Rensselaer Polytechnic Institute (RPI) Geotechnical Centrifuge

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Introduction

The Earthquake Engineering Simulation (CEES) at Rensselaer Polytechnic Institute is a multi-disciplinary research center. The center provides internal and external researchers a state-of-the-art facility to conduct experimental, analytical, analytical-experimental, and multi-disciplinary research in earthquake engineering and other geotechnical fields. CEES comprises a centrifuge and a number of unique pieces of equipment, including a 2D shaker, 2D laminar box, split boxes, a 4D robot, and state-of-the-art Data Acquisition (DAQ) software.

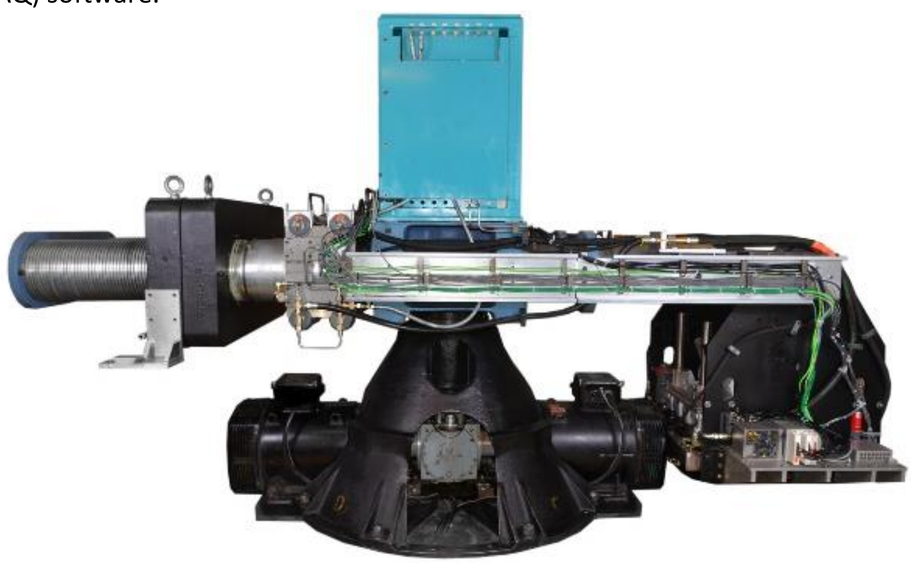

Figure 1. The upgraded Acutronic (Model 665-1) centrifuge at RPI.

Centrifuge

The original RPI centrifuge was commissioned in August 1989. It was manufactured by Acutronic, France and was the first of its type (Model 665-1). It belongs to a line of (about a dozen) Acutronic Machines that have the same basic mechanical structure and safety features. The centrifuge was upgraded in 2004 to 150 g-ton by Actidyn Systems within the context of the National Science foundation (NSF) Network of Earthquake Engineering Simulation Network (NEES). The upgraded Model 665-1 centrifuge (Figure 1) comprises: a) swinging basket; b) centrifuge boom; c) balancing counterweight; d) hydraulic rotary joint and electrical slip-rings assembly; e) drive system; f) aerodynamic enclosure; and g) in-flight imbalance measurement and automatic balancing systems including automatic shutdown if excessive imbalance is detected.

The main centrifuge performance characteristics are (see also Table 1):

- A platform radius of 3.0 m and a nominal radius of 2.7 m. The platform radius is the distance between the swinging basket platform and the centrifuge axis. The nominal radius is the distance between the center of payload and the centrifuge axis. Usable load capacity and acceleration are defined at this radius.
- Usable payload dimensions of a depth of 1.0 m, width of 1.0 m, height of 0.8 m, and a maximum height of 1.2 m.
- Performance envelope or the do not exceed limits of 160g, 1.5 Ton, and 150 g-tons (product of centrifugal level and payload weight) .
- Fiber optic rotary joint, 28 slip rings and wireless network for data transmission and hydraulic rotary joint with a total of 6 joint passages, with two of which are rated for 3,000 psi hydraulic oil.
- A forced-air ventilation system to provide cooling within the centrifuge enclosure, if necessary.
- A system of electronic locks and safety interlocks that prevent machine startup if the enclosure access doors are not securely locked.

Table 1. Centrifuge main characteristics and equipment

Manufacturer	Acutronic, France
Year established	1989
Radius to swinging basket platform	3.0 m
Capacity	150 g-ton
Payload area	1.0 m x 1.0 m x 0.8 m
Major equipment	2D shaker/Earthquake simulator
	2D Laminar container
	Split boxes
	4DOF Robot

2D Shaker

Figure 2. The integrated basket and 2D shaker.

Numerous case histories and cyclic loading experiments have shown the significance of two-dimensional shaking in causing higher densification in dry sands and larger excess pore pressures in saturated sands as compared to 1D shaking. Two-dimensional shaking is also an important factor affecting the permanent deformation and failure for a number of geotechnical systems especially in relation to sloping grounds.

The 2D shaker at Rensselaer (Figure 2) can apply biaxial shaking (in the horizontal plane) to centrifuge models while being spun at up to 100 g. The shaker is designed to conduct realistic in-flight earthquake simulations, where the base of a model (in a 2D laminar box container, for instance) is subjected to two horizontal shaking components. A wide variety of 2D motions can be produced with the shaker, including periodic, aperiodic, random, or scaled earthquake signals (in addition to 1D motions in one horizontal direction). The shaker can be used to support static model containers for tests of up to 150 g when it is not used to provide base input motions for dynamic testing

2D and 1D Laminar Containers

A laminar container provides the means to accommodate large soil lateral deformations (such as those observed when soil liquifies) with minor boundary effects. The 2D Laminar Container at RPI (Figure 3) was designed and manufactured by PVL Technologies specifically for use with RPI's 2D shaker. The design is based upon a similar container previously designed and manufactured by PVL Technologies for the centrifuge at the Hong Kong University of Science and Technology (HKUST). The RPI 2D laminar container incorporates several design enhancements, including a more rigid base plate and a modified "open top" restraint system, so as to facilitate access to the model surface by cameras and by the RPI in-flight robot.

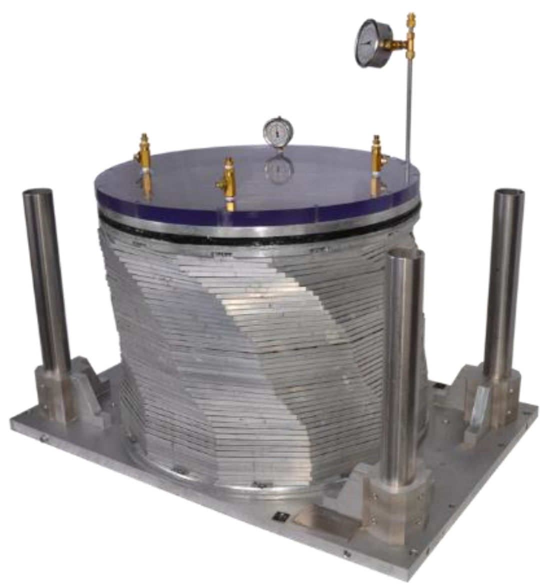

Figure 3. The 2D laminar box at RPI.

The container is constructed from 45 twelve-sided lightweight aluminum alloy rings arranged in a stack. Each ring is 8.9 mm in height with a 594 mm mean inside diameter and is separated from the rings above and below by 120 roller bearings, especially designed to permit translation in the two horizontal directions with minimal frictional resistance. Relative displacements of up to 2.5 mm between rings are achievable. The 2D laminar container is designed for use at centrifuge accelerations of up to 100 g. An adjustable restraint utilizing low-friction linear-rotary bearings is used to maintain a downward force on the ring stack. This restraint is adjustable to allow testing with different numbers of rings and container height. The laminar container is designed for use at centrifuge accelerations of up to 100 g.

The 1D laminar box (Figure 4) consists of a stack of up to 38 rectangular rings separated by linear roller bearings, arranged to enable relative movement between rings in the long direction with minimal friction. The rings are 9.35 mm in height. A relative displacement of up to 3.13 mm between adjacent rings is possible, which enables an overall shear strain up to 20%. The box is made mostly of high strength aluminum alloy and has internal dimensions of 35.5 cm (W) × 71 cm (L) × 35.5 cm (H). Bearings are placed between the rings to enable lateral displacement of the rings and to reduce friction. A clamp fitted with bearings is placed on top of the stack to prevent uplifting of the rings during shaking. Each ring is separated from the upper and lower adjacent rings by a total of 86 rollers. Bearing cages are used in order to maintain proper alignment and spacing of the rollers within the rings. The cages are separated from the top and bottom of each adjacent bearing by tiny Teflon pads glued to the cages. A coefficient of friction of 0.006 was measured between the rings under 8 kN vertical load.

Figure 4. The 1*D laminar box at RPI.*

Split Model-Boxes

The split model-boxes provide the means to simulate (in centrifuge testing) ground deformation in relation to (vertical and horizontal) fault motion simulations.

PVL Model CMC-SB3 (Figure 5) is a split model container for use in geotechnical centrifuge testing. The container has two movable half parts. Two actuators are used to produce controlled relative displacements of the container halves in the transverse and vertical directions (under a centrifugal acceleration of up to 75 g). Each half may be actuated independently, consecutively, or simultaneously to allow a wide variety of strain paths. A load cell is used to measure the horizontal shearing force applied by the actuators, and displacement transducers measure the resulting displacements in the horizontal and vertical directions.

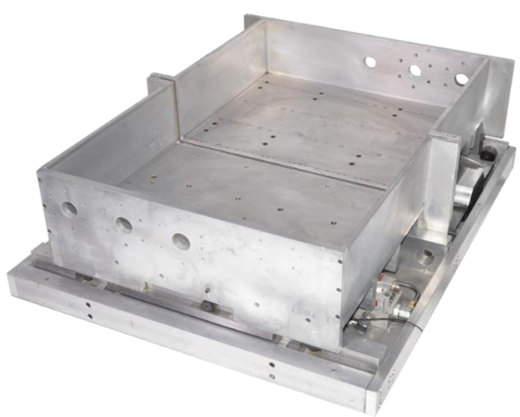

Figure 5. The s*plit*-b*ox* (PVL Model CMC-SB3) for simulation of h*orizontal*-v*ertical* fault motions.

PVL Model CMC-SB2B (Figure 6) is a split box that uses two hydraulic actuators to produce localized shear strains along one or two vertical interfaces in a soil model (under a centrifugal acceleration of up to 75 g). Load cells are used to measure the shearing force applied by the actuators. The maximum achievable displacement is 8 cm (in model scale). When operated at a supply pressure of 20.7 MPa the maximum dynamic force developed by each actuator is approximately 8.9 kN. The maximum achievable displacement is 3.2 inches (8 cm). The motion of each actuator is precisely controlled using a servo valves and feedback control system that can produce a variety of input strain distributions and time histories.

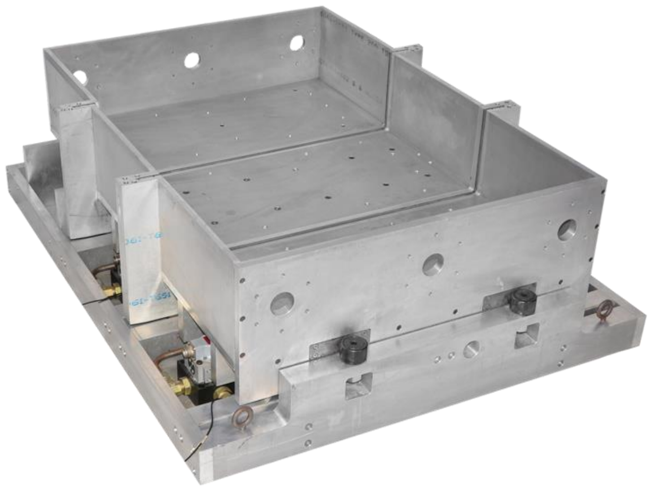

Figure 6. The split-box (*PVL Model CMC-SB2B*) for simulation of horizontal fault motions.

In-Flight 4 Degree-of-Freedom Robot and Attachments

Figure 7. The 4 Degree of Freedom Robot at RPI

The in-flight robot at RPI is designed to perform multiple tasks while the centrifuge is spinning. The ability to conduct in-flight field operations increases the accuracy and realism of experiments. The robot (Figure 7) is capable of articulating in three linear dimensions and rotating around one axis. The robot can carry several tools that aid in executing various tasks. These tasks include:

- In-flight sand and clay model construction
- Ground excavation
- Injection of contaminants or chemical stabilizers
- Placement of soil reinforcement in clay slopes
- Pile driving,
- Cone penetration test (CPT, Figure 8) and vane in-situ test
- Use of static/cyclic/dynamic loading devices

Researchers may also fabricate other custom tools to use with the in-flight robot.

Figure 8. CPT tool.