ISMS 2016

3RD INTERNATIONAL SYMPOSIUM ON MINE SAFETY, SCIENCE AND ENGINEERING

Operational and Environmental Mine Health and Safety Practice and Innovation

Symposium Program | Abstracts

August 13-19, 2016

McGill University, New Residence Hall, Montreal, CANADA

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GREETINGS

Dear Symposium Delegate

As General Chair, I am delighted to welcome you to the 3rd International Symposium on Mine Safety Science and Engineering (ISMS). I am particularly pleased that this symposium is being organized jointly with our partners, namely the University of Science and Technology Beijing (USTB), China University of Mining and Technology Beijing (CUMTB) and Henan Polytechnic University (HPU). This partnership resulted in a large number of technical papers, presentations and keynote lectures, covering a wide range of topics in many different fields and aspects of mine safety. Indeed, this marks the hallmark of the mining profession. ISMS 2016 promises to be one of the most international meetings of the year, with 76 technical presentations being delivered by delegates from more than 12 countries in Asia, Australia, Europe and North America. I know it will be a difficult task for you to choose between the presentations in the parallel sessions of the technical program.

The decision to publish the papers of this symposium into a set of refereeable online proceedings has been one that demanded much of the time of the members of the International Advisory Committee. It is thanks to their continuous support and patience that we now have a set of quality proceedings of more than 100 papers.

But ISMS 2016 is more than just excellent presentations and posters. The exchange, both technical and social, between the delegates from academia, industry, government, consulting, suppliers and manufacturers of mining products is equally important. I invite you to take advantage of this unique learning and networking opportunity.

I would like to thank the International Chairs Professor Xueqiu HE from USTB and Professor & President Xiaolin YANG of HPU for the dedicated support they provided to this symposium. I would also like to thank all members of the Technical Program Committee especially the Co-Chairs Professor Beisheng Nie from CUMTB and Professor Mustafa Kumral from McGill. Special thanks are due to Dr. Shahe Shnorhokian, ISMS Secretary and his counterparts from China Dr. Li, Dr. Gao and Dr. Chen. Many thanks to all those who helped on the local organizing committee. This event would not be the same without the incredible support of these people.

In closing, I thank you for joining us, and wish you an enjoyable time at the symposium, meeting old colleagues and making new friends. And don't forget to explore and enjoy the great city of Montreal.

Hani Mitri
General Chair, ISMS 2016

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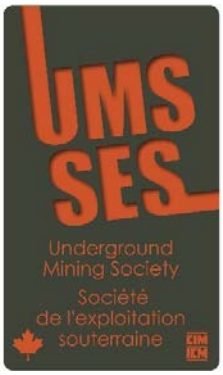

The CIM Underground Mining Society (UMS) was founded in 2011. The UMS exists to assist and promote the continued growth of mining in Canada by 1) Promoting and facilitating the exchange of information and data on all subjects related to the mining industry, 2) Educating the public on the many aspects of the mining industry, and 3) Promoting mining as a positive, growing and dynamic industry with many exciting opportunities. The goal of the UMS is to evolve in response to the needs of industry and the interest of its members

http://cim.org

Slope monitoring in the surface mining industry has become routine practice, supporting mining staff in geotechnical risk management. Interferometric radar technology, embedded in the IBIS solution, has emerged as a leading tool for this purpose. The success of IDS slope monitoring radar is attributed to its ability to rapidly measure slope movements with sub-millimeter accuracy over wide areas. IDS North America is the leading high-tech solution provider in radar technology for slope stability monitoring and blast vibration monitoring. IDS provides customized solutions to clients around the world in order to optimize mine safety through slope movement awareness even before displacement interferes with mining operations. Multi-scale monitoring provides for critical and long term monitoring and early detection of slow movements

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CALENDAR OF EVENTS

Saturday August 13: Registration from 1:00 to 5:00 pm at the New Residence Hall

Sunday August 14: Registration from 8:00 am to 7:00 pm at the New Residence Hall

Sunday August 14: Workshop: Auxiliary Ventilation from 8:30 am to 4:30 pm – New Residence Hall

Sunday August 14: Tradeshow from 5:00 to 7:00 pm

Sunday August 14: Ice-Breaker cocktail from 5:00 to 7:00 pm

Monday August 15: Registration from 7:30 am to 5:00 pm

Monday August 15: Plenary Session: “Operational and Environmental Mine Health and Safety Practice and Innovation” from 8:30 to 10:00 am

Monday August 15: Tradeshow from 10:00 am to 7:00 pm

Monday August 15: Exhibitors’ Meet & Greet from 5:00 to 7:00 pm

Tuesday August 16: Registration from 8:00 am to 1:30 pm

Tuesday August 16: Plenary Session: “Innovations in Mine Safety” from 8:30 to 10:00 am

Tuesday August 16: Tradeshow from 10:00 am to 3:30 pm

Tuesday August 16: Symposium Banquet from 7:00 to 10:00 pm

Wednesday August 17: Registration from 8:00 to 10:00 am

Thursday August 18: Field trip. Departure at 9:30 am from New Residence Hall

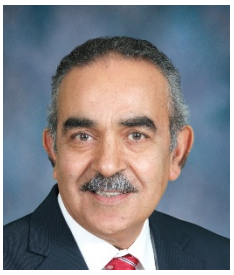
Friday August 19: Arrival from the field trip around 9:00 pm

Plenary Session "Operational and Environmental Mine Health and Safety Practice and Innovation"

Monday August 15, 2016

8:30 am **Safety share**
Shahe Shnorhokian – Symposium Secretary
McGill University, Montreal, Canada

8:40 am **Welcome**
Hani Mitri – General Chair
McGill University, Montreal, Canada



8:50 am **Keynote address - I**
Xueqiu HE, International Chair
University of Science and Technology in Beijing, China

9:05 am **Keynote address - II**
Xiaolin YANG, International Chair
Henan Polytechnic University, Henan, China

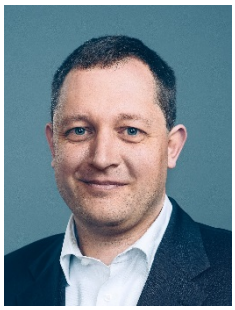
9:15 am **Working together for a sustainable future**

Speaker: Christian Provencher
Vice President, Canada
Agnico-Eagle Mines Limited
Toronto, Ontario, Canada

Over the past decade, Agnico Eagle Mines has had to adapt to a rapid growth in production and international expansion projects. To meet these challenges, the company has successfully developed and implemented a new management system integrating health, safety, environment and community relations. The success of the new system stems from the fact that the company entrusted its own people to use their expertise to quickly help roll out a development plan while allowing for continuous adjustment and self improvement. This keynote presentation will highlight the features of the new Agnico Eagle Mines' management system and the improvements made to continue to strive for excellence for the well-being of the company employees and local communities.

9:40 am **Toward interdependence in occupational health and safety**

Speaker: Tanguy Paquot
Director, Occupational Health and Safety
Quebec Mining Association
Quebec, Quebec, Canada



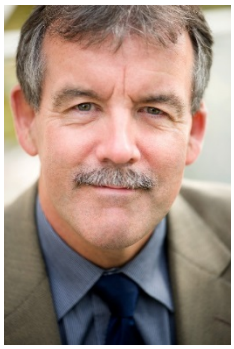
The Quebec Mining Association is developing a new and innovative approach for the reduction of accident rates in the mining industry. The new approach is based on analyzing the employee's behaviour through positive deviant analytical model. This model aims to stimulate employee worries and concerns about others while highlighting their good and positive behavior or methods of work. The goal is to create synergy and a new corporate culture in which zero accidents is not only attainable, but also achievable in the long run.

Plenary Session “Innovations in Mine Safety”

Tuesday August 16, 2016

8:30 am **Safety share and welcome**

Chair: **Damien Duff**
Vice President Geoscience and Geotechnical R&D
Centre for Excellence in Mining Innovation (CEMI)
Sudbury, Ontario, Canada



8:40 am **Canopy for Safety and Productivity**

Speaker: **Douglas Morrison,**
President & CEO
Centre for Excellence in Mining Innovation (CEMI)
Sudbury, Ontario, Canada

Safety is the primary care in all underground operations and especially important in new development headings in high-stress conditions. New bolting systems and in-cycle shotcrete have made things safer under conditions of surface strain-bursting, but they have also contributed to the decline of advance rates. As some mines began to experience bursting from the face, CEMI decided to develop the long-discussed canopy option that would provide a physical barrier to the hazards at the face and make it possible to increase advances rates significantly. The first operational version is now ready for use and the various applications of an individual canopy or a combination of three canopies will be described. Event simulation results show the current productivity gains as well as the possible gains with additional technologies.

9:05 am **Hydraulic Pre-conditioning of Highly Stressed Rock Masses**

Speaker: Pierrick Altwegg

Senior Researcher in Geomechanics
Mirarco, Mining innovation
Laurentian University, Sudbury, Ontario, Canada

Nowadays, ore extraction is carried out at increasingly greater depths below surface, thus posing the challenge of mining in highly stressed rock masses. This significantly increases the geotechnical hazard associated with seismicity and rockbursts, resulting potentially in equipment damage, injuries and even fatalities. This is especially true for ultra-deep mines, i.e., greater than 2500 m in depth. Thus, there is a pressing need to develop safe and cost-effective solutions to deal with highly stressed rock masses in order to mitigate such risks. This project aims to assess if one can effectively fracture the rock mass by means of hydraulic preconditioning, in an effort to reduce mining-induced seismicity, thus resulting in a safer and more productive workplace. Studies are underway to examine the possibility of integrating hydraulic preconditioning with the planned mining sequence. This project is funded under one of the strategic themes of the Ultra-Deep Mining Network (UDMN) in Canada.

9:30 am **Underground Mine Location Intelligence System - A tool for mine safety**

Speaker: Michel Serres

Manager, Mining Solutions ABB North America
Montreal, Quebec, Canada

The Underground Mine Location Intelligence System by ABB has been developed to combine 3D representation of data down into the mine and to correlate information available within the overall mine automation system. Over the past years, wireless communication development gave opportunities to bring information from underground to surface and vice versa, with people and machines. The correlation and usage of data remain a challenge for mining companies. A focus of the Mine Location Intelligence System is mine safety. If communication from surface into the mine is now possible, the treatment of real time information is capitals for safety aspects. As tracking of people and mobile equipment is possible, other aspects like air quality, blasting schedule, geo-fencing, traffic management, and critical situations like fire alarms can be controlled by where people and mobile equipment are located.

PROGRAM AT A GLANCE

MONDAY AUGUST 15, 2016

TIME	SESSION	ROOM A	SESSION	ROOM B
8:30	PLENARY: "Operational and Environmental Mine Health and Safety Practice and Innovation" S. Shnorhokian, H. Mitri, X. He, X. Yang, C. Provencher, T. Paquot			
10:00	MORNING COFFEE BREAK			
10:30	A-1 Seismicity and Rockburst I J-M. Galera	**Keynote: Seismic Risk Management at Agnico Eagle's Laronde Mine - P. Morissette (Canada)**	B-1 Mining Equipment Safety P. Cain and M. Tato Diogo	**Keynote: Integrated Surface Mining Safety System - V. Kecojevic (USA)**
		b-value as a criterion for evaluation of the rockburst hazard in coal mines - G. Mutke (Poland)		Electrical equipment certification in Canadian underground coal mines – problem solved? - P. Cain (Canada)
		Quantitative evaluation of stope damage induced by seismic waves - A. Sainoki (Canada)		Analysis of slag debris flow initiation based on laboratory tests of slag - H. Zeng (China)
		Influence of weak places on rockburst occurrence - A. Manouchehrian (Canada)		Improving shovel safety using SAFEmine's situational awareness technology - M. de Werk (Canada)
12:00	MONDAY LUNCH			
13:30	A-2 Seismicity and Rockburst - II P. Konicek and A. Sainoki	Rockburst experiences in Cheves hydropower project, PERÚ, JM Galera (Spain)	B-2 Behavioral Safety and Human Perception R. Mitra and M. De Werk	Risk management in the mining sector through complex systems - M.T. Diogo (Portugal)
		Lucky Friday No. 4 Shaft - Challenges and Possibilities - D. Berberick (USA)		Risk acceptance and risk perception of the Soma underground coal mine disaster - E. Yaylaci (Turkey)
		Rockburst mitigation experiences on underground projects in the Cheves Hydropower project in the Peruvian Andes - JM Galera (Spain)		From operational hazards to organizational weaknesses: changing the focus for improvement - M. Kumral (Canada)
		TBA		Application of Cognitive Task Analysis in Mining Operations - E. Abou-Jaoude (Canada)
15:00	AFTERNOON COFFEE BREAK			
15:30	A-3 Dynamic Supports and Destress Blasting S. Prusek	**Keyonte: Destress blasting on the border of safety pillars - P. Konicek (Czech Republic)**	B-3 Safety and Risk Management Tools S. Duzgun and V. Pakalnis	**Keynote: Hydrogeological challenges and strategies at McArthur River Operation - X. Yun (Canada)**
		Powered support selection for longwall workings in dynamic load conditions - S. Prusek (Poland)		Avoiding Workplace Accidents: The Importance of Pre-Job Safety Analyses - C. Morrish (Canada)
		Evolution of grouting methods for dynamic supports in broken ground - F. Charette (Canada)		Notification Systems and Risk Management - J.S. Gois (Portugal)
17:00		Large Scale Panel Destress Blasting parametric study - I. Vennes (Canada)		Full-scale fire experiments in an underground mine - R. Hansen (Sweden)

MONDAY EXHIBITORS' MEET AND GREET (17:00 - 19:00)

TUESDAY AUGUST 16, 2016				
TIME	**SESSION**	**ROOM A**	**SESSION**	**ROOM B**
8:30	**PLENARY: "Innovations in Mine Safety " D. Duff, D. Morrison, P. Altwegg, M. Serres**			
10:00	**MORNING COFFEE BREAK**			
10:30	**A-4 Ground Control Safety F. Laouafa**	Improving Ground Control Safety in Deep Vein Mines - J. Seymour (USA)	**B-4 Occupational Health and Safety - Tailings Dams Safety M. Scoble and M. Kumral**	Evaluation and implementation of DPF technologies in hard rock mines- J. Stachulak (Canada)
		Numerical investigation of EDZ development around a deep polymetallic mine - M. Souley (France)		Diesel exhaust exposures in an underground mine - G. Lachapelle (Canada)
		Dynamic Fracture Propagation in Rock - J. Nemcik (Australia)		Liquid-solid coupling analysis of tailings dam in complex engineering condition - S. Wang (China)
		Overview of how ground control departments use microseismic systems and other monitoring technology at underground mining operations - I. Leslie (Canada)		Numerical analysis of Westwood Mine tailings embankment stability during the restoration phase - Y. Coulibaly (Canada)
12:00	**TUESDAY LUNCH**			
13:30	**A-5 Pillar and Backfill Stability in Underground Mines M. Cai**	**Keynote: Numerical modelling of time-dependent skin degradation of an isolated pillar - A. Sainoki (Canada)**	**B-5 Advances in Operational Mine Safety R. Hansen and V. Kecojevic**	Keeping the bar high on personnel safety - S. Bowles (Canada)
		Analysis of haulage drift instability in hard rock mines with numerical modelling - S. Shnorhokian (Canada)		Application of an economy comparison model for mine cooling system technology - D. Miao (China)
		Minimum strength required for resisting cyclic softening/failure of cemented paste backfill at early age - T. Belem (Canada)		The strength properties of fibre glass dowels used for ground control in coal mines - A. Mirzaghorbanali (Australia)
		Analysis of failure in a salt room and pillar mine - F. Laouafa (France)		Operating conditions of a mine fan under conditions of variable resistance - Y.H. Zhang (China)
15:00	**AFTERNOON COFFEE BREAK**			
15:30	**A-6 Rock slope stability J-I. Kodama**	Lessons in slope stability management from Kinross' Tasiast mine, Mauritania - K. Tasoren (Mauritania)	**B-6 Ventilation E. De Souza and M. Liu**	**Keynote: Application of a ventilation management program for improved air quality - E. de Souza (Canada)**
		Effect of buttress on reduction of rock slope sliding along geological boundary - R. Moriya (Japan)		Reducing Heat Stress Exposures in Mines - R. Anderson (Canada)
		Assessment of empirical slope stability methods using road-cut case studies in southern Saudi Arabia - H. Basahel (Canada)		Numerical study of simultaneous methane and coal dust dispersion in a room-and-pillar mining face - A. Sasmito (Canada)
17:00		Which slope monitoring technology is best suited for my open pit mine operation: How to reduce risk & protect people while ensuring continued production - S. Behanish (USA)		Numerical research on the air flow structure of the ventilation in mine tunnels - C. Ding (China)
SYMPOSIUM BANQUET (19:00 - 22:00)				

WEDNESDAY AUGUST 17, 2016				
TIME	**SESSION**	**ROOM A**	**SESSION**	**ROOM B**
8:30	**A-7** **Slope stability and Ground Subsidence** **J. Ran and T. Belem**	**Keynote: Application of InSAR for Monitoring Deformations at the Kiirunavaara Mine - J. Sjoberg (Sweden)**	**B-7** **Coal and Gas** **A. Sasmito and Y. Zhang**	**Keynote: Development and realization of coal and gas outburst simulation device - B. Nie (China)**
		Achieving Zero Harm at Iron Ore Company of Canada - R. Saunders (Canada)		Mathematical model for gas diffusion from non-homogeneous coal particles - Y. Liu (China)
		Modeling the Impact of Particle Flow on Rigid Structures: Experimental and Numerical Investigations - G. Gao (Canada)		Numerical modeling and rescaled range analysis on spontaneous combustion under surface methane drainage in a Chinese coal mine - S. Yang (China)
		A versatile model for the evaluation of subsidence hazards above underground extractions- P. Cain (Canada)		Temperature Variation of Coal during the Gas Adsorption Process - T. Yang (China)
10:00	**MORNING COFFEE BREAK**			
10:30	**A-8** **Underground Mines Safety** **J-P. Tshibangu**	Thermomechanical impact of Underground Coal Gasification exploitation - F. Laouafa (France)	**B-8** **Coal Mine Ground Control** **N. Aziz and B. Nie**	**Keynote: Application of the strength reduction method in coal mine roof support design - G. Esterhuizen (USA)**
		Escapeway solutions - A. Deadman (Australia)		Numerical modeling of the goaf: methodology and application - S. Ahmed (France)
		Estimating stope vein footwall stability using various constitutive Models - A. Pyon (Canada)		Effects of immediate roof thickness on lower sub key strata movement in ends of large mining height panel - C. Liu (China)
		Drilling escape and rescue system in Wangjialing coal mine - N. Gao (China)		Numerical Simulation Technique for Gateroad Stability Analysis in Fractured Ground Condition - L. Jiang (China)
12:00	**WEDNESDAY LUNCH**			
13:30	**A-9** **Mining Geotechnique and Safety Management** **J. Nemcik**	Redesigning the geometry of the Makala Coal Mine to improve safety and productivity - J.P. Tshibangu (Belgium)	**B-9** **Innovations in Rock Supports** **F. Charette**	**Keynote: Behaviour of cable bolts in shear: experiment and mathematical modelling - N. Aziz (Australia)**
		SHEAR BEHAVIOUR OF REGULAR AND IRREGULAR ROCK JOINTS UNDER CYCLIC CONDITION - M. Niktabar (India)		The tensile properties of GFRP bars at different loading rates - W. Chen (China)
		Study on the performances of a protective door in coal permanent refuge havens - N. Gao (China)		A recent advance in ultrasonic monitoring of rockbolt conditions - Z. Sun (Canada)
15:00		Safety Management - Cornerstone of Continuous Improvement Process - B. Chanda (Canada)		Characteristics of acoustic wave velocity variation in the process of deformation and failure of loading coal - X. Li (China)

Monday August 15, 2016

Session A-1: Seismicity and Rockburst - I

Time: 10:30 to 12:00 am

Keynote: [PPT] Seismic Risk Management at Agnico Eagle's Laronde Mine - P. Morissette (Canada)

Agnico Eagle's LaRonde Mine is exploiting a world class Au-Ag-Cu-Zn massive sulphide lenses complex. The mine is located in the Abitibi region of Quebec, about 650 km northwest of Montreal. LaRonde is one of the largest gold deposits amongst operating Canadian mines with proven and probable reserves exceeding 4M oz. The mine reserves extend down to 3,110 m below ground surface and the orebody remains open at depth. LaRonde's ore production is approximately 6,025 tonnes per day, with open stopes being currently exploited down to 2,960 m below surface. Seismicity is a direct consequence of mining at great depth. At LaRonde Mine, seismic activity has been recorded since 2004. Over time, some seismic events have resulted in damage to mine excavations and ground support but none have resulted in personnel injury. This presentation reports on the efforts undertaken by the ground control team in order to manage the seismic risk and minimize the personnel exposure to seismicity and rockbursts at LaRonde Mine. The pro-active strategy employed at LaRonde Mine involves seismic data analyses, implementation of new ground support systems and ground support installation methods, and inspection of active workplaces for quality control and quality assurance.

[146] b-value as a criterion for evaluation of the rockburst hazard in coal mines - G. Mutke, A. Pierzyna & A. Baranski (Poland)

Every year, a few rockbursts with fatalities and several hundred meters of damaged excavations have occurred in the mines of the Upper Silesia Coal Basin (USCB) in Poland. This paper presents a method for assessing the levels of seismic and rockburst hazards, using continuous seismological observation in the Bobrek coal mine. This assessment is based on the study of the Gutenberg-Richter (G-R) relation for current and past mining in the coal field. According to many laboratory and field studies, the ***b***-value may be an indicator of fluctuations in stress levels, e.g., Scholz, 1968; Gibowicz, 1974, 1979, and the consequent seismic hazard. The novelty of the presented research is the development of a quantitative criterion based on ***b***-value changes, calculated in moving time windows with a 1-day step, and the anomalies resulting from the comparisons of the temporal values of ***b*** with its average value for the past seismicity in the field of coal mining; $A_{G\text{-}R}=[(b_m - b)/b_m]\cdot 100\%$ (where b_m is the average value of ***b*** for the field of coal mining and b is the temporal value of coefficient ***b***, calculated in time windows). This approach allows us to standardize the criterion to the current values of ***b*** in the investigated area (Table 1). In many measurement examples, high values of the temporal anomaly $A_{G\text{-}R}$ and at the same time downwardly trending and low ***b***-values before the occurrence of strong mining seismic events were documented in this paper and in studies by Pierzyna, 2014. Particularly interesting results were obtained from mining and geological conditions that led to the formation of local zones of stress concentration, e.g., Dubiński, 1989, and increases in seismic activity and seismic hazard. The ***b***-value criterion is in agreement with the four basic levels of rockburst hazard used in Polish coal mines, e.g., Mutke et al., 2015.

[180] Quantitative evaluation of stope damage induced by seismic waves - A. Sainoki & H. Mitri (Canada)

In the present study, a methodology to evaluate damage around underground opening due to seismic waves arising from mining-induced fault-slip is proposed. First, expressions for an associated flow rule with a failure criterion developed for biaxial stress conditions are derived, which are newly implemented into FLAC3D code. With the code, stope extraction is simulated, using a 3D mine-wide model encompassing a fault running parallel to a steeply dipping orebody. The failure criterion for biaxial stress conditions is applied to only the rockmass in the vicinity of stopes within the hanging wall. After extracting stopes in the orebody, mining-induced fault-slip is simulated in dynamic conditions, considering its trigger mechanism, i.e., stress drop caused by instantaneous shearing of fault surface asperities, using Barton's shear strength model. Damage to the rockmass caused by seismic waves is then evaluated with the increase in plastic strain. The proposed methodology takes into account the mechanism of mining-induced fault-slip, propagation of seismic waves, biaxial stress conditions on the surface of openings, and plastic strain as damage criterion.

[176] Influence of weak planes on rockburst occurrence - A. Manouchehrian & M. Cai (Canada)
Geological structures such as faults, joints, and dykes have been observed near excavation boundaries in many rockburst case histories. In this paper, the role of weak planes around tunnels in rockburst occurrence was studied. The Abaqus-Explicit code was used to simulate dynamic rock failure in deep tunnels. Firstly, the tool's usefulness for modeling geomaterials was improved by introducing material heterogeneity using Python scripting. The modeling results showed that heterogeneous models resulted in more realistic failure modes than homogeneous models. Secondly, rock failure near the excavation boundary of a tunnel without any adjacent geological structure was modeled and released kinetic energy from rock due to failure and velocity of failed elements at the tunnel wall were calculated. Then, a weak plane was added to the model. This resulted in more released kinetic energy and higher element velocity, indicating that rock failure became more violent in the models with weak planes. The modeling results confirm that the presence of geological structures in the vicinity of deep excavations is a necessary condition for the occurrence of rockburst. It can be used to explain localized rockburst occurrence in civil tunnels and mining drifts. The presented methodology in this paper for rockburst analysis can be useful for rockburst anticipation and control during mining and tunneling in highly stressed grounds.

Session B-1: Mining Equipment Safety

Time: 10:30 to 12:00 am

Keynote: [PPT] Integrated Surface Mining Safety System - V. Kecojevic, V. Kulathumani, A. Nimbarte, R. Kavi, R. Shashank Sabniveesu, A. Kavuri & M. Nakagawa (USA)

The objective of this research project is to develop and deploy an integrated safety system to help reduce equipment-related fatal and non-fatal injuries in surface mining operations. Specific aims were to (i) design a large-scale sensor network system geared towards surface mining safety; (ii) establish infrastructure communication platform and information management system for real-time situational awareness; (iii) provide a non-distractive user interface for equipment operators/drivers. The outcomes of this research project include: Collision avoidance using GPS + wi-fi based system in an ad-hoc mode (> 10m), and IEEE 802.15.4 radio based RF proximity warning system (< 10m). It also includes User interface, e.g. Unified GUI for collision avoidance with dynamic updating, and an automated user-interface evaluation based on Computer Vision. Other outcomes of this research are: Map-my-truck app for long term collision safety evaluation, Speed dependent logger for tracks of haul trucks, and Trucks visualization which can be used to analyze near misses. Fatigue monitoring was also examined using off the shelf lightweight EEG sensor based fatigue monitoring. The developed system has been tested in two operating surface mines in southern United States.

[208] Electrical equipment certification in Canadian underground coal mines – problem solved? - R. F. King & P. Cain (Canada)
Certification of electrical equipment for underground coal mines in Canada is problematic. EX protected electrical distribution equipment to Group 1 standards is not manufactured in Canada, and even if it were, there is no facility in Canada that is accredited to certify it. The Canadian Federal laboratories previously tasked with the job are now closed. Provincial regulations require certification by either a now-defunct facility or by the US authorities (MSHA). Unfortunately, the underground coal legislation in the US is significantly at odds with Canadian Provincial legislation and equipment approval requirements, which presents problems with equipment certified there. Although the underground coal mining industry in Canada is small, the western Provinces are blessed with substantial resources of high quality steel-making coal, much of which can only be accessed by underground mines. There are perhaps half a dozen large underground projects awaiting a price revival in Alberta and British Columbia, and it was the authors' experience at one of these projects that led to this paper. The project in question was owned by a Chinese company that wanted to use Chinese electrical distribution equipment certified in China to IEC equivalent standards. The process of convincing the Provincial regulators that the Chinese equipment was safer than the equipment that would be allowed under Canadian standards was arduous, but ultimately successful. The next step was to seek changes in the Canadian electrical standard applicable to mines so that the benefits could be felt across the country. This has recently also been accomplished.

This paper examines the problem through an important aspect of electrical safety in underground coal mines - protection against electric shock and arcing. It compares the requirements of the Canadian legislation, US, and UK legislation and IEC standards used by other countries. It concludes that the levels of safety against shock and arcing afforded by IEC-certified multi-point systems can be orders of magnitude better than the single point systems mandated or traditionally used in Canada. Additionally, multi-point systems may be better suited to protect high voltage equipment beginning to be deployed in large open pits than the current Canadian protection standards. The recommendations arising for changes to Canadian standards await ratification, and the authors are hopeful that they will be adopted by Provincial regulators as soon as practicable.

[132] Analysis of slag debris flow initiation based on laboratory tests of slag - H. Zeng & H. Yu (China)
Accumulated slags and waste in mines are major physical resources for slag debris flow, which are potentially major disasters that threaten mine safety. Initiated by heavy rain, slag debris flow has happened in Ganjiang gully around Luanchuan county, China. Studies have been carried out to further understand the formation and initiation mechanism of slag debris flows. Slag samples with different fines content were collected from the gully and the slag strength and permeability were investigated by direct shear tests and by falling head permeability tests, respectively. The results indicate that the fines content has a significant impact on both the strength and permeability characteristics of slags. With the fines content increasing, both the strength and the hydraulic conductivity of the slag decrease. The strength of saturated slag samples is extremely weak, meaning that water will easily soften the slag. In addition, as the fines content increases, the hydraulic conductivity would decrease at an accelerated rate, down to a very small constant. Based on the current investigation, it can be concluded that two different types of slag debris flow would form in the specific conditions: shallow debris flows are mainly dominated by surface erosion, while deep debris flows are dominated by bottom tearing and suffusion erosion.

[164] Improving shovel safety using SAFEmine's situational awareness technology - M. de Werk & T. Ruff (Canada)
Mining operations involve risks that can be controlled through engineering and process control. The human factor however, is extremely difficult to quantify and control. Best practices, proper rest, and a good work/life balance contribute to safer operating conditions, but there is no way of predicting when an employee has had a bad day. Impacts of external stressors that are beyond the control of the employer can be minimized by implementing safety technology such as Hexagon Mining's SAFEmine collision avoidance system. Technology is another layer of protection, but it does not give the desired outcome without proper implementation, business processes, and continuous effort to improve. Aecon has successfully completed a pilot project with the SAFEmine system and has committed to operating a 5500 shovel and supporting dozer with the system. This paper aims to outline the process and results obtained during the pilot project.

Session A-2: Seismicity and Rockburst - II

Time: 13:30 to 15:00 am

[157] Rockburst experiences in Cheves hydropower project, PERÚ – S. Veyrat, J.M. Galera, M. Sancho, H. Andersson, W. Thoese & C. Rietschel (Spain)
Cheves Hydropower Project is located in Peru and consists in more than 20 km of tunnels and two caverns. Most of the Headrace tunnel has been excavated in igneous and metamorphic rocks with high overburden reaching 1400 m. A high number of stress release events took place during the excavation of the tunnels and caverns. The intensity of these events varies from acoustic emissions to a violent rockbursts. The paper describes the methodology developed to mitigate the rockburst hazard.

[PPT] Lucky Friday No. 4 Shaft – Challenges and Possibilities (Hecla Limited) – D. Berberick (USA)
Hecla Mining Company celebrates its 125th anniversary in 2016. Achieving this longevity has required persistence, adaptation and innovation to thrive through changing market and world conditions. This same year the company will complete the largest capital project in its history; the No. 4 shaft at the Lucky Friday Mine located in Mullan, Idaho. The shaft has been excavated to a depth of 9,589 feet below surface. The project has overcome numerous engineering and technical challenges including depth induced ground pressure, squeezing ground conditions, high rock temperatures, and complex supply chain logistics. The challenging ground conditions were addressed by changing the design of the shaft excavation starting at the 7650 mine level to an elliptical cross section based on the overall stress field orientation as well as the orientation of the structure of the

host rock surrounding the shaft. Once complete the project will position the mine to access over 78 million ounces of silver reserves; nearly half of that mined in the 73-year history of the Lucky Friday Mine.

[156] Rockburst mitigation experiences on underground projects in the Cheves Hydropower project in the Peruvian Andes –S. Veyrat, J.M. Galera & M. Sancho (Spain)

The main problems related with the design and construction of tunnels and caverns under high overburden are analyzed in this paper. As an example, the recent experiences during the construction of the Cheves Hydropower project in the Peruvian Central Andes are described. During its construction, 850 rockburst events were recorded, enabling designers to collect data and make some correlations that may be useful for future projects.

Session B-2: Behavioral Safety and Human Perception

Time: 13:30 to 15:00 am

[141] Risk management in the mining sector through complex systems - A.L.F. Baptista & M.S.Q. Domingues & M.T. Diogo (Portugal)

There is a wide diversity of concepts related to complexity. What the Santa Fe Institute (USA) calls "systemic" corresponds to what Morin (Morin, 2006) calls "complex". Mariotti (2000) outlines the need for a unified terminology. When understanding complexity, it can be perceived as a fabric (what is woven together) of heterogeneous inseparably associated constituents (Morin, 2006). According to different authors, the main drivers of complexity can be found in human behaviour and in uncertainty. This structural of dynamic complexity can be organizational, technological, or nested in human relationships. The complex interrelationship that exists between individuals within an organization or project and its influence on competitiveness can be studied by individual emotional intelligence and organizational behaviour (Love, Edwards, and Wood, 2011). According to ISO 31000:2009, risk management "*refers to a coordinate set of activities and methods that is used to direct an organization and to control the many risks that can affect its ability to achieve objectives*". When concerning any sector, industry, services, project, or activity, the use of models or theories are required as guidelines. Therefore, when its basic elements comprehend human behaviour and/or uncertainty, in order for risk management to be effective and adapted as much as possible to reality, it must be operational within complex systems, as already demonstrated in different R&D environments. Risk management faces particular challenges when approaching more specific needs, such as in the mining sector. The ILO convention (C175, 1995) concerning Safety and Health in Mines, establishes "*that workers have a need for, and a right to, information, training and genuine consultation on and participation in the preparation and implementation of safety and health measures concerning the hazards and risks they face in the mining industry*", and furthermore recognizes "*that it is desirable to prevent any fatalities, injuries or ill health affecting workers or members of the public, or damage to the environment arising from mining operations*". In this context, risk assessment of integrated operations can be improved by complex risk models and dynamic environments (Grøtan, Størseth and Albrechtsen, 2011). Hence, complex systems can provide decision makers with a supporting tool comprising a three axis analysis model. Each of the three axes (X, Y and Z) comprehends a multi-variable linear function f i: X: f_1 (management variables related to mining); Y: f_2 (variables related to risk management systems) and Z: f_3 (variables related to complex systems. Designing, developing, and testing a risk management decision-making model within complex systems, transversal to other hazard sectors of all economic activities, may provide organizations with sustainable and integrated risk management indicators.

[183] Risk acceptance and risk perception of the Soma underground coal mine disaster - H. S. Düzgün & E. Yaylaci (Turkey)

The underground coal mine disaster that occurred in Soma-Eynez Mine (SEM), Turkey, is one of the largest coal mine disasters of this Millennium. A fire suddenly started in the mine and could not be controlled, resulting in 301 fatalities and approximately 100 injuries. Although the cause of the fire has not yet been determined and there are various hypotheses related to the ignition of the fire, most of the casualties were mainly due to decision-making related problems in various hierarchal levels. Moreover, the decision making related problems in the emergency management have cascading effects and impacts on the casualties, and are related to risk acceptance and perception of the mine management. In this paper, the casualties of Soma Mine Disaster (SMD) are analyzed in terms of risk acceptance and risk perception in order to establish related guidelines for better decision-making practice in case of emergencies in underground mines in Turkey. It is found that quite a high degree of risk was accepted for mine fires by the high-level decision makers, which led mine employees to have a false safety perception. This also resulted in almost full ignorance of self-escape, inappropriate use of personal safety

equipment, and unstructured emergency management which yielded large number of mine staff to wait in the mine during the fire instead of a quick implementation of the mine evacuation plan.

[71] From operational hazards to organizational weaknesses: changing the focus for improvement - G. Loiselle, D. Komljenovic & M. Kumral (Canada)

The daily operations in the mining industry are still a significant source of risk with regard to occupational safety and health (OS&H). Various research studies and statistical data world-wide show that the number of serious injuries and fatalities still remains high despite substantial efforts to decrease those numbers put in place by the industry in recent years. This paper argues that the next level of safety performance will have to consider a transition from coping solely with workplace dangers, to a more systemic model taking organizational risks into consideration. In this particular aspect, lessons learned from the nuclear industry may be useful, as organizational learning processes are more universal than the technology in which they are used. With the notable exception of major accidents, organizational performance has not received all the attention it deserves. A key element for reaching the next level of performance is to include organizational factors in low level events analyses, and approach management as a risk control system. These factors will then appear not only in event analysis, but also in supervision activities, audits, change management and the like. Many recent event analyses across various industries have shown that organizational factors play a key role in creating conditions for triggering major accidents (aviation, railway transportation, nuclear industry, oil exploitation, mining etc.). In the following paper, we will present a perspective that may be used in supervisory activities, self-assessments and minor events investigations. When ingrained in an organizational culture, this perspective has the highest potential for continuous safety improvement.

[135] Application of Cognitive Task Analysis in Mining Operations - S. Demir E. Abou-Jaoude & M. Kumral (Canada)

Through the advancement of human-machine interactions in various fields, understanding beyond the technical components has become prominent. Traditional methods for analyzing human behavior in a work setting, which mostly centralize in identifying material and observable traits, don't seem to fit modern technology and systems used in various industries today. The concept of Cognitive Work Analysis (CWA), in this regard, has gained interest in academic and business settings in the last few decades. A cognitive analysis expands the observation of worker's interactions to a more cognitive and behavioural level and sets a safety standard for a well-designed project. This research essentially aims to fully comprehend the five steps of CWA through the examination of cases and finally, seeks possible applications in the mining industry, where accidents due to human error are impactful. In this paper, an initial proposal of a CWA model for the mining industry is developed based on an existing model of quantifying human error in maintenance in various industries.

Session A-3: Dynamic Supports and Destress Blasting

Time: 15:30 to 17:00 am

Keynote: [64] Destress blasting on the border of safety pillars - P. Konicek, J. Ptacek & A. Mazaira (Czech Republic)

Destress blasting used at the border of safety pillars represents a special kind of destress blasting. The main goal of this type of destress blasting is to separate relatively more deformed mining areas from a non-mined safety pillar area such as a shaft pillar or cross-cut pillar, in order to reduce the impact of high stress concentration in areas within the safety pillar. Destress blasting is carried out in rigid, competent rocks adjacent to hardcoal seams 5 m to 6 m thick at depths ranging from 700 m to 1000 m below the surface. Total explosive charge of up to 3450 kg is fired simultaneously in three to seven fan-pattern and line-pattern boreholes drilled from the maingate and the tailgate, when the longwall face approaches to within round 100 m of the safety pillar border. Use of this type of destress blasting from hardcoal longwall mining in the Czech part of the Upper Silesian Coal Basin is described here. Natural and mining conditions are described together with the design parameters of destress blasting, registered seismic activity during longwall mining, and evaluation of the stress relief effect calculated from the monitored seismological data. The present study argues for using this kind of destress blasting as a proactive rockburst prevention method during mining of thick hardcoal seams. Destress blasting can decrease high stress levels and consequently minimize rockburst hazards on the border regions of the safety pillars.

[58] Powered support selection for longwall workings in dynamic load conditions - S. Prusek, S. Rajwa, A. Walentek & W. Masny (Poland)

Currently in Poland hard coal is mined in two Coal Basins namely, Upper Silesian and Lublin. In Poland, there were 30 underground hard coal mines that produced 72.5 million tons of coal in 2014. For underground hard coal (steam coal and coking coal) seam extraction, the longwall method is used. Retreat longwalls with natural roof caving in the gob are the most common. Currently it is estimated that about a half of the hard coal output in Poland originates from seams located in areas of rock burst hazard. In the paper, the most important data concerning the geological and mining conditions in Polish hard coal collieries were presented with particular emphasis on tremors, rock bursts and fatalities. Moreover, the article shows information about seismic events which occurred between 2003 and 2012 in underground mines belonging to one of coal companies in Poland. In addition, negative consequences of those dynamic phenomena in the longwall workings are described. In order to avoid damage of powered supports, in geo-mining conditions where dynamic phenomena occur, different types of protective means are applied. In the paper the methodology of assessing the powered support yield ability is described.

[165] Evolution of grouting methods for dynamic supports in broken ground - F. Charette & T. Skogseth (Canada)

Rockbursts are seismic events of deep or high stress mines that often lead to damages to the ground support system. Even when the rock at the contour of the excavation is broken, rockbursts can occur behind this soften zone and damage the support system further. In these broken conditions, the ductility of the ground support system is still critical, but the installation of grouted tendons is rendered tedious or very inefficient by the problems associated with inserting cartridges of resin inside the boreholes. The same practical issues with resin cartridges arise while bolting in squeezing ground conditions or in damaged pillars. This study aims at investigating alternative methods of grouting dynamic rockbolts by methods other than the polyester resin cartridges traditionally used by the mining industry. In particular, the use of injected resin grout for reinforcement is analysed in the field. The static anchorage capacity of the injected resin is evaluated using D-Bolts and Self-Drilling Bolts (SDB) by the mean of pull out tests, and compared with the performance of similar bolts anchored with resin cartridges in hard rock conditions, and grouted with cementitious grout. Drop tests evaluation of the resin was postponed due to scheduling difficulties. The study also includes a field evaluation of the installation method, sequence and bolting speed, for typical length tendons. The implications of the installation with injected grout on the resulting capacity and estimated safety performance are discussed.

[226] Large Scale Panel Destress Blasting parametric study - I. Vennes & H. Mitri (Canada)

The purpose of this parametric study is to quantify the effect of panel destressing on a steeply dipping remnant ore pillar. A large-scale destress blast program is simulated in the hanging wall of the ore pillar using the finite difference program FLAC3D. The simplified model consists of a 10MT ore pillar divided into 20 stopes on two levels. Two panels are destressed in the hanging wall to cover 8 stopes, followed by the mining of 4 stopes in the stress shadow in a retreat sequence. The varied parameters are the rock fragmentation factor (α) and stress reduction factor (β) of the destress panel. The effect of panel destressing is evaluated based on the volume of ore at risk in the stress shadow as well as the sudden stress change in the stope caused by the destress blast. Overall, a successful blast with a realistic stress reduction factor and rock fragmentation factor reduces the major principal stress in the nearest stopes by 10 MPa to 25 MPa. This yields a reduction of ore at risk volume ranging from 8% to 50% in the stress shadow as the first 4 stopes are mined.

Session B-3: Safety and Risk Management Tools

Time: 15:30 to 17:00 am

Keynote: [203] Hydrogeological challenges and strategies at McArthur River Operation - X. Yun, B. Tang, G. Murdock, B. McGill & B. Mattie (Canada)

High pressure, radon-bearing water has been identified as one of the most critical challenges in mining the high grade uranium deposit at the McArthur River Operation, Cameco Corporation. The ore deposits are located between 490 m and 640 m below the surface and surrounded by water bearing Athabasca sandstone, a graphitic fault zone, and highly altered ground. This paper introduces the inflow risk management program at McArthur River Operation which includes various hydrogeological challenges and the corresponding strategies applied, such as risk based probe and grout programs (geological, hydrogeological, and geotechnical), ground freezing programs, and comprehensive ground control programs. These programs have been developed, tested, and proven successful over years of mining practices. Working with this world-class deposit of high risk and low tolerance, the authors believe that these experiences might be beneficial to other mining operations with similar hydrogeological characteristics.

[145] Avoiding Workplace Accidents: The Importance of Pre-Job Safety Analyses - C. Morrish (Canada)

Careful, thorough, individual and group pre-job safety analyses completed by knowledgeable and competent individuals can significantly reduce workplace incidents. Benefits include: decreased costs, improved productivity and morale of employees, and an increased perception by those outside of positive safety consciousness. Pre-job safety analyses can be done either by a team of workers or by a solitary worker. In both cases these workers need to be trained in the completion of pre-job safety analyses. Supervisors must check to see that these analyses are completed competently. The current study presents pre-job safety analyses, namely the Neil George Five Point Safety system and a construction field level risk assessment. Workers may be guided by one of these systems to complete a pre-job safety analysis but must also have access to safe work procedures, and equipment and area inspection reports. Examples of accidents that were investigated during the author's 18 years as a Saskatchewan mine inspector will be discussed within the context of the above. The causes of the accidents will be explored with close reference to how pre-job safety analyses could have prevented their occurrence.

[148] Notification Systems and Risk Management - M.M. Antunes, M.T. Diogo & J.S. Gois (Portugal)

In an occupational context, "Notification" understood as "the act of telling someone officially about something, or a document that does this", (in Cambridge Advanced Learner's Dictionary & Thesaurus), may reveal a management approach. The ILO Code of Practice on Recording and Notification of Occupational Accidents and Diseases provides practical guidelines for establishing and use a national system for recording and notification of occupational diseases. In the European Union, there is a legal obligation to report occupational accidents and diseases. Such is the case, e.g. with RIDDOR making reporting certain incidents a legal requirement. The report informs the enforcing authorities about deaths, injuries, occupational diseases, and dangerous occurrences. Mandatory notification procedures may also arise from certain types of specific hazards, such as exposure to biological agents. Also relevant are reporting procedures in non-compulsory management systems, namely the ILO Guidelines on OH&S management systems, when considering performance monitoring and measurement, clearly states that "Reactive monitoring should include the identification, reporting and investigation of: (a) work-related injuries, ill health (including monitoring of aggregate sickness absence records), diseases and incidents".Findings from a case study over a 5-year period, based upon a notification system from one organization alone with 736 records and 915 workers directly involved, supports a main conclusion. A notification system is not by itself enough in prevention terms. The validity of the required information and the way it is demanded is also fundamental to obtain the best adequate records. The statistical data treatment is a critical stage, for changes regarding preventive actions and measures are based upon such findings and conclusions. Statistical treatment of data is fundamental to achieve adequate use of the data collected. Multiple correspondences analysis privileges tables of relevant size simultaneously comprising variables of distinct nature: quantifiable and qualitative. It helps in describing the complex relationships that may exist among variables, both independent and dependent (Dohoo, 1996). The mentioned study comprises a total of 47 management variables and a set of multiple sub-variables, resulting from the notification system analysed. The results obtained identify management variables that may be considered transversal to other economic sectors, from the workers' point of view (gender, professional classification and others) and specific to the sector if the employers' point of view is considered (day of the week, type of accident, communication procedures, contributing factors, etc.). The present study aims to design, implement and validate a

notification system as both a transversal and sectorial information system in OH&S risk management. A notification system should provide effective and adequate flow of information within a proactive prevention context.

[12] Full-scale fire experiments in an underground mine - R. Hansen (Sweden)

Few full-scale fire experiments have been performed in underground mines, therefore the information needed to validate calculations and estimations in preventive work, risk mitigation as well as incident planning is not readily available. This paper presents two full-scale fire experiments involving a loader and a drilling rig in a mine drift in Sweden. The heat release rate in the fire experiments was determined through oxygen calorimetry, i.e. by measuring the mass flow rate, gas concentrations and temperatures at certain heights at the far end of the mine drift, downstream of the fire source. The resulting heat release rate curve of the loader fire displays a fire that is initially dominated by a sudden increase in heat release rate when the first tire is engulfed by flames and then by the slowly declining heat release rates of the large tires of the vehicle. The calculated peak heat release rate of the loader was 15.9 MW and occurred approximately 11 minutes after ignition. The resulting heat release rate curve of the drilling rig displays a fire with high heat release rates and is relatively short lived – compared with the fire in the loader. Practically all the combustible items were ignited in the early phases of the fire. The calculated peak heat release rate of the drilling rig was 29.4 MW and occurred approximately 21 minutes after ignition. The fuel load of the loader consisted mainly of the tires, the hydraulic oil and the diesel fuel. The fuel load of the drilling rig consisted mainly of the hydraulic oil and the hydraulic hoses. The heat release rate curves were validated by comparing the summed up energy contents of the participating components with the integrated heat release rate curves.

Tuesday August 16, 2016

Session A-4: Ground Control Safety

Time: 10:30 to 12:00 am

[87] Improving Ground Control Safety in Deep Vein Mines - J. Seymour, D. Benton, M. Raffaldi, J. Johnson, L. Martin, S. Boltz & J. Richardson (USA)

Researchers with the National Institute for Occupational Safety and Health (NIOSH) in Spokane, WA, USA are conducting research in cooperation with the Hecla Mining Company at the Lucky Friday Mine in northern Idaho to improve ground control safety in deep vein mines. Because Hecla is mining at depths of more than a mile beneath the surface, the geology and ground stresses create unique requirements for mining and ground support. Special measures are being implemented by Hecla to limit the intensity of mining-induced seismic events and to avoid compromising the static and dynamic capacity of their ground support systems. NIOSH researchers are collaborating in these efforts by monitoring and assessing the fault slip mechanisms that initiate these seismic events and by quantifying the performance characteristics of the ground support systems.

[198] Numerical investigation of EDZ development around a deep polymetallic mine - M. Souley, M. Al Heib & V. Renaud (France)

This paper deals with the development of a non-linear constitutive model of rock mass and its verification to predict a damaged zone. Simulations of triaxial compressions provide a verification of the implementation with a good agreement between predictions and theoretical values of peak and residual strengths as well as the transition between brittle failure and ductile response. The applicability of the model to predict potential failure around stopes of a deep polymetallic ore mine is checked and highlighted the interest to consider more realistic rheology of hard rock masses compared with the elastic perfectly plastic models of underground deep mines.

[PPT] Dynamic Fracture Propagation in Rock – J. Nemcik & G. Venticinque (Australia)

Using static equilibrium conditions, the empirical and numerical analyses of fracture propagation in rock omit many of the important dynamic effects required to investigate the evolution of fractures in the rock mass. Through the application of dynamic theories and new principles, it is now possible to study and numerically model the entire development of brittle fractures through the rock masses in real time. The current numerical models successfully simulate dynamic fracture propagation through brittle to ductile range. Simulated outputs have successfully produced similar results to several laboratory tests carried out previously including, UCS, Triaxial and Brazilian Tensile tests. Compressive failure of coal pillars, demonstrated through the evolution of multiple dynamic fractures in coal ribs, has yielded realistic behaviour with results found agreeable with several forms of empirical formulae commonly used in pillar design. The application of this model to investigate various underground rock behaviour such as rockburst, coal burst and outburst phenomena, introduces a new potential to explore these highly dynamic cases. This project offers a significant opportunity towards improving safety of mining within or around complex geological structures.

[PPT] Overview of how Ground Control departments use microseismic systems and other monitoring technology at underground mining operations - I. Leslie (Canada)

A vital technology used routinely by many Ground Control departments for mine safety, planning ground support and for the evaluation of mining methods is the Microseismic (MS) system. These systems are used to monitor the state of the rockmass at the mine and evaluate regions of rock fracturing in real time. The stress redistribution that occurs during the mining process results in short term fracturing around excavations which can induce large magnitude rockbursts to occur on larger structural features. A number of software routines and procedures have recently been developed and enhanced at ESG for providing alerts to staff when a large event occurs and also to monitor aftershocks for the purposes of determining when a stope is safe to re-enter. In addition to the typical seismic monitoring tools, recent developments have been made towards the integration of other types of data such as blast vibration and ground monitoring instrumentation data such as Extensometers and Tiltmeters. This paper will focus on examples of real data recorded from MS systems, how these data are used at hard and soft rock mine environments and explain the advantages of moving towards a centralized system for many types of instrumentation data.

Session B-4: Occupational Health and Safety - Tailings Dams Safety

Time: 10:30 to 12:00 am

[PPT] Evaluation and implementation of DPF technologies in hard rock mines- J. Stachulak & C. Alan (Canada)
The reduction of diesel exhaust emissions in underground mines is a primary goal of the mining industry. A number of strategies are known to reduce diesel particulate matter (DPM), but the reduction at source using a diesel particulate filter (DPF) is the most effective. However, the devices used for DPM control must not increase the emission of nitrogen dioxide or other contaminants. For more than 10 years, DPF systems have been evaluated at Vale mines in Sudbury. The initial work was conducted under the Diesel Engine Emissions Program (DEEP) and was well reported at a number of conferences. More recent tests have been conducted at Vale's Creighton, Totten and Copper Cliff Mines with consortium support from Vale Thompson, Glencore Sudbury, Kidd Creek and KGHM. These tests have resulted in significant progress being made over what was learned during the Stobie Mine project under DEEP. This presentation summarizes the highlights of projects that Vale has been involved with in recent years, principally the Mining-CRT-DPF systems developed by Johnson Matthey for LHD vehicles. The presentation will also address the "business as usual" operation of DPF system applied to light duty vehicles.

[201] Diesel exhaust exposures in an underground mine - H. Coulombe, G. Lachapelle, E. Neesham-Grenon, S. Hallé & M. Debia (Canada)
The mining industry is a major contributor to the Quebec and Canadian economy. In Canada, more than 400,000 workers are involved directly or indirectly in the mining industry. Health and safety challenges in underground mines are unique due to the complexity of the environment. Exposure to diesel engine exhaust is a major concern in underground mines due to the presence of off-road diesel-powered machinery. Diesel engine exhaust has been linked to cardiopulmonary diseases and was classified as a human carcinogen by the International Agency for Research on Cancer in 2012. Here we present the results of a preliminary study conducted in an underground gold mine in the province of Quebec in 2014-15 to assess diesel engine exhaust exposures among mine workers. The goal of this study was 1) to compare three surrogates of diesel engine exhaust exposure (total carbon, elemental carbon and respirable combustible dust) and 2) to assess diesel exhaust concentrations among the similar exposure groups and the variability of the exposures. Results were also compared to the Ontario and Quebec occupational exposure limits for compliance purposes. Environmental and breathing zone measures were taken. Average environmental results of 0.31 mg/m^3 in total carbon, 0.24 mg/m^3 in elemental carbon, and 0.17 mg/m^3 in respirable combustible dust were obtained. Average breathing zone results of 0.32 mg/m^3 in total carbon, 0.19 mg/m^3 in elemental carbon and 0.36 mg/m^3 in respirable combustible dust were obtained. The highest exposures were obtained in the conventional, scooptram and jumbo workers. The average total carbon/elemental carbon ratio was 1.3 for environmental measures, and 1.9 for breathing zone measures. The variability observed in the total carbon/elemental carbon ratio shows that interferences from non-diesel related organic carbon can skew the interpretation of results when relying only on total carbon data. However, more data is needed to support this.

[125] Liquid-solid coupling analysis of tailings dam in complex engineering condition - S. Wang, H. Zhang, Z. Zou & S. Liu (China)
The tailings pond, a place for stockpiling tailings, is a necessary facility for maintaining normal production of a mine. On the other hand, the tailings dam is a major danger for metal and non-metal mines, because dam failure may occur. The present study takes the flat land tailings pond of the Sanshan Island gold mine, Shangdong Province, China, as an example. The tailings dam 3D numerical model was built using MIDAS/GTS and $FLAC^{3D}$ techniques. The safety factor and the potential slide face of the tailings dam were calculated under different conditions using the strength reduction method. It is concluded from the liquid-solid coupling analysis that there are three potential failure modes of the tailings dam under preloading. Under the present conditions, the tailings dam meets the safety requirements, however, it does not in the event of additional heaping. The height of the present heap must be cut to satisfy the stability requirements under the condition of rain infiltration.

[111] Numerical analysis of Westwood Mine tailings embankment stability during the restoration phase - Y. Coulibaly, T. Belem & L.Z. Cheng (Canada)
Stability analysis of Westwood Mine tailings embankment performed using SLOPE/W and SIGMA/W codes showed that the minimum factor of safety obtained is higher than the recommended value of 1.5 set by some authors and the Quebec Ministry of Natural Resources and Wildlife for static loading and steady flow conditions. Pore pressures that must be controlled are higher in bottom layers of the embankment, and these pressures move toward the downstream side. In addition, low electrical resistivity values (by geophysical method) associated with the high water content tailings layer, suggest its susceptibility to internal erosion.

Session A-5: Pillar and Backfill Stability in Underground Mine

Time: 13:30 to 15:00 am

Keynote: [154] Numerical modelling of time-dependent skin degradation of an isolated pillar - A. Sainoki & H. Mitri (Canada)

The present study focuses on the mechanism of instability of an isolated pillar caused by time-dependent skin degradation and strength heterogeneity. The time-dependent skin degradation is simulated with a non-linear rheological model capable of simulating tertiary creep. The inherent strength heterogeneity is realized with the Weibull's distribution. Results obtained from the analysis shows that the skin degradation is limited to regions near the surface until two months after extracting ore, but afterwards it starts to extend deeper into the inside, eventually leaving a highly stressed pillar core due to the stress transfer from the failed rock. Rockburst potential indices show that the risk increases exponentially at the core as time goes by. It is then demonstrated that the progressive skin degradation cannot be simulated with the conventional strain-softening model assuming brittle failure. The parametric study with respect to the degree of heterogeneity reveals that the heterogeneity is a key to the occurrence of progressive skin degradation. Although average UCS in the model with high degree of heterogeneity is almost the same as that in the model with low degree of heterogeneity, the degradation of rockmass extends deep into the pillar only in the highly heterogeneous model.

[236] Analysis of haulage drift instability in hard rock mines with numerical modeling - S. Shnorhokian, B. MacNeil & H. Mitri (Canada)

One of the more complex design parameters in underground mining is the relative distance of a haulage drift from the orebody as it runs parallel to its strike. Opposing considerations from operational and ground control teams are balanced, with the former preferring a shorter distance for increased productivity and the latter requesting a further distance for safety and stability. In this study, a simplified numerical model is constructed of a typical tabular orebody within the geological settings of the Canadian Shield, striking East-West and dipping steeply to the south. Three other formations with the same strike and dip are added to the model, along with two intrusive dykes at variable distances from the orebody and the drift. The rockmass properties for all formations are taken from a previous work on a case study mine in the Canadian Shield, and the model is calibrated based on in-situ stress measurements there. Two stope sequences comprising two simultaneous mining fronts are analyzed; a diminishing pillar one that moves from both east and west to the middle, and a centre-out option that moves from its centre to the sides. In both cases, 24 mine-and-backfill stages are needed to completely extract the orebody. A quantitative assessment of instability around the drifts, crosscuts, and stopes is conducted for a single level at a depth of 1490 m. The brittle shear ratio (BSR), uniaxial compression, and tensile failure are combined with volumetric analysis to estimate potentially unstable rockmass. The relative proximity of the drift and stopes to the dykes is evaluated as well and observed to have an impact on the results. A combined numerical-volumetric approach is found to provide a useful tool for comparing different sequences and obtaining information on the type, location, volume, and timing of instability.

[149] Minimum strength required for resisting cyclic softening/failure of cemented paste backfill at early age - T. Belem & M. Mbonimpa (Canada)

This paper attempts to assess empirically the liquefaction susceptibility of cemented paste backfill (CPB) at early age (≤ 7 days). Early age CPB can be categorized as a "clay-like" material because their plasticity index, PI ≥ 5 (PI = Liquid Limit, LL – Plastic Limit, PL). For clay-like material such as CPB, the liquefaction susceptibility can be characterized by the "cyclic softening" or "cyclic failure" which is assessed using an empirical method developed for clays and clay-like materials. This analysis allowed the determination of the minimum undrained shear strength required to resist cyclic softening (failure) of cemented paste backfills which is directly related to the unconfined compressive strength (UCS).

[166] Analysis of failure in a salt room and pillar mine - F. Laouafa & M. Ghoreychi (France)

Failure mechanisms have been investigated in a salt mine (Alsace Potash mines, East of France) excavated by the room and pillar method, a part of which is under study for chemical waste storage. This part is located at a depth of about 550 meters. Some singular failure modes appear in the roof mine. These modes are perpendicular to the axis of the gallery and are created by tensile stresses. Such a failure mode is rarely observed in classical mines (coal, construction stones, etc.). 3D modelling of the site has been required for accurate description of the physical mechanisms. The results show that the failures and more

generally the roof behaviour are controlled by the deformation of the pillars inducing tensile forces in the roof. The results also show that the creep or the viscoplastic behaviour of the salt is a key element that explains the existence of such failure and their evolution over time. A parametric analysis of the properties of overburden, geometrical pillar features slenderness, confirm the conclusion. Namely, time-dependent deformation of large salt pillars generates their lateral extension and induces roof deformation and failure in tension. The numerical results are in full agreement with in-situ observations.

Session B-5: Advances in Operational Mine Safety

Time: 13:30 to 15:00 am

Keynote: [PPT] Keeping the bar high on personnel safety – S. Bowles (Canada)

Safe field performance of a mining operation is achieved when all levels of the organization have common values regarding personnel safety and when management is committed to prioritize safety in business decisions. This requires mine safety management systems that sustain continuous improvements with rigorous verification processes by its leaders. This presentation will explore successful leadership strategies applied in a people-driven mining process and innovative techniques that enable the organization to focus on areas of higher risk. A case study outlining Raglan Mine's journey to Zero Harm in the challenging arctic fly-in fly-out environment will be presented. This includes the deployment of a strategy toward a step change in safety leadership with active field involvement within all levels of the business structure.

[213] Application of an economy comparison model for mine cooling system technology - D. Miao, D. Chang & D. Tan (China)

The existing selection methods for mine cooling schemes are complex and have incomprehensive index values. In order to rectify this problem in the specific circumstance of high temperature mines, this paper puts forward 13 index values, including the machine power, project investment, operation cost, etc. A comparative model of technical and economic benefit of mine cooling systems is established by using the objective entropy weight and TOPSIS method. Using objective entropy weight, the entropy weight of evaluation index and the weight decision matrix are determined. Using the TOPSIS method, the ideal solution and the negative ideal solution are determined. The optimal scheme can be determined by using the closeness degree calculation for the scheme sort. Optimization calculation and comparisons are carried out for four cooling schemes in a mine. Scheme 4 is found to be the optimal scheme for cooling systems.

[216] The strength properties of fibre glass dowels used for ground control in coal mines - A. Mirzaghorbanali, N. Aziz, W. Chen & J. Yuzhao (Australia)

Glass-Reinforced Polymer (GRP) bolts, commonly known as Fibre Glass (FG) dowels or plastic dowels are increasingly applied for strata reinforcement in mines as well as in concrete reinforcement in civil engineering. The most popular dowels used in Australian coal mines are the 22 mm diameter fully threaded type. FG bolts are cuttable, easy to handle, lightweight and corrosion resistant. The tested dowels were all black in colour, which is a favoured colour in coal mines. A series of tests were undertaken to evaluate various strength properties of FG dowels. These tests include the tensile failure test by the double-embedment method, single guillotine shear test, double shear test both in steel frame and in concrete blocks, and finally the punch shear test. The study found that the tensile strength by pull testing of the 22 mm diameter fibre glass dowels was in the order of 27 t. The shear strength testing of dowels in both single guillotine and double shear steel frames were in agreement with each other. In general, the shear strength values of dowels tested, using single shear guillotine testing, were around 20% of the axial strength in comparison with 70% in the same diameter steel rebar tests. The peak shear load values obtained from double shear tests in concrete blocks was influenced by the encapsulation grout type and the level of fibre glass axial pre-tension. The punch shear tests revealed that there was a more than threefold increase in the punch shear strength value of fibre glass dowels tested perpendicular as against parallel to the dowel axis.

[101] Operating conditions of a mine fan under conditions of variable resistance – Z. Yinghua, C. Li, H. Zhian & G. Yukun (China)

According to the basic fluid principles and ventilation laws combined with the ventilation network computing method, this study proposes the concepts of relative sensitivity and absolute sensitivity, and studies these two sensitivities' variation law under conditions of variable airway resistance. The result showed that when the airway resistance increased, the fan air

volume, relative sensitivity, absolute sensitivity and fan pressure's relative and absolute sensitivity tend to decrease. At the same time, fan pressure shows an increasing trend. Conversely, when the airway resistance goes down, the above parameters follow the opposite trend. These results provide a basis and guidance for adjusting the fan operation condition in the mine production process.

Session A-6: Rock Slope Stability

Time: 15:30 to 17:00 am

[15] Lessons in slope stability management from Kinross' Tasiast mine, Mauritania - K. Tasoren, G. Gardhouse & J. Ran (Mauritania)

The continued monitoring and optimization of a mining operation are essential extensions of a feasibility study. While the ultimate goal is to mine to the planned design in a safe and economic fashion, such efforts are challenged on a daily basis by changing ground conditions. Success in a dynamic mining environment requires a strong understanding of historical instabilities and wall control blasting, along with well-defined near wall excavation and clean-up procedures, and an advanced slope monitoring system. This paper presents several cases describing different modes of slope failure experienced at Kinross' Tasiast mine site, and the operational and design measures implemented to manage and monitor these instabilities. Routine data collection practices and blasting designs that have been introduced to minimize wall damage and steepen slope angles are also discussed.

[189] Effect of buttress on reduction of rock slope sliding along geological boundary - R. Moriya, D. Fukuda, J. Kodama & Y. Fujii (Japan)

In open−cut limestone mines in Japan, huge rock slopes with geological boundary between limestone and bedrock have been formed by mining activities. In addition, latent sliding plane near the toe of slope may be formed through the development of damaged zone with increase in size of rock slope. It has been reported that inelastic time−dependent sliding deformation of rock slope along both the geological boundary and latent sliding plane can occur. In this case, one of the countermeasures to suppress sliding deformation is an application of rock buttress to the slope surface where the sliding is taking place. However, effect of rock buttress on reduction of the rock slope sliding has not been clarified yet. In this paper, the effect of rock buttress on reduction of the rock slope sliding was discussed based on 2−dimensional finite element analysis using non−linear visco−elastic model. The results indicate that (i)degree of deterioration of sliding plane at the timing of the application of rock buttress significantly affects the expected life of rock slope, (ii)optimum height of rock buttress can exist, (iii)larger Young's modulus of rock buttress results in the longer expected life of rock slope and (iv)the balance of increase and decrease of normal and shear stresses on sliding plane by buttress is important and the obtained results can be changed by the difference of friction angle and the geometry of sliding plane.

[209] Assessment of empirical slope stability methods using road-cut case studies in southern Saudi Arabia - H. Basahel & H. Mitri (Canada)

Many classification systems have been proposed in the literature to identify the state of stability of rock slopes. Most of these classification systems involve factors relevant to the general condition of the rock mass, for example, intact rock strength (UCS), geometry and condition of discontinuities, and groundwater condition. Such factors represent the basic part of most of the classification systems, which refer to the well-known Bieniawski's Rock Mass Rating or RMR system. However, these factors were initially developed for underground excavations. Therefore, these classification systems have been subjected to many criticisms and were questioned for their suitability for rock slopes. In this paper, some of the common classification systems for rock slopes are used to identify their suitability for rock cuts. Twenty-two sites of rock cuts in mountainous roads affected by heavy rainfall in the southwestern part of Saudi Arabia have been selected as case studies, and four empirical methods are examined for these case studies. The selected methods are Slope Mass Rating or SMR (Romana, 1985), continuous SMR (Tomás, 2007), Chinese SMR (Chen, 1995), and a graphical SMR (Romana, 2012). The stability conditions for each site have been determined by each of these methods and a comparison between the results is made for the case of plane failure mode. It is shown that some of the empirical methods are not applicable such as Chinese SMR (for slopes less than 80 m high), and the graphical SMR method when the slope angle is more than 80°.

[PPT] Which slope monitoring technology is best suited for my open pit mine operation: How to reduce risk & protect people while ensuring continued production - S. Behanish (USA)
Slope monitoring is an integrated part of safety for all mine operations and slope failures can incur significant cost elements, including: cleanup, disruption to mine operations, damage to mine equipment and even personal injuries or fatalities. Choosing the correct monitoring technology that is appropriate for each operation is a task that should be handled properly be mine management in order to make proactive decisions instead of reactive decisions in the event of a possible slope failure. In this presentation, case studies and real-life examples of pit slope displacement monitoring are explained to highlight the different monitoring technology options that are available to mining operations to help them make the most informed decision to protect their assets. The pros and cons of different options are discussed.

Session B-6: Ventilation

Time: 15:30 to 17:00 am

Keynote: [163] Application of a ventilation management program for improved air quality - E. de Souza (Canada)

The continued monitoring and optimization of a mining operation are essential extensions of a feasibility study. While the ultimate goal is to mine to the planned design in a safe and economic fashion, such efforts are challenged on a daily basis by changing ground conditions. Success in a dynamic mining environment requires a strong understanding of historical instabilities and wall control blasting, along with well-defined near wall excavation and clean-up procedures, and an advanced slope monitoring system. This paper presents several cases describing different modes of slope failure experienced at Kinross' Tasiast mine site, and the operational and design measures implemented to manage and monitor these instabilities. Routine data collection practices and blasting designs that have been introduced to minimize wall damage and steepen slope angles are also discussed.

[120] Reducing Heat Stress Exposures in Mines - R. Anderson & E. De Souza (Canada)
Heat management must be maintained within the mine working environment to minimize stress on equipment and personnel. Proper application of engineering protocols and work practice controls will have a direct impact on the health and safety of workers and on productivity. Using monitoring stations placed in strategic locations throughout the mine to capture the environmental conditions, various strategies can be used in the planning and prevention of potential hazard exposure. Economic analysis is used to select the most feasible strategy for heat stress control.

[178] Numerical study of simultaneous methane and coal dust dispersion in a room-and-pillar mining face - Y. Lu, S. Akhtar, A. Sasmito & J. C. Kurnia (Canada)
In underground coal mines, uncontrolled accumulation of methane and fine coal dust often leads to serious accidents such as explosions. Therefore, methane and dust dispersion in underground mines is closely monitored and strictly regulated. Accordingly, significant efforts have been devoted to study methane and dust dispersion in underground mines. In this study, methane emission and dust concentration are numerically investigated using the computational fluid dynamics (CFD) approach. Various possible scenarios of underground mine configurations are evaluated. The results indicate that solitary existence of a continuous miner adversely affects the airflow and leads to increases in both methane and dust concentrations. Nevertheless, it is found that the negative effects of a continuous miner presence on concentrations can be minimized or even neutralized by operating the scrubber fan on suction mode. In addition, it was found that the combination of scrubber fan on suction mode and brattice results in the best performance of methane and dust removal from the mining face.

[133] Numerical research on the air flow structure of the ventilation in mine tunnels - C. Ding, X. He & B. Nie (China)
Based on 3D modelling of typical tunnels in mines, the air flow structure in the three hearts arch-section tunnel was investigated and the influence of air velocity and cross section on air flow distribution in tunnels was studied and the average velocity points were analyzed quantitatively. The results showed the feature of the air flow is similar with the shape of three hearts arch-section under different ventilation velocities and cross section areas. The shape of the tunnel cross section and wall were the critical factors influencing the air flow structure. The average velocity points were mainly close to the tunnel wall. Characteristic equations were developed to describe the average velocity distribution, and provide the theoretical basis for accurately measuring the average velocity in the mine.

Wednesday August 17, 2016

Session A-7: Slope stability and Ground Subsidence

Time: 8:30 to 10:00 am

Keynote: [73] Application of InSAR for Monitoring Deformations at the Kiirunavaara Mine - K. Mäkitaavola, B-M. Stöckel, J. Sjöberg, S. Hobbs, J. Ekman, M. Henschel & A. Wickramanayake (Sweden)

An integral part of sublevel cave underground mining is the associated caving of the surrounding host rock. This causes mining-induced ground surface deformations on both the hangingwall and footwall side of the orebody. The municipality of Kiruna, in northern Sweden, is located in close proximity to the LKAB Kiirunavaara mine and is thus unavoidably affected by the mining activities. To be able to plan for an urban transformation, as the effects of mining approach the city infrastructure, it is necessary monitor the ground deformations on a regular basis. Historically, GPS-monitoring has been used, with an extensive network of measurement hubs in place. New techniques for monitoring ground deformations are, however, constantly evaluated. As part of this process, LKAB has conducted a five-year research and development project on deformation measurements using radar satellites and the InSAR technology. The project has included a monitoring component and a research- and technology transfer component. The overall findings of the monitoring program, and the associated research and development work are presented. Particular emphasis is put on achieved accuracy and the implications for the ability to reliably monitor the progressing deformations toward the municipality and existing infrastructure. Lessons learnt from the conducted work are presented, followed by recommendations on future use of InSAR for this type of application.

[210] Modeling the Impact of Particle Flow on Rigid Structures: Experimental and Numerical Investigations - M.A. Meguid, G. Gao, M.M. Abouelkair & M.Z. Abdelrahman (Canada)

Gravity-driven debris flow of granular particles down an inclined slope is a problem of growing concern in mountainous regions and poses a significant risk to people, roads, and other infrastructure. Different aspects of the problem have been previously investigated using physical modelling and numerical analysis. However, three dimensional pressure distribution on a barrier wall resulting from debris flow over a rough slope is scarce in the literature. In this study, a series of experiments are conducted to track the movement of granular particles down a slope and measure the impact pressure imposed by the flowing particles on a nearby vertical wall. The particles are released from a container located at the top of the slope and the velocity profiles are recorded using marked pebbles and a high-speed camera. The effect of the debris volume, slope angle, and distance to the wall on the velocity profiles and impact forces are investigated. Validated using the experimental results, discrete element simulations are performed using PFC3D to evaluate the effect of particle sizes on the flow characteristics and final impact pressure on the structure. Analysis showed that impact energy is highly affected by the slope inclination, particle velocity, and runout distance.

[207] A versatile model for the evaluation of subsidence hazards above underground extractions - P. Cain & K. Zimmerman (Canada)

All underground extraction – oil, gas, water and minerals – results in subsidence of the surface to some degree. Subsidence can cause damage to infrastructure – roads, powerlines, gas and oil pipelines, buildings – and to the natural surface, with the development of cracking, potholes, changes in hydrogeology and destabilization of slopes. Pre-extraction estimates of the amount of subsidence and the hazards it might produce are difficult to determine with accuracy, and the most frequent approach is to model the surface movements in response to extraction using empirically based models.

There are a number of large underground coal mine projects on the drawing board in British Columbia and Alberta despite the current prolonged episode of reduced coal prices. Fortunately, almost all of these projects target metallurgical coal, for which windmills, hydro and nuclear “clean” power sources provide no substitute and in fact, on which they depend for their construction. Each of these projects will have to demonstrate satisfactory mitigation of hazards arising from potential subsidence before they will be allowed to proceed.

DMT Geosciences Ltd of Calgary, AB has recently worked with an underground mine proponent to model subsidence over an entire mine layout, in native coordinates and for multiple seam extraction, using a proprietary influence function model.

Currently calibrated using a best estimate of western coal subsidence characteristics, the model itself will undergo additional calibration as monitoring data above the actual mine is obtained.
The model itself is fairly easy to use, quick to run and provides results in an easily managed format for graphical display. As well as mining subsidence, it has in the past been shown to predict surface movements due to oil and water extraction at depth. For the current project, the results obtained in the initial subsidence prediction phase have allowed areas of potentially hazardous or damaging surface movements to be determined.

Session B-7: Coal and Gas

Time: 8:30 to 10:00 am

Keynote: [175] Development and realization of coal and gas outburst simulation device - B. Nie, S. Hu, X. Li, J. Meng & P. Fan (China)

Similar coal and gas outburst simulation devices both at home and abroad are analyzed and their advantages and disadvantages are examined. A large size experimental device of coal and gas outburst simulation is developed based on the congeneric testing device. This device consists of coal and a gas outburst model system, gas injection system, loading system, stress measurement system, gas pressure measurement system, temperature measurement system, electromagnetic radiation testing system, and high-speed photography system. The functions of the device are as follows: (1) to study the laws of roof break development and stress evolution during outburst process by simulating coal seam, roof and floor with similar material, (2) to simulate stress distribution of a roof at high strength springs of different sizes, (3) to realize the uniform adsorption in coal by 3 gas injection pipes that are pre-buried, (4) to induce coal and gas outburst at predetermined gas pressure by blasting bursting disc instantly that set on the outburst hole, (5) to observe and record fracture and migration process of coal in the cavity during outburst that is achieved by a visual glass window on the side of cavity.

[130] Mathematical model for gas diffusion from non-homogeneous coal particles - Y. Liu, M. Liu & H. Mitri (China)

By establishing model and experimental verification, this paper aims to improve the accuracy and applicability of gas diffusion mathematical models from coal particles in engineering applications. Firstly, based on Fick's second law and the continuity theory of gas diffusion in porous media, a new constitutive model for gas diffusion from non-homogeneous coal particles with three-layer pore structure is constructed by considering the difference of characteristics in pore structure between soft coal and hard coal. Then, the analytical solution is derived from the new model, that is, the quantitative relationship between gas diffusion rate ($Qt/Q\infty$) and diffusion time (t). The pore structure parameters of soft coal and hard coal from Juji coal mine are determined by using the mercury injection method. Gas desorption and diffusion rules of coal samples are numerically calculated and investigated by using physical simulation methods. Lastly, the applicability of the constitutive model is verified. The results show that the homogeneous model that is currently widely used only applies to the description of the gas diffusion process of the hard coal within the initial 10 minutes, while the new model can describe the gas diffusion law of different pore structure characteristics. The calculated results from the new model and the physical experimental results are nearly identical within the initial 30 minutes. The difference in the gas diffusion process between soft coal and hard coal can be effectively reflected by the parameters of pore structure in the new model.

[89] Numerical modeling and rescaled range analysis on spontaneous combustion under surface methane drainage in a Chinese coal mine - X. Hu, S. Yang, W. V. Liu, J. Cai & X. Zhou (China)

In China, surface boreholes have been used frequently to drain methane/gas emitting from overlying layers and longwall mining gobs in underground gassy coal mines. In this work, a numerical modeling was established using COMSOL TM to study the influence of surface drainage borehole on coal spontaneous combustion and Rescaled Range Analysis (R/S analysis) was employed to investigate the chaos characteristic of Nitrogen (N2)/Oxygen (O2) drained from the gob. The simulation results show that there is a circular “dissipation zone” around the drainage borehole all the time and an elliptic “spontaneous combustion zone” when the borehole locates in deep gob. It is also found that the advancement of drainage borehole has little influence on spontaneous combustion zone on the intake side of the gob but it can tremendously enlarge the width of “spontaneous combustion zone” in the middle gob and reduce the depth of self-heating zone near the return side. The R/S

analysis indicates that the influence of surface borehole on spontaneous combustion can be divided into two stages: the safety drainage stage (Hurst index > 0.85) and the spontaneous combustion initiating stage (Hurst index ≤ 0.85). It can be concluded that the gas drainage from gob through surface borehole can tremendously intervene spontaneous combustion "three zones" in gob. In addition, the length-fixed R/S analysis on N2/ O2 series from surface boreholes can effectively reflect coal spontaneous combustion condition in gob.

[33] Temperature Variation of Coal during the Gas Adsorption Process - T. Yang, B. Nie, X. Chen & P. Chen (China)
Using a self-made coal gas adsorption-desorption instrument, laboratory research on temperature variations of the adsorption process under different conditions was completed to study the adsorption law of coal gas and to reveal coal gas adsorption mechanisms. Under the same conditions, the order of unit mass of coal's gas adsorption and the temperature variation is: Zhenxing 2# Coal > Runhong 3# coal > Malan 8# coal. The results show that gas adsorption gets lower as the temperature increases. For the same coal sample under the same conditions, the smaller the particle size, the greater the pressure variations of the methane adsorption process and the larger the gas adsorption in the same period. The results of this paper reveal the mechanism of coal and gas outburst.

Session A-8: Underground Mines Safety

Time: 10:30 to 12:00 am

[127] Thermomechanical impact of Underground Coal Gasification exploitation - F. Laouafa (France)
Underground mining by coal combustion (Underground Coal Gasification - UCG) raises questions regarding the mechanical behavior of the site and the stability of the overburden rock layers. By studying the underground reactor, its inlet and outlet, we confirmed the key roles played by mechanical damage and thermo-mechanical phenomena. Deformation or collapse above the cavity may cause a collapse in the overlying layers or a subsidence at the surface level. These phenomena highly depend on the thermo-poro-mechanical behavior of the surrounding rock (host rocks). The numerical results presented in this paper were derived from models based on different assumptions describing a raw geological background. Both 3D and 2D nonlinear finite element modeling was conducted based on two different approaches. Based on the analysis of the numerical results, we were able to highlight the main factors influencing the behavior and mechanical stability of the overburden, and consequently the UCG process evolution.

[218] Escapeway solutions - A. Deadman, S. Durkin & V. Lawrence (Australia)
The requirement for secondary egress from underground workings has long been regulated in Australia. Escapeway systems have evolved from simple airleg rising ladders and timber ladders to steel galvanized ladders and more recently fully enclosed polyethylene ladders. The polyethylene ladder - Safescape Laddertube - was introduced to the underground mining industry in 2010. It is a cylindrical, enclosed, modular plastic ladder designed for use in underground escapeways and access ways. The design of Safescape Laddertube has many advantages, one of those being that it is enclosed therefore minimizing the risk to climbers of exposure to fretting rock. In 'standard' installations there have occasionally been changes in the ground conditions which have resulted in significant fretting or rock burst causing deformation in the Laddertube. In addition, there is on occasion a requirement to position an escapeway in ground that has highly stressed or squeezing ground conditions, presenting mines with potential for failure of ground resulting in serious damage to these escapeways. As a result, Safescape have developed a number of proactive solutions that can be used at the time of installation which will eliminate or minimize the effects of ground that is not 'competent'. These solutions address the need for ground support and eliminate the need for the traditional methods of ground support in a rise such as bolt and mesh, which also means we no longer need to put people in unsupported ground to complete this high risk work.
Despite being a recent development in escapeway systems, Laddertube is effectively being used in a variety of applications, meeting the specific needs of underground mines worldwide

[211] Estimating stope vein footwall stability using various constitutive Models - A. Pyon, A. Sainoki & H. Mitri (Canada)
Operating in weak narrow vein mines presents many issues in terms of ore productivity. Maintaining stable mining excavations and limiting unplanned overbreak are some of the main concerns in narrow vein mining. The use of numerical modelling has become a popular method because it is capable of examining stress patterns and identifying rockmass failure. This paper will focus on creating a 3-dimensional constitutive numerical model for narrow vein mines that incorporate weak

rockmass properties. The selected Case Study Mine is an underground narrow vein mine joining a weak material known as talc-chlorite-schist. The construction of this model will be associated with the unplanned ore dilution determined by surveyed profiles from the mine site.

[131] Drilling escape and rescue system in Wangjialing coal mine - Z. Huang, L. Jin, Y. Ma, H. Zhu & N. Gao (China)

Many problems are faced in the construction of emergency refuge systems, including the poor reliability of hedging facilities, the contradiction between hedge and escape, the high time consumption, high cost, and the big risk of drilling rescue technology. Shaft drilling escape and rescue systems are a combination of emergency refuge technology and drilling rescue technology. The key parameters of drilling escape and rescue systems are tested through man-loading and live sheep lifting experiments. Key parameters include no-supply guarantee time, response time, and human survival environment. This paper also examines the comfort and physiological parameters of experimenters and the influence drilling has over refuge chamber air supply systems.

Session B-8: Coal Mine Ground Control

Time: 10:30 to 12:00 am

Keynote: [49] Application of the strength reduction method in coal mine roof support design - G. Esterhuizen & I. Berk Tulu (USA)

Ground falls represent a significant proportion of injuries and fatalities in underground coal mines in the US. During 2013, ground falls were responsible for 4 of the 14 fatalities and 16.6% of the 1,577 reportable lost-time injuries. In addition, each year about 400 to 500 large roof falls are reported that can extend up to or above the bolted horizon. Support design for coal mine entries is largely based on past experience and a trial-and-error approach. A numerical model-based approach for support design is presented in which calibrated models are used to determine a stability factor for a supported entry. The stability factor is determined using the strength reduction method (SRM). Applying this technique, the relative merits of various support systems can be evaluated. The numerical models allow the contribution of individual support units to overall stability to be assessed. Two case histories are presented. In the first case the SRM approach is applied to assess the use of passive cable anchors as primary support in a room-and-pillar coal mine. The second demonstrates how the SRM approach was used to evaluate the impact of angled bolts at the rib-roof corner on roof stability. It is concluded that the SRM approach provides useful information to assess the overall degree of stability achieved by a support system, and allows support elements to be optimized for particular geological and stress conditions.

[177] Numerical modeling of the goaf: methodology and application - S. Ahmed, M. Al Heib, Y. Gunzburger, V. Renaud & J.-P. Piguet (France)

The mechanical behavior of the goaf is a critical issue that may affect the efficiency of longwall mining. Goaf numerical modelling as a continuous material is a challenge, especially because its large-scale mechanical properties are not precisely known. Many different values of the elastic modulus may be found in the literature to be used for representing the mechanical behavior of the goaf area. In the present study, the elastic numerical modelling is shown to be a useful tool for simulating the stress redistribution and displacement due to longwall mining, while taking into account the goaf geometry and its equivalent mechanical properties. The analysis is applied on the Provence coalmine, in the south of France, which had been in operation for more than 50 years, using the longwall mining method was used. A finite difference numerical model of the mine is constructed and two approaches are carried out in order to simulate the goaf area above the excavated panels where the panels have various length to width ratios. In the first approach, the caved zone and the fractured zone have different but homogeneous elastic modulus, both zones have elastic modulus lower than the unaffected host rock. In the second one, their elastic modulus varies linearly with the vertical distance above the panel, up to the elastic modulus of the host rock. In both cases with and without goaf, the subsidence at the ground surface is calculated and compared with in-situ measured values. Results show that attributing to the goaf area a low elastic modulus increases the vertical stress within the rib pillars as well as the subsidence at the surface. The elastic modulus for the direct roof above the panel after excavation has found to be 225 $\leq$ immediate-roof (MPa) $\leq$ 180 in order to satisfy the total convergence between the roof and the floor. Representing the

goaf area as a material with linearly varying elastic modulus gives rational results in terms of convergence and ground surface subsidence.

[134] Effects of immediate roof thickness on lower sub key strata movement in ends of large mining height panel - H. Li, C. Liu, D. Jiang, H. Li & J. Feng (China)

Based on the 58 geological drill holes around panel 42105 in the Ordos coal field, a 3D geological model and 2D numerical model with real strata conditions were established. With the models, the effect of the immediate roof thickness on the ground pressure as well as the roof movement patterns under the varying immediate roof thicknesses were explored. Mechanical models of the lower sub key strata under differing immediate roof thickness were achieved through the use of field measurement, theoretical analyses, and numerical simulation methods. Meanwhile the effect of immediate roof thickness on lower sub key strata movement in ends of large mining height coal faces was studied. The discrimination formula of the movement patterns was deduced. The results show that when the immediate roof is relatively thick, the fractured lower sub key strata can be hinged to form a stable "Voussoir Beam" structure, which makes the ground pressure not severe and the shield pressure small in the ends of the panel. When the immediate roof is thin, the arc triangular of the lower sub key strata in the ends of the panel loses mechanical contact to the caved immediate roof and assumes a "Cantilever Beam" structure, which makes the ground pressure severe and shield pressure large in the ends of the panel.

[159] Numerical Simulation Technique for Gateroad Stability Analysis in Fractured Ground Condition - L. Jiang, A. Sainoki, H. Mitri & N. Ma (China)

The ground stability of gateroads is a major concern in underground coal mines, especially where the surrounding strata are weak and fractured. This paper presents a novel numerical modelling technique for gateroad stability analysis based on a case study conducted in Zhaogu No.2 mine, China. Considering the occurrence of fractures and their weakening effect on the stiffness of rock mass, a tension-weakening model is implemented into FLAC3D, whereby the stiffness of rock mass is progressively decreased according to failure state. A relationship between the intensity of fractures and the residual properties is built. A parametric study of the tension-weakening model with respect to weakening parameters is carried out, and the results are compared to a perfect elasto-plastic model and strain-softening model. The comparison shows that the tension-weakening model exhibits a noticeable effect on ground deformation and rock support loading, and can simulate more realistic behaviour of a gateroad, which agrees well with field measurements. The proposed model provides a rigorous approach for gateroad stability analysis and can be utilized for rock reinforcement design under similar geotechnical circumstances.

Session A-9: Mining Geotechnique and Safety Management

Time: 13:30 to 15:00 am

[197] Redesigning the geometry of the Makala Coal Mine to improve safety and productivity - J.P. Tshibangu & F. Descamps (Belgium)

Makala is a room-and-pillar coal mine situated in the Katanga Province (DR Congo), close to the city of Kalemie (eastern part of the country). It exploits the so-named Lukuga Coal Basin, which is composed of four coal seams numbered 1 to 4. The economically mineable are 1 (about 2m thickness) and 2 (1 to 1.5m thickness). This coal basin shows some similarities with South-African deposits (Cahen 1961, in Carte Géologique du Zaïre). From the West the deposit plunges towards the East with an average dip of 8°. Mining operations using room-and-pillar method started in 1914 on the northwestern part of the deposit, following the outcrops of coal seams. Currently only seam 1 is being mined out and the workings are being developed southwards to avoid the higher overburden towards the East. Despite the increasing thickness of the overburden, the geometry of the method does not vary, and consists of rooms 4m wide and pillars of 8x6m, leading to a recovery of about 60%. The main gallery lays from North to South for more than a kilometer. Panels situated on the western part of the main gallery are composed with stable pillars, while on the eastern part one can observe some typical problems like pillar fracturing, ground heave and roof falls. In this last case we noticed that the roof of seam 1 is of poor mechanical quality. In order to understand the geomechanical problems, we first built a 3D geometrical model, updating the mine layout and incorporating both geological and topographical data. This modeling has been achieved using the GEOVIA-GEMS software. The approach helped in assessing as accurately as possible the overburden to be taken into account when calculating the weight to be supported by pillars. From the defined geometry, we used the modified tributary area method (Brady and Brown 1999) to redesign the pillars accordingly. 2D numerical modeling has been used as well to assess the stability of the roof and dimension timber support used in the mine.

[63] Shear behaviour of regular and irregular rock joints under cyclic condition - M. Niktabar, K. S. Rao & A. K. Shrivastava (India)
The correct evaluation of shear strength and deformation of irregular joints is very important for the analysis and engineering design of rock structures. These joints are often subjected to dynamic loads because of earthquake and blasting during mining and rock cutting. Hence, it is important to correctly evaluate the shear behaviour of regular and irregular rock joints under dynamic conditions. In the present study, synthetic rock joints are prepared with plaster of Paris and regular joints are replicated by keeping regular asperities with asperity angles 15°-15° and 30°-30°, irregular rock joints are prepared by keeping the asperity angles 15°-30° and 15°-45°. The sample size and amplitude of roughness are kept the same for both regular and irregular joints and they are 298×298×125 mm and 5mm respectively. Shear tests have been performed with a large scale direct shear testing machine by keeping the frequency and amplitude of shear loads constant under cyclic load conditions and varying the normal stress. The shear strength of rock joints increases with increase in the asperity angle and normal load during the first cycle of shearing. With the increase in the number of shear cycles, the shear strength reduces for all the asperity angles but the rate of reduction is more in the case of high asperity angles. Test results indicate that the shear strength of irregular joints is higher than regular joints at low normal stresses. The mechanism of the shearing for regular and irregular joints is different at low normal stresses. Degradation of joint asperities on regular joints between loading and unloading are the same, but for irregular joints they are different at low normal stresses.

[150] Study on the performances of a protective door in coal permanent refuge havens – N. Gao, L-Z Jin, L-Y Fan, J. Shen, W-X Wang & J-G Liu (China)
An effective protective door for an underground refuge haven must have anti-explosion properties, anti-pressure properties, and sealing capabilities. In this study, Wulan Coal Mine's situation and the technical requirements for the protective door in the permanent coal refuge haven were analyzed and a numerical simulation analysis for the anti-explosion performance was performed. The materials, structure, and the sizes of the protective door were confirmed. Further, two experiments on the protection and waterproof abilities of the door were conducted. The results showed that a 15 mm thick 16 manganese steel plate door meets anti-blast and economical requirements. In addition, a manual wedge-shaped lock structure, a single-cast door wall, and a welding steel supporting structure can satisfy the airtight sealing and anti-pressure requirements. In the numerical simulation of the blast effect, it was observed that the maximum displacement was at the centre of the door, and the region of the highest stresses was around the door. The protective door could bear a 1 MPa explosion impact, and it could withstand a 1.86 MPa static pressure load with a deformation of 5.8 mm. Further, the door maintained good sealing performance until the hydraulic pressure exceeded 1.6 MPa with a deformation of 14 mm

[PPT] Safety Management - Cornerstone of Continuous Improvement Process – B. Chanda (Canada)
Continuous Improvement (CI) had its origin in the statistical quality control system which was developed in the US during the 1930's. Although CI was embraced by numerous industrial and service organizations in last fifty years, its implementation in the mining industry has been comparatively slow. This presentation explains why focusing on continual cost reduction will benefit commodity producers, which are regularly subjected to large price swings. The success of a CI-based program depends on management's ability to lead the employees to enthusiastically participate and assume the ownership of the process. By minimizing losses and prioritizing the creation of a safe workplace, management can enlist the energy of the workforce to support CI. Methods by which safety management can become a catalyst for the successful adaptation of a CI based program will be elaborated.

Session B-9: Innovations in Rock Supports

Time: 13:30 to 15:00 am

Keynote: [217] Behaviour of cable bolts in shear: experiment and mathematical modelling - N. Aziz, A. Mirzaghorbanali, H. Rasekh, J. Nemcik & X. Li (Australia)

The application of cable bolts for ground support is increasing in underground coal mines worldwide. Currently, two methods of evaluating the performance of the cable bolt are favoured: the short encapsulation pull test, and the shear test. The former method can be used both in the laboratory and in the field while the latter can be undertaken mainly in the laboratory. There are two methods of shear strength testing: single and double shear tests. This paper examines the double shear testing of several cable bolts currently marketed in Australia under various pre-tension stresses. Both plain and indented wire cable bolts were tested. It was found that the shear strength of the cable bolt was a function of the wire geometry and initial pre-tension. Indented wire cable bolts were lower in shear strength than the plain wire cable bolts. A mathematical model was proposed to evaluate the shear strength of cable bolts using Fourier series and a linear relationship between shear and normal loads. The model coefficients were determined based on the experimental results. The findings from the mathematical modelling tallied well with the experimental results.

[187] The tensile properties of GFRP bars at different loading rates - W. Chen, J. Wu, Y. Jiao, J. Zheng & X. Li (China)

In order to study the effect of loading rates on the tensile property indexes of GFRP (Glass Fiber Reinforced Polymer) bars, the tensile property experiments were conducted at four different loading rates by utilizing the electro-hydraulic servo universal testing machine. The results show that: with increases in loading rate, the ultimate tensile strength and the ultimate tensile strain increase, while the elastic modulus almost remains constant with the average value 28.5 GPa; the failure mode of specimens belongs to splitting failure and the stress-strain curves show a linear relationship. Based on the results and analyses, a loading rate of 2 mm/min is recommended when conducting experiments to determine the tensile property indexes of GFRP bars.

[PPT] A recent advance in ultrasonic monitoring of rockbolt condition - Z. Sun, K-T. Wu, S.E. Kruger, D. Rocheleau, R. Royer, R. Lacroix & T. Anderson (Canada)

Rockbolts play a vital role in mine safety. It is estimated that hundreds of millions of rockbolts are installed annually in mines and tunnels worldwide. It would be extremely beneficial if the integrity and load condition of installed rockbolts could be assessed on time and in a practical and cost effective manner. In the last three years and in collaboration with CanmetMining of Natural Resources Canada, the National Research Council of Canada has made significant efforts developing a state-of-the-art ultrasonic technology for rockbolt condition monitoring. The technology has proven to be able to monitor rockbolt load and deformation in a wide dynamic range up to rupture. Furthermore, the technology is robust and has the potential to be low cost and easy to implement. This presentation will provide an overview of the technology.

[231] Characteristics of acoustic wave velocity variation in the process of deformation and failure of loading coal - X. Li, B. Nie, C. Yang, Z. Cui & Y. Mao (China)

This paper is concerned with the characteristics of acoustic wave velocity change during the deformation and fracture of loaded coal. A self-made acoustic parameter test system is used to study the characteristics of acoustic wave velocity change in deformation and fracture of loaded coal, the mechanisms of stress influencing the acoustic wave velocity change, and the relationship between stress and longitudinal wave velocity and the impossibility of longitudinal wave velocity forecasting. The research results show that during the deformation and fracture of loaded coal the longitudinal wave and shear wave velocity increase. When the coal is damaged the longitudinal wave velocity decreases and the shear wave disappears. The stress-strain change of coal is highly similar to the stress-wave velocity change. The formula of stress and longitudinal wave velocity are established based on coal structure. The longitudinal wave velocity can be predicted well under varying stress by the formula of stress and longitudinal wave velocity. Stress influences changes in acoustic wave velocity mainly through the mechanism of coal structure change.