Introduction to the Western Geotechnical Centrifuge Symposium

Associate Professor Tim Newson

Western

Civil and Environmental Engineering


Welcome to
Western's Geotechnical Centrifuge Opening & Symposium
May 2-3, 2019

Symposium Overview

Day #1 (Opening and Symposium): Thursday 2nd May 2019		
Time	*Event*	*Location*
9:30-10:45	Registration and Coffee	ACEB atrium
11:00-11:45	Official Opening Ceremony	ACEB atrium
11:45-12:30	Tour of Centrifuge Facilities	SEB 22
12:30-14:00	Buffet Lunch and Poster Display	ACEB atrium and 1450
14:00-14:30	Welcome and Introduction Tim Newson, Canada	ACEB 1410
14:30-15:15	Presentation #1: *Recent advances in centrifuge modelling at HKUST* Speaker: Charles Ng, Hong Kong	ACEB 1410
15:15-15:45	Tea/coffee and Poster Display	ACEB 1450
15:45-16:30	Presentation #2: *Application of centrifuge testing for sustainable infrastructure* Speaker: Hesham El Naggar, Canada	ACEB 1410
16:30-17:15	Presentation #3: *Offshore renewables: Is centrifuge modelling the right tool?* Speaker: Christophe Gaudin, Australia	ACEB 1410
18:00-21:30	Symposium and GRC Dinner London Delta Armouries Hotel 325 Dundas St, London, ON	

Day #2 (Symposium): Friday 3rd May 2019		
Time	*Event*	*Location*
8:00-8:40	Registration and Coffee	ACEB atrium
8:40-8:45	Welcome and Introduction Tim Newson, Canada	ACEB 1410
8:45-9:30	Presentation #4: *Centrifuge modelling for geotechnical instruction* Speaker: Jonathan Black, UK	ACEB 1410
9:30-10:15	Presentation #5: *Three decades of Canadian centrifuge modelling experience* Speaker: Ryan Phillips, Canada	ACEB 1410
10:15-10:45	Tea/coffee and Poster Display	ACEB atrium and 1450
10:45-11:30	Presentation #6: *Geotechnical centrifuge modelling: Capturing complexities to enable analytical solutions* Speaker: Michael Davies, UK	ACEB 1410
11:30-12:15	Presentation #7: *Tunnel-pile interaction: centrifuge and field tests* Speaker: Adam Bezuijen, The Netherlands	ACEB 1410
12:15-13:45	Buffet Lunch and Poster Display	ACEB atrium and 1450
13:45-14:30	TC104 Panel Session and Close	ACEB 1410
14:30-15:00	Tour of Boundary Layer Wind Tunnel	BLWT
15:00-17:30	Tour of Department Research Facilities	Department of Civil Engineering

CFI funded drum centrifuge

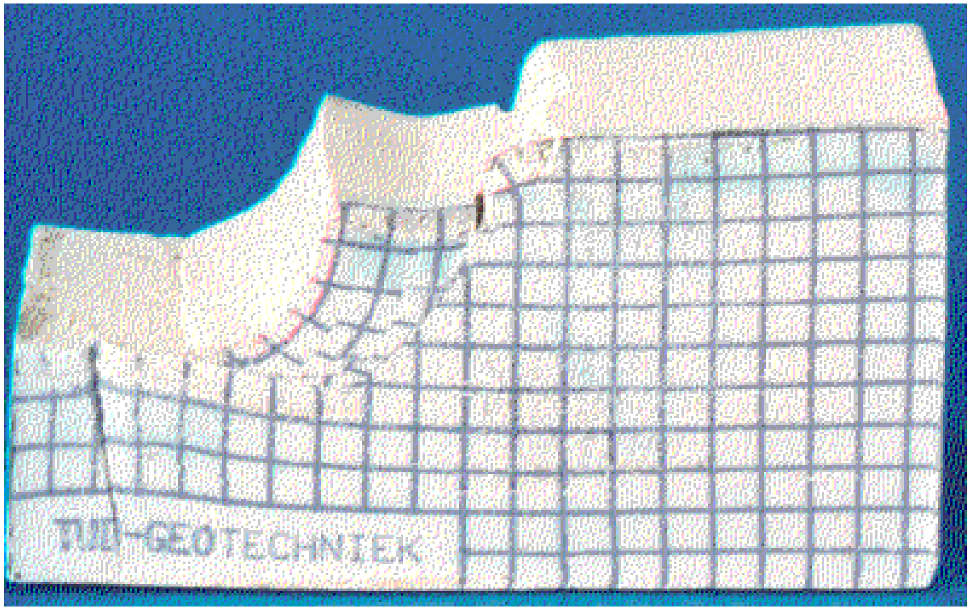
- Drum centrifuge and laboratory supported by $5.4 M grant from Canadian Foundation for Innovation (*Enhancing the Resilience and Sustainability of Critical Geotechnical Infrastructure*), led by Tim Newson and a consortium of 9 Canadian Universities.
- Project will concentrate on asset management of infrastructure that form parts of large public transportation or energy networks: *shallow and deep foundations, pipelines and slopes.*
- The geotechnical models will be subjected to different forms of stressor that commonly act on our infrastructure: rainfall, windstorms, waves, temperature, deterioration and earthquakes.
- How do geotechnical structures behave in the long-term? What are the effects of multiple stressors on structural performance? What are the most robust forms of geotechnical structure for new construction? What is the usable life of many geotechnical structures? What is the critical damage threshold where a structure must be replaced?

CFI Project # 33263

Principal Investigators	*Affiliation*
Newson, Timothy	University of Western Ontario
Atkinson, Gail	University of Western Ontario
Cascante, Giovanni	University of Waterloo
El Naggar, Hesham	University of Western Ontario
Hong, Hanping	University of Western Ontario
Kenny, Shawn	Carleton University
Meguid, Mohamed	McGill University
Sadrekarimi, Abouzar	University of Western Ontario
Vanapalli, Sai	University of Ottawa
Zhou, Wenxing	University of Western Ontario

Need for scaling in physical models

- Requirement for similitude between material properties in prototype & models.
- Stress-strain behaviour of soils is highly non-linear, stress level and stress history dependent.
- *Soil model can be placed in the enhanced rotating gravity field of centrifuge machine….*



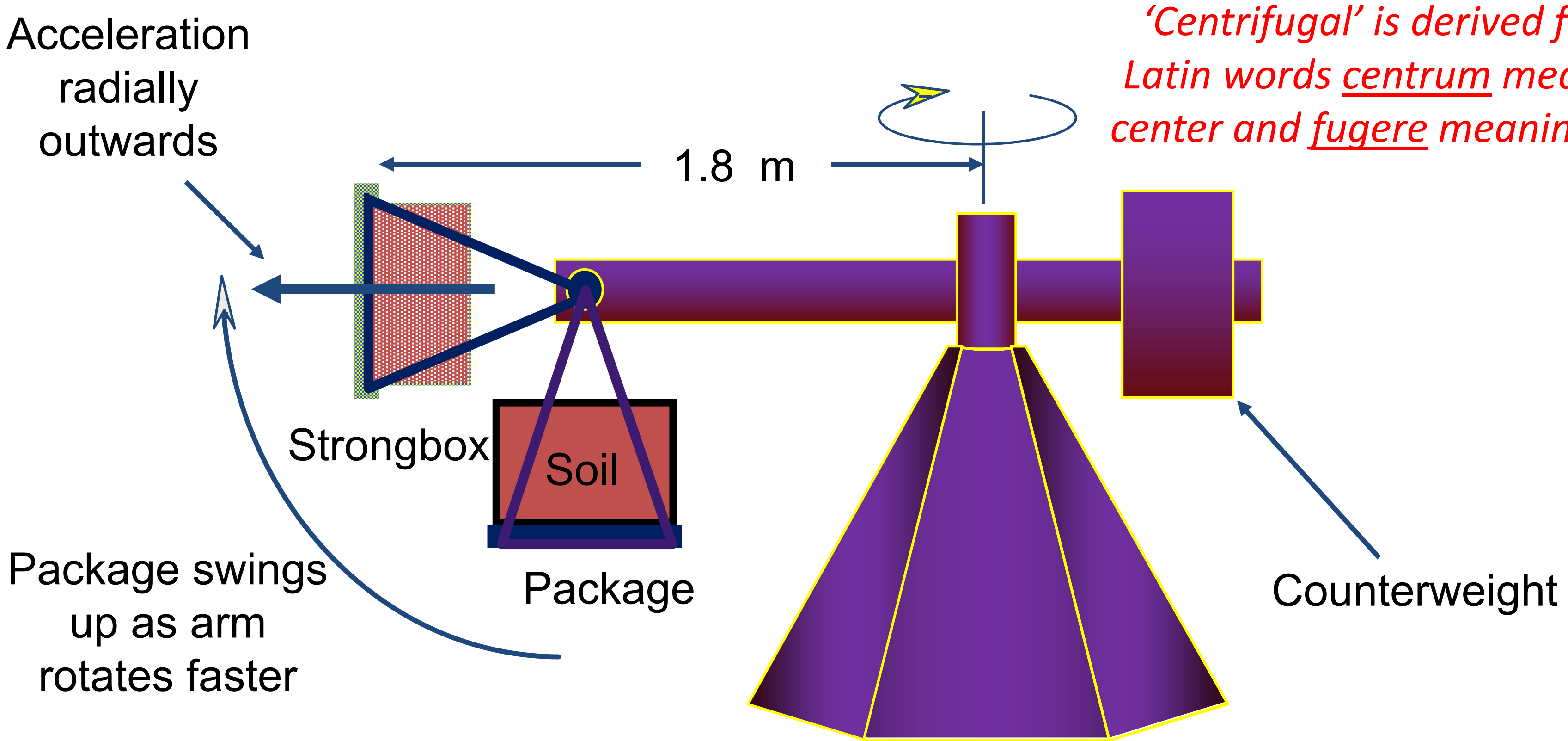
Creates centripetal force in the vertical plane of model, increasing the self-weight forces in soil.

- Vertical cutting in clay at 1g – *soil too strong for self-weight stresses.*
- Vertical cutting in clay at 100g – *correctly scaled failure mechanism.*

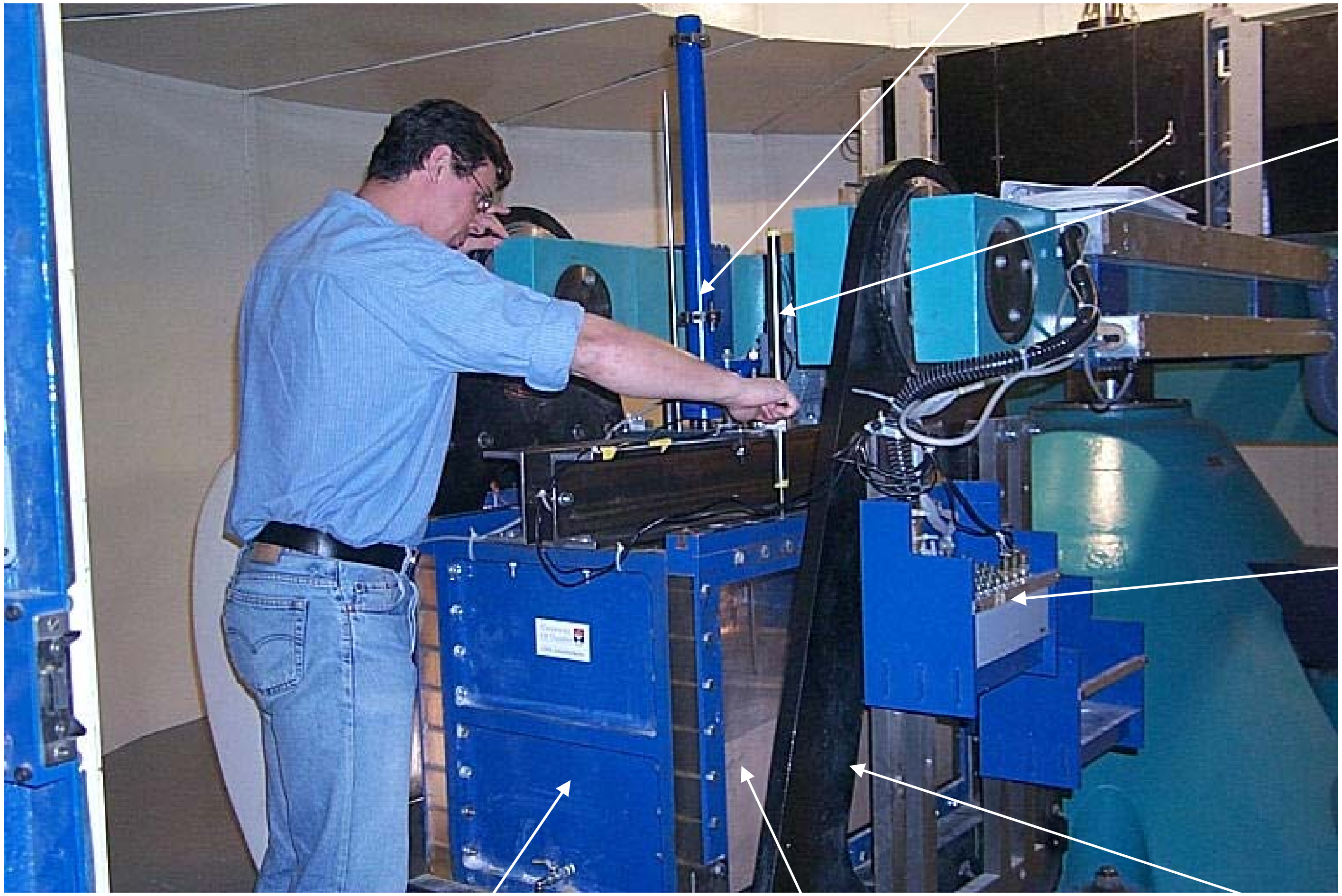
Schematic of a beam centrifuge

223 rpm gives a = 981 m/s/s = 100 g
i.e. 100 x Earth's gravity

'Centrifugal' is derived from Latin words centrum meaning center and fugere meaning flee



Model ‘package’ on centrifuge

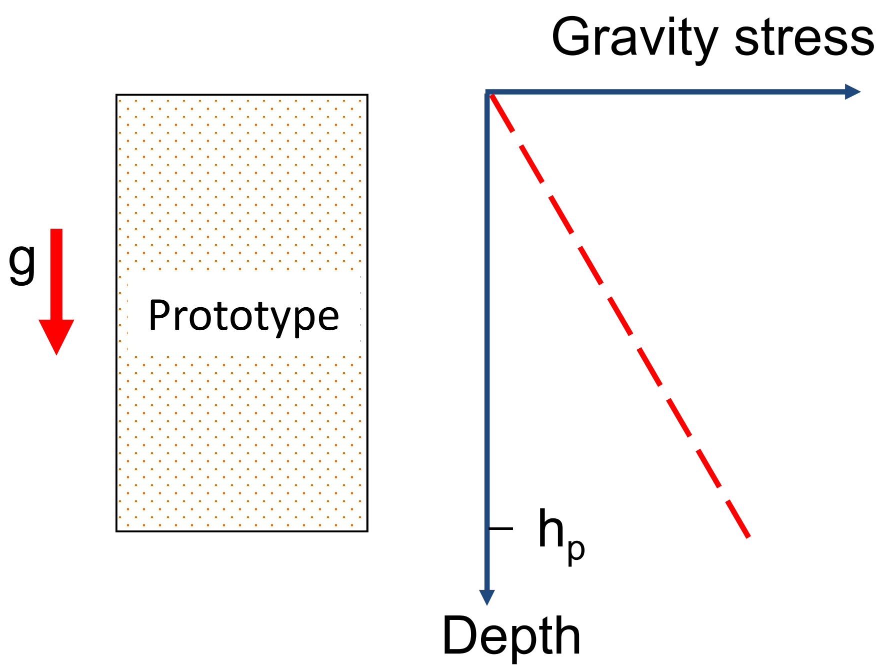


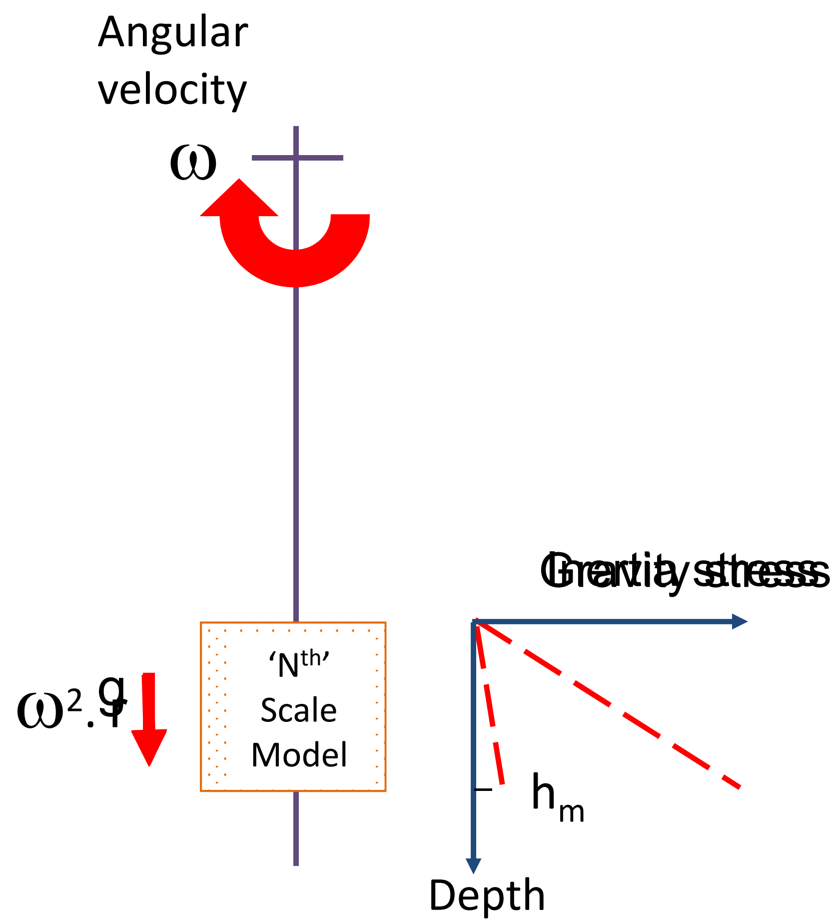
Centrifuge modelling advantages

- Close control over material properties and well defined boundary conditions in centrifuge models enable repeatability and confidence.
- The cost of centrifuge modelling is significantly less than full scale simulations and trials.
- Centrifuge modelling permits simulations of processes that would be highly time consuming or impossible to conduct (e.g. contaminant transport or blast protection).

Stress similitude: model v. prototype

$$\sigma_m = \frac{h_p}{N}\cdot(N.g)\cdot\rho \quad = h_p.g.\rho$$





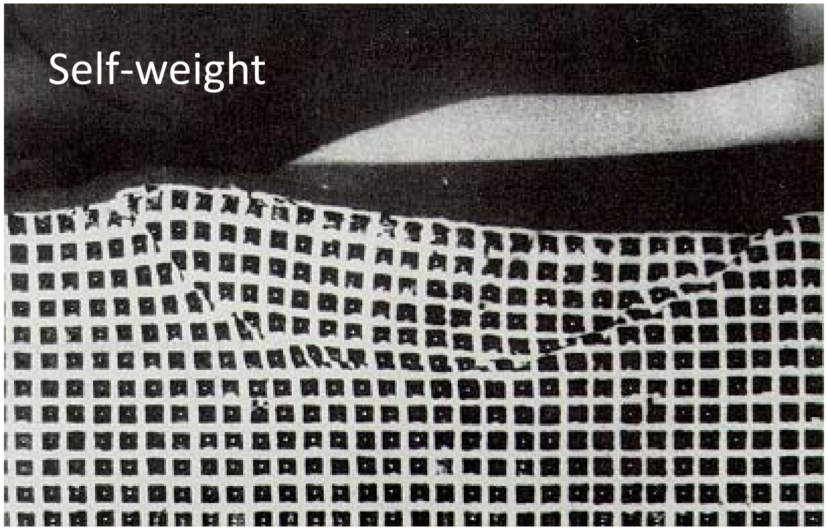
Centrifuge modelling laws

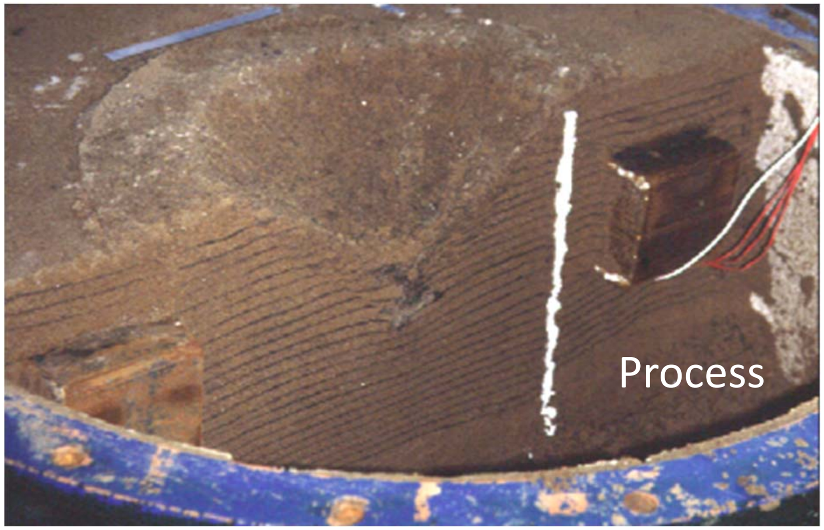
Physical quantity	*Prototype*	*Model*
Macroscopic length	1	1/N
Stress	1	1
Strain	1	1
Pore water pressure	1	1
Time :	1	
diffusion processes	1	$1/N^2$
inertial effects	1	1/N
Force	1	$1/N^2$
Interstitial water velocity	1	N
Heat flux	1	N

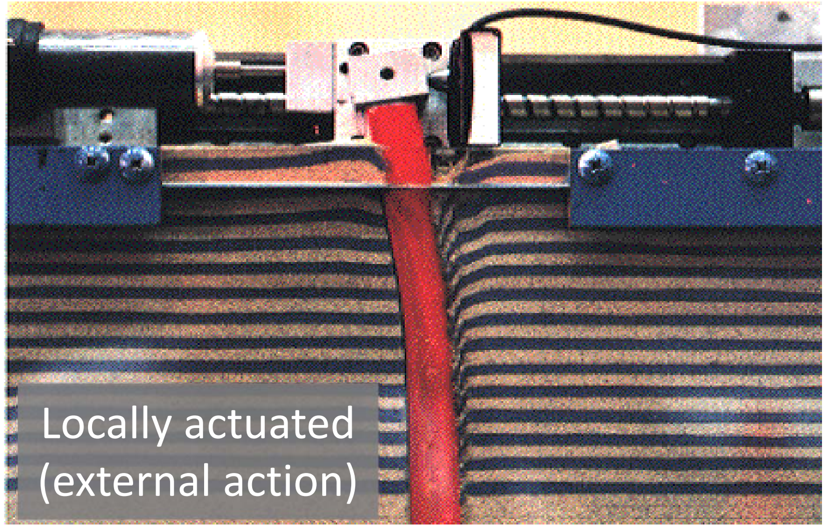
Typical uses of centrifuge

- Parametric studies may be used to identify trigger mechanisms, interpret observations and confirm hypotheses.
- Results of experiments may be used to validate theories and calibrate analytical/numerical techniques.
- Model prototype (full-scale) geotechnical structures or processes.
- Centrifuge modelling may be also used for design.

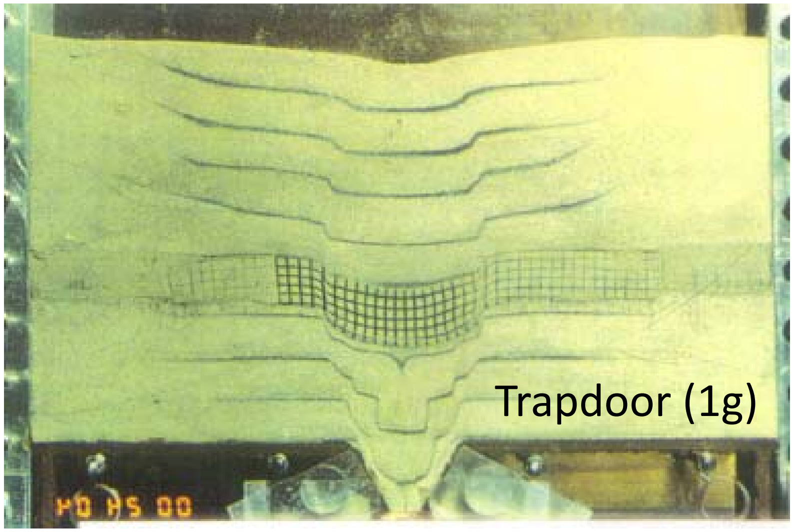
Wide range of studies possible

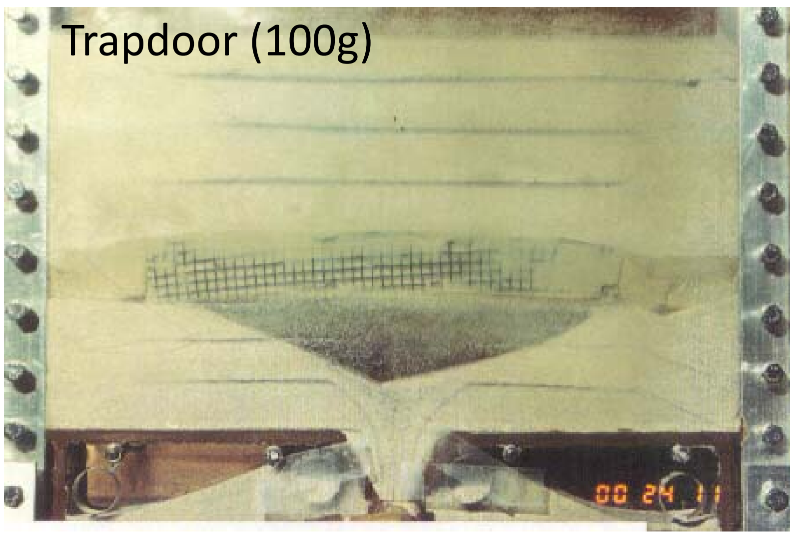


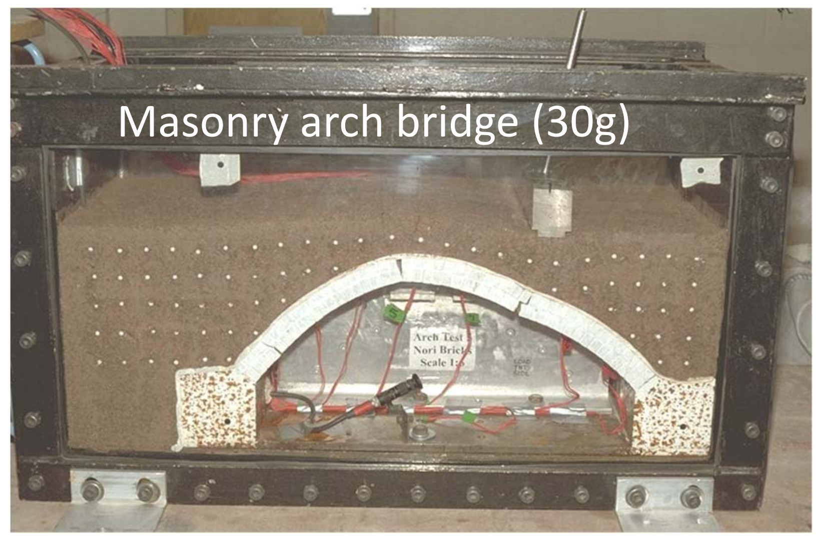




Modelling of models







Manufacturer of the machine

- The contract to build the machine was awarded to Thomas Broadbent and Sons Ltd., who are located in Yorkshire.
- Broadbent has more than 150 years of engineering experience creating centrifuge technology.
- Originally designed and manufactured to support Yorkshire's textile industry, Broadbent now delivers innovative separation solutions for chemical, mineral, pharmaceutical, sugar, laundry and processing industries.
- Recently, Broadbent has produced some extremely sophisticated geotechnical centrifuges.

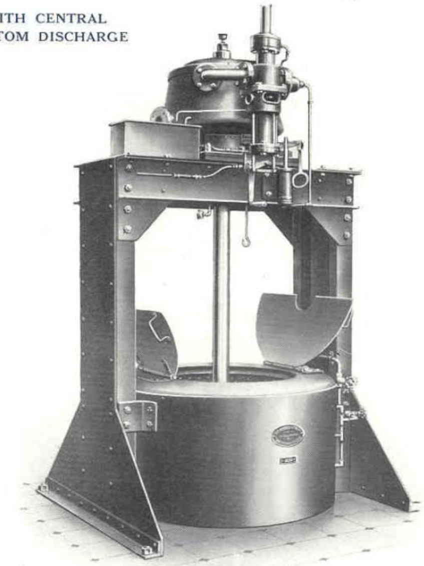
Manufacturer of the machine

Oil-Engine-Driven Centrifugal

WITH CENTRAL BOTTOM DISCHARGE

Water-Driven Centrifugal

WITH CENTRAL BOTTOM DISCHARGE

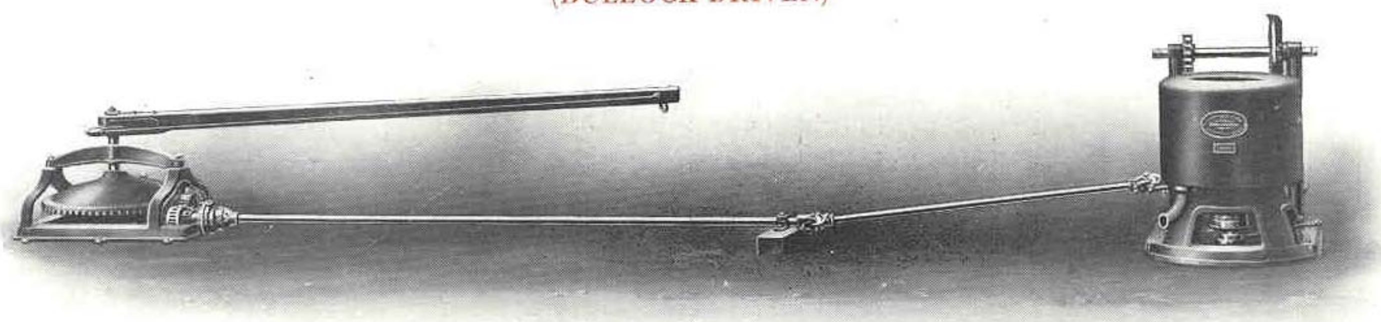


(HAND POWER)

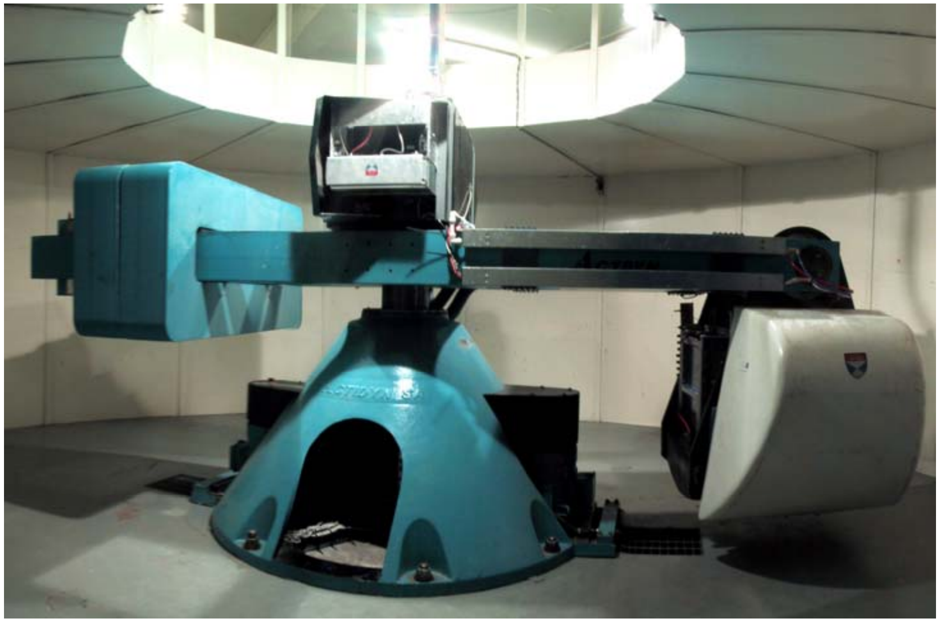
With Central Bottom Discharge.

18-in. Self-balancing Centrifuge

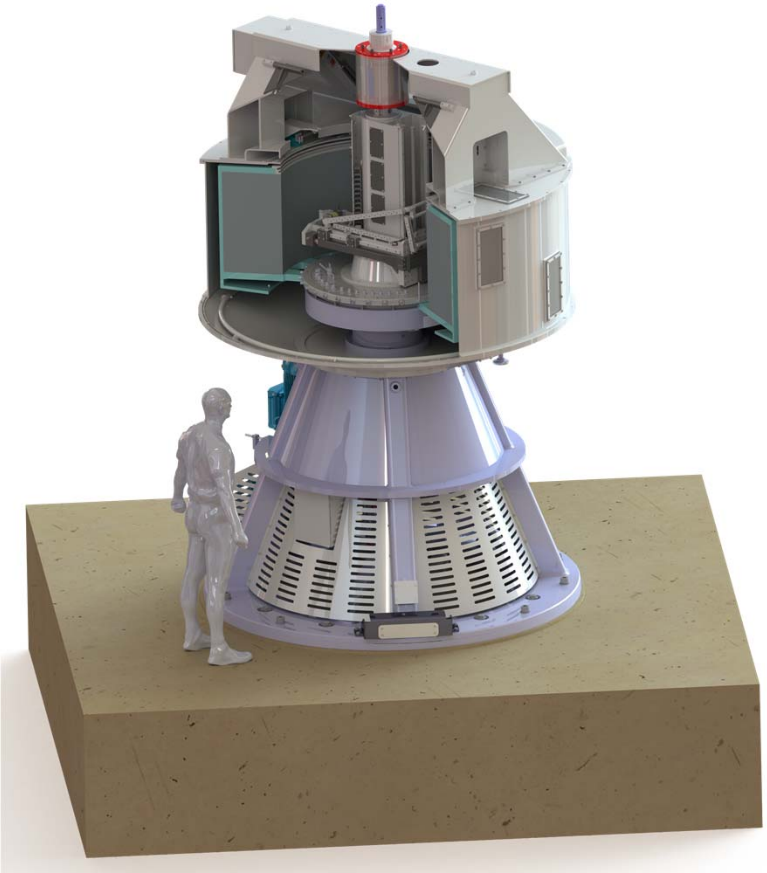
(BULLOCK DRIVEN)



Types of centrifuge technology



3.2 m Fixed Beam Centrifuge
(University of Dundee)



2.2 m Drum Centrifuge
(Western University)

Machine installation

The centrifuge base is attached to the ring and houses two independent induction motors (45 and 5.5 kW) to rotate the drum and the tool table.

Electrical and fluid services are passed through the base of the machine.

The 2.2 m diameter drum channel fits over the tool table and is located with a safety casing.

A soil expulsion system is located in the base of the casing to fluidize soil after testing to allow removal.

Final assembly

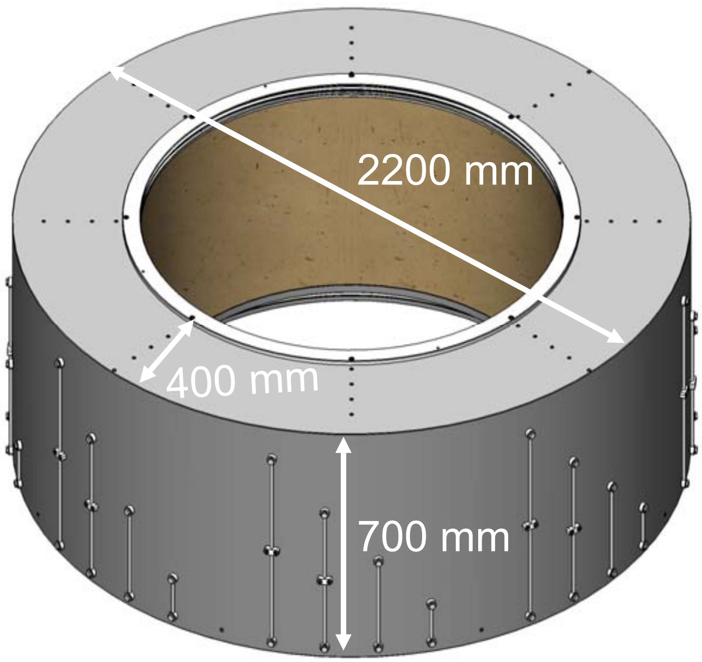
The 3D robot was installed on the centrifuge tool table in early 2019.

A fluid union and slip ring stack is fitted above the robot for power and fluid control in the machine.

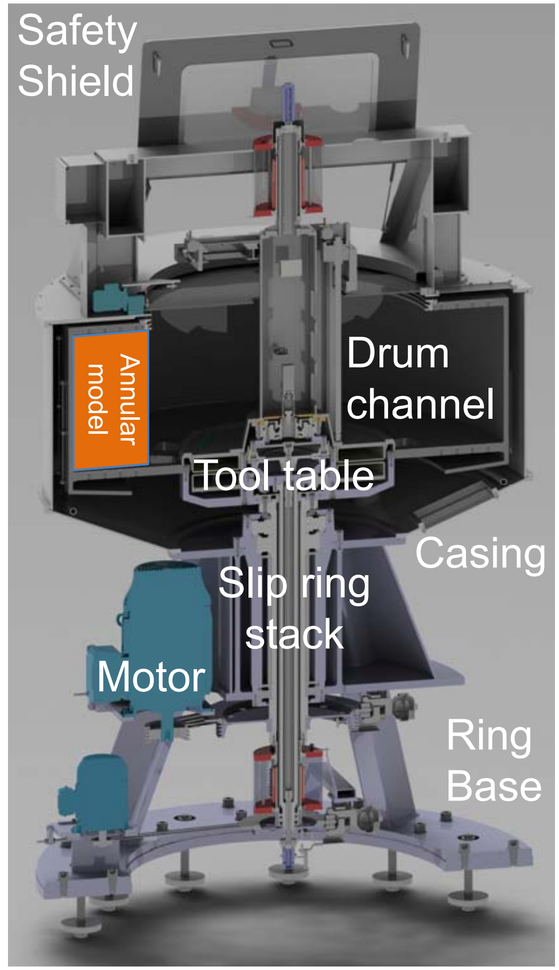
The annular DAQs were installed in April 2019 and allow instrumentation in models to be interrogated.

The upper casing is fitted with two glass safety doors and a shutter system that are interlocked with the machine control and electrical systems to prevent access to the machine drum environment during experimental operations.

Western drum centrifuge layout



Channel of Western U drum centrifuge with dimensions



Drum Specifications -

Diameter = 2.2 m
Maximum g = 400

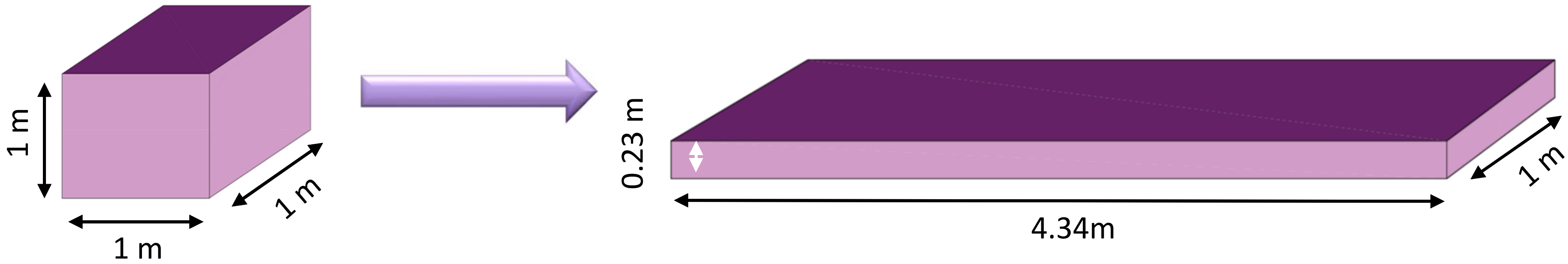
Drum Dimensions:

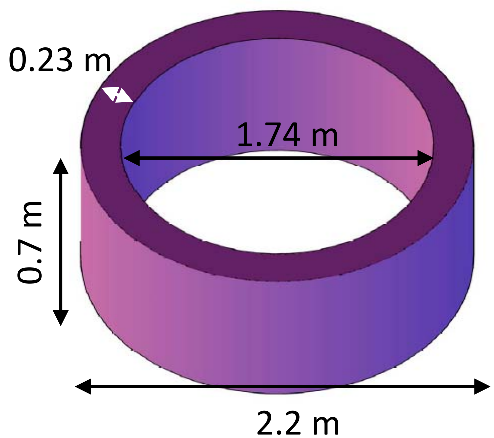
- Depth = 400 mm
- Max diameter 2.2 m
- Height = 700 mm

Maximum soil payload = 2600 kg

Extra features: tool table, high speed DAQ, fluid control system, 3D robot, high speed cameras

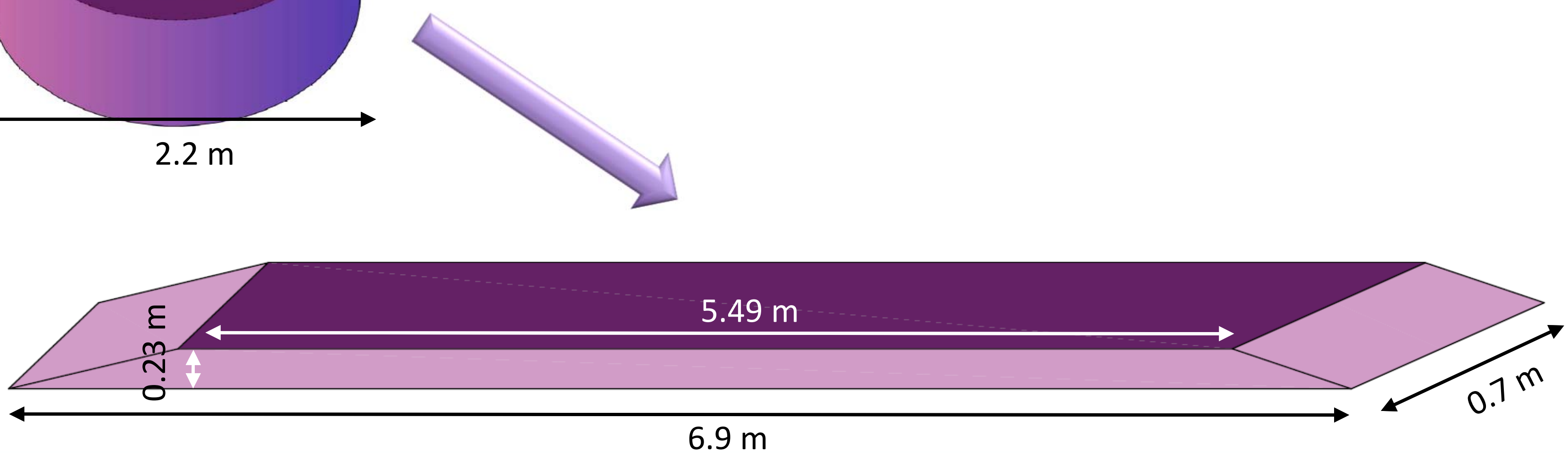
Relative real estate: beam vs drum





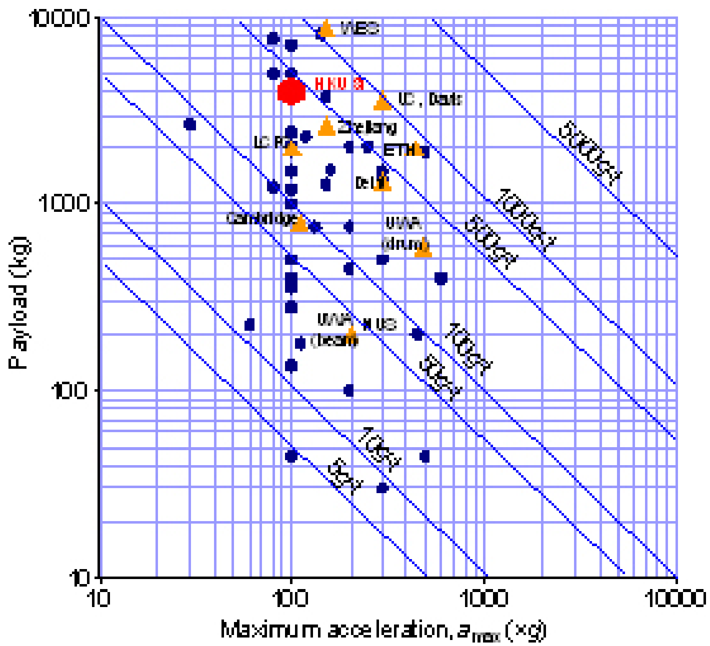
Beam: Plan area (100g) = 10,000 m^2

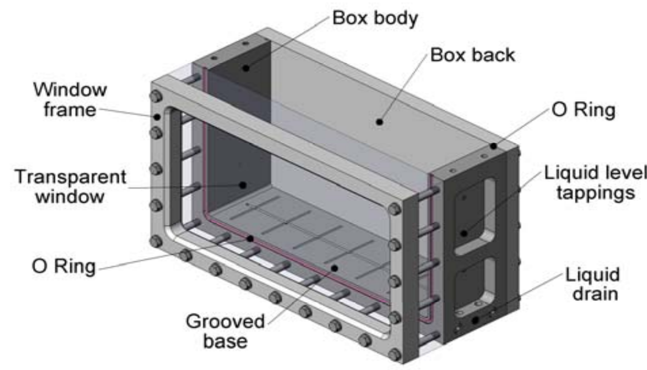
Drum: Plan area (100 & 400g) = 382,200 & 6.1M m^2



Advantages of drums

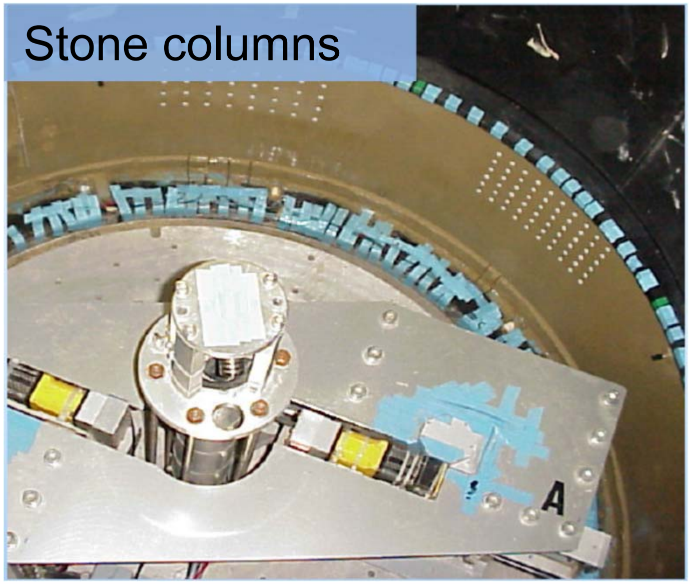
- Large model surface area
  (aspect ratio: Length >> Height > Depth)
- Significant volume of soil, 3D problems
- High g and hence g-tonne capacity
- Easy access to surface for actuators, remote sensing
- Classes of interactions dominated by surface processes
- Repeated tests in same soil (parametric studies)
- Cheating and running in 'beam' mode – partition drum (with boxes)



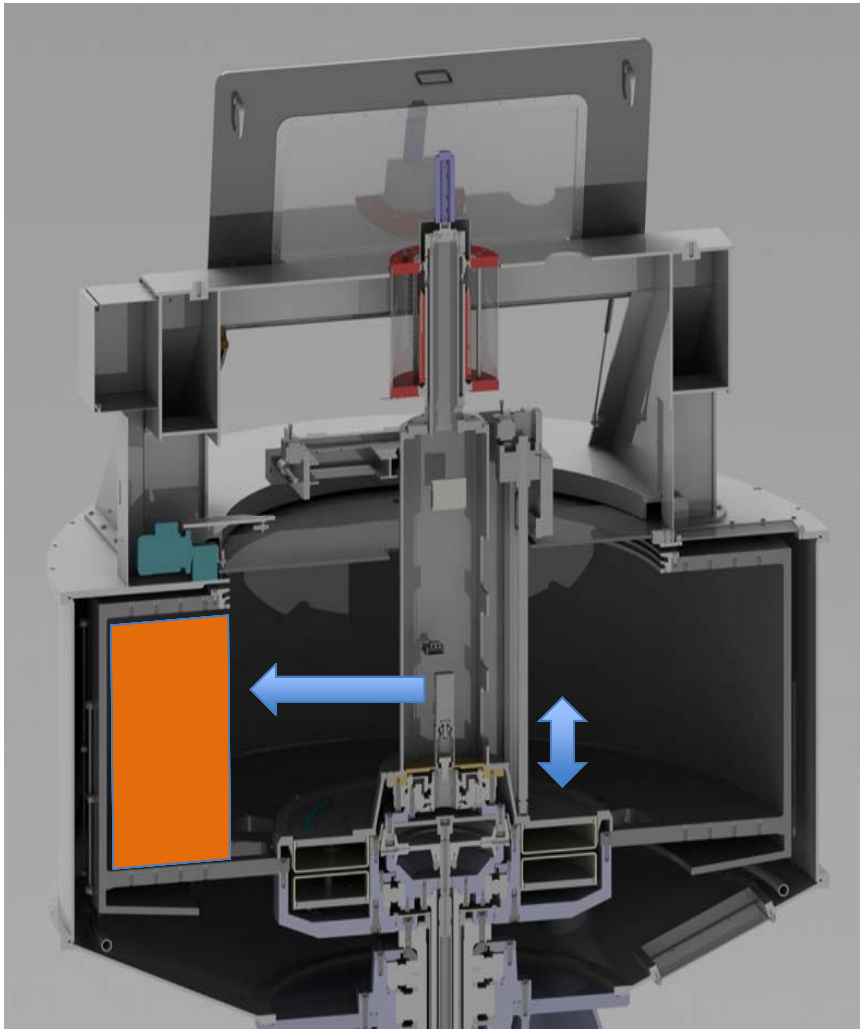


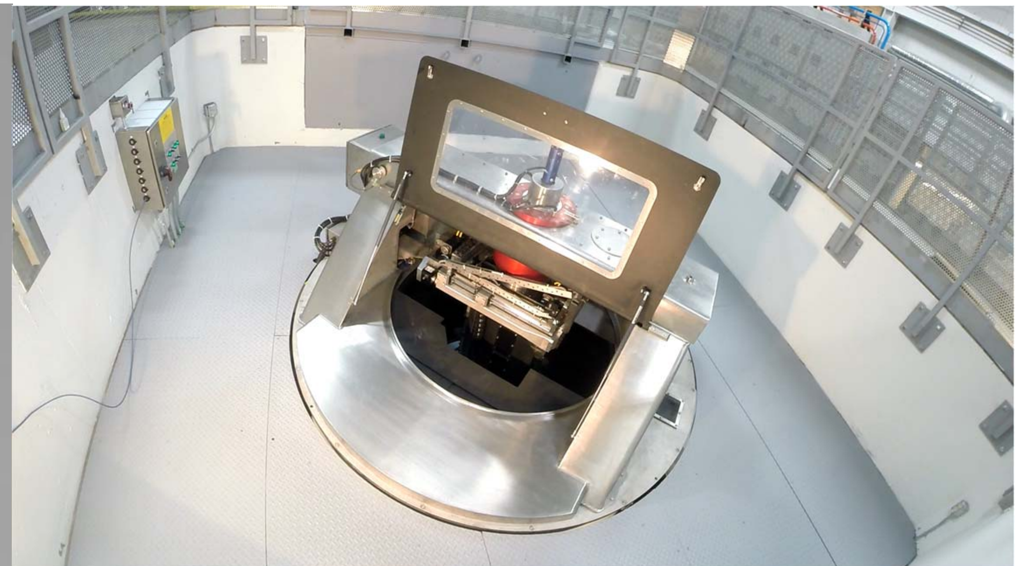
Advantages of drums

- Wide range of soils from loose, normally consolidated soils to dense soils, structured (layered) soils
- *Long structures*: e.g. embankments, tunnels, dams, pipelines, etc.
- *Long travelling loads*: anchors, ploughs, risers, fluid waves, etc.
- Shallow and deep footings
- Flow, runout processes, landslides
- Geoenvironmental problems



Measurement & actuation



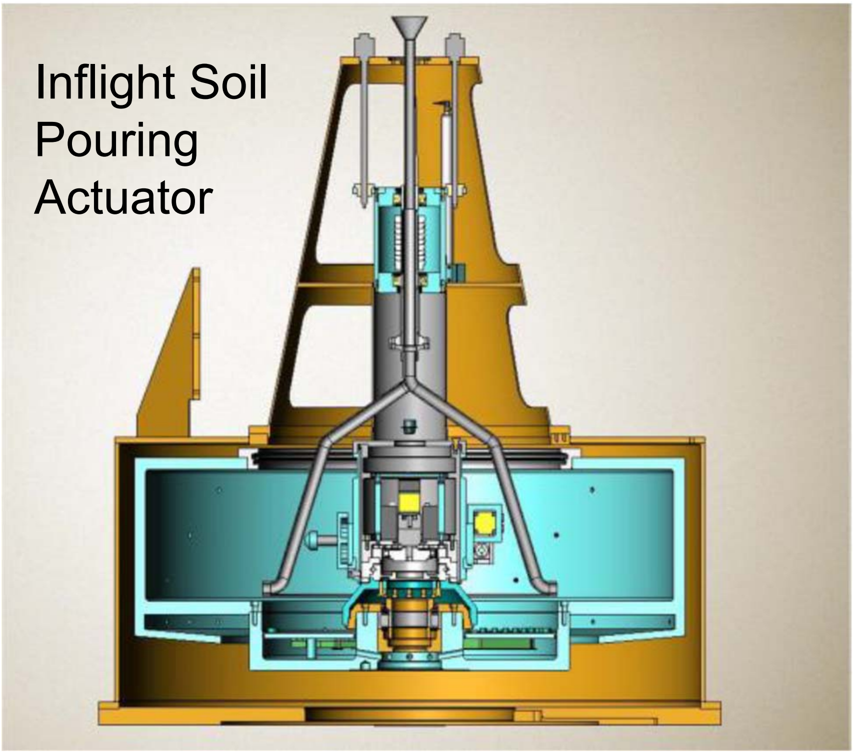


Tool table sits inside the rotating drum and can interact with both the *spinning soil surface* and the *outside world.*

Three axis robot sits on tool table and can load the soil or structures, probe the soil properties, etc..

LCPC robot = 4 tools and Western robot = ∞

Soil model construction

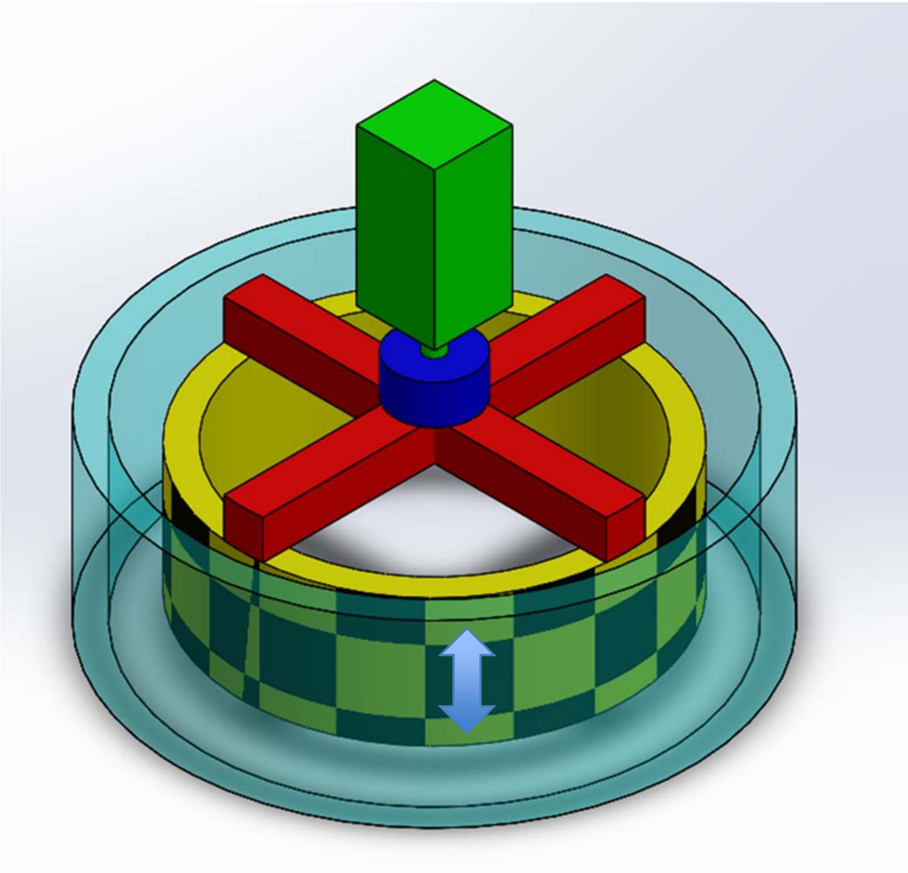


Programmable controlled digital servo drives for x/y/z control.

Motion commands via pre-program profiles or velocity control:– *hopefully leading to 3D printed soils!*

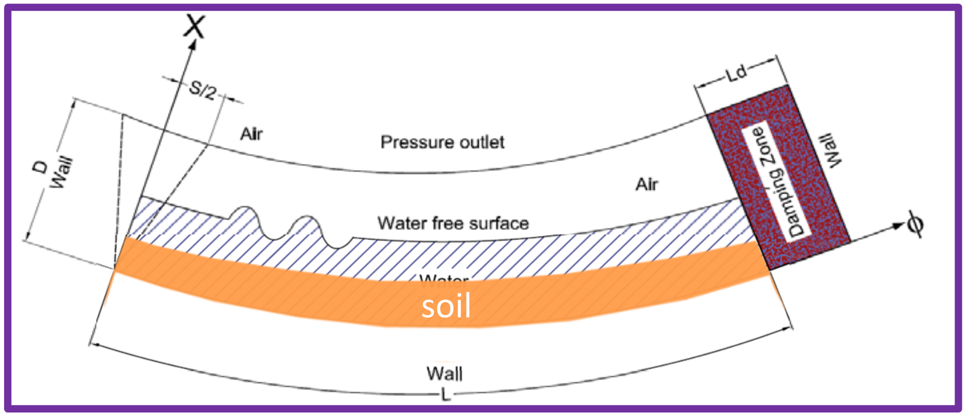
Model preparation actuator with profiles that can be programmed to shape the soil specimen surface in-fight.

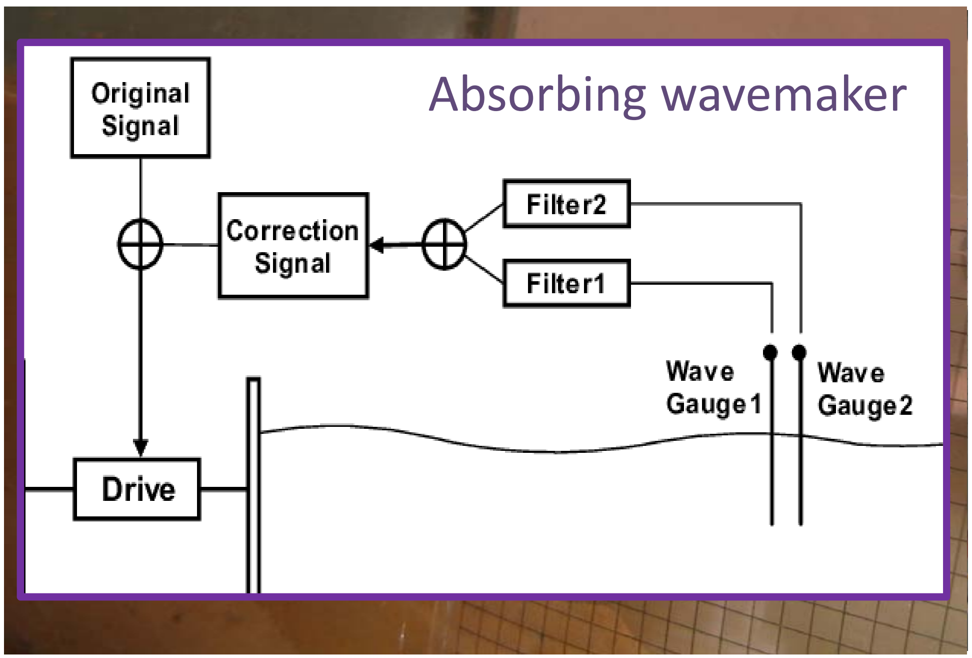
Earthquake actuator



- Ring shake table with diameter of 2.0 m and 0.8 m height; grid of radial mounting holes provided on inside diameter.
- Table guided to move in Y direction (1D) using approximately 24 laminated rubber bearings.
- Bare table mass of approximately 800 kg
- Maximum nominal payload of 1,000 kg.
- Actuator rated at 400 kN force.
- Peak achievable acceleration of 20 g.
- Peak table displacement of +/- 5 mm.
- Peak table velocity of 0.7 m/s.
- Frequency operating range 10-250 Hz.

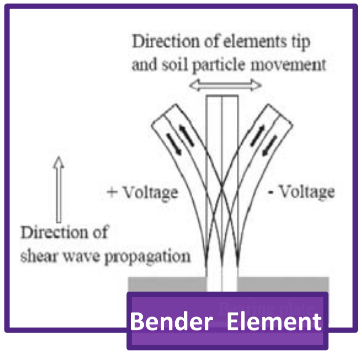
Active Fluid Wavemaker

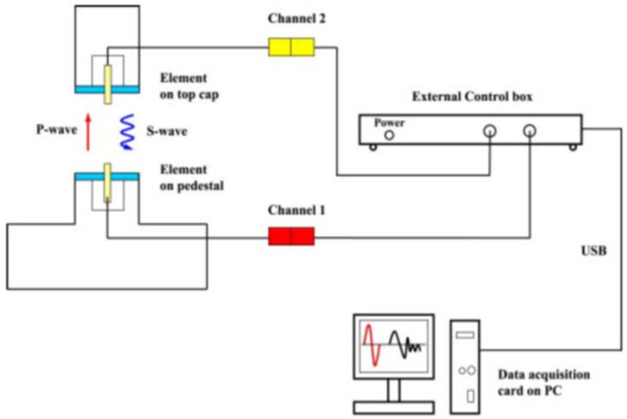


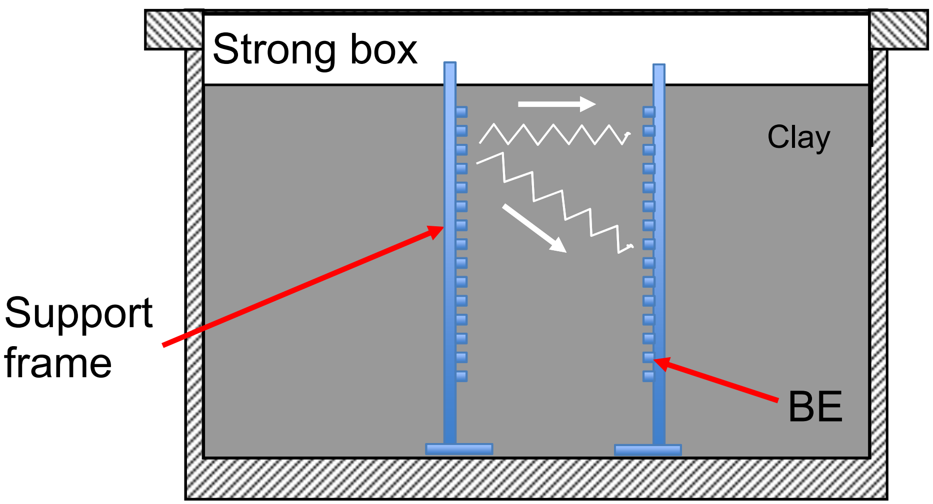


- Mechanical wave generator paddle (hinged flap type) to create small amplitude/high frequency wave trains along the length of the drum.
- Driving frequency of at least 30 Hz.
- Wave heights of 20% of water depth, in model water depths of 350 mm.
- Model wave periods of up to 0.06 sec and wavelengths of approximately the drum channel diameter.
- Active wave absorption reflection coefficients < 10%.
- Create simple standing & progressive sinusoidal waves, standard multi-spectral seas.

Bender element array







- Capable of both two and three dimensional measurements.
- Formed with parallel arrays of bender elements across 350mm x 350mm *area* or 100mm x 100mm x 100mm *volume.*
- The two systems would require approximately 80-100 bender elements.
- The systems will be capable of measuring both shear and compression wave velocities.
- At least a 10-20 mm spatial resolution [about one wavelength].
- Used to identify changes in elastic soil properties across models.

Summary

- Centrifuge modelling is a powerful laboratory technique for scaled physical modelling of a wide range of geotechnical processes and structures.
- We can improve our understanding of complex problems, centrifuge model tests can provide high-quality experimental data to verify/calibrate analytical and numerical methods, and we can perform design.
- We are extremely excited to have the opportunity to use this new state-of-the-art facility to conduct world leading geotechnical research.
- We'd like to welcome you to Western and hope you enjoy the symposium that we have planned over the next few days.

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