Missouri University of Science and Technology
Scholars' Mine

International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

2001 - Fourth International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

Mar 26th - Mar 31st

Soil Column Response and Liquefaction Analyses

Sanjeev Kumar
Southern Illinois University, Carbondale, IL

Follow this and additional works at: http://scholarsmine.mst.edu/icrageesd

Part of the Geotechnical Engineering Commons

Recommended Citation

Kumar, Sanjeev, "Soil Column Response and Liquefaction Analyses" (2001). *International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*. 7.
http://scholarsmine.mst.edu/icrageesd/04icrageesd/session10/7

This Article - Conference proceedings is brought to you for free and open access by Scholars' Mine. It has been accepted for inclusion in International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics by an authorized administrator of Scholars' Mine. This work is protected by U. S. Copyright Law. Unauthorized use including reproduction for redistribution requires the permission of the copyright holder. For more information, please contact scholarsmine@mst.edu.

SOIL COLUMN RESPONSE AND LIQUEFACTION ANALYSES

Sanjeev Kumar, Ph.D., P.E.
Department of Civil Engineering
Southern Illinois University-Carbondale
Carbondale, IL 62901

ABSTRACT

This paper presents the procedure and results of soil column response (ground response) and liquefaction analyses performed for a site located in St. Charles, Missouri. Synthetic earthquake time histories were developed since recorded strong ground motion data for Central United States are not available. For ground response analysis, synthetic earthquake time histories and ground motions from two earthquakes in Canada were used. Synthetic time histories were generated using attenuation relationships for Central and Eastern United States. Liquefaction analysis was performed using the widely used simplified procedure which involves comparison of Cyclic Stress Ratio (CSR) and Cyclic Resistance Ratio (CRR).

INTRODUCTION

Structures are frequently designed and constructed in floodplains of major rivers. In earthquake prone areas, a fundamental issue in the design of structures on saturated sandy soils is whether the design earthquake could initiate liquefaction in form of lateral spreading, sand boils, settlement, or cracking. In addition to liquefaction analysis, response of saturated sandy soils to seismic ground motion becomes very important to determine peak acceleration at the ground surface and stresses in the soil.

Liquefaction of saturated sands has been the topic of extensive research over the past three decades. A number of publications and special presentation papers have discussed the expanded interest in liquefaction and its effects (e.g., Arulanandan et al. 1995, Dobry et al. 1995, Finn 1991, Kutter 1995, O'Rourke and Pease 1995, and Youd 1993, 1995). Laboratory experimentation and field testing on soil liquefaction has provided valuable insight into the mechanism of excessive pore-pressure buildup (National Research Council 1985). Simplified ground response analysis assuming one-dimensional wave propagation through layered media is commonly performed using SHAKE91 program.

Damaging earthquakes occur infrequently in the Central Eastern United States (CEUS). The earthquakes of 1811-1812 caused damage in the St. Louis area, at least 280 kM (175 miles) from the main-shock epicenters. However, because of the sparse population and simple, log cabin structures in the region during this era, a relatively small number of deaths and minimum property loss was observed. The earthquakes of 1811-1812 caused liquefaction and landslides in an area of 15,000 square kilometers (6,000 square miles) in southeast Missouri, western Tennessee, and northeastern Arkansas. Although, surface indications of liquefaction during these earthquakes are rare in the St. Louis and St. Charles area, any liquefaction below the ground surface today could cause significant loss of life and property.

This paper presents results of simplified ground response and liquefaction analyses performed for a site located in the floodplain of the Missouri River, in St. Charles, Missouri. Ground response analyses performed showed that the ground motions at the site are likely to amplify as much as 1.4 to 2.25 times. Since strong ground motion data are not available for CEUS, synthetic earthquake time histories and recorded ground motion data from moderate earthquakes in Canada were used to perform ground response analyses. Based on the liquefaction analysis performed, it was concluded that the existing soils to depths of 35 to 40 ft have significant potential for initiation of liquefaction.

SOIL AND GROUNDWATER CONDITIONS

Stratigraphy within the footprint of the proposed building consisted of approximately 3 feet thick, fill; silty clay to clayey silt with occasional traces of sandy silt and silty sand to depths of approximately 10 feet; a comparatively thick sequence of floodplain alluvium; and Mississippian age bedrock. Fills in the planned building area included weathered shale and silty clay to clay. A total of 8 borings were drilled within the footprint of the building.

The sand stratum at the site consisted of loose to medium dense, fine to medium sand to depths of approximately 40 feet which was underlain by medium dense to dense, fine to coarse sand with traces of gravel. An approximately 5 ft thick layer of medium dense, fine sand was observed at approximate depths of 35 ft from the ground surface in all the borings drilled within the footprint of the building. Groundwater at the site fluctuates with water levels in the Missouri River which at the time of subsurface exploration was at the top of sand stratum (approximately 10 ft below the ground surface).

GROUND MOTION SELECTION

The recorded strong ground motion acceleration time histories for the CEUS are not available because no large earthquake has occurred since the installation of strong-motion accelrographs. The smaller recorded earthquakes for the CUS are inadequate for the ground response analysis at the site. Recorded acceleration time histories from Western United States (WUS) with some modifications have often been used for seismic analyses in the CUS. However, there are significant differences between characteristics of earthquakes from CUS (mid-plate earthquakes) and WUS (inter-plate earthquakes). Therefore, it was concluded that acceleration time histories from earthquakes in the WUS are not appropriate for the ground response analysis at the site.

To account for sensitivity of the results to the selected ground motion, ground response analyses are generally performed using a set of 2 or 3 ground motion time histories from different earthquakes. In the present study, time histories from two earthquakes recorded in Canada, and a suite of synthetic time histories were used.

Recorded time histories from the following moderate magnitude earthquakes from Canada were used as a part of the set of three earthquakes. Peak ground acceleration of these earthquakes was scaled to 0.08g to match the PGA recommended by USGS (1997).

- Nahanni earthquake of December 23, 1985, magnitude m_b of 6.4 (M_s 6.9), recorded at Site 3 at an epicentral distance of approximately 25 KM.

- Saguenay earthquake of November 25, 1988, magnitude M_s of 5.7, recorded at Site 1 at an epicentral distance of approximately 115 KM.

Synthetic ground motions were generated using the ground-motion relations for Eastern North America developed by Atkinson and Boore (1995). These relationships are derived from an empirically based stochastic ground motion model in which ground motion is modeled as bandlimited Gaussian noise. The radiated energy is assumed to be evenly distributed over a specified duration. According to Atkinson and Boore (1995), the spectrum at the site is given by:

$$A(M_0,R,f) = E(M_0,f)D(R,f)\,P(f)\,I(f) \qquad (1)$$

where:

$E(M_0,f)$ = earthquake source spectrum for a specified seismic moment
$D(R,f)$ = distance term that models the geometric and anelastic attenuation of the spectrum as a function of hypocentral distance, R, and frequency, f
$P(f)$ = high cut filter that rapidly reduces amplitudes at high frequencies
$I(f)$ = instrument response filter to shape the spectrum to correspond to the particular ground motion measure of interest
M_0 = seismic moment
R = hypocentral distance
f = frequency of interest

For detailed discussion on calculation of these terms the reader is referred to Atkinson and Boore (1995). From the site spectrum developed using above relationship, time histories were generated using random process theory, and information given in Ou and Herrmann (1990) and Boore (1983).

Figure 1 shows Fourier spectra at rock for the time histories used in this study. It can be seen that the predominant frequency content of recoded ground motions (Nahanni and Saguenay) ranges between 2 and 6 Hz. The synthetic time history also has the predominant frequency content within this range, however, this time history contains significant amount of other frequencies. For the purpose of performing ground response analysis, use of the selected ground motion time histories was considered appropriate.

SOIL COLUMN RESPONSE ANALYSIS

Soil column response or ground response analysis is defined as determining the stresses, strains, and peak accelerations at different depths in a soil column when waves from a seismic event pass through the soil. Soil column response analysis was performed using a computer program, SHAKE91 (Idriss and Sun 1992), which is an updated version of a well-known computer program SHAKE (Schnabel et al. 1972). The SHAKE91 program uses the theory of one-dimensional wave propagation through layered media.

Based on the soil column response analysis, it was concluded that the bedrock peak ground acceleration of 0.08g could be amplified to peak ground acceleration of 0.11g to 0.18g at the ground surface (i.e., by a factor of 1.4 to 2.25). Hwang and Huo (1997) conducted a study to compute peak ground acceleration when the peak acceleration at bedrock is known. The amplification computed in the present study is consistent with the 1997 NEHRP recommended provisions (BSSC 1998) and Hwang and Huo (1997). Peak ground acceleration of 0.16g was used to perform the liquefaction analyses. Figure 2 shows the peak acceleration response of the soil column selected.

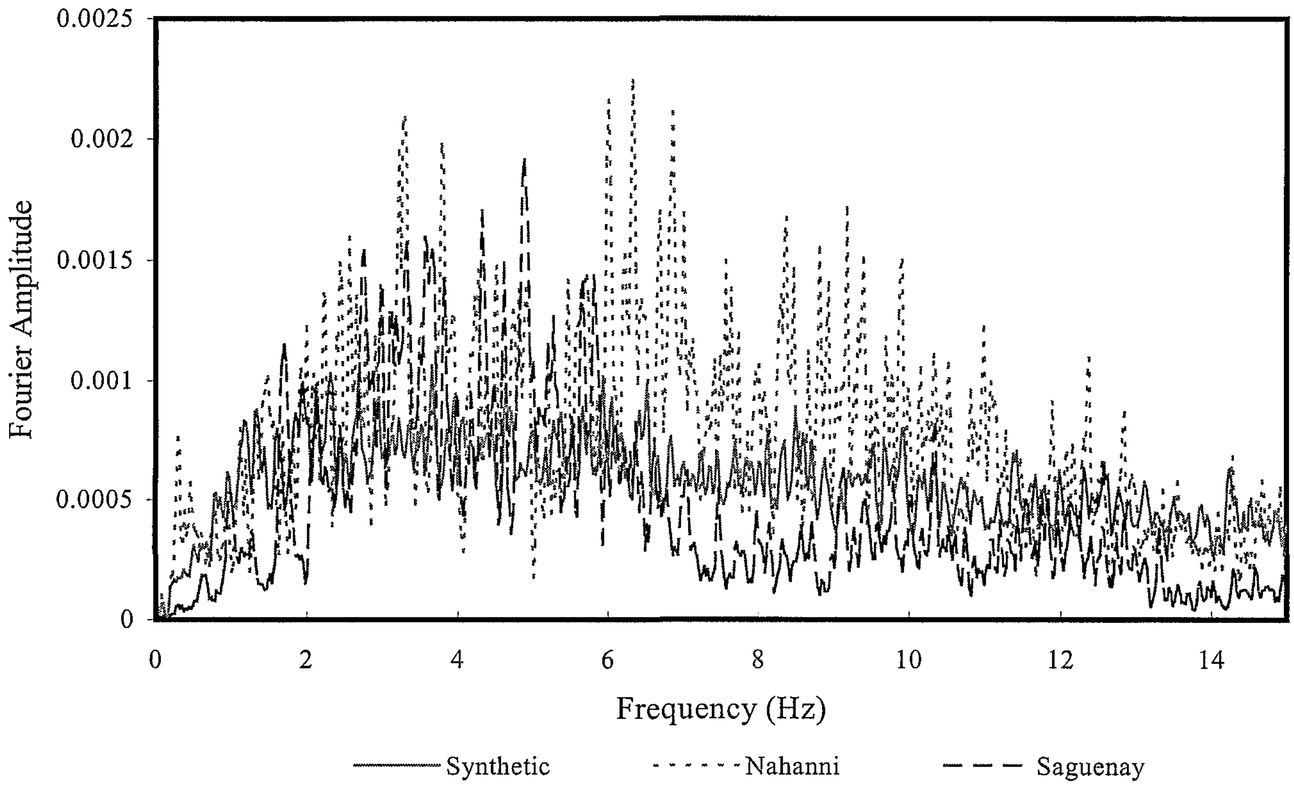

Figure 1. Fourier spectra for earthquake time histories used in the study

LIQUEFACTION ANALYSIS

As discussed earlier, the sand stratum at the site consisted of loose sands having a uniform grain size distribution soils to depths of 35 to 40 ft. Because of the presence of low density, saturated sands having relatively uniform grain size distribution, and level of ground shaking expected at the site from an earthquake, it was concluded that the site had potential for liquefaction. Liquefaction potential analysis at the site was performed using the well-known work of Seed et al. (1983, 1984, 1985) and Seed and Idriss (1971, 1982) referred to here as a simplified method. The results were also checked using the recommendations of NCEER workshop (NCEER 1997). The simplified method is based on the extensive analysis of field data from sites which liquefied or did not liquefy in various earthquakes in the past. Definition of what does or does not constitute liquefaction is still being actively discussed in the geotechnical community (Ishihara 1993, Robertson 1994, and Youd 1993). However, professional and regulatory practice often adopt this work as a design method and, to a significant extent, it also forms a standard against which other theories and methods of liquefaction assessment are judged (Fear and McRoberts 1995).

Figure 3 shows the Cyclic Resistance Ratio (CRR) determined based on the recommendations of simplified method. The Cyclic Stress Ratio (CSR) expected due a seismic event is also shown on the figure. From Figure 3, it is clear that for existing soils shallower than 40 feet (except at a depth of 35 feet), resistance to ground shaking is less than the expected stresses from ground shaking. A 5 feet thick layer of sand at a depth of 35 feet is not likely to liquefy. This observation is consistent with the type of soils encountered during subsurface exploration. Apparent liquefaction potential at a depth of 50 feet from the ground surface was observed to be in isolated zones. Based on the discussion presented above, it was concluded that the existing soils to depths of approximately 35 to 40 ft from the ground surface have significant potential for liquefaction.

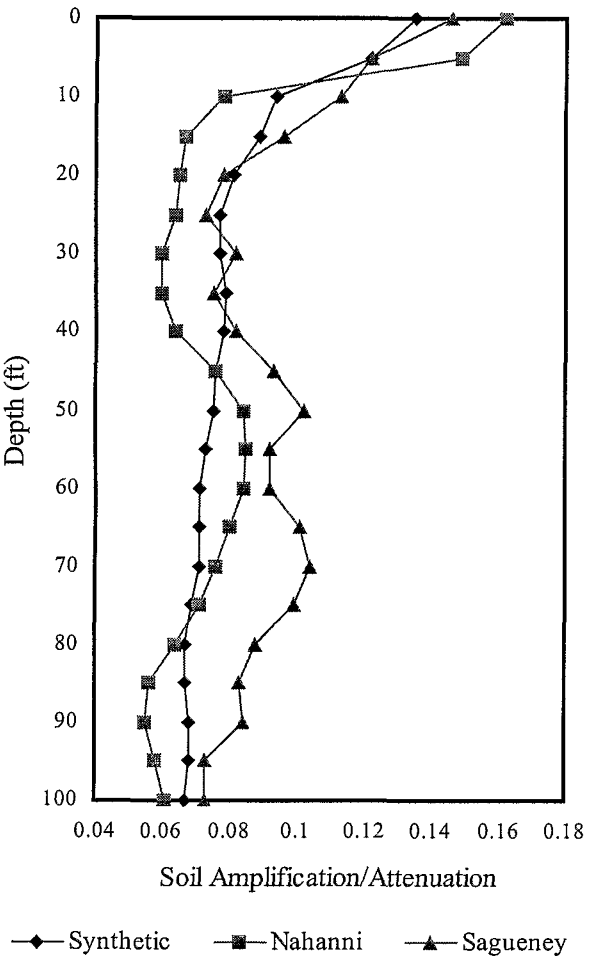

Figure 2. Response of soil column to earthquake ground motions

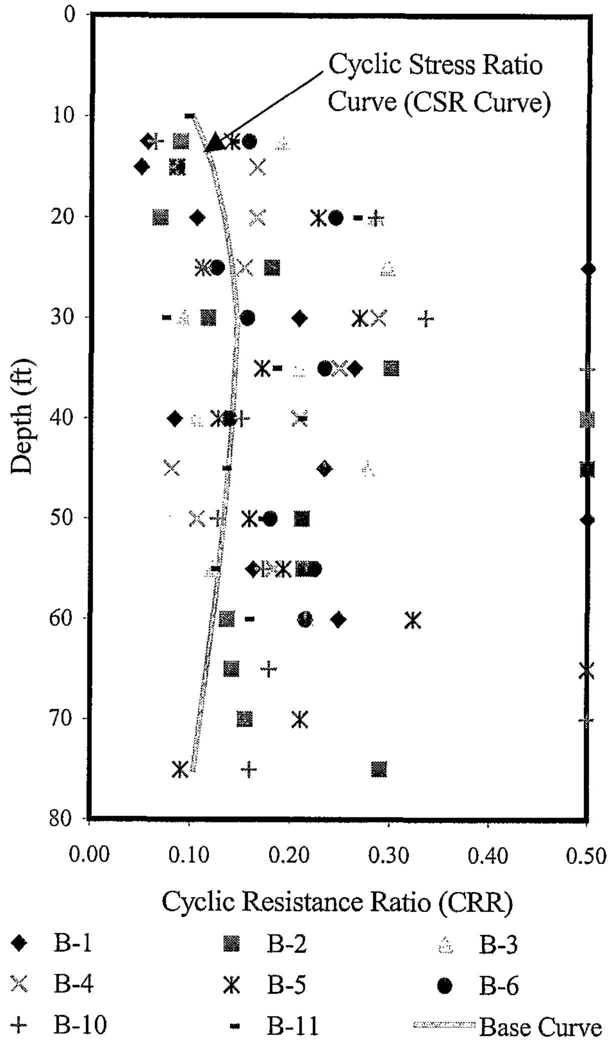

Figure 3. Results of liquefaction potential analysis

ACKNOWLEDGEMENTS

The author wishes to thank Geotechnology, Inc. for providing support to analyze the data, and OPUS Corporation for permission to publish the results.

REFERENCES

Arulanandan, K., Manzari, M., Zeng, X., Fagan, M., Scott, R. F., and Tan, T.S., 1995, Significance of VALACS Project to the solution of boundary value problems in geotechnical engineering, Special Presentation, *Proc. of Third Intl. Conf. on Recent Advances in Geotech. Earthquake Engrg. and Soil Dyn.*, S. Prakash (ed.), St. Louis, MO, April 2-7, **II**, 825-832.

Atkinson, G. M. and Boore, D. M., 1995, Ground-motion relations for eastern North America, *Bull. of the Seism. Soc. of Am.*, **85**(1), February.

Building Seismic Safety Council, 1998, 1997 Edition of NEHRP Recommended Provisions for Seismic Regulations for New Buildings and other Structures, issued by Federal Emergency Management Agency (FEMA), Washington, DC.

CUSES, 1994, Damages and losses from future New Madrid earthquakes, Center for Earthquake Studies, Southeast Missouri State University, Cape Girardeau, MO.

Dobry, R., Taboada, T., and Liu, L., 1995, Centrifuge modeling of liquefaction effects during earthquakes, *Proc. 1st Int. Conf. on Earthquake Geotech. Engrg. Spec*, Keynote and Theme Lectures, IS-Tokyo, Japan, 129-162.

Fear, C. E. and McRoberts, E. C., 1995, Reconsideration of initiation of liquefaction in sandy soils, *J. of Geot. Enger. Divn.*, ASCE, **121** (3), 249-261.

Finn, W.D.L., 1991, Assessment of liquefaction potential and post liquefaction behavior of earth structures: developments 1981-1991, State-of-the-Art Paper, *Proc. of Second Intl. Conf. on Recent Advances in Geotech. Earthquake Engrg. and Soil Dyn.*, S. Prakash (ed.), St. Louis, MO, March 11-15, **II**, 1833-1850.

Frankel, A., 1995, Mapping seismic hazard in the central and eastern United States, *Seism. Res. Letters*, **66** (4), July/August.

Frankel, A., 1996, Personal Communication.

Frankel, A., Mueller, C., Barnhard, T., Perkins, D., Leyendecker, E. V., Dickman, N., Hanson, S., and Hooper, M., 1996, Interim National Seismic Hazard Maps: Documentation, United States Geological Survey, Denver, CO.

Hwang, H. and Huo, J. R., 1997, Attenuation relations of ground motion for rock and soil sites in eastern United States, *Soil Dyn. and Earthquake Engrg* (in press).

Ishihara, K., 1993, Liquefaction and flow failures during earthquakes, *Geotechnique*, London, England, **43**(3), 351-415.

Idriss, I. M. and Sun, J. I., 1992, SHAKE91, a computer program for earthquake response analysis of horizontally layered sites, Program modified based on the original SHAKE91 program.

Kumar, S., 1999, Reduction of liquefaction potential using deep dynamic compaction and construction of stone columns, *J. of Geot. and Geol. Engrg* (accepted for publication).

Kutter, B. L., 1995, Recent advances in centrifuge modeling of seismic shaking, State-of-the-Art Paper, *Proc. of Third Intl. Conf. on Recent Advances in Geotech. Earthquake Engrg. and Soil Dyn.*, S. Prakash (ed.), St. Louis, MO, April 2-7, **II**, 927-941.

NCEER, 1997, Proceedings of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils, NCEER Technical Report Number NCEER-97-0022, Youd, T. L. and Idriss, I. M. editors.

National Research Council, 1985, Liquefaction of soils during earthquakes, *Committee rep. on Earthquake Engineering, Commission on Engineering and Technical Systems*, Housner, G. W., Chairman, National Academy Press, Washington, DC.

O'Rourke, T. D. and Pease, J. W., 1995, Lessons learned from liquefaction and lifeline performance during San Francisco earthquake, State-of-the-Art Paper, *Proc. of Third Intl. Conf. on Recent Advances in Geotech. Earthquake Engrg. and Soil Dyn.*, S. Prakash (ed.), St. Louis, MO, April 2-7, **II**, 1017-1038.

Robertson, P. K., 1994, Suggested terminology for liquefaction, *Proc., 47th Can. Geotech. Conf.*, Can. Geotech. Soc., Ottawa, Canada, 277-286.

Schnable, P. B., Lysmer, J., and Seed, H. B., 1972, SHAKE91, a computer program for earthquake response analysis of horizontally layered sites, *Report No. EERC 72-12*, University of California, Berkeley.

Seed, H. B. and Idriss, I. M., 1971. Simplified procedure for evaluating soil liquefaction potential, *J. of Soil Mechanics and Foundations Divn.*, ASCE, **97**(1).

Seed, H. B. and Idriss, I. M. 1982, Ground Motions and Soil Liquefaction During Earthquakes, *EERI Monograph*, Earthquake Engineering Research Institute, Oakland, CA.

Seed, H. B., Idriss, I. M., and Arango, I., 1983, Evaluation of liquefaction potential using field performance data, *J. of Geot. Enger. Divn.*, ASCE, **109**(3).

Seed, H. B., Tokimatsu, K., Harder, L. F., and Chung, R. M., 1984, The influence of SPT procedures in soil liquefaction resistance evaluations, *Report No. UBC/EERC-85/15*, Earthquake Engineering Research Center, University of California, Berkeley.

Seed, H. B., Wong, R. T., Idriss, I. M., and Tokimatsu, K., 1986, Moduli and damping factors for dynamic analyses of cohesionless sites, *J. of Geot. Enger. Divn.*, ASCE, **112**(11).

USCOE, 1981, Earthquake Potential of the St. Louis District, *Report prepared by U.S. Army Corps of Engineers*.

Youd, T. L., 1993, Liquefaction-induced lateral spread displacement, *Tech. Note N-1862*, Naval Civil Engrg. Lab., Port Hueneme, CA.

Youd, T. L., 1993, Liquefaction-induced lateral ground displacement, State-of-the-Art Paper, *Proc. of Third Intl. Conf. on Recent Advances in Geotech. Earthquake Engrg. and Soil Dyn.*, S. Prakash (ed.), St. Louis, MO, April 2-7, **II**, 911-925.