

Visualization of Experimental Earthquake Data

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ABSTRACT

We present a system that visualizes displacement, acceleration, and strain that were measured during an earthquake simulation experiment in a geotechnical centrifuge. Our visualization tool starts by reading the data describing experiment set-up and displaying this data along with icons for the sensors used during data acquisition. Different sensor types (measuring acceleration, displacement and strain) are indicated by different icons. One general experiment set-up is used in a sequence of simulated earthquake events. Once a user has selected a particular event, measured data can be displayed as a two-dimensional (2D) graph/plot by clicking the corresponding sensors. Multiple sensors can be animated to obtain a three-dimensional (3D) visualization of measured data.

Keywords: geotechnical centrifuge, experimental data visualization, acceleration, displacement, strain, sensor data

1. INTRODUCTION

Earthquakes are among the most devastating natural catastrophes on Earth. Besides being responsible for human casualties, they can also cause significant damage to buildings and infrastructure. Thus, civil engineering has substantial interest in understanding effects of earthquake events. Scientists at the Center for Geotechnical Modeling at the University of California, Davis, perform experiments to understand effects of earthquakes on soil and built structures. In these experiments, reduced-scale models of real 3D structures, *e.g.*, soil configurations, buildings, and bridges are placed on a centrifuge. By accelerating these models to several earth gravities and simulating earthquake scenarios via several “shaking” events, it is possible to obtain physically meaningful results applicable to real-size structures. During these simulated seismic events, displacement, acceleration and strain are measured at selected positions within the model.

We present a method to visualize the resulting data collected during seismic experiments. Data and meta-data [1, 2] is currently supplied in form of a PDF experiment report, sketches, illustrating an experiment, Microsoft Excel [3] spreadsheets detailing positions of sensors, calibration data and experiment history, and ASCII files containing the transducer recordings. Plans are to integrate our visualization tool in the emerging common NEES (Network for Earthquake Engineering Simulation) [4] data model, a unified system to be used in the future by experimental earthquake research groups throughout the U.S., developed by NEESGrid [5].

Results of these experiments were originally visualized as a set of 2D graphs plotting sensor data as a function of time. It is extremely difficult for a scientist to get an impression of what happens in a model containing hundreds of sensor by just looking at 2D graphs. Our visualization tool starts by reading the data describing experiment set-up and displaying this data along with icons for the sensors used during data acquisition, providing spatial context for each sensor. Different sensor types (measuring acceleration, displacement and strain) are indicated by different icons. One general experiment set-up is used in a sequence of simulated earthquake events. Once a user has selected a particular event, measured data can be displayed as a 2D graph/plot by clicking the corresponding sensors. Sensors can be animated to obtain 3D visualizations of measured data.

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2. RELATED WORK

Most published work on visualization of earthquake data deals with results from numerical simulations of earthquakes. Meyer and Chopra [6] presented a brief outline of an immersive visualization system for data resulting from a simulation of ground-motion and single-degree-of-freedom building motion. Data is supplied on a tetrahedral mesh, spanning 400km^2 of physical space. By restricting the visualization to the surface grid and building response to a selected region, Meyer and Chopra are able to achieve interactive visualization of ground motions and structural response in a CAVE. Based on their work, Chopra *et al.* presented an immersive system [7] for visualizing simulation results. Using a tetrahedral decimation scheme, their technique achieves interactive speeds for volume and surface visualizations. Scheuermann *et al.* [8] used visualization techniques for stress tensors resulting from 3D numerical simulations in computational geomechanics. Jeremic *et al.* [9] extended this work.

In contrast to large-scale data sets resulting from numerical simulations of earthquake-related phenomena, experimental data sets are sparse data sets. So far, visualization of the resulting data has been done mostly by the scientists performing the experiments using standard packages, such as Mathcad [10] or MatLab [11]. Kutter and Balakrishnan [12] described data acquisition, filtering and visualization. Data is visualized as 2D plots of sensors values as a function of time, or as an animation of a 2D slice of the model. Combining output of vertically aligned sensors, Kutter and Balakrishnan visualize displacement and acceleration as a function of height. Animations are created by generating a 2D cross-section for each measured time-step of an experiment. Oskay *et al.* [13] developed an interpolation method for visualizing results from physical earthquake simulations with 2D contour plots, and deforming model geometry according to strain and displacement. By creating a numerical model of the experiment set-up and using values measured in a physical simulation in that numerical model, they can calculate displacement and strain at arbitrary positions in a 2D slice of a model. These values are visualized by contour plots and model deformation.

Our work was done as part of the NEES [4] initiative that intends to create a network between earthquake researchers within the U.S. Data collected at participating sites will be available to other participating sites. Currently, data formats are being developed to store information about experiments in a standardized way, which will facilitate the use of visualization tools.

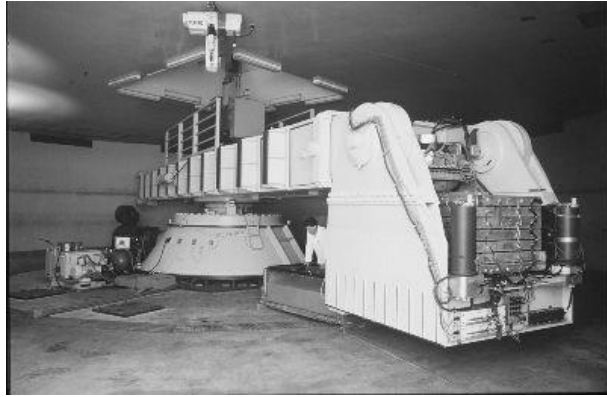
3. DATA ACQUISITION

Data is collected by performing experiments at the large centrifuge at the Center of Geotechnical Modeling at the University of California, Davis, see Figure 1. These experiments study geotechnical problems such as the strength, stiffness and capacity of foundations for bridges and buildings, settlement of embankments, stability of slopes, earth retaining structures, tunnel stability and seawalls. Materials such as soil and rock have nonlinear mechanical properties that depend on the effective confining stress and stress history. The centrifuge applies an increased “gravitational” acceleration to physical models in order to produce identical self-weight stresses in the model and prototype. The one-to-one scaling of stress enhances the similarity of models and makes it possible to obtain accurate data to help solve complex problems such as earthquake-induced liquefaction, and soil-structure interaction. Centrifuge model testing provides us with data to improve our understanding of basic mechanisms of deformation and failure. Furthermore, it leads to benchmarks useful for verification of numerical models.

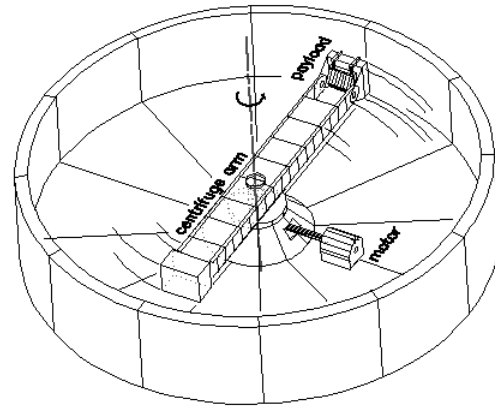
If a 1m-deep model container is filled with soil, placed on the end of a centrifuge and subject to a centrifugal acceleration of $50g$, the pressures and stresses are increased by a factor of 50. Thus, the vertical stress at the base of the model container is equivalent to the vertical stress at a depth of $1\text{m} \times 50 = 50\text{m}$ in the Earth. The 1m-deep model represents 50m of prototype soil. Centrifuge modeling and scaling laws are discussed in detail by Kutter [14]. While the model is accelerated on the centrifuge, it can be subjected to various loads, such as seismic events. The seismic events are generated using a servo-hydraulic shaking table, see Kutter *et al.* [15].

A small-scale model is instrumented with a variety of sensors, including these:

1. Accelerometers measuring acceleration at a point
2. Displacement sensors measuring displacement of a point
3. Strain sensors measuring strain at a point



(a)



(b)

Figure 1. Experiments are performed at the geotechnical centrifuge at the University of California, Davis. (a) Centrifuge at the center in Davis. (b) This 3D schematic illustrates how the centrifuge arm rotates to produce an artificial gravitational field on the soil model. The soil model is mounted on the end platform (labeled “payload”). The end platform is hinged from the arm, and subsequently rotates upwards during spinning. The resultant centrifugal acceleration (gravitational field) always acts perpendicularly to the base of the platform (and hence “down-wards” on the soil model).

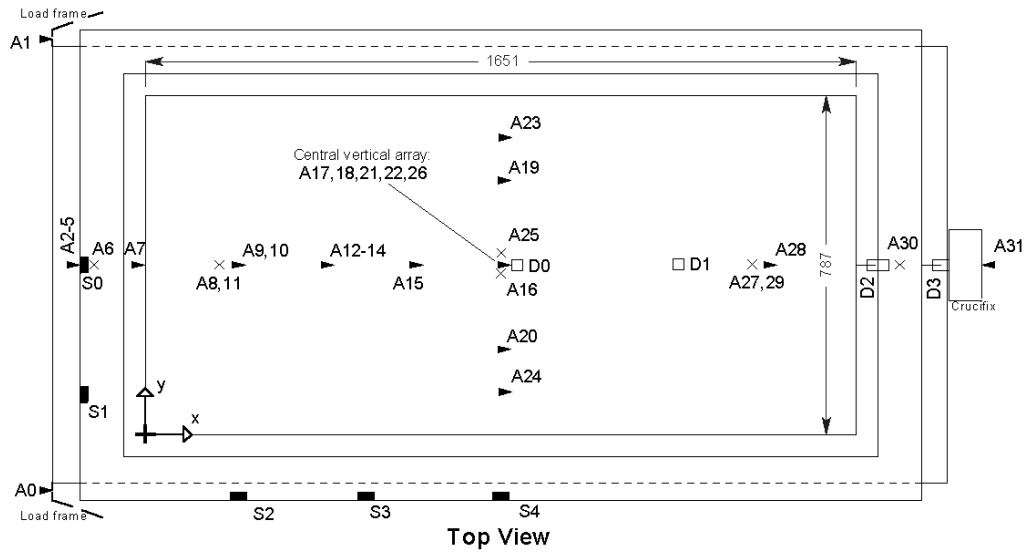
Sensors are usually unidirectional, *i.e.*, they measure an associated quantity along a single axis. Positions of all sensors are measured and recorded as they are placed and again at the conclusion of an experiment, as they can move during a series of simulated seismic events.

4. DATA FORMAT

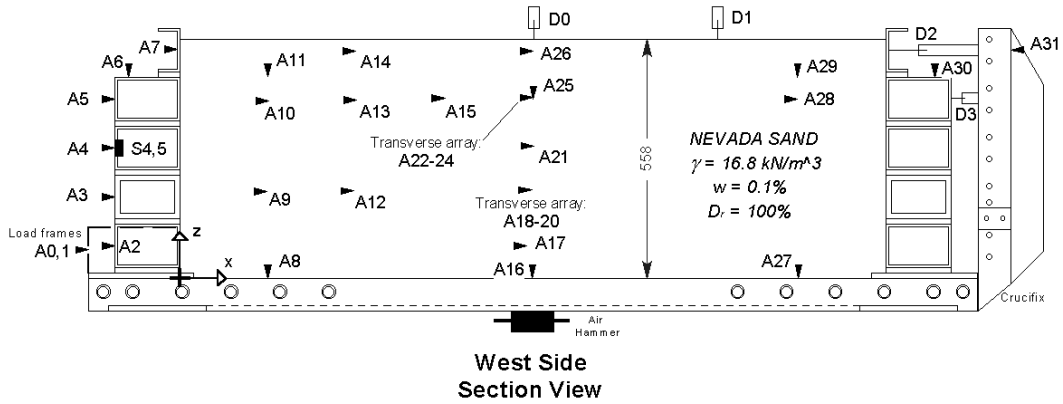
Our examples visualize results of an experiment on nonlinear site response [16]. This web-page links to a PDF file containing the complete experiment report with a detailed description of the experiment set-up and all measured data. The web-page also links to a set of sketches illustrating the experiment set-up. Figure 2 shows the set-up for the experiment used in our examples. Experiment layouts like this pose a problem, since in these instances the CAD system was merely used to draw 2D sketches of an experiment rather than to create 3D solid models of the set-up. Currently, we manually create an OpenInventor [17] scene graph representing simple geometry that illustrates a model and provides a reference for the sensor positions. Future experiments will be planned using a solid modeling approach, which would allow us to use exact geometry from the model descriptions in the visualization program.

In addition to the model, a model description (in form of an Excel spreadsheet) and ASCII log files (containing the measurements) are provided. The Excel file containing the report consists of several tables: a *test summary* table listing all simulated earthquake events. Each event is described by a line table, containing, among other information, the following details:

- Date
- Time
- Event description, *i.e.*, a brief textual description of the event
- Channel gain list (cgl) used, *i.e.*, a reference to another table that describes which sensors recorded data during the event, and calibration information for these sensors
- Output file, *i.e.*, the name of the file containing the sensor log for the event



(a)



(b)

Linear potentiometer	
Horizontal accelerometer	
Vertical accelerometer	
Strain gauge	
Air hammer	
ORIGIN	

(c)

Figure 2. Sketches illustrating model used in our examples.

An *instrument list* table lists all sensors by name. For each sensor, a line in the table specifies its name, sensor type (accelerometer, displacement sensor, or strain sensor), units of measurement, textual description of location, initial position in model coordinates, final position in model coordinates, direction, a detailed sensor description, and calibration information.

Not all sensors are active during each event. Several *channel gain lists* (in the form of spreadsheet tables) specify different sub sets of sensors that are active. For each event, the test summary references a channel gain list describing the sensor configuration used for that event. Sensor logs are ASCII files where each line corresponds to a measurement in time. Each column in a line corresponds to a value measured by a sensor at that time. We export each individual table comprising the experiment report in a separate file having the table name as filename. Each of these file is stored in comma-separated-value (CSV) format, where each column is separated by a tabulator instead of a comma.

5. VISUALIZATION TOOL

At start-up, our visualization tool presents a user with a main window, shown in Figure 3. It consists of a 3D OpenInventor examiner viewer that is used to display the experiment. On its right-hand side, several controls exist. A list view shows all events of a loaded experiment. A status button informs a user about possible actions. When the program is started, it asks a user to load a data set.

Once the tool has read a data set, the examiner viewer displays the experiment set-up. The information displayed entails the model geometry, and an icon for each sensor. Accelerometers are displayed as cones, strain sensors as spheres, and displacement sensors as boxes. When an experiment is loaded, the event-listbox shows a list of textual descriptions of all events comprising an experiment. The status button asks a user to select one of these events by executing a double-click on the corresponding list entry.

When a user selects an event, all sensors that were inactive during that event are colored gray to indicate that they are inactive. When a user selects one of the sensor icons by a double-click operation, further information about that sensor, along with a 2D graph of measured sensor data, is shown, see Figure 4(a). A user can zoom into any portion of that graph, see Figure 4(b).

Sensor icons can be animated to visualize data collected during a simulated earthquake event. Accelerometer data is visualized by displacing the sensor icons from their original position by an amount that is proportional to

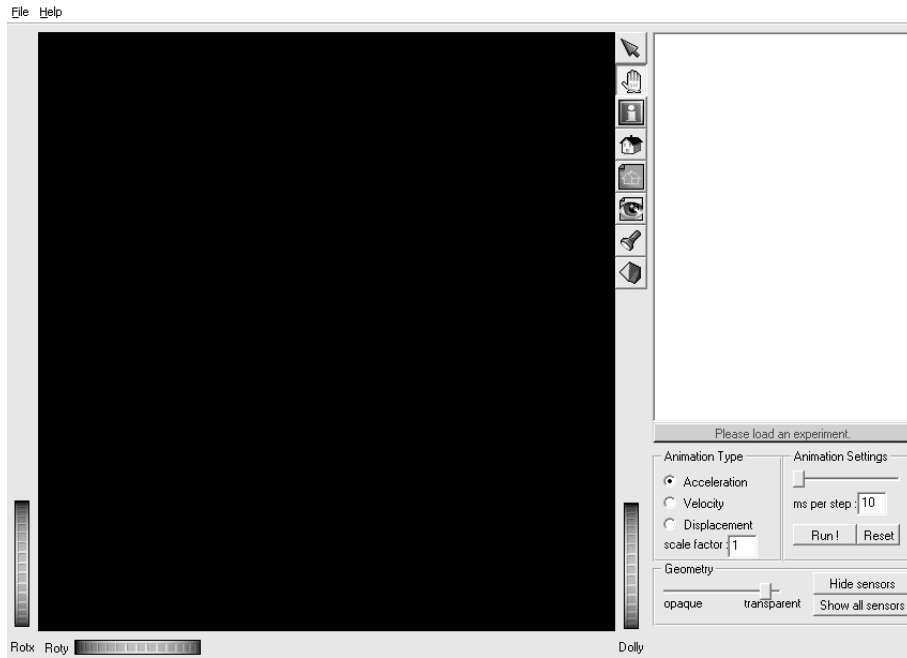
- acceleration,
- velocity, *i.e.*, integrated acceleration, or,
- displacement, *i.e.*, integrated velocity.

The animation type for accelerometers can be chosen via a set of radio buttons located below the status button. For each animation type of the accelerometers, a scale factor can be specified, since unscaled computed and measured values can be too small to have a discernible effect on a sensor animation. Integration is performed by assuming that acceleration varies linearly between two consecutive measurements. If a_i, v_i and s_i are acceleration, velocity, or displacement value displayed for an accelerometer at time step i , they are computed as follows. a_i is obtained by multiplying the sensor reading for that time step with the standard earth acceleration $g = 9.81 \frac{m}{s^2}$, since sensor values are specified as multiples of g . v_i and s_i are computed as:

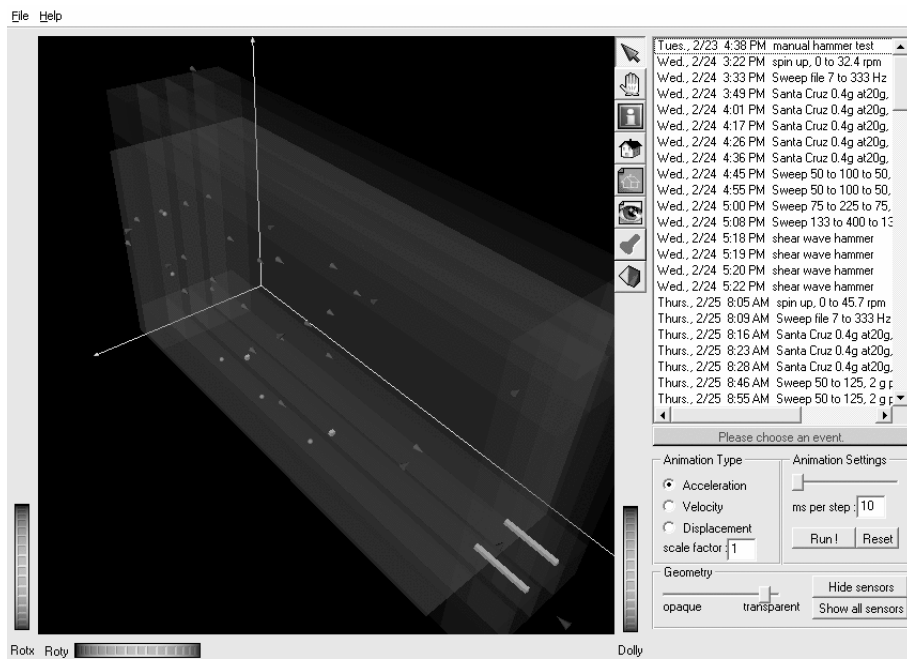
$$v_i = v_{i-1} + \left(\frac{a_{i-1}}{2} + \frac{a_i}{2} \right) \Delta t$$

$$s_i = s_{i-1} + v_{i-1} \Delta t + \left(\frac{a_{i-1}}{3} + \frac{a_i}{6} \right) \Delta t^2$$

Strain sensor icons are scaled in accordance to the measured strain value. The larger the measured strain, the larger the displayed icon. In addition, their color is varied continuously from blue to red depending on measured strain. Blue indicates a small measured value, and red indicates a large measured value. Displacement sensors are currently not animated. A sensor animation can be interrupted and resume at any time. A user can control playback speed by specifying the duration (in milliseconds) for the display of each measured/computed value.

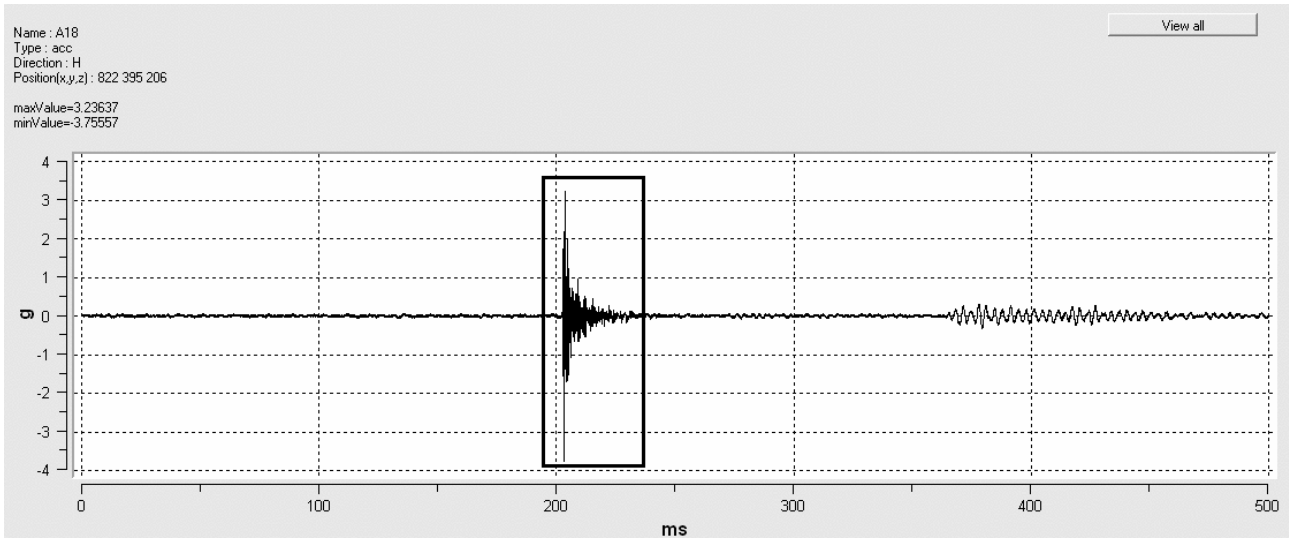


(a)

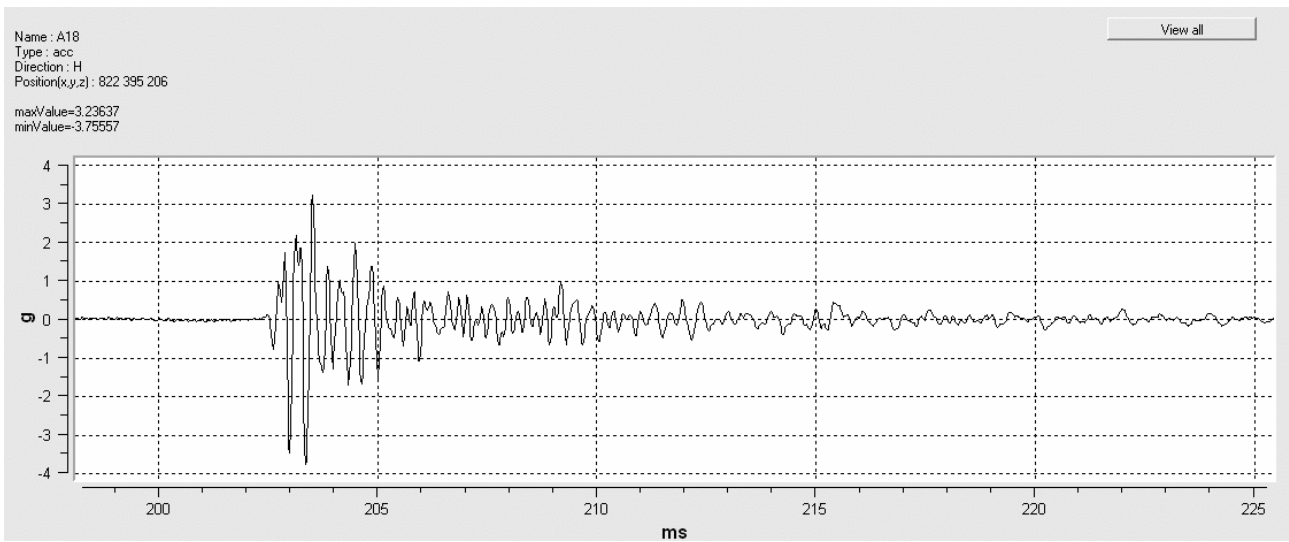


(b)

Figure 3. Shaker's main windows. (a) After program start-up. (b) When experiment is loaded.



(a)



(b)

Figure 4. Sensor log window. (a) All measurements of an event. (b) Close-up view of first peak of the event (area marked by a rectangle in (a)).

6. CONCLUSIONS AND FUTURE WORK

We have described a tool to visualize experimental earthquake data. This tool allows real time interaction with experimental setups involving a large number of sensors and to visualize raw experimental data of groups of sensors simultaneously by simple animations. Currently, we only display data at sensor locations. Interpolation is difficult, as finding an appropriate interpolation scheme is often part of the experiment evaluation. Discussions with users of our tool suggest that it would be best to de-couple data filtering and interpolation from the actual visualization tool, to allow a user to define interpolation and filter schemes. Elaborate visualizations, *e.g.*, contours or volume rendering, require an interpolation scheme. It will be necessary to make this interpolation scheme customizable and support a high-degree of user-interaction to define it. This requires a flexible way to integrate interpolation and processing into our visualization tool. Animating geometry in addition to sensors will help a user to understand experimental results better. In a first step we will derive displacement and rotation of solid objects in the model from measured sensor data and animate the geometry of a model accordingly.

Animations of sensors are easy to generate and could be used during the experiment to monitor results and possibly adjust boundary conditions. We plan to integrate our visualization tool into the unified NEESGrid environment. This will allow users from remote sites to visualize their data. We are also investigating migrating to a web-based visualization tool that would allow collaborators at remote sites to monitor ongoing experiments and work closely together in devising further tests. Results from our work will hopefully contribute to the common data models of the NEES initiative, leading to unified data formats for different sites in the future.

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