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Evaluation of liquefaction potential in Memphis area, USA

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ABSTRACT: This paper presents the evaluation of liquefaction potential in Memphis and Shelby County, Tennessee, in the event of a moment magnitude 7.5 New Madrid earthquake. For this study, about 8500 existing boring logs were collected to establish representative boring logs. Then, nonlinear site response analyses were carried out to evaluate the horizontal peak ground accelerations in the study area. For a soil layer, the factor of safety against liquefaction F_L was used to evaluate the liquefaction potential. In addition, the liquefaction potential index P_L was used to evaluate the severity of liquefaction potential at a site. On the basis of the P_L values evaluated for 575 sites, we established a generalized liquefaction potential map showing the areas of no, minor, moderate, and major liquefaction in Memphis and Shelby County, Tennessee.

INTRODUCTION

The City of Memphis and Shelby County, Tennessee, are geographically close to the southern segment of the New Madrid seismic zone (NMSZ) as shown in Figure 1. The NMSZ is regarded by seismologists, engineers, and public officials as the most hazardous seismic zone in the eastern United States. Thus, significant potential of seismic hazards exists in the Memphis area (Hwang 1991). The destructive effects of soil liquefaction induced by an earthquake have been well recognized since the 1964 Niigata earthquake and the great Alaska earthquake that occurred in the same year. Memphis and Shelby County are located in the Mississippi embayment, which is composed of mostly unconsolidated sediments. The upper soil layers comprise poorly-graded loose to medium dense alluvial sands (alluvium), and silt and clayey silt (loess) (Ng et al. 1989). These soils are susceptible to earthquake-induced liquefaction. In this study, we evaluated the liquefaction potential in Memphis and Shelby County, Tennessee, in the event of a 7.5 moment magnitude New Madrid earthquake.

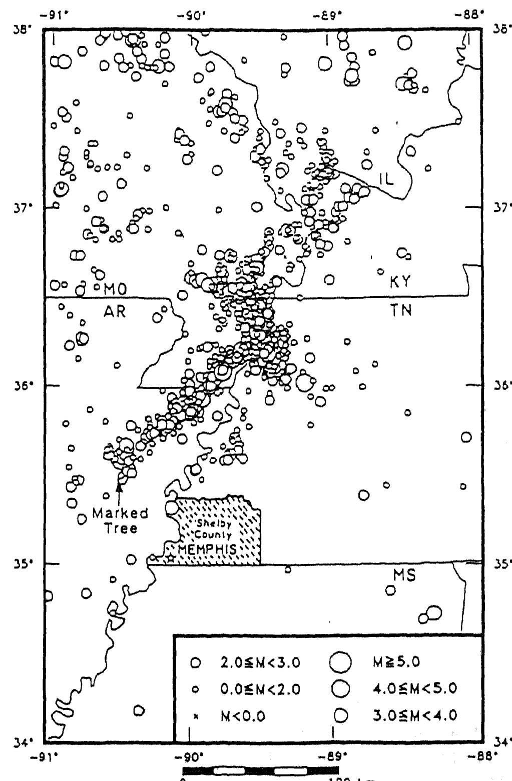

Figure 1. Seismicity in the New Madrid seismic zone (1974-1990).

EARTHQUAKE GROUND MOTIONS

Seismic hazard in the Memphis area is

entirely dominated by the New Madrid seismic zone. Hwang et al. (1989) used a seismologically based model, which includes physical characteristics of an earthquake such as source mechanism and path attenuation, to estimate the horizontal accelerations at the base of soil profiles in the event of a 7.5 moment magnitude earthquake at Marked Tree, Arkansas, where a moderate earthquake occurred in 1843. By using this model, a contour map showing the peak values of horizontal base acceleration was established. A normalized acceleration time history at an epicentral distance of 50 km was also generated. The horizontal acceleration time history for any site in the study area was established by multiplying the normalized time history with the peak base acceleration taken from the contour map.

Ng et al. (1989) studied the subsurface conditions in the Memphis area. About 8500 existing boring logs were collected, compiled, and analyzed by using a grid system that consists of rectangular cells with equal size of 30 seconds in both latitude and longitude. Most of the boring logs have good data such as blowcounts from the standard penetration test, depth of water table, and soil-type descriptions. These boring logs, supplemented by available data from water-well logs, soil surveys, and other technical publications, were used to create a representative boring log for each cell. On the basis of these representative boring logs, Hwang et al. (1990) performed nonlinear site response analyses by using the MASH computer program (Martin and Seed 1978) to estimate the horizontal peak acceleration at the ground surface in Memphis and Shelby County.

LIQUEFACTION POTENTIAL OF A SOIL LAYER

The liquefaction potential of a soil layer is affected by site parameters such as relative density, percentage of clay or fine content, effective confining pressure, and depth of water table, as well as by seismic parameters such as duration and amplitude of an earthquake. In practice, prevalent geotechnical data such as relative density, cone penetration resistance, and standard penetration resistance are used to characterize the liquefaction potential of a soil layer. In this study, the blowcounts from the standard penetration test N_{SPT} were used to evaluate the liquefaction potential of a soil layer. The factor of safety against liquefaction F_L of a soil layer is defined as

$$F_L = R/L, \quad (1)$$

in which R is the resistance shear stress ratio (cyclic stress ratio) and L is the earthquake-induced shear stress ratio. Figure 2 shows two resistance curves for sand and silty sand (Seed and Idriss 1982). These two curves are established on the basis of the field data of liquefied and non-liquefied sandy soils from several earthquakes around the world. By using the average of these two curves, Shinozuka et al. (1988) established a resistance curve for average sandy soils as follows:

For $0 \leq (N_1)_{60} < 25$,

$$R = 0.012 \times CM \times (N_1)_{60}. \quad (2)$$

For $(N_1)_{60} \geq 25$,

$$R = [0.0056 \times \{(N_1)_{60}\}^2 - 0.268 \times (N_1)_{60} + 3.5] \times CM, \quad (3)$$

where $(N_1)_{60}$ is the corrected blowcount from the standard penetration test and it can be computed from the N_{SPT} value. CM is a coefficient to account for the number of representative cycles, which is dependent on earthquake magnitude (Seed and Idriss 1982). The average resistance curve for sandy soils computed from equations (2) and (3) is also shown in Figure 2. In this study,

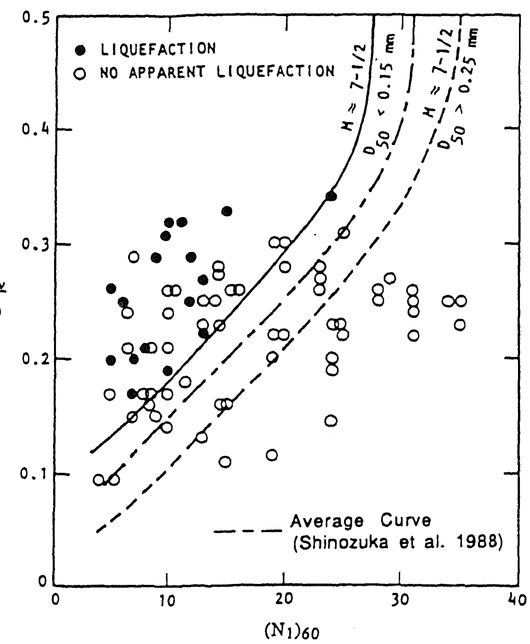

Figure 2. Liquefaction resistance curves for sand and silty sand (after Seed and Idriss 1982).

we used this average curve to compute the resistance of sandy soils.

On the basis of field data, Shi (1987) observed that silty soils with a high content of clay do not show any appreciable tendency to liquefy during an earthquake. Thus, he suggested that the liquefaction potential of silty soils is closely related to the percentage of clay in the soils and established the following formula to represent the liquefaction resistance of silty soils.

$$R = (4 + 2.17 P_c) \times (N_1)_{60} \times 10^{-3}, \qquad (4)$$

where P_c is the percentage of clay. For the silty soils in the Memphis area, the percentage of clay P_c was determined from a review of available boring logs. The ranges of P_c for silt, sandy silt, and clayey silt are 3-10%, 3-11%, and 9-21%, respectively. In this study, the percentage of clay for these silty soils is conservatively taken as the lower bound value, that is, 3% for silt and sandy silt, and 9% for clayey silt.

Seed and Idriss (1971) suggested that the shear stress ratio L induced by an earthquake can be determined as

$$L = 0.65\, a_{max} \times \left(\frac{\sigma_0}{\sigma'_0}\right) \times r_d, \qquad (5)$$

where a_{max} is the peak ground acceleration in g; σ_0 and σ'_0 are total and effective vertical confining pressure, respectively; and r_d is the stress reduction factor.

LIQUEFACTION POTENTIAL INDEX

The F_L value only indicates the liquefaction of a soil layer on a yes or no basis, and does not reflect the liquefaction severity of a site. The liquefaction potential of a site is affected by the severity, thickness, and depth of liquefied layers in a soil profile. In this study, the liquefaction potential index P_L developed by Iwasaki et al. (1982) was used to quantify the liquefaction severity of a site.

$$P_L = \sum_{i=1}^{n} Q_i \times W_i \times H_i, \qquad (6)$$

where H_i is the thickness of the i-th layer in meter. Q_i accounts for the severity of the i-th liquefied layer and is determined as follows:

$$Q_i = 1 - F_{Li} \quad \text{for } F_{Li} \leq 1.0 \text{ (liquefied)} \qquad (7)$$
$$Q_i = 0 \quad \text{for } F_{Li} > 1.0 \text{ (nonliquefied)} \qquad (8)$$

W_i accounts for the influence of depth of the i-th liquefied layer on the liquefaction severity of a site and is computed as

$$W_i = 10 - 0.5\, z, \qquad (9)$$

where z is the depth in meter measured from the ground surface. The maximum depth considered in this study is 20 m. On the basis of P_L values, the severity of liquefaction potential of a site is classified as no or little liquefaction ($P_L = 0$), minor liquefaction ($0 < P_L \leq 5$), moderate liquefaction ($5 < P_L \leq 15$), and major liquefaction ($P_L > 15$).

GENERALIZED LIQUEFACTION POTENTIAL MAP

By using the boring logs established by Ng et al. (1989), the P_L values of 575 sites were evaluated for a scenario earthquake of 7.5 moment magnitude. On the basis of these P_L values, a generalized liquefaction potential map indicating area of no (or little), minor, moderate, and major liquefaction in Memphis and Shelby County was established (Figure 3). The results indicate that a few isolated areas in Memphis and Shelby County are exposed to major liquefaction. The limited areas along the Mississippi River, Wolf River, Loosahatchie River, and a small area near Millington are exposed to moderate liquefaction. In general, the Mississippi alluvial plain and its adjacent area along the Wolf River are subject to minor liquefaction. A large portion of Memphis and Shelby County have no or little potential of liquefaction even in the event of a large earthquake.

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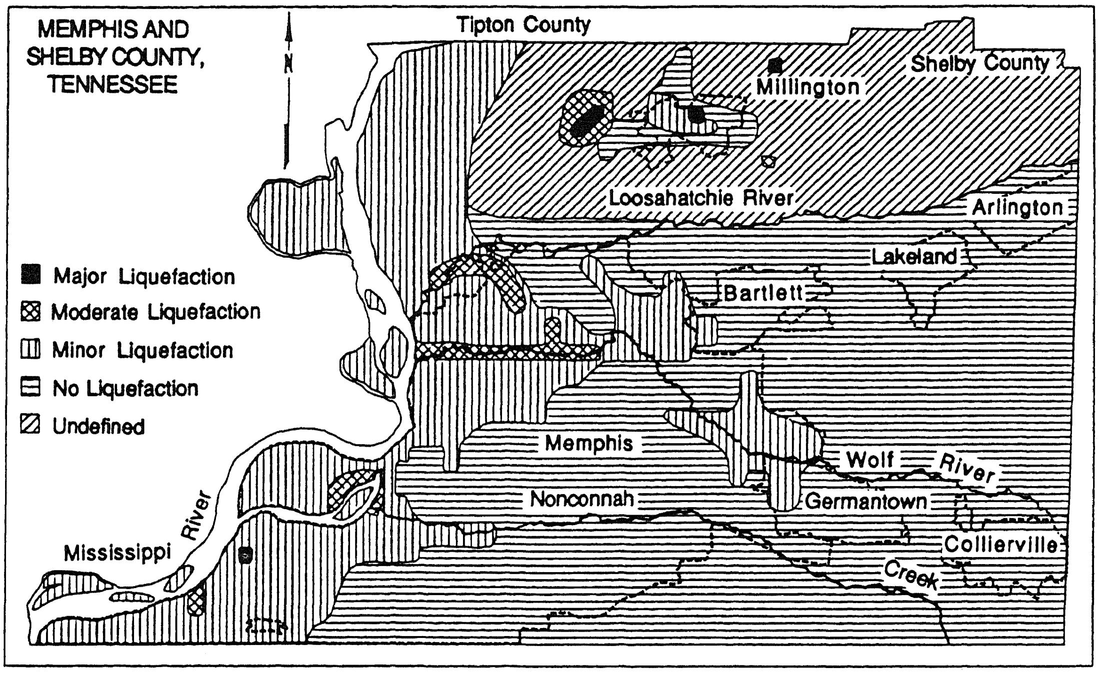

Figure 3. Generalized map for liquefaction potential.

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