Large Earthquake Simulator Mimics Soil Liquefaction and Effects on Civil Infrastructure Foundations

Part of NSF’s George E. Brown, Jr., Network for Earthquake Engineering Simulation (NEES), this simulator proves critical for studying what happens to soils beneath waterfront structures and facilities during strong earthquakes.

Researchers at the University at Buffalo (UB) and Rensselaer Polytechnic University (RPI) studying earthquake-induced “soil liquefaction” and its effects on foundations that support waterfront infrastructure have developed a large-scale earthquake simulator to model the response of water-saturated sand under earthquake forces. During strong shaking, loose sand often turns into ‘liquid-like’ material and causes damage to structures sitting on top or embedded in the soil. The goal of the research is to learn how soil becomes “liquefied” and contributes to failure of foundations that support bridges, ports and harbor structures, or buildings. The researchers have completed two successful liquefaction experiments using the large-scale earthquake liquefaction simulator and will conduct additional tests in the coming months. These experiments will be webcast live and will be available at http://www.nees.buffalo.edu/projects/NEESPiles/.

The results from this study will help engineers design and build earthquake-safe foundations to support civil infrastructure and mitigate earthquake damages that cost billions of dollars.

The earthquake simulator is part of the NEES@Buffalo equipment and research site, a National Science Foundation (NSF) George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) facility. NEES is an interconnected, nationally distributed system of 15 facilities for studying the effects of full-scale earthquake forces on structures and materials. Research data results are uploaded to the NEEScentral data repository and curated data is made available to the public for accelerated adoption into engineering practice.

The researchers have developed a new earthquake-induced liquefaction simulator using a 5 m long, 2.75 m wide and 6 m high laminar stack ring system capable of containing about 150 tons of sand at the NEES laboratory at the University at Buffalo, State University of New York. The rings are stacked vertically, separated by ball bearings allowing sliding between the rings. The laminar stack and its base sit on large bearings on the strong floor, and is slightly inclined in some experiments to simulate sloping ground. Free
After being filled with loose sand and water, when the base is shaken using two 100-ton hydraulic actuators with strong vibrations representative of those occurring at deeper firm ground during an earthquake, the soil liquefies and spreads laterally. A robust hydraulic fill method allowing sand grains to slowly fall through water mimicking natural alluvial deposition of sands in rivers, lakes, or man-made port islands is used to build the ground inside the laminar rings, at a target density verified by density tests and cone penetration measurements. A computer controlled shaker capable of 200 ton force powered by four MTS pumps each rated at 185 gallons per minute flow with 3,000 pounds per square inch working pressure was developed to provide precise synthetic or past records of earthquake motions at the base (http://nees.buffalo.edu/docs/labmanual/html/).

Advanced instrumentation techniques using a dense sensor array of MEMS accelerometers, piezometers, potentiometers, and digital image analyzers are used to closely monitor the time-history of accelerations, dynamic water pressures, and vertical and lateral spreading within the ground and along the piles, and additional strain gages on the piles monitor bending moments. The tricky part of the problem is to understand how the ‘liquefied sand’ constantly changes its response during and immediately following the earthquake and how it damages the foundations that support structures sitting on the ground. These sensors record the dynamic changes, and a three-dimensional viewer displays these responses on a computer screen allowing the researchers to visually capture the complex response of the soil during and following liquefaction and understand the phenomena.

Three other parallel efforts are underway to simulate the same effects using centrifuge technique using rather small scale models, and two types of computer modeling of the liquefaction phenomenon and effects using finite element modeling (FEM) and discrete element modeling (DEM) techniques. The ultimate aim is to develop, refine and validate computer models using the experimental results and use them to study this problem and design earthquake-safe foundations to support structures without failing in future earthquakes. Compatible data bases from the large-scale liquefaction simulator, centrifuge, FEM and DEM are fed to the 3D data viewer and integrated for a better understanding of the soil and pile foundation responses.

Ricardo Dobry at RPI is leading the overall research, and S. Thevanayagam at UB, State University of New York is leading the research on large-scale experimental simulation of earthquake-induced soil liquefaction. T. Abdoun at RPI is in charge of the centrifuge experiments, and A. Elgamal at UCSD and M. Zeghal at RPI lead, respectively the FEM and DEM simulations. Andrei Reinhorn at UB lead the development of the computer controls for the shaker.

More information about the study is available in the websites indicated below.

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Related Websites
http://www.nees.buffalo.edu/projects/NEESPiles/
https://central.nees.org/?projId=122&loc=Public#
Researchers setting the Base Shaker and assembling the Laminar Ring Stack

Researchers hydraulically placing the sand, building the ground and setting up instruments before earthquake shaking
Video of UB Liquefaction Experiment (https://central.nees.org/?projid=122&loc=Public#)

A 3-D Data Viewer software for visualization of the response of the ground and foundations during strong shaking

To run the 3-D Data Viewer:

**Step 1:** Download and save (in your computer) all four files from https://central.nees.org/?projid=122&loc=Public#

**Step 2:** Run the 3-D Data Viewer from http://nees.rpi.edu/3dviewer/