The Geomechanics Challenges of Contemporary Deep Mining: Technology as the Pathway to Increased Safety and Productivity

Fidelis T Suorineni
Nothing new to report on miner's death, says Ministry of Labour

By: Heidi Ulrichsen - Sudbury Northern Life Staff | Jan 09, 2013 - 2:07 PM

Ministry still investigating incident that killed Stephon Perry
Mine Accidents
No-one to blame for Beaconsfield death, says coroner

A Tasmanian coroner has criticised the mining company Beaconsfield Gold, but found it was not directly responsible for the 2006 disaster in which miner Larry Knight was killed.

The coroner, Rod Chandler, has handed down his findings in Launceston after a lengthy inquest last year.

Mr Chandler has ruled that the Anzac Day rockfall which killed Larry Knight and trapped Todd Russell and Brant Webb could not have been foreseen.

Mr Chandler told the court that a seismic event six months before the tragedy was a warning that more rock falls were likely and required a thorough risk assessment by the mining company, Beaconsfield Gold, which didn’t happen.

The coroner also found that the resourcing of Tasmanian mine inspectors was inadequate and
Outline

• Tribute to our predecessors
• Status of Key Issues in Geomechanics
  – Stress measurements
  – Rock mass characterization
  – Failure Criteria
  – Numerical Modelling
  – Research model
Outline Cont.

• Challenges of our time
• Pathway to success
  – Technology
  – Genuine multidisciplinary collaboration
• Conclusions
• Acknowledgements
Mining is Global
Tribute to Our Predecessors

School of Mining Engineering
Christian Otto Mohr  Charles A. Coulomb

Civil Engineer  Physicist

1835-1918  1736-1806

Mohr-Coulomb Failure Criterion
Karl Terzaghi
B.Sc. - Mechanical Engineering
Geosciences
Ph.D. - Mechanical Engineering

“Father of modern Geotechnical Engineering”

1883-1963

Courtesy: MIT Museum
Leopold Müller

- B.Sc. – Civil Engineering
- Doctor in Technical Geology
- Taught 1st Rock Mechanics course in the world in 1964 in Technical University of Munich
- Founder and 1st President of the International Society for Rock Mechanics

1908 - 1988

Courtesy: ISRM
J.A Franklin: 1940 - 2012

(Dusseault and Graham, 2012; ISRM)

- Point Load Test
- Slake durability test
- Hoek-Franklin triaxial cell
- Strength-size classification system
- Block size determination
  - WipFrag
- ISRM Education
- ISRM suggested methods

• B.Sc. Civil Engineering
• M.Sc. Engineering Geology
• Ph.D. Rock Mechanics
Nick Barton

- B.Sc. – Civil Engineering
- Ph.D. Rock Slope Engineering

- Q-system
- Shear strength of rock joints

1944 -
M.G.D. Salamon

- Pillar Design
- Rockbursts and Seismicity

Courtesy: Mertnet
1933-2009
N.G.W. Cook

- The stiff testing machine
- Pioneered full-wave form continuous recording for rockburst monitoring

Courtesy: National Academy of Sciences
1938 - 2007
Z.T. Bieniawski

RMR – System

- Rock properties
  - laboratory
  - in-situ

1936 -
Dennis H Laubscher

D. H. Laubscher

Block Caving

From Stacey (2003)
Evert Hoek

B.Sc. Mechanical Engineering

- Hoek-Brown Failure Criterion
- Geological Strength Index (GSI)

1933 -
E.T. Brown

Hoek-Brown Failure Criterion

Courtesy: ISRM
1938 -

AUSSIE!
Brittle Hoek-Brown Failure Criterion

\[ \sigma_1 - \sigma_3 = \frac{\sigma_{ci}}{3} \]

Martin (1994)

1950 -
Classification of Generations

1860-82
- Missionary generation
  - The lost generation

1883-1900
- The Greatest generation

1901-24
- Architects of the modern age
  - Crushed by the great depression

Terzaghi

Leopold Muller
## Contributions of the Generations

<table>
<thead>
<tr>
<th>Period</th>
<th>Generation</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1925-42</td>
<td>The silent</td>
<td></td>
</tr>
<tr>
<td>1943-60</td>
<td>Baby boomers</td>
<td></td>
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<tr>
<td>1961-80</td>
<td>Generation X</td>
<td></td>
</tr>
<tr>
<td>1980-2000</td>
<td>The Millennials</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>High unemployment</td>
</tr>
</tbody>
</table>

- **The lucky few**
  - Like Luxury
    - pleasure
  - The Yuppies

- **Bored generation**
  - Gossipers: Me Me
  - We We

- **Contributors**
  - Evert Hoek
  - E.T. Brown
  - J.A. Franklin
  - M.D.G. Salamon
  - Z.T. Bieniawski
  - N.G.W. Cook
  - N.R. Barton
  - C.D. Martin

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*Image Source: UNSW*
In-situ Stress Measurements

The Challenges
Reliability of In-situ stress measurements

“Techniques for measuring in-situ stress while greatly improved from what they were still give an amount of scatter which would be unacceptable in almost any other branch of engineering”

Hoek (1994)
Stress Measurement Errors & Effects

Error ranges

- **Magnitude**
  - ±15% to ±30%

- **Orientation**
  - ±15° to ±30°

Effect

Grabinsky et al. (1997)

(Suorineni et al. (2011)
Consequences of Stress Measurement Errors

Orientation errors

- Oblique major principal stress orientation relative to orebody increases risk of rockbursting

Douglas Hay Medal
Depth Range

Martin (2001)
Recent Focus – Acoustic Emission

• Key issues
  – Rock memory over time and different geological episodes
  – Sample homogeneity
  – Sampling difficulty
  – Temperature
  – Heim’s rule
Rock Mass Classification Systems

What Next?
RMR Database Rock Types

By Genesis

- Sedimentary (63%)
- Igneous (20%)
- Metamorphic (17%)

By Sedimentary Rock Type

- Claystone
- Salt
- Conglomerate
- Limestone
- Argillite
- Coal
- Breccia
- Greywacke
- Siltstone
- Sandstone
- Mudstone
- Shale
RMR and Stand-up Time
MRMR and Block Caving

- **MRMR**
  - RMR Adjustment
    - Weathering
    - Stress
    - Blasting
    - Jointing

![MRMR and Block Caving Diagram](image)
Caving Problem Source

Caving depths

Depth range of RMR database

**Caving depths**

**Depth range of RMR database**
Q-system

Scandinavian

\[ Q = \left( \frac{RQD}{J_n} \right) \left( \frac{J_r}{J_a} \right) \left( \frac{J_w}{SRF} \right) \]

- \( \frac{RQD}{J_n} = \text{Blocks size} \)
- \( \frac{J_r}{J_a} = \text{Interblock shear strength} \)
- \( \frac{J_w}{SRF} = \text{Active stress} \)

- Rock mass is blocky
  - All joint sets continuous
- Ambiguous
Q-system Database

Rock types by Origin

- Metamorphic (52%)
- Igneous (20%)
- Sedimentary (28%)

Depth range

15 m - 200 m
Civil Tunnels
Implication of Q-weaknesses in Practices

Support selection

Stability Graph &

ISRM Recommendation for Joint Persistence Determination

\[ T_i = \left( \frac{100N_i}{2(N_i + N_a + N_o)} \right) \]

- \( N_i \): # jt ends terminating in intact rock
- \( N_a \): # jt ends terminating in other jts
- \( N_o \): # jt ends obscured by excavation limits

High \( T_i \)-> More massive rockmass
Sound Engineering Judgment in Geomechanics Overrides Precision of Numbers!

Agree!

“...as soon as equations are presented in the field of rock mechanics and rock engineering, possible restrictions are quickly forgotten and the equation is easily applied uncritically.”

Palmström and Broch (2006)
Accounting for Joint Persistence

The problems of measuring the persistence of rock joints, determining the most likely failure mode for a rock containing a number of intersecting Structural features ........... are as formidable as always

Hoek (1994)
Mohr-Coulomb Failure Criterion

\[ \tau = C + \sigma_n \tan \phi \]

- \( \tau \): Shear stress
- \( C \): Cohesion
- \( \sigma_n \): Normal stress
- \( \phi \): Angle of internal friction

What does this mean?
Hoek-Brown Failure Criterion

• Heavily jointed rock masses (1980)

\[ \sigma'_1 = \sigma'_3 + \sigma_{ci} \sqrt{m \sigma'_3 / \sigma_{ci} + s} \]

• Disturbed rock masses (1988)

\[ m_b / m_i = \exp\left( (RMR - 100) / 14 \right) \]
\[ s = \exp\left( (RMR - 100) / 6 \right) \]

Undisturbed or interlocking rock masses

\[ m_b / m_i = \exp\left( (RMR - 100) / 28 \right) \]
\[ s = \exp\left( (RMR - 100) / 9 \right) \]

\[ E = 10^{((RMR-10)/40)} \]

\[ m_b, m_i \] are for broken and intact rock, respectively.

• Redefinition of \( m_b, s \) and \( a \) (2002)

\[ \sigma'_1 = \sigma'_3 + \sigma_{ci} \left( m_b \left( \frac{\sigma'_3}{\sigma_{ci} + s} \right) \right)^a \]

\[ m_b = m_i \exp\left( GSI - 100 / 28 - 14D \right) \]
\[ s = \exp\left( GSI - 100 / 9 - 3D \right) \]

\[ a = \frac{1}{2} + \frac{1}{6} \left( e^{-GSI/15} - e^{-20/3} \right) \]

\[ E_m(GPa) = \left( 1 - \frac{D}{2} \right) \sqrt{\frac{\sigma_{ci}}{100}} \cdot 10^{((GSI - 10) / 40)} \]
Hoek – Brown Failure Criterion

“Our approach was entirely empirical and we worked from very limited data of rather poor quality. Our empirical criterion and our estimates of the input parameters were offered as a temporary solution to an urgent problem”

“The fact that the criterion works more by good fortune than because of its inherent scientific merits, is no excuse for the current lack of effort or even apparent desire to find a better way.”

Hoek (1994)
The Challenge

“It is my hope that .......... someone who has the skill and the motivation to pickup the challenge and to lead in the development of better tools for providing us with the input data which we need for engineering designs of the future.”

Hoek (1994)

NOT YET!
Brittle Hoek-Brown/m-zero Criterion

Origin

- AECL
  - URL (Pinawa), Canada
- In-situ testing and monitoring
- Diligent laboratory testing
  - acoustic emission

\[ \sigma_1 - \sigma_3 = \frac{1}{3} \sigma_{ci} \]

\[ \sigma_1 - \sigma_3 = \sqrt{s} \sigma_{ci} \]

\[ m = 0 \]

\[ s = 0.11 \]
In-situ Observations

- Granite
  - Tunnel in granite - Failed
  - $\sigma_3 = 14 \text{ MPa}$
  - $a = 1.75 \text{ m}$

- Granodiorite
  - Tunnel in granodiorite - Stable
  - $\sigma_1 = 55 \text{ MPa}$
Experience with Suphides

- Massive
- Disseminated
- Host (Waste)

**Geology is key in Geomechanics!**

**Question: All Rocks Have Same “s”?**


![Diagram showing relationship between Brittle Parameter "s" and Density (kg/m^3)].

R^2 = 0.4029

“There is deficiency in the training of rock mechanics engineers today. That deficiency is the absence of sufficient geology in the curriculum of civil and mining engineering programs.”

Courtesy: ARMA (2010)
Here Is The Problem

Letter to the Editor

From: Evert Hoek, Consulting Engineer

The Challenge of Input Data for Rock Engineering

Hoek (1994)
The Problem

There was a time, not too many years ago, when our ability to collect geotechnical data far exceeded our ability to use it for meaningful engineering analysis. This situation has been turned completely on its head and we are now faced with severe data limitations in our analyses of rock engineering problems.

Hoek (1994)
Data Collection Tools Vs. Computer Power Growth

Hoek’s Frustration

“I see almost no research effort being devoted to the generation of the basic input data which we need for our faster and better models and our improved design techniques. These tools are rapidly reaching the point of being severely data limited.”

Hoek (1994)

Moore’s law

Computer chips double in power roughly every 18 months!

Intel Co-founder, Gordon Moore
Numerical Modelling

Read and Martin (1996)

The Consequences
We Got it Right Only After the Fact!

Hajiabdolmajid et al. (2000)
The Northparkes E48 Block

The Prediction

The Reality

24th August 2010

10th September 2010

Strom (per. Comm.)
The Big Question!

Since continuum models with conventional failure criteria (Mohr Coulomb or Hoek and Brown) apparently have such difficulty to model the “main event” that they are designed to model—namely failure, why are we with such confidence describing in our reports, papers and tribunals—“the onset of plastic behaviour,” the “plastic zone,” the “area (volume) requiring rock bolts,” “the depth of potential failure” etc.?

Barton (2004)
Rockbursts and Seismicity

Seen the Light?
“A disconcerting feature of rockbursts is that they defy conventional explanation.”

Salamon (1983)
Consequences of Rockbursts
Research Status

Vasak and Suorineni (2011)

Vasak et al. (2008)

Kaiser et al. (2006)

Vasak and Suorineni (2011)
Geomechanics Research
Approach Now
Research Silos

• Research “Silos” stifle the progress of young brilliant researchers
  – No pedigree for grants!

• Narrow focus

• Nepotic collaborations
  – Not genuine

• Peripheral research
  – Avoid the core research questions
  – Recycle publications
Genuine Collaboration

• **Best** minds together
  – multidisciplinary
  – Not based on relationships but Strengths

• **Share** the investigation

• **Share** the data

• **Share** the credit
Obstacles to Genuine Collaboration

• Who owns the credit for what is achieved?
• Who owns the Intellectual Property?
• Who is the lead author of the paper
• How many papers can I publish?
• How much of the money can I get
Challenges of Our Time
The Cancers and Higgs Bosons in Geomechanics
Our Challenges

• Rockburst is the Cancer in Geomechanics
  – Rockburst prediction a priority
  – Stand-up to Rockbursts (SU₂R)
Remote mining technology

- Remove people from the workface!
  - Robotic applications
    o Charging
    o Scaling
    o Support installation
    o Mapping!
    o etc
Our Challenges

• Development of a realistic failure criterion for rocks
  – Based on rock fabric and structure

• How?
  – Genuine multidisciplinary collaboration
  – Technology
  – Money!
  – Dedication
Our Challenges

Numerical modelling

- Development of a realistic numerical modelling code
  - Excavation performance prediction

In-situ stress measurements

- Accurate in-situ stress measurement technology
  - Minimize the large errors
Our Challenge

• Training
  – Need to strengthen and **emphasize geology in our programs**
    o Mining Engineering
    o Civil Engineering

“-------- John profoundly understood the intersection between geosciences and rock engineering, an attitude that pervaded his career.”
My Wish!

Medical

Geomechanics

Etemad (2012)

Chai (2012)
Technology
Drives Mine Productivity and Safety
Technology and Mine Productivity

Productivity (Tons/Person-Year)

Year

Baiden (per. comm.)


0 1,000 2,000 3,000 4,000 5,000 6,000 7,000 8,000

Projected

Telemining
Significance of Technology

“It is the knowledge management benefits of new IT technology that will provide the greatest benefit to the industry.”

“Although mine operations are generating more data, such information is rarely well utilized.”

Peterson et al. (2001)
Significance of Scientific Visualization

“Investments in 3D visualization worldwide
– US$16.5 billion in 2010 > $20 billion in 2015!”

Virtual Reality Facility - nD

- Enhances ability to integrate complex / large data sets from different sources
- Enables easy understanding of complex data - Identify linkages and trends
- Encourages interdisciplinary team collaboration and brainstorming
- Provides great environment for strategic planning and negotiating – Seeing is believing!
Virtual Reality Facility -nD
Model for Research Success

“Bring the best and most talented possible people together, fund them generously, oversee their progress rigorously, and shoot for big payoffs in a tight schedule”

(Time – April 1, 2013)
Medical Research Success Drivers

• Enabling technologies

  – Dazzling scientific and research advances in:
    o Bioengineering
    o Nanotechnology
    o Drug compounds and data gathering
    o Cheaper and power computers

• Collaboration – Strength in numbers
Successful Medical Projects

Cancer

• Stand Up to Cancer

Taking advantage of strength in numbers, researchers are tackling cancer, armed with a range of enhanced weapons, from genomics to drug development to diagnostics to better ways to raise and allocate funds

 o biochemists
 o surgeons
 o Nurses etc

Genomics

• The Human Genome project
  – 27 Institutions
Unlikely Minds Working Together

**DR. DANIEL VON HOFF**
Physician in Chief, Translational Genomics Research Institute

**DR. PETER JONES**
Molecular biologist, USC/Norris Comprehensive Cancer Center

**DR. STEPHEN BAYLIN**
Chief, cancer biology division, Johns Hopkins University
Successful Science Projects

• Physics
  – Higgs Boson (God’s Particle)

• NASA
  – Space exploration
    o Curiosity
    o Lunar Module
    o etc
Discovery of the Higgs Boson

The Effort

Detecting the Higgs was the primary goal of the $10 billion Large Hadron Collider, built by Europe's CERN particle physics lab on the Swiss-French border.

The Collaboration

Nearly 2000 physicists from U.S. institutions—including 89 U.S. universities and seven U.S. Department of Energy laboratories—participate in the ATLAS and CMS experiments, making up about 23 percent of the ATLAS collaboration and 33 percent of CMS at the time of the Higgs discovery.
The Big Pay-Off

The Discovery

The Reward

Nobel Price Winners in Physics

Francois Englert  Peter Higgs
Lessons from Science & Medicine

- True multidisciplinary collaboration
- Money!
- Technology
- Dedication
- Planning and organization
- High level *rigorous* progress reviews
Conclusions

• Our predecessors solved the problems of their time

  – Those solutions appear to have reached their limits today
Conclusions

• Need paradigm change in research attitude in geomechanics
  – Peripheral to Core
  – Pretence to Genuine multidisciplinary collaboration

• Funding agencies can influence collaboration

• Need to work with technology developers
Conclusions

Let us Turn Pain and Deficits into Joy and Profits
Thank YOU
Acknowledgements

• My Family
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  – Maree Magafas and her team
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