Rock Mechanics Research at Nottingham

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University of Nottingham

- UK campuses – University Park, Jubilee, King’s Meadow and Sutton Bonnington, in the vicinity of Nottingham City
- UNIM (KL,Malaysia) and Ningbo (China)
University of Nottingham

• Student and Staff numbers
  – 2007/08
    • 30,444 full and part time, u/g and p/g in Nottingham
    • 2,637 in UNIM and
    • 2,765 in Ningbo.
  – 5786 employees, incl. 2770 teaching and research staff
  – overseas percentage in Nottingham
    • u/g 18%, pgt 53%, pgr 51%

• Income for research and teaching
  – Total income was £382m in 2006/07
  – Research income totalled £78m
Mining Related Teaching

• Mining Degree courses for undergraduates were offered at Nottingham between 1912 and 2002.
Mining Related Research

• Minerals related research continues and focuses on mineral processing, carbon capture and storage, environmental issues associated with mining and rock mechanics.

• Nottingham Centre for Geomechanics (NCG) was formed in 2003 bringing together:
  – civil and mining engineering,
  – soil and rock,
  – underground and surface,
  – theory and practice,
  – research and commercial activity,
  – geotechnics teaching.
Staff and postgraduates

6 staff, incl. Professor Hai Sui Yu, who is also Dean of Engineering
1 Experimental Officer
4 Post-Doc. Research Fellows
4 Lab. Technicians
2 Admin.
13 postgraduate students
The Outputs

- Satisfy the requirements of our sponsoring organisations – provision of reports and data
- Train our postgraduates as researchers (possibly for an academic career and possibly overseas) and supervise their progression to PhD
- Publish our work in both conferences but also refereed journals
- Satisfy university requirements with respect to RAE which measures level of activity and includes establishing and maintaining an international profile
- Feed research into teaching material
• Research approaches available
  – **Analytical approaches**, commonly using numerical modelling to develop an understanding of fundamental geomaterial behaviour.
  – **Experimental approaches** based on laboratory work to validate theoretical approaches and modelling results, also to obtain parameters to feed into numerical models
  – **Field observations** to validate model data
NCG Facilities

• Soils laboratory element testing equipment and CPT truck (£500K).
• Railway ballast testing equipment.
• Geotechnical centrifuge (£500K)
• Rock Mechanics laboratory testing equipment.

• Extensive numerical modelling capability.
Element testing (soil mechanics)
Understanding the fundamental behaviour of small samples of soil
Granular Material Behaviour
Element and full-scale testing of Railway Ballast

Nottingham Centre for Geomechanics
Cone Penetrometer Test Truck
• Geotechnical engineers are interested in the behaviour of 'soil' at say 10 m for deep piled foundations.
• Testing a scale model using actual soil would be attractive. However, the behaviour of soil at depth is influenced by the 'confining stress' resulting from the weight of material above it.
• In a geotechnical centrifuge full scale confining stresses are generated in a reduced scale model by applying a centrifugal acceleration many times greater than normal gravitational acceleration to effectively increases the 'self-weight' of the soil.
• Testing at (say) 100g makes the soil behave as if the model was 100 times larger!

Centrifugal acceleration many times larger than normal gravity
Centrifuge specification

- Beam with counterweight & one swinging platform
- Platform radius - 2.0 m
- Max. size of payload - 0.6-0.9 m
- Max. payload - 500 kg up to 100g
- Max. acceleration - 150g
- Speed - 280 rpm (200 km/hr!)
- The machine is one of 5 of its type in the UK
Geotechnical centrifuge - Ongoing work

• Sinkhole migration
• Piled embankments
• Slope stabilisation

Miniature devices measure loads and water pressures. Digital cameras are used to ‘track’ movement of the soil at the ground surface, or through a window.
Centrifuge Modelling of Reinforced Piled Embankments
Slope stabilisation with discrete pile row

- Bulging (restraint of the upslope movement)
- Bulging with transverse cracks
- Predefined slip
- Position of pile row
- Underlying stable material
- Displacement vectors (GeoPIV)
- Sliding direction

Nottingham Centre for Geomechanics
Rock Mechanics

- Laboratory Facilities
  - Rock test sample preparation
  - RDP Howden 1000kN stiff press
  - Shear rig
  - Tensile test machine/ 500 t press
  - Creep rig
In-house, monitored, rock test sample preparation facility
Rock Mechanics

- Laboratory facilities
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Used for research and commercial testing
RDP 1000 kN Stiff Rock Testing Press

- Stiff press is main facility for rock testing at Nottingham
- Used to determine properties of rocks, grouts and resins, and support elements
- Testing results feed into most of our research work
RDP 1000 kN Stiff Rock Testing Press
- New System Concept -

A Software Driven Machine

- Hydraulics/Frame in good condition
- Old system essentially analogue
- Control and monitoring hardware 20 years old
- Reliability issues - component life
- Safety issues – component failure
- Operating limitations
New Hardware

- Logging card and PC conditioning cards
- Rack to hold above -
- All are off the shelf - standard components
- Sensors – pressure/displacement
- Moog valve controllers
Software Driven Control

• All control functions moved from hardware systems to software allowing much greater flexibility

• Windows based system all coded in MS Visual Basic
  – Customised directly to our requirements
  – Can be modified and adapted as required
  – No shells – No licenses
Young’s Modulus / Poisson’s Ratio
Multi stage triaxial testing
Multi Stage Triaxial Test

Stress-strain curve illustrating how elastic modulus changes with confining pressure.
Rock Mechanics

- Rock test sample preparation
- RDP Howden 1000kN stiff press
- Shear rig
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- Creep rig

Used for research and commercial testing
Dennison 20t tensile rig

Shear rig
Rock mechanics lab

- Rock test sample preparation
- RDP Howden 1000kN stiff press
- Shear rig
- Tensile test machine/ 500 t press
- Creep rig

Used for research and commercial testing
Time Dependency Testing

- New Testing Rig
- 100 tonne capacity
- Temperature control
- 2 Vertical, 3 horizontal displacements
- Automatic logging
Time Dependency Data
Numerical Modelling of Rock Excavations

Highly deformed coal mine roadway

Partial extraction layout 3D model

Modelled using FLAC - a commercial finite difference code
FLAC allows the user to set up excavations in rock, insert support elements, both free-standing and internal to the rock mass (bolts), specify rock bed thicknesses and rock mass properties, and also specify external loads resulting from field stresses.
Modelling a “mixed” support system using FLAC to establish the supporting role played by both steel standing supports and rockbolts.
Sensitivity Studies

30's gateroad FLAC Modelling of Support Design

Modelling the effects of changes in support density and excavation width

Comparing modelled results with actual displacements
FLAC can also be used to identify flow paths for water of methane through rock masses affected by longwall mining.
Shear Strain $>3$mm/m developed around the collapsed goaf and tailgate
Confining stress contours with positions of gas standpipe boreholes
Steel Conveyor and Boulder Model
Impact Breakage of Rock

High speed camera system
100,000,000 frames/second

FLAC numerical representation of fracture development

Crack propagation from dynamic impact of cylindrical rock specimen
Stress relief

FLAC3D 2.10

Step BC536 Model Perspective
14:43 Sat Oct 25 2003

Enter: Rotation:
-1.097e+002 X: 279.379
-3.150e+002 Y: 60.000
1.063e+002 Z: 163.012
St: 7.825e-002 Mag.: 1.5
Ang.: 22.500

Plane Origin: Plane Normal:
1.430e+002 X: 1.000e+000
0.000e+000 Y: 0.000e+000
0.000e+000 Z: 0.000e+000

Contour of SMmin
Plane: on behind
Minfac = 0.000e+000

Gradient Calculation
-2.8670e+006 to -2.8700e+006
-2.8900e+006 to -2.8800e+006
-2.5000e+006 to -2.4900e+006
-2.3100e+006 to -2.3000e+006
-2.1000e+006 to -2.1100e+006
-1.9300e+006 to -1.9200e+006
-1.7400e+006 to -1.7300e+006
-1.5200e+006 to -1.5400e+006
-1.3600e+006 to -1.3600e+006
-1.1000e+006 to -1.1600e+006
-9.8000e+005 to -9.7100e+005
-7.9000e+005 to -7.8000e+005
-6.0000e+005 to -5.9000e+005
-4.0000e+005 to -4.0000e+005

Geomechanics
Nottingham Centre for Geomechanics
University of Nottingham
Layout of Shaft Model

Take a 2D horizontal slice across shaft
Layout of Shaft Model

JOB TITLE: FLAC Layout

FLAC (Version 4.00)

LEGEND

17-Jul-08 20:14
step 2710
-3.192E+00 < x < 9.131E+01
-4.109E+00 < y < 9.040E+01

User-defined Groups
User: gap

Grid plot

Beam plot

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FLAC Grid

Displacement monitoring points for graphs
Input Parameters for Rock Type

• Stiffness
  • Modulus \( E = 1 – 6 \) GPa
  • Poisson’s ratio \( \nu = 0.35 \)

• Strength
  • Cohesion 0.1 – 5 MPa
  • Friction Angle 10 – 35°

• Stress
  • \( \sigma_{xx} \) 14.24 MPa
  • \( \sigma_{yy} \) 16.51 Mpa
Example Model in Yield

Displacement vectors:

LEGEND

15-Jul-08 13:08
step 4069
2.833E+01 < x < 6.030E+01
2.839E+01 < y < 6.036E+01

Displacement vectors
Max Vector = 2.619E-02

0 5E-2
Example Model in Yield

![Diagram of a yield zone with annotations]

- **x Elastic**
- *** At Yield**

**Legend**
- 15-Jul-08 13:21
- step 4167
- 2.167E+01 <= 6.866E+01
- 1.951E+01 <= 6.640E+01
Research funding

• **RFCS**
  – EU Research Fund for Coal and Steel
  – provides 60% funding for projects
  – requires partnerships to be established across national boundaries
  – preference to projects with members from industry
  – coal focus

• **EPSRC**
  – Govt. funded Research Council
  – 100% funding
  – ring-fenced for the university sector, but very competitive

• **Industrial**
  – very welcome, but generally very short term
  – strategic relationships to promote large scale multi-disciplined research
  – income from commercial work, especially rock testing

• **Scholarships**
  – some potential help from scholarships
  – self-funded research students
What research are we doing today?
IMPREX Project

Objective

RFCS Funded project with the objective of improving coal recovery from otherwise sterilised reserves such as roadway pillars and remnants

Deliverable

Feasibility study recommending an economic safe extraction method & potential location/s

Partners

UK Coal, Rock Mechanics Technology Ltd, plus German and Polish partners
Selection of an Extraction Method

A typical Auger system
Problems

• Continuity
  – feast and famine of research work (and funding)

• People
  – attracting the best skills in return for low pay and lack of security
  – uncertain prospects of an academic career
  – keeping our good people long enough to complete the research

• Maintaining our hardware and software

• Delivering all the outputs
Thank you.