SCIENTIFIC VISUALIZATION OF SOIL LIQUEFACTION

T. L. Biddlecome
Army Corps of Engineers
Engineering Research and Development Center
Major Shared Resources Center
Vicksburg, MS 39180

F. Amini
Department of Civil & Environmental Engineering
Jackson State University
Jackson, MS 39217-0168

S. Rahman
Department of Civil & Environmental Engineering
Jackson State University
Jackson, MS 39217-0168

M. K. Sharp
Army Corps of Engineers
Engineering Research and Development Center
Geotechnical and Structures Laboratory
Vicksburg, MS 39180

ABSTRACT

Little is known about the soil liquefaction behavior and visualization at depth. This study focuses on the liquefaction behavior at different depths, and uses the scientific visualization to enhance our understanding of the liquefaction phenomenon. A scientific visualization scheme incorporating combination of three-dimensional volume visualization and ray casting techniques with animation is developed for the purpose of studying the liquefaction behavior. A fast parallel volume rendering algorithm using raycasting, sparse octree techniques, and interactive transfer functions has been developed to establish coupled techniques for evaluation of soil liquefaction data. Data from the experimental centrifuge tests including cyclic shear stress (to result in liquefaction), cyclic shear strain, acceleration, and excess pore pressure as a function of time for four different depths ranging from 2.12 m to 12.65 for a two-layer soil specimen was used. The results have indicated that the scientific visualization is a valuable tool that can properly characterize the liquefaction behavior and provide an insight into a phenomenon that was not previously possible.

1. INTRODUCTION

Liquefaction of saturated soils has often been a major cause of damages to seismic earth dams and other structures during earthquakes. The soil liquefaction refers to a phenomenon when the effective stress within the soil approaches zero during a seismic event. The determination of the soil liquefaction is needed during the design and maintenance of large seismic dams. The maintenance of seismic dams is under the jurisdiction of the U.S. Army Corps. of Engineers. Most federal embankment dams were built before seismic hazards were recognized, and before effective defensive design measures had been developed. Seismic safety analyses of existing dams with current techniques indicated a number of dams needed remedial construction. Remedial construction costs for seismic deficiencies are typically about $20M to $100M per dam for embankment dams, and $5M to $100M for reservoir control structures.

Liquefaction analysis is generally performed using simple procedures developed by Seed et al (1983). However in many situations it is necessary to evaluate liquefaction at very large depths. This is true for both homogenous and layered soils. To address the issue of liquefaction at depth, experiments have been recently conducted by the U.S. Army Corps of Engineers, Engineering Research, and Development Center (ERDC) Centrifuge Research Team to investigate the effect of confining pressure on liquefaction potential. In addition to the experimental approach, numerical studies have been recently performed to interpret centrifuge system response results and to study the effect of depth on soil liquefaction for deep sand deposits (Amini and Duan, 2002a; Amini and Duan 2002b). This project focuses on the liquefaction behavior at different depths, and uses the scientific visualization to enhance our understanding of

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the liquefaction at depth. The primary objective of the research was to develop a scientific visualization scheme that can properly characterize the soil liquefaction behavior. This paper, for the first time, uses the combination of multiple three-dimensional surface visualization and ray casting techniques with animation to enhance our understanding of the liquefaction phenomenon. The liquefaction data from the experimental centrifuge modeling tests including cyclic shear stress was used for the purpose of visualization.

2. CENTRIFUGE MODELING

A centrifuge modeling technique is used to simulate gravity-induced stresses in soil deposits at a reduced scale model of geotechnical structures through centrifuge loading (e.g., Sharp et al., 2003; Taboada-Urtuzuastegui and Dobry, 1998). The technique essentially consists of increasing the confining environment in the model soil, so that the confining stress is identical in both model and prototype at homologous points. The technique allows soil liquefaction tests to be performed at a conveniently reduced scale and provides data appropriate to full-scale problems.

In this study, data from the experimental centrifuge modeling tests including cyclic shear stress (to result in liquefaction) as a function of time for four different depths ranging from 2.12 m to 12.65 for a two-layer soil specimen in the centrifuge apparatus was used. The soil specimen included a loose sandy layer (with a relative density of 50%) followed by a layer of dense sandy soil (with a relative density of 75%). The centrifuge data includes cyclic shear stress, cyclic shear strain, acceleration, and excess pore pressure as a function of time and at different depths.

3. SCIENTIFIC VISUALIZATION

Due to the large amounts of data and the difficulties encountered during exploration and evaluation, the soil liquefaction phenomenon cannot be understood by statistical methods alone. In this study, a scientific visualization technique is introduced to explore the effects of large volume dataset of the liquefaction data. In this approach, visualization techniques are used to represent the data graphically as a means of gaining understanding and insight into the features within the data. Volume visualization is a field in scientific visualization that is concerned with the abstraction, interpretation, rendering, and manipulation of large datasets. It is widely used in both scientific and engineering applications, and is invaluable as a means to gaining understanding of these datasets. The volume visualization allows the user to create or generate volumes enclosed by iso-surfaces for any one or all of the parameters (e.g., stress, strain, acceleration, etc.) involved in the soil liquefaction phenomenon. The user is able to choose any value of the parameter(s) to create the iso-surfaces and interactively observe the surfaces from any angle by rotating the view. Animation of the time sequence allows the user to observe the temporal and spatial evolution of the iso-surfaces of his or her interest.

In addition to rendering techniques, ray casting provides the ability to generate volumes within or around the selected iso-surfaces to effectively see inside the data (e.g., Hanrahan and Purgathofer, 1995; Klimaszewski and Sederberg, 1997). In this study, a fast parallel volume rendering algorithm using raycasting, sparse octree techniques, and interactive transfer functions has been developed to establish coupled techniques for evaluation of soil liquefaction data. One key component in this process is the transfer function design that maps the volume’s intensity values to color and opacity values for display. Given the unknown nature of values in large datasets, transfer function selection is often a slow trial and error process. Some work has been recently performed in the area of fast transfer function design (Fang, et al., 1998). The transfer function provides the ability to filter the values of the parameter(s) and select ranges of values to observe the surfaces or volumes generated by those certain ranges of values and their evolution with time and loading history. Using slicing planes or slicing volumes the user is able to observe the contours of the parameters on desired multiple planes and their temporal and spatial evolution. For further data exploration, the user could also select particle(s) at different locations within the soil specimen and can observe the travel path(s) of those particles for various loading cycles.

Six programs were written for surface rendering, volume rendering, VR viewing and VTK software rendering and viewing. These are briefly described below.

1. Data Converter: This is an independent program, written in C, which prepares the output of the centrifuge model for iso-surface generator and sequence viewer.
2. Iso-Surface Generator: This program generates the iso-surfaces of stress, strain, acceleration, and excess pore pressure, or any data.
3. Sequence Viewer: It uses the output files created by iso-surface generator to view the animated iso-surface development history.
4. Raycaster: Fast interactive ray casting using an octree data structure for fast image generation was used. A template file allows the user to adjust transfer function values,

scaling values, and lighting, without octree regeneration.

5. VR Immersion: Real time interactive viewing of iso-surfaces on a FakeSpace RAVE was achieved. This allows the user to view time sequences of iso-surfaces from any directed POV.
6. Three-Dimensional Texture Mapping: This program involves Interactive 3D texture mapping with transfer function controls.

4. RESULTS AND CONCLUSIONS

The soil liquefaction model used in this study is shown in Figure 1. The scientific visualization for a) cyclic shear stress; b) excess pore pressure; c) cyclic shear strain; and d) acceleration as a function of time and at different depths were obtained. In addition, scientific visualization for combined shear stress and excess pore pressure, as well as combination of all above four parameters (shown in figure 2) was obtained. The scientific visualization provided the ability to view both excess pore pressure and cyclic shear stress development simultaneously. The results have indicated that the scientific visualization is a valuable tool that can provide an insight into a phenomenon that was not previously available.

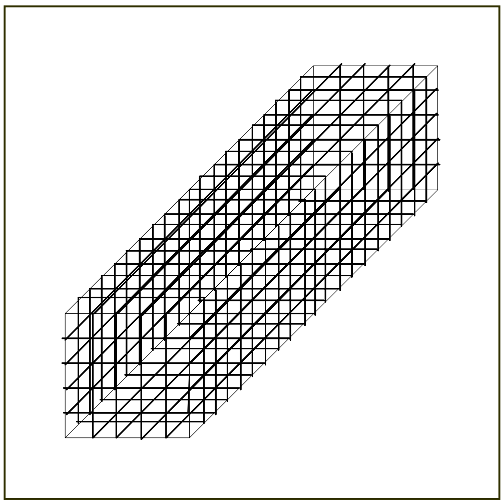

Fig. 1. Soil liquefaction model (39.8mx15.7mx15.0m)

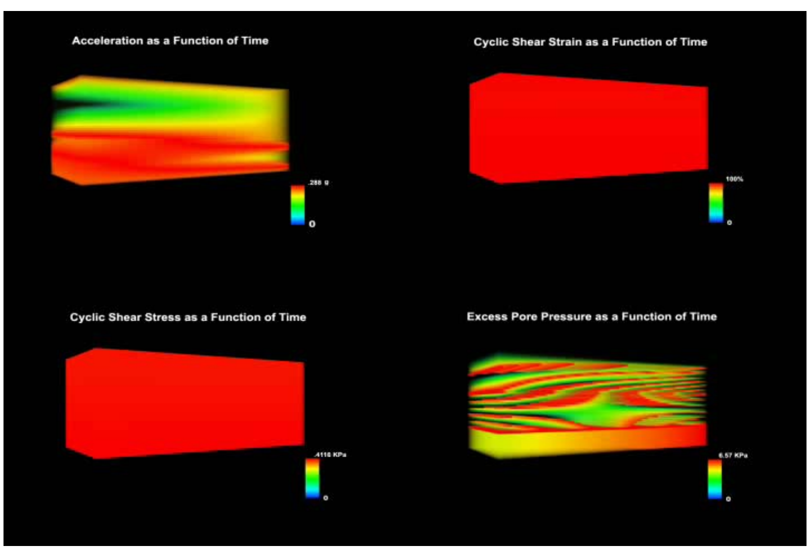

Fig. 2. Scientific visualization of acceleration, shear strain, shear stress, and excess pore pressure as a function of time.

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