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COMPILATION OF DATABASES AND MAP PREPARATION FOR REGIONAL AND LOCAL SEISMIC ZONATION STUDIES IN THE CUSEC REGION: COLLABORATIVE RESEARCH - ORGANIZATION OF CUSEC STATE GEOLOGISTS WITH ASSISTANCE FROM USGS AND ADMINISTRATIVE SUPPORT FROM CUSEC

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Element V: Application of Research Results Providing Geologic Hazards Information Services

Keywords: Seismic Zonation, Regional Seismic Hazards, Geologic Mapping (Surficial Deposits), Database

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TECHNICAL ABSTRACT

The Central United States Earthquake Consortium (CUSEC) State Geologists recognized the need to transfer geologic research and develop map information on earthquake hazards for the CUSEC regions State emergency managers. The complexities of dealing with a multi-state region to produce a coherent display of geology across state lines is overcome as the State Geologists provide a coordination of the methodology to develop the soil amplification potential map showing the seismic shaking hazard for the 1 x 2 degree (scale 1:250,000 or 1 inch . 3.9 miles) Belleville, Rolla, Vincennes, Evansville, Dyersburg, St. Louis, Poplar Bluff, Blytheville, and Memphis quadrangles. Shear wave velocity values for the surficial materials were gathered and used to classify the soils as to how much they may amplify earthquake ground motions. Base geologic maps of surficial materials or 3-dimensional maps previously existing or produced for this projected were used in conjunction with shear wave velocities to classify the soils for the upper 15 to 30 meters. These maps are produced in an electronic form suitable for inclusion in FEMA♣s Earthquake Loss Estimation Program (HAZUS).

NON-TECHNICAL ABSTRACT

The Central U.S. Earthquake Consortium (CUSEC) State Geologists have gathered information on soils properties in the Midwest and produced maps showing how the soils would amplify earthquake ground motions. The first three maps previously produced covered parts of the states of Illinois, Missouri, Kentucky and Indiana for the Paducah map; Indiana, Ohio and Kentucky for the Cincinnati map and Mississippi, Arkansas and Tennessee for the Memphis map. The second set of maps, 1 x 2 degree maps of the Belleville, Rolla, Vincennes, Evansville, Dyersburg, St. Louis, Poplar Bluff, Blytheville, and Memphis quadrangles cover parts of Arkansas, Illinois, Indiana, Kentucky, Missouri, and Tennessee. The coordinated effort of the State Geological Surveys assures a uniform, coherent display of geology across state lines and an agreement in assigning the same amplification values to the soils. This will produce electronic maps of soil amplification potential that are critical in producing more realistic estimates of earthquake damage in the Federal Emergency Management Agency's Earthquake Loss Estimation Program (HAZUS). This computer program is available free to local and state governments to assess their vulnerability to earthquake damage. These soil amplification maps produced by the state geological surveys replace the default data maps in the HAZUS program which shows only one soil type for the entire Midwest, versus the 6 soil types that exist.

INTRODUCTION

It is understood that not only distance to an earthquake is important in defining risk but also the type and thickness of sediments that exist across the landscape. Many surficial materials amplify earthquake ground motions resulting in damage to structures resting on these materials far from the epicenter of the earthquake. Defining these areas and conveying this information to emergency managers and responders is important in their planning for response and conducting exercises. Additionally, land use planners and officials can use this information for community planning in reducing future damage.

The Central U.S. Earthquake Consortium (CUSEC) organization of State Geologists has been guided by State and Federal Emergency Management Agency (FEMA) Emergency Managers in producing various earthquake related maps of the Midwest and setting up the CUSEC Earthquake Prediction Evaluation Council for the Midwest. The first CUSEC seismic hazard map was produced at a scale of 1:2,000,000 or about 1 inch = 31 miles for a seven state area. This map shows areas of higher and lower potential for amplification of earthquake ground motion by nonlithified geologic materials (soils) or for liquefaction of these soils.

The next level of detailed mapping was started with a previous NEHRP award where mapping at a scale of 1:250,000 or 1 inch = 3.9 miles was performed for the 1 x 2 degree quadrangles of Paducah, Cincinnati and parts of the Memphis and Blytheville. This NEHRP award covers nine more 1 x 2 degree quadrangles of Belleville, Rolla, Vincennes, Evansville, Dyersburg, St. Louis, Poplar Bluff, Blytheville, and Memphis. All together this mapping covers the high risk area of the New Madrid Seismic Zone in the states of Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, Ohio and Tennessee.

1:250,000 Scale General Mapping Procedures

Seismic zonation literature was reviewed for amplification of seismic waves by soils (FEMA 249, Borcherdt, 1994; Borcherdt et al., 1991; Fumal and Tinsley, 1985; Mabey et al., 1993; Martin and Dobry, 1994; Tinsley and Fumal, 1985; and Woodward-Clyde, 1991). It was agreed that the general methodology outlined in Borcherdt (1994) was the best and latest technology that could be applied. Later it was learned that the same classification system was incorporated into the then developing Federal Emergency Management Agency♣s Earthquake Loss Estimation Program (HAZUS). This methodology assigns soil classification letters of A, B, C, D, E_1, E_2, and F as defined by the soil♣s shear wave velocity, thickness and potential to liquefy. Other engineering parameters were later added (FEMA 222A) to assist in the soil classification work in the absence of shear wave velocity data (table 1). This classification system appears in the 1994 NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings (FEMA 222A), in the FEMA Earthquake Loss Estimation Program (HAZUS), and in the Uniform Building Code of 1997.

Information was gathered on existing shear wave velocity values of sediments in the Midwest (Harris et al., 1994) and other shear wave velocities were measured and collected during the study (table 2). A comparison of the Midwest shear wave velocity values and soil descriptions to the Borcherdt's (1994) classification indicated that they matched very well, but there were questions concerning soil materials that do not exist in California and how they fit into the classification. The small amount of shear wave velocity values helped classify most of these materials. Table 3 shows the correlations of the central U.S. geologic materials to the NEHRP/UBC general soil description/soil profile type. Based on these correlations, soil classification values were assigned to each unit in the mapping areas (table 4).

Arkansas Portion of the Popular Bluff and Memphis Quadrangles

A map defining soil amplification potential during an earthquake was created on the 1 x 2 degree Memphis quadrangle. The map was digitized in ArcView GIS to delineate regions based on the standard FEMA 222A soil classification (A thru F).

Saucier's (1994) maps were used to define the geology of the Lower Mississippi River Valley which was then traced onto mylar, and then transferred onto a paper copy of the 1 x 2 degree Memphis map. The final 1 x 2 degree Memphis soil amplification potential map was digitized map into ArcView GIS from a traced paper copy.

The Ozarks (western portion of the map) was assigned class "B" because it is underlain by sedimentary rocks (sandstone, limestone, shale). Crowley's Ridge was designated class "D" because it is composed of sand and gravel and capped by loess in several locations. Some Tertiary formations were assigned class "C" since they are stiff soils. In other locations, Tertiary formations are thin veneers overlying Cretaceous rocks and were assigned class "B". The rest of the map is loose unconsolidated sediment and is designated class "F". Blow count from bridge construction data near rivers was attained from the Highway Department in Little Rock and was used to modify Saucier's data in some locations.

Tom Hart of the Tennessee Division of Geology classified the city of Memphis and the hills to the north of the city. The eastern part of the map was digitized based on Mr. Hart's data.

Illinois Portion of St. Louis, Vincennes and Belleville Quadrangle

State wide Stack-Unit Map (Berg and Kempton, 1987) was used for the Belleville Quadrangle area. The stack-unit map shows the layers of materials (units) down to a depth of 15 meters below the ground surface at a scale of 1:250,000. Each of the components of the stacked units, represented as a polygon on the map, were entered into a spreadsheet. Each unit in the stacks was assigned a shear wave velocity value and thickness. Average shear wave velocities of the units were used based on existing shear wave velocity values of sediments in the Midwest and some collected during the study (table 2). The average shear wave velocity value for each stacked set of units was calculated according to the formula presented in FEMA 222A (table 1). The resulting calculations were assigned the NEHRP/UBC soil classification as per the shear wave velocity ranges for each soil classification and therefore each stacked unit polygon on the map.

The areas east (Vincennes) and west (St. Louis) of the Belleville 1 x 2 degree quadrangle up to the state boundaries were also included in the work of the Illinois Survey. This would allow state wide type coverage which would be easier for communities to use and understand versus quadrangles that most are not familiar with.

Indiana Portion of the Vincennes Quadrangle

Shear wave velocity data that had been collected in the past (Eggert et al., 1993) was used to classify the different soil types that were present on the Vincennes 1:250,000 scale regional geologic map. Shear wave values from specific sites were summed and averaged so that one value could be assigned to the soil type that was present in the area. After the shear wave average was determined the soil type was placed into categories from NEHRP (FEMA 222A, table 1). Since geographical coverage was neither continuous nor uniform, some blow count data was also collected from the Indiana Department of Transportation and applied in the same way (FEMA 222A). The results give average values for soil types in the area, however, not all of the average values fall into the same category. This might be attributed to several factors: 1) thickness of the sediment was not taken into consideration; 2) homogeneity of the soils was assumed; and 3) compaction or density of the soils varies from location to location. The first problem is the only one of the three addressed in detail here.

Once this information is quantified and grouped accordingly, then it can be used to help classify the sediments in the area of the project. Before this can be accurately accomplished, however, a method must be found that will take into account the thickness of the sediments. Gamma log data was used to do this once.

<u>Methods</u>

The data used in Eggert et al., (1993) was first separated into useable formats. The first was a large table format that was probably the first table calculated from each set of data. The data preserved in this format was useful for determining the location of the site and the geologic classification of the surficial soil type that was present at the site. It also recorded the shear wave velocities that were recorded from a surface refraction line at the site. The descriptions of the soil types consisted mostly of grain size and color information. No information on the depth of the sediment or of the stratigraphic column was recorded in these tables. The second type of readable data was a series of tables that showed calculated vertical seismic profile data. This data has depth information provided but has no recorded information on the geology that is present. The geology was taken from the regional 1:250,000 scale geologic map in both circumstances.

Results

Calculations of the data and interpretation of the map led to the quantifying of 5 types of soils in the area (table 5), although others are present, alluvial, lacustrine, loess, eolian sand (dry and saturated), and outwash. Alluvial, loess, sand, and lacustrine sediments are well constrained as they were present in many places. Outwash, however, was only present in the Vincennes area and is not constrained at all for other areas of the map.

Conclusions

The results show that most of the sediment in the Vincennes 1:250,000 scale regional geologic map can be classified using FEMA 222A. In order for the finished product to be completely accurate, the first 100 feet of the stratigraphic manual must be taken into consideration. This was done for three spots using data from Eggert et al., (1993) and one spot using gamma log data. The best answer for this problem may be to use gamma log data to ascertain accurate information when available. Another option is to combine the digital copy of the 1:250,000 scale regional geologic map with the corresponding sediment thickness map and then average the value from the surficial sediment with the amount of bedrock present in the top 100 feet in order to get an accurate finished copy.

Kentucky Portion of the Evansville Quadrangle

Geologists at the Kentucky Geological Survey, University of Kentucky, Lexington, compiled the Kentucky portion of the Evansville quadrangle. Although most of the surficial geology had been mapped at a scale of 1:24,000 between 1960 and 1978, very little work has been done to characterize the unconsolidated sediments in the region. Consequently, hazard assessment relied on work from Indiana and Illinois plus communications with researchers in the area (Street et al 1995, 1997, personal communications)

The geology was compiled from 1:24,000 scale geologic quadrangle maps using Arc/Info software. The quadrangle is composed primarily of either Paleozoic-age rocks or nonlithified Quaternary-age material. Since the rock units (shale, sandstone, and some limestone, interbedded with coal seams) exhibit essentially the same shear wave velocities, they were not differentiated when digitized. The Quaternary-age sediments consist of glacial outwash, lacustrine deposits, and loess, plus alluvium. Original mappers of each quadrangle had varying levels of interest in the Quaternary deposits, thus there is a wide range of detail between maps and, sometimes, between the same mapper of multiple quadrangles. Digitizing these units preserved the original Quaternary detail and no attempt was made to rectify the geology across map boundaries.

The map units were evaluated for their ground motion amplification characteristics using the NEHRP (FEMA 222A) six-category classification system based on the average shear wave velocity of each of the units. The shear wave velocity of each material category was correlated to known measured test values in adjoining areas of Indiana and Illinois or estimated based on discussions with researchers familiar with the material characteristics of the area. Because of the lack of information, the thickness of the sediment was estimated and homogeneity of the soils was assumed. Dr. Ron Street provided average shear wave velocities for the upper 30 meters of unconsolidated materials for a number of sites from his field research, which is funded by the USGS through the National Earthquake Hazards Reduction Program (Street, et al, in review).

Kentucky Portion of the Dyersburg Quadrangle

Geologists at the Kentucky Geological Survey (KGS), University of Kentucky, Lexington, compiled the Kentucky portion of the Dyersburg quadrangle. The primary source of the digital geology was obtained from the existing 1:500,000 Geological Map of Kentucky (Noger, 1988) which was digitized by the USGS. The surficial geology in this coverage is relatively rudimentary, especially for the Quaternary-aged unconsolidated sediments. KGS supplemented this coverage with data obtained from 1:24,000-scale digital geologic quadrangle maps digitized at KGS. There is also a lack of sub-surface information for this area and thickness of the unconsolidated sediments could only be estimated

The KGS was also responsible for compiling all of the Dyersburg 1:250,000-scale map from coverages provided by Tennessee and Missouri. The geology was rectified along the state boundaries and was generalized as much as possible without compromising the hazard evaluations. There is very good agreement between the coverages, although the area surrounding Lake Barkley and the Land Between the Lakes is somewhat more disjointed than it could be. However, resolving this area will require additional investigations and field-work.

As with the other coverages, the map units were evaluated for their ground motion amplification characteristics using the NEHRP (FEMA 222A) six-category classification system based on the average shear wave velocity of each of the units. Shear wave velocities for the Kentucky portion are based on information from published research (Street et al 1995, 1997, personal communications), similar work done in surrounding areas, and from discussions with other researchers familiar with this area.

Missouri Portion of the St. Louis, Rolla, Poplar Bluff, Dyersburg, and Paducah Quadrangles

The Missouri Department of Natural Resources, Geological Survey was responsible for the 1:250,000 scale mapping of the Missouri portion of the St. Louis, Rolla, Poplar Bluff, Dyersburg, and Paducah quadrangles, which includes about one-quarter of the state of Missouri. Adequate existing 3-dimensional maps of the upper 50 to 100 feet of surficial materials needed for interpreting the ground motion amplification did not exist. Therefore, new unpublished 3-D surficial mapping was undertaken as a part of this project. Two existing subsurface databases of well log information were utilized to construct five surficial materials type maps, one each for total thickness of surficial materials, alluvium thickness, residuum thickness, glacial materials thickness, and undifferentiated materials thickness. Total thickness was contoured into four categories: <6', 6'-20', 20'-50', and >50'. Alluvium was contoured into four categories: none, <20', 20'-50', and >50'. Residuum was contoured into three categories: none, <20', and >20'. Glacial materials were contoured into three categories: none, <20', and >20'. Glacial materials were also subdivided into primarily loess, in southern Missouri south of the Missouri River, and till plus loess, in northern Missouri north of the Missouri River. Undifferentiated materials were contoured into two categories: none and >20'. Undifferentiated materials were also subdivided into Tertiary and Cretaceous unconsolidated sediments in extreme southeast Missouri and Pennsylvanian residuum in central Missouri. Using ArcView GIS software these five maps were combined into one final 3-D map containing over fifty units which identified the thickness, distribution, and stacking of the various materials.

The final 3-D map units were then evaluated for their ground motion amplification characteristics using the NEHRP (FEMA 222A) six-category classification system based on the average shear wave velocity of each of the units. The shear wave velocity of each material category was correlated to known measured test values or estimated based on material characteristics. Then the average shear wave velocity was calculated for each of the final 3-D map unit stacks of materials. Because the thickness of the various materials were mapped into ranges, several calculations of the average shear wave velocity had to be made for each final 3-D map unit. After the range of the average shear wave velocity for a unit was determined, the most representative value was selected, and based on this value, the unit was classified. This process was facilitated by constructing a spreadsheet into which the sequence of material shear wave velocity values and material thickness values could be entered, and then the spreadsheet calculated the average shear wave velocity for the stack. The average shear wave velocity was calculated using the formula in table 1. The average shear wave velocity was calculated to a depth of 30 meters or approximately 100 feet.

After the average shear wave velocity of a stack of units was calculated, the ground motion amplification classification was assigned based on this value and the NEHRP classification system. The exception to this is the classification F for soil liquefaction, which does not have a shear wave velocity associated with it. It is classified F based on material descriptions and saturation.

Tennessee Portion of the Blytheville and Dyersburg Quadrangles

In Tennessee, standard penetration test blow-count data, widely available, were taken as a proxy for rarely available shear-wave velocity data. An exception is for flood plain alluvium, as discussed below. Engineering boring logs with blow counts were compared with information from surface geologic maps (mostly published), a manuscript map (by author Thomas A. Hart) of thickness of surficial deposits for Shelby County, geophysical logs, and for certain situations driller's logs (for water wells generally located approximately). Geologic units were identified in the boring logs in comparison with the other data sources and from such correlations, characteristic blow-count values of the various units were determined. In all cases, such blow-count data range widely for a given geologic unit and the estimated blow-count value used for mapping was of necessity a compromise, such data not being available uniformly throughout the area.

The soil classification category appearing on the map were derived as follows: The influences of the various geologic units on earthquake amplification potential were proportioned to their estimated respective fractions of the top 100 feet [about 30 meters] that they occupy at a given place, as inferred from the geologic and thickness maps and engineering, geophysical, and driller's logs cited above. Driller's logs were used only to estimate a generalized boundary between classification E or 5 and D or 4, where these reflect, respectively, the predominant and subordinate influence of loess and its derivatives.

As mentioned above, flood plain alluvium (and low terrace deposits) present a separate problem. It is known that such deposits widely liquefied close to the 1811-1812 New Madrid earthquake epicenters and this was taken as the basis for placing them into classification F or 6. Where a sufficiently thick (10 meters) fine-grained top stratum is present to suppress eruption of sand, the classification is E or 5. (Use of the blow counts as in other situations would give quite different results in most cases.)

Geologic maps cited as information sources are 1:24,000 scale, mostly published, available from the Tennessee Division of Geology. These are available for extensive areas of the eastern part of western Tennessee. The state geologic map at 1:250,000 scale was seldom useful, especially because the Wilcox and Claiborne Formations are not mapped separately on it. The author's map of thicknesses of surficial units in Shelby County is of 1:100,000 scale. The author depended on 1:24,000 scale topographic maps to distinguish flood plains and low terraces.

Base maps for the Tennessee portions of the earthquake amplification potential maps were as follows: For Memphis Metro quadrangle, the Memphis East, Memphis West, Holly Springs, and Helena 1:100,000 topographic quadrangles, reduced to 1:250,000. For Blytheville and Dyersburg quadrangles, the standard 1:250,000 topographic quadrangles. All plotting was by hand on mylar overlays, digital plotting technology (and experience) not being presently available in the Tennessee Survey. Digitizing and geographic information system work was performed at the Kentucky Geologic Survey.

Limitations for Mapping

One limitation for mapping at this scale is the type of information available for depth to groundwater and its use in seismic evaluations. The information from rural wells is widely spaced and does not display the depth to the first unconfined aquifer (groundwater table), but the hydrostatic head of an aquifer or collection of aquifers spanning the screened section of the well.

Another limitation of the soil amplification potential map is the same as any other geologic maps and that is the location of the boundaries between similar materials. The soil amplification potential maps are based on existing and specially produced surficial and 3-dimensional geologic base maps which have had their boundaries of similar materials defined by varying densities of boreholes across the mapped areas.

A comparison was made between soil classifications produced from the surficial map and stacked-unit map of the Paducah Quadrangle. This comparison showed that 37% and 27% of the stacked-unit soil classifications were one and two higher soil classification units (less amplification) respectively, than classifications based only on a surficial map. This shows that the use of only surficial maps for soil classification would produce a conservative map showing more amplification throughout an area.

These limitations clearly show that these maps are not to be used for site specific analysis of structures. Site specific investigations should be performed to document or confirm conditions.

SUMMARY

The 1 x 2 degree quadrangles of Belleville, Rolla, Vincennes, Evansville, Dyersburg, St. Louis, Poplar Bluff, Blytheville, and Memphis which cover parts of Arkansas, Illinois, Indiana, Kentucky, Missouri, and Tennessee were mapped using a soil classification system to indicate how the soils will amplify earthquake ground motions. Various geologic base maps of these areas were used along with some shear wave velocity measurements of individual geologic units to classify the soils according to the NEHRP/UBC classification for soil amplification from earthquake ground motion. The geologic base maps varied in details from maps showing stacked units down to 15 meters to surficial maps that were extrapolated in 3 dimensions through input from experts in the areas. In some cases, work maps were produced showing materials in 3 dimensions so that more accurate soil classifications could be assigned. These maps of soil amplification will produce more realistic estimates of damage in the Federal Emergency Management Agency's Earthquake Loss Estimation Program (HAZUS). These maps may also be used by themselves to show relative areas of shaking and areas where liquefaction may occur. Also earthquake response, recovery and mitigation efforts may be planned using this information.

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Table 1. Soil profile type classification for seismic amplification (FEMA 222A).

SOIL PROFILE TYPE CLASSIFICATION FOR SEISMIC AMPLIFICATION				
Soil Type	General Description	Avg. Shear Wave Velocity [1] (feet/sec)	Avg. Blow[2] Counts	Avg. Shear[3] Strength (pounds/sq. ft.)
A	Hard Rock	> 5,000		
B	Rock	2,500 - 5,000		
C	Hard and/or stiff/very stiff soils; most gravels	1,200 - 2,500	> 50	2,000
D	Sands, silts and/or stiff/very stiff clays, some gravels	600 - 1,200	15 - 50	1,000 - 2,000
E	Small to moderate thickness (10 to 50 feet) soft to medium stiff clay, Plasticity Index > 20, water content > 40 percent	< 600	< 15	< 1,000
E_2	Large thickness (50 to 120 feet) soft to medium stiff clay Plasticity Index > 20, water content > 40 percent	<600	<15	<1000
F_1	Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils.			
F_2	Peats and/or highly organic clays greater than 10 feet thick			
F_3	Very high plasticity clays greater than 25 feet thick with Plasticity Index > 75			
F_4	Very thick soft/medium stiff clays greater than 120 feet thick			

1, 2 & 3 explanations - see next sheet.

Explanations for table on Soil Profile Type Classification for Seismic Amplification.

1 - Average shear wave velocity ($\overline{v_s}$) is for the upper 100 feet of the site

$$\overline{v_s} = \frac{\Sigma d_i}{\Sigma \frac{d_i}{v_{si}}}$$

d_i is the thickness of any layer between 0 and 100 ft and Σd_i is equal to 100 ft.

v_{si} is shear wave velocity of individual layers.

$\Sigma \frac{d_i}{v_{si}}$ is summation of all the layers♣ thickness divided by their shear wave velocity value.

2- Average Standard Penetration Resistance ($\overline{N}$) is:

$$\overline{N} = \frac{\Sigma d_i}{\Sigma \frac{d_i}{N_i}}$$

where Σd_i is equal to the thickness of soil and $\Sigma \frac{d_i}{N_i}$ is the summation of all the one foot intervals divided by its blow counts, for the entire soil column.

N_i is the Standard Penetration Resistance, uncorrected.

3 - Average Shear Strength (undrained) is calculated in a similar way to the shear wave velocity and blow counts.

If shear wave velocities are available for the site, they should be used. However in the recognition of the fact that in many cases the shear wave velocities are not available, alternative definitions of the site categories can be made with geotechnical parameters. The use of the standard penetration resistance for cohesionless soil layers and the undrained shear strength for cohesive soil layers is less uncertain than the use of the shear wave velocities.

Table 2. Shear wave velocity data collected and compiled during study.

Illinois - Downhole S-wave data

Material	Range of S-wave Velocity	Average S-wave Velocity
Basal Till - Chicago	656-1,312 ft/sec	
Alluvium	570-654 ft/sec	599 ft/sec

Indiana - Downhole S-wave data

Lacustrine - Evansville	400-682 ft/sec	563 ft/sec
Alluvium	676-873 ft/sec	816 ft/sec
Loess		528 ft/sec
Till	1,040-1,455 ft/sec	1,230 ft/sec
Till/Outwash		1,030 ft/sec

Kentucky - Refraction S-wave data

Alluvial

Sand/Silt/Clay		620 ft/sec
Gravel		1,190 ft/sec
Loess	581-820 ft/sec	681 ft/sec

Table 3. Central U.S. geologic materials in comparison to Soil Profile Types of NEHRP (FEMA 222A, 1994).

Soil Type	Generic Description found in Borcherdt (1994)	Avg. Shear Wave Velocity (feet/sec)	Central U.S. Deposits
A	Hard Rock	> 5,000	limestone, dolomite, & most unweathered sedimentary bedrock
B	Rock	2,500 - 5,000	some shales?, weathered bedrock?
C	Hard and/or stiff/very stiff soils; most gravels	1,200 - 2,500	some tills, gravels (cemented), most Tertiary/Cretaceous deposits which are sands, clays and gravels of the Mississippi Embayment
D	Sands, silts and/or stiff/very stiff clays, some gravels	600 - 1,200	tills, alluvium, lacustrine, loess, some sands, clays and gravels of the Mississippi Embayment
E_1	Small to moderate thickness (10 to 50 feet) soft to medium stiff clay, Plasticity Index > 20, water content > 40 percent	< 600	some lacustrine and loess deposits
E_2	Large thickness (50 to 120 feet) soft to medium stiff clay Plasticity Index > 20, water content > 40 percent	<600	
(F)	Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils.		Most alluvium deposits and sensitive materials that may fail in seismic induced landslides such as the Kope Formation near Cincinnati

[2] Site-specific geotechnical investigations and dynamic site response.

Table 4. Example units and the shear wave velocity used for each in Illinois mapping.

	Vs (m/sec)
Cahokia Alluvium	230
Parkland Sand - dunes	330
Carmi Member of Equality	170
Mackinaw - Henry sand & gravel	200
Peoria Loess and Roxanna Silt	200
Glasford till	365
Sand & Gravel of Glasford	200
Mounds Gravel	360
Tertiary clay & sand	324
Cretaceous sand and gravel	280
Cherty residuum	200
Sandy residuum	200
Sandy cherty residuum	200
Tertiary, Cretaceous or Miss.	2,000
Penn. shale	1,500
Penn. sandstone	2,000
Miss. shale	2,000
Miss. limestone	2,900
Devonian limestone	2,900
Silurian limestone	2,700
Devonian & Silurian dolomite/ls	2,900
Ordovician shale	2,000
Ordovician sandstone, dolomite	2,000
Ordovician dolomite	2,900
Ordovician sandstone	2,000
Ordovician limestone/dolomite	2,900

Table 5. Shear wave velocities, soil type and locations for Indiana mapping work.

Material	**Shear Wave Velocity** meters/second	**Shear Wave Velocity** feet/second	**Location**	**Soil Profile Type**
Alluvial	214.50	703.56	Jasper	D
	240.93	790.26	Huntingburg	D
	213.71	700.98	Newburgh	D
	232.33	762.05	Wheatland	D
	251.42	824.64	Oaktown	D
	208.20	743.24	Carlisle	D
	256.14	840.15	S. Evansville	D
	286.30	939.06	Vincennes	D
	221.87	727.73	Vincennes	D
Lacustrine	191.89	629.41	Jasper	D
	246.63	808.93	Huntingburg	D
	173.50	569.08	N. Evansville	E
	194.71	638.66	S. Evansville	D
Loess	261.31	857.09	Newburgh	D
	263.77	906.62	Newburgh	D
	243.80	799.66	N. Evansville	D
	172.43	565.55	Wheatland	E
	208.20	683.02	Oaktown	D
	171.10	561.21	Carlisle	E

Eolian Sand	212.00	695.36	Newburgh	D
	298.77	881.56	Newburgh	D
	182.66	599.14	N. Evansville	E
	222.35	729.32	S. Evansville	D
	212.14	695.83	S. Evansville	D
	352.56	1156.38	S. Evansville	D
Outwash	295.75	970.06	Vincennes	D
	369.73	1212.71	Vincennes	C