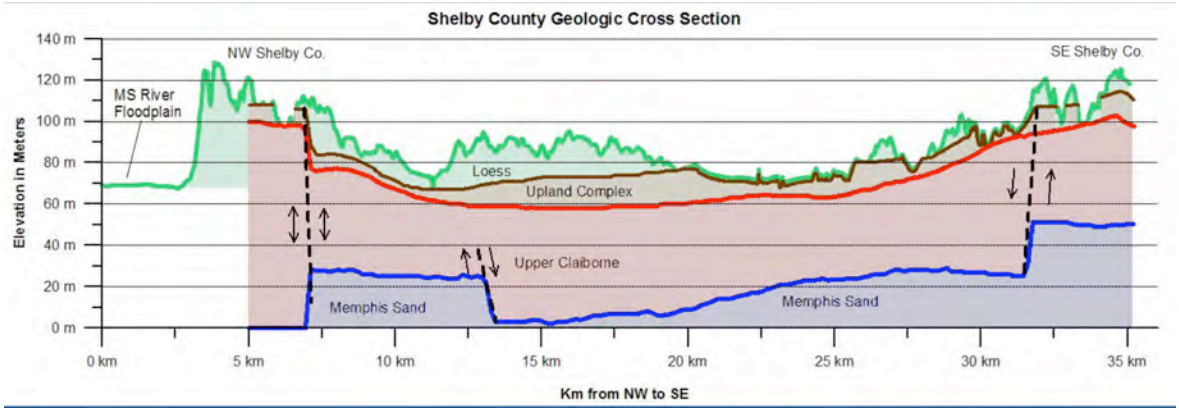


Figure 11: Cross-section from NW to SE across Shelby County of the fault/offset portion (top four layers) of the updated 3D geology model.

Updated Seismic Hazard Maps
(work by Chris Cramer and Mahesh Dhar)

Urban seismic hazard maps add in the effect of local geology on the amplification of earthquake ground motions in order to have more realistic ground motions for earthquake hazard analysis within the study area. To do this, information is needed about the local distribution and thicknesses of soil in the urban area. Basically, two pieces of information are needed: what are the thicknesses at a site of each soil type (lithology) and what are each soil type's physical (geotechnical) properties that affect ground motion amplification. Site amplification is determined by taking a soil profile (soil type thicknesses and physical properties) and subjecting that soil profile to earthquake shaking (time history) originating in the solid rock at the bottom of the soil profile to calculate the expected shaking at the ground surface. The change in amplitude of the shaking at a given frequency from the bottom to the top of the soil profile is site amplification.

Initially, we calculated preliminary seismic hazard maps using two versions of the 3D geologic model: smoothed and with faults/offsets. The smoothed geology seismic hazard maps followed the approach of Cramer et al., 2004, which used the geology smoothing approach of Gomberg et al., 2003. The Gomberg et al. approach smoothes through the geologic borehole information for the top of each layer providing a more averaged depth to the top of each layer. The faults/offsets geology seismic hazard maps used the updated approach of Cramer, 2011 from the St. Louis urban-hazard mapping project with the above fault/offset geology model (faults/offsets in the top surface of the second, third, and fourth layer). The geologic profiles at grid points where the second layer is missing (west of the bluff line and near the eastern edge of Shelby County, were adjusted appropriately for the missing layer. For both cases we used the 2008 USGS National Seismic Hazard Model (seismic sources and ground motion prediction equations – GMPEs) and the 2004 suite of time histories.

Figures 12 and 13 show the results for a 12-quadrangle area in the heart of Shelby County. These maps are for 2%-in-50yr probability of exceedance peak ground acceleration (PGA) hazard. For the smoothed geology version, the three western quadrangles are not shown

because the smoothing procedure does not model well the disappearance of the Uplands Complex (second) layer west of the bluff line. In the 2004 maps, the Mississippi River floodplain (lowlands) geology with the missing second layer was not available and the geologic smoothing incorrectly projected the uplands model east of the bluff line to the west out into the lowlands. Comparing Figure 12 with the 2004 6-quadrangle results shows a similar smoothed character to the seismic hazard and lower seismic hazard in Figure 12 than in 2004 because of the GMPE changes in the 2008 USGS hazard model from the 2002 model used in the original Memphis urban hazard maps. In contrast, Figure 13 shows lower seismic hazard in the lowlands and similar seismic hazard in the uplands with greater detail than the smoothed geology version of the model. Figure 13 is much more reminiscent of the St. Louis lowlands vs. uplands seismic hazard results (Cramer et al., 2013).

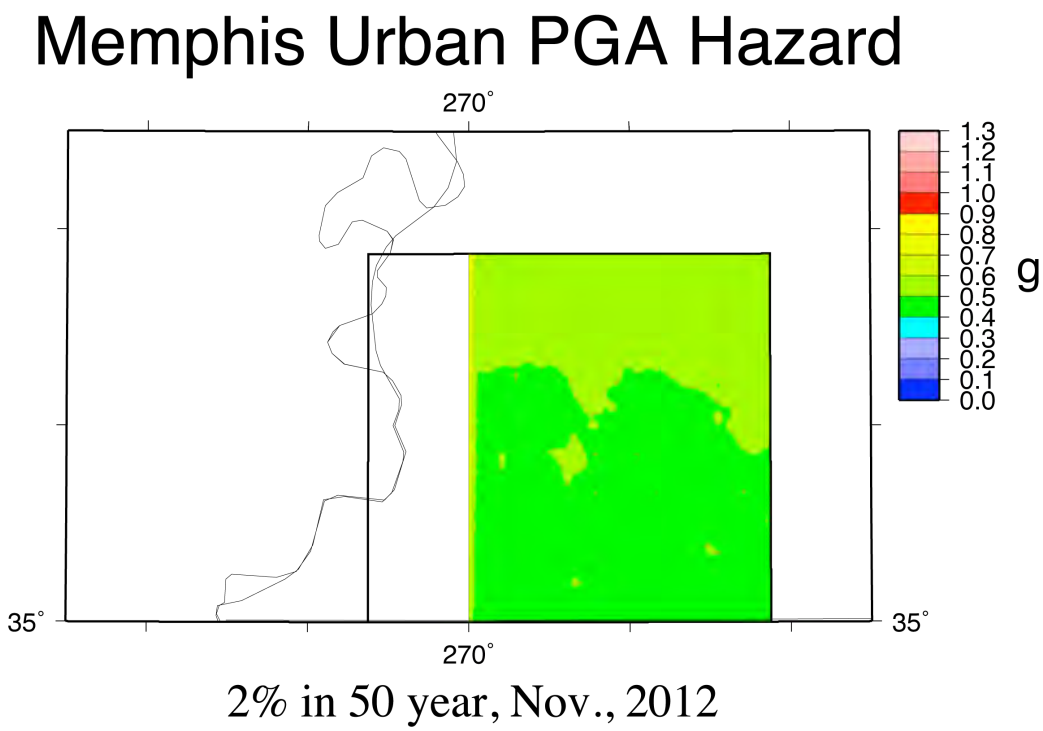


Figure 12: Smoothed geology initial PGA seismic hazard map for 2%-in-50y probability of exceedance covering 12 full quadrangles within Shelby Co. See text for explanation for the three missing quadrangles on the western edge of the map.

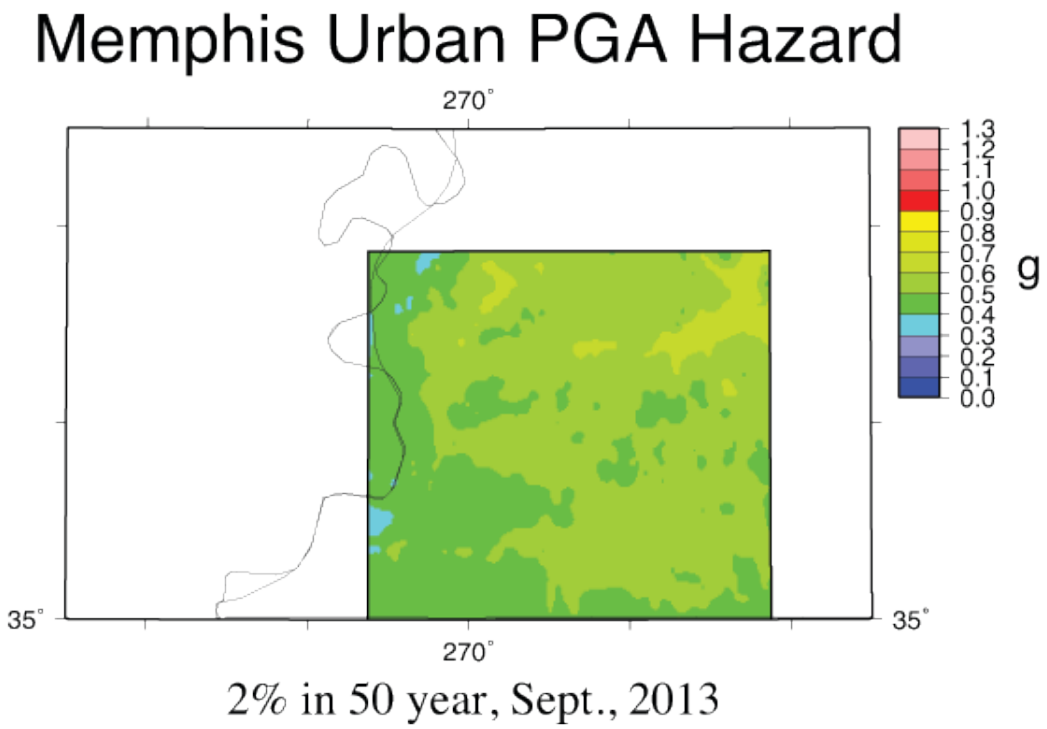
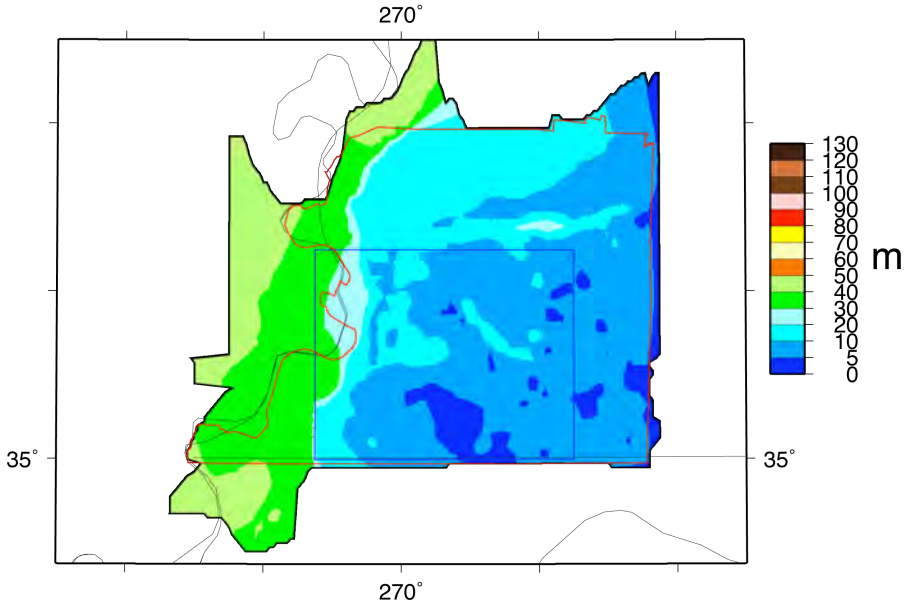


Figure 13: Faulted/Offset geology initial PGA seismic hazard map for 2%-in-50y probability of exceedance covering 12 full quadrangles within Shelby Co.

An investigation into the reasons for the differences between Figures 12 and 13 revealed two major contributors to the difference: smoothing of the geology model and the strong influence of the alluvium/loess first layer. Besides the uplands smoothed geology being projected into the lowlands due to a lack of lowlands geology information, the averaging effect of the geologic smoothing tends to model the first layer as more uniform than what is actually present in much of the study area. As seen in Figure 14, the original six quadrangles have an uplands alluvium/loess thickness generally less than 10 m, which leads to lower ground motion hazard due to a lack of soil amplification and resonance from the thin, very low Vs cover. The low shear-wave (Vs) of the alluvium and loess (169±24 and 191±35 m/s, respectively) compared with that of the Upland Complex and Upper Claiborne layers (268±72 and 360±50 m/s, respectively) along with the greater spatial variability in alluvium/loess thickness (Figure 14) influences the seismic hazard in Figure 13. This is also reflected in the soil resonance frequency of the first layer (Figure 15). The uplands alluvium/loess thickness is thinner (less than 10m) in the SE portion of the county with a resonance frequency above 6 Hz, and thickens markedly to the NW (20 m) with a resonant frequency from 2 to 6 Hz. This thickness gradient is similar in character to the decrease in ground motion away from the New Madrid Seismic Zone from NW to SE. In the lowlands the alluvium (no loess) thickens to the west from near 30 m near the bluff line to 40-50 m near the western edge of the greater Memphis study area and has a resonance frequency below 2 Hz.

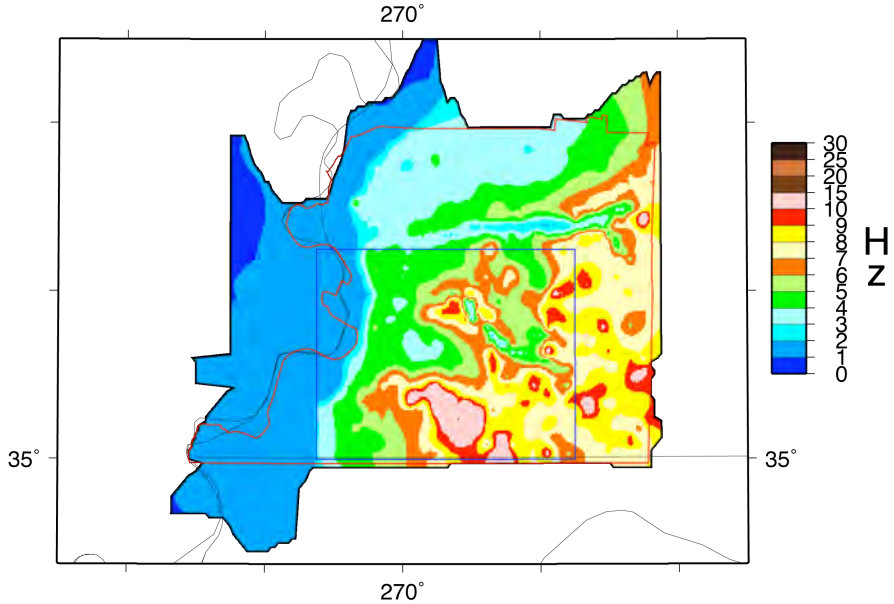
Memphis Alluvium/Loess Thickness



Offset Geology, Feb. 2013

Figure 14: Alluvium/Loess thickness map for the greater Shelby County study area. The blue box shows the original 6-quadrangle study area for the 2004 Memphis urban hazard maps. The red polygon is the outline of Shelby County.

Memphis Alluvium/Loess Frequency



Offset Geology, Feb. 2013

Figure 15: Quarter-wavelength resonant frequency based on a Vs of 180 m/s and the thickness map of Figure 14. The original 2004 study area and outline of Shelby County are shown as in Figure 14.

Based on this initial investigation, it is clear that the fault/offset geology provides a better representation of the 3D geology beneath Shelby County. Also this more realistic geology model leads to some changes in seismic hazard in Shelby County than the previous (and flawed) smooth geology model. However, these new seismic hazard maps must be considered as preliminary as the effect of Vs variations with depth (Romero and Rix, 2001) in the first geologic layer has not been incorporated into the seismic hazard maps.

Technical Seismic Hazard Maps

Figures 16 – 18 show probabilistic seismic hazard maps for the greater Memphis study area. These maps use the updated fault/offset geology and the USGS national seismic hazard model of Petersen et al., 2008. The maps are for 2% probability of exceedance in 50 years and represent peak ground acceleration (PGA), 0.2 s spectral acceleration (Sa), and 1.0 s Sa.

Figure 16-18 compare the urban seismic hazard maps with the effect of local geology with the 2008 NSHMP B/C boundary (Vs30 = 760 m/s) hazard maps. For PGA, the urban maps shows 30-50% reduced ground motions in the lowlands (west of the bluff line) and similar ground motions in the uplands compared to the NSHMP B/C boundary map. For 0.2 s Sa, the urban map shows similar to a 30% reduction in the uplands and greater than 50% reduction in the lowlands. For 1.0 s Sa, the urban map generally shows about a factor of two increase in both the lowlands and uplands, with a little less amplification in the lowlands.

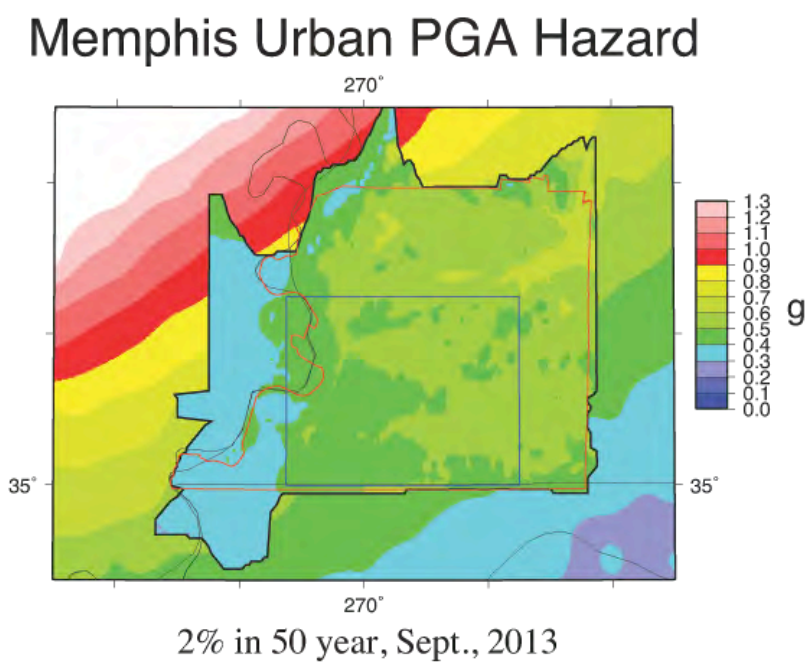


Figure 16: Memphis urban PGA hazard map inserted in the 2008 NSHMP B/C boundary PGA hazard map, both for 2%-in-50y probability of exceedance. The 2004 6-quadrangle study area and Shelby County outline are shown as in Figure 14.

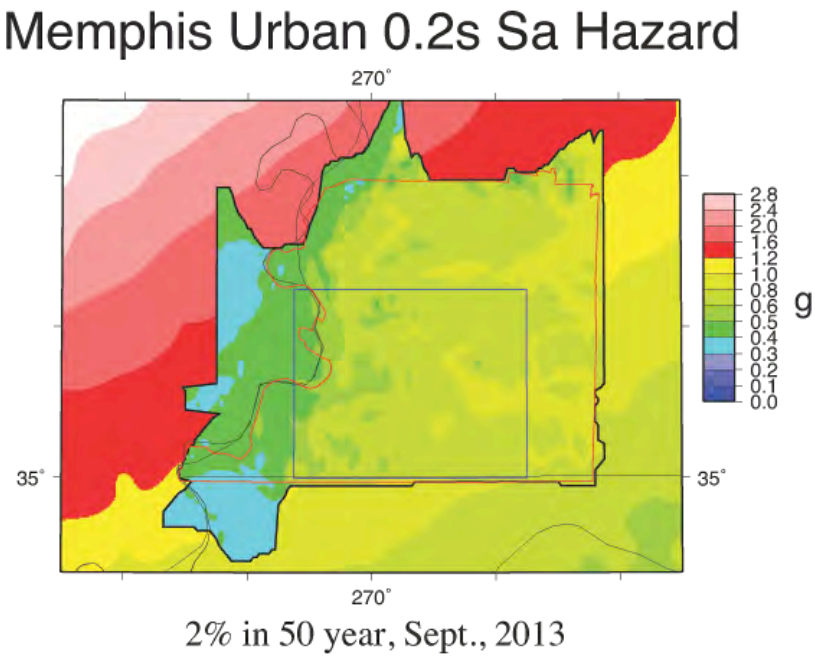


Figure 17: Memphis urban 0.2 s Sa hazard map inserted in the 2008 NSHMP B/C boundary 0.2 s Sa hazard map, both for 2%-in-50y probability of exceedance. The 2004 6-quadrangle study area and Shelby County outline are shown as in Figure 14.

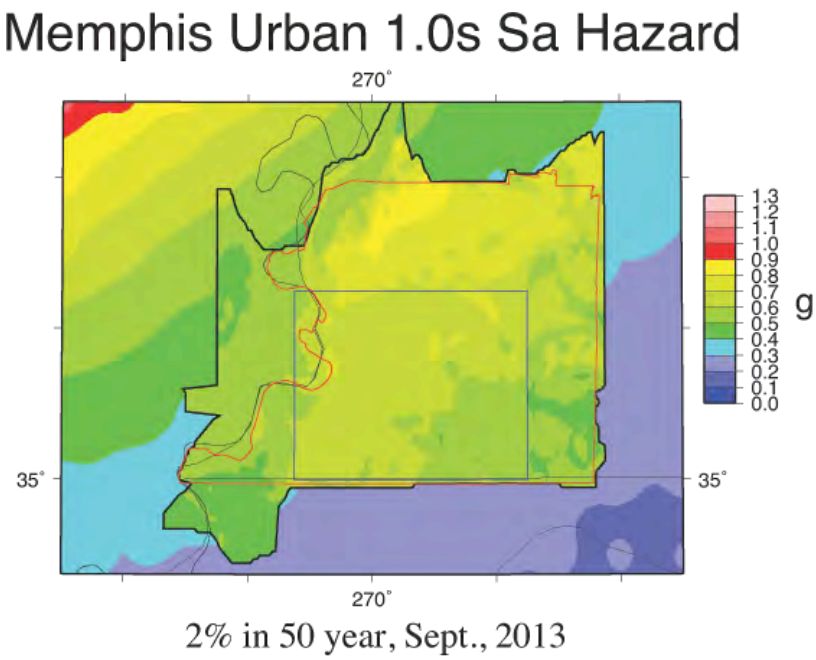


Figure 18: Memphis urban 1.0 s Sa hazard map inserted in the 2008 NSHMP B/C boundary 1.0 s Sa hazard map, both for 2%-in-50y probability of exceedance. The 2004 6-quadrangle study area and Shelby County outline are shown as in Figure 14.

Scenario seismic hazard maps for a M7.7 on the SW arm of the New Madrid Seismic Zone (NMSZ) have also been produced. Figures 19 – 21 present these maps for PGA, 0.2 s, and 1.0 s, respectively. For short periods (PGA, 0.2 s Sa) the lowlands have lower seismic hazard due to nonlinear soil effects in thick alluvium (> 30 m) than the uplands with its thinner alluvium/loess (< 20 m). For long periods (1.0 s Sa) lowlands and uplands have similar seismic hazard due to long period resonance with little nonlinear soil effects. At 1.0 s the NW portion of the uplands has increased seismic hazard due to thicker alluvium/loess (10-20 m) and increased resonance than the SE portion (< 10 m) (Figures 14 and 15).

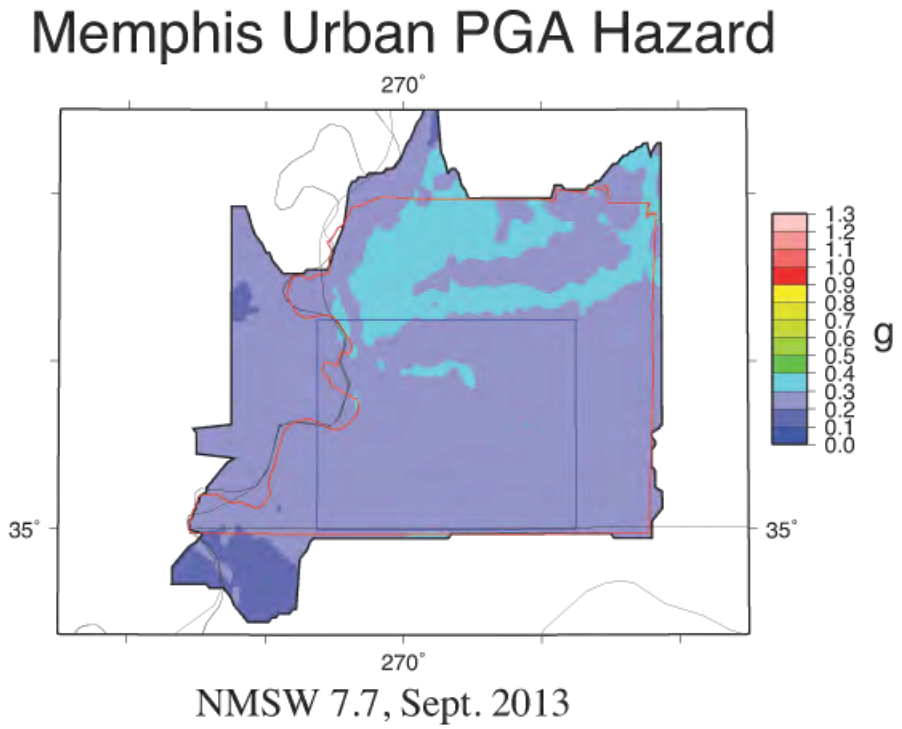


Figure 19: Scenario PGA hazard map for a M7.7 on the SW arm of the NMSZ. The 2004 6-quadrangle study area and Shelby County outline are shown as in Figure 14.

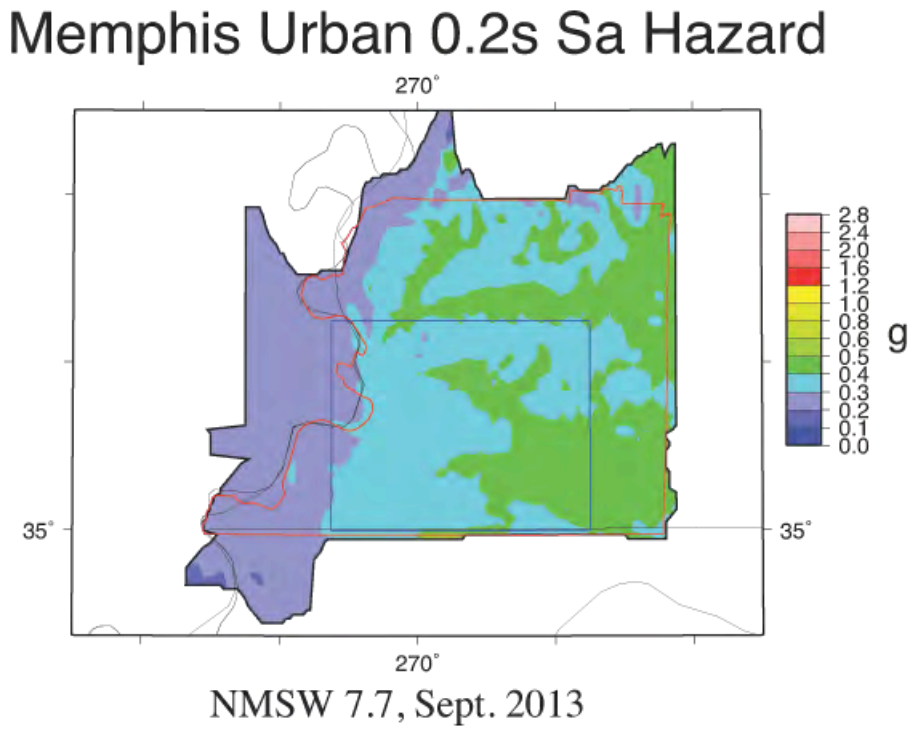


Figure 20: Scenario 0.2 s Sa hazard map for a M7.7 on the SW arm of the NMSZ. The 2004 6-quadrangle study area and Shelby County outline are shown as in Figure 14.

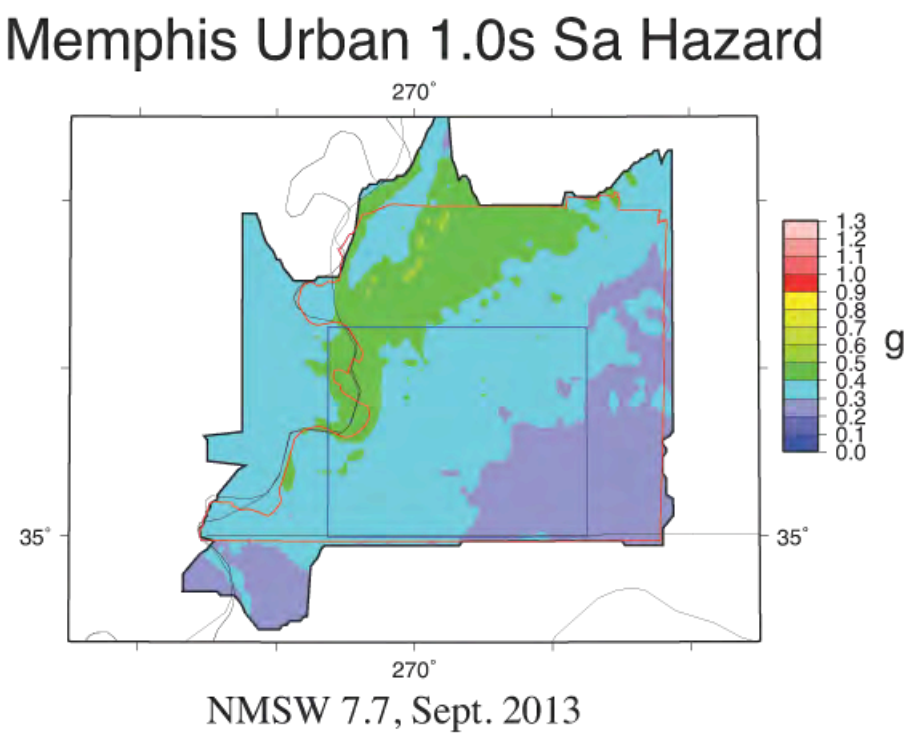


Figure 21: Scenario 1.0 s Sa hazard map for a M7.7 on the SW arm of the NMSZ. The 2004 6-quadrangle study area and Shelby County outline are shown as in Figure 14.

Simplified Shaking Maps

We also derived simplified shaking hazard maps for Modified Mercalli Intensity (MMI) and from the PGA M7.7 scenario map. The MMI hazard map is derived from the 1.0 s Sa scenario map of Figure 21 by applying the ground motion vs. intensity relation of Dangkua and Cramer, 2011. The result is shown in Figure 22 with MMI hazard ranging from MMI VIII to IX. The PGA based simplified hazard map shown in Figure 23 is derived by assigning PGA < 0.1 g to a low shaking hazard category (no to minimal damage), 0.1 ≤ PGA < 0.25 g to a moderate shaking hazard category (significant damage to weak buildings like unreinforced masonry; minimal damage to stronger buildings with modern construction), and PGA ≥ 0.25 g to a severe shaking hazard category (significant potential for building damage). Generally the uplands in Shelby County are subject to severe shaking hazard.

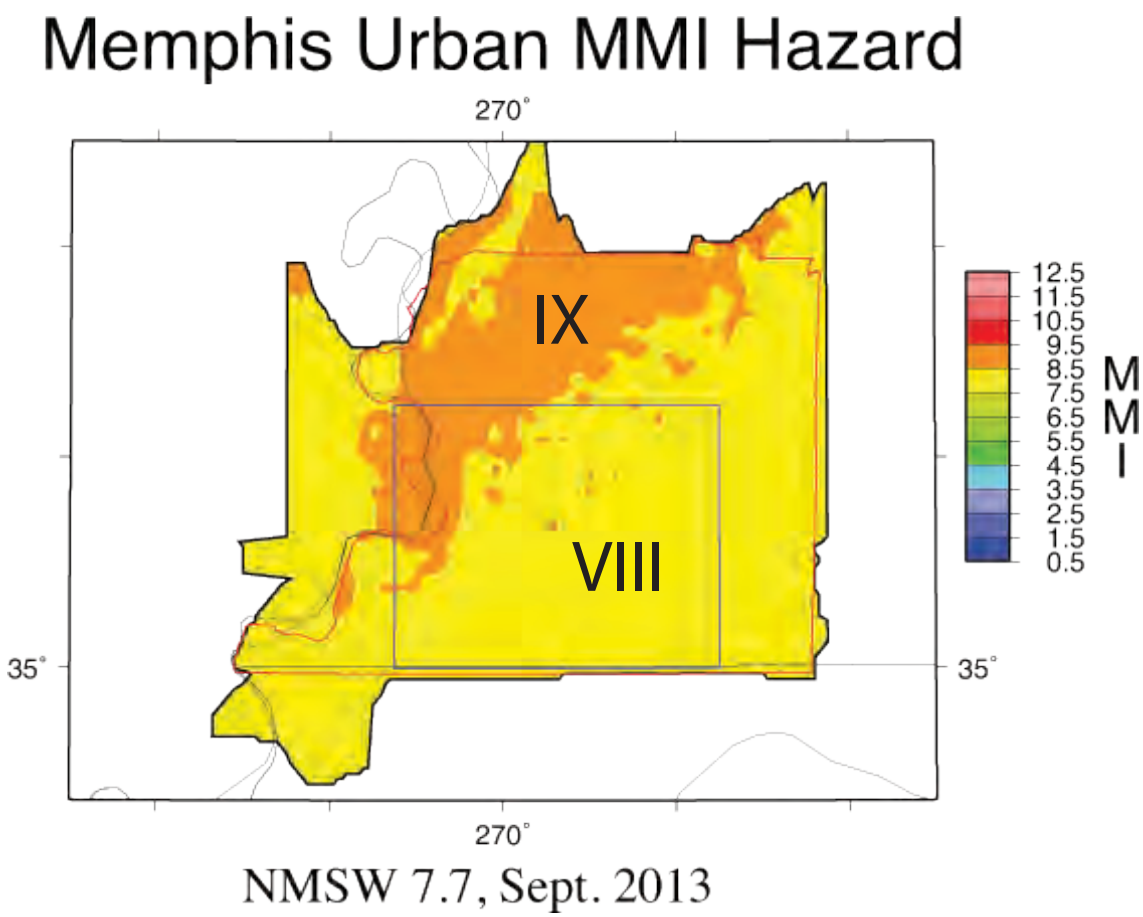


Figure 22: Estimated MMI shaking hazard from a M7.7 on the SW arm of the NMSZ. The 2004 6-quadrangle study area and Shelby County outline are shown as in Figure 14.

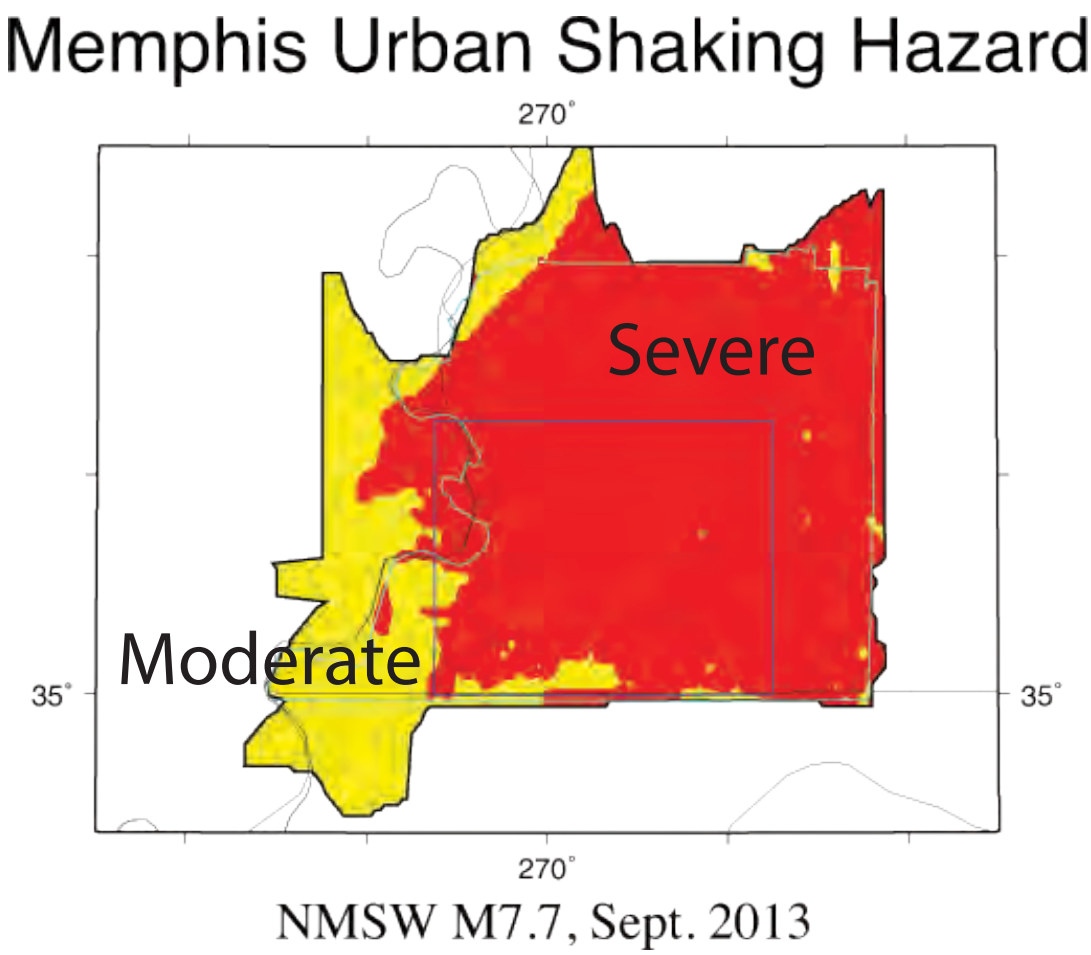


Figure 23: Simplified earthquake shaking hazard map based on a M7.7 earthquake on the SW arm of the NMSZ. The 2004 6-quadrangle study area and Shelby County outline are shown as in Figure 14, except the Shelby County outline is in light blue.

Updated Liquefaction Hazard Maps
(work by Chris Cramer and Mahesh Dhar)

For the liquefaction hazard maps, the approach of Cramer et al. (2008) used to produce the 2004 Memphis liquefaction hazard maps has been applied to all of Shelby Co. Liquefaction probability curves, which are a function of peak ground acceleration (PGA) and earthquake magnitude, have been combined with earthquake scenario seismic hazard maps to produce scenario liquefaction hazard maps, both technical and simplified. Due to problems discussed below with some of the 2004 liquefaction probability curves, updated probabilistic liquefaction hazard maps were not produced. The liquefaction hazard maps were generated using a geographical information system (GIS) by calculating separate liquefaction hazard maps for each surface geology type and combining these separate maps using a cookie-cutter approach inside a GIS with a surface geology map as a guide. Figure 24 presents the updated surface geology map used in this process. Because the tributary streams to the major rivers are filled with reworked loess deposits, they are shown as loess

in the surface geology map along with the Nonconnah Creek sediments, which are also reworked loess.

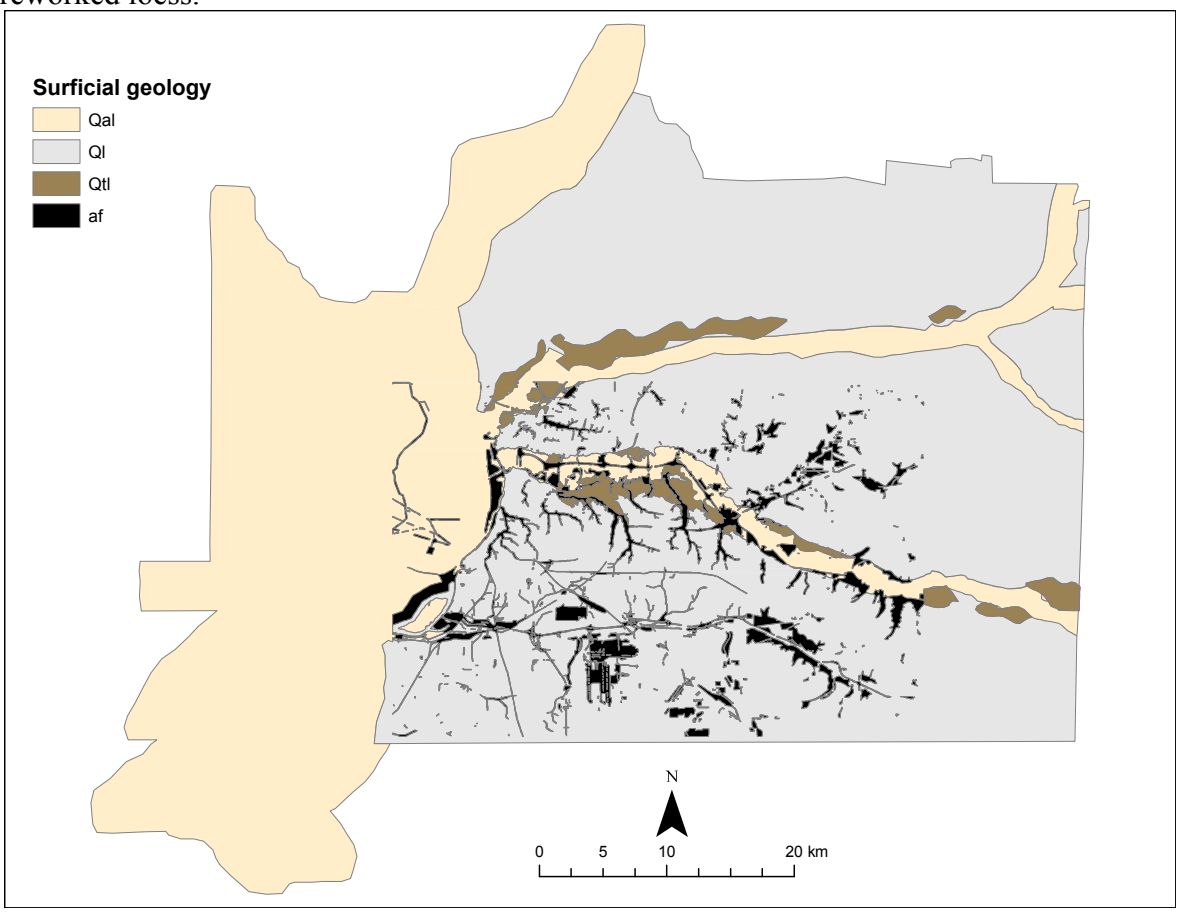


Figure 24: Surface geology map used in producing the liquefaction hazard maps. Qal is alluvium in major river valleys, Qt is loess deposits (mainly in the uplands), Qtl is river terrace deposits, and af is artificial fill, much of it of unknown engineering quality. Thus the black areas are special studies zones requiring geotechnical expertise to evaluate the quality of the fill and hence the liquefaction hazard.

The geotechnical data and analyses have not been updated as part of this grant as it was not part of the proposed work. We have applied the 2004 liquefaction probability curves (Figure 25) to the updated M7.7 scenario seismic hazard map for PGA (Figure 19) using the surface geology map (Figure 24).

Table 1. Number of SPT and CPT profiles in each geologic unit used in the 2004 hazard maps.

Geologic Unit	Number of SPT Profiles	Number of CPT Profiles
Qal	104	0
Qa	113	12
Ql	370	4
Qtl	36	2
Total	623	18

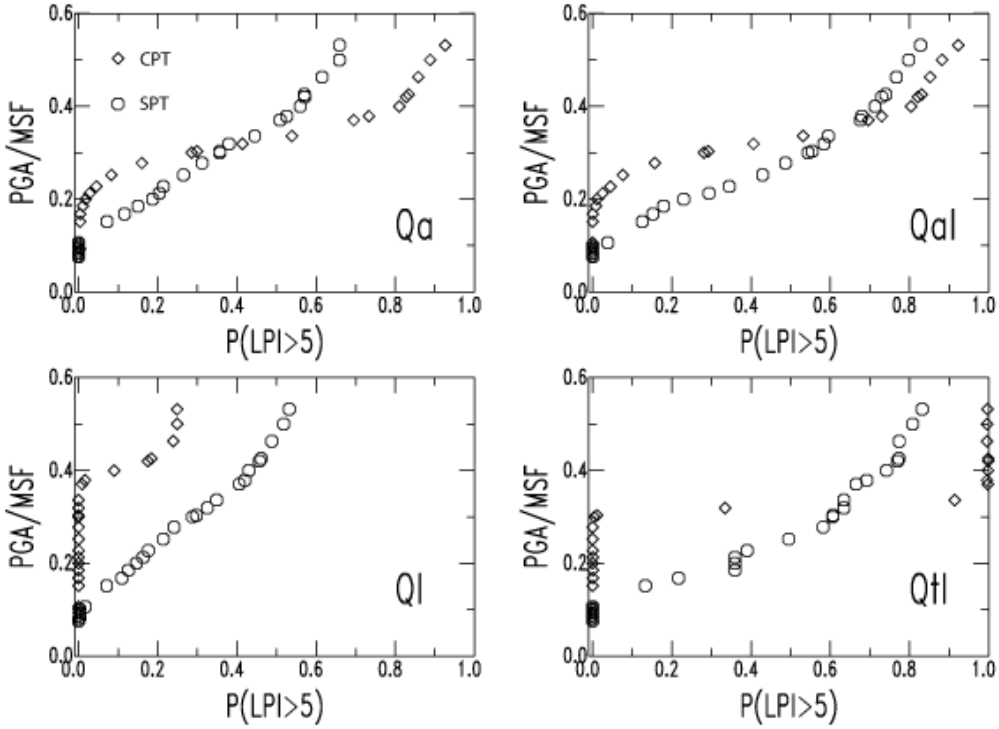


Figure 25: Values of peak ground acceleration divided by magnitude scaling factor (MSF) for indicated probabilities of exceeding LPI 5 (moderate liquefaction potential) from Romero-Hudock and Rix (2005) for the Memphis area. Qa, Qal, Ql, and Qtl are for different surface geology type (alluvial flood plain, loess, and terrace). Diamonds are for CPT measurements and circles are for SPT measurements.

Technical Liquefaction Hazard Maps

We noted that the 2004 liquefaction hazard maps in Cramer et al. (2008) showed loess deposits liquefying more than the geotechnical experts on our TWG expected. So we produced liquefaction hazard maps separately for both kinds of liquefaction probability curves in Figure 25: cone penetration test (CPT) and standard penetration test (SPT). Table 1 relates the number of profiles available in 2004 for each surface geology type from both types of measurements. There were fewer CPT than SPT measurements available so in 2004 the SPT results were weighed twice the CPT results in the producing combined liquefaction hazard maps presented in Cramer et al. (2008).

Figures 26 and 27 show the CPT and SPT based liquefaction hazard maps for a M7.7 on the SW arm of the NMSZ. These maps are for the Liquefaction Potential Index (LPI) exceeding 5 and show the probability of LPI>5, which is considered the onset of liquefaction that manifests at the surface. For the loess deposits, the CPT liquefaction hazard map of Figure 26 appears more reasonable, although maybe still high, than the SPT liquefaction hazard map from a geotechnical point of view. Loess in not expected to liquefy due to the very fine-grain nature of the loess deposits.

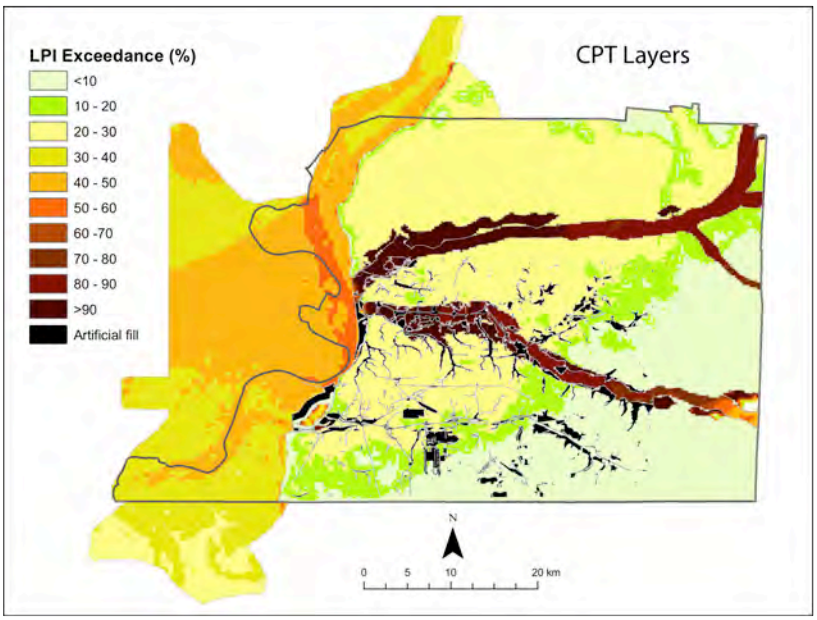


Figure 26: 2013 liquefaction potential index (LPI) > 5 scenario hazard map for Memphis, Shelby Co., TN for PGAs in Figure 19 based on CPT liquefaction probability curves (Figure 25).

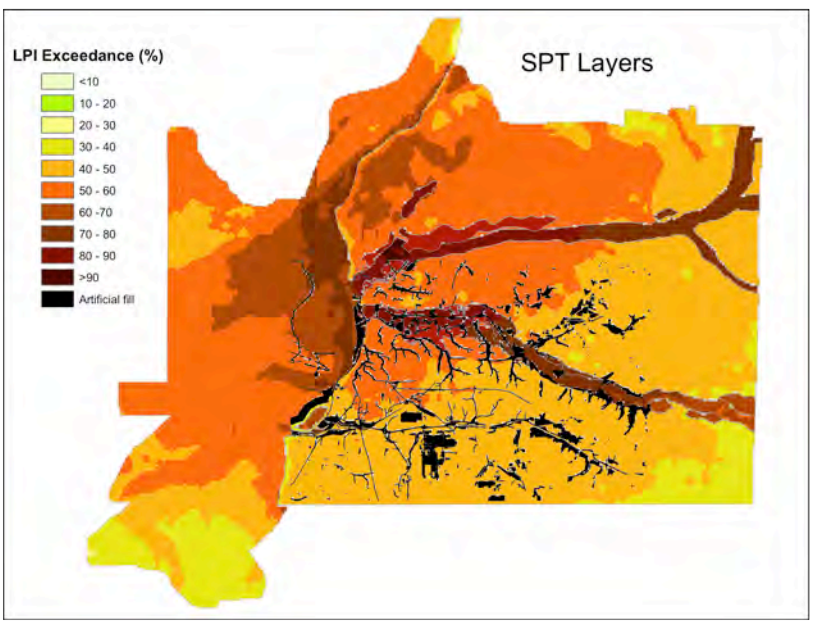


Figure 27: 2013 LPI > 5 scenario hazard map for Memphis, Shelby Co., TN for PGAs in Figure 19 based on SPT liquefaction probability curves (Figure 25).

In Figure 26, we have used the shallow water table (1.5 m) liquefaction probability curve of Holzer et al. (2011) for the Mississippi River floodplain (west of the bluff line). The Holzer et al. curve has a lower PGA for the onset of liquefaction than the 2004 Qal CPT curve. The CPT measurements that were used to develop the Holzer et al. curve are from the Mississippi River floodplain adjacent to Memphis and should be a more reliable indicator of liquefaction

hazard than the Qal CPT measurements from the Wolf River and Mud Island at the mouth of the Wolf River.

Based on the results shown in Figures 26 and 27, the geotechnical component of the Memphis TWG strongly recommended an updating of the Memphis geotechnical data and liquefaction probability curves to improve the reliability of the Memphis liquefaction hazard maps. This has been proposed to the USGS NEHRP external research program as part of a June 6, 2013 proposal.

Simplified Liquefaction Hazard Map

A simplified liquefaction hazard map based on Figure 26 has been produced and is shown in Figure 28. The CPT liquefaction hazard map (Figure 26) is considered a better representation of liquefaction hazard and can be interpreted as the percent area likely affected by liquefaction. To simplify it we set a probability below 40% as low liquefaction hazard, 40-60% as moderate liquefaction hazard, and above 60% as severe liquefaction hazard. Due to the uncertainty in the values of liquefaction hazard from a small number of CPT observations, the liquefaction hazard in the Mississippi River floodplain is shown as severe in Figure 28, pending an update of the Memphis geotechnical information.

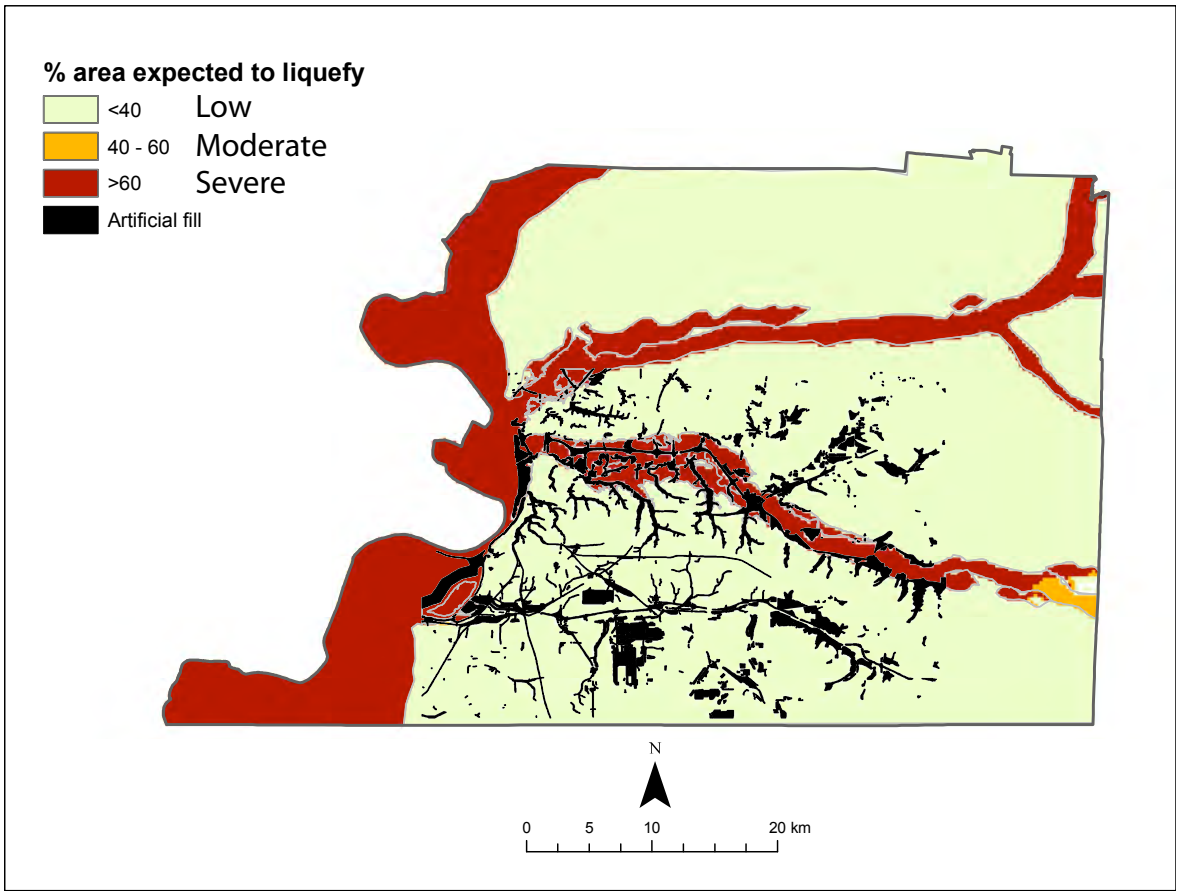


Figure 28: Simplified liquefaction hazard map for Shelby County.

Conclusions

One obvious conclusion from the simplified seismic and liquefaction hazard maps (Figures 23 and 28) is that in the uplands the seismic hazard is severe and in the lowlands the liquefaction hazard is severe. In general the earthquake hazard in the Memphis and Shelby County area is a serious issue.

Also the impact of the 2014 update to the NSHMP hazard maps and model for the CEUS needs to be taken into account. The 2014 NSHMP update will add new-since-2008 GMPEs and these GMPES will tend to lower the seismic hazard in the Memphis area. Also the 2014 NSHMP will be adding some new-since-2008 seismic sources in the vicinity of Memphis, which will tend to increase seismic hazard, but not as much as the expected decrease in ground motions from the added GMPEs. It is important to incorporate these changes into the Memphis urban hazard maps quickly to smooth out the ups (2012-2013 geology model update) and downs (2014 NSHMP update) in hazard in the Memphis area, which can be a detriment to the user community.

Finally, the geotechnical data and liquefaction hazard curves for the Memphis urban hazard maps need updating as recommended by the TWG and explained above. This has been proposed to the USGS NEHRP external grant program as of June 6, 2013, along with the including of the NSHMP 2014 update information. This should be done before the 2012-2013 updated Memphis urban hazard maps are officially released.

Workshop
(work by Gary Patterson, Chris Cramer, and Roy Van Arsdale)

On March 13, 2013 a workshop was held at the University of Memphis at which we presented the updated Memphis urban hazard maps, discussed mitigation efforts in Shelby County, informed participants about the hazard impacts of the 2010-2011 Christchurch, NZ earthquakes, and held breakout sessions to obtain user community input on Memphis area hazard mapping, mitigation, and future directions. The workshop was co-sponsored by the West Tennessee Seismic Safety Commission, the U.S. Geological Survey, the Mid South Association of Contingency Planners, and the Center for Earthquake Research and Information at the University of Memphis. The agenda is attached in Appendix A. There were 100 registrants and, of these, 85 participated. Presentations from the workshop are available for downloading at https://umdrive.memphis.edu/ktucker1/public/MemphisHazardMaps_Workshop/.

Publications to Date

There are no publications on this work to date.

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Appendix A:

ANNOUNCEMENT OF MEMPHIS AREA EARTHQUAKE HAZARDS MAPPING PROJECT (MAEHMP) WORKSHOP ON MARCH 13, 2013
University Of Memphis, University Center
9:00 AM – 3:00 PM

Sponsors: WTSSC, USGS, MSACP, CERI

We will be holding a workshop of the Memphis Area Earthquake Hazards Mapping Project's (MAEHMP) updated seismic and liquefaction hazard maps on March 13th from 9 AM – 3 PM (lunch included) at the University Center (UC) Ballroom at the University of Memphis (map at http://map.memphis.edu/). The goal of the workshop is to present updated Memphis/Shelby urban seismic hazard maps, interact with the user community, and obtain feedback on user needs concerning seismic hazard education, outreach, and mitigation. We seek not only earth science and geotechnical engineering experts to attend and participate but also members of the engineering, public agency, and private sector user community to help provide input and guidance to our hazard mapping efforts beyond the current project.

Please consider attending and let us know your interest and feedback on needed urban seismic and liquefaction hazard mapping for Memphis and Shelby County. Please respond (ccramer@memphis.edu) and let us know if you will be attending (attendees get both lunch and validated parking). Below is the agenda for the March 13th meeting.

Please circulate this announcement to others you think might be interested in attending.

Workshop Agenda

8:30 Registration and Coffee
9:00 Plenary Sessions:
- Welcome and Introductions – Gary Patterson (5 min)
- Project Overview – Chris Cramer (5 min)
- Geology Update in Hazard Maps – Roy Van Arsdale (30 min)
- New Seismic and Liquefaction Hazard Maps – Chris Cramer (30 min)
- Christchurch, NZ Earthquakes: Lessons for Memphis – Oliver Boyd (30 min)

10:40 Break
11:00 Mitigation Efforts: Business, Industry, and Government
- Jay Stressel – MLGW mitigation efforts (30 min)
- Involving Community and Sustaining Earthquake Mitigation – Phyllis Steckel (30 min)

12:00 Lunch
12:30 Lunch Speaker: Ashref Elsayed – mitigation at the Pyramid (30 min)

1:00 Breakout Sessions on User Community Needs and Sustaining Mitigation Efforts:
- Utilities and Business Continuity (leader: Rick Bowker)
- Urban Planning, Chamber, Government (leader: Phyllis Steckel)

Engineering/Architecture (leader TBA if needed)
Emergency Management (leader TBA if needed)

2:30 Closing Plenary – Breakout Session Reports

3:00 Closing remarks – Chris Cramer (5 min)