Equipment Site Description

The UC Davis centrifuge has the largest radius, and largest platform area of any geotechnical centrifuge in the US; it is one of the top few in these categories in the world. The centrifuge can carry 5 ton payloads and operate at 75 g (at the effective radius of 8.5 m). Typical geotechnical model testing in the past used very limited amounts of instrumentation that provide observations at selected points in a physical model. Progress in earthquake engineering was hindered by incomplete and ambiguous data sets that allow for subjective and potentially mistaken interpretation. The development of the NEES Centrifuge at UC Davis capitalized on the size of the facility and revolutions in instrumentation and information technology to enable researchers to enable generation of much higher resolution information (more control, sensors and images) and more realistic physical models that will provide unambiguous experimental data for assessments of Model Based Simulation theories.

UCD NEES Centrifuge

The 9-m radius centrifuge at UC Davis (Fig. D.7-1) is the largest in the US, and it can carry five-ton payloads to accelerations of 75 g. The large size and available resources allow researchers to perform detailed experiments of complete geotechnical engineering systems.

An earthquake simulator, mounted on the end of the centrifuge, is designed to operate in either a biaxial (horizontal-vertical) or uniaxial (horizontal) shaking mode (Fig. D.7-2). The servo-hydraulic shaking tables are capable of simulating broad-spectrum earthquake events as well as step- and sinusoidal-wave type motions, and can vary intensity from microtremors to extreme shaking events.

The 2-m long x 1-m wide uniaxial shaking table is the largest centrifuge-based shaking table in the US and is among the largest available anywhere in the world. Uniaxial models may be constructed, depending on the project priorities, using flexible shear beam containers - designed to deform with the soil profile during shaking, a rigid container - with clear side walls for observing below grade behavior with video cameras, or a hinged-plate container – which allows permanent lateral deformations among its advanced features. These containers are all on the order of 1.7-m long x 0.7-m wide x 0.7-m deep. The useable volumes are among the largest centrifuge model containers available in the world, and when testing at 75 g’s the models simulate a site that is approximately 130 m x 50 m x 50 m in size. A 1-m long x 0.5-m wide x 0.4-m high flexible shear beam container is available for biaxial shaking. While smaller than those available for the uniaxial shaker, it is still considered to be a large centrifuge container.

Figure D.7-1: The 9-m radius geotechnical centrifuge at UC Davis. NEES upgrades include streamlining and drivetrain improvements that increased centrifuge capacity from 40 g to 75 g.
A large inventory of transducers and signal conditioning equipment can be used to monitor model behavior during an experiment. Arrays of pore pressure transducers, for example, can be used to monitor spatial variation of liquefaction. Arrays of accelerometers can be used to study wave propagation. Many projects also include arrays of custom transducers, e.g. strain gauges on model structures. This data acquisition system was overhauled as part of NEES. It currently records up to 160 transducers, and can be expanded as need arises.

A distributed high-speed wireless data acquisition system can be used to record data from up 400 MEMS accelerometers / inclinometers in a single test. The system consists of 50 miniature eight-channel high-speed data acquisition systems that can be buried in the soil. As dense arrays of accelerometers the transducers can be used to study spatial variability of wave propagation. As inclinometer arrays the transducers can be used to quantify the internal deformations of the soil profile. For example, a closely spaced vertical array of these sensors would produce information to define the permanent shear strain distribution within a soil deposit. Assuming a smooth shear strain distribution, the shear strain could be integrated over the depth to accurately quantify the permanent displacements within the soil deposit.

A gantry robot with changeable manipulator tools and an on-board tool rack can be used to perform multiple tasks without stopping the centrifuge (Fig. D.7-3). Onboard robotics, for example, allow more accurate simulation of construction processes, which can, for example, control effectiveness of soil improvement and influence behavior of geotechnical systems such as pile groups. Users can use the gripper tool to drive piles sequentially, apply load cycles to structures, and manipulate objects to simulate construction processes.

The robot can be used to perform in-flight in-situ site characterization tests using geophysical testing methods. These tests can help relate data in the centrifuge models to field conditions and can be used to study the evolution of material properties through a series of shaking events. Soil strengths can be indexed using the cone penetrometer (Fig. D.7-3) and vane shear robot tools. A needle probe tool may be used to measure porosity variation at millimeter resolution. An ultrasound tool may be used to measure the deformation of a submerged surface or subsurface during flight based on sound waves. Users can also inspect the exposed model surface with a stereo camera tool.

The robot has a versatile tool interface to support future growth. A preliminary design for a new tool for soil improvement has been completed, pending funding through research projects. We will develop new tools on a project-specific basis as need and funding arises.

Various imaging techniques are used to monitor evolution of the surface and interior of centrifuge models during testing. An array of high-speed video cameras can be used to image the surface of models and track deformations during shaking events. An eight-channel array of bender element sources may be
Figure D.7-3: A 4 degree-of-freedom robot has been added to the centrifuge. An onboard tool rack holds up to five tools for use during in-flight inspection and construction. The robot is fully operational in conjunction with shaking table tests.

monitored using up to sixteen receivers, allowing interpretation of shear-wave velocity distributions by direct methods or tomographic inversion. An electrical resistivity tomography system uses 48 electrodes to monitor changes in electrical resistivity between any combination of electrodes. Inversion methods may also be used to create images of resistivity distribution that can be correlated to porosity distribution.

The various independent systems are interconnected in the data acquisition network and can share data and timing signals so that everything works together. The network structure can easily accommodate future growth or custom data acquisition systems developed on a project-specific basis.

A 470 m² building, opened in 2003, houses the 42 m² visualization room, where we use 3-D software and our Geowall stereo display to explore data from hundreds of sensors collected in simulated earthquake events (Fig. D.7-4). The visualization room is also outfitted with video conferencing and telecollaboration equipment so that remote researchers can interact with local staff during experiments.

NEES Research using the UCD NEES Centrifuge

The UCD equipment portfolio is unique in that the size and available resources allow researchers to perform detailed experiments of complete geotechnical engineering systems. An example of an envisioned research project is to evaluate the efficiency of vibroflotation to mitigate liquefaction-induced lateral spreading. Hundreds of millions of dollars per year are spent in the US on ground improvement to mitigate liquefaction hazards. The fundamental effects of ground improvement by deep vibration, as just one example, are incompletely understood; deep vibration densifies the soil and increases the lateral confining pressures and the improvements are dependent on soil properties and the power of the tool. Quality control of improvement is usually monitored by before and after penetration resistance measurements. However, the changes due to ground treatment have different, time-dependent effects on the quality control measures used and on the triggering and consequences of liquefaction. Furthermore, ground improvement creates a heterogeneous distribution of soil properties in the ground, and engineers do not yet have established procedures to account for heterogeneity on the liquefaction behavior.
For this example the researcher might be interested in determining how to evaluate the composite behavior of a treated soil mass, and how far to extend treatment extend beyond a structure's edges to protect it from the effects of liquefaction in the surrounding soils. These and other issues can have large effects on the cost and reliability of ground improvement works.

The soil model might consist of a saturated layer of loose sand overlying dense sand, with the entire model sloping in the hinged-plate container, which will allow largely unrestrained lateral deformations (Fig. D.7-5). We would treat a portion of the loose sand with a robotic vibrating probe in flight. Measurements of pore pressures, accelerations, and geophysical properties around the vibrating probe would provide information on the treatment mechanism. The cone tool, needle probe tool, and/or electro resistivity tomography equipment, and bender element arrays would be used to characterize the extent and degree of treatment, as well as variations spatially within the treatment zone.

The model would be shaken to induce lateral spreading of the untreated zones. Spatial variations in accelerations and pore pressures within and adjacent to the treatment zone would provide data on the composite behavior of the treatment zone and its interaction with liquefied soils around it. Dense MEMS accelerometer / inclinometer arrays will provide the ability to study the physics of composite material behavior through measurements of the spatial variation in dynamic response, rather than inferring the physics from a few select measurement points. Post-shaking measurements would characterize changes in soil properties, and the robot stereo imaging equipment would scan the surface to map the surface manifestation of the zones of influence of the improvement.

This complicated model test would be performed by a team of researchers. Operating the shaker, the robot, and the tomography equipment requires specialized training, and a single researcher cannot efficiently and safely operate all of this equipment simultaneously. The overall experiment would be managed by the lead project engineer, a researcher working at UC Davis. This engineer would oversee the construction of the model and ensure all of the physical equipment is in place for testing. During the experiment the lead engineer would be responsible for gathering data during seismic tests. Another researcher would be responsible for operating the robot in-flight. A third researcher would operate the tomography and imaging equipment in-flight. These two engineers could be remote operators, collaborating via the high-performance network but performing their work independent of location.
The database from this experimental project would provide the basis for evaluating and developing Model Based Simulations for years to come because of the completeness of information obtained using the NEES equipment.

Research on the UC Davis NEES centrifuge will involve cross-disciplinary collaboration that will infuse student researchers with the latest advances from several fields, from earthquake engineering to robotics to MEMS to networks to data management and visualization. This cross-disciplinary team environment will open opportunities for these students to envision other fruitful connections throughout their careers. Once the equipment is established, student researchers will become familiar with these advanced technologies and be better equipped to champion their application to other civil engineering applications.

Experimental data obtained with the new equipment will become increasingly attractive for use in case-study instruction of earthquake engineering at universities because of the completeness of the data. We already have used some experimental data as "cases studies" for use in our case-based instruction of geotechnical engineering. With the new equipment, we would increase the use of experimental data as cases because the students could watch the high-resolution high-speed videos, work with site characterization data (e.g., CPT, vane, geophysical methods), work with ground improvement data, and assess the performance during earthquakes over a range of shaking levels.

Figure D.7-5: Ground Improvement for mitigating Liquefaction Hazards. The robot could manipulate a vibroflot tool to improve a zone of soil. Resistivity tomography is used to characterize the porosity distribution in the soil before and after improvement and shaking. The Hinged Plate Container allows the liquefied soil to spread during shaking. The mesh of MEMS record the distribution of motions within the layer during shaking, and the permanent deformation patterns within the soil layer after shaking, for comparison to MBS. The stereo robot eyes are used to scan and inspect the model after shaking, looking for surface manifestations of liquefaction and spreading.