24th Seminar & Courses on

Monitoring and Modelling Seismic Rock Mass Response to Mining

Seminar: 05 & 06 May 2014, Asara Wine Estate, Stellenbosch, SA

Sunday 04 May, 09h00 - 16h00: Mine Seismology Primer.
Sunday 04 May 09h00 - 17h00: Meeting of the International Research Advisory Board of the Institute of Mine Seismology
Sunday 19h00 - Wine tasting evening hosted by the Institute of Mine Seismology
Monday 05 May 08h45: Lectures and Presentations on Passive and Active Seismic Monitoring in Mines
Monday 19h00: Dinner hosted by the Institute of Mine Seismology
Tuesday 06 May 09h00: Lectures and Presentations on Modelling the Seismic Rock Mass Response to Mining

Courses: 07 – 09 May 2014, IMS Offices, Stellenbosch, SA

07 May, 09h00-13h00: Dynamic Rock Support Considerations by P. K. Kaiser
07 May, 09h00-17h00: Microseismic Monitoring in Oil and Gas, by L. Eisner
07 May, 14h00-18h00: Strong Ground Motion Hazard
08 May, 09h00-13h00: Numerical Modelling with Seismic Data
08 May, 14h00-18h00: Analysis & Interpretation Tools: Ticker3D & Vantage
09 May, 09h00-13h00: Seismological Processing of Waveforms with Trace

For more details & registration contact Rynelle.Eksteen@IMSeismology.org, or www.imseismology.org
Objective of the 2014 Seminar

Considerable progress has been made in the quantification of seismic sources and in the quantification of seismicity. Most modern seismic systems quantify seismic sources by their seismic potency, moment and their tensors, radiated seismic energy and other derivatives. Seismicity is routinely characterised by its size and time distributions, including spatio-temporal clustering and migration, and by parameters reflecting changes in the strain and stress regime and the rheological properties of the rock mass deformation associated with the seismic radiation. Seismic waveforms do not provide direct information about the absolute stresses and strains, but they do provide useful information about stress orientation and about the spatial and temporal strain and stress changes.

However, the progress in quantitative integration of seismic observations and numerical stress modelling has been slow. In numerical modelling assumption of a homogeneous rock makes strain and stress distribution equivalent. But, even for a constant elastic moduli, seismically inferred stress and strain changes are independent: seismic strain is proportional to seismic potency and seismic stress is proportional to the ratio of seismic energies to seismic potency. Thus contours of seismic strain and seismic stress in a real rock mass may be qualitatively different. It is the difference between the modelled stress and/or strain distributions and the observed ones that need to be explained and reconciled while mining.

Progress in the quantification of rock mass properties and monitoring their changes in space and time has also been slow. Numerical modelling experts rely both on results of sparse stress measurements and on somewhat involved sensitivity analyses to determine the values of rock mass parameters used in their models. Recent advances in active seismic monitoring, seismic interferometry and ambient noise analysis achieve a resolution at least 100 times better than classical seismic velocity inversion. This may be of great help in reducing the uncertainties for more accurate stress modelling.

The main objective of the 2014 Seminar is to present recent progress made in passive and active seismic monitoring and in integration of numerical modelling with seismic data.

We have invited the leading researchers and practitioners in the field to debate the following issues:
- Progress in Passive Seismic Monitoring
- Active Monitoring Seismic Rock Mass Properties
- Integration of Numerical Modelling with Seismic Observations
- Quantification and Imaging of Complex Seismic Sources
- Methodologies to Estimate the Induced Hazard
- Application of Seismic Monitoring to Tabular and 3D Mass Mining

Instruction to speakers. When presenting please tell us: (1) why you did this work, (2) how you did it, (3) what you found, (4) what you think it means, and (5) what are the limitations.

Looking forward to see you in Stellenbosch, South Africa in May 2014
Aleksander J. Mendecki
Chairman and Head of Research
Institute of Mine Seismology
Confirmed Presentations on Passive and Active Seismic Monitoring in Mines

Monitoring the Earth’s Interiors Using Ambient Seismic Noise: From a Regional (Japan) to a Local (Mine) Scale
Dr Florent Brenguier, Institut de la Terre in Grenoble, France

New Understanding of Geomechanical Interaction Between Hydraulic Fracture and Induced Microseismicity
Dr Leo Eisner & Frantisek Stanek, Czech Academy of Sciences, Prague

Observational Studies to Mitigate Seismic Risks in South African Mines
Prof. Hiroshi Ogasawara, Ritsumeikan University, Japan & Prof. Ray Durrheim, University of the Witwatersrand, South Africa

Development of Automatic Hypocenter Location with Accuracy Compared to Manual Picking
Shigeki Horiuchi, Home Seismometer Corporation, Dr Makoto Naoi & Dr Masao Nakatani, University of Tokyo & Prof. Hiroshi Ogasawara, Ritsumeikan University, Japan

Acoustic Emissions Down to Magnitude $M_{vw} = -5$ Delineating Damages Around Mining Stopes and Pre-existing Faults: Spatial Distribution, Temporal Change and Source Parameters
Dr Makoto Naoi, University of Tokyo & Dr Hirokazu Moriya, Tohuku University, Japan (see Note 1 below for the full list of authors)

Monitoring Seismogenic Regions of Mines Through Acoustic Properties of Active Transmitted Waves and Seismic Stress Parameters
Prof. Hironori Kawakata & Dr Osamu Murakami, Ritsumeikan University, Japan (see Note 2 below for the full list of authors)

Retrospective Assessment of the Spatial and Temporal Relationship between Seismic Responses and Blasting
Kyle Woodward, Australian Centre for Geomechanics & University of Western Australia

Continuous Monitoring of Stress Changes in Mines with Ambient Seismic Noise
Gerrit Olivier, Institute of Mine Seismology

Seismic Velocity Imaging Using Active and Passive Sources
Dr Richard Lynch, Institute of Mine Seismology

Cave Front Tracking Using Active Seismic Sources
Mark Green & Dr Richard Lynch, Institute of Mine Seismology

High Resolution Imaging of Crush Pillars Over Time
Gerrit Olivier and Mark Green, Institute of Mine Seismology
Fluid Included Seismicity in the Central Basin Area, Johannesburg
Dr Artur Cichowicz, Council for Geoscience, South Africa

Sigh_Napse: Events and Signals That Go Missing Under the Seismic Radar With or Without a TRACE
Kevin Riemer, Group Seismologist, Sibanye Gold, South Africa

Full Waveform Automatic Location of Seismic Events
Dr Richard Lynch, Institute of Mine Seismology & Sahil Brijraj, University of KwaZulu Natal, South Africa

Routine Automatic Waveform Processing for Mines
Cornel du Toit, Institute of Mine Seismology

Seismic Hazard Rating for Mines
Dr Daryl Rebuli, Institute of Mine Seismology

Monitoring Seismic Ground Motion
Dr Aleksander Mendecki, Institute of Mine Seismology

On-line Mine-scale Continuous Ground Motion Mapping
Dr Ernest Lötter, Institute of Mine Seismology

Note 1. Dr Makoto Naoi, Dr Masao Nakatani (University of Tokyo), Dr Hirokazu Moriya, Prof. Kenshiro Otsuki, Dr Yasuo Yabe (Tohoku University), Dr Osamu Murakami, Prof. Hironori Kawakata, Prof. Hiroshi Ogasawara (Ritsumeikan University), Dr Shigeki Horiiuchi (Home Seismometer Corp.), Thabang Kgarume, Prof. Raymond Durrheim (CSIR), Sifiso Khambule (Sibanye Gold), Thabang Masakale (OHMS), Luiz Ribeiro, Anthony Ward (SeismoGen cc) and Dr Joachim Philipp (GMuG).

Note 2. Prof. Hironori Kawakata (Ritsumeikan University), Dr Nana Yoshimitsu (CIDIR/ERI, University of Tokyo), Dr Masao Nakatani (ERI, University of Tokyo), Dr Osamu Murakami, Y. Sasaki (Ritsumeikan University), Dr Joachim Philipp (GMuG), Dr Issei Doi (DPRI, Kyoto University), Dr Makoto Naoi (ERI, University of Tokyo), Anthony Ward (Seismogen CC), Vlok Visser, Thabang Masakale (OHMS), Sisifo Khambule (Sibanye Gold), T. Kgarume, Dr Alexander Milev, Prof. Raymond Durrheim (CSIR), Luiz Ribeiro, Anthony Ward (Seismogen), Prof. Ogasawara (Ritsumeikan University).

Confirmed Presentations on Modelling Seismic Rock Mass Response to Mining

Relevance of Ground Motions for Support Design
Prof. Peter Kaiser, CEMI, Canada

Dynamic Simulation of Support
Dr David Beck, Beck Engineering, Australia

A New Constitutive Model for Rock Failure: Using Microseismic Records to Generate Rock Properties
Dr Richard Brummer, Itasca Consulting Canada
The Match Between Seismic Monitoring, In-Situ Stress and Numerical Modelling  
Dr Stephan Arndt, Coffey, Australia

Seismic Monitoring and Mine Design  
Dr Javier Vallejos, University of Chile

Seismic Source Evolution and Dynamic Rupture in a Damage-Breakage Framework  
Dr Vladimir Lyakhovsky, Geological Survey of Israel, Jerusalem

Modelling of the Rupture Initiation, Propagation and Arrest Under Specified Loading  
Dr Assen Ilchev, Institute of Mine Seismology

Seismic Risk Associated With Off Reef Development  
William Joughin & Shaun Murphy, SRK, South Africa

Some Extensions to a Simple Limit Equilibrium Model for Tabular Face Fracturing and Layout Design  
Dr John Napier, University of Pretoria, South Africa

In-Situ Stress Estimation From Borehole Breakout and Core Disking  
Dr Yasuo Yabe, Tohoku University

Crush Pillar Failure and Seismicity  
Dr Steve Spottiswoode, J. Poggenpoel, L. Ledwaba & M. Drummond, South Africa

Measurement and Modelling of Stresses in Seismogenic Volume  
Gerhard Hofmann, AngloGold Ashanti, South Africa & Prof. Hiroshi Ogasawara, Ritsumeikan University, Japan

Dual Grid, Non-Constant DD BEM for Better Stress Values Close to Excavations  
Jacques Gerber, Institute of Mine Seismology

Simulation of Mining Induced Seismicity Using Salamon-Linkov Method  
Dr Dmitriy Malovichko & Dr Gerrie van Aswegen, Institute of Mine Seismology

Pre-Seminar Seismology Primer  
Sunday 04 May, 09h00 - 16h00, IMS Offices, Stellenbosch

Course Instructors  
Dr Daryl Rebuli & Olaf Goldbach, Institute of Mine Seismology.

Course Objectives. The objective of the course is to explain basic seismological concepts of seismic waves and sources to non-seismologists to facilitate better understanding of lectures, presentations and training courses offered during the Seminar week.
Course Programme.
1. What is a seismic event, objectives of seismic monitoring.
2. Types of seismic waves, sources of seismic waves, velocity of ground motion (particle velocity) vs. wave speed (propagation velocity).
3. Event locations, network configuration, velocity calibration, Wadati diagram.
4. Direct source parameters: origin time, X, Y, Z location, spectra (Fourier transformation, frequency decomposition), corner frequency, radiated energy, moment magnitude, magnitude scales.
6. Types of faults, radiation patterns and fault plane solutions.
7. Size distribution (Gutenberg-Richter relation), risk and probabilities, hazard maps.
8. Time histories, histograms, cumulative plots.

Presentation and the relevant publications will be available in electronic format.

Post-Seminar Courses and Lectures

A Short Course on Dynamic Rock Support Considerations
Wednesday 07 May, 09h00 - 13h00, Asara Wine Estate, Stellenbosch

Course Instructor
Prof. Peter K Kaiser, Director, Rio Tinto Center for Underground Mine Construction (RTC-UMC at CEMI), Professor of Mining Engineering and Chair for Rock Engineering and Ground Control at Laurentian University.

Peter is a specialist in applied research for mining. His particular interests lie in geomechanics, tunneling, and applications of new technologies to mining operations in order to increase safety and productivity. He brings extensive experience to this area from both the industrial and academic sectors having served as consultant to numerous consulting engineers, mines and public agencies. He is the author of more than 300 technical and scientific publications in the field of geomechanics, tunneling and mine design, and is a Fellow of the Engineering Institute of Canada and the Canadian Academy of Engineers.

Brief Description
Hard rock mines are being mined at great depths from 2500 to 3000 m in Canada and South Africa and hard rock tunneling is being conducted in some countries at depth greater than 2000 m. As mining and civil tunneling progresses to deep grounds, excavation-induced seismicity and rockburst problems increase and cannot be prevented. However, seismic risk can be reduced by selecting appropriate mining methods and sequences and by placing developments and infrastructure strategically. As a last line of defense, burst-resistant rock support is used to prevent or minimize damage to excavations and thus enhance workplace safety. This half-day course will touch on methods to control and mitigate seismic risk by focussing on issues of strain-bursting and on the use of rockburst resistant support to mitigate damage.

The course is based on research findings from the Canadian Rockburst Support Handbook (CRBSHB, Kaiser et al. (1996)) but is supplemented by a new design guidebook which includes recent development and experiences as well as a design tool called
BurstSupportTM which significantly simplifies the support design task. Under contract with CEMI, the Institute of Mine Seismology (IMS) has developed a ground motion assessment tool (S-GMAT) that helps to eliminate deficiencies of scaling laws and thus provided means for better rockburst damage assessment and for support design. Attendees will derive the most benefit from the course if familiar with basic rock mechanics, underground excavation’s, and the outline and general content of the CRBSHB, summarized in the related CIM-Bulletin papers.

Course Programme
1. Introduction
   1.1 Brittle failure of rock
   1.2 Dynamic rock support design principles
   1.3 Excavation response behavior and controlling bulking process with rock support
2. Strong Ground Motion Assessment for Support Design
   2.1 Strong ground motion assessment approach (with S-GMAT demo/result)
   2.2 Forensic analysis of rockburst damage and support design verification
   2.3 Dynamic fault rupture modelling (IMS presentation)
3. Seismically Induced Strain Burst
   3.1 Mechanism of seismically-induced strain burst
   3.2 Rock support design principles for seismically induced strain burst
   3.3 Case examples
4. Integration of New Development and Validation
   4.1 Recent development to overcome design deficiencies
5. Discussion

Useful References and Course Material

Presentation and the relevant publications will be available in electronic format.

A Course: Microseismic Monitoring in Oil and Gas Reservoirs
Wednesday 07 May, 09h00 - 17h00, IMS Offices, Stellenbosch

Course Instructor
Dr Leo Eisner. Leo’s academic studies were completed by obtaining his Ph.D. in Geophysics from the California Institute of Technology. He spent six years as a Senior Research Scientist with Schlumberger Cambridge Research where he filed five patents and issued numerous publications. The papers and extended abstracts cover a broad range of subjects, including the seismic ray method, finite-difference methods, seismological investigations of local and regional earthquakes and microearthquakes induced by hydraulic fracturing, etc. He joined MicroSeismic Inc in 2008 and was promoted to Chief Geophysicist in 2009. In 2010 he has accepted honorary position of Purkyne Fellow at the Czech Academy of Sciences in Prague. He is also part time consultant for MicroSeismic Inc as a geophysical advisor and he also directs seismic consulting company Seismik s.r.o. Since 2011 he is teaching continuous education
class for SEG. He is author or coauthor of 23 peer reviewed scientific publications, more than 40 extended abstracts, and more than 10 patents or patent applications.

**Brief Description**
This course will discuss principles of microseismic monitoring. A brief historical overview of earthquake and microearthquake monitoring techniques will allow basic insight and provide list of most important publications. Downhole monitoring techniques will be described with detailed examples of complete process from velocity model building, through geophone orientation to microseismic event locations. Then the principles of surface monitoring with examples of velocity model calibration, location of microseismic events and source mechanism analysis. The course will also explain principles of source mechanisms inversion. Finally, case studies and broader discussion of felt seismicity in the vicinity of oil and gas fields will be discussed.

**Course Objectives**
1. **Design** an optimal array for passive seismic (surface or downhole) monitoring and estimate uncertainties of locations for microseismic events.
2. **Orient** downhole geophones from a perforation or calibration shot, estimate approximate distance and depth of a recorded microseismic event.
3. **Locate** from the surface monitoring array and estimate source mechanisms of visible microseismic events, pick first arrivals on surface array.

**Course Programme**
1. **Definition of micro-seismicity**, induced/triggered seismicity, a brief review of micro-seismicity outside of oil industry: water reservoirs, mining, geothermal. Historical review of micro-seismicity in oil industry with focus on hydraulic fracturing (M-site, Cotton Valley, Barnett, etc). Review of the main results obtained to date. Brief overview of the hydraulic fracturing.
2. **Location techniques for earthquakes**: number of unknowns, differences from active seismic. Large earthquake locations: Grid search techniques. Relative locations. Order of magnitude estimates of locations. Earth velocity model and crustal waves. Introduction to anisotropy.
5. **Source mechanisms**: concept of source mechanism, definition of dip, strike and rake for shear source. Description of shear, tensile, volumetric, CLVD source through moment tensor. Inversion for source mechanisms from single monitoring borehole/ multiple monitoring boreholes/ surface P-only data, class exercise. Picking of data for determination of source mechanisms. Radiation pattern of various source mechanisms. B-value, moment, magnitude, Stress drop, source dimensions.

Presentation and the relevant publications will be available in electronic format.
A Short Course: Strong Ground Motion Hazard

Wednesday 07 May, 14h00 - 18h00, Asara Wine Estate, Stellenbosch

Course Instructors
Dr Aleksander Mendecki, Head of Research at IMS
Dr Ernest Lötter, Head of Computational Seismology at IMS

1. Seismic Hazard – Definitions and Objectives
2. Size Distribution Hazard
   2.1 Power law distribution in time and in volume mined domain.
   2.2 The physics of the exponent and its interpretation: inhomogeneities, stress, stiffness, Shannon entropy, stress transfer, $\log E$ vs $\log P$, apparent stress.
   2.3 Probabilistic description.
   2.4 Largest possible event, $m_{\text{max}}$ and the next records breaking event.
   2.5 Limitations of size distribution hazard.
3. Ground Motion Characteristics and Ground Motion Hazard
   3.1 Near source ground motion, peak ground velocity ($PGV$), acceleration ($PGA$), displacement ($PGD$), duration: bracketed, uniform and significant duration of GM, Arias intensity, Cumulative Absolute Velocity ($CAV$), Cumulative Absolute Displacement ($CAD$), Husid plots.
   3.2 Scaling of ground motion.
   3.3 Ground motion prediction equation (GMPE), its interpretation.
   3.4 Volume of strong ground motion ($V_{SGM}$) and its applications.
   3.5 Site effects.
4. Deterministic Hazard
   4.1 Finite-Difference 3D kinematic modelling of strong ground motion in the presence of underground excavations.
   4.1.1 Point sources in heterogeneous media.
   4.1.2 Extended complex sources in heterogeneous media.
   4.2 Directivity and super shear.
   4.3 Limitations.

Presentation and the relevant publications will be available in electronic format.

Thursday 08 May, 09h00 - 13h00, IMS Offices, Stellenbosch

A Short Course on Modelling with Seismic Data

Course Instructors
Dr Dmitriy Malovichko, Head of Applied Seismology at IMS
Dr Gerrie van Aswegen, Senior Consultant at IMS
Jacques Gerber, Numerical Modelling Consultant at IMS

1. Forensic analysis of rockbursts and large seismic events
   1.1 Modelling of source parameters and source mechanisms.
   1.2 Testing of sources.
2. Validation of numerical stress model by seismic data
   2.1 Absolute and differential stresses vs location and source parameters of events.
2.2 Differential maps.
2.3 Stress orientation vs seismic source mechanisms.

**3. Improvement of numerical stress models**
3.1 ‘Trial and error’ model calibration.
3.2 Stress inversion.
3.3 Adaptive adjustment of the boundary-element model.

**4. Modelling and assimilation of seismicity**
4.1 Simulation of seismicity using Salamon-Linkov approach.
4.2 Incorporation of seismicity into the boundary-element model.

Presentation and the relevant publications will be available in electronic format.

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**Thursday 08 May, 14h00 - 18h00, IMS Offices, Stellenbosch**

**A Course Monitoring Seismicity & System Performance with Ticker3D and Seismic Visualisation and Analysis with IMS-Vantage**

**Course Instructors**
- **Dr Dmitriy Malovichko**, Head of Applied Seismology at IMS
- **Dr Ernest Lötter**, Head of Computational Seismology at IMS
- **Dr Daryl Rebuli**, Head of Mine Seismology at IMS

1. **Ticker3D (14h00 - 15h30)**
   - 1.1 Initial Configuration
   - 1.2 Viewing recent seismicity.
   - 1.3 System Health and Management.

2. **Vantage Visualisation**
   - 2.1 Interacting with the 3D viewer.
   - 2.2 Loading and customising mine plans.
   - 2.3 Loading seismic data from IMS Database Server.
   - 2.4 Colouring and sizing of events.
   - 2.5 Parameter, temporal and spatial filtering of the data.
   - 2.6 Displaying source mechanisms.

3. **Vantage Analysis**
   - 3.1 Analysis in temporal, spatial and parameter domains.
     - 3.1.1 Time histories.
     - 3.1.2 Contours (event parameter gridding onto meshes).
     - 3.1.3 Energy-potency or energy-moment plots.
     - 3.1.4 Rank statistics of ground motions.
   - 3.2 Event size distribution: open-ended and upper-truncated models, maximum size of event, probability table
   - 3.3 Source mechanisms: stereo-net of principals axes, nodal planes and poles, Hudson's source type plot, Frohlich's ternary graph.

Attendees that bring a modern laptop will receive a license for IMS Vantage with which to perform hands-on tasks during training and gain experience. Presentation used during the course and the relevant publications will be available in PDF format. Note that in order to run IMS Vantage, we strongly recommend a machine with at least 4GB of RAM and a modern 3D graphics card (NVidia or AMD) with up to date drivers installed.
Friday 09 May, 09h00 - 13h00, IMS Offices, Stellenbosch
A Short Course on Seismological Processing with *IMS-Trace*

**Course Instructors**
**Dr Ernest Lötter**, Head of Computational Seismology at IMS  
**Dr Daryl Rebuli**, Head of Mine Seismology at IMS

1. **Location Primer**  
1.1 P- and S-wave arrival picks.  
1.2 Polarisation analysis.  
1.3 Locating seismic events: absolute, relative or with ray tracing.  
1.4 Marking events as accepted, rejected or blasts.  
1.5 Travel time processing.

2. **Source Parameter Primer**  
2.1 Basic source parameters: seismic energy, seismic potency and moment, magnitude.  
2.2 Derivative source parameters: apparent stress, energy index, apparent volume.  
2.3 Source spectra.  
2.4 How to improve source parameter estimates.  
2.5 Mechanisms of seismic events.  
2.5.1 Decomposition plots.  
2.5.2 Hudson diagram.  
2.6 Dealing with noisy data.

3. **Velocity Structure**  
3.1 Velocity calibration.  
3.2 Wadati diagrams.  
3.3 How to build a 3D velocity model.

4. **Alternative Ways to Browse Seismic Data**  
4.1 Exporting information from the database.  
4.2 Parameter filters.  
4.3 Automatic queries.  
4.4 Exporting seismograms.

5. **User Management**  
5.1 Plugin installation.  
5.2. Viewing events in 3D.  
5.3 Integration with *IMS-Vantage*.

Attendees that will bring a modern laptop will receive a license for *IMS-Trace* with which to perform hands-on tasks during training and gain experience. Presentation used during the course and the relevant publications will be available in pdf format.