

**Equipment Site Description**

The 150 g-ton geotechnical centrifuge NEES facility is located in the basement of the Jonsson Engineering Center (JEC) of the RPI campus in Troy, NY. This building also contains the offices of essentially all personnel listed in this proposal, offices of graduate students conducting centrifuge and associated analytical research, and offices available for visiting users. The layout of the facility is shown in Fig. D.4-1 and is all in one level without interfering stairs. Main spaces shown in blue color in Fig. D.4-1 include the centrifuge itself and surrounding circular enclosure (Fig. D.4-2), as well as the connecting tunnel housing the variable speed motor controller and power electronics cabinets. Other main spaces of the centrifuge facility shown in blue in Fig. D.4-1 are: (i) two model preparation rooms; (ii) state-of-the-art control and teleparticipation room with four plasma screens and capacity for 6+ on-site operators/visitors; (iii) robot room; (iv) electronic development room; (v) state-of-the-art teleconference room; (vi) two rooms containing respectively the data acquisition (DAQ) and LAN servers; and (vi) geotechnical computer laboratory.

![Diagram of RPI NEES geotechnical centrifuge facility](image)

Figure D.4-1: Layout of RPI NEES geotechnical centrifuge facility (blue spaces) and other soil and structural research and educational facilities (yellow spaces)

The spaces included in the layout of Fig. D.4-1 contain the various centrifuge equipments, sensors, data acquisition and other hardware and software listed in Section A.1, with corresponding connections to the high speed RPI network, providing the physical infrastructure needed to support the NEES vision of high quality physical testing, shared use and combined real-time experiments with other facilities. More details are provided later in this proposal and can also be found for all pieces of equipment in www.nees.rpi.edu. Especially important for our aim of more realistic centrifuge models and for RPI’s contribution to the teleparticipation/shared use/model-based simulation NEES mode of research, are our new robot, new state-of-the-art 2D shaker, and advanced sensors and high speed camera, which are discussed below.
The in-flight 4-degree-of-freedom robot (Fig. D.4-3) allows for a stroke of 0.8 m in the x and y prototype directions, a stroke of 0.5 m in the y vertical prototype direction, and a 270° rotation around the vertical axis. It has a high degree of accuracy which makes it ideal for use in teleparticipation, and load capacities of +/- 1000 N and +/- 5000 N, respectively in the horizontal and vertical directions, as well as a torque capacity of +/- 5 NM around the vertical axis, applicable to uses such as static in situ cone penetration and loading tests of models of piles or shallow foundations. The robot will play a key role in teleparticipation, with remote users able to implement realistic simulations of construction and excavation operations, pile driving, ground Remediation, cone penetration, and model foundation loading tests without stopping the centrifuge. The horizontal, vertical and torque loading capabilities of the robot will play a central role in combined real-time, soil-structure interaction tests involving other experimental facilities and/or feedback from simultaneous numerical simulations.
The in-flight 2D shaker servohydraulic multiactuator system (Fig. D.4-4) is capable of producing periodic or random motions in the two prototype horizontal directions as determined by the input signal. The nominal shaking force is 50 kN in each axis, capable of exciting a 965 x 660 x 711 mm payload at a centrifugal acceleration of 100 g with a nominal shaking frequency range of 0 to 350 Hz. The shaker excites the base of a 2D flexible wall laminar box container with the soil or soil-structure model; similarly to the 1D laminar box containers also available at RPI, the flexible walls of the 2D laminar box allow realistic simulation of the shear beam free field ground conditions during horizontal shaking. Two-dimensional shaking allows more realistic in-flight earthquake simulations for both soil and soil-structure models; available laboratory and field information indicates that two-dimensional shaking causes significantly higher densification in dry sands and excess pore pressures and liquefaction in saturated sands compared to 1D shaking. We also anticipate that this 2D shaking capability will play a key role in clarifying the relation between ground surface slope and topography, on the one hand, and direction of shaking on the other; for slope failure, flow failure and lateral spreading phenomena involving soft clays as well as saturated sand liquefaction.

Figure D.4-4: Two-dimensional in flight servohydraulic shaker (two prototype horizontal directions)

Figure D.4-5 illustrates some of the advanced monitoring and sensing technologies now being developed or under examination for centrifuge modeling at RPI. They include MEMS accelerometers (which we are exploring together with the UC Davis NEES experimental site), tactile pressure sensors and fiber optic shape tape, as well as our newly acquired Vantom 4 high-speed camera with associated image processing software. As new and extremely promising measurement technologies continue to appear in the market at a rapid rate, and evaluation (and in some cases, also some development) is needed before they can be reliably used in centrifuge tests, it is difficult to anticipate exactly which techniques will be available for shared users at the RPI centrifuge 2-3 years from now. However, it is clear that there will be continued improvement in the quantity and quality of the data, with greatly increased resolution (in space and time) of the model response. More and better soil (as well as foundation and structural) response data such as permanent and cyclic deformations, accelerations, pore water pressures, bending moments, etc., will become available. This is extremely important, as the centrifuge’s contribution to the NEES vision will be greatly enhanced by the use of dense arrays of advanced sensors and of high-speed cameras to provide high-resolution measured model response. This, in conjunction with our networked data-acquisition system and remote-access capability, will lead to a major advance in the use of the geotechnical centrifuge data at RPI, allowing better teleobservation, shared use of data, test visualizations, system identification, numerical computations, and development of model-based simulations. The RPI team has started to explore some of these possibilities and is getting ready to expand their use to the maximum in research applications, especially investigations on large deformation behavior of soil deposits which are both subject to
liquefaction and interact with other structures. For example, in the current US-Japan research project involving some RPI researchers as well as UCSD, pile foundations in inclined soil deposits are subject to liquefaction and lateral spreading in the RPI centrifuge and in large prototype laminar boxes (as high as 6m) in shaking tables in San Diego and NIED in Japan. The size of the prototype experiments in the 1g shaking tables allow extensive use of large amounts of sensors including dense arrays at critical locations, while both 1g and centrifuge experiments are instrumented with advanced sensors and the comparisons of experimental results make systematic use of system identification and visualization techniques, and numerical simulations are both calibrated by the measured results and are used in the planning of further tests and refinement of sensor locations. We expect to make these and other sensing technologies available to shared users of the RPI centrifuge as soon as their feasibility and reliability have been confirmed.

Figure D.4-5: Advanced monitoring and sensing technologies (tactile pressure sensors, fiber optic shape tape, and high speed camera)

Figure D.4-6: Vision of interactive, real-time NEES SSI research involving several structural and soil experimental facilities

Figure D.4-6, presented by B. F. Spencer, Jr. of the U. of Illinois at the 8/7/03 Summit Meeting in Chicago (http://worktools.si.umich.edu), illustrates the vision of NEES for combined, pseudo-dynamic real-time soil-structure tests involving several 1g structural NEES experimental facilities for structural response, and a geotechnical centrifuge NEES facility such as RPI’s for the foundation and soil response. In this type of
experiment, which is conducted with the foundation-soil centrifuge model always spinning, important roles should be played by our robot (which will apply the loading to the foundation-soil model), by our advanced sensors and data acquisition system, and, of course, by our teleparticipation capability. Figure D.4-6 shows very clearly the kind of research now made possible by NEES with the participation of the RPI centrifuge, which was not possible before.

Figure D.4-7: Visualization of quay wall response to base shaking and soil liquefaction from data measured in a centrifuge test

Visualization tools, especially those that provide a real-time (or almost real time) picture of the response and behavior of the soil or soil-structure model during and after the shaking, are extremely important as part of our centrifuge contribution to NEES’ tasks and vision, including shared use, teleparticipation, and real-time experiments such as illustrated by Fig. D.4-6. At the most basic level, they are the answer to the question of how to integrate in a meaningful way the vast mass of data to be provided by the dense arrays of advanced sensors together with the high speed cameras. For real time teleparticipations and combined experiments such as that of Figure D.4-6, timely human decisions by the shared users may be needed that will depend on their understanding of how the model is responding, and this can only be obtained through automated routine visualizations of the model’s response. The RPI team will provide an increasing number of these visualization tools to the shared users as part of the capabilities available to them. Examples of visualization capabilities that are already available can be viewed in www.nees.rpi.edu. Figure D.4-7 is a frame – corresponding to one time instant during shaking – obtained from one such visualization. The visualization of Figure D.4-7 corresponds to the shaking and liquefaction of loose saturated sand behind a waterfront quay wall centrifuge model, which approximated the conditions at Port Island during the 1995 Kobe earthquake. In this visualization, blue = ocean, black = quay wall, red = liquefied sand with high positive pore water pressure, yellow = sand with some positive pore pressure, and green = sand with negative pore water pressure. The visualization clearly shows that the sand in the free field liquefied both behind the quay wall and under the ocean bottom, while a complicated soil-structure interaction pore pressure response was taking place near the quay wall, including the development of negative pore pressures under the quay wall as this structure both rocked under the shaking and slid toward the ocean.