industrial process division

geotechnical centrifuges
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A selection of Broadbent G-Max’s Geotechnical client base include:

- UNIVERSITY OF WEST AUSTRALIA, AUSTRALIA
- ETH, GEOTECHNICS, ZURICH, SWITZERLAND
- TOKYO INSTITUTE OF TECHNOLOGY, JAPAN
- TOYO CONSTRUCTION, JAPAN
- KISOJIBAN CONSTRUCTION, JAPAN
- CAMBRIDGE UNIVERSITY, UK
- UNIVERSITY OF RIO DE JANEIRO, BRAZIL
- DUNDEE UNIVERSITY, UK
- ETH, MINERALOGY, ZURICH, SWITZERLAND
- NOTTINGHAM UNIVERSITY, UK
- UNIVERSITY OF TEXAS AT AUSTIN, USA
- DALIAN UNIVERSITY OF TECHNOLOGY, PR CHINA

(1) - Modular beam centrifuge GMB GT50/1.7
(2) - Permeameter rotor for hydraulic conductivity testing
KEY APPLICATIONS OF CENTRIFUGE MODELLING

The primary scientific reason for the use of centrifuge modelling to investigate geotechnical systems is due to the dominance of material self-weight. The fundamental mechanical behaviour of soil is highly non-linear and stress-level dependent and to simulate accurately a prototype at small scale, the in situ stresses must be reproduced correctly in the model. In order to replicate these gravity induced stresses of a prototype in a 1/Nth scale model, it is necessary to test the model in a gravitational field N times larger than that of the prototype. Thus the dimensions and many of the physical processes of the prototype can be scaled correctly if an Nth scale model is accelerated by N times the acceleration due to gravity. Physical modelling plays a vital role in geotechnical engineering in the following areas:

- Parametric studies
- Investigation of new phenomena
- Verification of analytical or numerical methods

The physical modelling of soil behaviour under load has always played a pivotal role in helping design engineers acquire a better understanding of the actual behaviour under similar stress conditions of real construction projects. In particular, centrifuge modelling is currently regarded as an invaluable means of soil testing that markedly enhances the understanding of the physical behaviour of soils under complex static or dynamic situations. Examples include:

- Slope Stability
- Retaining Structures
- Embankments
- Foundations
- Pile – Soil Interaction
- Tunnels
- Heat Transfer
- Diffusion
- Seepage
- Earthquakes
- Wave Loading
- Contaminant Transport
- Freeze/Thaw
- Effects Of Deep Mining

By creating stress conditions in a small soil laboratory model, where the effects of gravity on a real structure on real ground conditions are simulated by generating a centrifugal force field throughout the soil sample, geotechnical research scientists and engineers can obtain insight into the factors affecting geotechnical risk in major and complex construction projects.

Centrifuge testing of soils is a recent development in geotechnical modelling that is growing rapidly worldwide, having had its birth in the UK in the early 1980s. Centrifuge modelling enhances markedly the understanding of the physical behaviour of soils under complex static or dynamic stress fields, and has been successfully applied to classical engineering problems.

Traditional laboratory techniques, such as triaxial, consolidation, shear box and penetrometer testing have been accepted for many years as providing useful support data in adumbration of field site survey information but they are too limited in scope to provide the detailed and incontrovertible scientific evidence required for the newly emerging approach to the geotechnical risk management of major projects.
MODULAR CENTRIFUGE: GMB/D GT50/1.7 GT880/2.2

Beam Systems

**Platform Radius** 2.0m
**Payload Effective Radius** 1.7m
**Maximum Payload Size** W = 0.6m circumferential, L = 0.8m wide (vertical in flight)
H = 0.9m high (radial in flight)

**100G Performance**
500kg at 100g at 1.7m radius (230rpm)

**Minimum Acceleration**
500kg at 10g at 1.7m radius (75rpm)

**Maximum Performance**
330kg at 150g at 1.7m radius (280rpm)

**In-Flight Balancing Capability**
From a maximum +/- 50kg-m
(+/- 30 kN at 230rpm, +/- 45kN at 280rpm)

**Maximum Residual Out of Balance**
to a residual value of less than +/- 1.7 kg-m
(+/- 1 kN at 230rpm, +/- 1.5kN at 280rpm) +/- 50kN

**Drive Motor**
55kW - 4 pole - 415V - 3 phase - 50Hz, D250M frame induction motor

**Inverter**
55kW PWM non-regenerative inverter

**Plane Strain Box (Internal)**
0.2m circumferential x 0.7m wide x 0.4m high

**Axisymmetric Tub (Internal)**
0.5m diameter x 0.5m high

**User Hydraulic Unions**
4 ports air/water/oil, 10 bar g, 10 to 50°C

Drum Systems

**G-Level at Channel Wall**
Maximum 440g

**Channel Aspect Ratio**
L x W x D, 2.2m x 0.80m x 0.30m

**Maximum Speed**
600rpm

**Channel Volume**
1.6m³

**Soil Payload**
2 tonnes at 440g, 880g-tonnes

**Tool Table Drive**
Servo controlled

**Tool Table at Rest**
Start, stop capability with integrated safety shield

**Tool Table Payload**
180kg

**Out of Balance for Channel**
Maximum 10kgm at 440g, 22.5kg at 200g

**Out of Balance for Tool Table**
Maximum 1kgm at 440g
MODULAR CENTRIFUGE:
GMB/D GT50/1.7  GT880/2.2

Beam and Drum Systems

FABRICATION
Material: High strength structural carbon steel
Welds: Non destructively tested
Paint: To Broadbent standard: optional client specification

INSTALLATION SPECIFICATIONS
Floor Specification: Concrete foundation and reinforced enclosure required
Vibration Isolation: Rigid mount, no vibration isolation available due to low RPM of beam

CONTROL AND INSTRUMENTATION
Embedded Logic: PLC controller
Interlocks / Guards: Designed and built to BS 5304
Vibration Monitoring: Accel / LC monitoring with vibration alarms and drive trip
Speed Sensors: Speed measurement by proximity switch and toothed disk
Motor Protection: Motor thermistor and over current protection

The aspect ratio of the soil channel is 2.2m diameter x 0.80m wide x 0.30m deep. Smaller test environments are available. The drum centrifuge environment produces high acceleration levels due to the aerodynamic efficiency of the ring channel. The 2.2m environment produces a radial acceleration of 440g on a test payload of 2 tonnes.

At 400g the prototype dimension modeled are:

- Sample Length: 2765m
- Sample Width: 320m
- Sample Depth: 120m
- Sample Volume: 100m³

Twin concentric shafts allow separate control of a central tool table and the soil ring channel. Together with multipurpose test specific actuators and robotic servo controllers, which can be fitted to the tool table, radial, circumferential and vertical control of construction processes or test activities may be modelled.

The drum is mounted on the outer of the two shafts, which is rotated by the main centrifuge drive motor, common to both test environments. The inner shaft is connected to a separate tool table on which test specific actuators can be mounted. These shafts can be linked to rotate together, or can be operated independently of each other. In the latter case, a separate closed loop position and velocity servomotor drives the inner shaft.

A safety shield offers complete protection when manual access to the stopped inner table is required. This feature isolates the user from the rotating faces of the drum ring channel when the tool table is stopped.

Safety shield not shown in photographs.

Test environment 2: 2.2m diameter, 880g-tonne drum
MODULAR DRUM CENTRIFUGE: 1.4M
GMD GT450/1.4

The GMD series of centrifuges are drum centrifuges for civil engineering research and teaching. Drum centrifuges with their high acceleration capability and large model surface area, have enabled modelling of pile-foundation interaction grouting, cold regions, pollution migration and associated remedial measures.

Thomas Broadbent and Sons Ltd., fully support their Geotechnical drum centrifuge range with on site commissioning and maintenance agreements. Coupled with an extensive range of test specific instrumentation and equipment provide a complete turn key service for the civil engineer end user.

The GMD series offers standard laboratory floor installation with anti vibration isolation. Large expensive specialist concrete containment structures are not required with the GMD centrifuge.

(5) - GMD GT450/1.4
(6) - Drum Siphon Drain - Model fluid level control over entire speed range of centrifuge. Siphon works on drainage channel plumbed to drum drains. The drainage channel is mounted beneath drum channel.
(7) - 1.4m Diameter - 450g-tonne drum channel-complete with multiple drainage points, bottom mounted siphon drainage channel (not shown) and soil partition box quadrature mounting points.
(8) - Centrifuge Modularity - The drum is removed and a permeameter rotor added to create a high g, hydraulic conductivity testing environment, designated GMP GT18/1.5.
### TECHNICAL SPECIFICATION OF GMD GT450/1.4

#### Base Machine

<table>
<thead>
<tr>
<th>Specification</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum Speed</strong></td>
<td>875rpm</td>
</tr>
<tr>
<td><strong>Maximum Acceleration Vertical</strong></td>
<td>600g at 0.7m radius</td>
</tr>
<tr>
<td><strong>Drum Channel Aspect Ratio</strong></td>
<td>4.4m circumferential, width 0.35m, depth 0.27m</td>
</tr>
<tr>
<td><strong>Drum Channel Volume</strong></td>
<td>0.42m³</td>
</tr>
<tr>
<td><strong>Soil Payload: Maximum</strong></td>
<td>750kg at 600g, 450 g-tonne</td>
</tr>
<tr>
<td><strong>Ring Channel Soil partition boxes</strong></td>
<td>2 off</td>
</tr>
<tr>
<td><strong>Tool Table Payload</strong></td>
<td>120kg</td>
</tr>
<tr>
<td><strong>Tool Table Diameter</strong></td>
<td>0.75m</td>
</tr>
<tr>
<td><strong>Out of Balance for Channel</strong></td>
<td>2.5kg-m at 600g max</td>
</tr>
<tr>
<td><strong>Out of Balance for Tool Table</strong></td>
<td>0.5kg-m at 600g max</td>
</tr>
</tbody>
</table>

#### Tool Table Systems

<table>
<thead>
<tr>
<th>Specification</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>User Hydraulic Union</strong></td>
<td>2 ports air/water/oil, 10 bar g, 10 to 50°C</td>
</tr>
<tr>
<td><strong>Electrical Slip Ring Stack: Control</strong></td>
<td>50 rings, 1000V RMS at 7.5A ea</td>
</tr>
<tr>
<td><strong>Electrical Slip Ring Stack: Video</strong></td>
<td>2 x high bandwidth 50 MHz video channels</td>
</tr>
<tr>
<td><strong>Fibre Optic Rotary Joint</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Integrated DAS</strong></td>
<td>32 channel, 200 kHz, 16 bit, on board ethernet based</td>
</tr>
</tbody>
</table>

#### Drum Systems

<table>
<thead>
<tr>
<th>Specification</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fluid in</strong></td>
<td>2 x fluid feeds to drum</td>
</tr>
<tr>
<td><strong>Fluid Out</strong></td>
<td>Remote controlled siphon drain</td>
</tr>
<tr>
<td><strong>Electrical Slip Ring Stack: Control</strong></td>
<td>36 rings, 1000V RMS at 7.5A ea</td>
</tr>
<tr>
<td><strong>Electrical Slip Ring Stack: Video</strong></td>
<td>2 x high bandwidth 50 MHz video channels</td>
</tr>
<tr>
<td><strong>Integrated DAS</strong></td>
<td>32 channel, 200 kHz, 16 bit, on board ethernet based</td>
</tr>
</tbody>
</table>

#### Fabrication

<table>
<thead>
<tr>
<th>Specification</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material</strong></td>
<td>High strength structural carbon steel</td>
</tr>
<tr>
<td><strong>Welds</strong></td>
<td>Non destructively tested</td>
</tr>
<tr>
<td><strong>Paint</strong></td>
<td>Broadbent standard - optional</td>
</tr>
<tr>
<td><strong>Client specification</strong></td>
<td></td>
</tr>
</tbody>
</table>

#### Installation Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Floor Space</strong></td>
<td>4m x 4m, allowing access for drum channel removal</td>
</tr>
<tr>
<td><strong>Floor Specification</strong></td>
<td>Flexible mount: anti vibration floor isolators to permit laboratory floor location</td>
</tr>
</tbody>
</table>

#### Control and Instrumentation

<table>
<thead>
<tr>
<th>Specification</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Embedded Logic</strong></td>
<td>PLC controller</td>
</tr>
<tr>
<td><strong>Interlocks / Guards</strong></td>
<td>Designed and built to BS 5304</td>
</tr>
<tr>
<td><strong>Vibration Monitoring</strong></td>
<td>Accelerometer monitoring with vibration alarms and drive trip</td>
</tr>
<tr>
<td><strong>Speed Sensors</strong></td>
<td>Speed measurement by proximity switch and toothed disk</td>
</tr>
<tr>
<td><strong>Motor Protection</strong></td>
<td>Motor thermistor and over current protection</td>
</tr>
</tbody>
</table>
The High g mineralogy table offers a platform to conduct high gravity, large payload, tests in a safe laboratory environment. Primarily aimed at producing high gravity fields for mineralogy research to model deep earth, sub surface melt processes, the centrifuge equally offers a robust platform to facilitate small scale machine modularity offering a drive platform to accommodate small beam rotors and drum ring channels for lower g geotechnical modelling.

With a view to further extend the scope and flexibility of this product, the 3000g centrifuge can be further upgraded to offer large payload hydraulic conductivity testing by adding a permeameter rotor to the main drive shaft, complete with fluid unions and data acquisition. Hence with one base machine acquisition the following four detachable test environments can be supplied to offer the complete high g earth testing platform:

- **Hydraulic Conductivity**: 45kg to 3000g
- **Geotechnical Drum Modelling**: 1.4m diameter, 400g
- **Geotechnical Beam Modelling**: 0.55m effective radius, 200g
- **Mineralogy Testing**: 1.3m Table, 3000g

The centrifuge containment enclosure provides machine integrity and safety at all acceleration levels. The small footprint allows easy, floor mount emplacement. Vibration isolators permit the location of the centrifuge in a standard soils laboratory environment. Though for anticipated continuous high g runs pit mounting offers additional security.

**MT GT 150/1.6**

- 1.6m DIAMETER TABLE
- MAXIMUM SPEED 2850rpm
- MAXIMUM ACCELERATION 3000g AT 0.33m RADIUS
- TABLE PAYLOAD 45kg AT 2850rpm (BALANCED)
- 2.1m², SMALL FOOTPRINT
- INTEGRAL SAFETY CONTAINMENT ENCLOSURE
- 300A AC POWER SLIP RINGS
- INSTRUMENTATION SLIP RINGS
- ON BOARD DAS
- 2 PORT HYDRAULIC ROTARY UNION

(9) - MT GT150/1.6 - Safety enclosure casing not shown for clarity

(10) - Table apertures with 45kg hydraulic ram test payload and counter weight for testing to 3000g
G EOTECHNICAL C ENTRIFUGES

HIGH G MINERALOGY TABLE
MT GT 1 5 0 / I . 6

Base Machine

**Weight** 3900kg
**Diameter** 1.64m
**Max Width with Vibration Isolators** 1.9m
**Height** 2.0m
**Maximum Table Speed** 2850rpm
**Minimum Table Speed** 300rpm
**Maximum Table Acceleration** 3000g at 0.33m diameter at 2850rpm
**Table Weight** 860kg
**Table Payload** 45kg at 2850rpm
**Table Payload Volume** 0.025m³
**Table Payload Centre** 0.33m radius

**Centrifuge Drive**
- **Drive Transmission**
  - Toothed belt

**Power Slip Ring Stack**
- 30 rings 500 VDC at 20A ea

**Instrumentation Slip Ring Stack**
- 26 rings at 50 VDC at 1A ea

**Hydraulic Rotary Union**
- 2 ports air / water 7 bar-g at 2850rpm

**Fabrication**
- **Material** High strength structural carbon steel
- **Welds** Non destructively tested
- **Paint** To Broadbent standard: optional client specification

**Installation Specifications**
- **Floor Space** 4m x 4m for easy access
- **Floor Specification** Flexible mount: anti vibration floor isolators to permit laboratory floor location

**Control and Instrumentation**
- **Embedded Logic** PLC controller
- **Interlocks / Guards** Designed and built to BS 5304
- **Vibration Monitoring** Accelerometer monitoring with vibration alarms and drive trip
- **Speed Sensors** Speed measurement by proximity switch and toothed disk
- **Motor Protection** Motor thermistor and over current protection

(11) 3000g Laboratory test environment
ONBOARD ETHERNET BASED DATA ACQUISITION SYSTEMS

Our geotechnical data acquisition systems are designed for high gravity operation, Windows based; with multi-channel, on-board digitisation, utilising TCP/IP networked communication and control. The LAN based architecture of the data acquisition systems permits a total solid-state hardware implementation that excludes the need for any rotating data storage media such as hard disk drives and any cooling fans.

Typical Data Acquisition System (DAS) Specifications

ADC specification
Type: successive approximation
Resolution: 16 Bit
Max sampling: 200 kHz
Conversion: 5us
Linearity: +/- 1bit

Analogue Input and Output
Input channels: 8 DE, expandable to 256 DE
Band width: 500KHz
Ranges: bipolar: +/-10v, +/- 5v, +/- 2.5v, +/- 1.25v, +/- 0.625v, +/- 0.312v, +/- 0.156v
Output channels: 4 DAC
DAC resolution: 16 bits
Update rate: 100kHz
Output range: +/- 10v

Digital I/O
Input: 24 bits isolated, individually programmable
Output: 24 bits isolated, individually programmable
Dig I/O expandable: 272 bits
Frequency/pulse: 2 x frequency/pulse 16 bit Generator channels
4 x cascadable frequency/pulse 16 bit counter channels

High g Transducer Interfacing
Channel capacity: 16 to 128 channels
Enclosures: integrated to drum or on beam located centrally and arm end
High g signal conditioning: multichannel channel decade software PGA and transducer PSU cards
g-rating: 400g
PGA Gain: x1, x10, x100, x1000
Transducer excitation: precision +/-10.000v, +/-5.000v
Connectors: individual channel connections to Mil C-26482

The DAS interfaces directly to the centrifuge via rotating services. These services include, slip ring stacks for electrical power and Fibre Optic Rotary Joints (FORJs) for ethernet communications and control.

User facilities include:
- **DEDICATED SLIP RINGS FOR TEST AND CONTROL**
- **DEDICATED ANALOGUE VIDEO CHANNELS**
- **HYDRAULIC ROTARY UNIONS**

Information on our range of test specific actuators and instrumentation available on request.

The specification build process will differ greatly between clients. The flexible nature of the system architecture permits customisation of the final DAS delivery to meet the particular requirements of the end user.
ACQLIPSE 3001: ETHERNET BASED DATA ACQUISITION SOFTWARE

Acqlipse™ interfaces the user to their centrifuge test via a simple, easy to use front end. The standard program environment is designed as a 128 channel, medium speed, data logger interfaced to Ethernet based acquisition hardware mounted on the centrifuge. For drum and tool table applications the user utilises the first 32 channels only. Currently Acqlipse™ 3001 offers the following standard features:

- 128 CHANNELS AT 1000Hz SAMPLING PER CHANNEL TO DISK
- FLEXIBLE LOGGING RATE WITH BUILT IN SAMPLING DIAGNOSTICS TO DETERMINE OPTIMAL AND CONFIRM CHOSEN RATES
- INDIVIDUALLY CONFIGURABLE CHANNEL SET UP
- INDIVIDUAL OR BLOCK CHANNEL ACTIVATION
- TRANSDUCER CALIBRATION
- ENGINEERING DATA DISPLAY
- PER CHANNEL ZEROING, WITH FLAG INDICATORS AND ZERO OFFSET RECORDING
- SOFTWARE SELECTABLE INTEGRATION FOR NOISE REJECTION
- X Y PLOTS
- MULTIPLE GRAPH WINDOWS, 8 TRACES PER GRAPH, WITH GRAPH SAVE AND RECALL FEATURE
- GRAPH REDRAW, WITH USER CONTROL OF NUMBER OF DATA POINTS AND PLOT INCREMENT
- INDIVIDUAL TRACE FORMATTING IN REAL-TIME
- INDIVIDUAL GRAPH FORMATTING IN REAL-TIME
- GRAPH ZOOM FACILITIES
- DATA FILE SAVE FORMULATED FOR SPREADSHEET AND TEXT OUTPUT
- TEST AUDIT INFORMATION AND COMMENTS SAVED TO FILE
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Web: www.broadbent.co.uk

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Conformity Statement
The centrifuge is designed and constructed in accordance with harmonised Type C standard BS EN 12547 ‘Centrifuges - Common Safety Requirements’. This ensures compliance with all relevant UK Regulations (Supply of Machinery (Safety) Regulations SI 1992/2073, Electrical Equipment (Safety) Regulations SI 1992/3260, EMC Regulations SI 1992/2372) and EU Directives (Machinery, Low Voltage, EMC). The centrifuge will be CE marked and supplied with a Certificate of Conformity to allow the client to comply with the Health and Safety at Work Act 1974 and the Provision and Use of Work Equipment Regulations SI 1992/2932.

We reserve the right to change specification without notice 07/06