ITASCA™

40 YEARS

Underground Mining Services and Statement of Qualifications

ICG21-SOQ-UNGD-01

GEOMECHANICS • HYDROGEOLOGY : CIVIL • MINING • ENERGY

"Forward Thinking Engineering and Science"

CONTENTS

Itasca "the true source"

In 1832, an expedition to the Upper Mississippi by Henry Rowe Schoolcraft and William T. Boutwell discovered the source of the Mississippi River; Lake Itasca, an amalgamation of Latin syllables meaning the true source.

ITASCA INTERNATIONAL

Itasca International Inc. is an engineering consulting and software development company founded in Minneapolis, Minnesota with 9 offices worldwide. Itasca specializes in solving complex geomechanical, hydrogeological and microseismic issues in mining, civil, oil & gas, energy and manufacturing. Itasca works directly with industry, government, research and education institutions and as a specialist to other consulting engineering firms.

Founded in 1981, Itasca has gained practical and technical knowledge of world-class mining challenges and solutions. Itasca is staffed by leading engineers in the fields of rock mechanics, hydrology, hydrogeology, geochemistry, mining engineering and software engineering. Our experienced staff work on projects ranging from practical field solutions to design issues to applications of Itasca modeling tools for solving difficult or unusual problems, including a wide range of mining methods (from large open pits to deep underground operations) and materials (from soil and engineered materials to soft and hard rock).

Itasca understands the logistical constraints that often are encountered in solving engineering problems. Therefore, we believe in using the most appropriate levels and methods of engineering investigation that examine both technical and economic factors in order to provide practical solutions using the most suitable and best-available technology.

Use of numerical simulation software is an integral part of our consulting. Our state-of-the-art numerical modeling programs are among the most widely used and respected tools of their kind. Development of our advanced numerical simulation software sets Itasca apart from other geotechnical and mining consulting firms. Itasca benefits from the dynamic interplay between our consulting, software development and contract research activities.

Our software is developed and proven with real-world problem solving driven by our consulting work.

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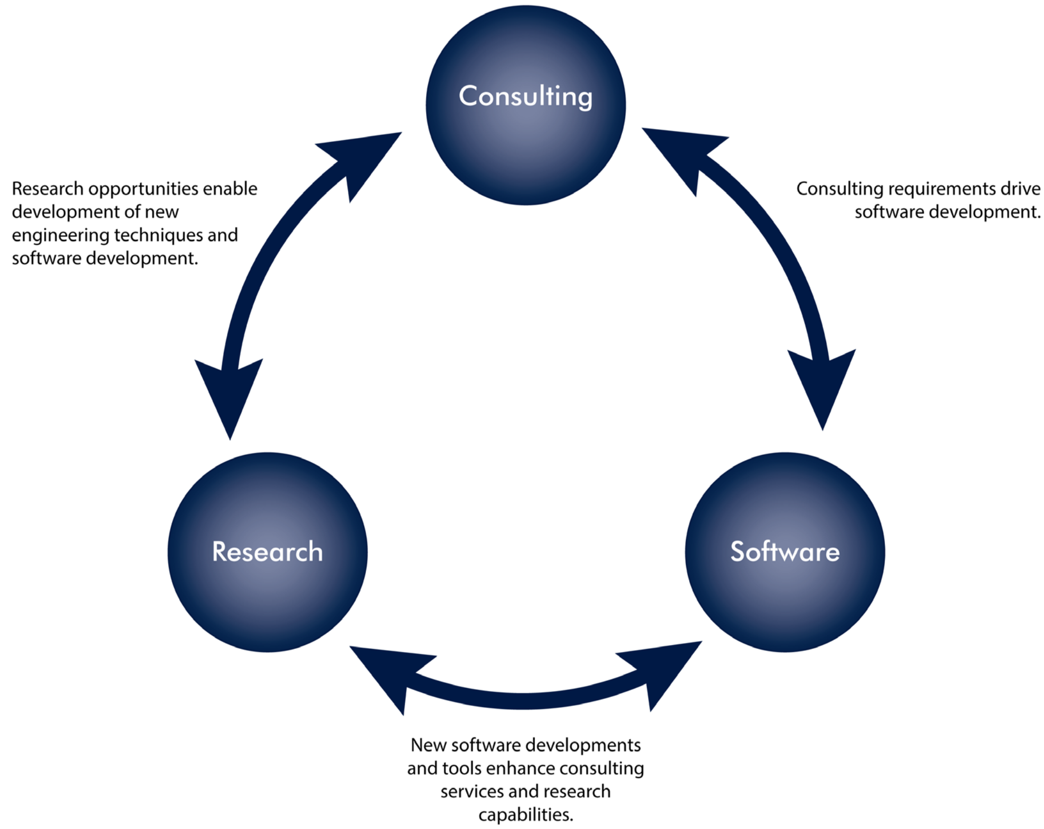


Itasca's consulting and research evolves our software, which in-turn provides more advanced tools for us to use towards solving complex problems for our clients.

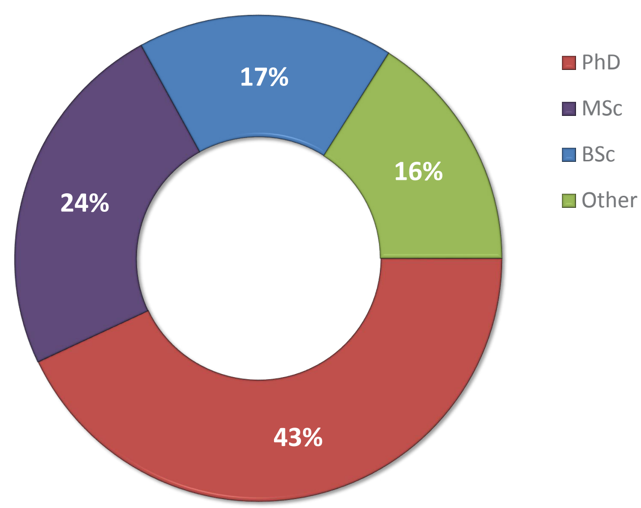
Our engineers and software developers have a proven track record of innovation, leading to new strategies and tools to better understand the complex environments in which mines exist.

With a large portion of our engineers possessing advanced degrees and mining experience, Itasca has been selected as the lead research group for three important mining consortia:

- International Caving Study (ICS)
- Large Open Pit (LOP);
- Mass Mining Technology (MMT);
- Hybrid Stress Blast Model (HSBM); and
- Caving 2040 Mining Consortium

Each of these projects brought together international mining companies that pooled their resources to tackle problems of common interest.

Itasca also fosters education and university research worldwide though the Itasca Education Program (IEP) and Itasca Teaching Program (ITP), which offer our software free to qualified students and lecturers.



In addition to practical experience, two-thirds of Itasca personnel have advanced degrees in engineering, science or computer programming.

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10 main **consulting offices** in 9 countries, and **software agents** based in another 11 countries, focused on servicing the global mining, civil, and energy industries.

MINING SERVICES

Itasca's global experience and expertise in geomechanics, hydrogeology and microseismics are employed by our clients to select the mining method, sequence and ground support that will maximize ore recovery, excavation stability and operational safety while minimizing development costs and maximizing ore recovery.

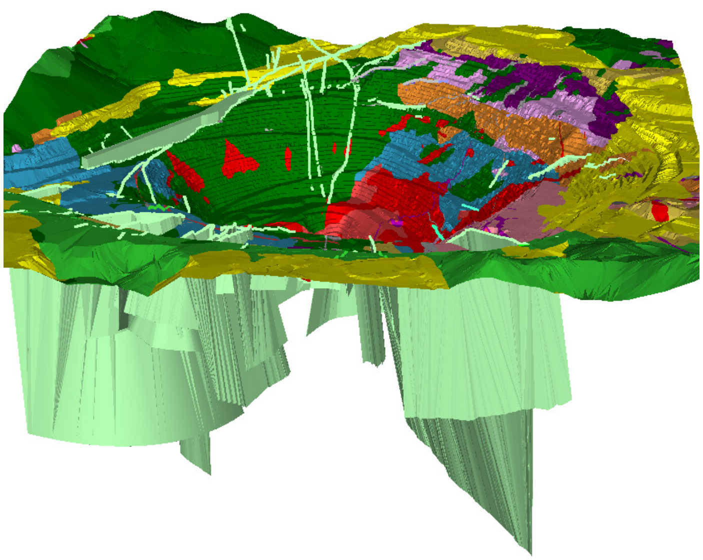
Itasca has analyzed the behavior of excavations in all types of rock and at all scales, from individual boreholes and access tunnels to the complete sequencing of the largest underground mines and deepest open pit mines in the world. Individual projects often require analyses over a wide range of scales due to the complex interaction between the overall mine advance, in-situ stresses and the loading conditions experienced on the scale of critical infrastructure.

Itasca is a recognized leader worldwide in geomechanical numerical modeling of complex mining environments. While this remains our core focus, Itasca's capabilities extend beyond this as a complete mining engineering service provider, as shown in the next sections.

Although Itasca has a reputation for numerical modeling, our consultants are out in the field every day assessing site conditions and characterizing the structural geology and rock mass data crucial for good engineering solutions.

Structural Geology and Rock Mass Characterization

In order to develop a robust structural geology model, Itasca assesses the existing data in collaboration with our clients to assess any gaps, and then applies a number of techniques as appropriate. These can include lineament analysis, precise structural mapping (outcrop, open pit and underground), drill core logging, televiewer analysis and stereophotos.



Datamine plot of a structural fault model with pit geology.

Rock mass strength estimation is required in order to predict the excavation response at the mine site. Obtaining accurate rock mass strengths requires an understanding of the intact rock and joint properties of each geotechnical unit and the in-situ stress state. Itasca can facilitate, interpret and apply both field/laboratory strength testing and in-situ stress measurements. We use traditional engineering approaches including mechanical, empirical and numerical to estimate rock mass strengths, and have pioneered innovative numerical techniques such as Synthetic Rock Mass (SRM) simulations. This approach allows our consultants to model rock mass behavior for any given range of anisotropies, scales, properties and conditions, giving Itasca an understanding of rock mass that is second-to-none.

Site Investigation 2012

Project Description

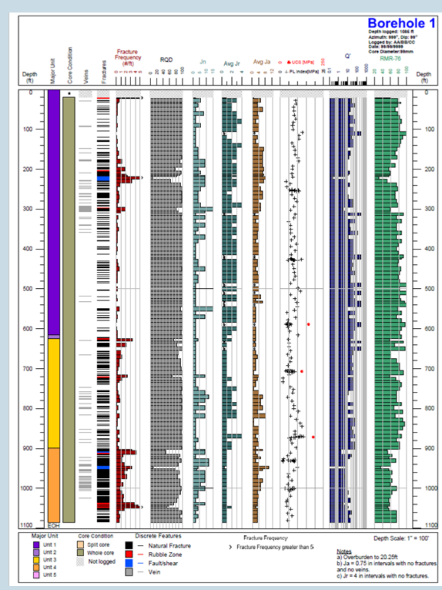
Itasca was asked to conduct a geotechnical field program for the prefeasibilty study of a mine. The site investigation involved data collection and analysis for rock mass characterization.

Itasca's Contribution

The field program included geomechanical core logging, point load testing and analysis of down hole acoustic televiewer (ATV) logging data from exploration boreholes. Geomechanical core logging data and point load strength testing data were used to empirically estimate rock mass quality using both the Q' system and RMR system. Itasca performed quality checking of ATV logging data as well as an assessment of various logged parameters on a global and local basis. From the ATV logs, Itasca identified borehole breakouts to investigate in-situ stress orientation. A fracture frequency comparison was conducted to identify possible bias between ATV logging and geomechanical logging.

Outcomes

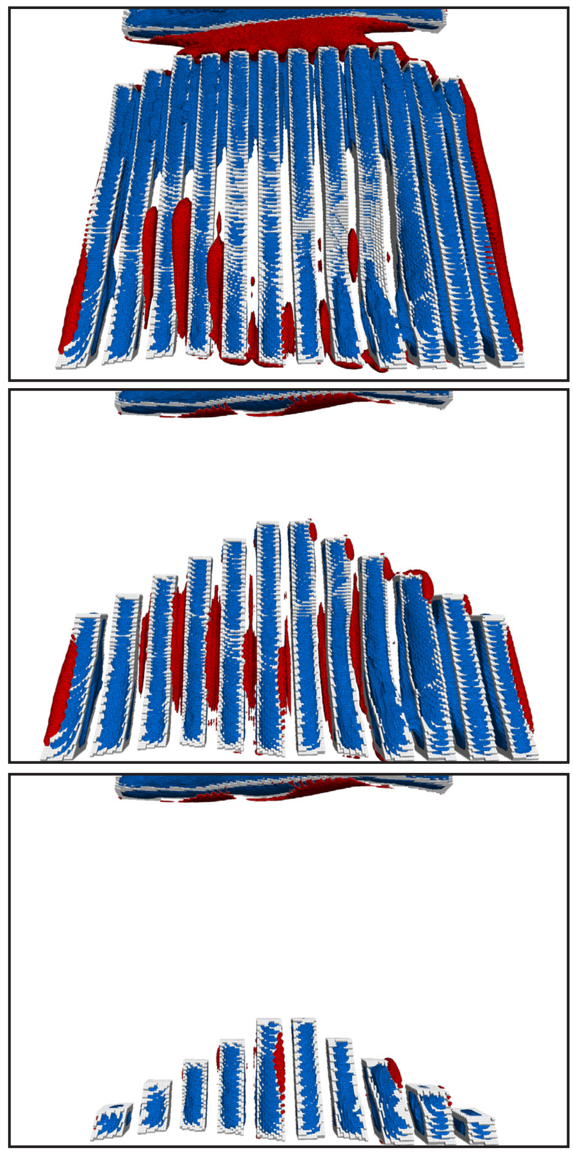
Itasca used core logging data and ATV logging data to identify distinct domains in the area of interest to produce summary statistics and graphics showing global and local distributions of Q' and RMR. Borehole breakouts provided an estimate of the principal horizontal stress magnitude and direction. Fracture frequency comparison of core and ATV logging showed a slight bias in the core logging.



Summary of bore hole logging data.

Mining Method Selection

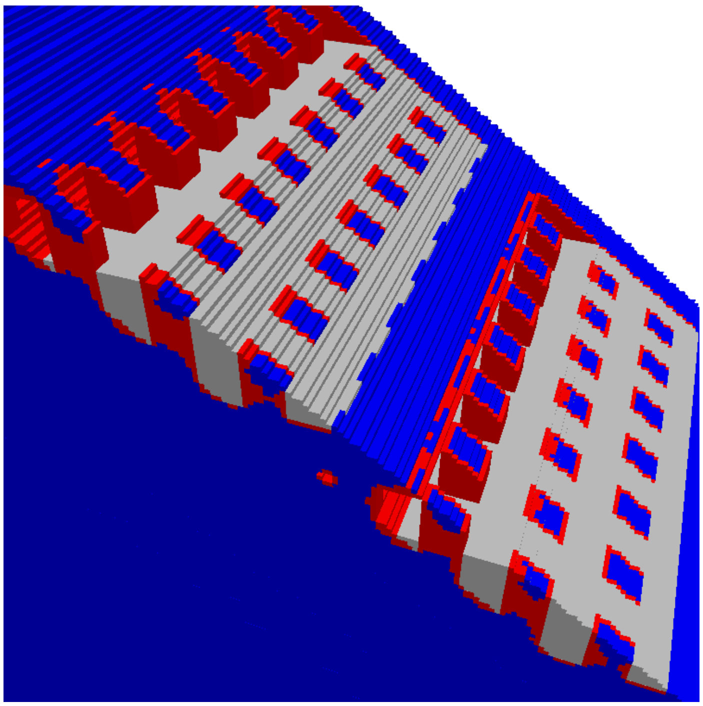
Combining our experience, conventional approaches and numerical modeling tools, Itasca is able to simulate mining of our client's sites first, so as to select mining methods appropriate to the orebody geometry and rock mass strength conditions. Itasca understands the economics involved in any mine design and ensures that mineral recovery is optimized while maximizing excavation stability. Using our suite of modeling software, Itasca can implement any number of mining methods with a range of property, economic and site condition sensitivities to virtually excavate the mine. Designs, properties and conditions can be revised readily over time using the best information available.



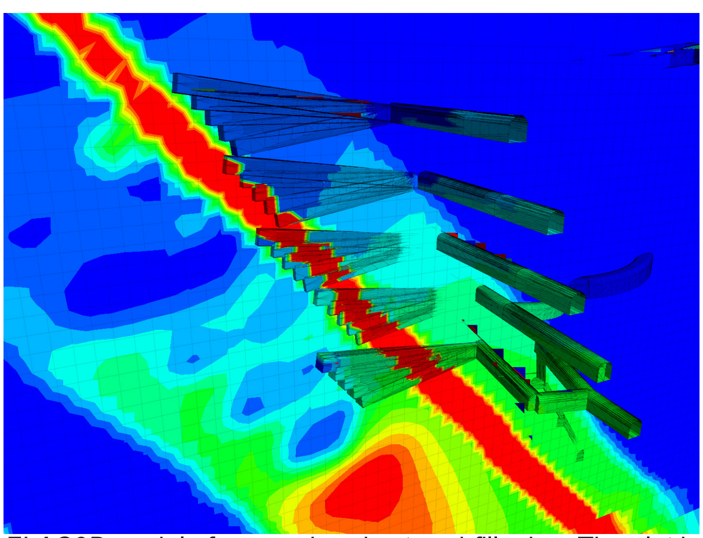
FLAC3D model of pyramid mining sequence of a panel showing mining-induced stress changes around the advancing stopes. Stress is seen concentrating (red) in the sill pillar between panels.

Stope Design

Itasca regularly performs evaluations and designs for long-hole, cut-and-fill, room-and-pillar, longwall and solution stopes. As with all our work, our engineers combine a practical engineering approach with numerical modeling technologies where appropriate. Itasca's software is particularly good at representing the stress-strain response of intact, blocky or bedded materials exhibiting plastic, brittle and creep behaviors over all scales of mining; thus, any combination of mine geology can be simulated.



FLAC3D model of a step room-and-pillar stope sequence with fill (gray) is used to optimize pillar and room dimensions.



FLAC3D model of an overhead cut-and-fill mine. The plot is shown in section with mine infrastructure extending out-of-the-plane.

[1]Brunswick Mine 2011

Project Description

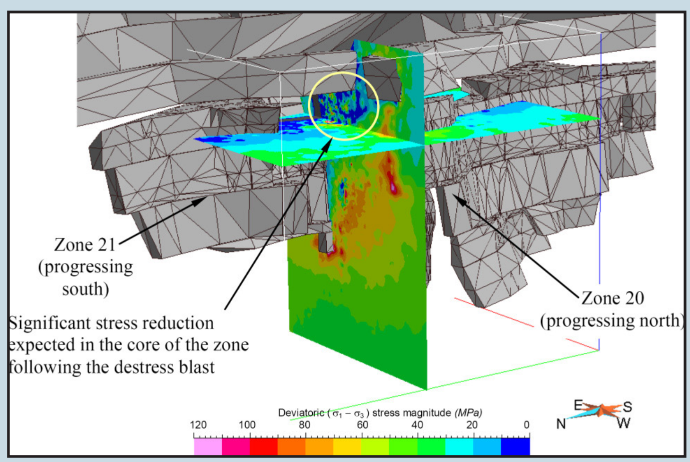
In continuous operations since 1964, the Xstrata Zinc Brunswick Mine has experienced considerable rock mechanics challenges with increasing extraction ratios, while maintaining safety and production. For example, in Zone 20-21, two mining fronts converge with critical life-of-mine orepass infrastructures located between them, and in Zone 11 mining is conducted at depth in close proximity to a main orepass and a critical ventilation raise in difficult settings.

Itasca's Contribution

Itasca developed a systematic iterative process, combining state-of-the-art mine-wide seismic monitoring, underground instrumentation and observations, and advanced three-dimensional inelastic numerical modeling to optimize the extraction sequence in the various mining fronts.

Outcomes

The continuous loop between recorded seismicity, underground observations and numerical modeling has led to numerous strategy revisions in both zones, which have resulted in a viable, economical and successful design in both areas, in spite of a highly adverse set of conditions.



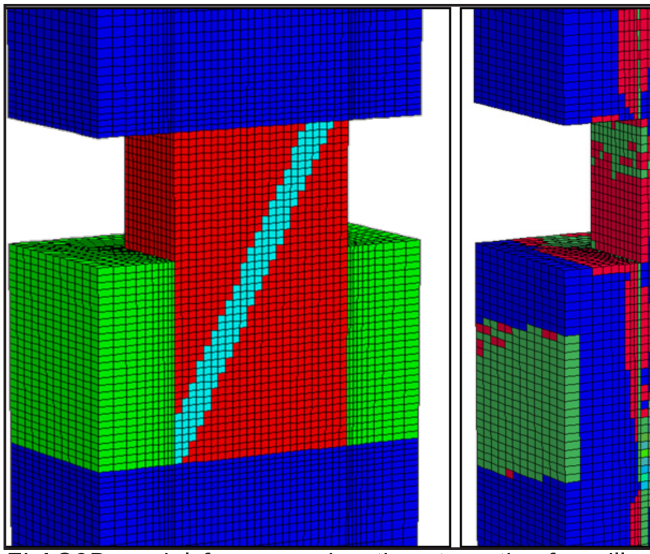
Isometric view looking south-east at the deviatoric stress levels predicted with *3DEC* in the regional pillar core after the destress blastings, with additional stopes between the converging zones.

Pillar Design

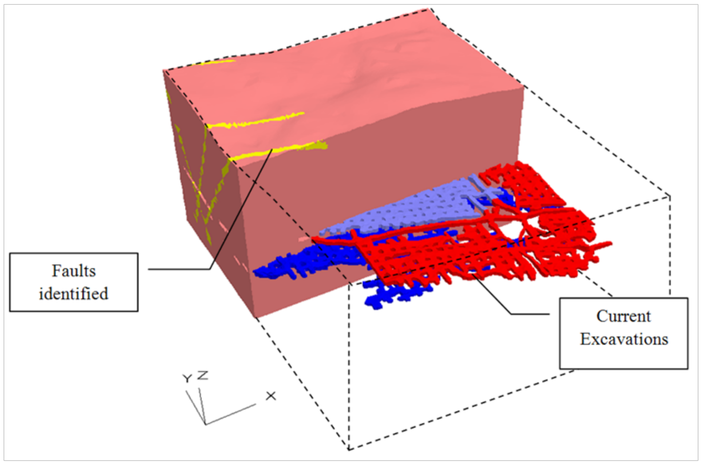
Itasca routinely performs mine design and evaluations of room-and-pillar and longwall operations excavated in rock ranging from limestone and granite to coal and trona.

Unique and robust approaches to pillar design have been developed that recognizes the importance of understanding the rock behavior from down to intact rock cores through to bedded sequences and up to the overall mine scale. Itasca's rock-engineering software is capable of representing the stress-strain response of continuous, blocky or bedded materials exhibiting plastic, brittle or creep behaviors; thus, any combination of lithology comprising the pillar-floor-roof system can be analyzed.

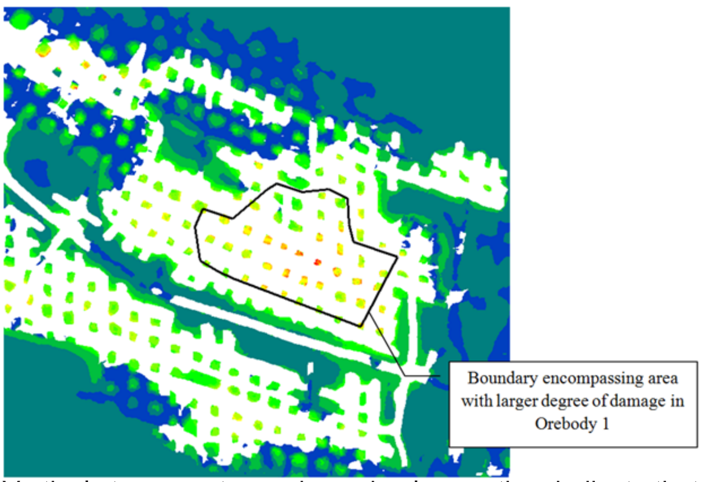
Itasca simulations are capable of reproducing the complex combination of pillar sloughing (rib rash) and floor heave experienced at different extraction levels and vertical stress levels throughout a mine. Information derived from these pillar-scale models forms an essential input to larger-scale models, which have been used extensively for design of individual panels (width, remnant stub width and extraction ratio) as well as barrier pillars, and the overall mine layout and extraction ratio. These larger-scale models have been validated through successful back-prediction of the timing and nature of large-scale catastrophic collapses experienced in the region.



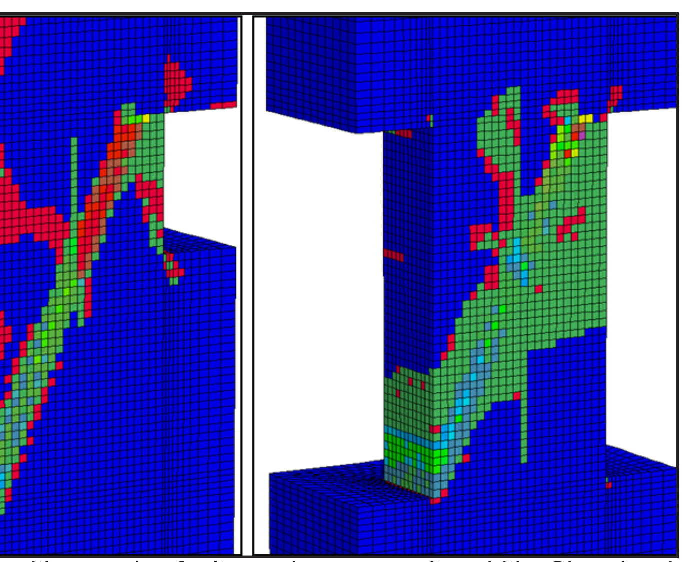
FLAC3D model for assessing the strength of a pillar observed in beyond the initial floor of the level, becomi



Mine-scale *FLAC3D* model including large faults that are represented by a ubiquitous joint material.



Vertical stress contours shown in plan section, indicate that an area observed to have a larger degree of pillar damage coincides with the highest pillar stress concentrations in the model.



with a major fault running across its width. Shearing is ng more extensive as mining progresses.

[2]Inclined Pillars 2013

Project Description

Mines often rely on worldwide empirical estimates of ultimate pillar strength for room-and-pillar mine planning. Many operations face the need to design their pillars in schistose rocks within inclined orebodies. In such cases, design curves are limited by the following.

- The empirical data does not include real failures with width to height (W/H) ratios greater than about 1.5. Modern designs can have W/H ratios exceeding 2.
- The design curves do not explicitly account for inclined orebodies, square pillars or weak hangingwall and/or footwall contacts.
- There are no foliated rocks in the empirical database.

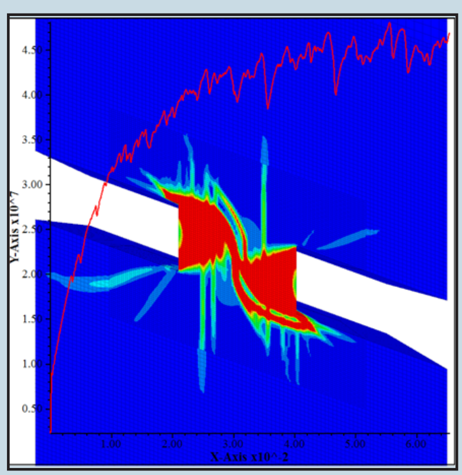
Itasca's Contribution

The pillar ultimate strength and/or transition to pillar hardening behavior are largely dependent on the post-peak material response, including softening rate, residual strength and brittle-to-ductile transition. For this work, the pillar rock behavior model used a strain-softening material model (i.e., cohesion and tension varied from peak to residual strength over a defined amount of plastic shear strain).

Outcomes

As expected, models indicated a reduction in pillar strength (wrt to design curves) due to pillar inclination and anisotropy in shear strength (i.e., schistosity).

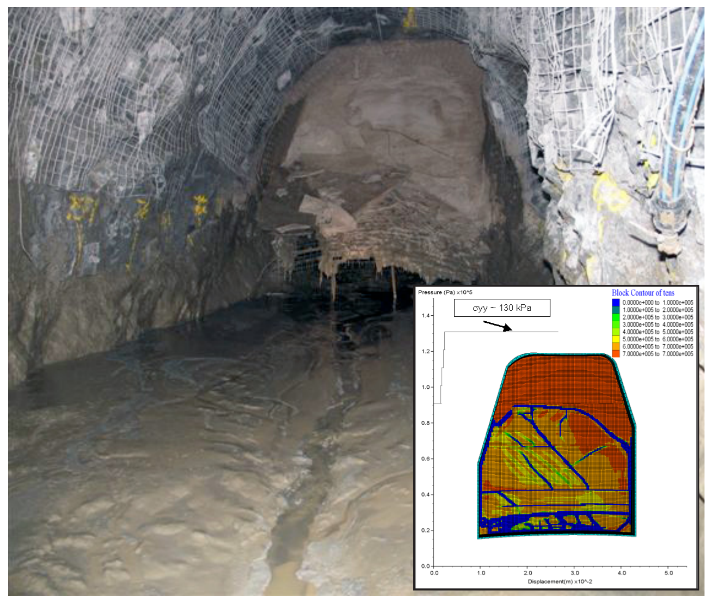
Pillar strength was estimated to reduce by approximately 10% for a pillar with W/H ratio of 1.8 and lower strengths resulted from steeper inclinations (i.e., greater than 20°).



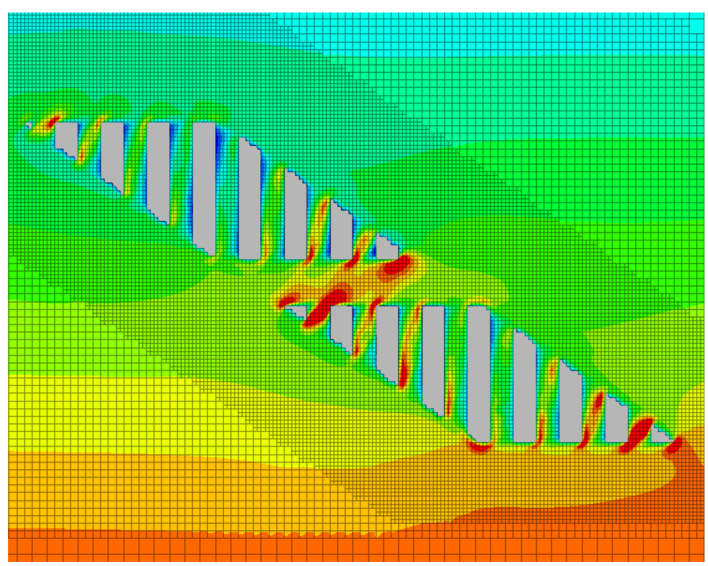
Shear strains within the pillar during the post-peak strength. Load applied on the inclined pillar is overlain in red.

Backfill Design

Itasca offers services in backfill characterization, specification, design of backfill mixing and delivery systems, stability analysis (exposure stability, reinforcement and closure resistance), dynamic modeling to examine stability and liquefaction potential under rockburst and rockfall conditions, and instrumentation and testing of placed backfill. These services cover a wide range of backfill products (paste fills, hydraulic fill, cemented aggregate fill and rockfill) and have been applied to mining operations throughout the world. Itasca also has developed specialized methods for simulation of the deformation and yielding of backfill, bulkheads and backfill mats.



Itasca uses *FLAC3D* models in order to better understand and improve backfill barricade designs.



Section view through orebody with backfilled stopes showing the predicted ground stress response to a particular mining method, sequence and stope design.

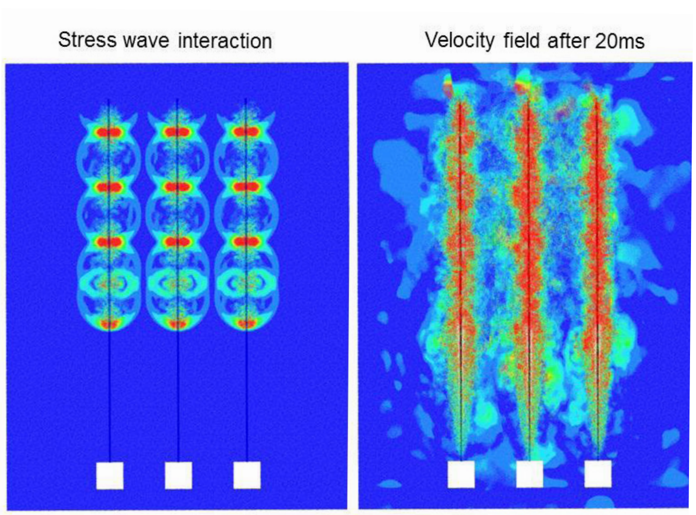
ITASCA™

Blast Design

Itasca provides consulting services for:

- Drilling and blasting engineering;
- Blast optimization:
  - Fragmentation;
  - Muckpile profile;
  - Throw;
  - Vibrations;
  - Back control;
- Large-scale destress blasting; and
- Design monitoring systems, so that performance can be assessed and optimized.

In addition to conventional analytical and empirical methods, Itasca has developed proprietary tools for blast analysis as part of the HSBM consortium that can be used to understand blasthole-to-blasthole interaction, optimize fragmentation and throw, and minimize undesirable damage (e.g., smooth blasting for wall control). This unique blasting simulator is capable of modeling a variety of geometries. Blasthole patterns and explosives loading may be defined individually or as groups (patterns). *Blo-Up* simulation results include final muckpile profile, fragment velocities, blasthole gas pressure and fragmentation and material distributions. Although *Blo-Up* is not available commercially, Itasca does use it in consulting work.



Velocity plots of a *Blo-Up* simulation for parallel blasts indicating stress wave interaction.

[3]Paste-Fill Exposures at Raleigh Mine 2007

Project Description

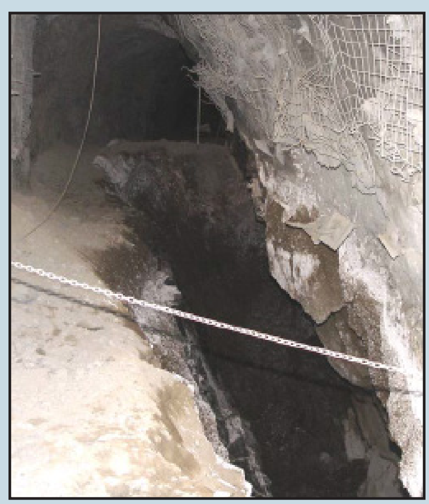
In order to prevent excessive ore dilution, any mine backfill must be of sufficient strength to prevent failure during exposure. The up-hole bench extraction strategy at the Raleigh Mine required simultaneous horizontal and vertical exposure of narrow (2.5 - 3.5 m) paste filled stopes. Due to the narrow exposure span, high closure strain caused by deformation of the adjacent rock mass is likely to cause a stiff, brittle fill material to undergo crushing failure.

Itasca's Contribution

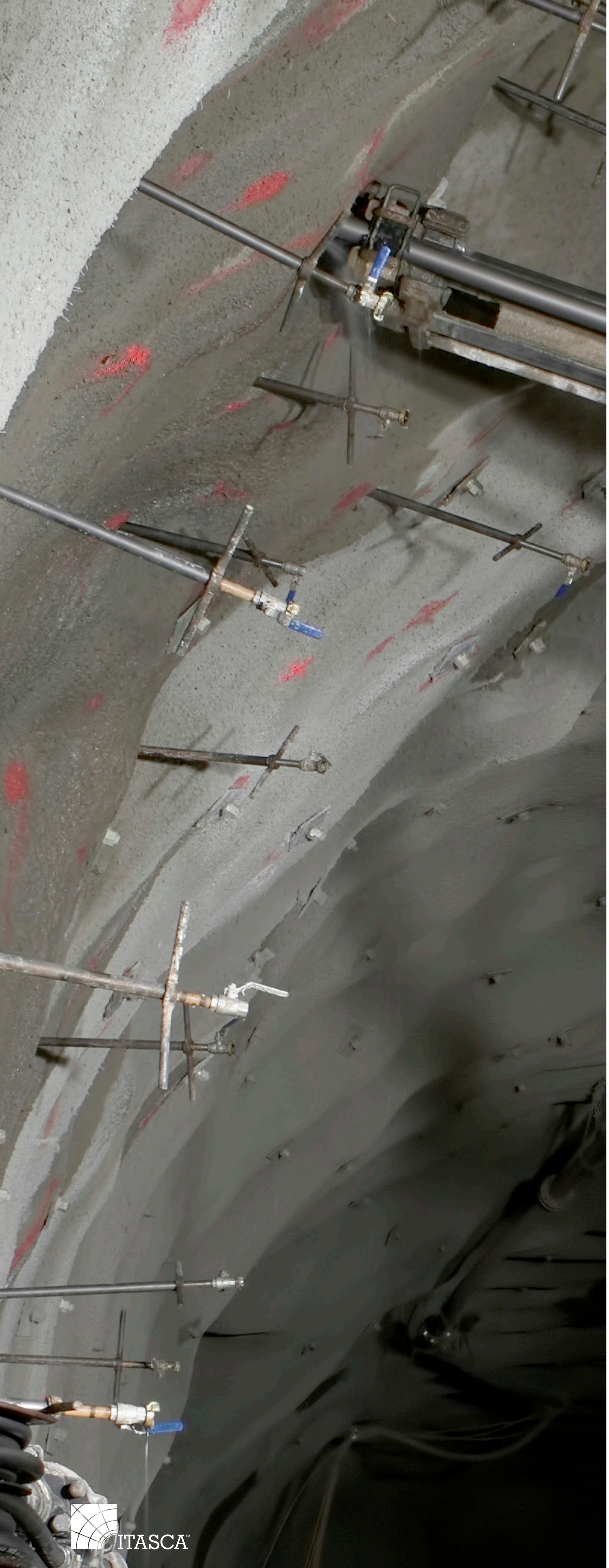
A numerical modeling methodology was developed to accurately simulate the initial stress distribution within paste filled stopes, together with the strain-softening loading response of paste fill material. The stability of paste fill exposures at the Raleigh Mine was determined by conducting a series of three-dimensional numerical models that incorporate the extraction, filling and exposure sequence of paste filled stopes.

Outcomes

Stability charts for 2.5-m and 3.5-m wide simultaneous horizontal and vertical exposures have been derived based upon the numerical modeling results. Implementation of the stability charts has proved successful in limiting the amount of ore dilution from paste fill and provides a basis to optimize paste fill cementation and stability throughout the life of the mine.

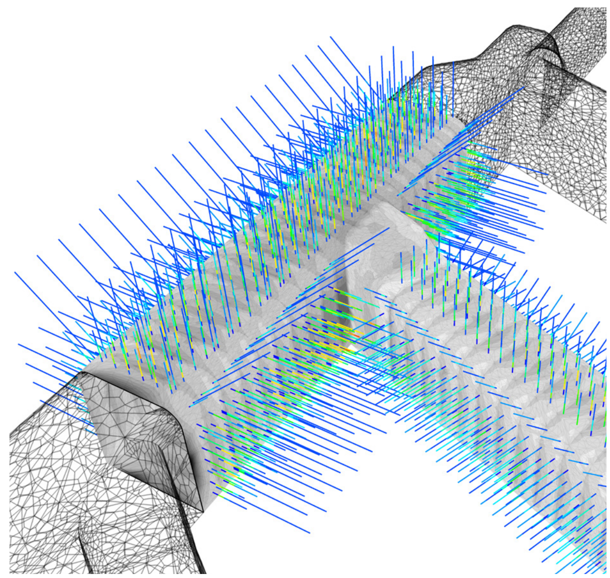


Vertical paste fill exposure at the Raleigh Mine.

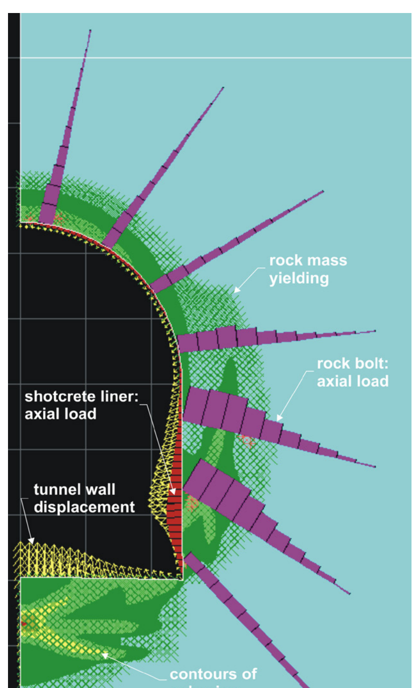


Ground Support Design

Itasca designs the ground support layout and specification necessary to reinforce, retain and hold the rock mass around excavations. We design ground support using a combination of engineering tools such as Ground Reaction Curves and practical numerical modeling tools based on instrumentation data where available. Ground support elements (rock bolts, cables, liners, etc.) are an integral component of much of Itasca's software. We also design instrumentation programs to validate and subsequently monitor the support design over the life of the excavation.



Evaluation of an underground cable bolt and shotcrete support design using *FLAC3D*. Loads acting axially along the cables are indicated.



FLAC model of a mine horseshoe drift supported with rock bolts and a shotcrete liner. Plasticity around the drift indicates the depth of yielding expected. Other results shown include tunnel convergence and forces acting on both the liner and rock bolts.

4 Support Audit 2005

Project Description

In the life of any aging underground mine comes a moment when the quality of previously installed ground support needs to be evaluated. This can be driven by a number of reasons, including the following.

- Old mine workings need to be used again. Existing ground support must be evaluated and likely brought to the current standards.
- Critical infrastructure must remain problem-free during the entire life of the operation. Any potential instabilities have to be identified early and addressed.
- Management wants to ensure that the underground infrastructure is in good condition and continuously maintained.

Itasca's Contribution

Itasca was asked by the Xstrata Zinc Brunswick Mine to assist the operation's Ground Control Department with a mine-wide ground support audit. The inspections themselves were carried out over a two-week period, and were followed by digitization of the collected data and the development of a custom data management system.

Outcomes

Following an audit, the collected information was digitized, cataloged in a database and linked to the mine's CAD system. In this form, it became available electronically, and hence, easy to query. Having the ability to relate collected information to ongoing rehabilitation work made the database application more versatile, providing its users with a means of assessing how the information collected by the audit was addressed.

5 Stope Modeling 2012

Project Description

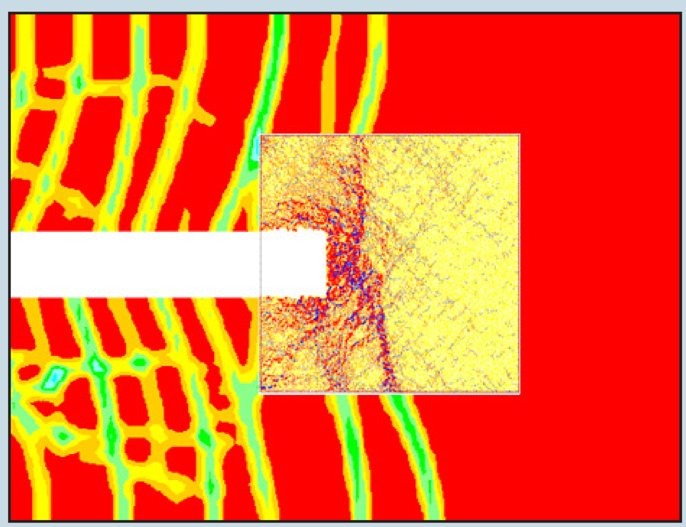
Itasca has been working with AngloGold Ashanti to understand rock behavior, especially brittle failure mechanisms, inherent in deep gold mines in South Africa. The ultimate goal of this work is to develop a rational methodology for mine design and pillar dimensioning, especially as mining continues deeper.

Itasca's Contribution

A generic mechanical model for rock behavior around advancing stopes in deep gold mines has been developed using a coupled continuum-discontinuum technique, where a larger-scale continuum region is modeled by *FLAC* and a more detailed discontinuum region near the stopes is modeled by a *PFC2D* model embedded within a larger *FLAC* model.

Outcomes

The simulations can reproduce the well-defined shear fractures and stope-parallel extension fractures similar to those observed in the field, where the discrete material exhibits formation of conjugate shear fractures that correspond with shear fractures in the continuum material. Additional damage structures appear to be present within these shear fractures — e.g., en echelon fracturing is similar to what is observed in actual shear fractures underground, evidence of spalling at the stope face, distributed damage ahead of the stope face and formation of extension fractures.

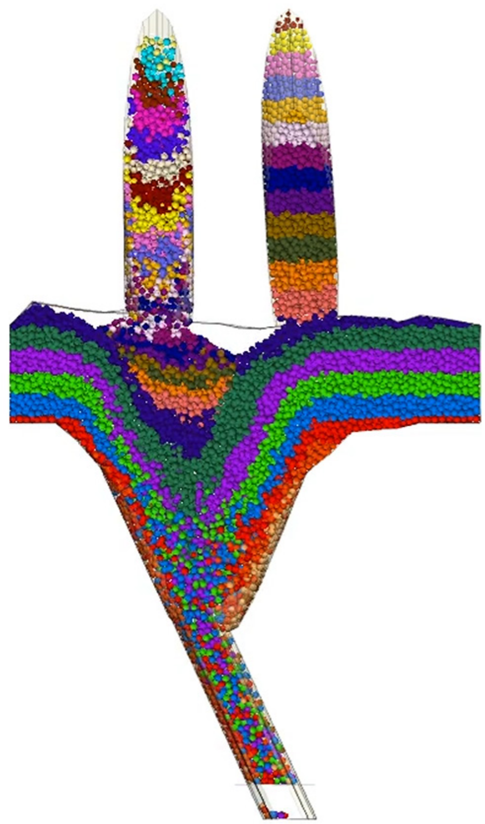


Superimposed, coupled models at stope half-length of 19.2 m. The plots indicate the maximum shear strain (*FLAC*, outer domain) and microcrack damage (*PFC2D*, inner domain).

Infrastructure Design

Robust designs for critical infrastructure (access and ventilation shafts, crusher stations, haulage drifts, etc.) are essential to ensure the long-term stability, mine viability and safety of personnel. Once the location, orientation and geometry of an excavation have been designed, long-term considerations such as the impact of future adjacent excavations on stability must be considered.

A number of design issues require consideration when developing infrastructure in rock or soil that impact an excavation's long-term stability; in-situ and mining induced stress, geologic structures and other intersecting developments can be assessed by Itasca in order to compensate the design as necessary. We perform complete analyses using the most appropriate empirical, analytic and numerical tools available.



Ore passes experiencing preferential pull were simulated with a particle flow model (*PFC3D*) using surveyed excavation geometry in order to evaluate remediation methods.

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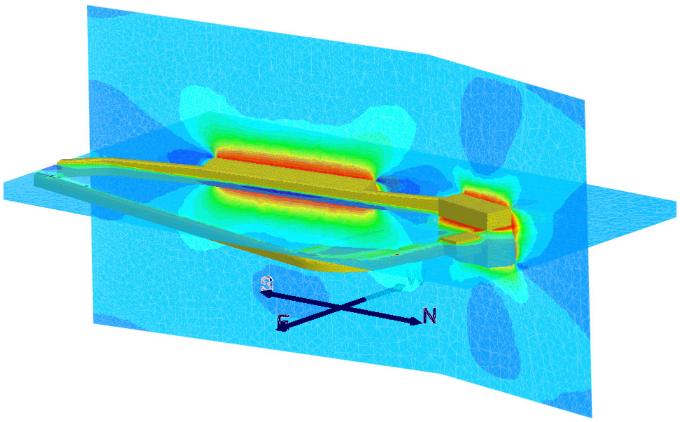
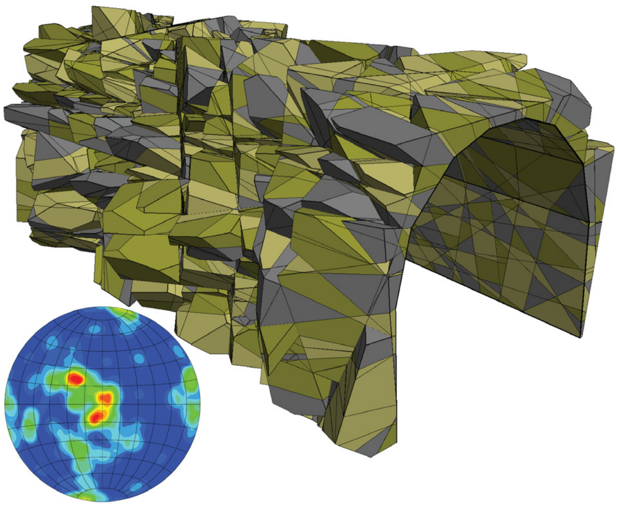
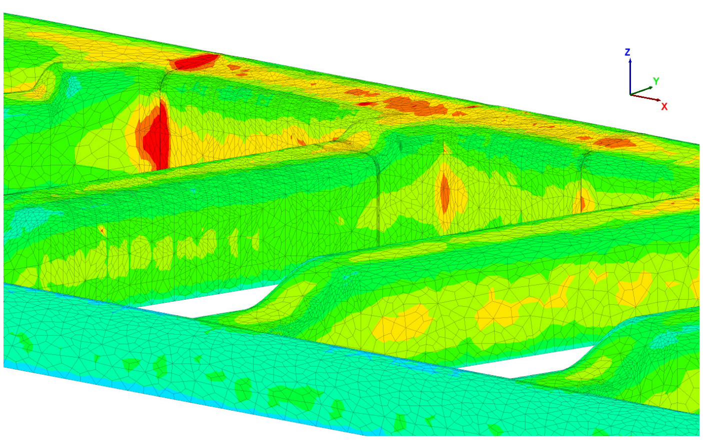


Stress plots along several cut-planes suggest very little interaction would be expected between two large underground caverns constructed in close proximity.



By simulating all of the wedges surrounding a horseshoe tunnel using multiple DFN realizations, block size and ground support can be estimated to minimize stability risks for critical openings.



Stresses at the junction, walls and back of several mining bays in close proximity permit offset and support needs to be estimated prior to development.

Crusher Chamber 2010

Project Description

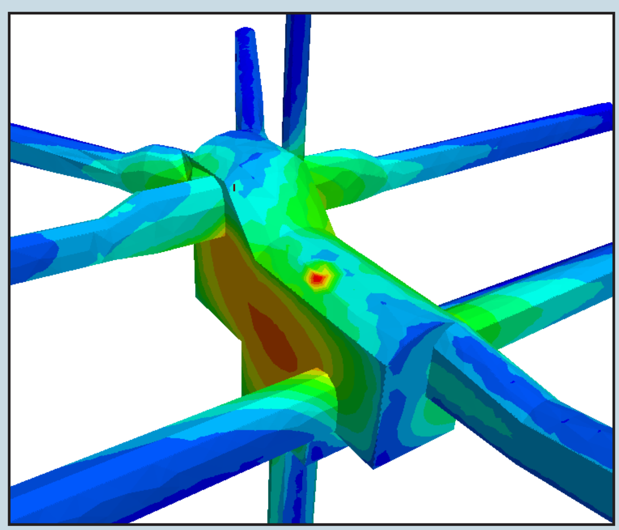
A crusher chamber with a relatively complex shape is located less than 100 m from an active cave boundary. The crusher feeds an orepass to a transfer station below.

Itasca's Contribution

The chamber was analyzed using a combination of empirical, analytical and numerical stability estimates. *FLAC3D* numerical models incorporated both a strain-softening material in order to assess the location and severity of damage to the surround rock and a mining induced stress path that evolved from nearby cave propagation over the 15 years of mining. Separate analyses also were conducted to examine the potential of structural instability and design the ground support.

Outcomes

The analysis indicated stable unsupported excavations under the worst stress conditions with closure strains, which generally indicate supportable conditions using rockbolts, cables and shotcrete. The estimated depth of failure around the excavation was up to 3 m thick. A sensitivity study in which the strength was varied from the base case failure envelope by ±10% showed only incremental differences in failure depth or deformations from the base case. A simple assessment of potential seismic impacts from cave-related rockbursting indicated only minor impacts to ground support loading.



FLAC3D model of a crusher chamber and nearby drifts and passes. Contours of displacement are indicated.

HYDROGEOLOGY

Itasca hydrogeologists have extensive experience in assessing key hydrogeologic issues related to underground mining operations and projects, including:

- Groundwater inflow to mine workings for determining pumping and handling requirements;
- Pore-pressure distributions for assessing underground infrastructure and slope stability;
- Pore-pressure reduction methods;
- Prediction of moisture content for evaluating mud-rush potential; and
- Prediction of water quality for meeting regulatory discharge limits.

In addition to conventional data collection, field investigation and field monitoring, Itasca is unique in that our hydrogeologists and geomechanical engineers work closely together to account for the influence of mining over time in both hydrogeological and geomechanical models. Nearly all of the work involves three-dimensional transient groundwater flow simulations.

Itasca's models have simulated the temporal propagation of the enhanced permeability efficiently and realistically within the extent of disturbed rock due to mining. Itasca has constructed three-dimensional groundwater flow models to predict both inflow and pore-pressure distribution for dozens mining projects.

Geochemistry

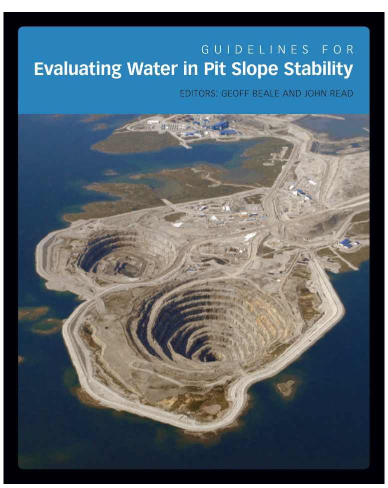
Itasca geochemists are experienced in predicting the water quality of mine water. Itasca investigates the effects of fine caved materials on the enhanced leaching of chemicals from caved material to groundwater, the water quality of potential pit lakes including open pits or transition from the open pits to underground workings, and the temporal/spatial distribution of key chemical components.

MINEDW

Itasca's *MINEDW* is commercially available groundwater flow software that is specifically designed to simulate complex mining-related groundwater conditions. In contrast to the general industry modeling practice, which requires many intermittent yearly models, *MINEDW* models are computationally efficient and robust, reducing overall modeling costs and avoiding complex management of modeling files and data. *MINEDW* three-dimensional groundwater flow models are capable of simulating enhanced permeability around the mine and over the life of the mine using a single transient model simulation. The calculated two- and three-dimensional pore pressures from *MINEDW* can be imported seamlessly into Itasca's suite of geomechanical software for use in geomechanical stability analyses requiring a minimal amount of time, on the order of minutes. For example, a Chuquicamata Open Pit and Block Cave groundwater flow model required only one transient simulation to calibrate past open-pit operation calibration, starting in 1970, through to the end of block caving. The entire running time for this simulation (on a regular desktop) was less than one day.

LOP

As part of the Large Open Pit (LOP) project, Itasca has been instrumental in the publication of **Guidelines for Evaluating Water in Pit Slope Stability**, a comprehensive account of the hydrogeological procedures that should be followed when performing open pit slope-stability design analyses. (Click on the cover image below for more information.)



[6]Hydrogeology 2013

Project Description

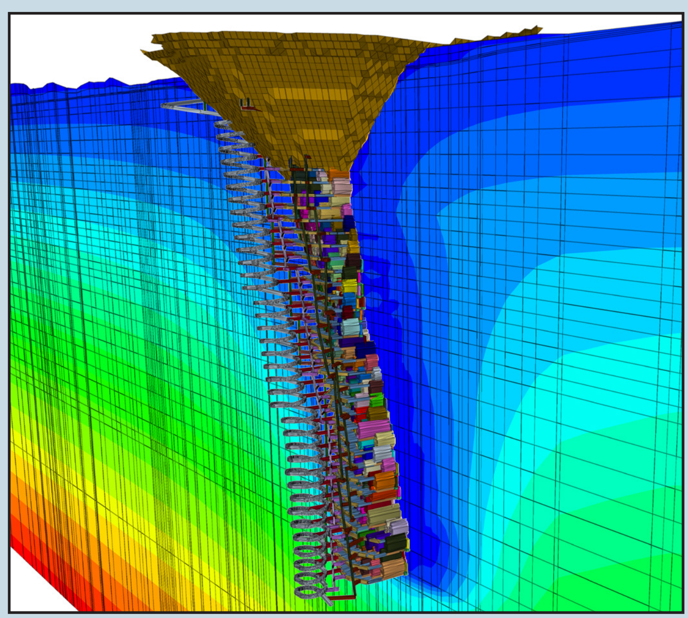
A combined mining method of open pit mining, open benching and sublevel retreat (SLR) is proposed for a steeply dipping pipe-shaped deposit in Guyana. Highly foliated sericitic schist bound the orebody on two sides extending along strike beneath the Cuyuni River. Of potential concern was the increased hydraulic conductivity created along these foliated bands due to mining-induced disturbance or relaxation.

Itasca's Contribution

Two numerical models were created in conjunction such that the staged results could be coupled, providing a more appropriate approximation of pore water pressure distribution (*MINEDW*) to the mechanical model (*FLAC3D*), and providing the hydrogeologic model updated zones of higher permeability.

Outcomes

Results of the coupled modeling indicate that rock mass disturbance is not likely to propagate along the weaker foliated schist found on either side of the orebody during SLR mining. No material increase in water inflow into the mine openings was modeled for the proposed mining plan. The open benching and SLR method were shown to be an acceptable and economic mining method for the deposit. These results were used to help determine the water management systems designed within the mine.

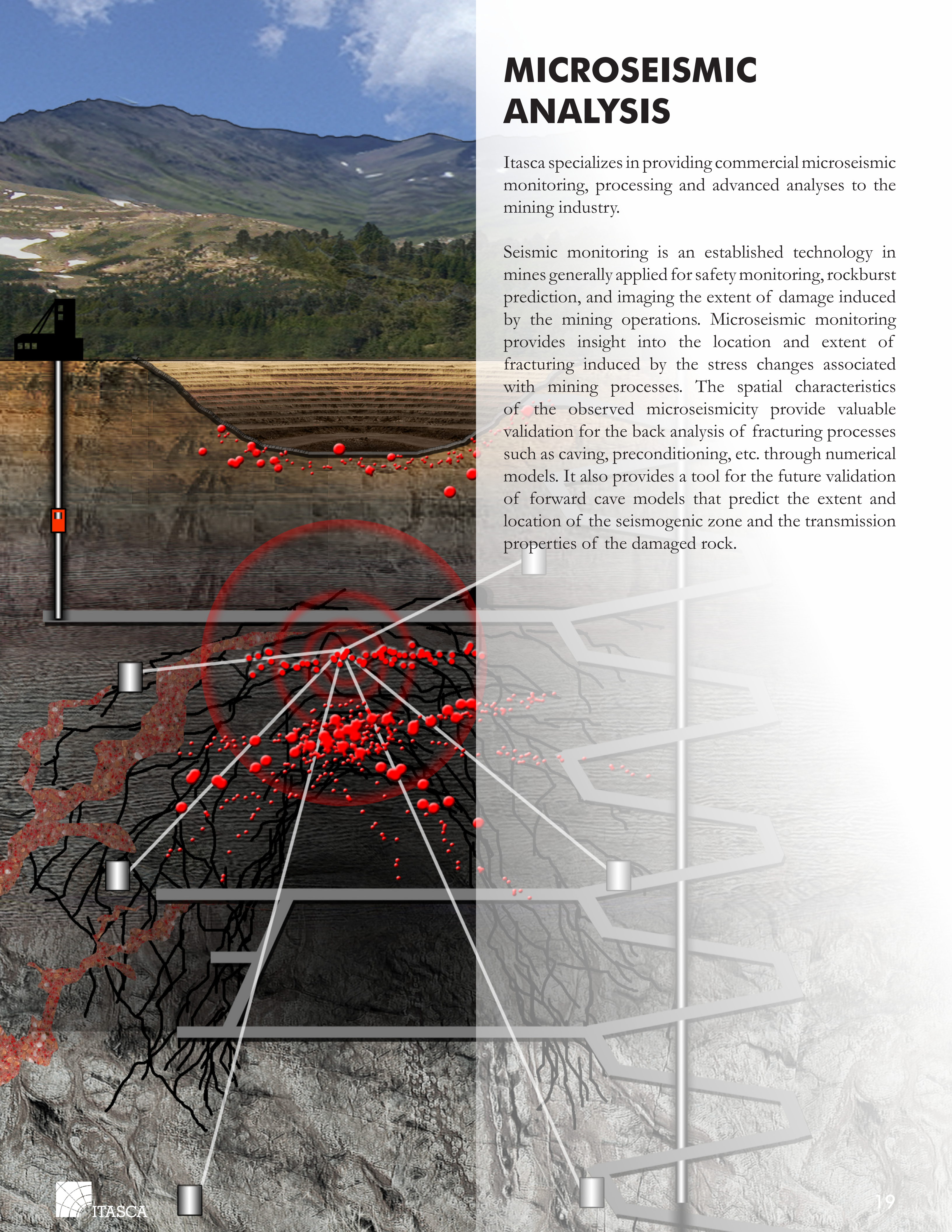


Cross-section of pore-pressure distribution of a *MINEDW* model with multiple open pits and underground mining.

MICROSEISMIC ANALYSIS

Itasca specializes in providing commercial microseismic monitoring, processing and advanced analyses to the mining industry.

Seismic monitoring is an established technology in mines generally applied for safety monitoring, rockburst prediction, and imaging the extent of damage induced by the mining operations. Microseismic monitoring provides insight into the location and extent of fracturing induced by the stress changes associated with mining processes. The spatial characteristics of the observed microseismicity provide valuable validation for the back analysis of fracturing processes such as caving, preconditioning, etc. through numerical models. It also provides a tool for the future validation of forward cave models that predict the extent and location of the seismogenic zone and the transmission properties of the damaged rock.



The post-process analysis of seismic catalogues, seismic record, or real-time analysis can provide feedback for:

- early warning on localized induced damage to mine infrastructure,
- slope stability in open-pit mines,
- extent and positioning of damage zones in underground operations,
- imaging the cave progress and extent in underground caving mines,
- imaging the persistence, spacing and mechanism of induced and mobilized fractures,
- progress of subsidence zones above underground operations, and
- effectiveness of preconditioning operations.

Itasca has developed a series of novel analyses that enhance the information provided by existing microseismic catalogues to monitor the evolution of the fracturing processes and that provide:

- advanced post-processing, analysis, and interpretation of client data to identify fracturing modes, the fraction of newly opened and reactivated fractures, and a full geometrical characterization of fracturing;
- active and passive source tomography for imaging of damage induced by mining operations;
- acquisition system-independent seismic processing software for automatic, real-time processing of induced seismicity;
- in-depth understanding of fracture mechanisms through the integration of acquired data and SRM models;
- structure imaging and velocity inversion combining the illumination capability of controlled seismic sources and passive seismic events;
- p-and s-wave time-lapse tomography to image the degradation of host rock and structures in terms of elastic modulus and fracture density;
- temporal and spatial clustering of microseismic events to quantify damage accumulation and identify areas of localized fracturing;
- fully-featured microseismic training courses focused on the principles behind the technology, processing algorithms, and hands-on experience of using processing software; and
- design, optimization and quality check of seismic monitoring arrays.

[7,8]Underground & Open Pit Interaction 2008/12

Project Description

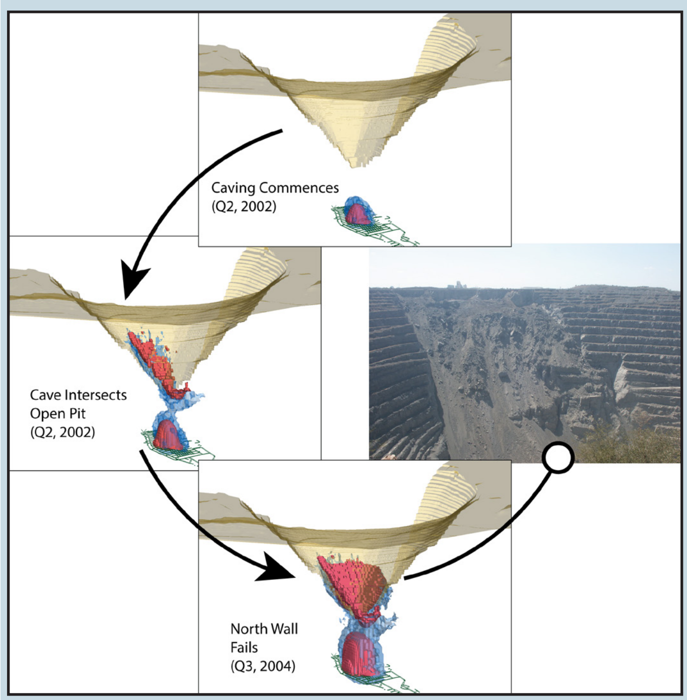
As the Palabora Mine (South Africa) transitioned from surface to underground mining, a large-scale failure occurred in the pit slope as a result of cave mining. This resulted in the dilution of ore reserves and instability in mine infrastructure. A microseismic (MS) monitoring system was in operation.

Itasca's Contribution

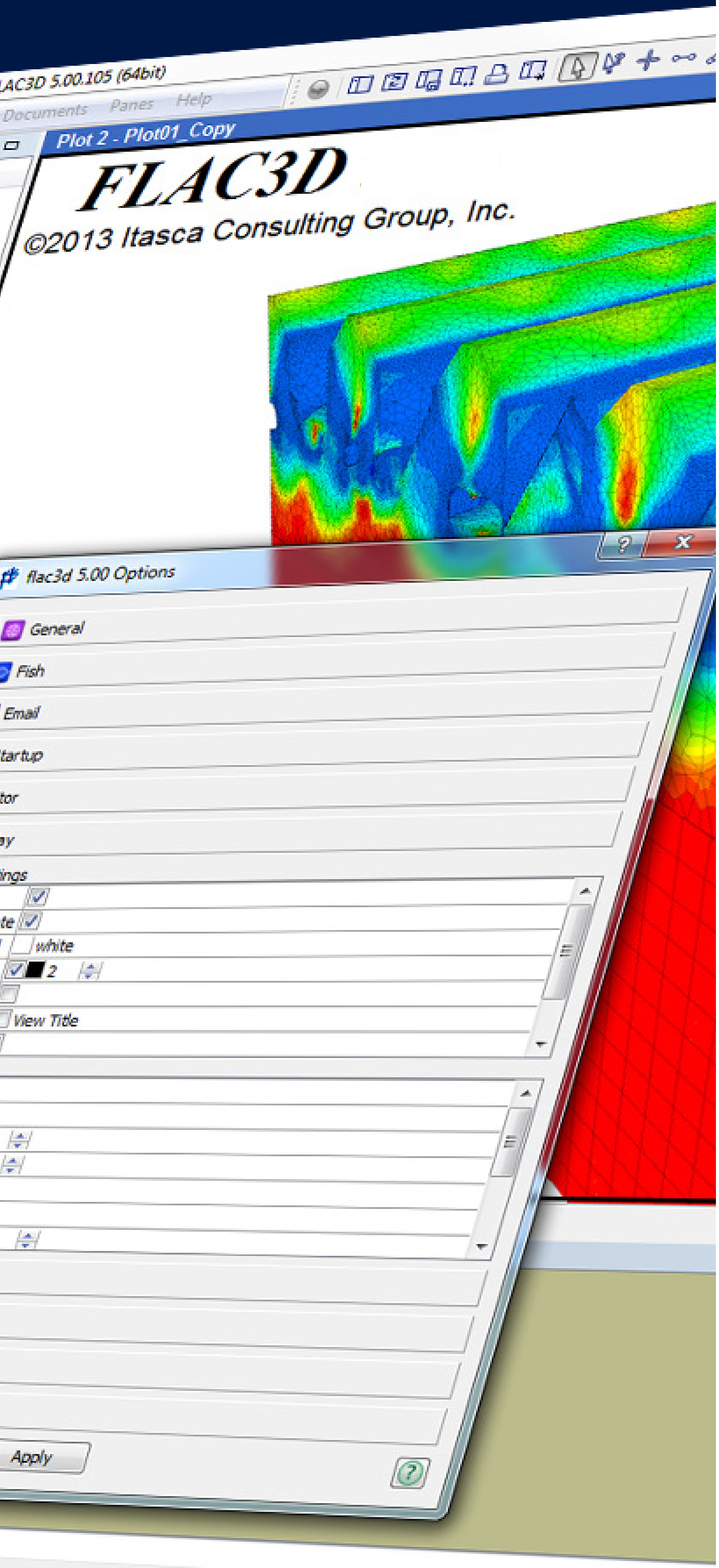
Synthetic Rock Mass (SRM) responses were developed for the rock mass domains at Palabora. Production was simulated and the advancing cave and north wall failure area was assessed.

Outcomes

Microseismicity strongly indicated the development of significant damage in the rock mass below the north slope in the months preceding its failure. *FLAC3D* models, due to higher stresses induced by the underground mining, describe very similar macro behavior to that observed in-situ. The combination of numerical analyses and SRM modeling with MS analyses provides a preliminary assessment of potential volumes of rock failure during caving operations to be completed prior to production start-up.



Development of the pit slope failure mechanism at the Palabora mine at various stages of production.



SOFTWARE SERVICES

Itasca first commercialized its software in 1985 when clients asked to have access to the software tools that our engineers used in their analyses. Itasca has pioneered and continues to innovate the application and development of numerical modeling software. Our software are among the most widely used and respected tools of their kind for analyzing and solving problems in geomechanics, hydrogeology, microseismic analysis, and other engineering fields. The result is a set of software that provides unparalleled speed, power, and proven capability for handling engineering problems ranging from traditional design work to understanding the most complex natural phenomena encountered in some of the most challenging environments.

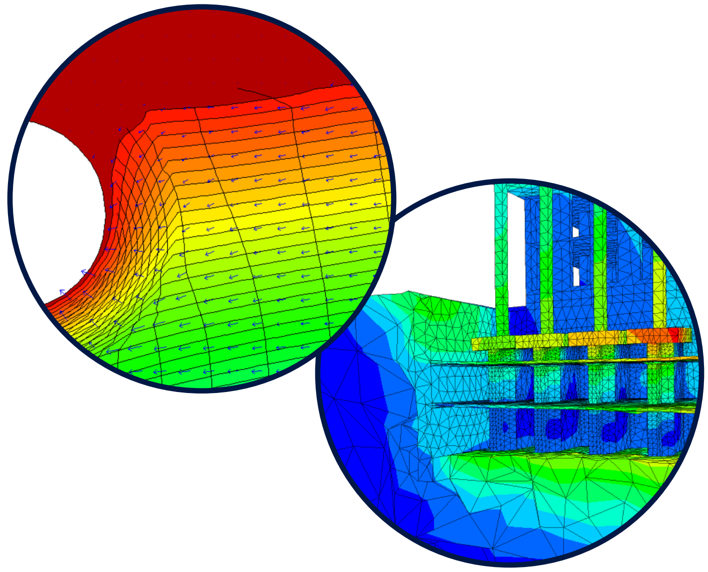
Itasca programs are used for design of major mining and civil construction projects, design of nuclear waste repositories, and oil reservoir treatment programs and have been used in a large portion of rock mechanics research projects worldwide. More than 4,000 mining and civil construction companies, consultants in rock and soil mechanics, and university and government researchers use these programs worldwide.

Itasca software programs include the two- and three-dimensional continuum programs *FLAC* (including *FLAC/Slope*) and *FLAC3D*, the two- and three-dimensional discontinuum programs *UDEC* and *3DEC*, the two- and three-dimensional particle-flow simulation programs *PFC2D* and *PFC3D*, the three-dimensional, finite-element groundwater flow code *MINEDW*, and the three-dimensional code *DFN.lab* for simulating 3D DFNs for engineering and research problems.

Itasca often performs custom modification or development of these programs for specific project or client needs. Development of all software is governed by input from Itasca's consulting practice. Consequently, clients are assured that these software are practical, efficient analysis tools with a proven record of solutions to real-world problems.

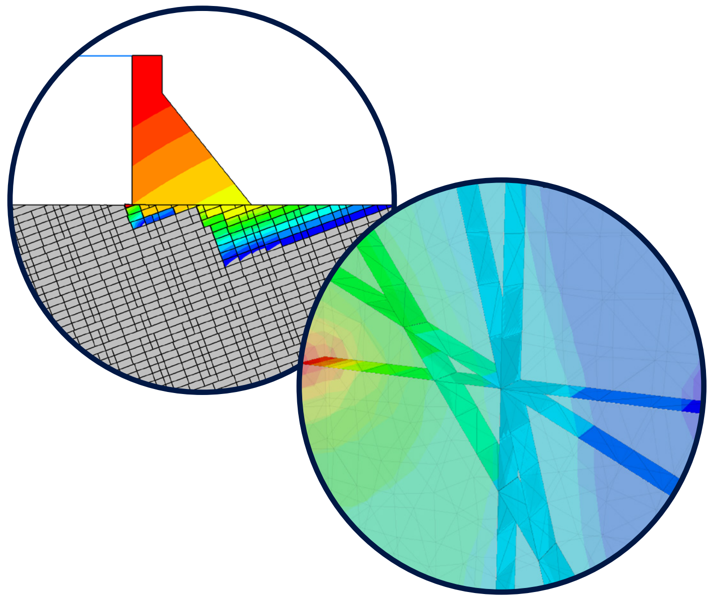
For more information or to download a free software demo, please visit: www.itascacg.com/software.

FLAC® – FLAC3D™



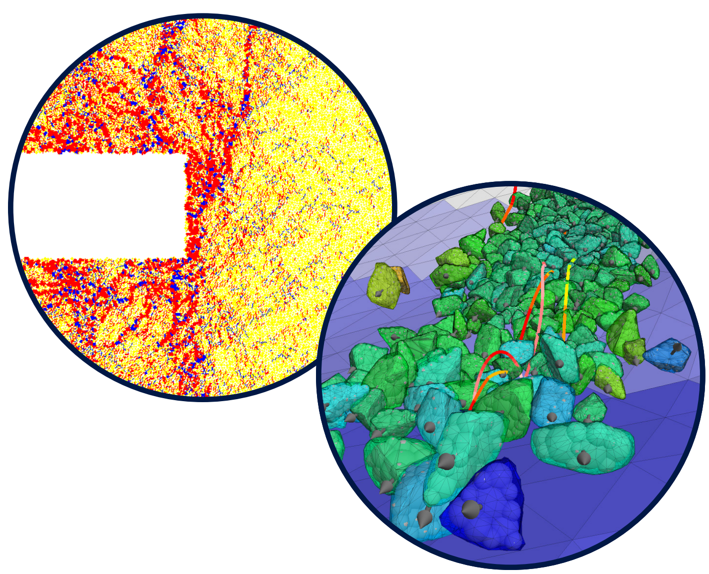
These are two- and three-dimensional explicit finite-difference programs for engineering mechanics simulations. These programs model the behavior of soil, rock, or other materials that are subject to plastic yielding. Materials are represented by a continuum of zones, which form a grid that is adjusted by the user to form the shape of the model to be simulated (e.g., tunnel, open pit, tailings dam, etc.). These programs are capable of simulating large strains (including unstable physical processes such as collapse), joints along which slip and/or separation can occur, groundwater flow, multiple excavation sequences (including backfilling), and dynamic processes and includes structural elements (e.g., liners, rock bolts, cables, beams, etc.).

UDEC™ – 3DEC™



Two- and three-dimensional distinct element codes for modeling discrete or jointed systems (e.g., rock mass, rock grains, hydro-electric dams on jointed rock foundations, masonry structures). Materials are represented by a network of blocks cut by discontinuities with surface (boundary) conditions. Blocks are able to rotate and slide along joints and joints can open or close. Blocks can be rigid or deformable (allowing yielding). The programs are capable of simulating large block displacements, groundwater flow along discontinuities, multiple excavation sequences, and dynamic processes and include structural elements (e.g., liners, rock bolts, cables, beams).

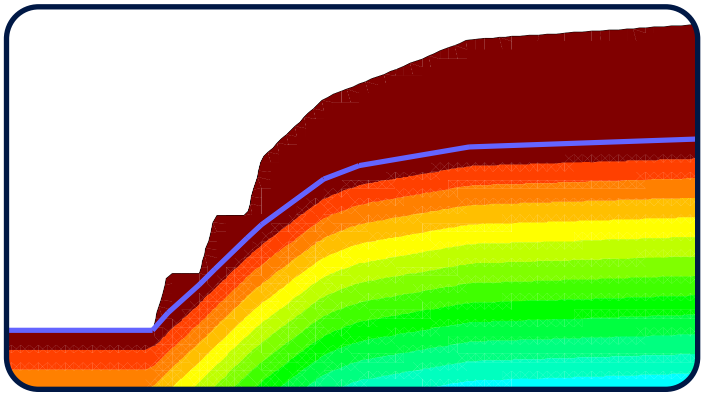
PFC Suite™



Two- and three-dimensional distinct element programs for modeling the movement and interaction of assemblies of arbitrarily sized circular or spherical particles. *PFC Suite* includes both *PFC2D* and *PFC3D*. The codes create an ideal environment for study of the behavior of synthetic materials, modeling bulk flow and materials mixing, studies of micro- and macro-damage (cracks) in solid bodies, including damage accumulation leading to fracture, dynamic breakage, and seismic response. *PFC2D* is also sold separately.

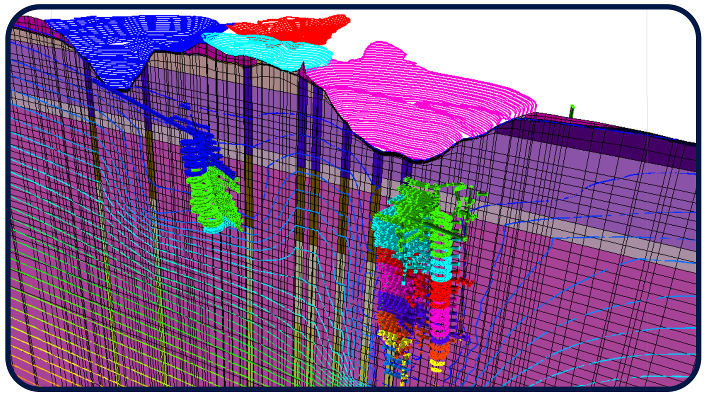
FLAC/Slope™

FLAC/Slope is a free, specialized version of *FLAC* designed specifically for slope stability factor-of-safety analysis. This code allows rapid generation of problem geometries and factor-of-safety calculation using the shear-strength reduction technique. One particular feature of this code is the ability to overlay DXF plots to speed model generation. Users can also specify water tables and pseudostatic earthquake loading.



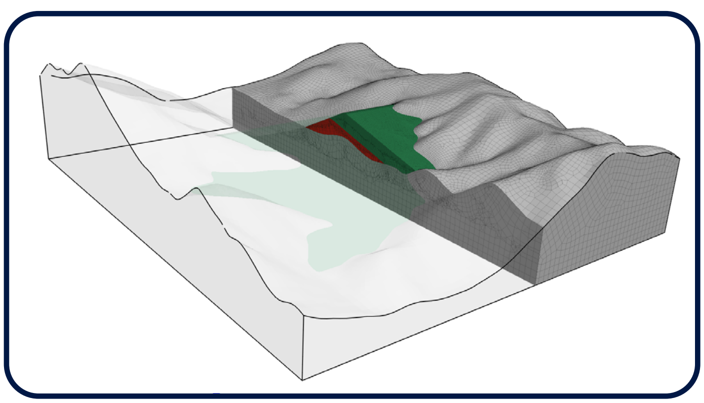
MINEDW™

Itasca's hydrogeological software has been specifically developed for simulating groundwater conditions. *MINEDW* (www.itascadenver.com/minedw) is very efficient in simulating complex geometry and spatial and temporal change of hydraulic conductivity of disturbed rock as the results of excavating. The simulated pore pressure distribution from *MINEDW* model can be readily imported into Itasca's geomechanical models.



Griddle™

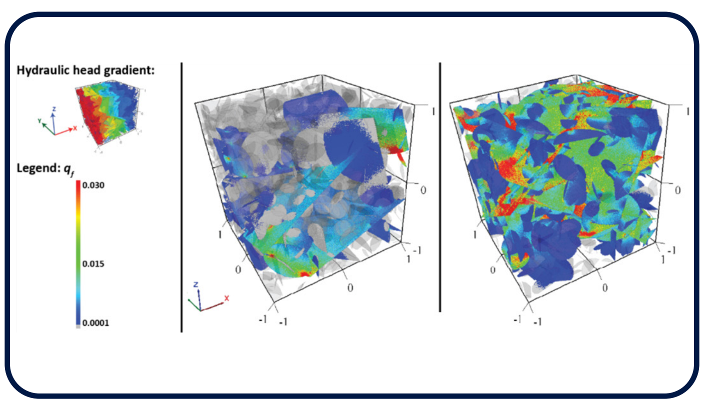
Griddle is a fully interactive, general-purpose mesh generation plug-in for the *Rhinoceros* 3D CAD software (www.rhino3d.com). *Griddle* can be used to remesh *Rhino* surface meshes to comply with precise size specifications and type (triangle or quad-dominant). Surface meshes can then be used as boundaries for *Griddle's* volume mesher, which produces high-quality tetrahedral or hex-dominant meshes. The volume meshes are ready for importing into most engineering analysis packages, including *FLAC3D* and *3DEC*.



DFN.lab™

DFN.lab is used for simulating fluid flow and trasport in 3D discrete fracture networks (DFNs) for engineering and research problems. *DFN,lab* is capable of:

- generating genetic models containing millions of fractures based on the physics of fracturing,
- compute stationary and transient flow with various boundary conditions in significantly large systems,
- characterize the DFN structure and hydraulic properties using novel statistics and graph methods



KATS

Kinematic Analysis Tools for Slopes (*KATS*) is a tool aimed at assessing instabilities caused by daylighting wedges and planar failures formed when different structural sets interact with the orientation of a given slope. The main application of the code is the so-called bench-berm scale analysis, which is understood as a first step in the mining slope design process for moderate and competent rock masses. However, it is possible to perform a kinematic analysis in inter-ramp scale. Unlike other tools currently available, through a single automated process, *KATS* allows performing a probabilistic or deterministic assessment of the behavior of a large number of slope configurations defined by many structural domains and many orientations and geometries of the slope. The results from the analysis can be provided using a variety of parameters, such as loss of crest, spill lengths, bench face angle distribution, etc. All these results allow a geometric definition of the interramp (IRA) angles that achieve the acceptability criteria defined by the operation from the point of view of stability and safety of personnel and equipment.

Software Customization

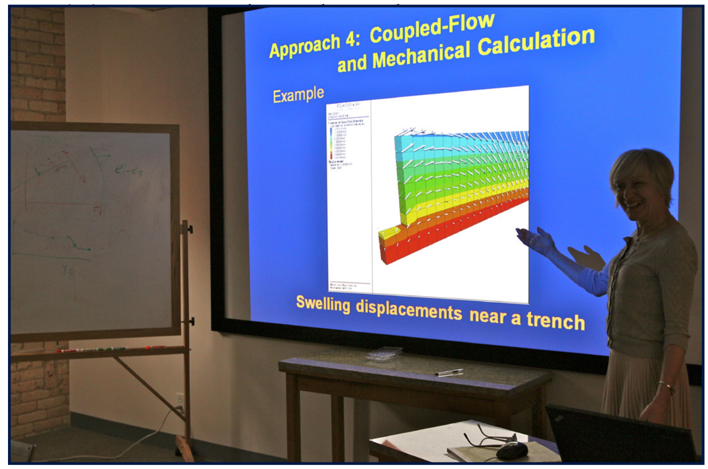
Itasca's software development is directed and refined by Itasca's consulting practice and client feedback. Itasca develops specialized material constitutive and contact models, *FISH* and Python functions, or even entirely novel simulation software in consultation with clients or as part of research collaborations. The software *REBOP* (cave mining), *Blo-Up* (blast design), *Slope Model* (slope stability), and *XSite* (hydraulic fracturing) were created in this manner and are used for both consulting and research.

For more information, please contact us at:

info@itascainternational.com

Training

Itasca offices worldwide routinely offer software



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LEAD PERSONNEL, UNDERGROUND MINING

Martin Brown
Itasca Chile SpA
Hydrogeology Manager,
Water Management Engineer
martin.brown@itasca.cl

Mr. Brown is a civil engineer who holds Diplomas in Water and Environmental Management from the University of Bristol (UK) has worked in the field of water and tailings management and dewatering systems for major mining operations and projects in Chile and South America for over 15 years, the last of which is for Itasca.

He has a diverse background in mining applied hydrogeology. For mining operations his experience includes planning and management of water resources and open-pit dewatering systems through 3D hydrogeological and pore pressure numerical models and support in the elaboration of environmental impact assessments. Has also been fluids transport manager with responsibility over tailings storage facilities, water supply systems and slurry pipelines. While in Itasca his experience includes elaboration of 3D hydrogeology numerical models for open-pit mines, assessment of dewatering systems and support in the elaboration of environmental permits related to groundwater management.

Richard Brummer
Ph.D., P. Eng.
Itasca Consulting Canada, Inc.
President and Principal
Geomechanics Engineer
rbrummer@itasca.ca

Dr. Brummer has 35 years of experience in geomechanics consulting, practical mining applications, research and academia. His areas of specialization are all aspects of the behavior of highly stressed rock in deep mines or in extensively mined workings. He also has expertise in rockbursts, the design of microseismic and general instrumentation systems, the design of backfill and backfill systems, and particularly in the optimization of mining layouts to reduce risk and maximize value. He is the author of over 50 technical articles. Dr. Brummer is a Registered Professional Engineer in Ontario, Quebec, Saskatchewan & the Northwest Territories, and is a Designated Consulting Engineer with Professional Engineers Ontario.

Christopher O'Connor
M.A.Sc.
Itasca Consulting Canada, Inc.
General Manager & Principal
Geomechanics Engineer
coconnor@itasca.ca

Mr. O'Connor is a mining engineer with a Master of Applied Science degree in Mineral Resource Engineering. He has worked in the mining field for over 20 years focusing on advanced numerical modeling and geomechanics. Mr. O'Connor has returned to Itasca after four years working at Glencore's Nickel Rim South Mine as the Senior Ground Control Engineer for the site.

Branko Damjanac
Ph.D.
Itasca Consulting Group, Inc.
Principal and Geotechnical
Engineer
branko@itascacg.com

Dr. Damjanac has experience in the design and analysis of underground and open pit mining excavations in both hard and soft rocks. He developed numerical models and methodologies for analysis of mine stability.

He has investigated mechanism of large-scale panel collapses in room-and-pillar trona mines. Developed a methodology to provide guidelines for safe mine design (extraction ratios, pillar sizes and panel spans) accounting for interaction between pillars and overburden. For large room-and-pillar salt mines analyzed mine-scale convergence rates due to salt creep and investigated the effect of creep and associated damage on long-term stability.

Participated in development of a novel numerical method for simulation of slope stability in fractured rock masses, with intended application to large open pit slopes. Investigated the mechanics and the effects of rock mass preconditioning by hydraulic fracturing for block caving operations.

Tryana Garza-Cruz
M.Sc., Ph.D.
Itasca Consulting Group, Inc.
General Manager and
Principal Geomechanics Engineer
tgarza@itascacg.com

Dr. Garza-Cruz is a geomechanics engineer with experience in the application of three-dimensional continuum and discontinuum numerical methods to assess the stability of mining excavations, caveability, extraction level performance, surface subsidence, primary fragmentation, and stope-back behavior, as well as to evaluate underground mining methods and understand the creep behavior of excavations in frozen ground.

She has applied numerical models to formulate recommendations on mine design criteria (pillar, room, stope, and panel dimensions), as well as regional barrier-pillar and crown-pillar dimensions, sequencing, and set back of infrastructure and accesses. She has also developed specialized tools using Bonded Block Models in *3DEC* for the study of spalling rock mass response at tunnel scale.

Patricio Gómez
Itasca Chile SpA
General Manager,
Applied Geotechnical Engineer
patricio.gomez@itasca.cl

Mr. Gómez is a civil engineer who holds a Diploma in Geomechanics Applied to Mining from the University of Chile and has worked in the field of soil and rock mechanics for major mining projects in South America for over 35 years, 25 of which are for Itasca. He has a diverse background in mining applied geomechanics. On underground operations his experience includes assessment of mining methods and recommendation of mining sequences for block caving operations, stability analyses for underground chambers and ore-pass sectors, as well as the evaluation of ground-support methods, analysis of rock mass degradation, caveability analyses, and stress field calibration. His main area of expertise is geomechanics for open-pit mines, including slope design at several scales, stability assessments and back-analysis of slope failures and dynamic analysis of slopes under effects of earthquakes. Surface consulting projects include static and dynamic stability analyses and the liquefaction potential of tailings dams, water reservoirs and waste dumps in highly active seismic areas.

Houmao Liu
Ph.D., P. Eng.
Itasca Denver, Inc.
General Manager and
Principal Hydrogeologist
hliu@itascadenver.com

Dr. Liu has more than 25 years of project experience in mining hydrogeology, geochemistry, and groundwater flow modeling. He has worked on and directed numerous mining hydrogeology projects in southern Africa, South America, Turkey, North America, Russia, and East Asia. He has also been the Principal-in-Charge of Itasca's hydrogeologic projects for key mining companies such as Alrosa, De Beers, Cameco, Anglo American, Debswana, Doe Run, Freeport McMoRan, Rio Tinto, Goldcorp, and Codelco. These projects include mine dewatering, slope depressurization, water management of surface and underground mines, environmental impacts, and mine water quality. In addition, Dr. Liu has extensive experience in the code development of *MINEDW*, as well as more than 25 years of groundwater flow modeling experience using other commercial codes such as MODFLOW, MT3D, and FEFLOW. He also provides expert opinions for regulatory hearings and due diligence reviews and has taught numerous hydrogeologic courses.

Loren Lorig
Ph.D., P. Eng.
Itasca Consulting Group, Inc.
Itasca S.A.
Principal Mining Engineer
loren.lorig@itasca.cl

Dr. Lorig has more than 35 years of experience in engineering projects requiring specialized geomechanics consulting. His area of expertise is in the application of numerical models to provide solutions to stability, support and dynamics problems in civil and mining engineering. Dr. Lorig has worked extensively at some of the largest open pits in the world and currently is working on studies involving transition from open-pit to underground mining at sites around the world. He has served as a member of consulting and peer review boards for several large projects. He has conducted over 40 short courses, authored more than 50 technical articles and made ten keynote presentations. He is a Registered Professional Engineer in several U.S. states.

Glenn Sharrock
Ph.D., MAusIMM CP (Geotech)
Itasca Australia Pty. Ltd.
General Manager and Principal Geotechnical Engineer
gsharrock@itasca.com.au

Dr. Sharrock's has 15 years industry experience in a wide range of rock mechanics positions such as Principal Geotechnical Engineer (Newcrest Mining NL), Rock Mechanics Engineer (Mt Isa Mines), Senior Geotechnical Consultant (AMC Consultants), Senior Lecturer in Geotechnical Engineering (UNSW) and Associate Professor - Caving Geomechanics (UQ). His last position was as Principal Geotechnical Engineer at Newcrest's Cadia East, Ridgeway Deeps, Ridgeway SLC and Telfer Mines. In addition to Newcrest, consulting experience includes Argyle, Perseverance, North Parks, Koffiefontein, Resolution, Goldex, Afton, Ekati, Perseverance Deeps, and Ridgeway Deeps (Lift 2).

Jonny Sjöberg
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Itasca Consultants AB
General Manager and Principal Engineer
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Dr. Sjöberg is a rock mechanics engineer with experience in operations, research and consulting within mining and civil engineering. He holds a Ph.D. in the area of open-pit slope stability, and has worked on underground and surface mining projects in rock mechanics, civil engineering tunneling projects, stress measurements and various other numerical modeling projects. Dr. Sjöberg also is an Adjunct Professor in Rock Mechanics and Rock Engineering at Luleå University of Technology.

40 YEARS

"More than 40 years of solving mining challenges through engineering and computer simulation."

Thank you for your interest in Itasca's services to the mining industry. Please let us know how we can assist you with your work.

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