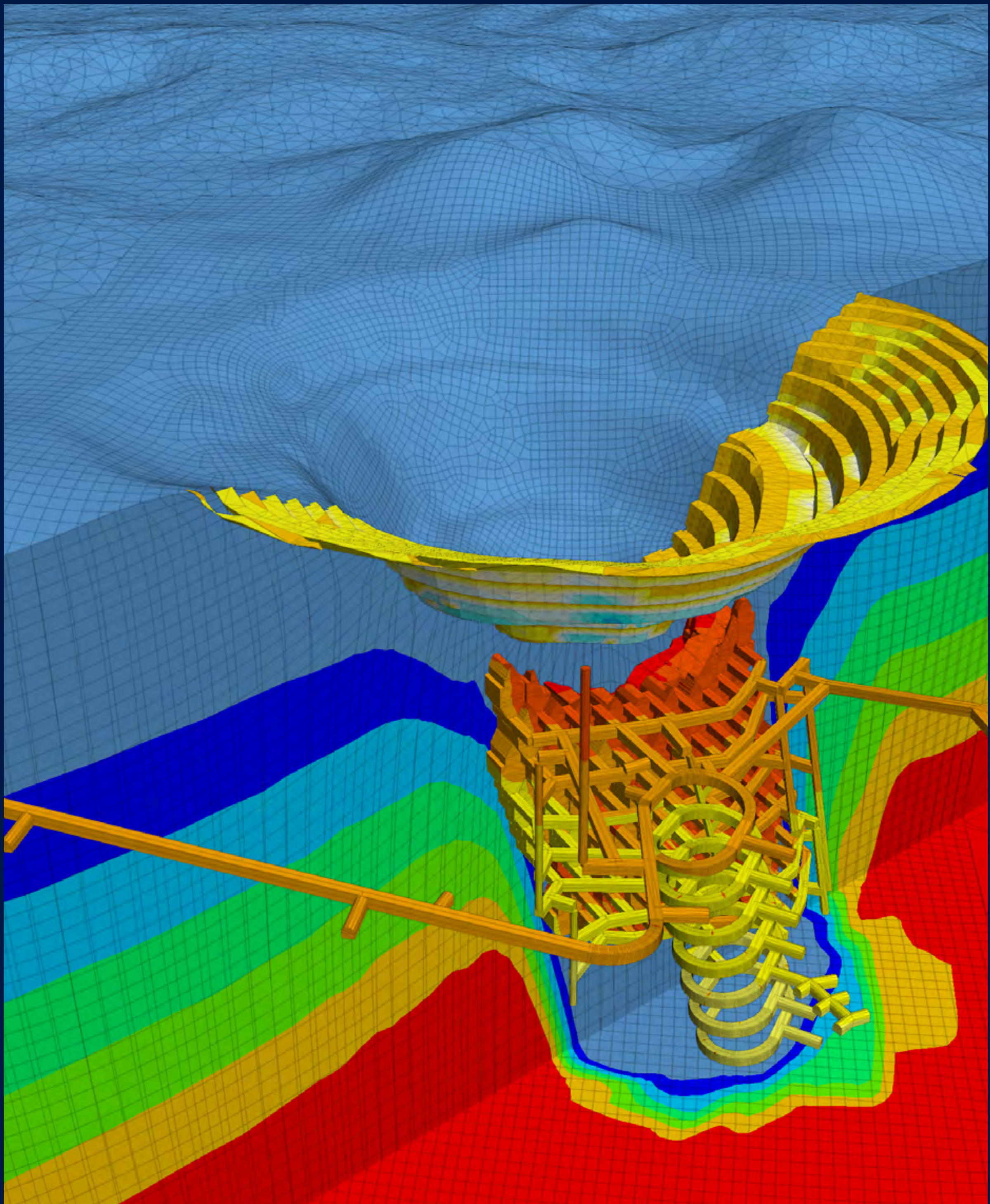
ITASCA™

Mass Mining Services and Statement of Qualifications



ICG18-SOQ-MASS-US-02

CIVIL • ENERGY • ENVIRONMENTAL • MATERIALS • MINING

“Forward thinking engineering and science”

ITASCA

CONTENTS

ITASCA INTERNATIONAL

Itasca International Inc. is an engineering consulting and software development company founded in Minneapolis, Minnesota, with 15 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.

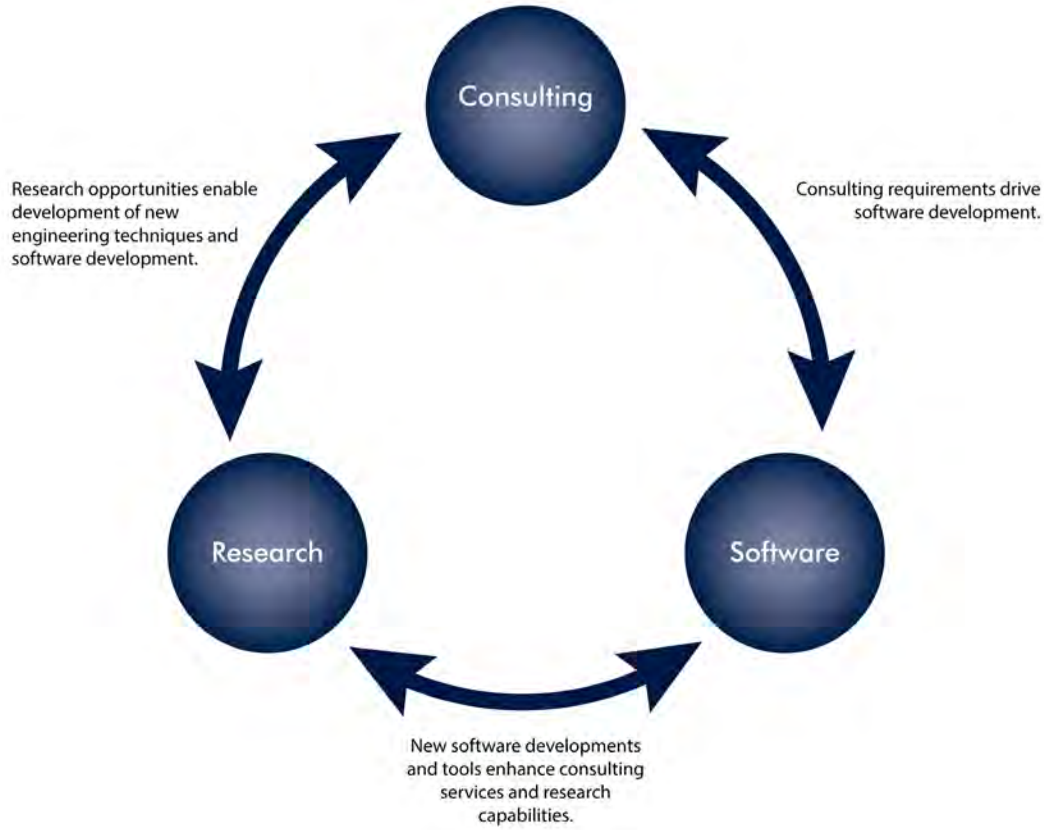
Use of numerical simulation software is an integral part of our consulting. Our state-of-the-art numerical modeling programs are among the most widely used and respected tools of their kind. Development of our advanced numerical simulation software sets Itasca apart from other geotechnical and mining 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.

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'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.

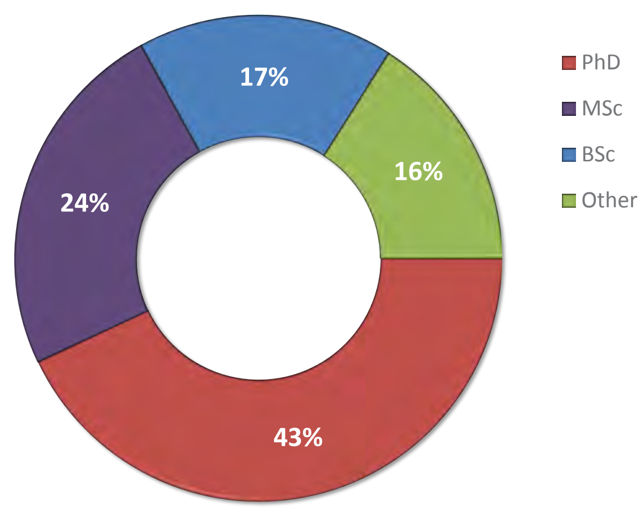
Our engineers and software developers have a proven track record of innovation, leading to new strategies and tools to better understand the complex environments in which mines exist.

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:

- Large Open Pit (LOP);
- Mass Mining Technology (MMT); and
- Hybrid Stress Blast Model (HSBM).

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

Itasca also fosters education and university research world-wide 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.

Itasca Offices

NORTH AMERICA

Itasca Consulting Canada, Inc.
166 Douglas Street
Sudbury, Ontario
P3E 1G1 Canada
T. (+1) 705- 522-2697
F. (+1) 705-522-6564
itasca@itasca.ca
www.itasca.ca

Itasca Consulting Group, Inc.
111 Third Avenue South, Suite 450
Minneapolis, Minnesota 55401
USA
T. (+1) 612 371-4711
F. (+1) 612 371-4717
info@itascacg.com
www.itascacg.com

Itasca Denver, Inc.
143 Union Boulevard, Suite 525
Lakewood, Colorado 80228
USA
T. (+1) 303 969-8033
F. (+1) 303 969-8357
itasca@itascadenver.com
www.itascadenver.com

EUROPE

Itasca Consulting Ltd
5 Claremont Buildings
Claremont Bank
Shrewsbury, Shropshire
SY1 1RJ United Kingdom
T. (+44) 1743 271440
F. (+44) 1743 260921
info@itasca-image.com
www.itasca-image.com

Itasca Consultants AB
Luleå Office (main)
Aurorum 2
SE-977 75 Luleå
Sweden
T. +46 (0)76 768 22 55
jonny@itasca.se
www.itasca.se

Stockholm Office
Isafjordsgatan 39B
Kista
SE-164 40 Stockholm
Sweden
T. +46 (0)70 256 78 53
axel@itasca.se
www.itasca.se

Itasca Consultants S.A.S.
Centre Scientifique A. Moiroux
64 Chemin des Mouilles
69134 Ecully Cedex
France
T. (+33) 4-72-18-04-20
F. (+33) 4-72-18-04-21
itasca@itasca.fr
www.itasca.fr

Itasca Consultants GmbH
Leithestrasse 111a
45886 Gelsenkirchen
Germany
T. (+49) 209 147-5630
F. (+49) 209 147-5632
info@itasca.de
www.itasca.de

Itasca Consultores S.L.
Parque Empresarial Asipo I
Secundino Roces Riera 1,
Planta 1a, Puerta 11
33428 Cayés, Llanera,
Asturias, Spain
T. (+ 34) 985-98-01-67
F. (+ 34) 985-98-01-68
itasca@itasca.es

SOUTH AMERICA

Itasca Perú S.A.C.
Calle Dos de Mayo N° 534, Of. 603
Miraflores, Lima 18
Lima, Perú
T. (+51-1) 445-9608
itascaperu@itasca.pe
www.itasca.pe

Itasca Chile SpA
Av. Pedro de Valdivia 291, 2nd Floor
Providencia
C.P. 7500524
Santiago, Chile
T. (+56-2) 2434-1300
itascachile@itasca.cl
www.itasca.cl

AFRICA

Itasca Africa (Pty) Ltd.
P.O. Box 3918
Rivonia, 2128
Johannesburg, South Africa
T. (+27) 11 883-0490
dduthe@itasca-africa.com

ASIA

HydroChina - Itasca R&D Center
No. 201 Gaojiao Road
Yuhang District
Hangzhou City
Zhejiang Sheng 311122, China
T. (+86-571) 5662-5702
F. (+86-571) 5662-5703
itasca@itasca.cc
www.itasca.cc

Itasca Consulting China Ltd.
Suite 20-2-603, Gezhouba Sun City
Park
No. 40, Gaoxin 4th Road,
Wuhan City
Hubei Sheng 430205, China
T. (+86-27) 8786-2349
F. (+86-27) 6784-5165
itasca@itasca.cn
www.itasca.cn

Itasca India Consulting Pvt. Ltd.
Prayag Enclave
Block 301, Plot #17
Shankar Nagar, WHC Road
Nagpur, Maharashtra 440 010
India
T. (+91) 0712-256-9853
info@itasca.in

AUSTRALIA

Itasca Australia Pty Ltd.
Melbourne Office (main)
106A South Parade, Blackburn
Melbourne VIC 3130.
Australia
T. (+61) 3 9894 1141
itasca@itasca.com.au
www.itasca.com.au

Brisbane Office
Level 5, Toowong Towers
9 Sherwood Rd.
Toowong QLD 4066
Australia
T. (+61) 7 3310 8810
itasca@itasca.com.au
www.itasca.com.au

15 main **consulting offices** in 13 countries, and **software agents** based in another 11 countries, focused on servicing the global civil works industry.

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.

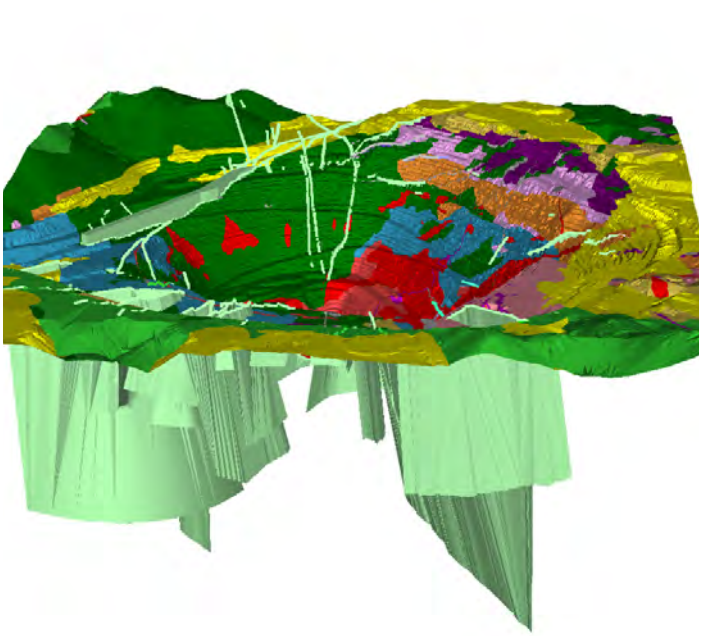
Itasca has analyzed the behavior of excavations in all types of rock and at all scales, from individual boreholes and access tunnels to the complete sequencing of the largest underground mines and deepest open pit mines in the world. Individual projects often require analyses over a wide range of scales 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.

Structural Geology and Rock Mass Characterization

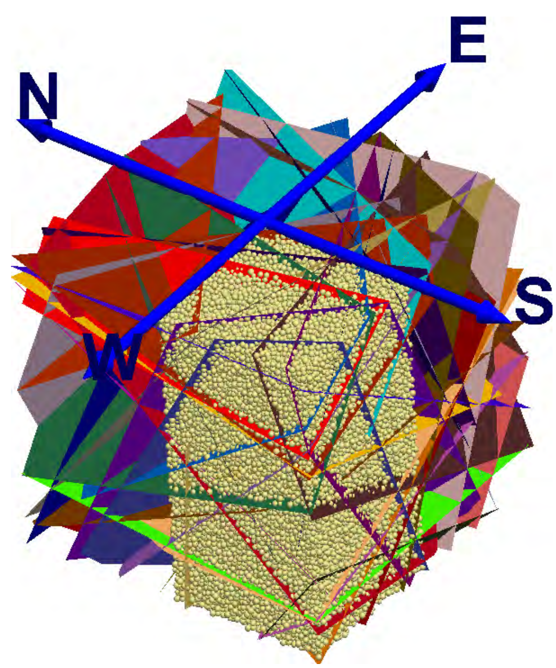
In order to develop a robust structural geology model, Itasca assesses the existing data in collaboration with our clients to assess any gaps and then applies a number of techniques as appropriate. These can include lineament analysis, precise structural mapping (outcrop, open pit and underground), drill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

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.



Datamine plot of a structural fault model with pit geology.

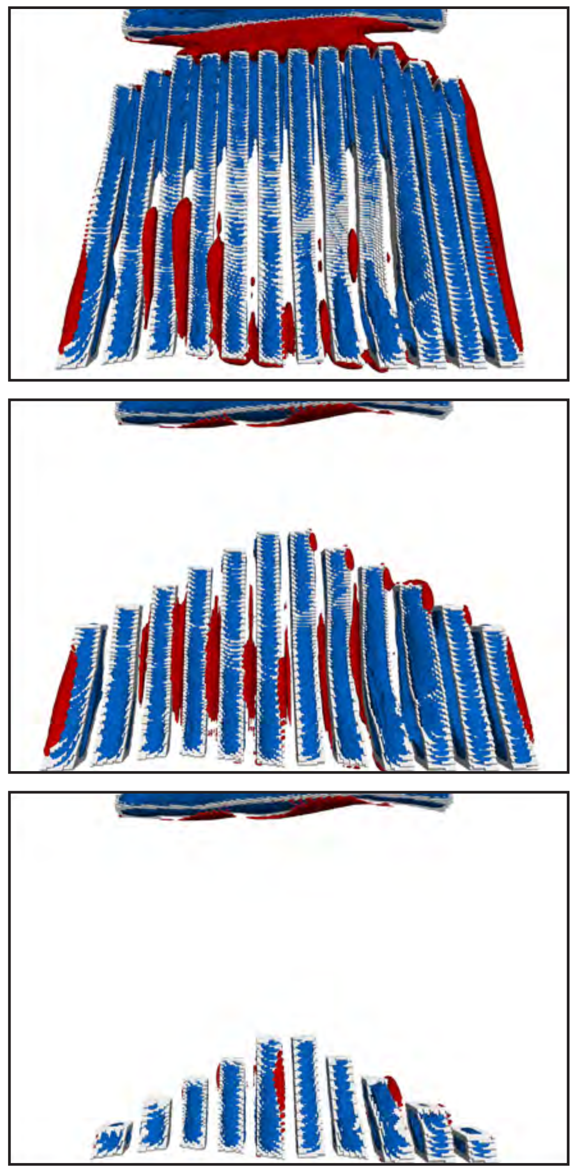
Rock mass strength estimation is required in order to predict the excavation response at the mine site. Obtaining accurate rock mass strengths requires an understanding of the intact rock and joint properties of each geotechnical unit and the in-situ stress state. Itasca can facilitate, interpret and 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 the rock mass that is second-to-none.



Synthetic Rock Mass, a technique invented by Itasca, consists of simulated joint sets embedded in intact rock with properties calibrated to match observed behaviors.

Mining Method Selection

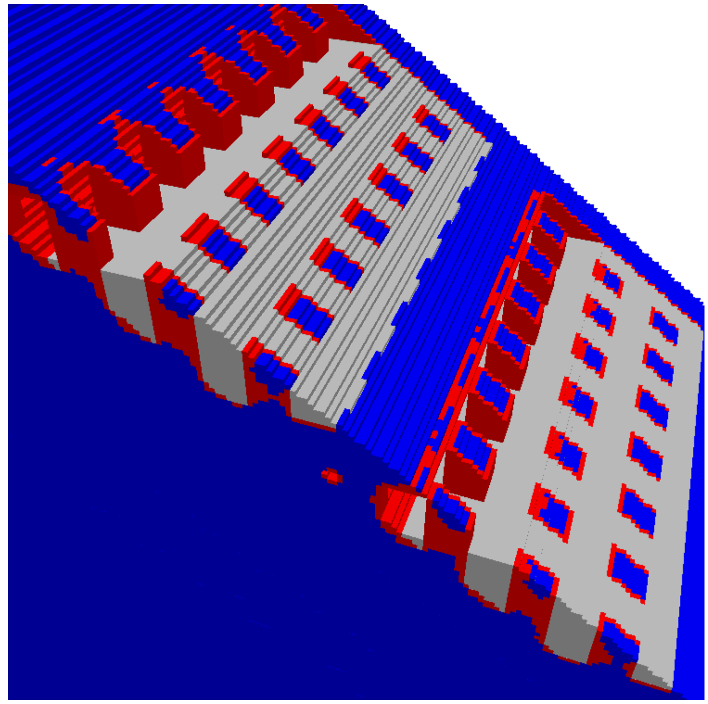
Combining our experience, conventional approaches and numerical modeling tools, Itasca is able to simulate mining of our client's sites first, so as to select mining methods appropriate to the orebody geometry and rock mass strength conditions. Itasca understands the economics involved in any mine design 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.



Pyramid mining sequence of a panel showing mining-induced stress changes around the advancing stopes. A concentration of stress in the sill pillar between panels can be seen.

Stope Design

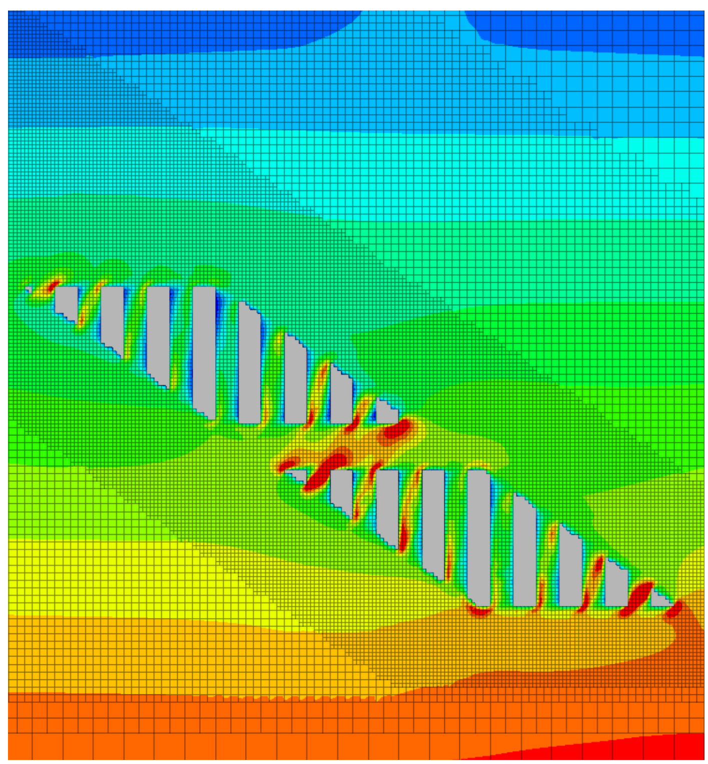
Itasca regularly performs evaluations and designs for long-hole, cut-and-fill, room-and-pillar, longwall and solution stopes. As with all our work, our engineers combine a practical engineering approach with numerical modeling technologies where appropriate. Itasca's software is particularly good at 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.



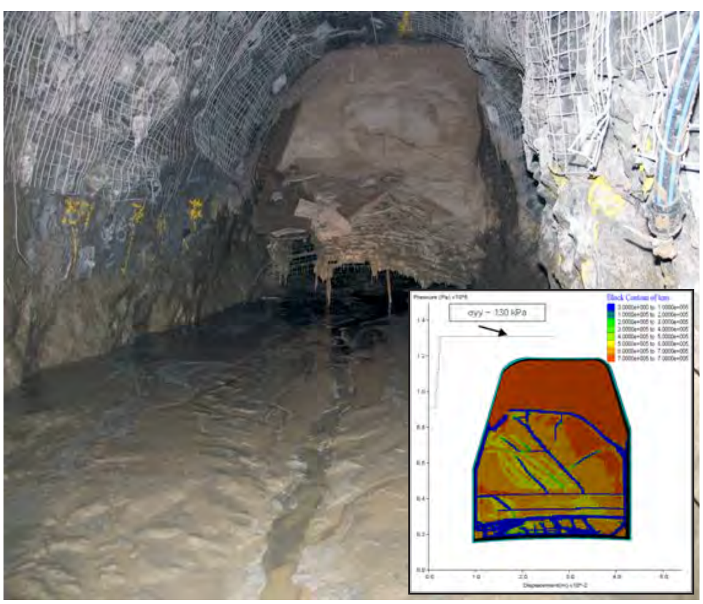
Step room-and-pillar stope sequence with fill (gray) is used to optimize pillar and room dimensions.

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.



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

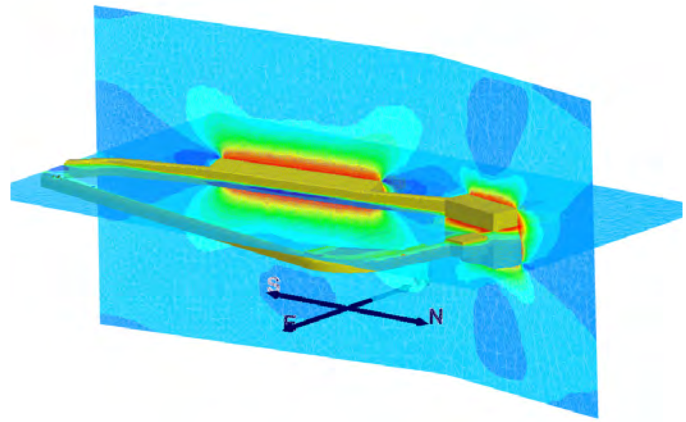


Itasca uses *FLAC3D* models in order to better understand and improve backfill barricade designs.

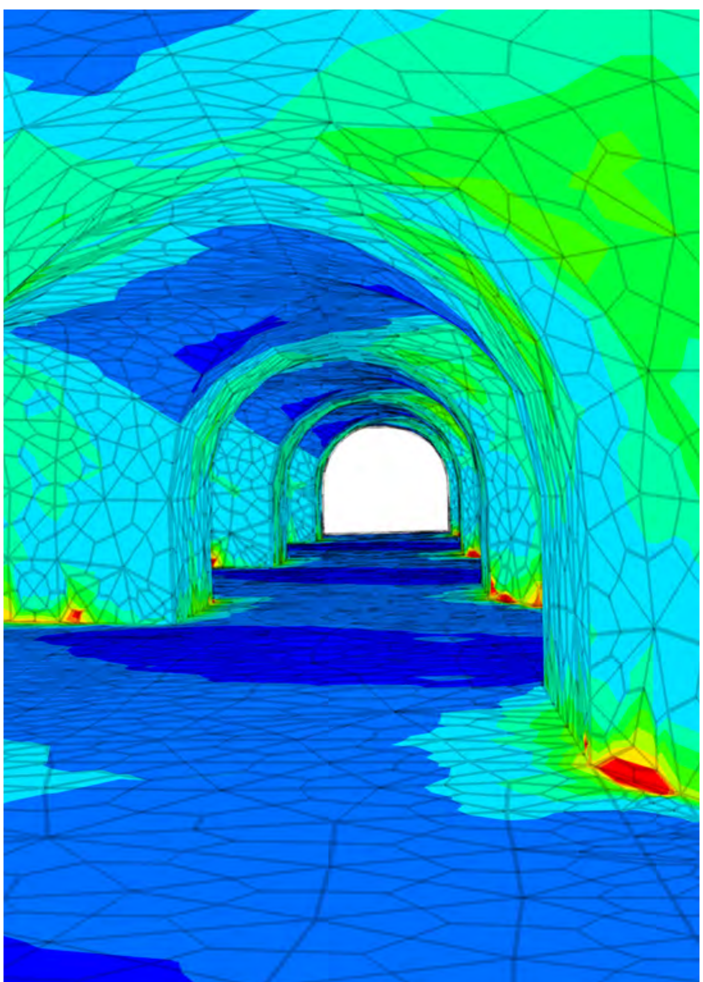
Infrastructure Design

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.

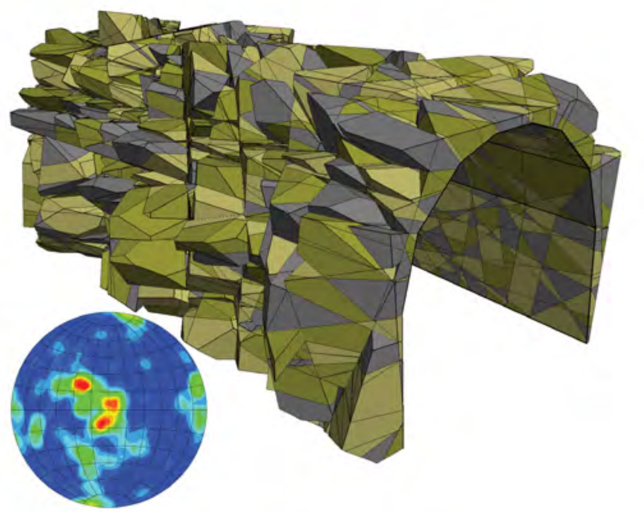
A number of design issues require consideration when developing infrastructure in rock or soil that impact an excavation's long-term stability: in-situ and mining induced stress, geologic structures and other intersecting developments can be assessed by Itasca in order to compensate the design as necessary.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



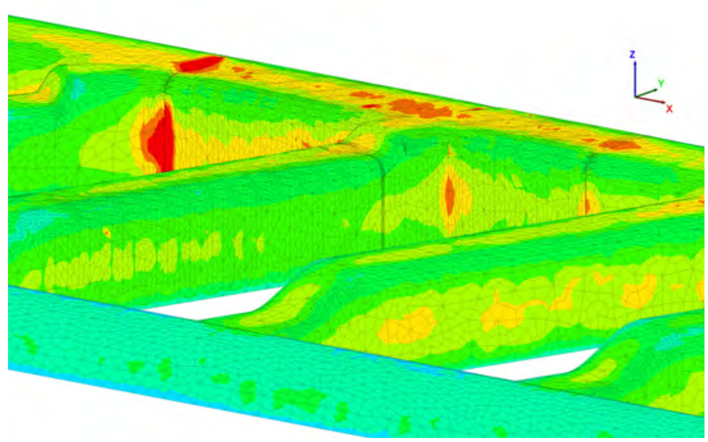
Stress plots along several cut-planes suggest very little interaction would be expected between two large underground caverns constructed in close proximity.



Haulageway in a block caving mine with stress contours shown.



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.



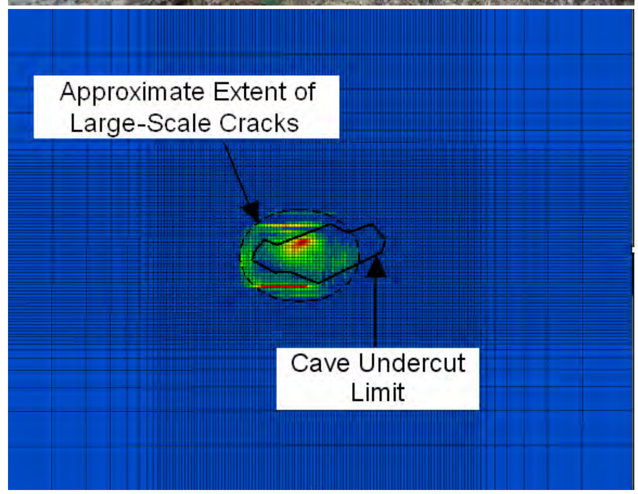
Stresses at the junction, walls and back of several mining bays in close proximity permit offset and support needs to be estimated prior to development.

Surface Subsidence Evaluation

Surface subsidence is often an inevitable consequence of many mining methods. Itasca evaluates mining-induced subsidence related to the extraction of ore from both underground and open pit mines, together with dewatering-induced subsidence. We provide services ranging from field investigation for acquiring geomechanical and hydrogeological properties to subsidence back-analysis, to prediction of the magnitude and extent of subsidence related to a particular mine design in order to optimize location of infrastructure and understand any impacts on existing property and the surface environment.

Traditionally, empirical and analytical methods have been used to assess the limits of subsidence from underground mining. However, these methods generally are restricted to simplified, regular mining geometries and often limited to two-dimensional problem geometries.

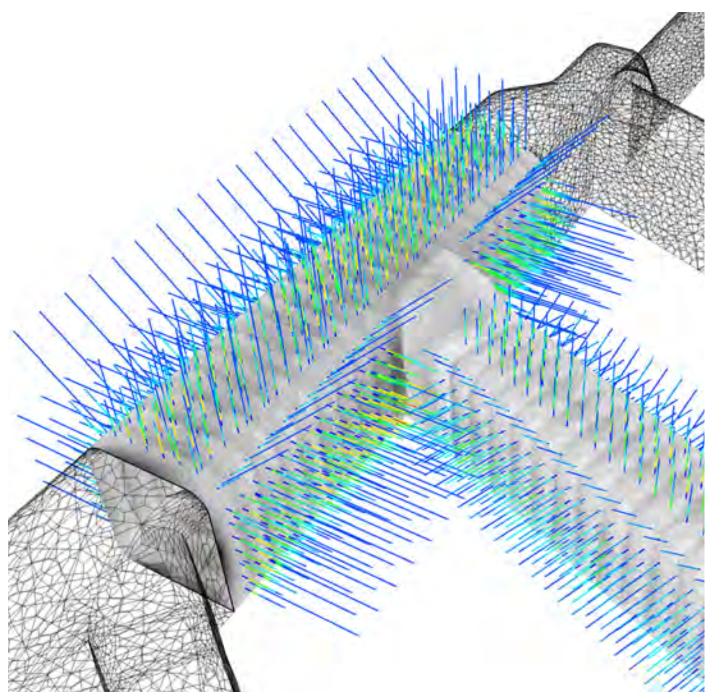
Itasca engineers have performed more three-dimensional assessments of mining-induced subsidence than any other group. Through the calibration of observed and measured subsidence features at a number of operating and abandoned mine sites, we have developed a rigorous methodology that predicts the limits of large-scale surface cracking and ground strains capable of causing damage to surface infrastructure.



A back-analysis of the closed Grace cave mine shows excellent agreement with the observed actual extent of surface subsidence.

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.



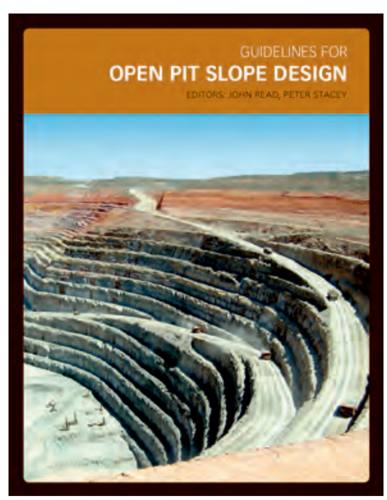
Evaluation of an underground cable bolt and shotcrete support design. Loads acting axially along the cables are indicated.

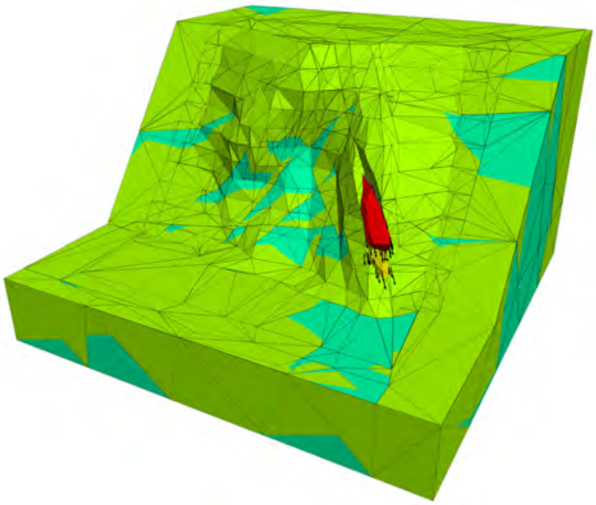
Slope Stability and Design of Pit Slopes

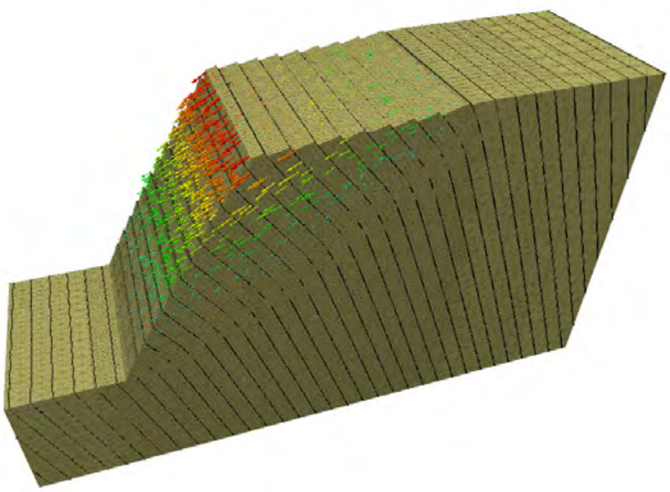
Itasca specializes in the assessment of slope stability and design of pit slopes on bench, inter-ramp and global mine scales. Itasca performs slope, instrumentation and remediation design at some of the world's largest open pit mines. We also analyze the static and dynamic stability of waste dumps, leach piles and tailings dams.

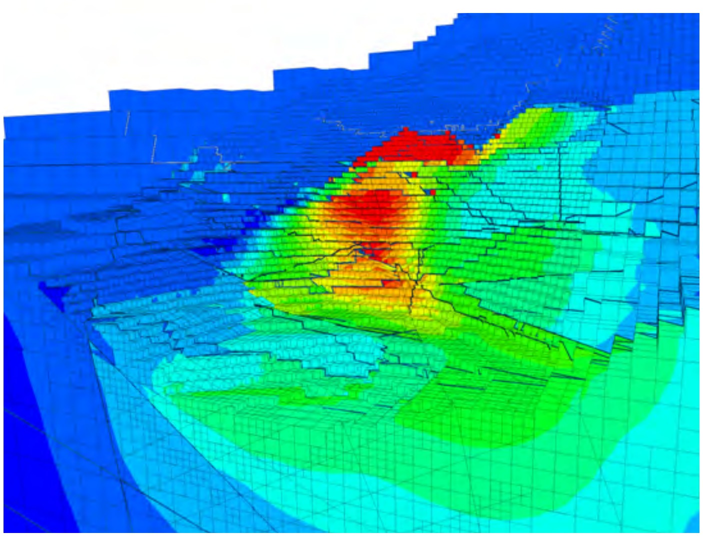
Itasca is particularly well-known for examining difficult problems involving slope instabilities and remediation methods. Itasca pioneered the use of accurate and efficient methods to determine safety factors using numerical methods that use the shear-strength reduction technique, which allows failure surfaces to develop naturally; an important advantage over more traditional limit-equilibrium solutions that are restricted to prescribed failure surface geometries. Currently, a vast majority of work involves three-dimensional analysis. We have found that three-dimensional analysis provides a much more realistic simulation of actual slope behavior in many cases. We have worked with our software developers to significantly reduce the run-times that have traditionally impeded 3D analysis.

Itasca is the lead researcher for the Large Open Pit (LOP) project and has been instrumental in the publication of **Guidelines for Open Pit Slope Design**, a comprehensive and modern reference for the best-practices slope design processes and tools that are available for mine design. (Click on the cover image below for more information.)

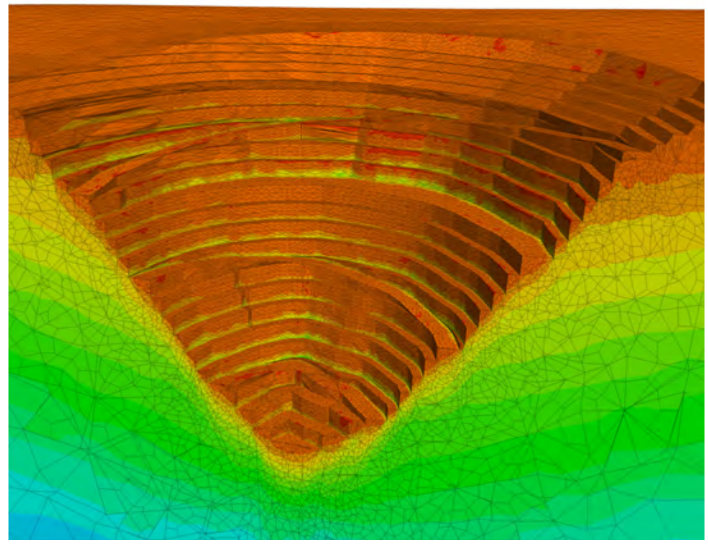




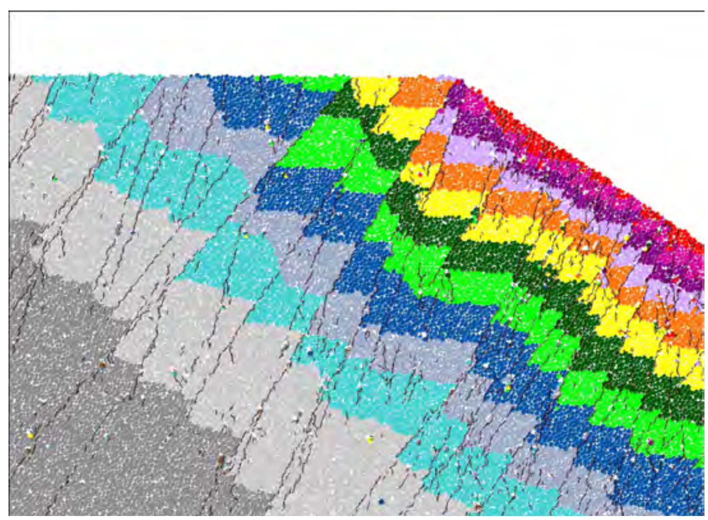




Itasca engineers have a wide variety of experience with all types of slope failure mechanisms and the tools to analyze them. Shown from top to bottom are large wedges sliding out from a slope, simple rock slope toppling and a large open pit with more complex mechanisms. All contours indicate displacements.



Cut through open pit showing a new stress state due to mining.



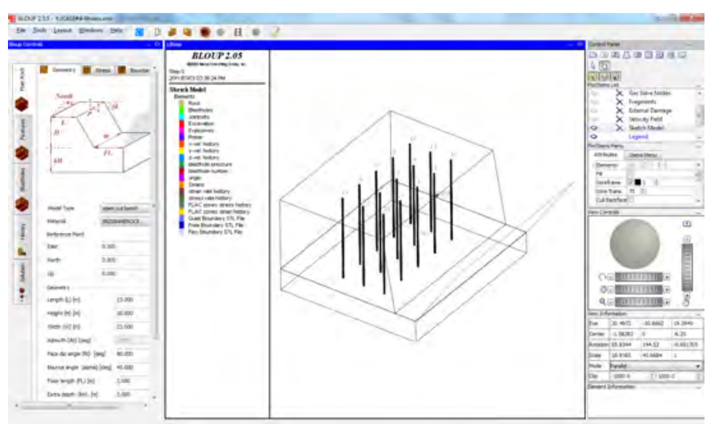
One of Itasca's first applications of SRM was a challenge by the LOP project to model an open pit based on a the rock mass properties and the mining sequence. This *PFC2D* model correctly predicted the dominant failure mechanism (toppling and rock sliding) experienced at the mine site, Chuquicamata. Colors and dark lines indicate horizontal displacements and joints opening up or undergoing shear.

Blast Design

Itasca provides consulting services for:

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

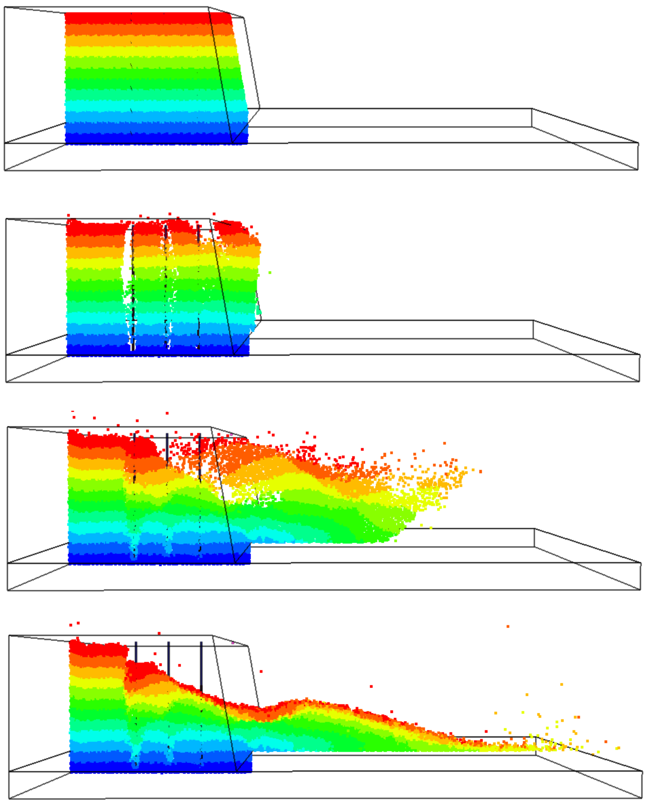
In addition to conventional analytical and empirical methods, Itasca has developed proprietary tools for blast analysis as part of the HSBM consortium that can be used to understand blasthole-to-blasthole interaction, optimize fragmentation and throw, and minimize undesirable damage (e.g., smooth blasting 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.



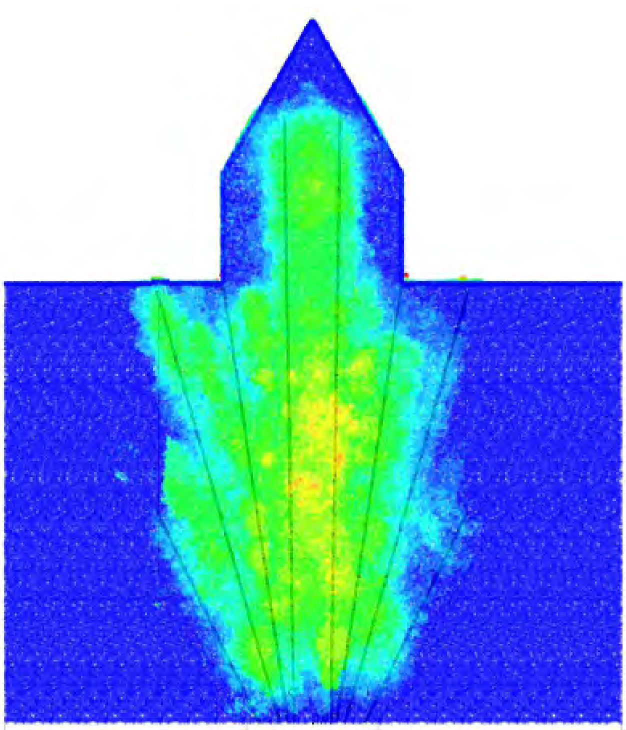
Blo-Up simulates explosive detonation, dynamic shock wave propagation and interaction, rock fragmentation and muck pile formation.

Model Work Flow

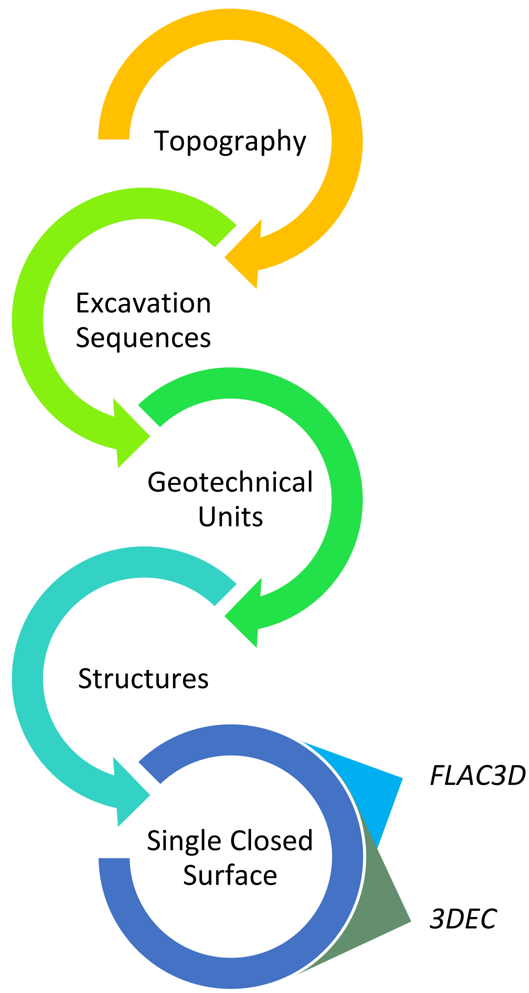
Based on decades of experience using and developing numerical tools, Itasca has developed a rigorous and efficient work-flow for addressing sophisticated geomechanical and hydrogeological problems. This process allows our consultants to bring all of the necessary information from a variety of mine planning and CAD software together as a single closed surface. From this point, we can generate any number of complex *FLAC3D* and *3DEC* models rapidly, flexibly and reliably. Soon, Itasca plans to expand this technology to include *PFC* and other proprietary 3D software.



Blo-Up simulation showing a section though a 3D bench and subsequent muck pile.



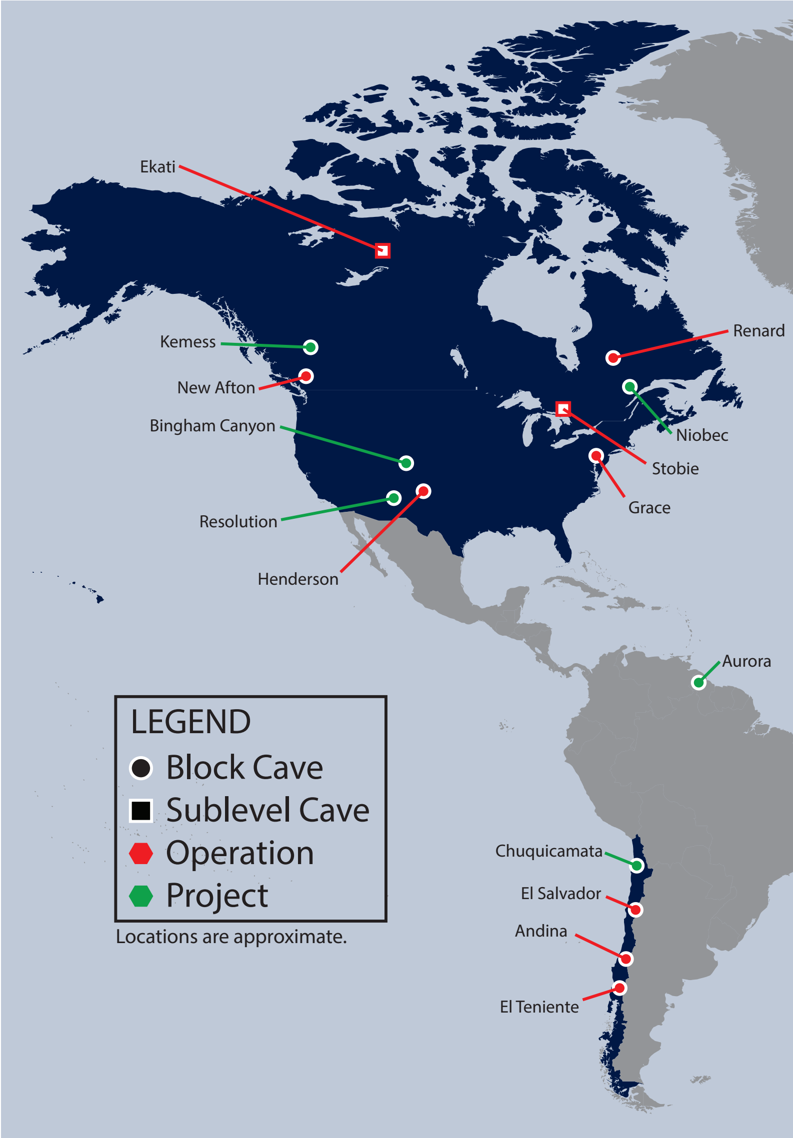
A sublevel caving (SLC) module has been added to *Blo-Up* for ring blasting simulation.



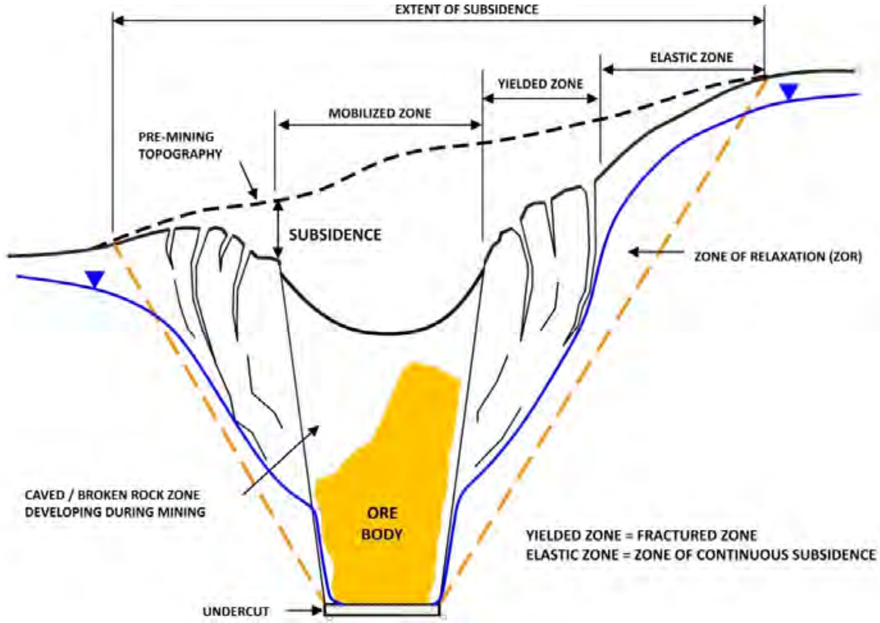
Itasca's work flow for numerical model development is a process of unifying all relevant information into a single, well-defined closed surface. Multiple geomechanical models can be rapidly prototyped.

CAVING EXPERIENCE

Itasca has been at the forefront of cave mining geomechanics for more than 20 years, pioneering the development of a number of industry leading tools for the analysis of caving, subsidence, fragmentation, flow, infrastructure stability and groundwater inflow. These tools have been applied at more than 30 block, panel and sublevel caving (SLC) operations and projects worldwide, and have been validated through direct comparison of observed and predicted behaviors. Itasca also relies on a number of experiential guidelines and empirical relations for caving that have been developed by Itasca and other experts based on a large number of case histories. Itasca engineers work directly with mining companies and other consultants in all phases of design, ramp-up, operation and closure in order to provide advice and make predictions aimed

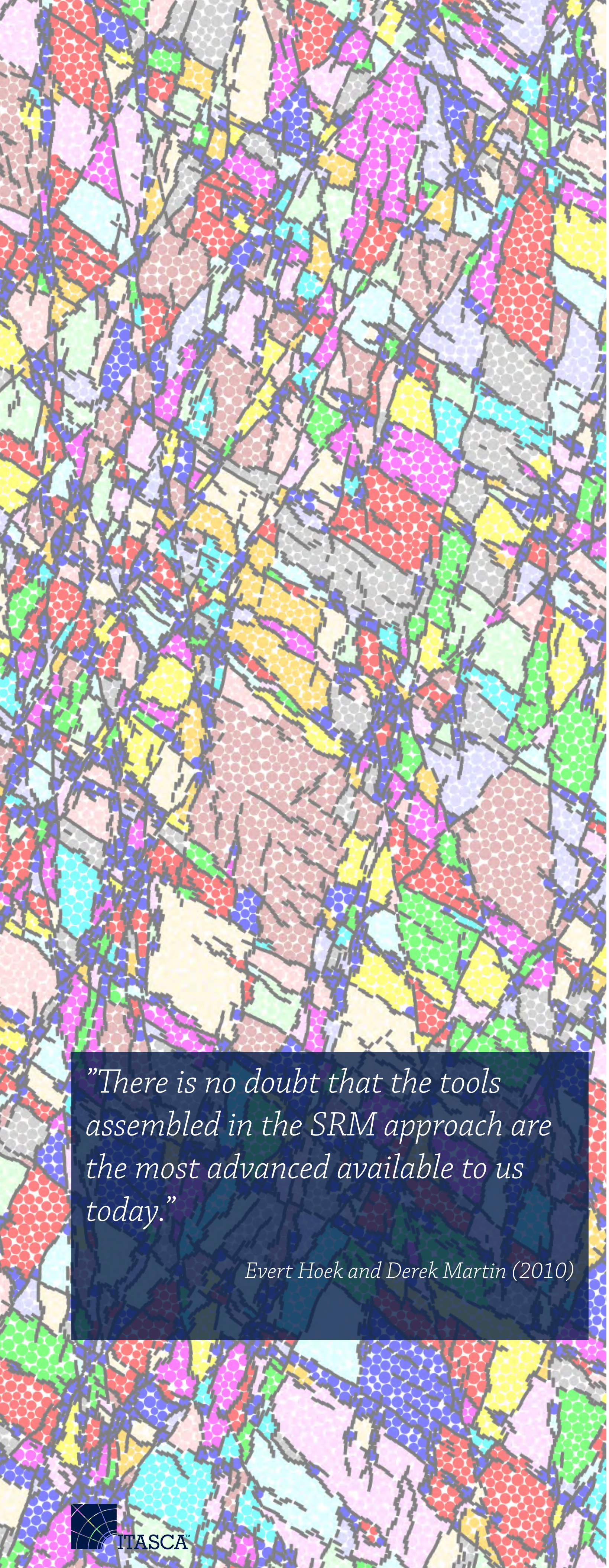


at optimizing recovery and managing risk. The tools are designed to employ as much of the existing rock mass data and monitoring data as possible in order to add maximum value to projects and operations.



With more than 20 years of practical and advanced applications, Itasca designs and analyses every aspect of block, panel and sublevel cave mine mechanics and engineering.

Select caving projects and operations that Itasca has consulted on, ranging from mud-rush potential and orepass stability to caving and fragmentation prediction.



Fragmentation

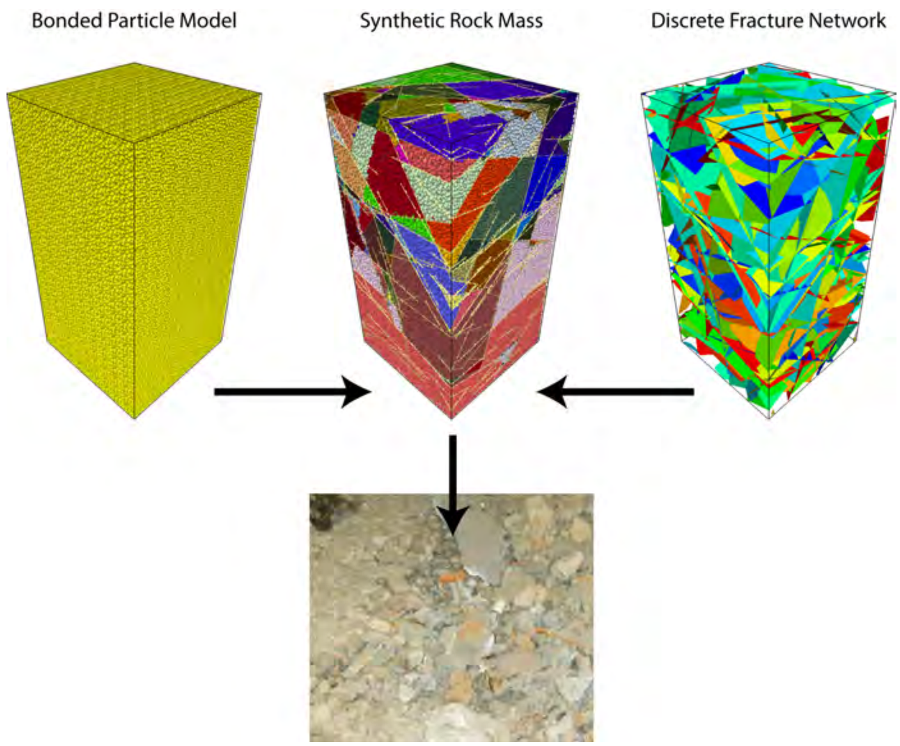
Fragmentation exerts a significant control on the width of flow zones associated with draw from the cave and must be understood to select a drawpoint spacing that promotes uniform drawdown and optimizes ore recovery. Primary fragmentation (the size of rock blocks produced at the onset of caving) is a key input to forecasting of recovery, dilution, drawpoint availability and secondary breakage requirements. Accurate forecasting of drawpoint availability and fines production from the cave also requires an understanding of secondary fragmentation, the attrition of blocks over time as they move through the cave. Itasca has conducted primary and secondary fragmentation studies at a number of different projects and operations, including Ridgeway Deeps Mine (to understand the impact of cave shape on primary fragmentation) and the Chuquicamata, Kemess and Niobec projects, where veining is expected to exert a significant control on primary fragmentation.

Itasca employs Synthetic Rock Mass (SRM) modeling techniques for primary fragmentation prediction and *REBOP* for secondary fragmentation prediction.

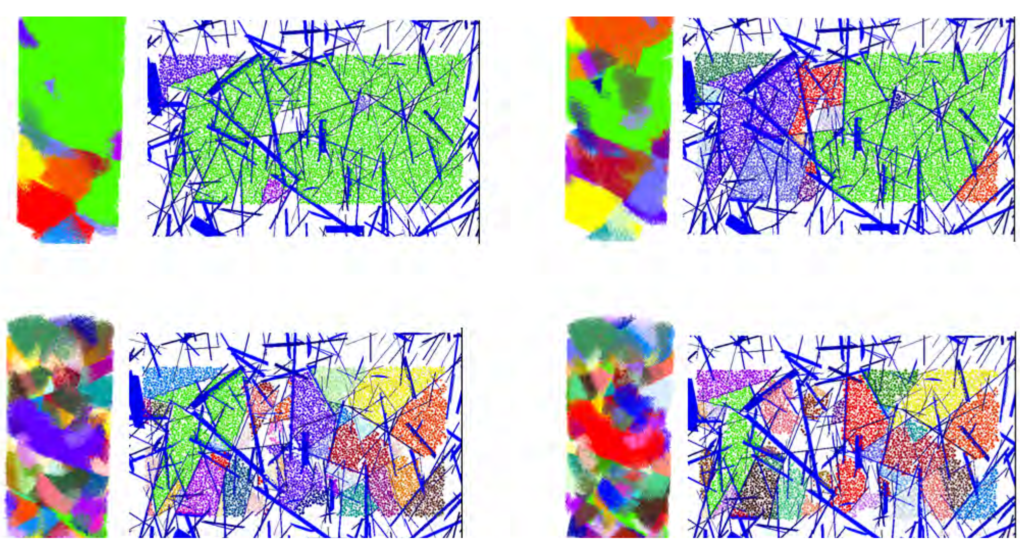
SRM technology was developed as part of the industry-funded Mass Mining Technology (MMT) project and is unique in its capability of explicitly accounting for the impacts of existing fractures (joints or veins), as well as new fracture growth, on fragmentation. In this approach, Discrete Fracture Networks (DFNs) first are developed to describe the in-situ fracture network geometry based on available frequency, orientation and trace length data. The properties of the fractures are established on the basis of laboratory testing and/or empirical relations for stiffness and strength (i.e., based on logged and/or mapped roughness, alteration and waviness). These DFNs are embedded within large-scale (5-20 m), three-dimensional bonded particle/block models of the intact rock (developed with *PFC3D* and/or *3DEC*) and strained to simulate the primary fragmentation process as a function of expected cave back stresses. Results are presented in the form of fragment size and volume distribution plots and three-dimensional block models of expected primary fragmentation.

Primary fragmentation measurements or predictions can be input to *REBOP*, a gravity flow simulator developed by Itasca to predict the flow and drawdown associated with production from hundreds of drawpoints over the life of the mine. Using a user-defined drawpoint layout and production schedule, secondary fragmentation can be predicted as part of a draw simulation with blocks breaking down in the column as a function of stress and strain and the rock block strength.

SELECTED FRAGMENTATION CLIENTS	
Operations	**Projects**
El Teniente	Bingham
Henderson	Chuquicamata
Northparkes	Kemess
Palabora	Niobec
Ridgeway Deeps	Oyu Tolgoi



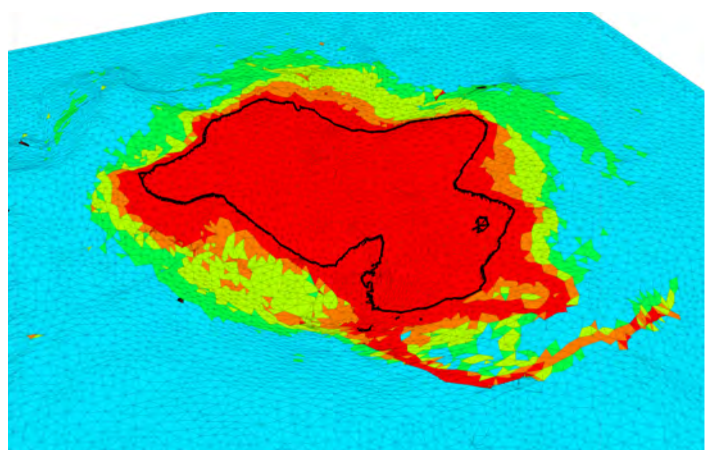
Synthetic Rock Mass testing methodology for fragmentation prediction.



Use of Synthetic Rock Mass (SRM) testing to estimate primary fragmentation as a function of evolving cave back stress. The sample (colored by fragment) is shown on the left, while the underlying DFN is shown on the right.

Caving and Subsidence

Caving is being applied to increasingly deep, large, strong and heterogeneous orebodies, increasing the risk of ore loss due to unexpected cave shape. In addition, the transition from open pit to cave mining that many companies are contemplating offers challenges in terms of timing and the management of large-scale caving-induced slope collapses. Itasca has pioneered methods for analyzing undercut advance, cave growth and surface impacts under these conditions, providing predictions and analysis of caveability, subsidence (including induced slope failures), cave shape, caving rate, bulking and the potential for hang-ups and air-gap development. The results of these studies are used to optimize column height, footprint layout, undercut/draw strategy (including advance direction, lead-lag and undercut shape) and standoff distance for infrastructure and transitioning strategies. When combined with empirical strain-based criteria (e.g., for the limits of observable cracking on surface) and structure-specific criteria (e.g., for cracking of masonry structures), the results of cave-scale modeling can be used to predict the surface expression of the cave (e.g., timing, extent and depth of the crater) and estimate limits of caving-induced subsidence. The predictions obtained from these analyses commonly focus on the location of planned or existing surface infrastructure, such as shafts, process plant, water diversion structures and tailings dams.

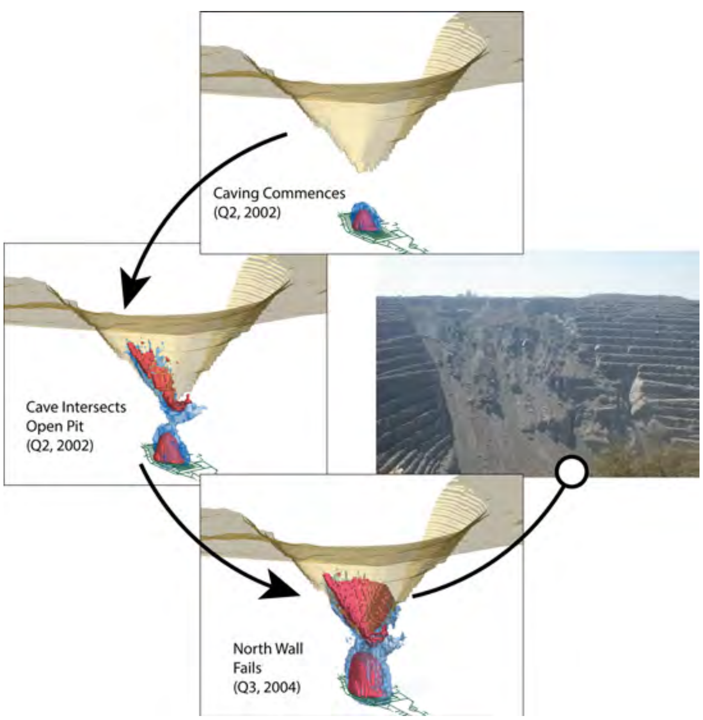


Predicted surface expression for a series of caves developed beneath a large open pit, including the crater limit (black line) and zones outlining the expected severity of damage to masonry structures (color contours).

ITASCA

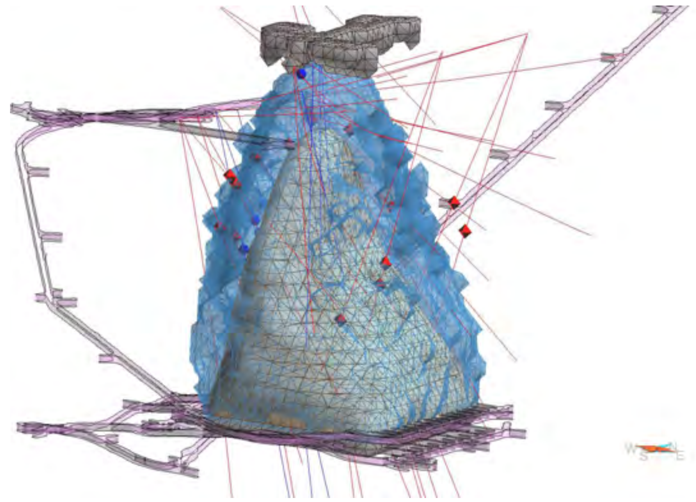
Itasca developed the first numerically based tools for caving prediction in the late 1980s, and these subsequently have been advanced and expanded through application at more than 20 different operations and projects around the world, and through funding provided by the International Caving Study (ICS) and Mass Mining Technology (MMT) projects. Both *FLAC3D* and *3DEC* are used for caving simulation and employ a "caving algorithm" that is production-driven and incorporates material behaviors that are essential to the prediction of rock mass response to undercutting and draw (including cohesion weakening, modulus softening and shear- and tension-induced bulking).

The key inputs to the caving algorithm include rock mass strength, modulus and brittleness estimates from the characterization efforts (e.g., empirical relations and/or SRM testing), in-situ stresses, base-case layouts (footprints) and production schedules (e.g., from *PCBC*). In addition, major structures can be added to the model to account for their impact on cave shape and caving rate.



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

Evolution in the seismogenic, yielded, mobilized and abutment stress zones is tracked as a function of production and are visualized as a series of three-dimensional isosurfaces that can be exported as DXF wireframes for comparison to monitoring data (e.g., microseismic events, TDR breakages, open hole blockages) and other cave operation and management activities.



Result of a cave-scale model indicating predicted extents of yielded zone (blue surface) and mobilized zone (white surface). Open-hole blockages (red diamonds) and Time-Domain Reflectometer (TDR) breakages (blue spheres) correspond well with the leading edge of the predicted yielded zone.

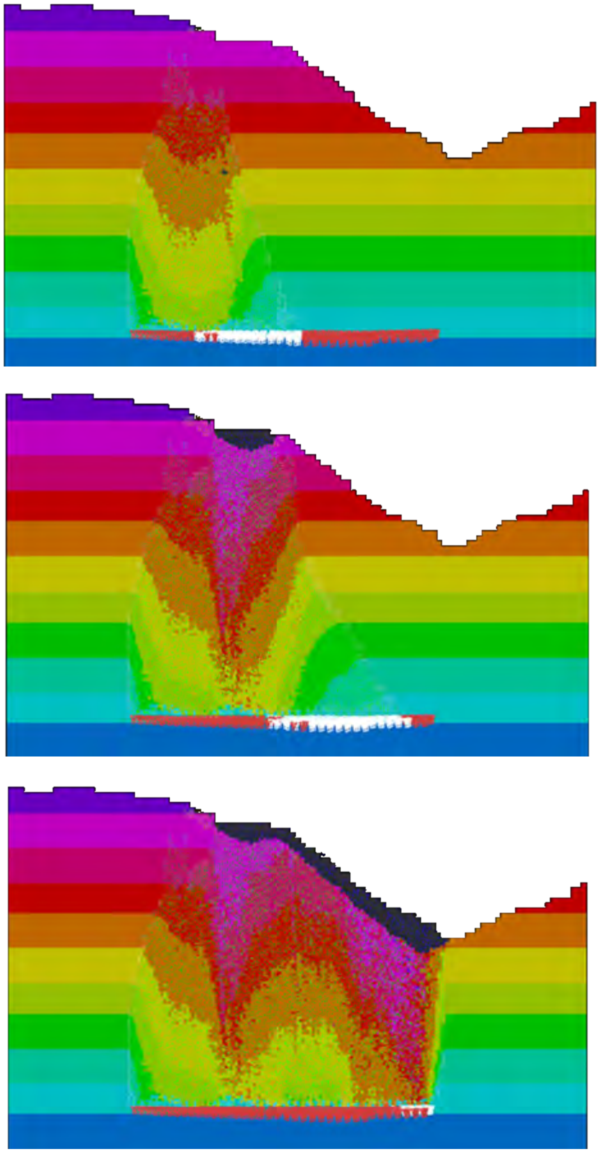
SELECTED CAVING and SUBSIDENCE CLIENTS	
Operations	**Projects**
Andina	Bingham
Argyle	Cadia East
Cullinan	Chuquicamata
Ekati	Ernest Henry
El Salvador	Far South East
El Teniente	Jwaneng
Fabian	Kemess
Finsch	Niobec
Grace	Orapa
Henderson	Oyu Tolgoi
Kapten	Resolution
Kiruna	Venetia
Koffiefontein	
New Afton	
Northparkes	
Palabora	
Renard	
Ridgeway Deeps	

Draw Control, Flow and Recovery

Understanding of how material flows within a cave is required to make appropriate decisions at the design stage (i.e., drawpoint spacing, drawpoint layout, drawbell geometry) and during operation (draw rates, draw ramp-up and scheduling). Draw strategy in particular is the key control that operators use to maximize recovery, minimize dilution and manage hazards associated with caving (hang-ups and mud rush). Itasca has been involved with a number of caving projects and operations worldwide in both the design and operating stages to help with decisions relating to drawpoint spacing and draw scheduling, and to forecast what is likely to be extracted from the cave over the life of the mine. We also have assisted mines with identifying targets for remnant recovery through life-of-mine draw reconstruction and simulation (e.g., Cullinan Mine), and developed mix matrices for incorporation into grade forecasting and draw scheduling software (e.g., Henderson Mine).

Flow analyses are conducted by Itasca using *REBOP*, a tool specifically developed to provide rapid analysis of the movement and extraction of fragmented rock under draw in mine operations that use block, panel or sublevel caving techniques.

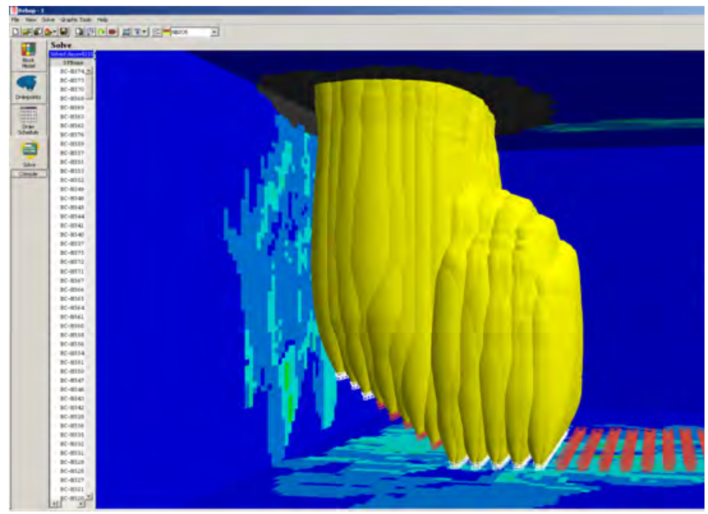
SELECTED DRAW CONTROL, FLOW and RECOVERY CLIENTS	
Operations	**Projects**
Andina	Niobec
Argyle	Oyu Tolgoi
Cullinan	Resolution
El Teniente	Venetia
Finsch	
Henderson	
Kiruna	
New Afton	
Northparkes	
Palabora	
Renard	
Ridgeway	
Salvador	



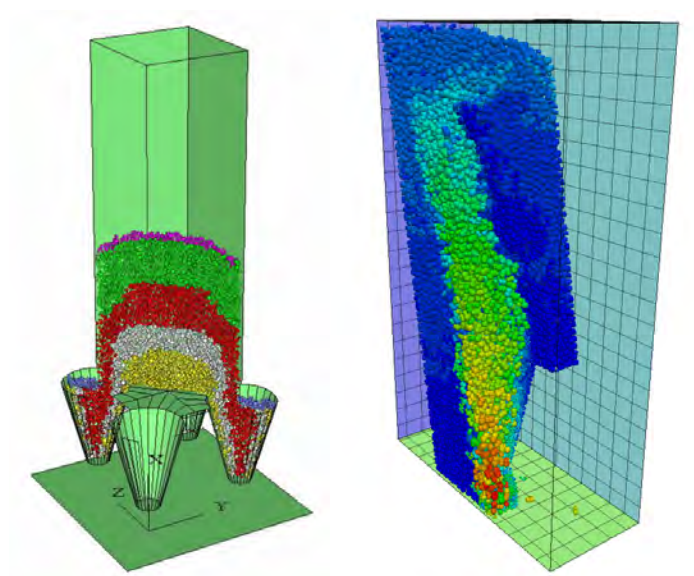
Example of *REBOP* simulation of drawdown (shown in section) associated with the development of a panel cave beneath an open pit over time. Black blocks indicate surface rilling.

The key inputs to *REBOP* include measurements or predictions of primary fragmentation and evolving cave shape and intact rock strength. The primary output from a draw analysis includes time- or tonnage-based histories of extracted ore grades and other rock properties, plots of material distribution above the drawpoints and three-dimensional visualization of the movement and extraction zones associated with each drawpoint.

In addition, secondary fragmentation, rilling and fines migration all can be accounted for within *REBOP* simulations. The rilling logic and the ability to represent complex surface topography allow simulation of the impacts of local or large-scale failures in overlying open pit slopes or weak overburden. In addition to estimating recovery and dilution, the fragmentation exiting drawpoints can be estimated over time to help establish likely drawpoint availability and secondary breakage requirements. In sublevel caves, the percentage of ring ore reporting to different sublevels can be tracked (i.e., primary, secondary, tertiary recovery) and tracer markers can be used to test the code against the results of in-situ marker trials.



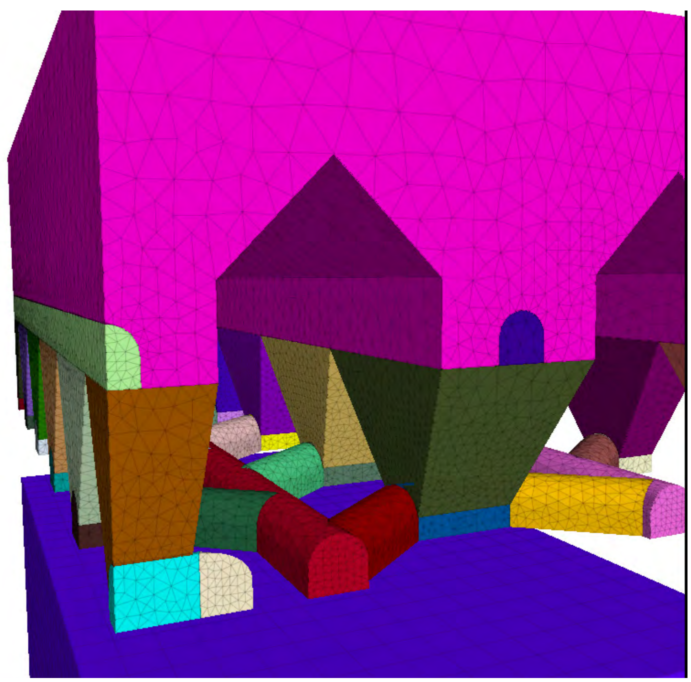
REBOP software showing drawpoints and zones of broken rock draw for each.



Block cave drawbells and sublevel cave draw points simulated using *PFC3D*. These types of models were used to investigate draw control and flow mechanics. The knowledge gained by this innovative work has been applied to *REBOP* for more rapid, mine-scale simulations.

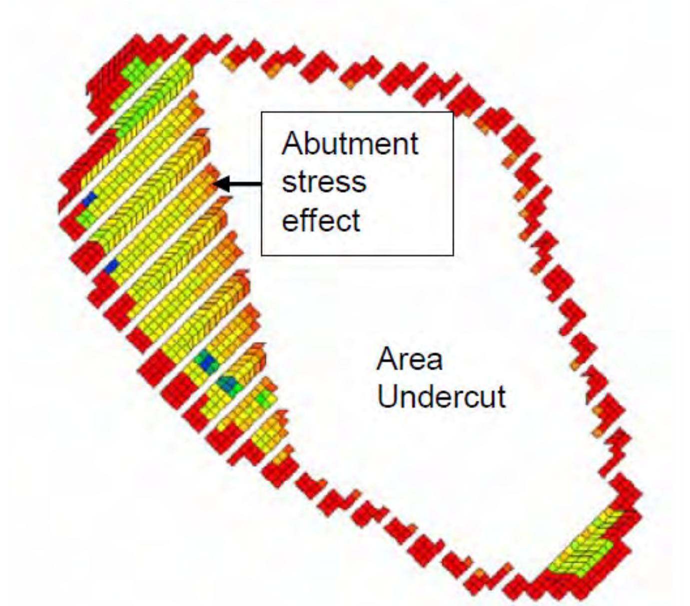
Infrastructure Stability

Itasca's expertise in cave mining has been used by companies to make critical decisions regarding the orientation and geometry of the undercut, the layout of the extraction level and the degree of support in access and infrastructure required to ensure worker safety and long-term stability. Itasca is a leader in the design and analysis of undercut- and extraction-level infrastructure for underground block- and panel-cave mining methods. Itasca has conducted investigations of excavation behavior at many of the world's caving mines. Itasca engineers have been successful in optimizing the extraction-level development prior to undercutting, as well as developing sound designs for the level and timing of ground support. Due to the three-dimensional nature of typical undercut- and extraction-level mining geometries and the complex interaction between cave shape, cave growth and abutment stresses, three-dimensional analyses at both the tunnel and cave scales are required to simulate the loading conditions of undercut- and extraction-level drives. Three-dimensional, non-linear analysis of such mining geometries has become routine using *FLAC3D* and *3DEC*.

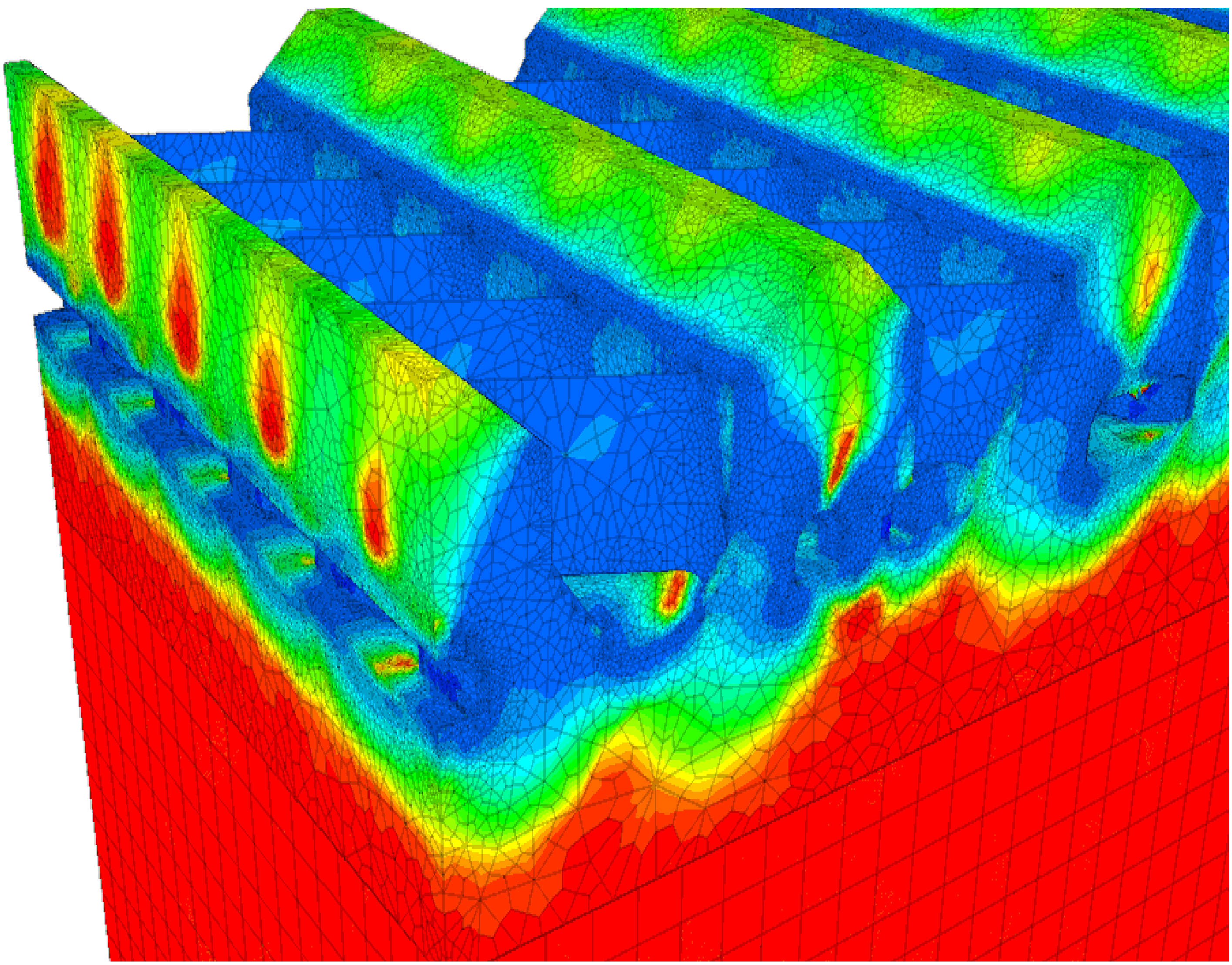


FLAC3D model of undercut and extraction-level development used to investigate closure strains associated with different undercut strategies.

Itasca software permits careful consideration of the complex stages of loading, unloading and yielding at both the cave and drift scale that occur during undercutting and subsequent cave growth. They offer a means to assess the induced stress changes and potential for yielding around the planned infrastructure including shafts, crusher chambers, extraction-level development and undercut drives. These predictions can be combined with empirical criteria to infer potential for instability and to suggest where more detailed modeling may be required to examine stability further and to test proposed support designs.



Example of abutment stress analysis in a *FLAC3D* model (plan view section) of an inclined cave.



FLAC3D model showing stresses acting on the undercut level of a proposed block cave layout.

HYDROGEOLOGY

Itasca hydrogeologists have extensive experience in assessing key hydrogeologic issues related to caving projects, including:

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

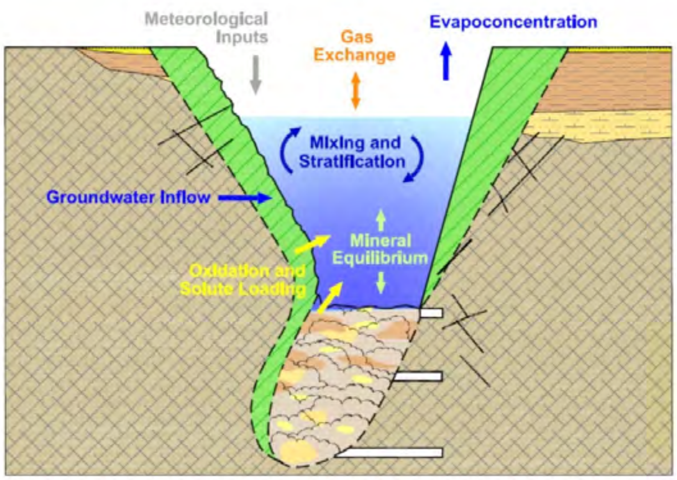
In addition to conventional data collection, field investigation and field monitoring, Itasca is unique in that our hydrogeologists and geomechanical engineers work closely together to account for the propagation of caved rock over time in geomechanical models. In doing this, caving can be accounted for in our 3D 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 caving. Itasca has constructed 3D groundwater flow models to predict both inflow and pore-pressure distribution for a number of open pits transitioning to block or sublevel cave mining and caving projects.

OPERATION	PROJECT
Chuquicamata	Aurora
Ernest Henry	Grasberg
Mina Ministro Hales	
Venetia	

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.



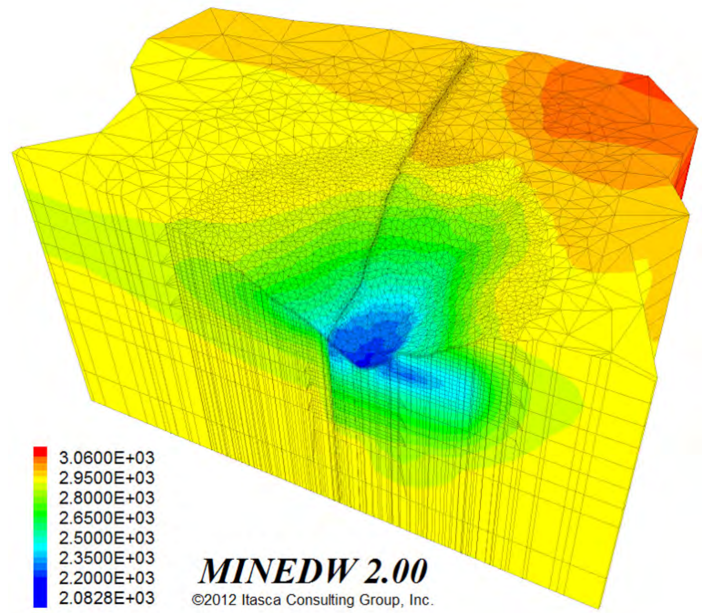
Conceptual model of water quality for open pit/block caving operation.

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* 3D 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 2D and 3D pore pressures from *MINEDW* can be imported seamlessly by 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.

Mud-Rushes

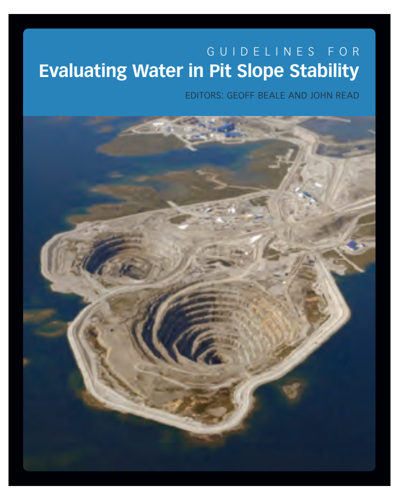
Itasca's hydrogeologists have worked jointly with the geomechanics group to study the mud-rush potential of caved material for various caving projects. The predicted inflow from the 3D groundwater flow model, the development of subsidence and surface-water recharge were key input parameters for the mud-rush assessment. Itasca used various unsaturated flow codes to predict the moisture contents for the geomechanical group to use as input in their assessment of potential mud-rush occurrences.



MINEDW model plot showing water head around an open pit.

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.)



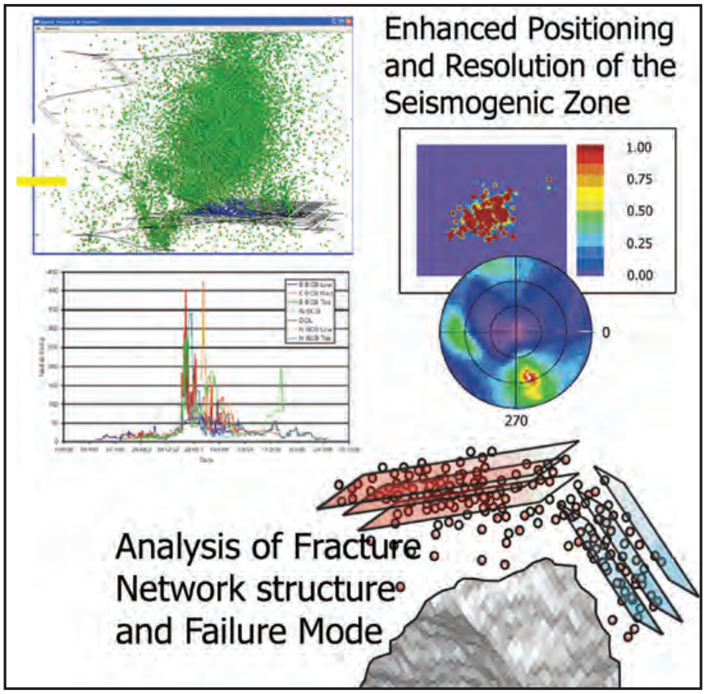
MICROSEISMIC ANALYSIS

Itasca specializes in providing commercial microseismic monitoring, processing and advanced analyses to the mining industry. Microseismic monitoring provides a unique insight into the fractures induced by mining operations, which has implications for:

- Early warning on localized induced damage to mine infrastructure;
- Reactivation or creation of structures affecting slope stability;
- Effectiveness of preconditioning campaigns; and
- Progress of deep underground caving projects.

Itasca has developed a series of novel services that enhance the information provided by existing microseismic assets to monitor the evolution of the fracturing processes, including:

- Structural analysis of microseismic event distribution for imaging of induced or mobilized fracture geometry;
- Analysis of microseismic source parameters to identify fracturing modes and the fraction of newly opened and reactivated fractures;
- Temporal and spatial clustering of microseismic events to quantify damage accumulation and identify areas of localized fracturing;
- In-depth understanding of fracture mechanics through the integration of acquired data and Synthetic Rock Mass models; and
- Fully featured, microseismic training courses focused on the principles behind the technology, processing algorithms and hands-on experience of using processing software.



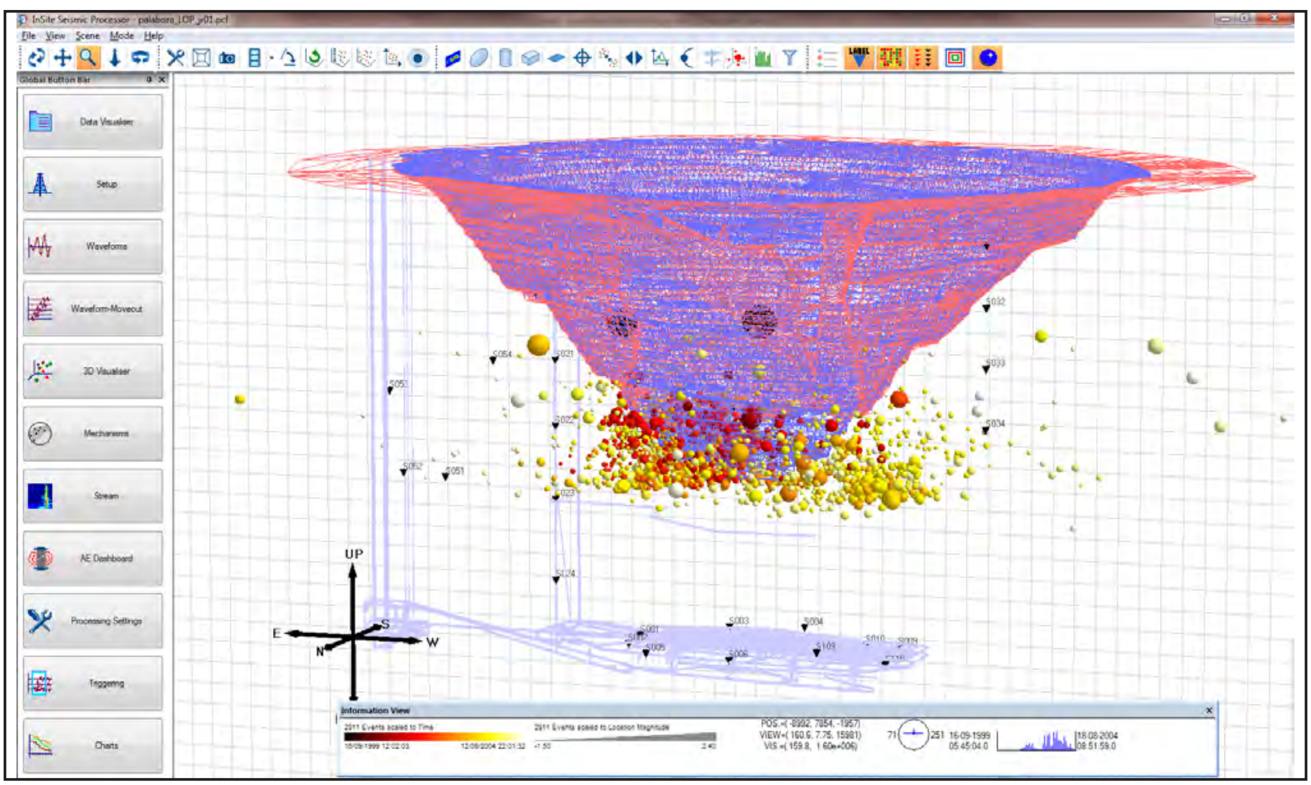
Microseismic analysis.

InSite, Itasca's integrated tool for seismic data acquisition, signal processing and data management and visualization, is independent of the acquisition hardware used at the mine site. It can be integrated with most commercial hardware packages to perform real-time data capture and processing. Processing algorithms are being developed continuously to meet the complexities of processing microseismic activity in challenging environments such as high-noise operating mines, complex velocity structures or limited coverage sensor arrays.

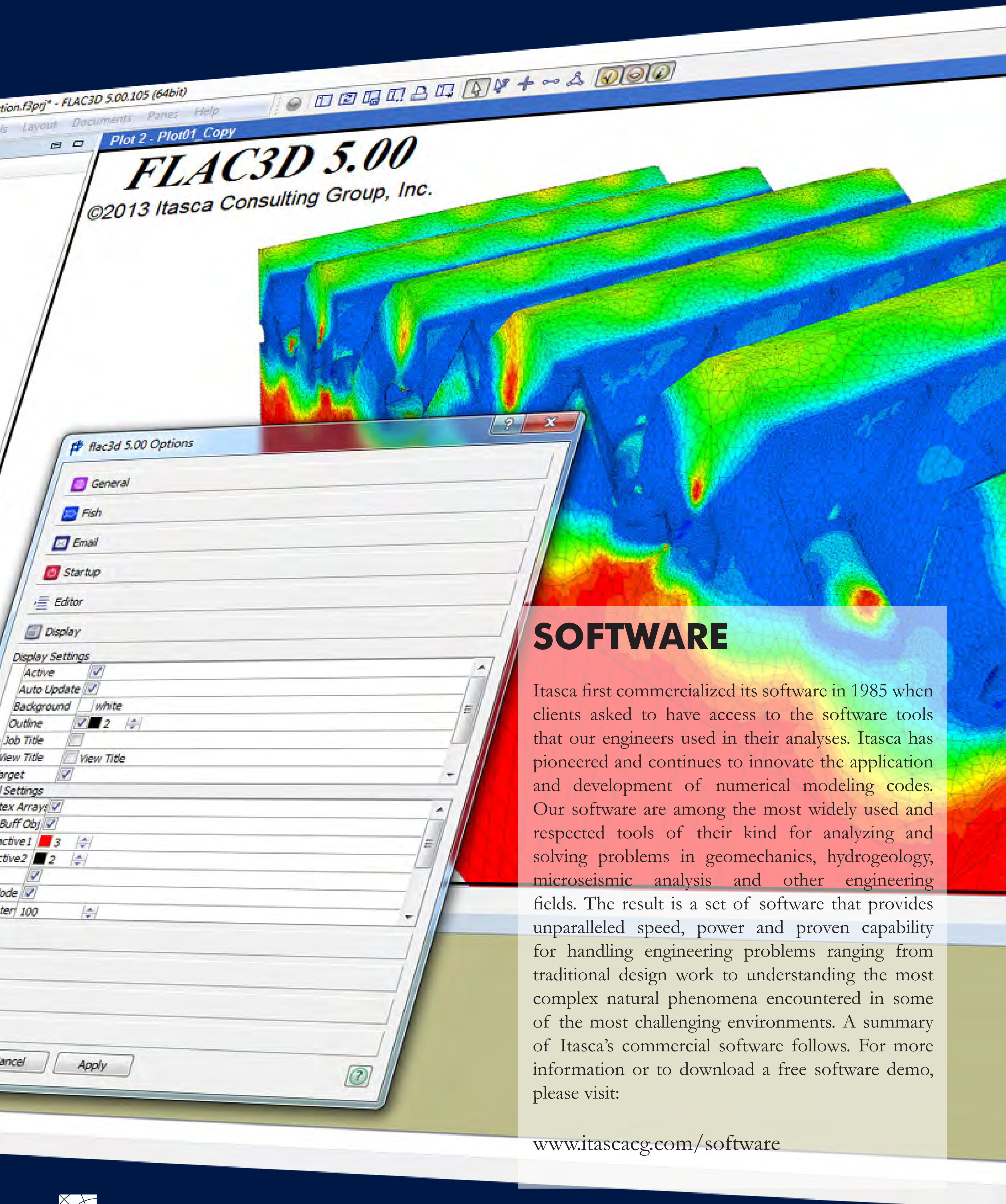
Itasca has a comprehensive range of cost-effective seismic data acquisition systems from sensors and signal conditioning to high-speed data acquisition. We provide an in-depth and objective analysis of the type and design required, including a three-dimensional site analysis to recommend the optimal positioning of a sensor array.

Additional microseismic services provided:

- Standard and advanced software tools for do-it-yourself processing;
- Advanced database technologies for networking remote microseismic stakeholders;
- Microseismic project management, array design, data hosting and integrated processing systems;
- Geophysics team for provision of complete processing service solution; and
- Quality assurance of third party microseismic processing results.



Microseismic events from a mining operation viewed with *InSite*.



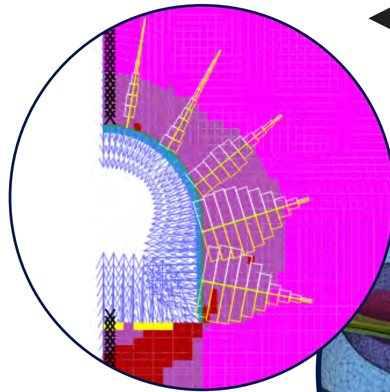
SOFTWARE

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 codes. 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. A summary of Itasca's commercial software follows. For more information or to download a free software demo, please visit:

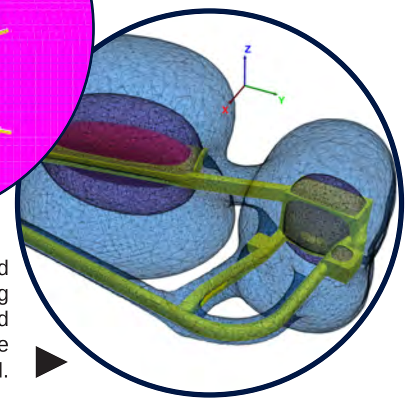
www.itascacg.com/software

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), dynamic processes and includes structural elements (e.g., liners, rock bolts, cables, beams, etc.). *FLAC/Slope* is a specialized version of *FLAC* designed specifically for slope stability factor-of-safety analysis.



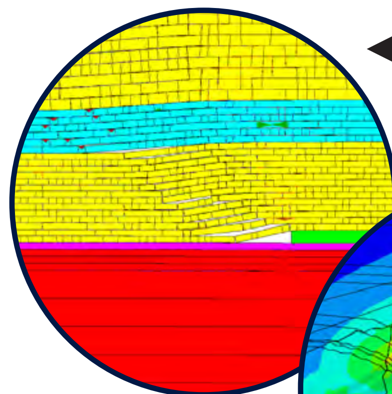
Drift with a shotcrete liner and rock bolts. Plastic yielding around the drift, bolt loads and displacements are shown in this *FLAC* model.



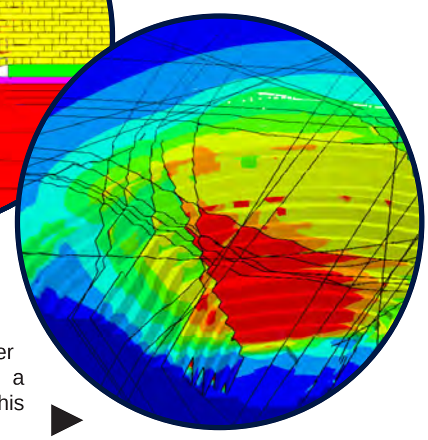
Iso-contours of ground displacements surrounding two large caverns and several access drifts are shown in this *FLAC3D* model.

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, etc.). 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, and groundwater flow along discontinuities, multiple excavation sequences, dynamic processes and include structural elements (e.g., liners, rock bolts, cables, beams, etc.).



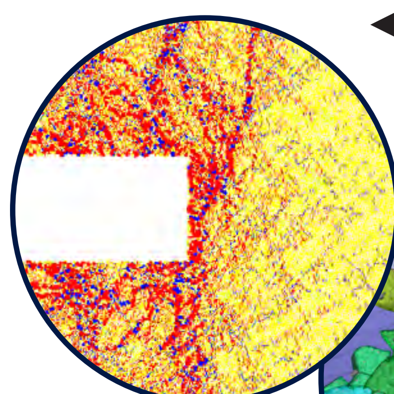
Layers of sedimentary rock collapsing during retreat mining are shown in this *UDEC* model.



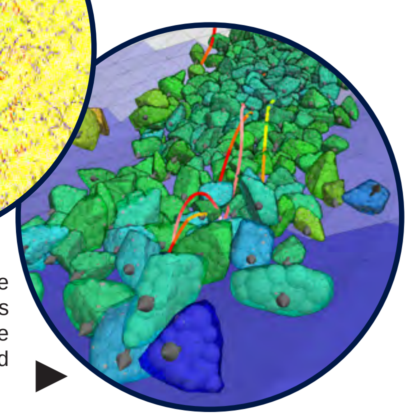
Open pit being mined though a series of large faults shows higher displacements along a portion of the pit wall in this *3DEC* model.

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.



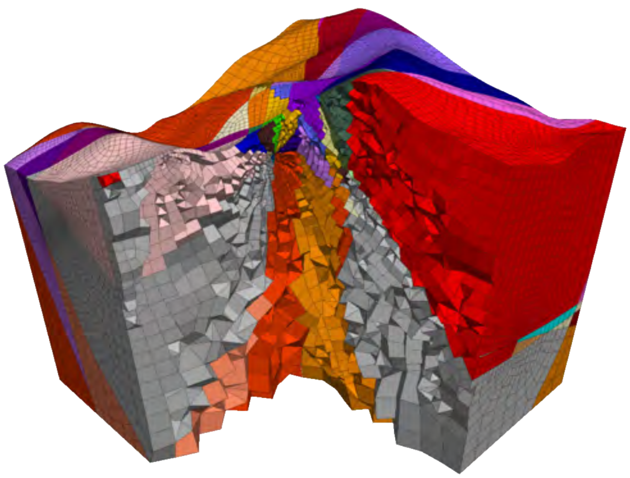
PFC2D simulation of a drift advancing within a stress mining environment indicting predicted damage in the surrounding rock.



PFC3D model using particle clumps to simulate rocks sliding down a slope. Some rock paths are being tracked (colored lines).

Griddle™

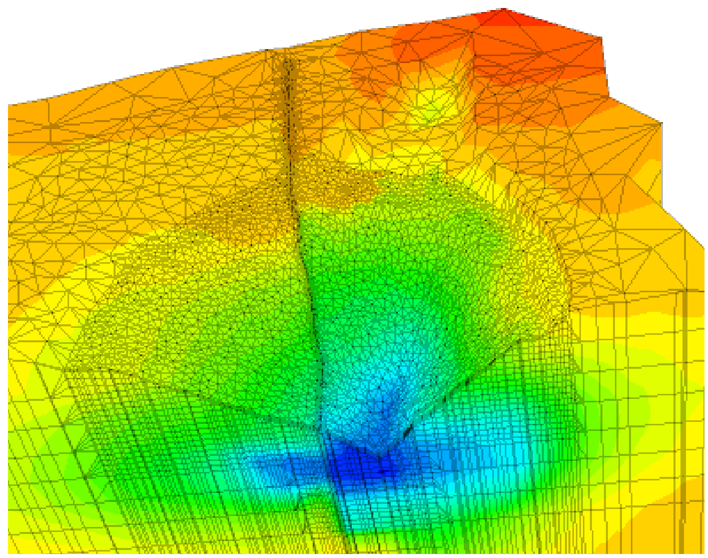
Griddle is a fully interactive, general-purpose mesh generation plug-in for the *Rhinoceros* 5.0 3D CAD software (www.rhino3d.com). *Griddle* can be used to remesh *Rhino* surface meshes to comply with precise size specifications and type (triangle or quad-dominant). Surface meshes can then be used as 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*.



Griddle-generated hexahedral-dominant *FLAC3D* model with nine intersecting faults modeled using interfaces.

MINEDW™

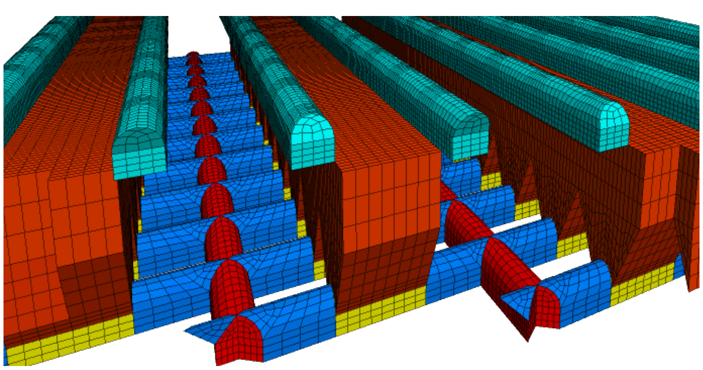
Itasca's hydrogeological software specifically developed for simulating groundwater conditions related to open-pit and underground mining. Our software is very efficient in simulating multiple pushbacks, the transition from the open pit to underground mining and spatial and temporal change of hydraulic conductivity of disturbed rock as the results of mining. The simulated pore pressure distribution from *MINEDW* model can be readily imported into Itasca's geomechanical models.



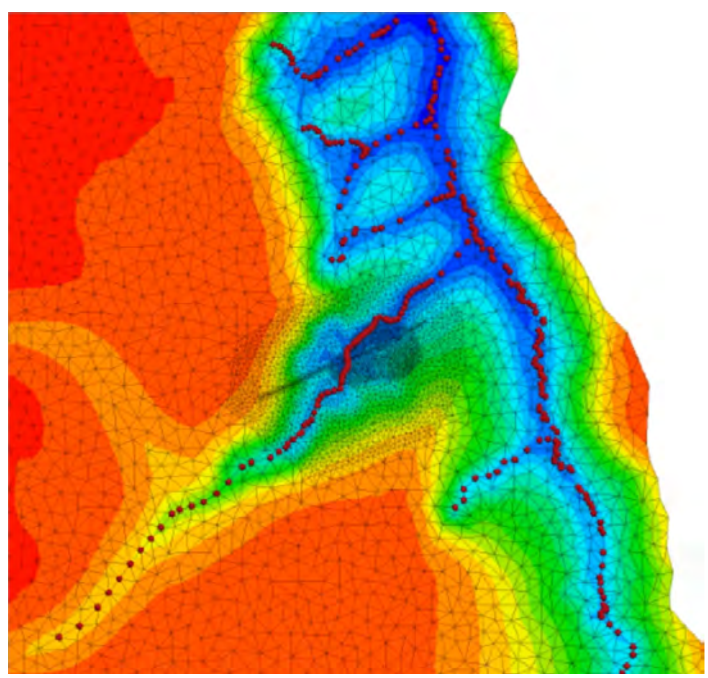
MINEDW simulation of an open pit mine showing the water head after 48 years of mining.

BlockRanger™

BlockRanger (*BR*) is a fully interactive, volume mesh generation plug-in for the *Rhinoceros* 5.0 3D CAD software (www.rhino3d.com). *BlockRanger* converts *Rhino* 5 solids into blocks of high-quality hexahedral (brick) elements for use with *FLAC3D* and *3DEC* software, making it ideal for models that require hexahedral meshing and a strict control of element quality, spatial distribution, and orientation.



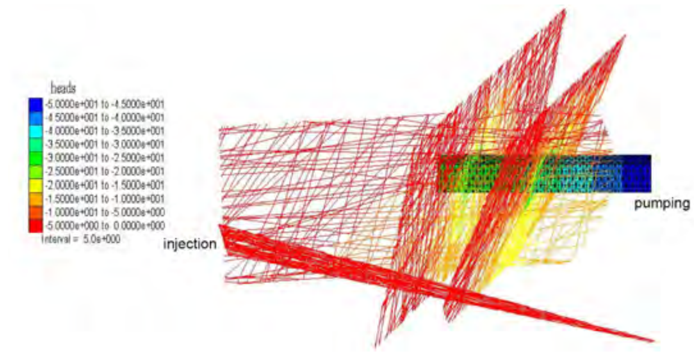
A FLAC3D model of an underground block caving mine generated using BlockRanger.



MINEDW simulation of ground topology, river and streams (plan view).

3FLO

Itasca software developed to simulate 3D fluid flow and transport in porous and/or fractured media through a 3D network of pipes on any assembly of planes. Each pipe can be assigned conductivity values from a wide range of statistical distributions or an aperture map can be simulated using a grid of pipes. Geometrical properties of the space between fractures, such as size, shape and connectivity distributions can be quantified. *3FLO* is capable of 3D mesh generation; simulating both steady and transient fluid flow; solute transport and diffusion and can account for most types of reactions (e.g., precipitation, dissolution, adsorption, oxydo-reduction and kinetics). *3FLO* takes full advantage of Itasca's *FISH* scripting language which allows users to create new variables, meshing procedures, particle detection procedures, custom graphical output and work with any type of statistical distribution (e.g., for use in fracture generation).

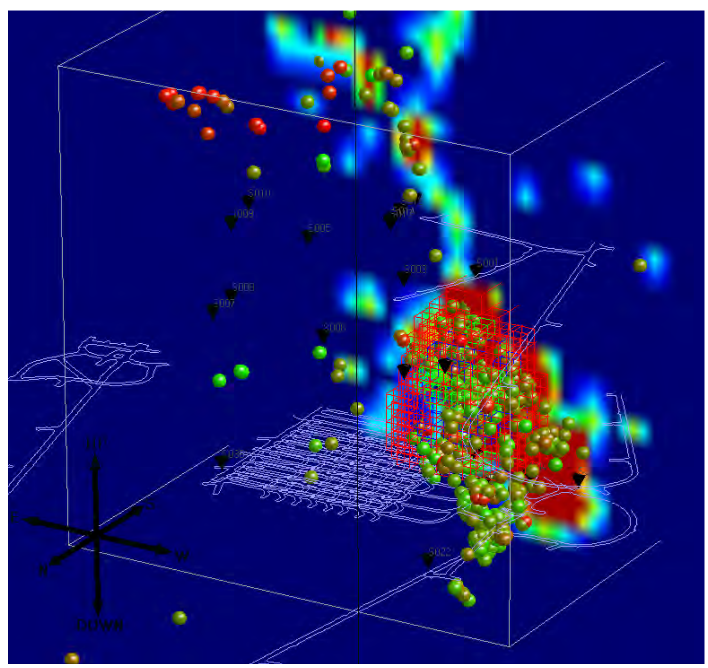


Water head of a coupled fractured/continuum model.

InSite Seismic Processor

Itasca's integrated seismic data acquisition, processing, management and visualization software for seismological analysis ranging in scale from acoustic emissions in the laboratory, through microseismics around underground excavations up to regional-scale earthquakes. The software is independent of acquisition hardware and can be integrated with hardware packages to perform real-time data capture and processing. *InSite* software is used by many international companies and organizations for in-house processing and management of microseismic data. Download a Demo version of *InSite* here:

www.appliedseismology.com/software/demo-download



Microseismic event locations and event density in the *InSite* 3D visualizer.

Customization

Our software development is directed and refined by Itasca's consulting practice. Itasca consultants can obtain custom additions to any Itasca software for specific projects or client needs. Itasca also can develop entirely new simulation programs in consultation with clients or as part of research collaborations. The software programs *REBOP*, *Blo-Up*, *Slope Model* and *HF* (Hydraulic Fracturing) were created in this manner.

LEAD PERSONNEL, CAVE 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.

Luigi Cotesta
M.Eng., P. Eng
Itasca Consulting Canada, Inc.
General Manager & Principal
Geomechanics Engineer
lcotesta@itasca.ca

Mr. Cotesta has over 20 years of experience in geomechanics. He has lead & managed numerous geomechanical mine design studies (scoping through execution), he has provided solutions to help solve operational rock mechanics and ground control problems, and has relevant experience in Research and Development.

His experience spans a wide range of mineral deposits for both greenfield and brownfield projects and involves collection, analysis and interpretation of site characterization data, integration and analysis of multidisciplinary datasets (mine planning/production, geological, geomechanical), sequence evaluation and optimization, stope and crown pillar design, numerical modeling, ground control & support design, pit slope design, backfill strength requirements and stability, seismic data analysis & risk evaluation, caveability, subsidence evaluation, trade-off studies and mining method evaluation.

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

Dr. Garza-Cruz is a geomechanics engineer whose background is in numerical modeling. She has 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, stope-back behavior, re-evaluation of underground mining method, and to understand the creep behavior of excavations in frozen ground.

She has applied numerical models to provide 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 access. She has also developed specialized tools 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 over 20 years of experience in mining and environmental hydrology, geochemistry and development implementation of numerical models. His area of expertise is in applying multidisciplinary knowledge of engineering, hydrology and geochemistry in solving various problems. Dr. Liu is also a Sun Micro Certified Java programmer with extensive experience in the development of software, internet applications and databases. He is a registered Professional Engineer in Colorado.

Loren Lorig
Ph.D., P. Eng.
Itasca Consulting Group, Inc.
Itasca Chile SpA
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
Ph.D.
Itasca Consultants AB
General Manager and Principal Engineer
jonny@itasca.se

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.

“Over 37 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.

Contact us at:

Itasca International Inc.
111 Third Avenue South, Suite 450
Minneapolis, MN 55401 USA

Tel: 1 (612) 371-4711
Fax: 1 (612) 371-4717
itasca@itascainternational.com
www.itascainternational.com

Follow Itasca:

ITASCA™