Interactive Web-based Visualization Tools for Teaching and Learning Experimental Earthquake Physical Modelling

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ABSTRACT: *Interactive web-based visualization tools using Java and VRML (Virtual Reality Modelling Language) are developed to teach/learn fundamental concepts involved in simulation of earthquakes and large scale experimental seismic response of physical models. Experimental earthquake databases usually include numbers of records of time-histories of different measured quantities such as accelerations, displacements, pore water pressures, earth pressures, strain gauges and other quantities. Through animations, interaction and manipulation of images, the visualization tools enable the user to understand relations between measured quantities in space- and time-domains that are difficult to understand by using other means, especially in a large scale experiment environment where hundred of sensors are deployed. A 3-D rendering allows the user to visualize the real experimental model and experimental setup. Concepts such as seismic wave amplification, liquefaction occurrence and extent, and effect of input motion on seismic response can be illustrated by using the proposed interactive visualization tools. These are available at* http://geotechvisual.ucsd.edu

1   INTRODUCTION

Interactive web-based visualization tools called data visual analyzers are developed using experimental data from a large scale shake-table testing of full-size piles. The experimental facilities include the world's largest laminar container (6.0m high, 3.1m wide, 11.6m long), and a high density of employed sensors deployed in the ground and piles, 190 sensors deployed for monitoring sand and pile behaviours in each test; or 570 time histories for the three shaking events of the experimental program. Details of the experimental program are given by Abe et al. (2004).

This effort of developing interactive teaching/learning tools is the result of the integration of high-level research and education in geotechnical earthquake engineering; students can learn from a sophisticated, state-of-the-art research environment. Also it is the result of international collaboration between USA and Japan - a US university with both a private company and a research organization in Japan.

2   THREE-DIMENSIONAL RENDERING

With the aid of a VRML viewer such as *Cortona*, the three-dimensional experimental model, setup and instrumentation arrays can be displayed. *Cortona* is a fast and highly interactive Web3D viewer that is ideal for viewing both simple 3D models and complex interactive solutions on the Web. *Cortona* works as a VRML plug-in for popular Internet browsers. Using its capabilities, it is possible to visualize the entire experimental setup, structural model and sensor arrays from different angles and distances; i.e., the entire container can be rotated with respect to any axis, zoomed-in and -out, and translated (Fig. 1). In a teaching/learning environment, this three-dimensional viewing allows a better understanding of the experiment design principles, location and importance of the number of sensors and sensor arrays, and geometry of the structural physical model. These visualization features benefit an instructor/student relation.
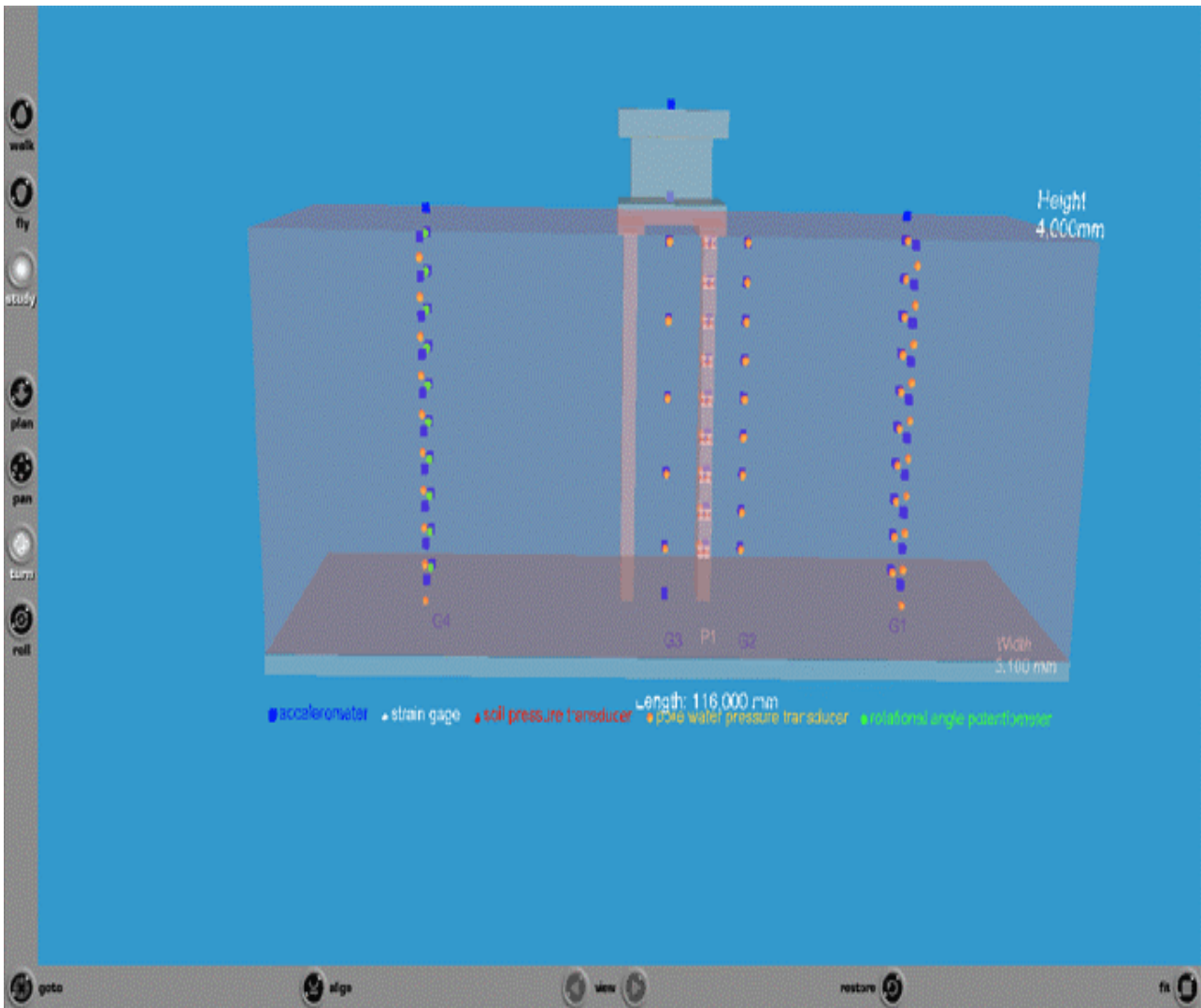
Figure 1 – Interactive three dimensional rendering of experimental model and setup

3 DATA VISUAL ANALYZERS

Data visual analyzers are software applications that have portable, robust and expandable implementations using Java technology, running under a web platform. They provide interactive animated data visualizations for time history records such as accelerations, horizontal displacement, pile curvature, soil pressure, effective stress, pore water pressure and P-y curves, using easy to use graphical user interfaces. Data visual analyzers provide means for (1) displaying and comparing 2D-plots of time-variant data and (2) displaying data variations within time- and space- domains.

3.1 Java applet animations for displaying and comparing time histories records

Figure 2 shows a Java Applet application for data visual analysis that plots the time variation of depth vs. pore water pressure along a vertical array (graph of the left-hand side), and pore water pressure time-histories for each sensor within the array (on the right-hand side). Available vertical arrays are composed of 5, 9 or 10 sensors at pre-defined depths. Animation variations occur along each depth. Vertical arrays are available for the following measured quantities: accelerations, horizontal displacement, pile curvature, soil pressure, effective stress and water pressure.
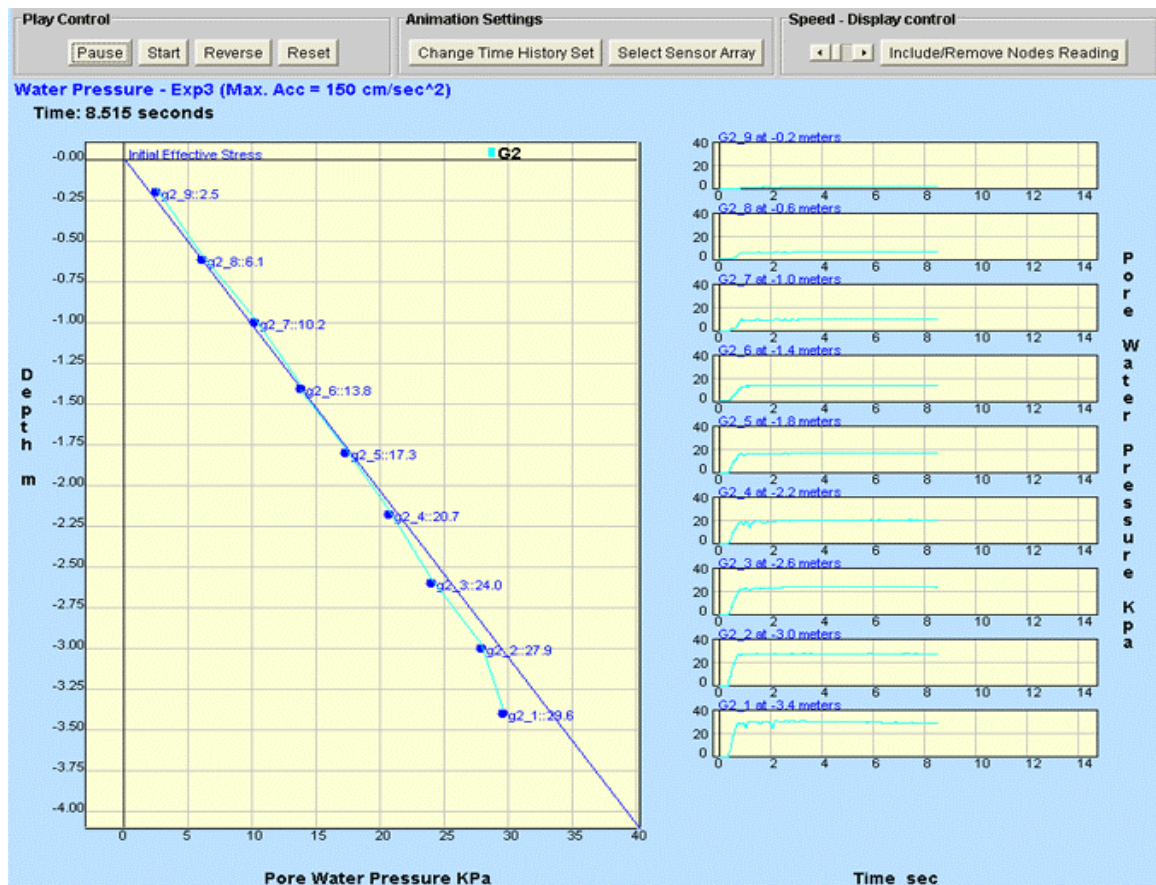
Figure 2 – Data Visual Analyzer

For improving the visualization of results, and helping interpreting the data, the application provides animation control mechanisms, making animations fully interactive. A control panel located on the upper portion of the window consists of "*Play Controls*", "*Animation Settings*" and "*Speed-Display Control*." "*Play Controls*" contains four buttons, i.e., "Pause", "Star", "Reset", and "Reverse". "Pause" button stops animation at current time frame, "Start" starts or restarts paused animation, "Reset" restarts the animation from time 0, and "Reverse" moves animations forward or backward in time. "*Animation Settings*" contains two buttons labelled "Change Time History Set" and "Select Sensor". "Change Time History Set" provides a mechanism to switch between time-history sets if multiple vertical arrays are being simultaneously animated. "Select Sensor" button allows the selection or removal of vertical arrays at any time during an animation. "*Speed- Display Control*" contains a speed slider and the "Include/Remove Nodes Reading" button. The speed slider manipulates the animation flow by varying the time delay per data variation, making the animation go faster or slower. The "Include/Remove Nodes Reading" button enables or disables the appearance of data readings and sensor labels displayed at the vertical arrays nodes.

As mentioned above the software application can switch vertical arrays at any time during the animation, customizing the number of arrays per animation trial. A new window pops up with options to select or deselect data arrays, providing a dynamic illustrative display of all available vertical sensor arrays and their physical location within the experiment setup (Fig. 3). This window could be accessed at any time during animation by clicking the "Select Sensor" button located in the control panel, Figure 2. As seen in Figure 3, the window provides buttons for selecting vertical arrays. These buttons change in color once they have been selected and go back to their original color when deselected. A "Start" button at the left bottom corner of the window starts the animations and closes the current window after pressed. Also a status bar of current selected arrays is shown at the bottom of the window. This window is always presented at the beginning of the animation.
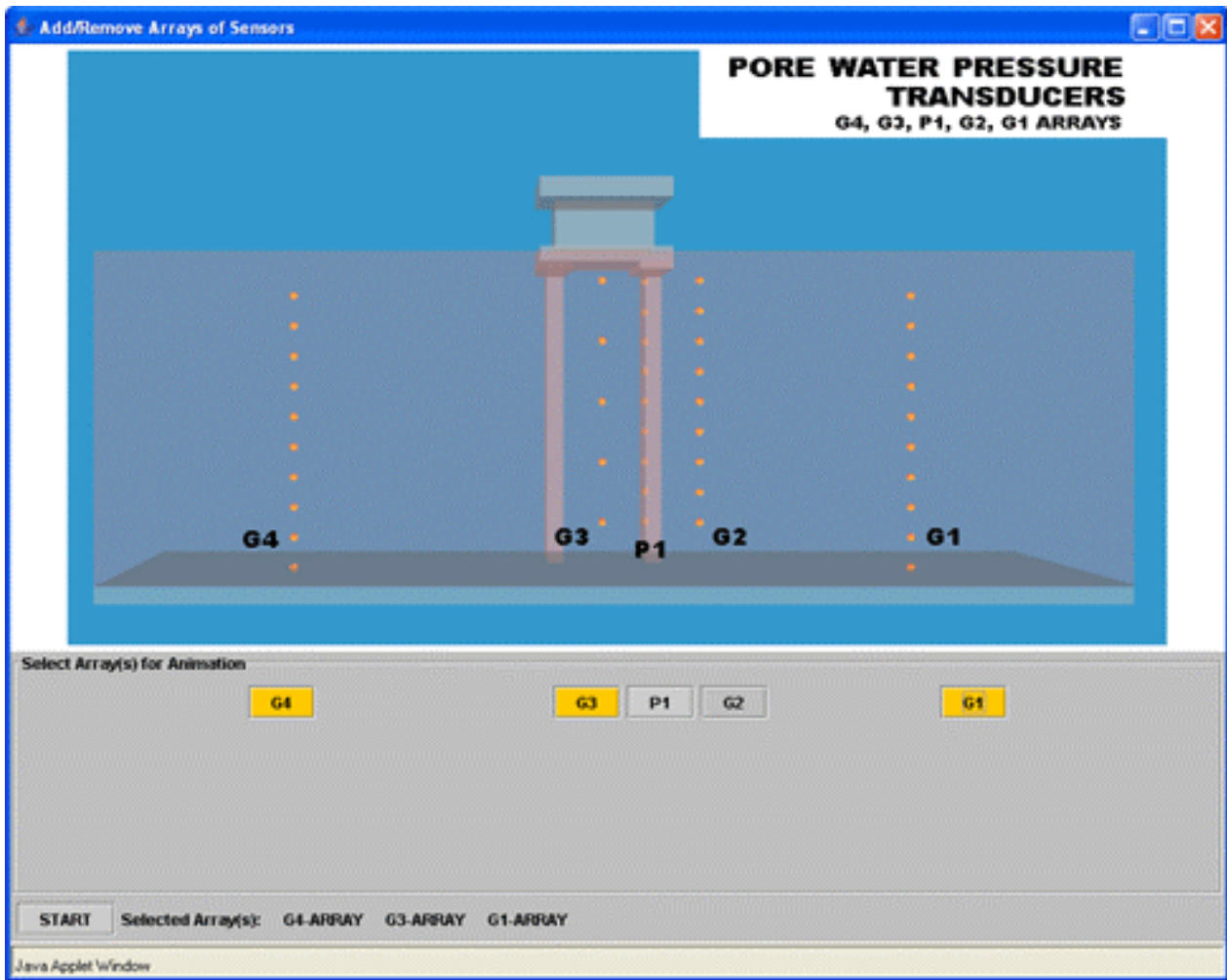
Figure 3 – Window for the Selection of Sensor Arrays

A useful feature for pore water pressure (PWP) and effective stress animations is provided and consists of an inclined line to represent the initial effective stress. So when the vertical array showing the variation of PWP reaches and coincides with the initial effective stress line, visualization of sand liquefaction would be achieved as shown in Figure 2.

Another Java Applet application compares data obtained from 3 different experiments with varying maximum amplitude of the earthquake input motion, using the same vertical sensor arrays and experimental setup. Comparisons are available for the following measured quantities: accelerations, horizontal displacement, pile curvature, effective stress and pore water pressure. This software application uses a similar graphical layout as the one described above except that a new graphical user interface control was added and an existent one was modified to allow selection of only one vertical array and multiple experiments. Figure 4 shows the added control "Select Experiment for Comparison". It provides three options: "Experiment 1 (Max. Acc = 150cm^2)", "Experiment 2 (Max. Acc = 100cm^2)", and "Experiment 3 (Max. Acc = 50cm^2)." This allows multiple selections of experiments for comparison purposes. Also, the mechanism for the "Select Pore Water Pressure Transducer Array" controls, containing the buttons for selection of available vertical arrays, was modified to allow only the selection of one array per animation. The application displays the selected array and experiment number during animation.
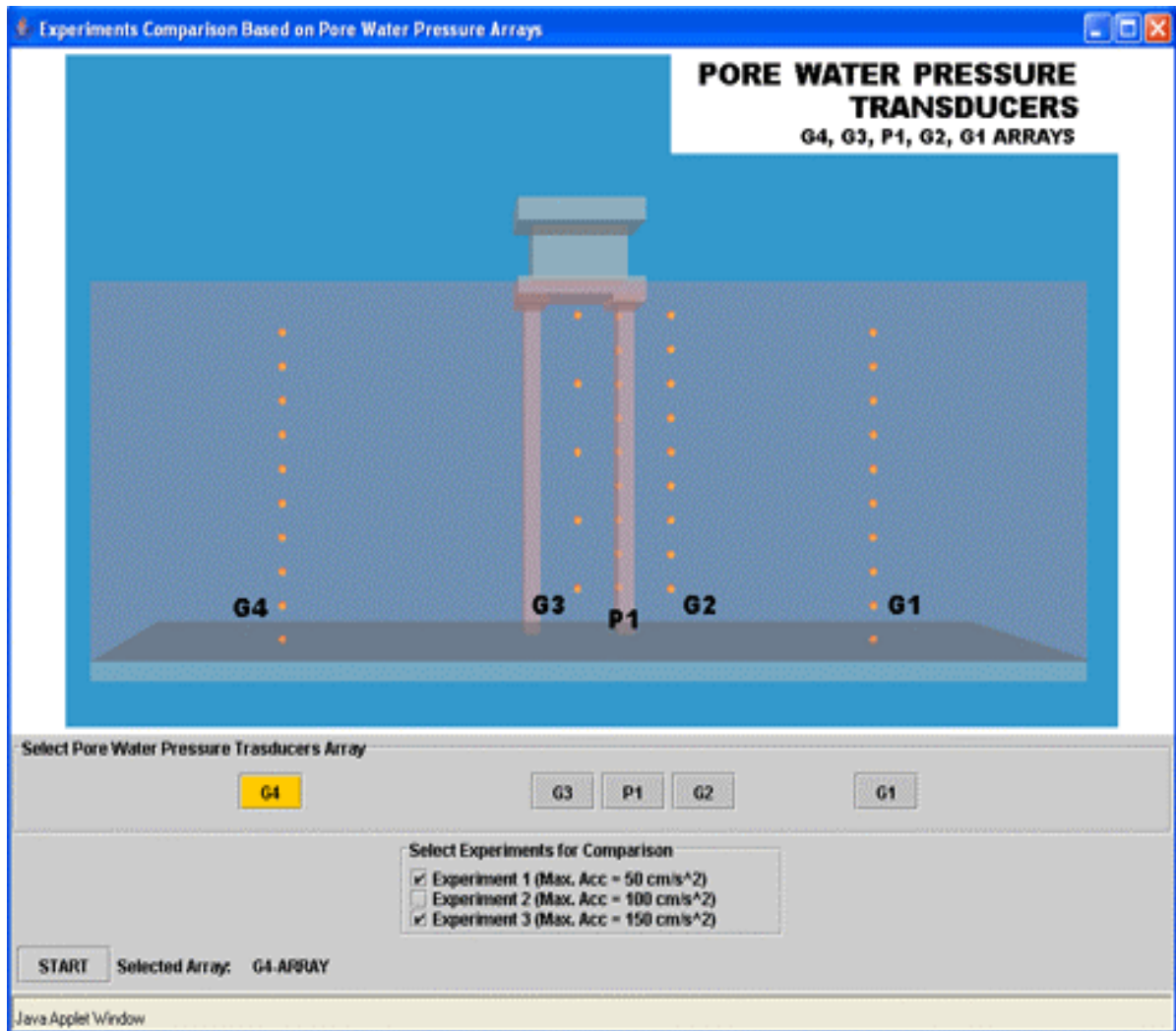
Figure-4 – Window for Comparing Experiments with Different Input Motions

A distinct Java Applet application for data visual analysis was created for P-y curves. Figure 5 shows a snapshot of P-y curves interactive graphical animation interface. The application displays a set of 12 animated time histories of soil pressure vs. displacement at specific depths. The set is displayed on the right-hand side of the window. There is a mechanism that allows simultaneous replication of any of the 12 animations on a magnified plot on the left-hand side of the window. This is achieved by just clicking on the desired animation. The application also provides mechanisms to control the animations. An easy to use control panel located at the upper portion of the window is presented. It is composed of "*Play Control*", "*Speed*" and "*P-Y/P-YPile Animation*" controls. "*Play Control*" consists of five buttons, "Pause", "Star", "Reset", "Reverse" and "Grid." The first four buttons provide the same functionalities as in the previous applications. The "Grid" button modifies the grid layout of the magnified plot at any time during the animation. There are three grid layouts available; each one with a different width. "*Speed*" consists of a horizontal slider that provides high or low speed visualizations, and adjusts and displays the delay per animation frame from 0 to 200 milliseconds. Finally "*P-Y/P-YPile Animation*" consists of four options, "P-YPile", "P-y", "SP (calculated)", "SP (measured)". "P-YPile" option plots soil pressure versus pile displacement, "P-y" option plots soil pressure versus relative displacement between the soil and the pile, "SP (calculated)" option uses back-calculated soil pressure data, and "SP(measured)" option uses soil pressure data from soil pressure transducers.
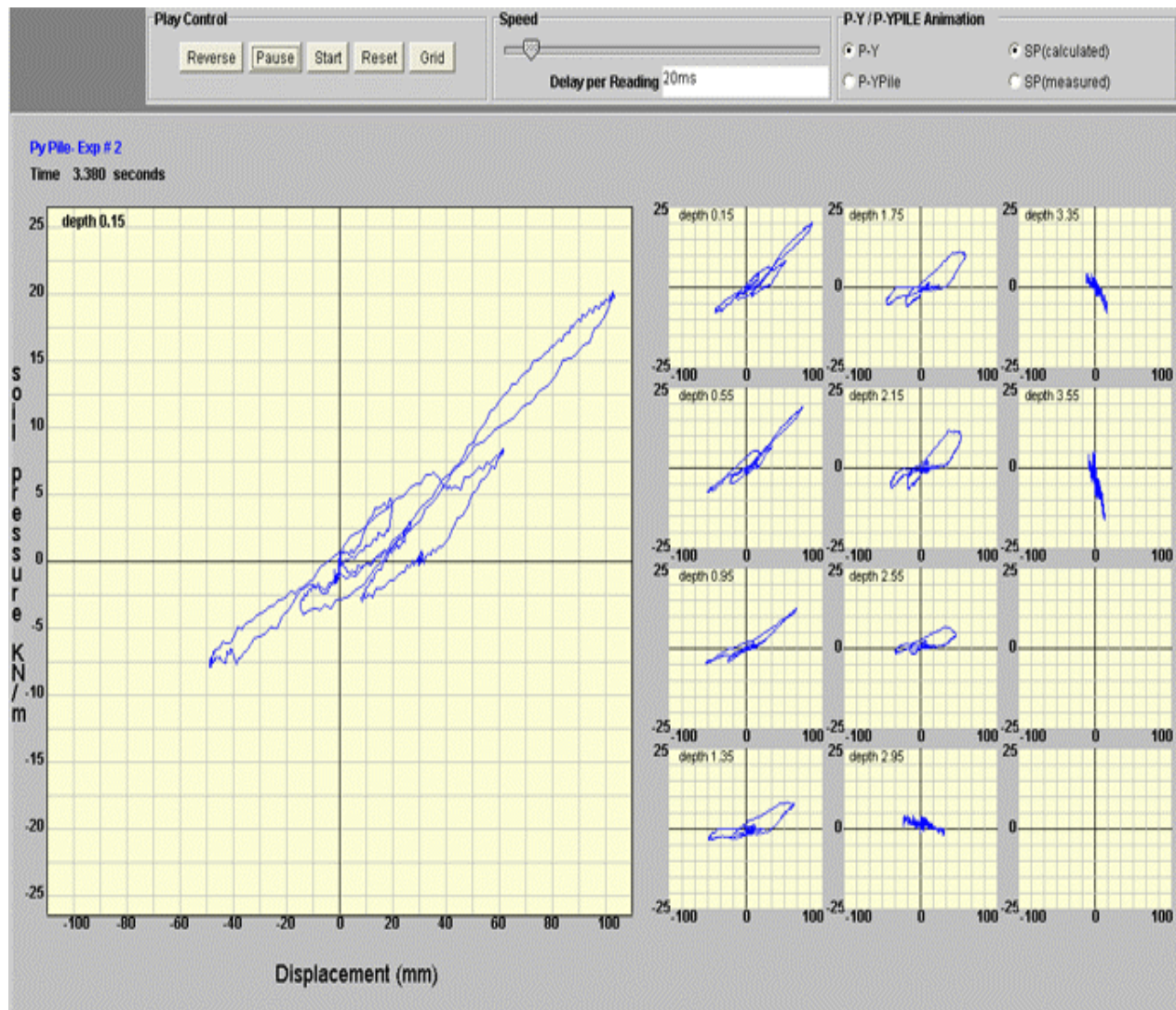
Figure 5 – P-y Curves Data Visual Analyser

3.2 Java applet animations for displaying data variations in space- and time-domain

This Java Applet application, for data visual analysis, provides an interactive animation of pore water distribution inside sand foundation and pile moments. Pore water pressure (PWP) development over time inside a sand foundation model and temporal variation of moments for the piles are shown in Figure 6. The application provides interactive control capabilities to facilitate data interpretation and viewing. A control panel composed of "*Play Controls*" and "*Speed*" controls is included. These controls provide the same functionalities as in the previous applications. To enhance the visualization, the displacements of the laminar container have been amplified five times. This animation is particular effective in showing that the most important part of liquefied sand-pile interaction is during the period of PWP increase and immediately after reaching $r_u = 1.0$ (r_u = pore pressure ratio = excess PWP/initial effective stress). During this period, the moments inside the pile significantly increase. After the sand is completely liquefied the interaction between piles and sand indicate small flexural moments along the pile. Just for visualization purposes, the moments calculated for the only instrumented pile have been replicated to the other. This graphical interface also provides an animation of the base input acceleration time-history.
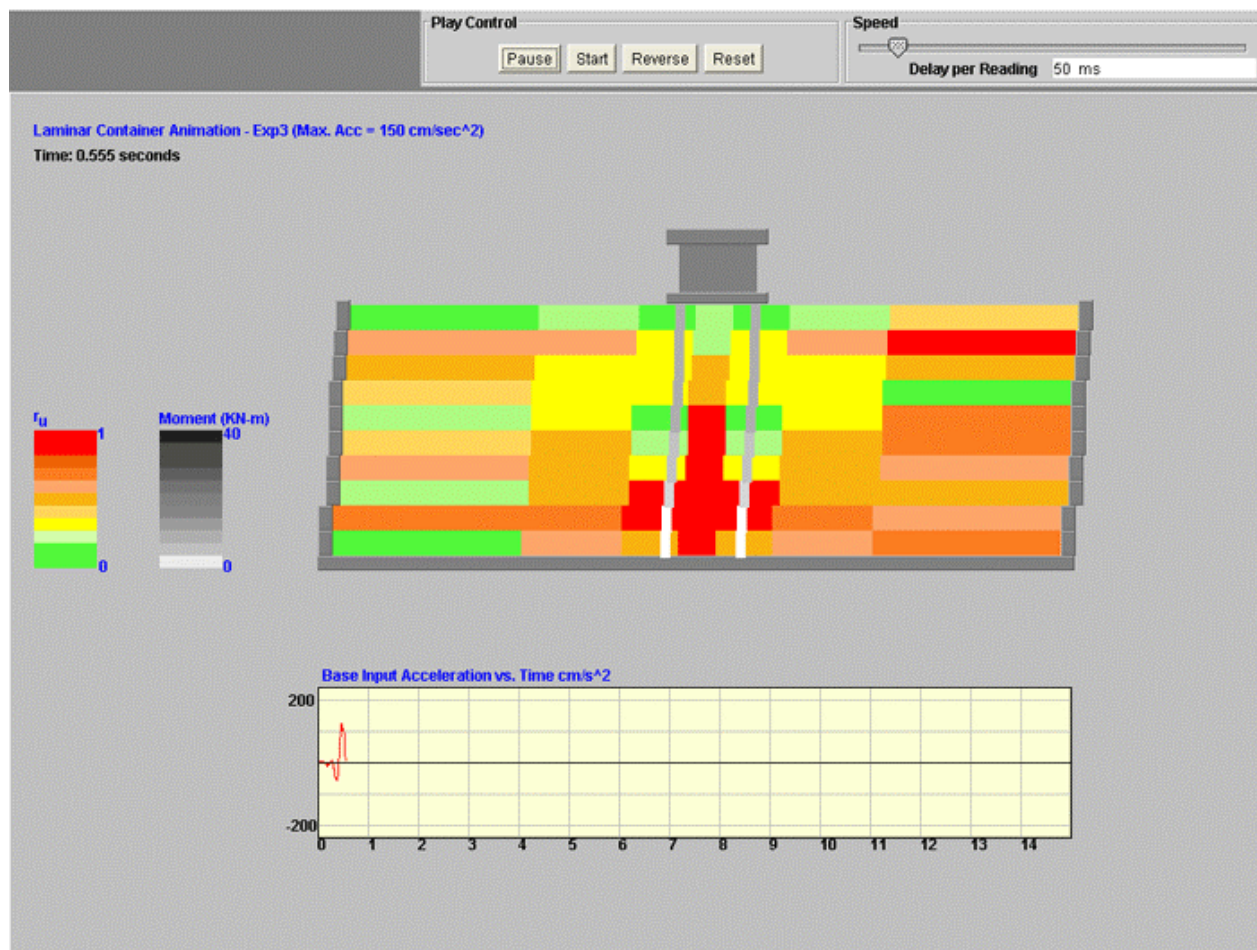
Figure 6- Laminar Container Animation

4 TEACHING/LEARNING BASIC CONCEPTS OF GEOTECHNICAL EARTHQUAKE ENGINEERING

The opportunity of accessing invaluable large scale earthquake testing information and the development of web-based data visual analyzers provide excellent tools for teaching/learning basic concepts of geotechnical earthquake engineering. Concepts such as seismic wave modification, liquefaction occurrence and extent, effect of input motion on seismic response of physical models, and soil-pile seismic interaction can be easily understood by using the developed visualization tools. Still pictures or graphs cannot provide the same learning experience as highly interactive applets in which the student see and "feel" the development and variation of quantities of interest.

An important issue in earthquake engineering is the understanding of the modification of the bedrock excitation during the transmission or passage through the overlying soils. The amplitudes of the seismic waves can be amplified or attenuated depending upon several factors. The large scale nature of the experimental setup can simulate a bedrock excitation as a base input motion on a shake table, and the overlying soils as a 4m-high sand deposit contained by the world's largest laminar container. Several vertical arrays of accelerometers are placed at different locations inside the container. Each array consists of several accelerometers located at different elevations to track the variation of the accelerations with depth and time. The data visual analyzers allow a simultaneous visualization of the time histories of accelerations at different depths; a student can view how the base input motion is modified along the depth inside the sand layer. The interactive capabilities of the visual analyzers allow students to better understand the phenomenon of amplification or attenuation of seismic waves.

The identification of occurrence time and extent of sand liquefaction are very important in geotechnical earthquake engineering. The variation with depth and time of pore water pressures and effective stresses during earthquakes is crucial. If the development of the liquefaction front is upwards or

downwards is also essential for the understanding of the effects of liquefaction on foundations. The proposed interactive visual analyzers allow students to see, feel and finally understand how the liquefaction front moves, and how and where liquefaction occurs. One visual analyzer displays the increase of PWP and also shows a line representing the initial effective stress; once the PWP plot coincides with this line, it is said that liquefaction or zero effective stress is achieved in this portion of sand. Another visual analyzer can display the variations of effective stresses; once the effective stresses reaches a vertical line or the zero value, it is said that the sand is liquefied. The interactive capabilities allow a student to learn how this process occurs, and an instructor to teach it.

The effect of input motion on seismic response of physical models can be understood by using the data visual analyzers developed for comparison purposes. After selecting a particular array of sensors, it is possible to choose 1, 2 or 3 input motions and then see how the response of the array varies for each input motion. The comparison is made simultaneously for the selected input motions. The interactive capabilities enhance the teaching/learning experience.

Liquefied soil-pile interaction during earthquakes is one of the most interesting research topics. One approach for studying this phenomenon is by using the so called p-y curves. Still graphs or snapshots of time variations of these curves are not sufficiently clear to understand the interaction process. Simultaneous display of these curves showing its variation with time and depth are very illustrative for teaching/learning the interaction process. The data visual analyzers also show different ways of calculating the p-y curves illustrating in an interactive way the differences between them.

5   CONCLUSIONS

Interactive web-based data visual analyzers are developed to teach and learn basic concepts of geotechnical earthquake engineering. Experimental data from a large scale physical modelling of soil-pile interaction is the basis for the development of the visualization tools. Students learn from an advanced research testing environment; research and education are integrated. International cooperation and university-industry collaboration are essential for this integration.

ACKNOWLEDGEMENTS

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