Center for Infrastructure, Energy and Space Testing: Geotechnical Centrifuge Facilities

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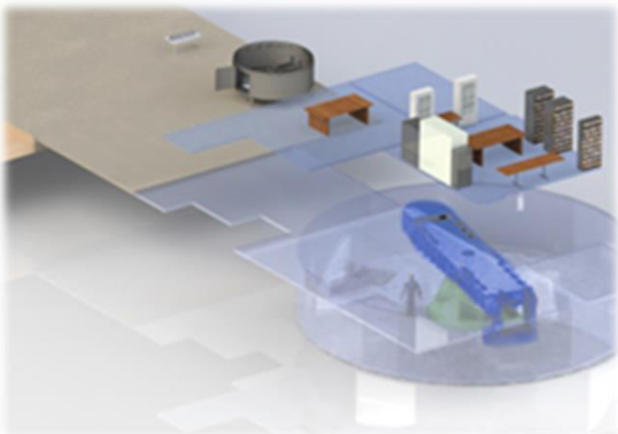
Introduction

The Center for Infrastructure, Energy, and Space Testing (CIEST) provides a centrally managed experimental testing facility offering geotechnical centrifuge, structural dynamics and materials testing. The facility boasts unique large-scale, fast loading rate, gravitational and environmental control capabilities. These facilities are available for use by both academic institutions and industry, see Getting Started | CIEST.

This document focuses on the medium and large Geotechnical beam centrifuges housed within CIEST. There is also a small, 'instructional centrifuge' used primarily for undergraduate teaching (e.g., see GTJ Instructional Centrifuge). The medium and large centrifuges feature an operational radius of 1.2 m (15 g-ton capacity) and 5.51 m (400 g-ton capacity) respectively. Across both machines a variety of actuators, miniature field-testing equipment, specialized testing devices and sensors are utilized. Significant innovations are detailed in this document (e.g., the new servo-hydraulic earthquake actuator) with additional information (e.g., complete container and sensor lists) provided on the CIEST website: Geotechnical Centrifuges.



Overview of the Large and Medium Geotechnical Centrifuge Facilities within the Center for Infrastructure, Energy and Space Testing (CIEST)

Key Technical Specifications

400 g-ton Asymmetric Rotor Arm Centrifuge	
Manufacturer	Design: Wyle Laboratories, Fabricated by: Alabama Dynamics
Year established	1988
Radius to top of swing platform	5.51 m
Design Capacity	400 g-ton (2 US ton @ 200 g)
Bucket area	1.22 x 1.22 m
Major equipment	**Servo-Hydraulic Earthquake Simulator** **Robotic 'Spot' Pluviator**

	Automated Saturation System

15 g-ton Symmetric Dual Swing Beam Centrifuge	
Manufacturer	Genisco (modified by CU Boulder)
Year established	1981
Radius to top of swing platform	1.2 m
Design Capacity	15 g-ton (136 kg @ 100 g)
Major equipment	**Normal Fault Rupture Simulator**
	Axial Pipe Pull-out apparatus

400 g-ton Asymmetric Rotor Arm Centrifuge

The 400 g-ton centrifuge, designed by Wyle Laboratories and fabricated by Alabama Dynamics, began operation in 1988. It has an asymmetrical rotor arm with a swinging payload platform on one end and a fixed counterweight compartment on the other. The swinging platform helps keep the net acceleration 'downwards' with respect to the soil model at the centrifugal acceleration is increased. The operating radius with the swing platform extended is 18 feet (5.49 m). It can accommodate a payload volume and mass of 4x4x3 ft (1.22x1.22x0.91 m) and 4000 lb (17.8 kN) respectively, ranking it amongst the most powerful geotechnical centrifuges worldwide.

A 900 horse-power (671 kW) Direct Current (DC) drive system powers the centrifuge through a right-angle gearbox with a 6.4 to 1 gear reduction. The centrifuge is capable of accelerating a payload to a maximum of 200 g in about 14 minutes. Four large, pneumatically actuated, disk brakes are used to stop the centrifuge in emergency situations. Other prominent features of the centrifuge include a cooling system along the centrifuge chamber wall and a dedicated real-time control and safety monitoring system.

The data acquisition system for the 400 g-ton centrifuge includes a NI PXI data acquisition system combined with a 12-slot SCXI chassis, with modules suitable for signal conditioning for LVDTs, strain-gauge-type sensors, accelerometers, capacitance-type differential pressure transducers and high-speed cameras. Motor control capabilities are also possible to operate brushed electric servomotors, solenoids, and electronic flow valves. Camera acquisition software can be used to track deformation of points or planes. Tactile pressure sensing systems suitable for seismic tests (sampling rates up to ~800 Hz) and depth sensing camera hardware are available. The 400 g-ton centrifuge also includes 3 hydraulic rotary union lines which can be used to supply pressurized fluid to the centrifuge platform.

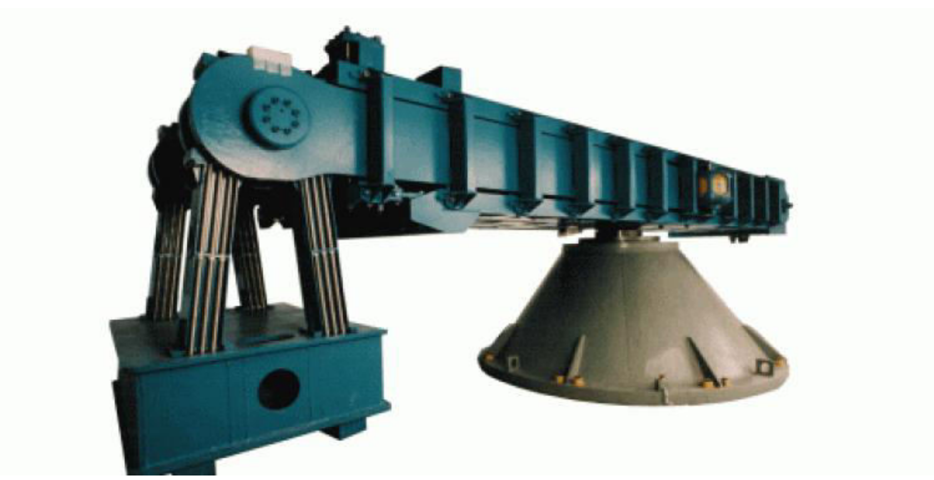
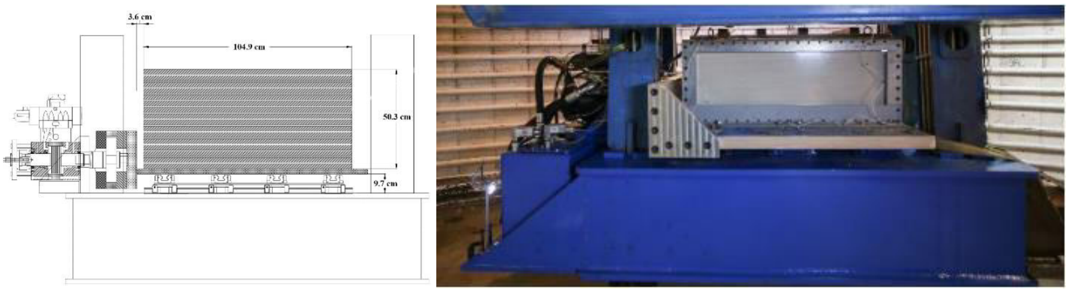


Photo of the 400-g ton centrifuge at CU Boulder

<u>Servo-Hydraulic Earthquake Simulator</u>

A custom designed 1D servo-hydraulic shaker, or 'earthquake simulator', was designed and constructed for the 400 g-ton centrifuge by Servo-Hydraulic Solutions (LLC). It is designed to deliver up to 52 g to a payload of 500 kg, e.g., an equivalent prototype acceleration of 0.65 g at 80 g. The shaking is driven by hydraulic fluid, pressurized by a piston pump above the centrifuge chamber that continuously charges a high-pressure accumulator stored within the centrifuge swing basket. This drives a 3-stage servo valve and double acting, double ended actuator capable of producing simple, single frequency motions and reproducing more complex, multi-frequency earthquake motions in the rotation direction. Recirculation of the oil in-flight means large magnitude earthquake motions can be continuously applied to models in sequence without the need to swing down the centrifuge.

The actuator exerts a shaking force above the base of the container that also counteracts the inertial moment from the payload. This, in combination with the modified pre-tensioned linear bearings connecting the shake table to the swing basket, has been verified to minimize parasitic out-of-plane and vertical accelerations transmitted to the payloads. To improve the accuracy, precision and reproducibility of the earthquake motions, a controller from VibrationResearch™ is used. Broadly, this utilizes an iterative learning control scheme to improve the shake table control. Acceleration feedback from the table informs the necessary modifications to reduce any errors between demanded and achieved signals in the ‘closed loop’ PID feedback system that controls the table displacement.



Schematic and Photo of New 1D Servo-Hydraulic Shake Table and modified Swing Basket

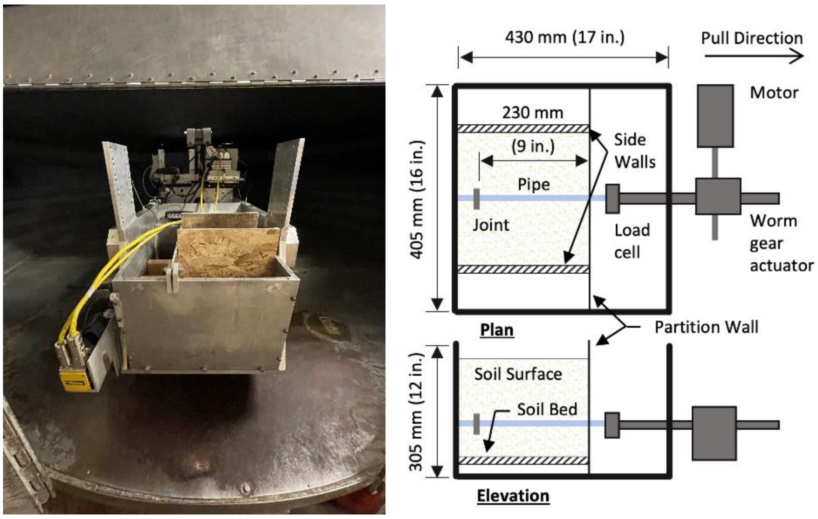
15 g-ton Symmetric Dual Swing Beam Centrifuge

The 15 g-ton centrifuge, operational since 1981, is a Genisco 1230-5 accelerator modified for geotechnical applications. The symmetrical dual-swing basket design can accelerate a 300 lb (136 kg) 18 x17.5 x 23 in. (45.7 x 44.5 x 58.4 cm) payload up to 100g. A 25 horsepower (18.6 kW) electric motor with a toothed-belt drive was recently incorporated to power the 15 g-ton centrifuge. This system provides programable g vs. time profiles akin to the 400g-ton and instructional centrifuges. The closed loop control also provides accurate speed regulation that is immune to line voltage variations and mitigates speed instabilities.

Photo and schematic of 15 g-ton centrifuge at CU Boulder

<u>Axial Loading Equipment (e.g., to study underground soil-structure interaction)</u>

The 15 g-ton centrifuge testing capabilities include the axial displacement test box, which applies horizontal loading to embedded infrastructure. Shown in the figure below, the experimental set up includes a soil chamber, test specimen (e.g., jointed pipeline), load cell, actuator, and motor. The specimen is connected to a 305 mm (12 in.) stroke worm-gear actuator, which converts rotational movement from an electrically driven Parker Motor into linear movement. The Parker Motor is displacement controlled via LabVIEW which interfaces with a National Instruments DAQ system mounted at the center of the centrifuge. A 4500N (1 kip) Interface® load cell, housed within a partitioned region of the chamber, links the leading end of the embedded test specimen to the actuator. A similar setup and instrumented cone are also available for cone penetration tests to supplement various experimental programs.



Photos of 15 g-ton centrifuge and horizontally actuating soil-structure interaction equipment

Further Details of CIEST Geotechnical Testing Facilities and Expanding Capabilities

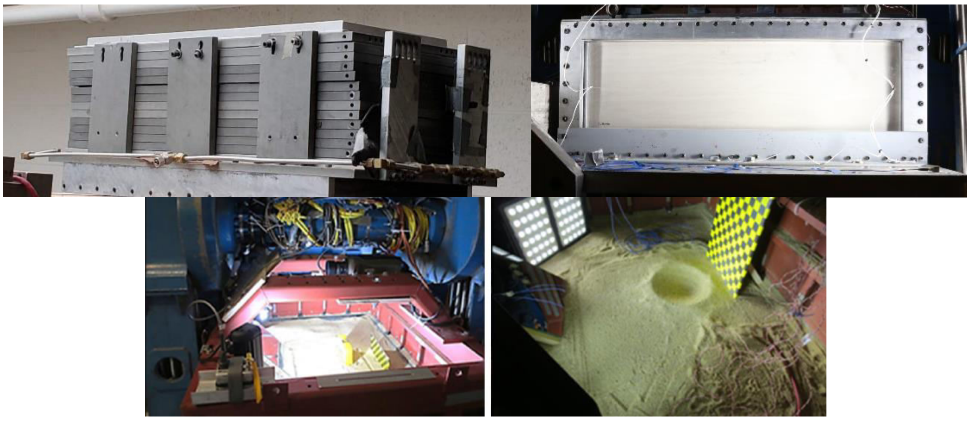
<u>Model Preparation</u>

To enable high quality and reproducible models an automatic pluviator is used to produce samples of sand and similarly coarse-grained materials with a controlled and uniform density for the centrifuge testing at CIEST. The system is a spot pluviator with the nozzle tracing over the container plan area and incrementing its height to maintain a consistent drop distance. Additional sensors to allow real time density estimates and feedback control of the pluviator are currently being incorporated.

Photos of Automatic Sand Pourer in use at CU Boulder

For testing saturated soil beds, e.g., centrifuge experiments concerned with soil liquefaction, an automatic saturation system is available for use with a variety of the centrifuge containers. The system controls the fluid (water or viscous solutions) flux into the container by adjusting the pressure differential between the container (held close to a full vacuum) and fluid supply. Typically, the fluid is introduced from the base of the centrifuge containers through a series of porous stones underlying the soil models.

A large number of containers have been developed and utilized over the history of centrifuge testing at CU Boulder. These are designed to provide well defined boundary conditions for a variety of problems (e.g., fixed or approximating semi-infinite soil extents), including static and dynamic (i.e., seismic) testing of above ground and buried infrastructure and explosives testing.



Photos illustrating the variety of centrifuge contianers at CU Boulder providing well defined boundary condtions for static plane-strain tests, earthquake testing and explosives testing

Recently Commissioned

In this section, a brief overview of recently commissioned equipment is provided to showcase the expanding capabilities of centrifuge testing at CIEST.

Dam-break Wave Generator

A dam-break wave generator to be used with the 400 g-ton centrifuge is under construction to enable the testing of coastal and other waterfront civil engineering infrastructure to varying levels of hydrodynamic wave loading (e.g., ranging from small bores to Tsunami waves). Key design aspects include an overflow chamber to maintain centrifuge balance and recirculation of the fluid to enable multiple wave impacts in-flight.

Climate Chamber

A novel climate chamber for the 400 g-ton centrifuge has been commissioned to explore compound environmental hazards, in recognition of the increasing intensity and frequency of extreme weather events. The chamber is intended to explore the resilience of slopes and soil-structure systems to variations of temperature, moisture, water influx and wind.

Airfield Pavement tester

A miniature airfield pavement tester has been externally commissioned to utilize the 400 g-ton centrifuge to replicate the wheel loading imparted on a pavement surface by taxiing aircraft. The first iteration incorporates a scaled F-15 fighter aircraft wheel. The design leverages pneumatic actuators and a fixed pulley system to enable multiple wheel traverses to be simulated.

Fault Rupture

A miniature vertical fault rupture / trap door container is under construction for the 15 g-ton centrifuge. The primary purpose of this equipment is to observe the performance of a range of buried infrastructure, e.g., pipelines of varying structural properties, under specified amounts of normal fault displacement.