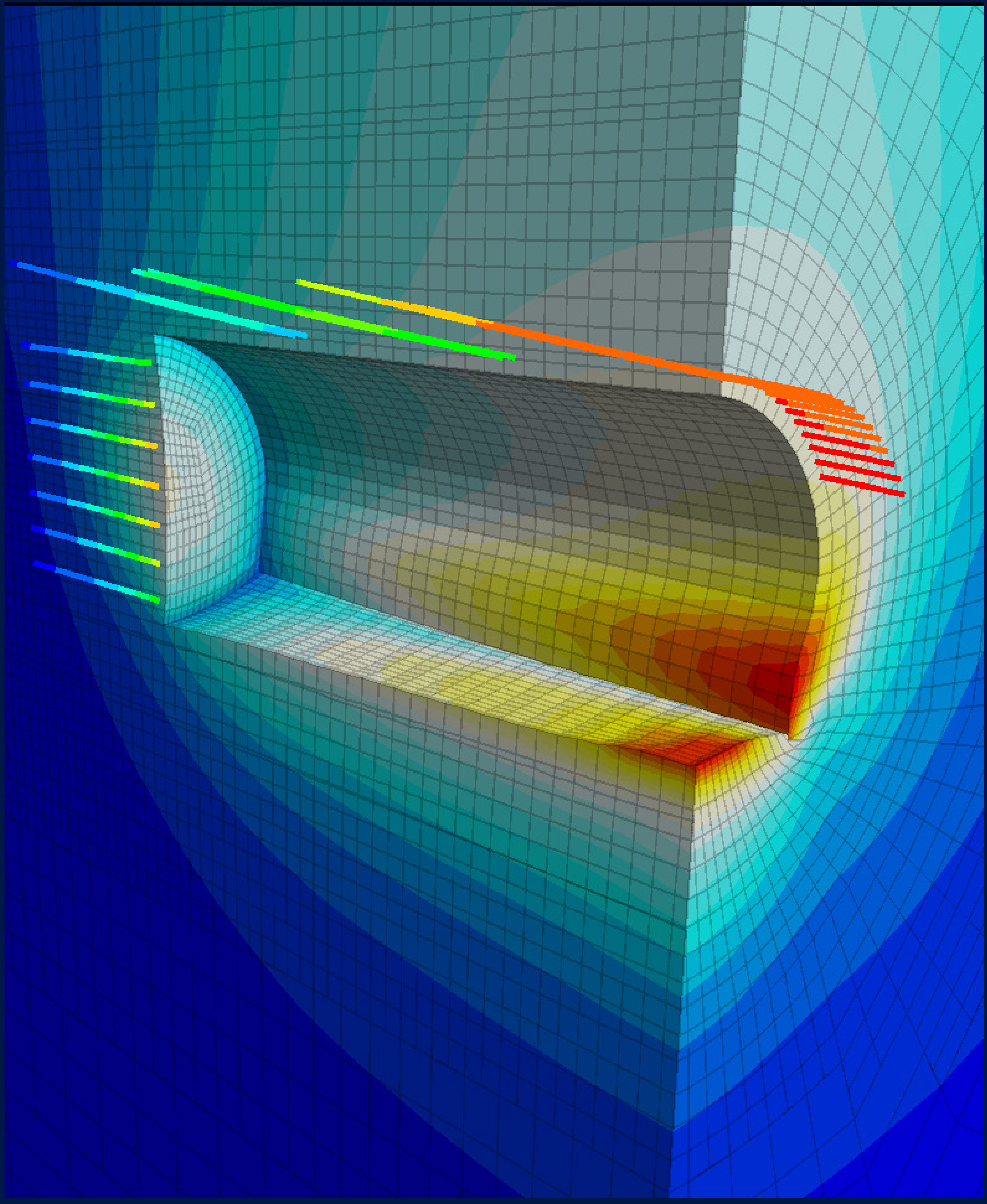
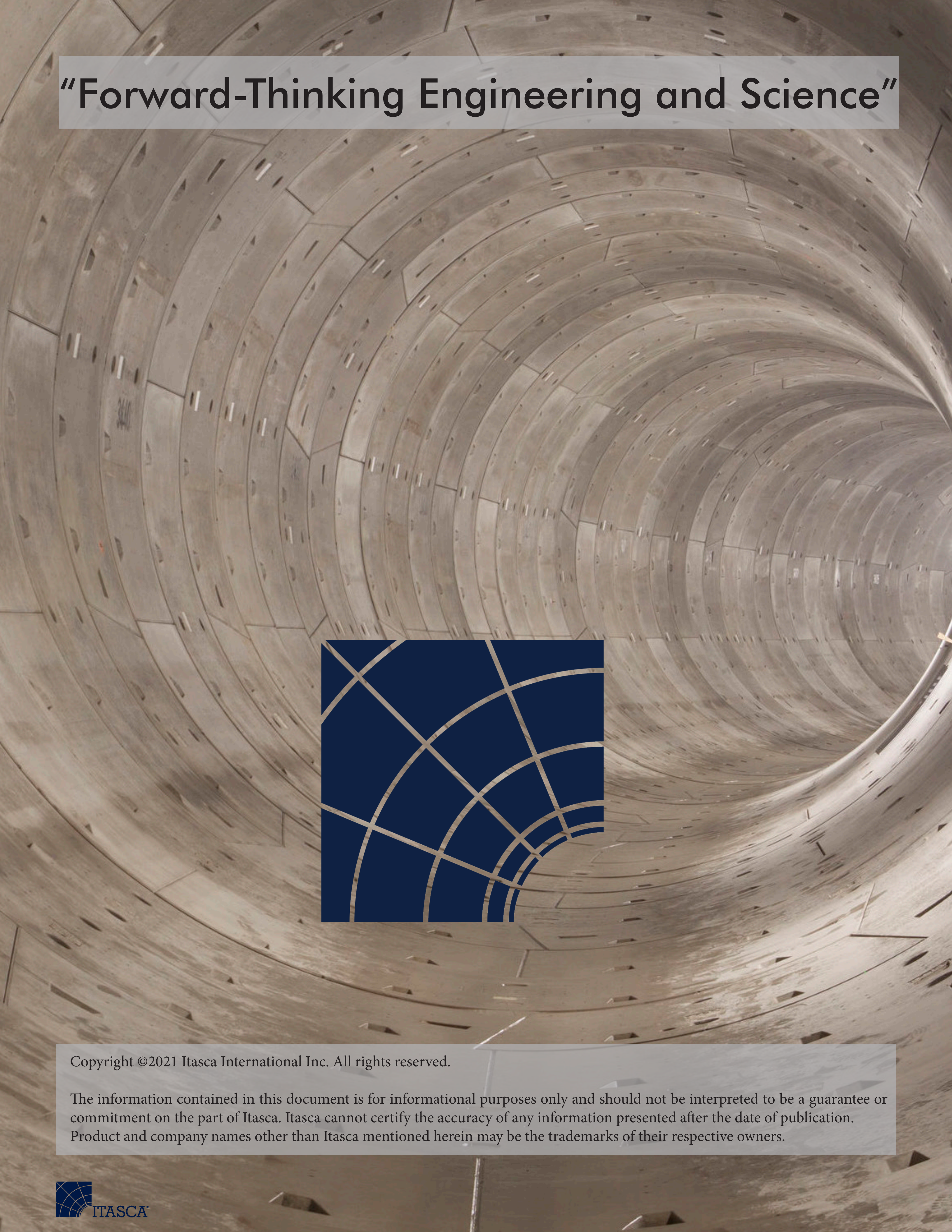
ITASCA™

Civil Engineering Services and Statement of Qualifications



ICG21-SOQ-CVL-01

GEOMECHANICS • HYDROGEOLOGY : CIVIL • MINING • ENERGY



"Forward-Thinking Engineering and Science"

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ITASCA™

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.

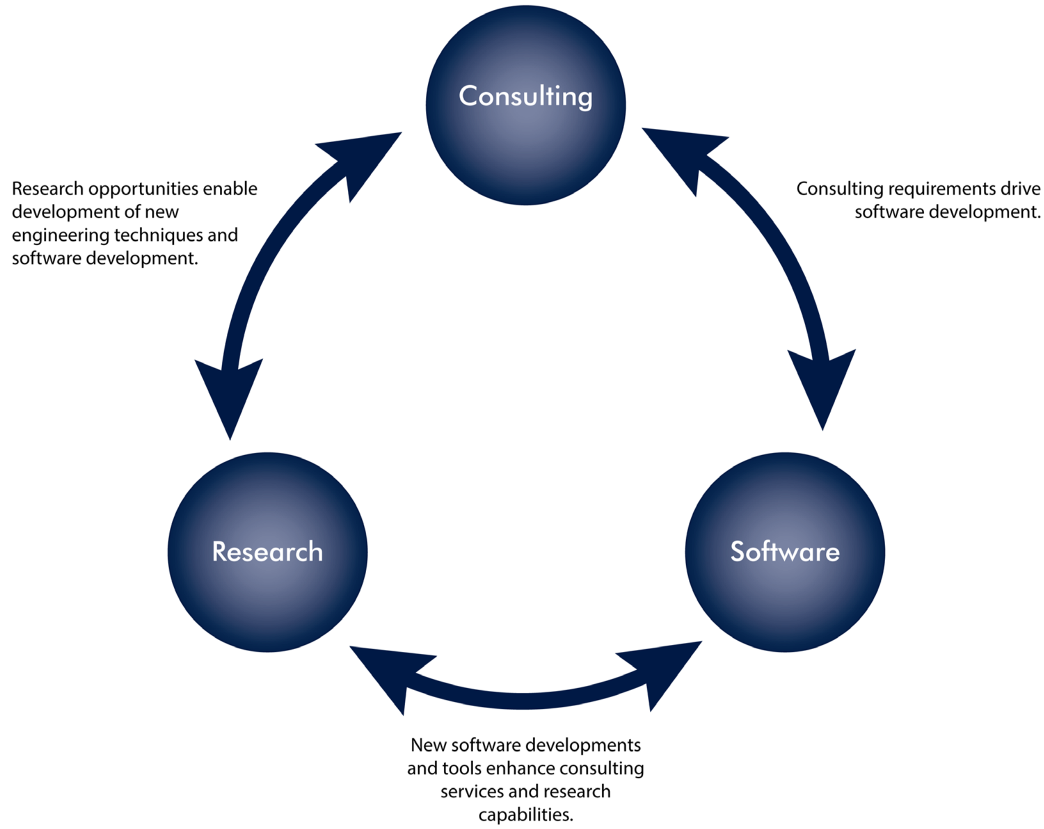
ITASCA INTERNATIONAL

Itasca International Inc. is an engineering consulting, research, and software development company founded in Minneapolis, Minnesota now with 10 main offices worldwide. Itasca specializes in solving complex geomechanical, hydrogeological, and microseismic issues in civil, environment, manufacturing and material processing, mining, oil and gas, and power generation. Itasca works directly with industry, government, research and educational institutions, and as a specialist to other consulting firms.

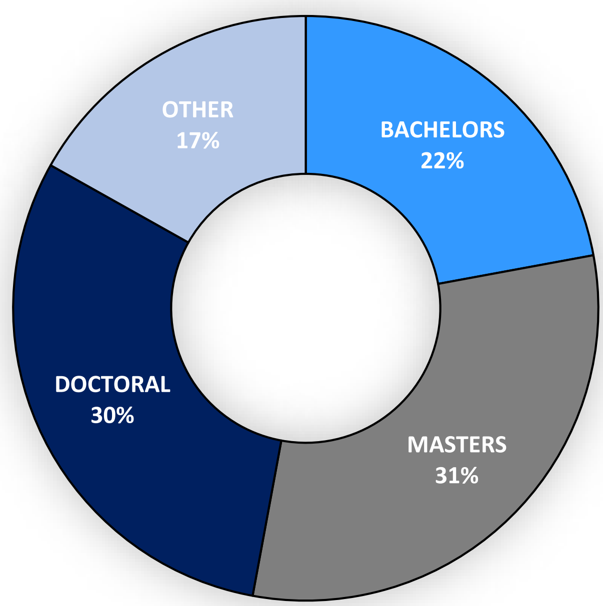
Founded in 1981, Itasca has gained practical and technical knowledge of world-class engineering challenges and solutions. Itasca is staffed by leading engineers in the fields of site characterization, soil- and rock-mechanics, hydrology, hydrogeology, geochemistry, and software engineering. Our experienced 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 civil works (from urban transportation infrastructure to large underground caverns) 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 software are among the most widely used and respected tools of their kind. Development and application of our advanced numerical simulation software sets Itasca apart from other engineering consulting firms. Itasca benefits from the dynamic interplay between consulting, software development, and contract research activities.



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



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

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

With a large portion of our over 180 personnel possessing advanced degrees, 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 we work.

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 professors.

Itasca Offices

NORTH AMERICA

Itasca Consulting Canada, Inc.
888 Regent St., Suite 205
Sudbury, Ontario
P3E 6C6 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
itasca@itascadenver.com
www.itascadenver.com

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, Segundo Piso, Providencia
C.P. 7500524
Santiago, Chile
T. (+56-2) 2434-1300
itascachile@itasca.cl
www.itasca.cl

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

EUROPE

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

Stockholm Office
Isafjordsgatan 39B
Kista, Sweden
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
itasca@itasca.fr
www.itasca.fr

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

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

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.

CIVIL ENGINEERING SERVICES

Itasca approaches all projects, from the routine to the most complex, with a solid background in civil engineering and an unparalleled knowledge of numerical modeling and engineering analysis techniques.

Our global experience and expertise in geomechanics, hydrogeology, and microseismics provide innovative, practical solutions to the following array of work.

- Fieldwork
- Material property review
- Soil- and rock-mechanics design and stability analyses (analytical, empirical, and numerical)
- Ground support design
- Static and dynamics (seismics, blasting, and vibrations)
- Settlement and convergence
- Liquefaction potential
- Groundwater flow
- Geochemistry
- Heat transfer
- Coupled thermo-hydro-mechanical processes
- Creep
- Design review
- Risk analysis
- Back analysis and owner's review
- Safety and quality control
- Permitting, Litigation, and expert witness
- Observational method
- Monitoring and instrumentation

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

These form the core of Itasca's services in an extensive range of projects such as:

- site characterization;
- slope stability and design;
- urban tunnel infrastructure;
- underground space;
- surface transportation;
- ground-structure interaction;
- caverns;
- dams;
- marine structures and levees; and
- hydroelectric power plants.

Itasca applies a client-tailored process that determines which factors (efficiency, exhaustiveness, utility, effectiveness) are of greatest importance to the project.

Itasca is a recognized leader worldwide in geomechanical numerical modeling of complex geotechnical environments and we look forward to bringing our experience, software, engineers, and software developers to work with you in solving your most challenging problems.

SITE CHARACTERIZATION

In order to predict how an excavation or structure will behave, an understanding of the adjacent earth properties is required. To this end, Itasca reviews any existing data, in collaboration with the client, to identify any knowledge gaps.

As required, Itasca works with third parties and across our offices using best-practices to facilitate or perform a wide range of laboratory and in-situ geomechanical, hydrogeological, and seismicity testing. This includes piezocone and dilatometer testing, lineament analysis, precise structural mapping, drill core logging, televiewer analysis, pressuremeters, stereophotos, and laboratory testing.

Itasca consultants can interpret and model earth and engineered-material behavior for any given range of anisotropies, scales, properties, and conditions, which gives Itasca an understanding of your project that is second to none.

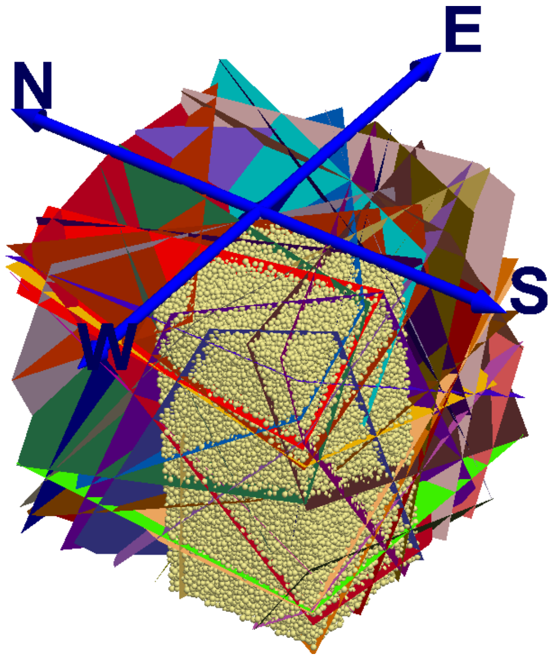
Soils

Specific services provided include:

- assessment of soil stratigraphy;
- identification of soil types;
- estimation of mechanical properties;
- estimation of water table and consolidation parameters;
- liquefaction potential; and
- estimation of parameters for empirical assessment and calibrated numerical modeling for engineering design

Structural Geology and Rock Masses

Rock mass strength estimation is required in order to predict the excavation response at a project 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. In order to estimate rock mass strengths, Itasca uses the full gamut of engineering approaches, from analytical and empirical to numerical, and Itasca pioneers innovative techniques such as Synthetic Rock Mass (SRM).



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

Specific services provided include:

- lineament analysis;
- precise structural mapping;
- drill core logging and televiewer analysis;
- photogrammetry and stereophotos; and
- laboratory property assessment.

Site Investigation 2015

Project Description

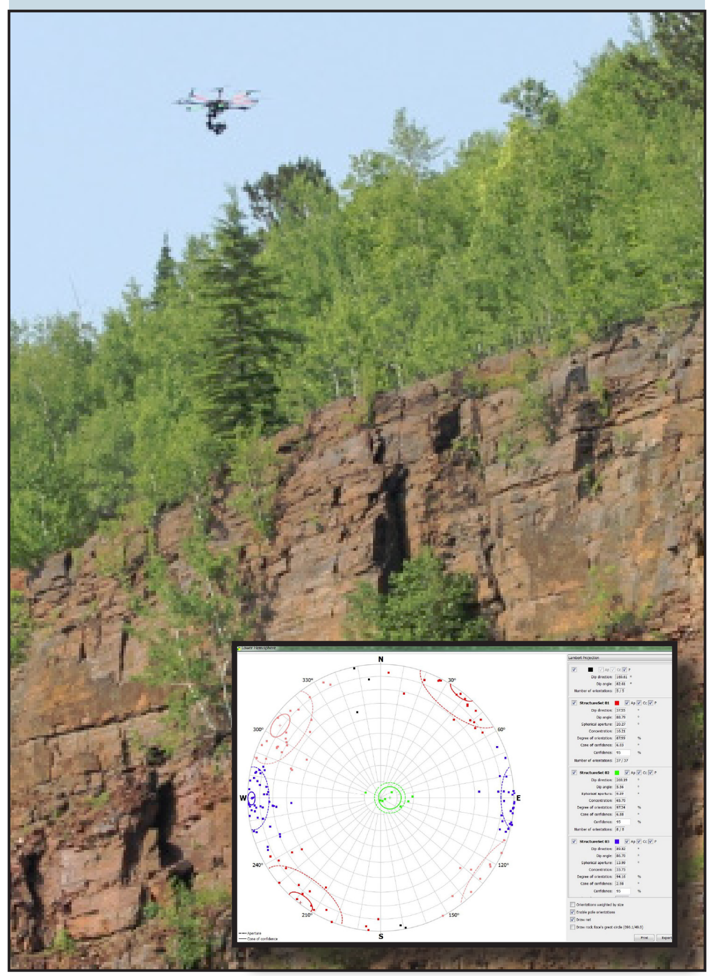
The Minnesota Department of Transportation (MnDOT) is relocating Hwy 53 near Virginia, Minnesota. The project includes a bridge across an existing mine pit and must accommodate future iron ore mining up to 500 ft deep adjacent to the non-bridge portions of the alignment.

Itasca's Contribution

Itasca mapped joints in the pit walls of the historic Rouchleau Pit using digital photogrammetry via an unmanned aerial vehicle (UAV) for photo acquisition. Based on mapping needs and photogrammetric principles, Itasca devised autonomous flight plans ahead of the field work.

Outcomes

Over 3,000 photos were acquired along approximately 3 km of the slope walls with structural mapping identifying over 3,100 joints.



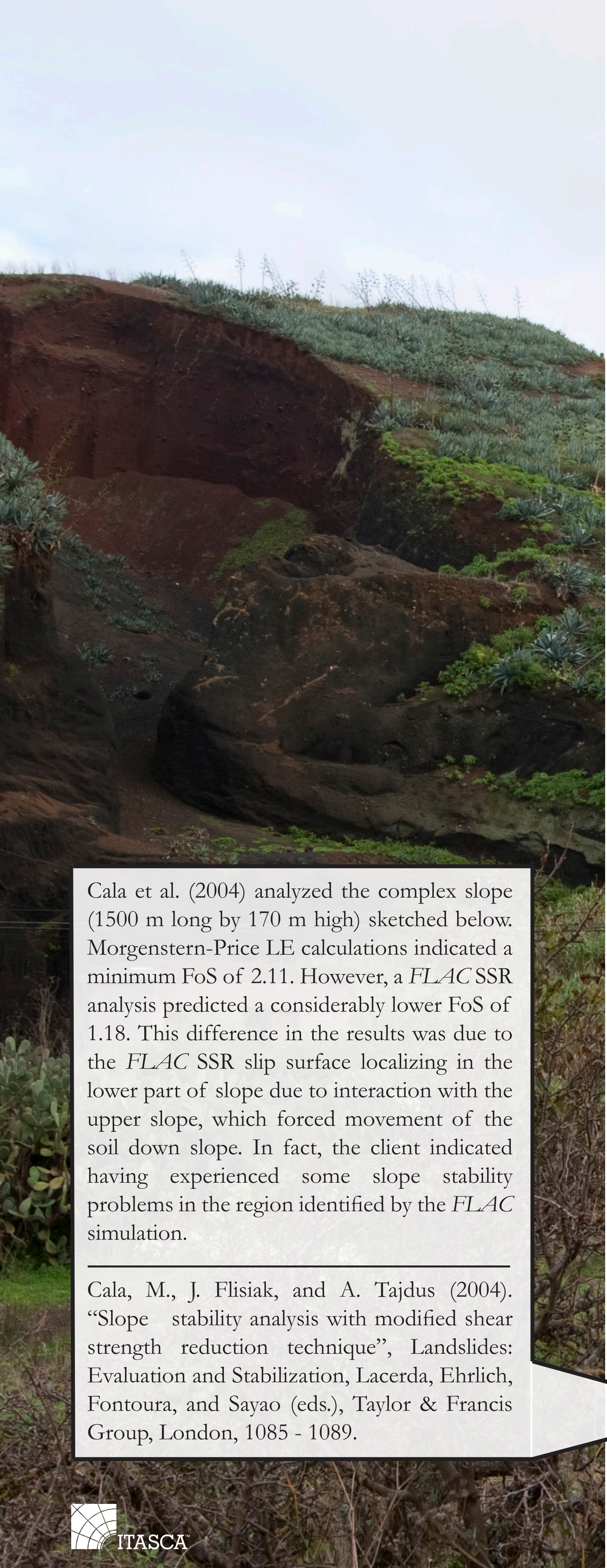
SLOPE STABILITY and DESIGN

Itasca is particularly well-known for examining difficult problems involving slope instabilities. We specialize in the assessment of slope stability and design on scales ranging from civil engineering slopes in soil and rock, including portals, to mine benches and inter-ramps to many of the world's largest open-pit mines. We also routinely analyze both the static and dynamic stability of waste dumps, leach piles, and tailings dams. Itasca's roles include slope design, instrumentation, and remediation engineering.

Specific services provided include:

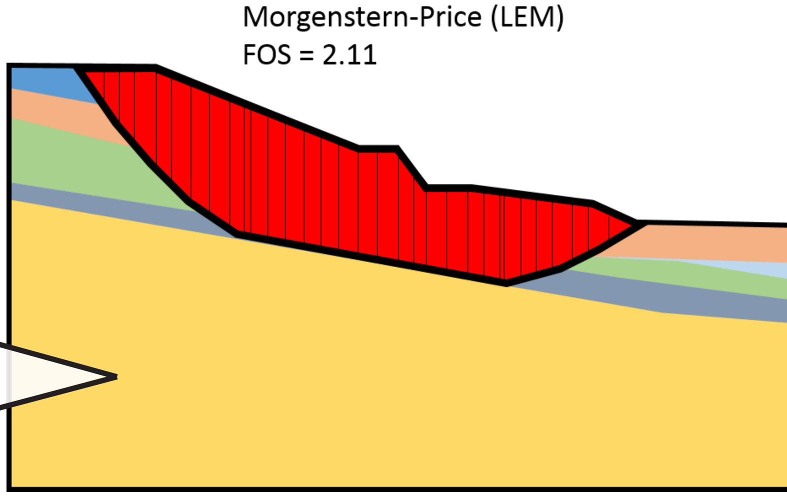
- geotechnical mapping and assessment of rock mass structure and in-situ properties for use in design;
- dewatering and coupling of the dewatering program to geotechnical stability of the slopes;
- blast design;
- specification of instrumentation for monitoring slope movements;
- numerical modeling to design and assess stability, and estimate slope factors of safety (FoS); and
- specification of slope remediation measures.

Itasca is recognized as a world leader in the development and application of geomechanical and hydrogeological computer software. However, in addition to numerical modeling, Itasca engineers use a range of approaches, as appropriate, to design and analyze slopes including analytical methods and empirical data.



Cala et al. (2004) analyzed the complex slope (1500 m long by 170 m high) sketched below. Morgenstern-Price LE calculations indicated a minimum FoS of 2.11. However, a *FLAC* SSR analysis predicted a considerably lower FoS of 1.18. This difference in the results was due to the *FLAC* SSR slip surface localizing in the lower part of slope due to interaction with the upper slope, which forced movement of the soil down slope. In fact, the client indicated having experienced some slope stability problems in the region identified by the *FLAC* simulation.

Cala, M., J. Flisiak, and A. Tajdus (2004). "Slope stability analysis with modified shear strength reduction technique", Landslides: Evaluation and Stabilization, Lacerda, Ehrlich, Fontoura, and Sayao (eds.), Taylor & Francis Group, London, 1085 - 1089.



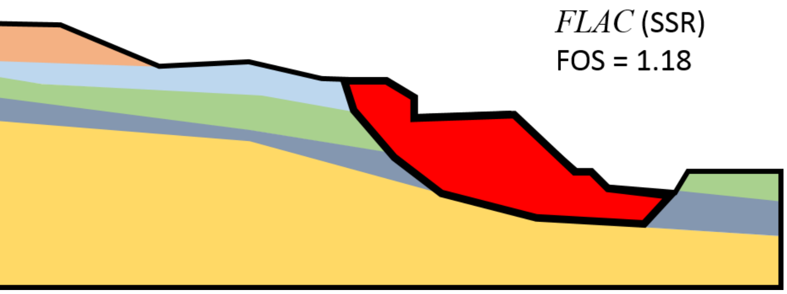
We Don't Limit Our Work

Itasca has pioneered the use of accurate and efficient methods to determine safety factors using numerical methods. The Shear Strength Reduction (SSR) technique allows failure mechanisms to develop naturally, an important advantage over more traditional limit-equilibrium solutions that are restricted to prescribed failure surface geometries (circular, log spiral, segmented, etc.). SSR can also be extended to estimate the probabilities of failure, which are important in formalized risk assessment. Other important advantages with SSR over more traditional limit-equilibrium solutions include the following.

Simple: Once the model is set up, a single **SOLVE fos** command or click of an icon starts the automatic analysis that uses a bracketing approach to estimate the FoS as quickly as possible.

Powerful: Failure mechanisms, including multiple failure mechanisms, occur naturally. SSR incorporates material and stress anisotropy, dilation and stress-dependent behavior, ground support elements, complex construction history, non-linear progressive failure, and soil saturation and groundwater flow. Observe displacement developments—is the Service Limit State more critical than the Ultimate Limit State? *FLAC* can also calculate multiple minimum-states throughout the model to plot FoS contours for a safety map.

Accurate: SSR provides better insight into the more complex slope behavior and evolution of failure based on geomechanics. Solutions satisfy both local and global equilibrium and a valid solution is always produced, even for unstable physical systems. Deformations at the *failure state* are kinematically valid. Solutions match analytical solutions. The SSR method has been used extensively for stability analysis for three decades.



Landslide Stabilization

Project Description

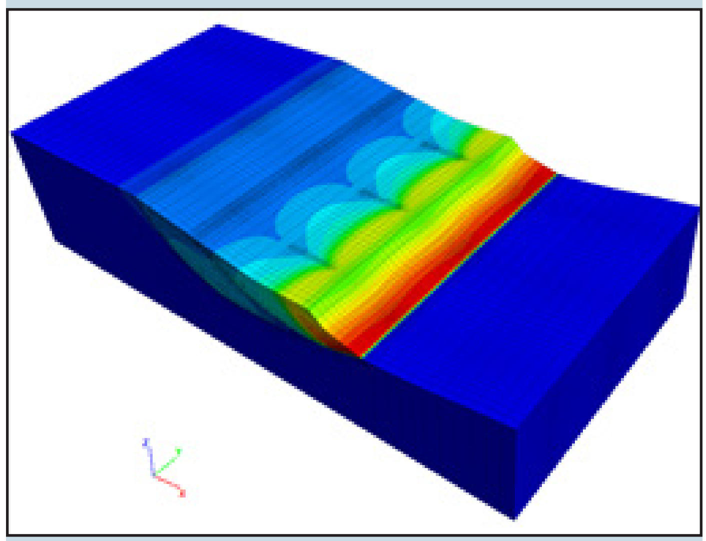
In 2003 a landslide developed along the river bank inside the city of Crookston, Minnesota. Although several attempts were made to solve the problem, in 2008 a second event occurred. Extensive instrumentation was then put in place to monitor the slope and have a better understanding of the situation. In 2013, the Minnesota Department of Transportation issued a design and build project to improve the stability of the river bank.

Itasca's Contribution

The general contractor (Nicholson) proposed a solution with a slurry shear wall (about 30 m long and 24 m spacing), and Itasca was asked to develop a detailed 3D model to study the interaction of the slope and the shear walls.

Outcomes

The numerical analyses have shown the efficacy of the solution allowing for significant optimization. The project was awarded in 2013.



Chenab Bridge Abutment

Project Description

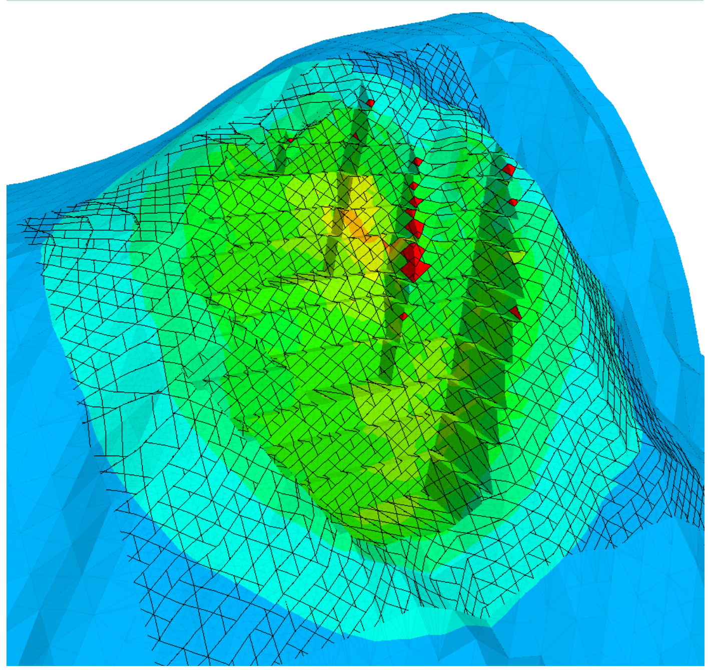
The USBRL is the railway line that will link Kashmir Valley to the rest of India. The design and construction of the section of the railway line between Katra and Banihal are extremely challenging engineering tasks with 88 km and 11 km requiring tunnels and bridges/ viaducts, respectively. The bridge over the Chenab River will be a concrete-filled truss steel arch bridge. After construction, it will be the highest bridge deck and the seventh-longest spanning arch bridge in the world. The Bakkal-side of the bridge abutment is shown to the left, with a *3DEC* model shown below.

Itasca's Contribution

Itasca reviewed the available data to estimate both rockmass and joint properties, and joint set orientation and spacing. A calibration model was also used to estimate rockmass strength anisotropy. Itasca analyzed deformation and stability of the critical slopes and foundations for the Chenab Bridge for a range of design static and dynamic loadings.

Outcomes

Based on the results of the analyses, Itasca was able to recommend if additional (compared to design) ground support measures were necessary.



Fountain Slide

Project Description

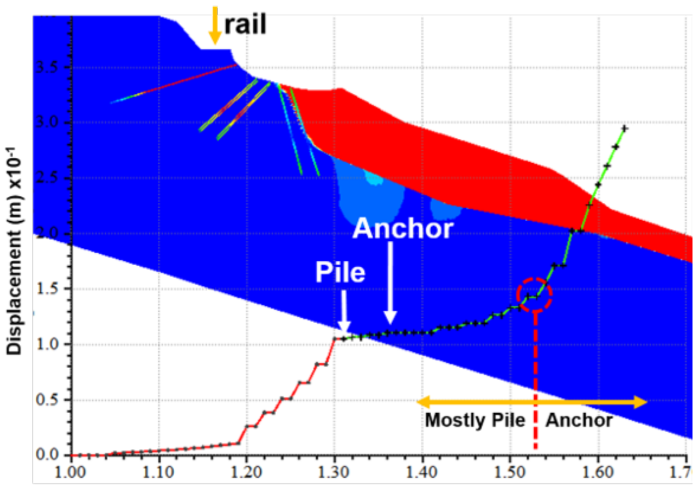
Fountain Slide has had a long history of stability problems. The slope is bounded downhill by the Fraser River (Canada) and uphill by a highway and a railway. This project stage focused on stabilization of a section of the railway that has suffered extensive damage to its retaining system.

Itasca's Contribution

Itasca analyzed the complex structure interaction using *FLAC3D* models, applying a Strength Reduction Method (SRM) approach. This method allowed development of performance charts for different levels of displacements and also provided important insight on the distribution of load between anchors and micropiles.

Outcomes

With Itasca's support design, a combination of micropiles and anchors have been placed downhill from the railway to create an efficient system to reinforce and support part of the sliding soil. Moreover, each component mobilizes its reaction for a different level of displacements, creating a hierarchical support system. Slope displacement versus Strength Reduction Factor (SRF) with structural elements in place is shown below.



Slope Stabilization using an Anchored Concrete Shaft

Project Description

The section of highway A14 between Senigallia nad Ancona (central Italy) has been suffering from continuous movements of the slope for decades. The Engineering branch (SPEA) of the Highway Agency designed a structural improvement composed by three concrete shafts with anchors at the top. The realization of the concrete shaft necessitated a 37 m deep excavation to be filled with concrete.

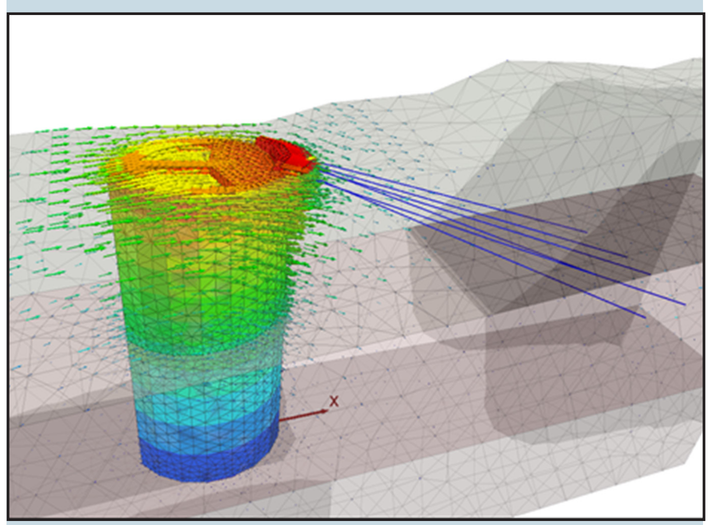
The general contractor wanted to propose an alternative solution without excavation by using a hydromill to realize a sequence of secant concrete panels. This alternative solution, without excavation, is faster and safer to construct. However, there were concerns that this composite system would not behave like a continuum, compromising the global performance.

Itasca's Contribution

Itasca analyzed the performance of the requested and proposed alternative solution using *FLAC3D*.

Outcomes

The *FLAC3D* model has allowed the detailed study of the composite structural behavior of the alternative solution showing substantial equivalence in term of performance and interaction with the landslide.



TUNNELING INFRASTRUCTURE

Itasca has experience with the main tunnel construction methods:

- Cut-and-cover
- Conventional tunneling
- Partially mechanized
- Fully mechanized (TBM)

Transit Tunnels

Project Description

The Regional Connector Transit Corridor (RCTC) project (Los Angeles, USA) requires 579 m of cut-and-cover tunnel and two sections of twin-bored tunnels totaling approximately 1,460 m in length with three underground stations proposed. As part of the engineering design, the settlement induced by the excavation on the 4th Street Overpass and on the exiting Red Line tunnels must be estimated. Volume loss estimates were deemed to be inappropriate.

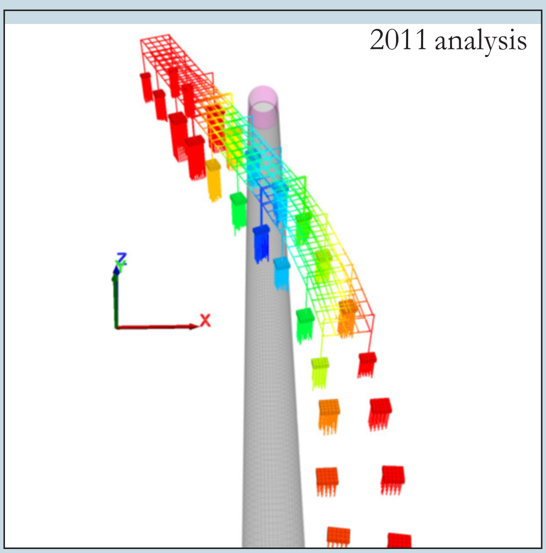
Itasca's Contribution

In order to obtain an accurate estimation of the deformation in the pre-existing tunnels and overpass, *FLAC3D* numerical modeling was used for:

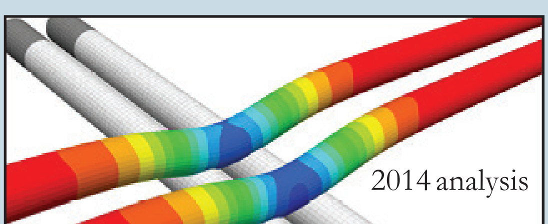
- complex distribution and behavior of soil layers, including non-linear deformability;
- presence of groundwater;
- complex 3D geometry around the TBM;
- sequential simulation of multi-stage excavations and lining in drives;
- working face pressure (explicitly considered);
- geometry and stiffness of pre-existing structures (explicitly considered); and
- comparison of different mitigation measurements.

Outcomes

The *FLAC3D* simulations estimated that the maximum settlement at the end of construction of both tunnels is 12.4 mm, which is near but below the maximum admissible level.



2011 analysis



2014 analysis

Twin Road Tunnels

Project Description

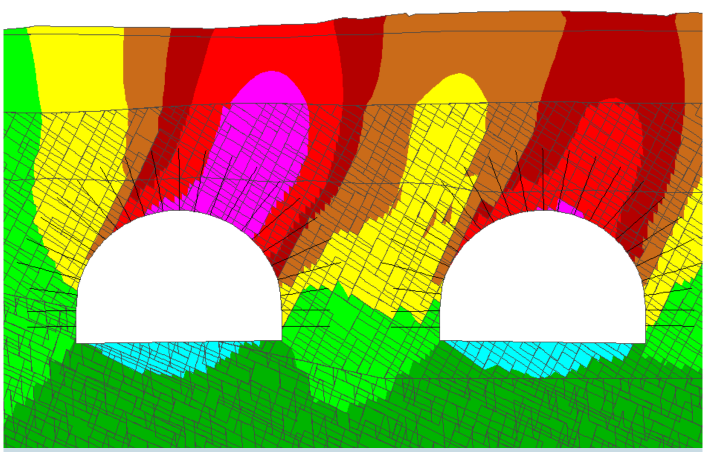
Twin parallel road tunnels have been designed and built with connecting cross passages and a piggyback busway tunnel as part of a large infrastructure project in Australia. The tunnels were excavated in poor to fair quality rocks using road headers using temporary ground support.

Itasca's Contribution

Arup (Brisbane) requested Itasca to perform numerical analyses to analyze the expected behavior of the tunnels during excavation. Structural defects in the rock are explicitly included in the *UDEC* analyses to examine the potential for localized ground instability. The stress redistribution is captured in *FLAC3D* modeling with an accurate representation of the complex excavation geometry and the detailed excavation and support sequence.

Outcomes

Numerical modeling has increased confidence in the tunnel design and was used consistently throughout the project's design and construction and formed an integral part of the design process for this tunneling project. Both *FLAC* and *UDEC* have been used consistently by the on-site design team to provide rapid assessment of proposed support designs and excavation sequences. The models have also been regularly updated to incorporate new geotechnical data as it became available during tunnel excavation. Where particularly more complex geometry was needed, detailed *FLAC3D* and *3DEC* models were utilized.



UDEC model plot showing blocks surrounding the twin tunnels and contours of vertical displacement.

Norra länken

Project Description

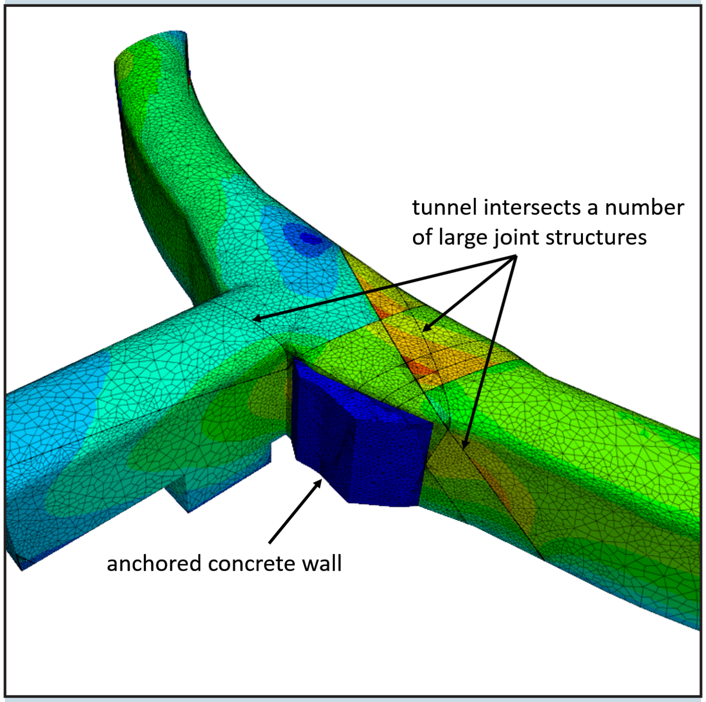
The Northern Link (Norra Länken) is part of a major road system surrounding the Stockholm metropolitan area.

Itasca's Contribution

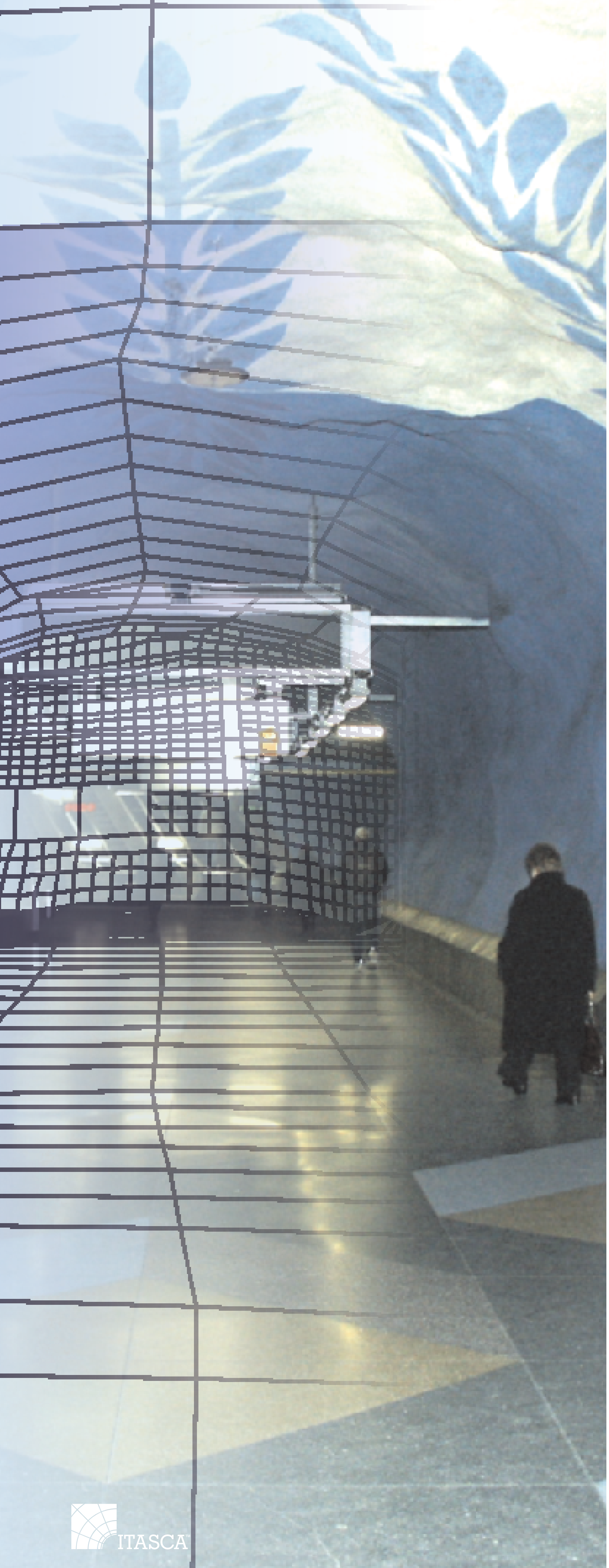
As part of the design work for this project, Itasca performed a three-dimensional numerical study to analyze the effect of a large surface load being applied on top of a tunnel intersection with low (4 m) rock cover. The analyses were performed using *FLAC3D*, with the model constructed using *KUBRIX Geo* in conjunction with *Rhinoceros* 3D CAD software. With incomplete data, fracture planes were assumed as infinite with a lower friction angle that typical, and a minimum rock mass strength for the area was assumed. Water was not considered at this stage.

Outcomes

Even with the conservative properties used, the trend of the displacements, and the bolt and shotcrete responses convey a tunnel system that remains stable upon application of the surface load in all the cases modeled.



FLAC3D model plot showing the total displacements along the excavation boundary for a case with an anchored concrete wall. Tunnel support includes both rockbolts and shotcrete. Model created using a combination of the KUBRIX Geo mesh generator and Rhinoceros 3D CAD software.



UNDERGROUND SPACE

Itasca provides consulting services in a wide range of civil underground space, including:

- Libraries and museum
- Sculptural art
- Parking
- Sports arenas
- Railway and subway stations
- Water treatment facilities
- Scientific research centers.

Parking Ramp over LRT Station

Project Description
On-airport parking provides about 22,900 parking spaces and is frequently at or near capacity. A parking ramp expansion has been prosed at Terminal 1-Lindbergh. It will be constructed over the north end of the LRT station. The station is constructed in the St. Peter sandstone and Glenwood shale, with a flat roof of the Platteville limestone. Three subvertical limestone joint sets were identified during its construction.

The parking ramp expansion involves two principal impacts on the LRT station:

- column loads on the Platteville limestone above or nearby the station, and
- excavation of the soil cover and some of the Platteville limestone above the station.

Itasca's Contribution
Itasca assessed the magnitude of the above impacts by conducting three-dimensional geostructural analyses of the LRT station using *3DEC* based on surface settlement and safety factors of the limestone vertical joints and bedding planes. Nearly 2,000 rockbolts were incorporated into the model.

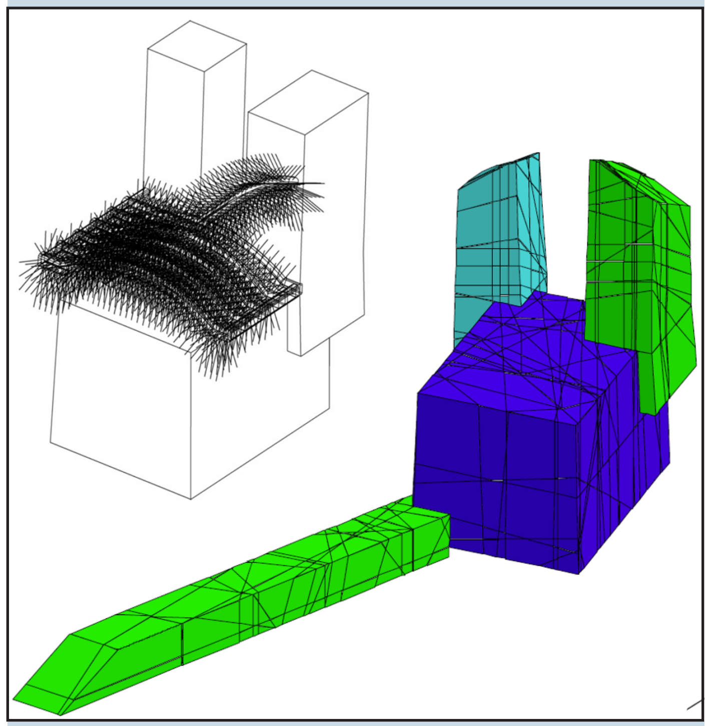
Outcomes
Of the six design options evaluated, all but one were predicted to be geostructurally feasible.

Mount Tindaya

Project Description
A sculptural cavern art project proposed by Eduardo Chillida excavated inside Mount Tindaya, Canary Islands. The "carved space" would be one of the largest caverns ever constructed (45 m x 50 m x 65 m) and the only one of its kind designed with a flat roof.

Itasca's Contribution
Several cavern designs were evaluated using *3DEC* models to reproduce the unique nature of the discontinuities of the rock and to optimize operations to help boost the rock to support itself.

Outcomes
Numerical modeling indicated that unsupported, the volume of unstable rock would be over 10,000 m^3 and over 4,500 m^3 from the roof and walls, respectively. The hybrid support design was selected as the best approach should this project go forward.



GROUND-STRUCTURE INTERACTION

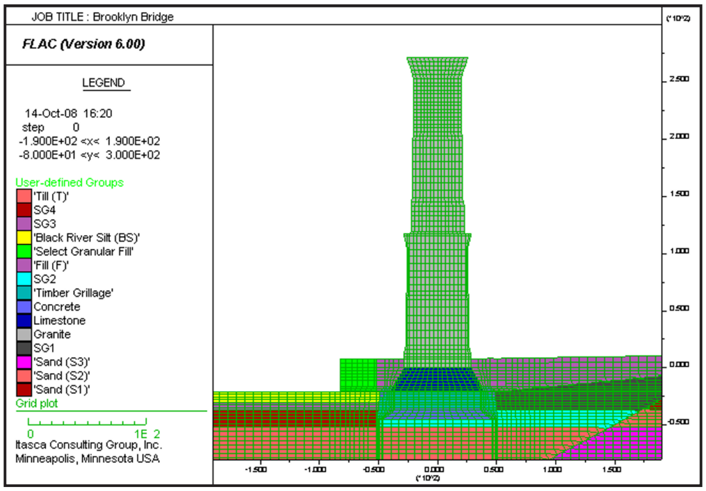
Retaining Structures

Itasca has provided analysis of nearly all types of retaining structures, including slurry-supported reinforced concrete diaphragm walls, sheet pile walls, soil-nailed walls, and tieback walls. As with dams, water pressure acting within the soil mass is often a key issue. The ability to predict water pressures is an important element in understanding the behavior of retaining structures. We routinely study the flow through soil and use the resultant pore pressures to determine effective stresses used in constitutive relations.

Foundations

Experience in foundations includes application of Itasca's software to problems where existing techniques are either not available or are known to be inaccurate. For example, *FLAC3D* was used to determine the subgrade reaction modulus for a thick concrete slab placed over fill with varying thickness. In another case, an industrial machine produced a cyclic vibration. The effect of the vibration on nearby foundations supporting other machinery was studied dynamically by applying the cyclic loading to one location and measuring the vibration levels at other locations. A similar study was performed to evaluate the dynamic effects on nearby buildings due to trains running in subway tunnels at a shallow depth. Various remedial measures were evaluated numerically before selecting the recommended solution.

A high-profile case involved the dynamic analysis of foundations for the Brooklyn Bridge in New York City. In this case, each bridge tower, its caisson and surrounding soils were modeled using *FLAC*. The earthquake response, including slip and separation at the foundation base, was determined for each tower.



FLAC model used to compute kinematic motions, foundation stiffness, and damping coefficients for the Brooklyn Bridge (below).

Viaduct Pont de Candí*

Project Description

One of the main bridge structures along the Madrid-Barcelona high-speed railway in Spain is the Pont de Candí Viaduct. Leveling of the railway tracks indicated uplifting (up to 17 cm) of the central pillars. The support system approached its strength limit in August 2008. After considerable site investigation, the swelling of anhydrite was identified as the problem.

Itasca's Contribution

At the request of the Spanish Administrator of Railway Infrastructure (Adif), during construction Itasca calibrated the behavior of the bridge-soil system (below, right) using *FLAC3D*. Another *FLAC3D* model was developed to evaluate the effectiveness of using an earth fill approach (below, left) to mitigate the swelling process.

Outcomes

This type of soil heave behavior on the Viaduct pillars is believed to be unique. After the embankment was constructed, the maximum heave rate fell off substantially; the Viaduct currently remains in service.

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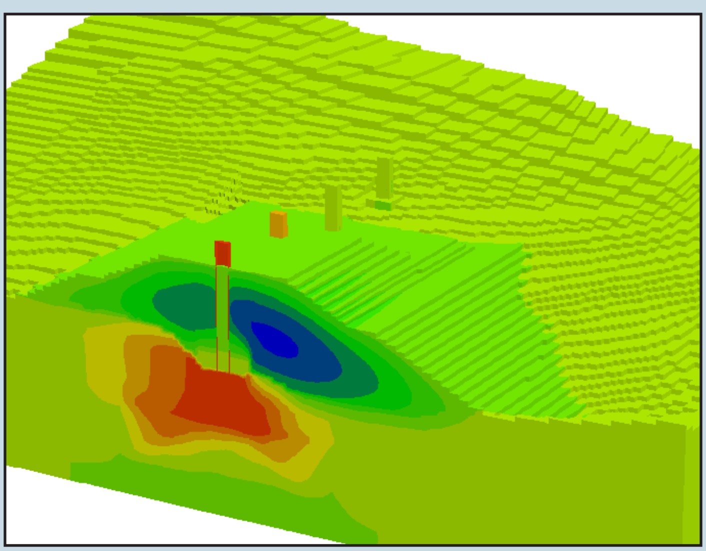
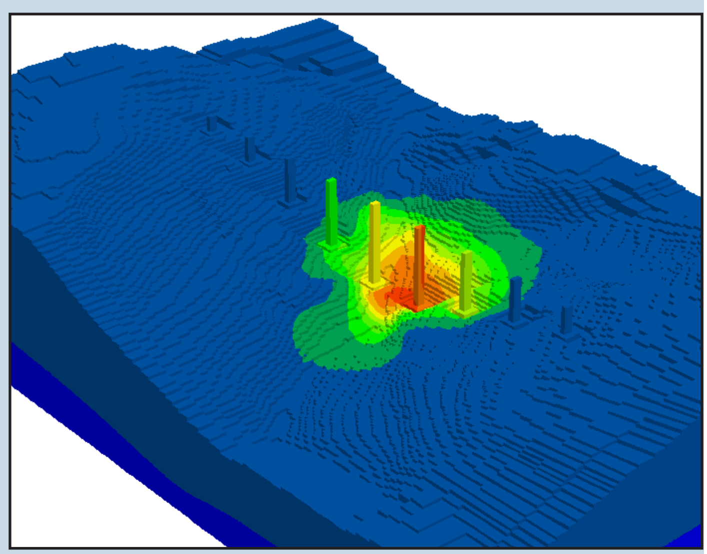
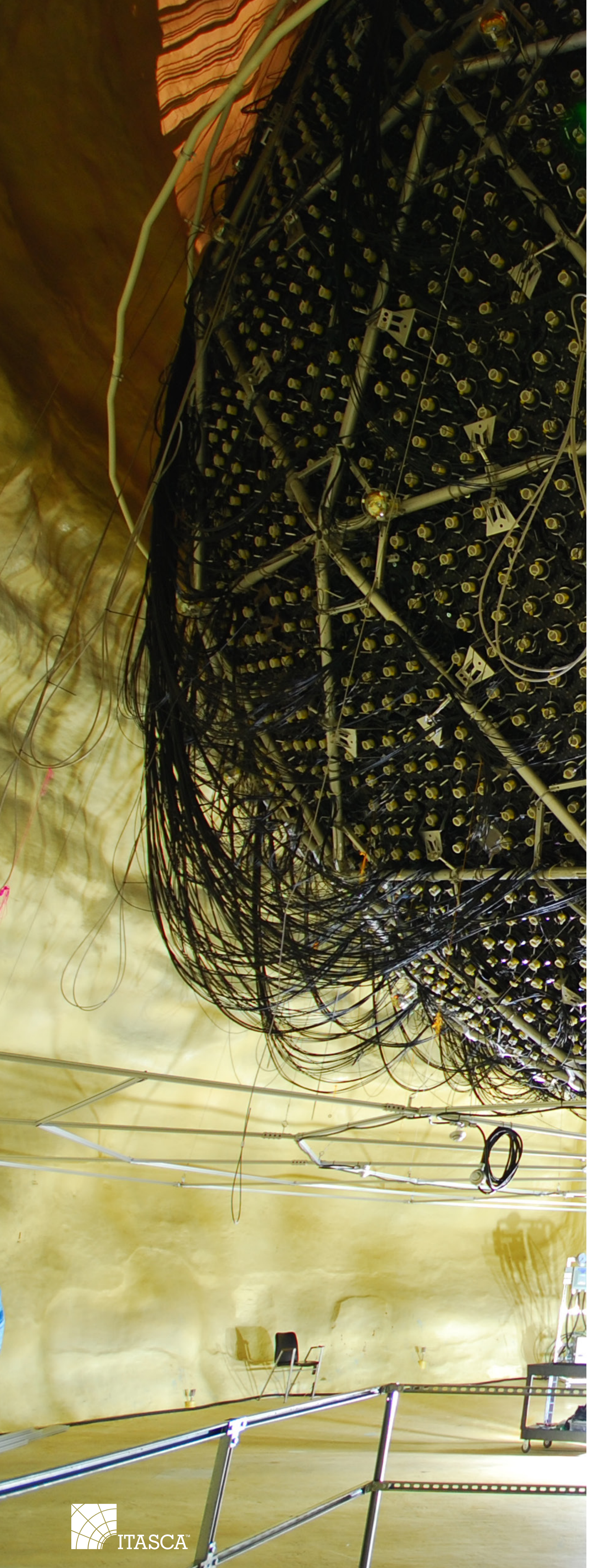
*Alonso, E. (2012). Crystal growth and geotechnics. Rivista Italiana di GeoTecnica 4/2012, 44 pages.



FLAC3D model plot showing the vertical displacement after earth filling.



FLAC3D model plot showing the vertical displacement due to swelling.



OTHER CAVERNS

Itasca has extensive independent and team experience in the analysis of large excavations for civil, mining, oil and gas, and power generation engineering for a wide variety of engineering works with spans from 6 to 60 m and depths from near surface to more than 2.5 km.

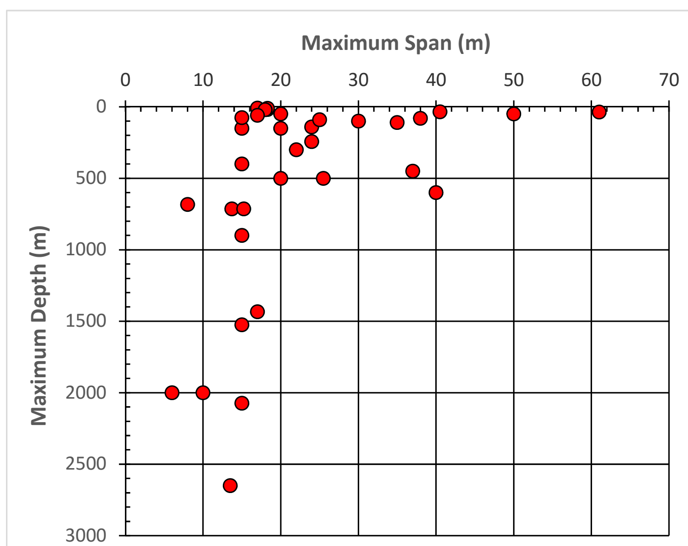
Mining Engineering

- Hoist room
- Open stopes
- Ore transfer stations
- Crusher and mineral sizer stations
- Solution mining

Oil and Gas Engineering

- Lined rock cavern for LPG storage
- Domal salt storage of petroleum products

Itasca has performed analyses for some of the largest and most important underground caverns in the world, including the main detector hall for the Superconducting SuperCollider project (USA) and the Large Hadron Collider for CERN.



Sudbury Neutrino Lab

Project Description

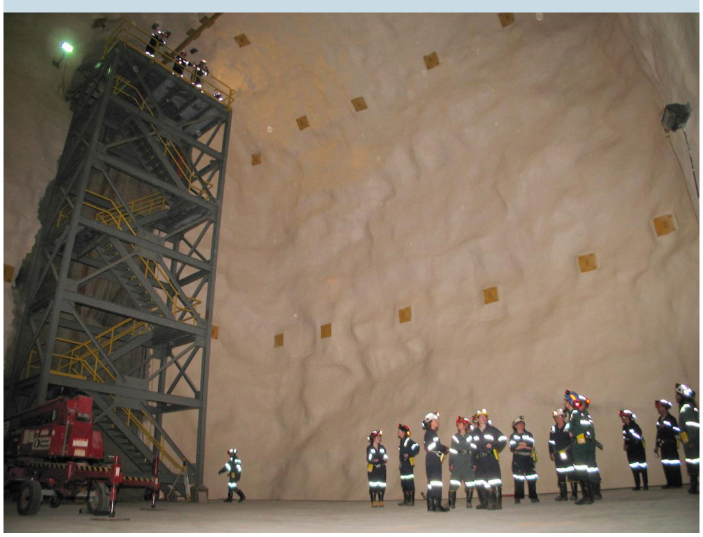
SNOLAB is an underground science laboratory specializing in neutrino and dark matter physics. Located 2 km below the surface in the Vale Creighton Mine, near Sudbury Ontario Canada. SNOLAB is an expansion of the existing facilities constructed for the Sudbury Neutrino Observatory (SNO) solar neutrino experiment. Not only are these large excavations in a deep and highly stressed region, they are also in close proximity to an actively mined ore body that is seismically active.

Itasca's Contribution

Itasca was responsible for the geomechanical design, numerical modeling, and technical support during construction of the Sudbury Neutrino Observatory (SNO) expansion project between 2003 and 2008. This included reviewing mine seismic records, advanced modeling for assessing stress distribution and failure zones around the proposed excavations, the use of ground support and the impact of a limiting seismic event. Empirical analyses of the ground support systems were also completed. Itasca also assisted with positioning the temperature controls for it advance cooling systems.

Outcomes

The SNOLAB continues to operate safely and has been jointly awarded the *2016 Breakthrough Prize in Fundamental Physics*. Itasca continues to consults for SNO on an ongoing basis.



Crusher Station

Project Description

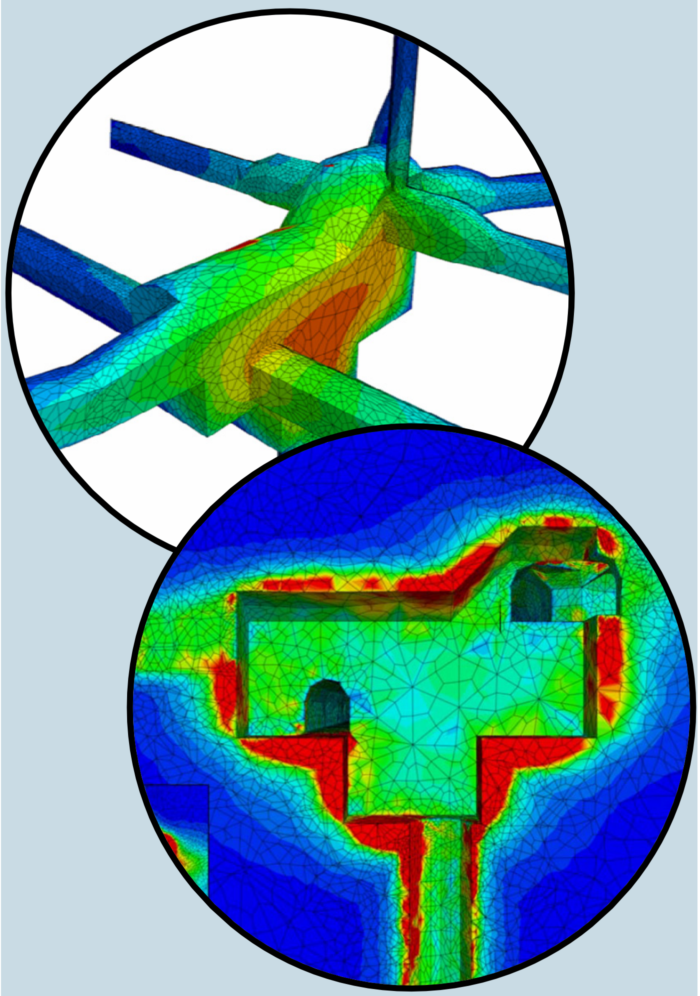
The chamber houses large-scale rock crushers and is approximately 12 m wide, 26 m high, and 40 m long. A series of these chambers is located relatively close to the mining front.

Itasca's Contribution

Itasca examined the cavern stability and provided ground support recommendations. The analyses take into account predictions of the evolving stress state resulting from the nearby cave propagation over the 15 years of mining operation.

Outcomes

The analysis indicated stable unsupported excavations for the peak stress condition with moderate closure strains, indicating supportable conditions using rockbolts, cables, and shotcrete.



FLAC3D model showing displacements at the excavation boundary (top) and maximum principal strain contours (bottom).

DAMS

Itasca performs analyses for concrete/masonry dams (such as arch, gravity, RCR - roller compacted concrete) and embankment dams (earth, rockfill, and mine tailings dams), including:

- Short- and long-term mechanical behavior analysis of dams on fractured rock
- Optimizing dam design based on criteria constraints
- Analyzing thermo-hydro-mechanical behavior of a concrete dam subjected to thermal variations and to variations in the water level in the reservoir

By analyzing ground strength, stresses, and dynamic events, Itasca can estimate foundation, slope, tunnel, and cavern stability, and suggest successful remedial solutions as needed. Itasca assesses risk by interpreting modeling results and incorporating on-site monitoring information where available.

Static Design and Safety Services

Frequently, a key to understanding dam behavior is accurate prediction of water pressures and flow within the dam components and its foundations. Itasca has experts in water flow in both porous media and jointed rock. We can examine the causes of leakage and erosion, predict failure modes and evaluate the results of remedial measures. Structural elements, artificial interfaces, and natural jointing can be included in models to predict the effectiveness of rock and soil reinforcement and reduced-permeability zones may be included to predict the viability of grouting and curtain walls. Itasca also has considerable experience incorporating material creep and thermal-hydro-mechanical coupling in evaluating seasonal variations in temperature and water level and concrete curing.

Dynamic Response Services

The dynamic behavior of dams can be simulated by performing nonlinear analysis of dam behavior in the time domain. In many places, the dynamic behavior of a dam during dynamic events is critical, with re-evaluation of existing dams becoming more important for jurisdictions with evolving design codes. Itasca can perform fully non-linear analyses of a dam's response to dynamic loading in the time domain. The behavior of the dam in real time allows design weaknesses to be identified and corrected. The effects of earthquakes, blasting, soil liquefaction, hydrodynamic influences, and water flow can all be modeled to predict any design weaknesses and optimize remediation for enhanced safety and longer infrastructure life.

Selected examples of Itasca dam projects can be seen in the following table.

Type	Dam Name	Country
Arch	Alcolea	Spain
	Asfalou River	Morocco
	Bin el Ouidane	Morocco
	Krokströmmen Kraftstation	Sweden
	RMEL	Morocco
	Saint Maria	Switzerland
	Vargfors	Sweden
Earth/ Rock Fill	Albages	Spain
	Bennett	Canada
	Bisri	Lebanon
	Chalupas	Ecuador
	Convento Viejo	Chile
	El Bato	Chile
	Koldam	India
	Laguna del Maule	Chile
	Lautaro	Chile
	Los Loros	Perú
	Lukovo Pole	Macedonia
	Malvecino exp	Spain
	Martil River	Morocco
	Moreau	Guadeloupe Island
	Reyunod	Argentina
	Saint-Christophe	France
	Wirgane	Morocco
	YESA expansion	Spain
Dome	Busanga	DRC
	El Mauro	Chile
	El Morro	Chile
	Laguna Seca	Chile
	Mantos Blancos	Chile
	Ovejería	Chile
	Pampa Pabellón	Chile
Concrete	Idriss 1er	Morocco
	Yaté	New Caledonia

Junction Dam

Project Description

Part of the Upper American River Project (UARP) and completed in 1961, Junction Dam is a double-curvature concrete arch dam located on Silver Creek, California. The dam is in a relatively narrow canyon with steep sides and retains the Junction Reservoir. The dam is 168 ft high with a crest length of 525 ft. It has a reservoir capacity exceeding of 2,600 ac-ft.

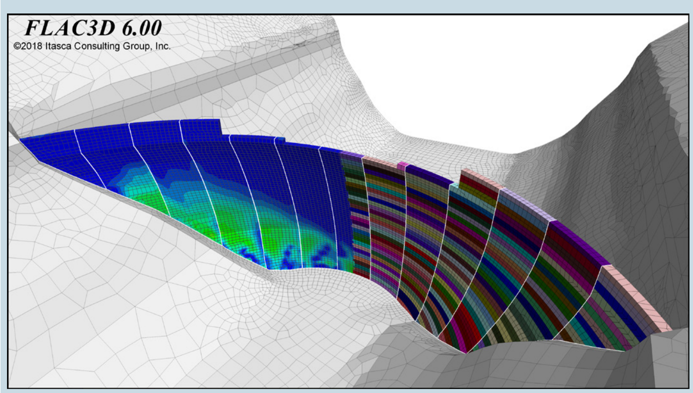
Itasca's Contribution

Itasca's evaluation of Junction Dam included static loading, thermal loading, reservoir loading, and seismic loading using *FLAC3D*. Load cases and load combinations were applied according to the FERC Engineering Guidelines for Arched Dams and three sets of input ground motions were considered in the dynamic analysis. Itasca evaluated the concrete dam and surrounding rock mass material properties. Several sensitivity analyses were conducted in order to bracket the predicted performance of the dam.

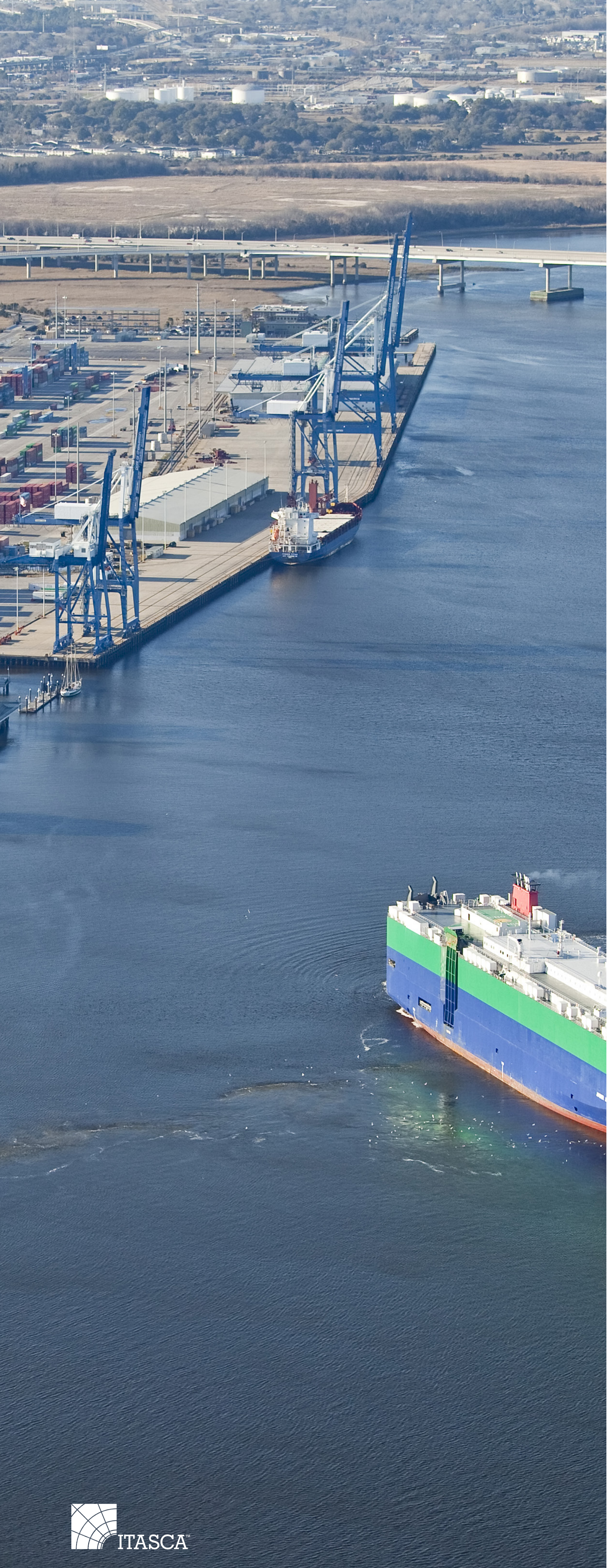
Particular attention was devoted to the structural joints of the dam with the vertical contraction joints modeled explicitly using interfaces, permitting the evaluation of dislocation and separation.

Outcomes

The dam was predicted to perform very well for all conditions. Maximum compressive stresses during static and dynamic conditions were well below the allowable limits with seismically induced deformations on the order of 10 mm. Tensile stresses were predicted to be generally low with only some highly localized areas with higher tension.



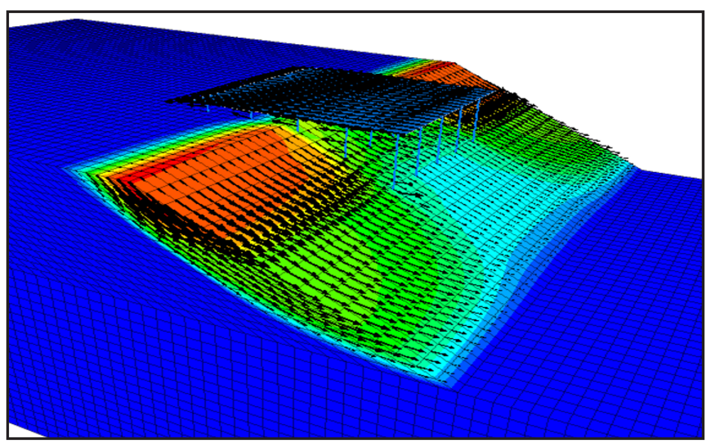
Dam looking downstream showing dynamic stresses with compression blue (left) and model geometry (right).



MARINE STRUCTURES

Many of the retaining structures Itasca has studied are associated with port facilities, including the Port Said project in London, the North Charleston port, 33 South Wharf (Melbourne), and the Port of Long Beach container wharf. For the Port of Long Beach, the busiest port on the west coast of the United States, Itasca developed a *FLAC* model for Kleinfelder, Inc. that was used to perform detailed seismic deformation of a dike, pile, and wharf system. The *FLAC* model provided deformations, pile rotations, and an estimate of shear and moment for each row of piling as a function of elevation. Plots of lateral displacement of piling, pile curvature, and shear stress for various earthquake assumptions were also generated. The information was used to check the adequacy of the piles supporting the wharf.

Itasca has developed models for The Port and Harbor Research Institute (Tokyo) to study the liquefaction of soils and their effect on support structures in harbors. These material models generate pore pressures as soil structure collapse under cyclic shear. The soil collapse increases pore pressures leading to liquefaction when effective stresses vanish. This work included simulation of a massive concrete block used to retain soil adjacent to the waterfront. Dynamic simulation showed the behavior of the massive concrete blocks during earthquake loading and subsequent liquefaction of retained soil.



Example of a *FLAC3D* model consisting of zoned soil, a wharf deck of nearly 650 shell elements, and 25 supporting piles. Itasca's uses an SSI (Shear Strain Increment) approach for dynamic analysis. This example was subjected to a series of seismic simulations, including one for liquefaction potential.

ITASCA

LEVEES and FLOODWALLS

Levees are often used to protect properties within and adjacent to the natural floodplains. Levees tend to be designed to withstand a 100 year storm event and are not normally designed to provide floods protection for a prolonged period[3].

Floodwalls are considerably more expensive to design and construct than levees and so tend to be used near urban areas. The most commonly used floodwall types are cantilever T-type and cantilever I-type walls[3].

Itasca is proud to work frequently with the United States Army Corps of Engineers (USACE) in their work to oversee and maintain levees and floodwalls throughout America. Itasca provides software, engineering design, and model review.

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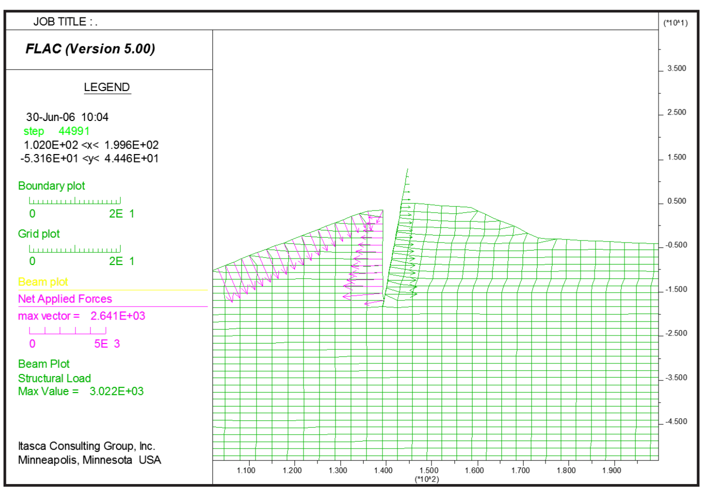
[3]Colorado, 2006. Chapter 13 Hydraulic Analysis and Design, Section 4 Levees. Colorado Floodplain and Stormwater Criteria Manual, 11 pp.



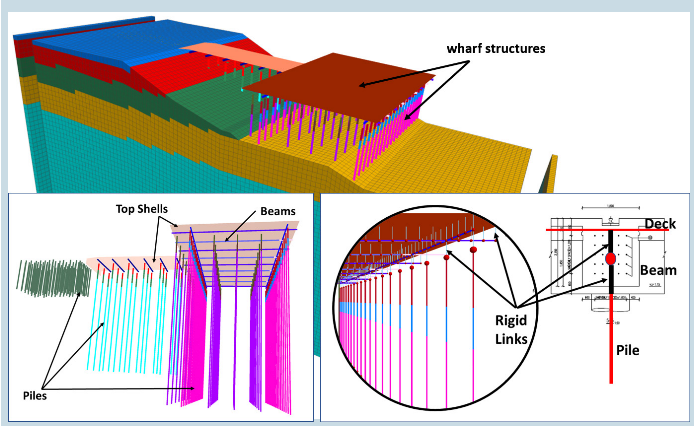
This *FLAC* model plot illustrates large failure and translational displacement comparable to that observed at 17th Street Canal breach location.

Honduras Container Terminal

Project Description
Itasca conducted a seismic performance evaluation of the trestle-wharf section of the OPC Puerto Cortes Container Terminal, located in Honduras.

Itasca's Contribution
FLAC3D modeling considered the full coupling between the soil and the terminal structure. Structures are represented explicitly considering nonlinear behavior for the pile--concrete-plug portions of the piles. The steel-pipe portion of the piles are modeled as elastic. The model is dynamic and considers liquefaction, including cycle dependent pore-pressure generation, modulus reduction, and damping.

Outcomes
The conclusion is that the soil can liquefy, although mostly locally. The bulk of the permanent deformations are due to stiffness degradation of the soil due to pore pressure generation during the seismic event. In general, the structural performance for this level of seismic excitation is adequate, with only a few elements that can exhibit plastic behavior at the connection with the deck located in the first three rows of piles in the trestle closest to shore. These can be relatively easily repaired in case such an event would manifest.



Structures are modeled as volumeless beams or shells. Rigid links are adopted to connect the single structures.

POWER INFRASTRUCTURE

Itasca works at the interface between electrical power generation and the subsurface environment on which we live to help develop sustainable power for future generations. Unlocking this energy in the most efficient manner requires careful engineering of the host rock. By-products and waste from power generation need storage or disposal in a manner safe to human life and with minimized impact on the natural environment for thousands, if not millions, of years to come. Itasca has a wide range of experience with power infrastructure projects, including:

- Engineered Geothermal Systems (EGS);
- nuclear reactor plants and waste isolation;
- wind energy turbines;
- thermal plants; and
- CO_2 sequestration.

Itasca has pioneered rock engineering research and development in underground nuclear waste isolation for over 30 years worldwide for all rock types, spanning hard rocks, salts, and clays over geological time periods. Sites include Yucca Mountain (USA), Deep Geological Repository (Canada), and Forsmak (Sweden). Itasca is transferring knowledge of complex rock processes to thermal and chemical behavior in fracture network engineering of geothermal systems and the underground confinement of CO_2 in sequestration projects.

- Excavation damage and disturbed zones
- Engineered barrier evaluation
- Dynamic response to earthquakes
- Water supply and groundwater infiltration
- Deep well injection of blowdown waters
- Impacts of ash disposal on groundwater quality
- Rock characterization & geophysical investigations
- Non-destructive examinations
- Microseismic and acoustic emission
- Cap rock integrity
- Site feasibility and suitability
- In-situ and laboratory testing
- Coupled hydro-mechanical-thermal-chemical
- Fracture flow analysis
- Regulatory guidance and review
- License application review

Deep Geological Repository

Project Description

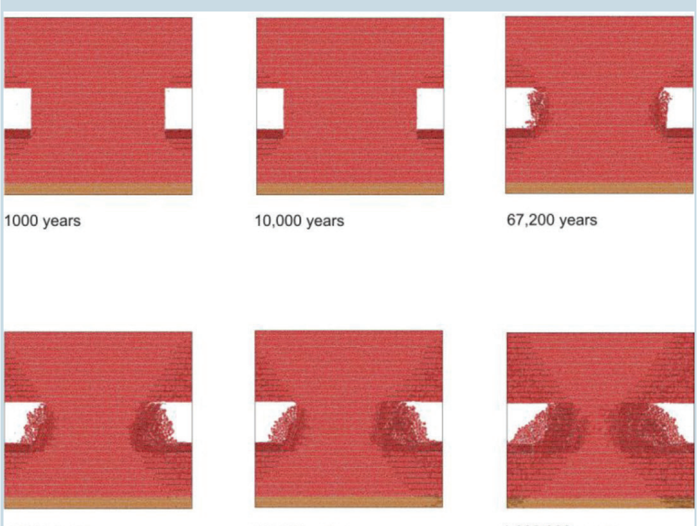
Ontario Power Generation (OPG) is designing an underground repository for long-term management of low/intermediate level waste. The waste is to be placed at a depth of 680 m without backfill to allow room for gas expansion during decomposition. The near-shaft service areas will be backfilled and sealed after the operating period of 100 years. The integrated shaft seal design is intent on mitigating wall damage to prevent a pathway for mass transport.

Itasca's Contribution

UDEC models included conservative assumptions for strength, degradation (stress corrosion), pore pressure, glacial loading, and seismic disturbance. Bedding planes were modeled discretely with the intact rock represented as a Voronoi hybrid. Parameter and sensitivity studies allowed for a rational but conservative approach to analysis of the stability and long-term safety of the repository.

Outcomes

It is predicted that the surrounding limestone will break down, effectively filling the cavern in 200,000 to 300,000 years and choking the cavern and suppressing further failure above. The ultimate failure zone will not reach into the shale formations above the repository. Surface settlements during the first 300,000 years would not lead to unacceptable disturbance or yield of the overlying shales, a critical element in the geo-barrier concept.



Monopile for Offshore Wind Turbine

Project Description

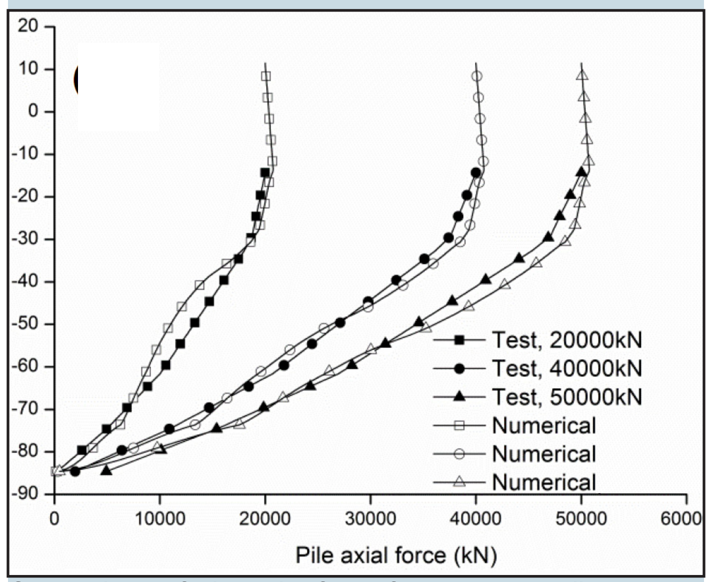
A 150MW capacity offshore wind farm is planned in the East China Sea. The wind farm is 25 km off shore, about 200 km from Shanghai. To cope with the combination of weaker soils and extreme weather conditions, very large monopiles are being utilized.

Itasca's Contribution

Itasca used Mohr-Coulomb *FLAC3D* models to back analyze a series of in-situ vertical and horizontal pile tests conducted for calibration of the offshore monopile design. Calibrated model results were also compared to lateral pile loading using the API recommended p-y curve back analysis method.

Outcomes

The numerical results from the back analysis presented good agreement with the measured data. It demonstrates that the non-linear strain-compatible soil stiffness has significant effect on the soil-pile interaction. The results from the p-y curve method were found to be conservative for design as they overestimated both the pile displacement and bending moment for large diameter piles in clay.



Comparison of pile axial force for several loading stages shows that the pile axial force from the static *FLAC3D* back-analysis agrees well with the pile test.

HYDROELECTRIC POWER PLANTS

Itasca projects include hydroelectric underground powerhouses in Israel (Gavet), China (Baihetan, JinPing), India, and Colombia (Guavio and Sogamoso).

Hydroelectric Project

Project Description

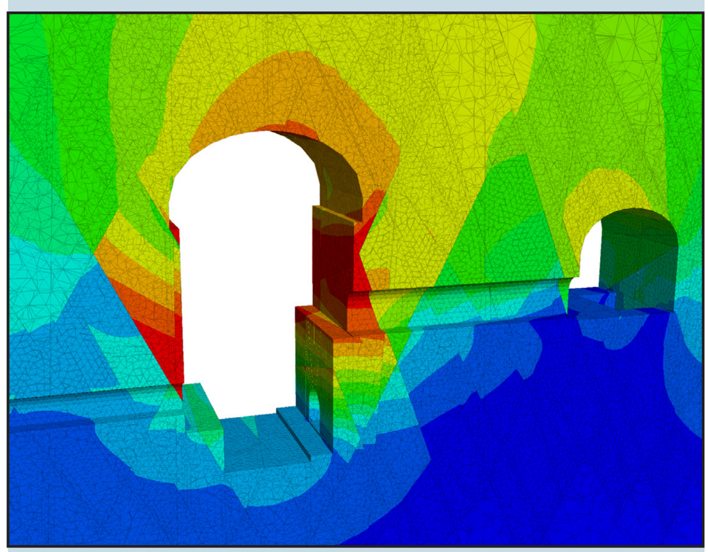
Itasca was asked to analyze the stability of underground caverns, excavated in fractured gneiss and amphibolite rock, for an hydro-electric project located France.

Itasca's Contribution

Itasca developed a *3DEC* model consisting of the two main caverns and three smaller galleries. Rock support integrity was estimated using 30 *3DEC* simulations to account explicitly for the various orientation of surrounding fractures. The rock mass was modeled as a Mohr-Coulomb material with Coulomb sliding joints. The structural elements were activated in sequence with the excavation advancement and consisted of cable and shell elements. Sixteen excavation phases are reproduced explicitly, using 3 m (vertical) by 6 m (horizontal) passes.

Outcomes

At the end of the excavation sequence, *3DEC* models indicate that the fractures govern displacements and forces. However, cavern convergences remained small at the end of excavation and cable loads are only about 40% of their capacity. The liners undergo serious stresses where joints slide, but liner damage can be avoided by installing them later.



3DEC model showing displacement contours around the main caverns at the end of excavation.

Gilboa Pumped Storage Plant

Project Description

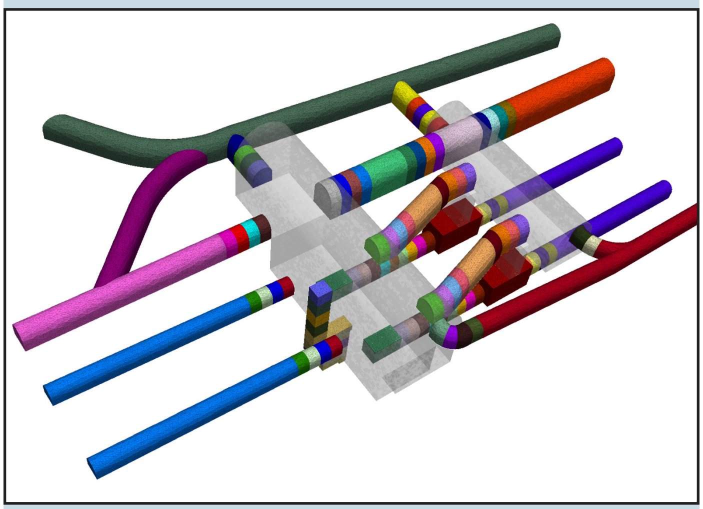
Electricité de France (EdF) asked Itasca to study the excavation stability during the construction of an underground hydroelectric power plant located in Giloba, Israel. It consists of two main caverns and several adjacent galleries.

Itasca's Contribution

Itasca generated a 3D tetrahedral mesh, based on cross-sections from the client, with our automatic mesh software *Kubrix Geo*. The mesh near excavations was split into hexahedral zones for improved plasticity. Concrete support was modeled explicitly by liner structural elements while the effect of rockbolts was approximated by increasing the rock cohesion around the excavation. It required 47 excavation stages to reproduce the construction sequence.

Outcomes

The stresses in the liners at some intersections can be very high (up to 50 MPa in compression and up to 10 MPa in tension); support needs to be designed accordingly in these areas. The plant remained stable during the excavation.



FLAC3D model with excavation stages for the galleries indicated. Each color corresponds to one construction stage.

Baihetan Hydropower Station

Project Description

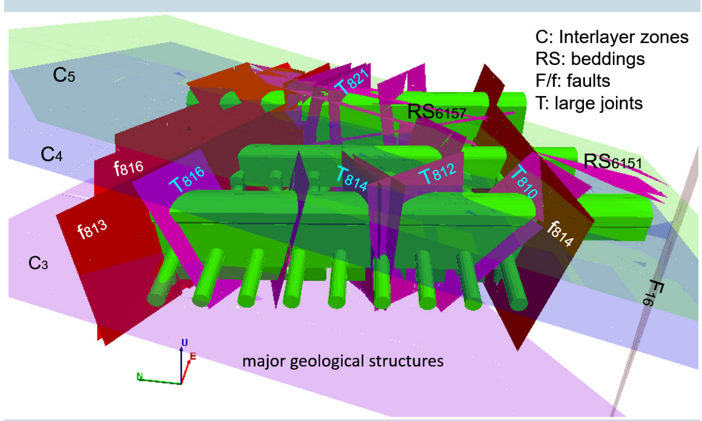
The Baihetan hydropower station in China is a 2 ,000 MW capacity double-arched dam with twin caverns located inside either river bank. The caverns are each 438 m long x 34 m wide x 86.7 m high. Stability concerns were observed in adjacent adits with ground falls in the crown, stress-induced spalling, and active shearing near a major shear zone.

Itasca's Contribution

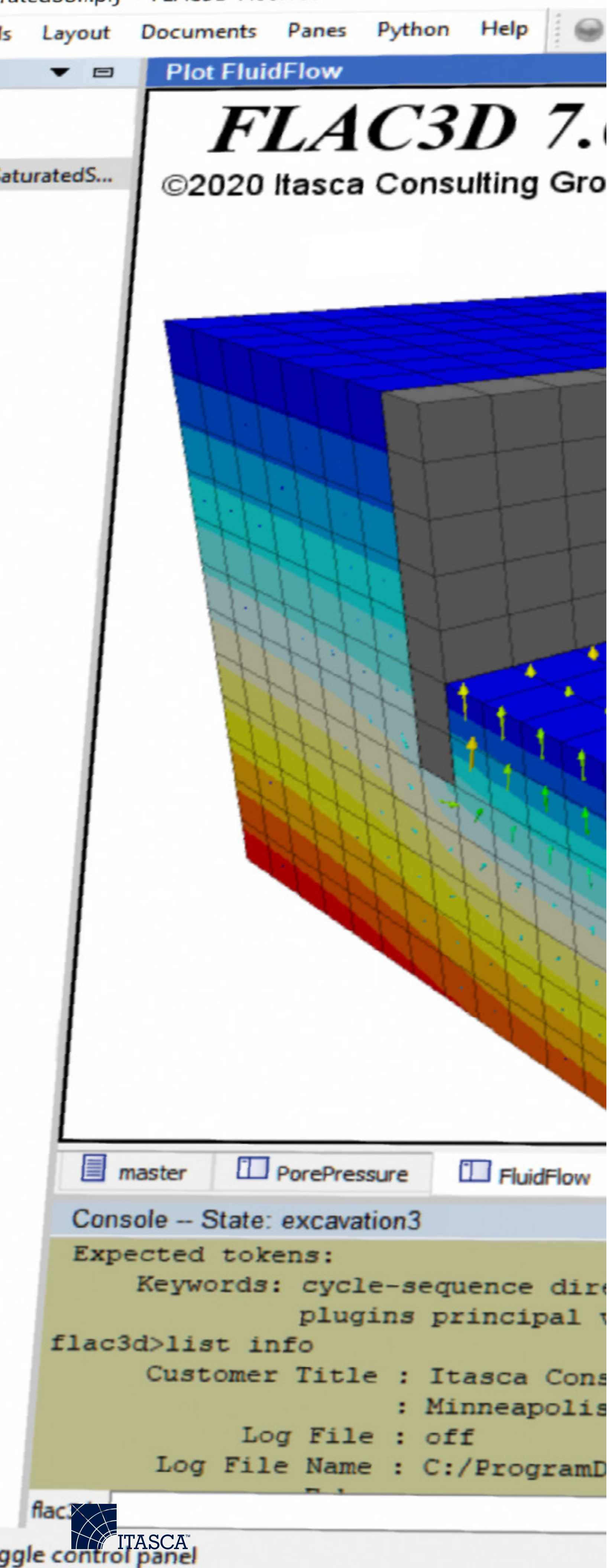
Itasca has been involved in the Baihetan Project since 2005 throughout various design stages from the prefeasibilty study to detailed construction design. For this case, Itasca evaluated the crown stability in the right-bank cavern using over one hundred *3DEC* simulations. Itasca also performed site characterization, reviewed in-situ stress measurements, evaluated and modified ground support design, and optimized the underground facility layout design, including the surge chamber geometry.

Outcomes

Itasca concluded that the ground fall problem was mainly governed by beddings and joints in the crown. Since these tend to occur at relatively small scales, large-volume ground fall hazard in the crown is unlikely and conventional rock support systems are sufficient to maintain overall cavern integrity. Stress-induced failure in the form of spalling is anticipated in the footwall side of the shear zone and it was estimated that a maximum depth of failure of 8 m can be expected.



The geological structures include shear zones, interlayer shear zones, faults, and large steeply dipping joints.



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.

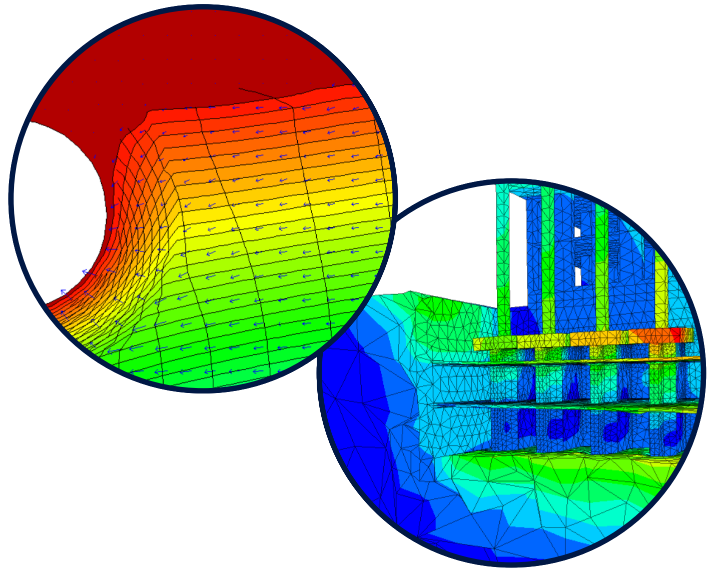
Itasca software programs include the two- and three-dimensional continuum programs *FLAC* (including *FLAC/Slope*) and *FLAC3D*, the two- and three-dimensional discontinuum programs *UDEC* and *3DEC*, the two- and three-dimensional particle-flow simulation programs *PFC2D* and *PFC3D*, the three-dimensional, finite-element groundwater flow code *MINEDW*, the integrated seismic data acquisition, processing, management and visualization software *InSite* for seismological studies, 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.

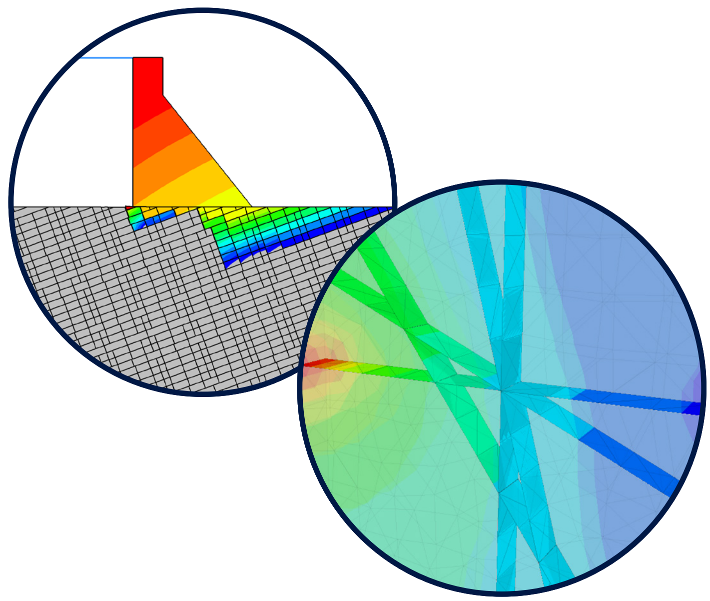
FLAC® – FLAC3D™

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.).



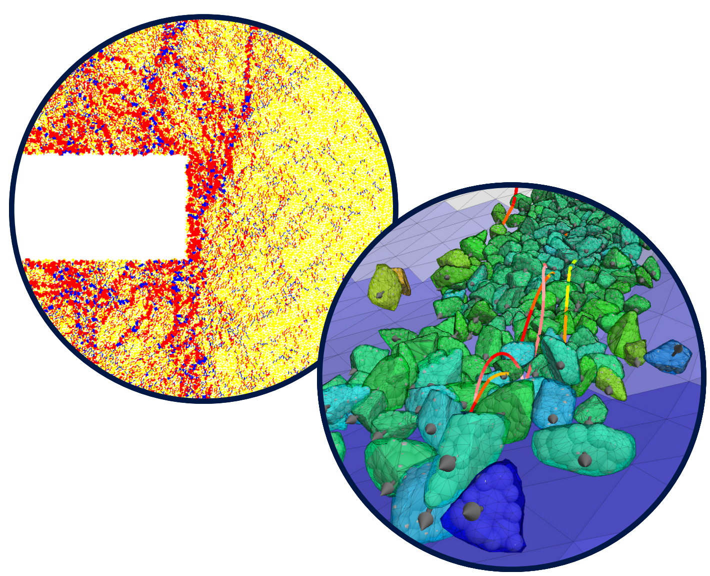
UDEC™ – 3DEC™

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).



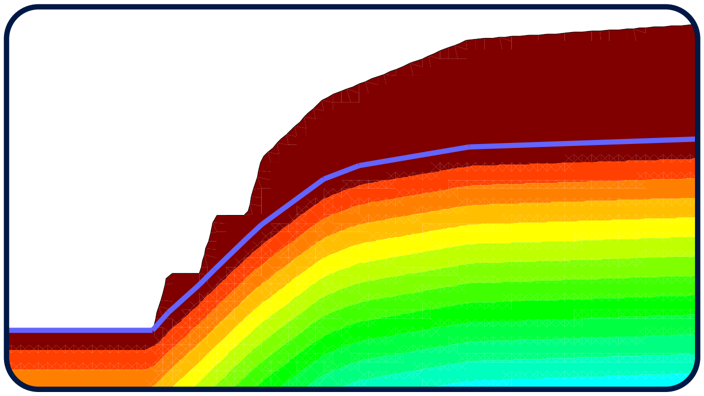
PFC Suite™

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.



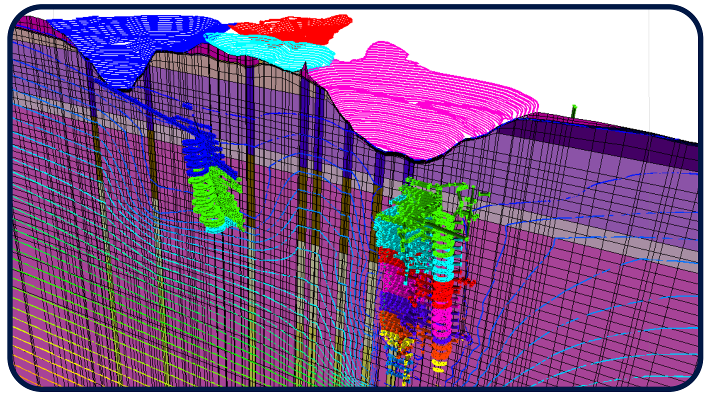
FLAC/Slope™

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.



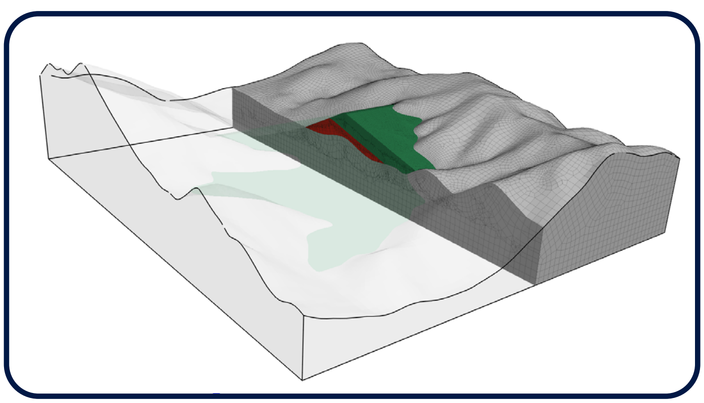
MINEDW™

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.



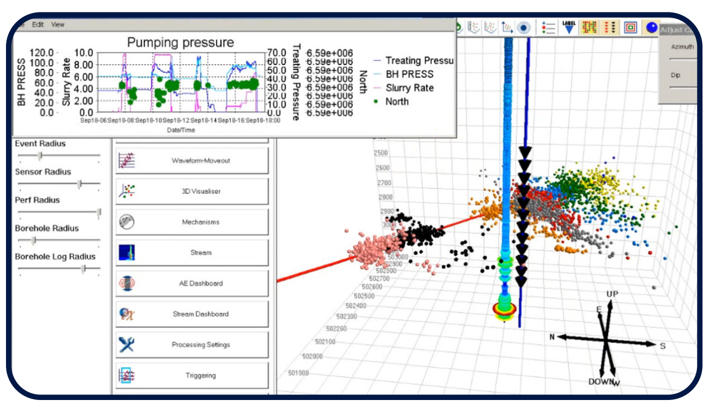
Griddle™

Griddle is a fully interactive, general-purpose mesh generation plug-in for the *Rhinoceros* 6.0 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*.



InSite™

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. *InSite* is available as *InSite-Geo*, *InSite-HF*, and *InSite-Lab* for geomechanical, hydraulic fracturing, and laboratory applications. *InSite-Lite* is also provided as a free microseimicity viewer.



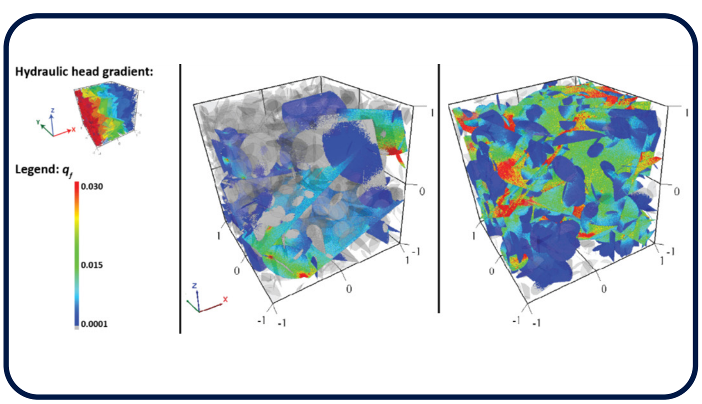
KATS

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.

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



Software Customization

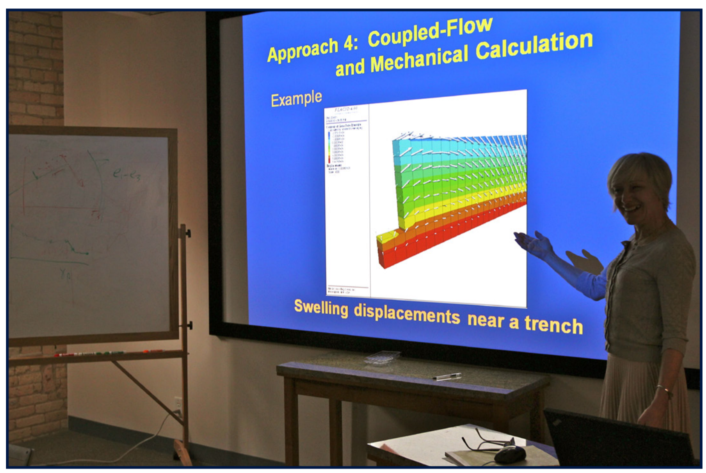
Itasca's software development is directed and refined by Itasca's consulting practice and client feedback. Itasca develops specialized material constitutive and contact models, *FISH* and Python functions, or even entirely novel simulation software in consultation with clients or as part of research 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 training courses throughout the year.



You can find out which courses are currently available here:

www.itascainternational.com/training

Custom engineering or software training courses can also be arranged at one of our offices or at your organization. Online web forms can be found at the following address.

www.itascainternational.com/engineering-training

www.itascainternational.com/software-training

LEAD PERSONNEL, CIVIL ENGINEERING

ITASCA™

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

Dr. Brummer has over 38 years of geomechanics consulting, practical mining applications, research, and academia experience.

His consulting and field work includes projects for underground mines and large excavations, including rock mass classification, stope design, rockburst risk evaluation and prevention, pillar design, backfill, seismic monitoring, risk assessment, determination of ground support methods, and investigation of roof stability problems. Dr. Brummer was the Lead Geomechanics Engineer for Design of Sudbury Neutrino Lab II (SNOLab).

He has worked extensively in hard and soft rock with geomechanical instrumentation systems and industrial plants for routine site monitoring, as well as robust industrial data acquisition and control systems. This includes the design, planning, installation, and operation for measuring in-situ stress, displacement, pressures, temperatures, loads, blast monitoring, gas outbursts, vibrations, etc.

Marco Camusso
Ph.D., P. Eng.
Itasca Consultants S.A.S.
Geomechanics Engineer
m.camusso@itasca.fr

Dr. Camusso is a geomechanics engineer with extensive experience in geotechnics and rock mechanics. His consulting activities have been carried out primarily in the modeling of the long-term behavior and the coupled THM processes of rock for the design of nuclear waste disposal sites.

He has also worked on several geotechnical consulting projects in France. These mainly include tunnel excavations and support design verifications, slope stabilities, and retaining structure studies. Most of Dr. Camusso's numerical modeling expertise comes from using Itasca's *FLAC* and *FLAC3D* codes.

Weijang Chu
Ph.D., P. Eng.
HydroChina-Itasca R&D Center
General Manager and
Geomechanics Engineer
wchu@itasca.cc

Dr. Chu is a geomechanics engineer with extensive experience in rock mechanics and geotechnics. His consulting and field work include projects for large span underground cavern design, rock slope design, rockburst risk assessment and determination, deep overburden tunnel design and analysis, and offshore pile foundation design and analysis.

Dr. Chu has worked on numerous geomechanics consulting project in China. These projects including underground cavern complex stability, high stress failure control in deep tunnel and underground powerhouse, subway tunnel stability assessment, bridge foundations, and large rock slope stability.

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 excavations for oil storage and waste isolation. He has been involved in stability analyses of underground and open pit mines in both hard and soft rocks.

He has developed a 3D numerical model to simulate the coupled hydro-mechanical response of a fluid-saturated rock mass. Dr. Damjanac was involved in a number of projects in petroleum, geothermal and mining industries with objective of design and operation optimization of rock mass treatment by fluid injection.

Christine Detournay
Ph.D. (Civil Engineering)
Itasca Consulting Group, Inc.
Principal Engineer
christine@itascacg.com

Dr. Detournay has experience in the development of numerical models for application to coupled fluid-thermo-mechanical problems. She is a principal developer for the groundwater-flow and thermal logic in *FLAC3D*, and has been involved in the development of several of the constitutive models available with Itasca continuum codes.

She has worked in consulting and development for various projects related to the oil and gas industry, including hydraulic fracturing, as well as on projects pertaining to underground waste repository, geothermal applications, slope stability, soil liquefaction and CO_2 sequestration.

Patricio Gómez
Dipl. Applied Geomechanics
Itasca S.A.
General Manager and Applied Geotechnical Engineer
patricio.gomez@itasca.cl

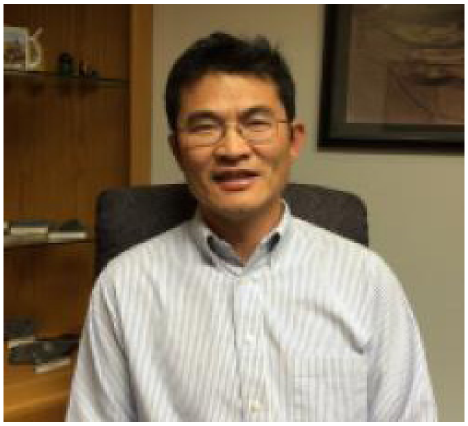
Mr. Gómez is a civil engineer from the University of Chile, he holds a diploma in Geomechanics Applied to Mining from the same university and has worked in the field of soil and rock mechanics for major mining projects in South America for over 30 years, twenty of which are with Itasca. He has experience in all aspects of stability analysis and modeling of rock masses.

Civil engineering consulting includes static and dynamic stability analyses of tailings dams, water reservoirs, and waste dumps in highly active seismic areas. Extensive application of numerical models for the analysis of liquefaction potential in saturated sands under seismic loading. Structural analysis of tunnels and retaining walls, geotechnical characterization of soils, and the design of foundations.

Yoann Hebert
Geotechnical Engineer
Itasca Australia Pty. Ltd.
Principal Geotechnical Engineer
yhebert@itasca.com.au

Mr Hebert is a civil engineer with extensive experience in geotechnics, rock mechanics and numerical modelling both in the civil and mining industries. His consulting activities have been focused on the design and analysis of underground excavations (tunnels, caverns and nuclear waste disposals), dams and foundations, in various parts of the world (France, Morocco, Switzerland, Australia, Sweden, USA). He also has consulting and research experience in large-scale open pit mining, cave mining and assessment of induced subsidence. Mr Hebert is particularly well versed in the use of *FLAC3D*, *3DEC*, and *KUBRIX*.

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. (Civil Engineering), P. Eng.
Itasca Consulting Group, Inc.
Principal Engineer
loren@itascacg.com

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 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 50 short courses, authored more than 100 technical articles and made ten keynote presentations. He is a Registered Professional Engineer in several U.S. states.

Augusto Lucarelli
M.Sc. (Eng.)
Itasca Consulting Group, Inc.
Principal Engineer
alucarelli@itascacg.com

Mr. Lucarelli has a background in soil mechanics, numerical modeling of geotechnical processes, shallow and deep foundation design, soil improvement, slope stability, mechanized excavation, conventional tunneling in urban areas, deep excavation, and support structures in difficult environments. He has numerical software experience in *FLAC*, *FLAC3D*, *UDEC*, *Plaxis2D*, *Plaxis3D Foundations*, and *Plaxis3D Tunnel*.

Lee Petersen

Ph.D., P.E.
Itasca Consulting Group, Inc.
Principal Engineer
lpetersen@itascacg.com

Dr. Petersen has experience in the analysis and design of underground excavations for occupancy, science facilities, transit, and mining. He conducts soil-structure interaction analysis, numerical modeling, in-situ soil modulus measurement, vibration assessment and monitoring, design of deep hard-rock caverns, and shallow soft-rock caverns. Dr. Petersen also has worked on planning, layout, design, and construction of deep, occupied underground space, including managing multidisciplinary design teams of structural, electrical and HVAC engineers and architects. In addition, he has specified, installed, and monitored structural and geotechnical instrumentation.

Glenn Sharrock

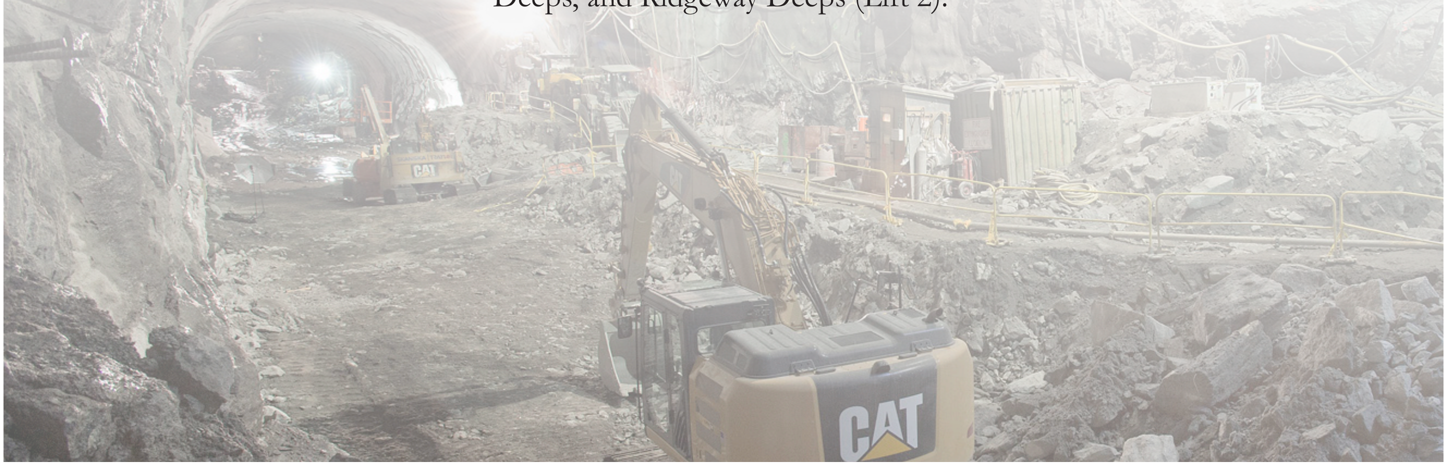
Ph.D., MAusIMM CP (Geotech)
Itasca Australia Pty. Ltd.
General Manager and Principal Geotechnical Engineer
gsharrock@itasca.com.au

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

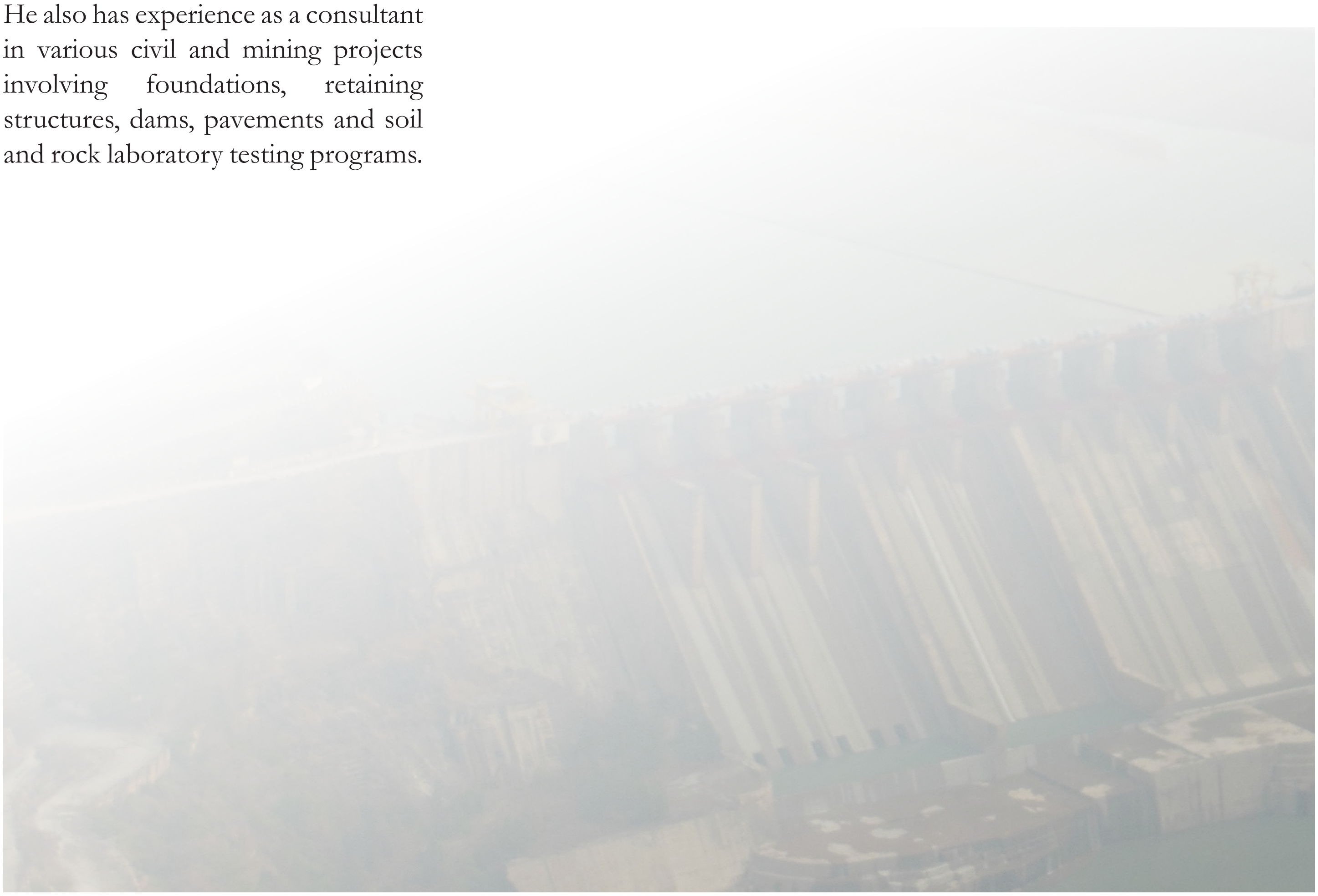
Ph.D.
Itasca Consultants AB
General Manager and Principal Engineer
jonny@itasca.se

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.



David Wines
ME, CPEng
Itasca Australia Pty. Ltd.
Principal Geotechnical Engineer
dwines@itasca.com.au

Mr. Wines is a geotechnical engineer with extensive experience in both the mining and civil industries. He has on-site and research experience in the analysis, design, implementation, and monitoring of large-scale open pits. He also has experience as a consultant in various civil and mining projects involving foundations, retaining structures, dams, pavements and soil and rock laboratory testing programs.



SELECT CIVIL CLIENT REFERENCES

Billy Camp
Technical Principal/Vice President
S&ME
620 Wando Park Boulevard
Mt. Pleasant, SC 29464 USA
Phone: (843) 884-0005 | ext. 32018
Email: bcamp@smeinc.com

Ahmed Chraibi
Expert
NOVEC SA
Immeuble NOVEC
Park Technopolis
11100 Sala Al Jadida
Rabat Salé
Email: ach@novec.com

Derrick Dasenbrock
Geotechnical Office
Minnesota Department of Transportation (MnDOT)
1400 Gervais Avenue
Maplewood, MN 55109 USA
Email: derrick.dasenbrock@state.mn.us
Phone: (651) 366-5597

Arnaud Delacourt
Works Director
Eiffages travaux publics
Laboratoire de recherche souterrain
Email: arnaud.delacourt@eiffage.com
Phone: 03-29-75-69-90

Rick DesChamps
Vice President
Nicholson Construction Company
12 McClane Street
Cuddy, PA 15031 USA
Email: rdeschamps@nicholsonconstruction.com
Phone: (412) 221-4500

Bill Holman
Principal Geotechnical Engineer/Senior Project Manager
Stanley Consulting Group
5775 Wayzata Boulevard
Suite 300
Minneapolis, Minnesota 55416
Email: HolmanBill@StanleyGroup.com
Phone: (952) 546-3669

Hannes Lagger
Ove Arup and Partners, ARUP
Director, Principal Infrastructure Americas, Global Infrastructure
13 Fitzroy Street
London W1T 4BQ, UK
Email: hannes.lagger@arup.com

François Laigle
Underground Works Expert
EDF CIH
73373 - Le Bourget du Lac Cedex
Email: francois.laigle@edf.fr
Phone: 04-79-60-60-91
Benjamin Lecomte
Design Office Director
Vinci Grands Projets
5 cours Ferdinand de Lesseps
92851 - Rueil Malmaison
Email: benjamin.lecomte@vinci-construction.com
Phone: 01-47-16-32-73

Scott Ludlow
SJL Engineering
450 E. 96th Street
Suite 500
Indianapolis IN 46240 USA
Email: sludlow@sjlengineers.com
Phone: (317) 371-5539

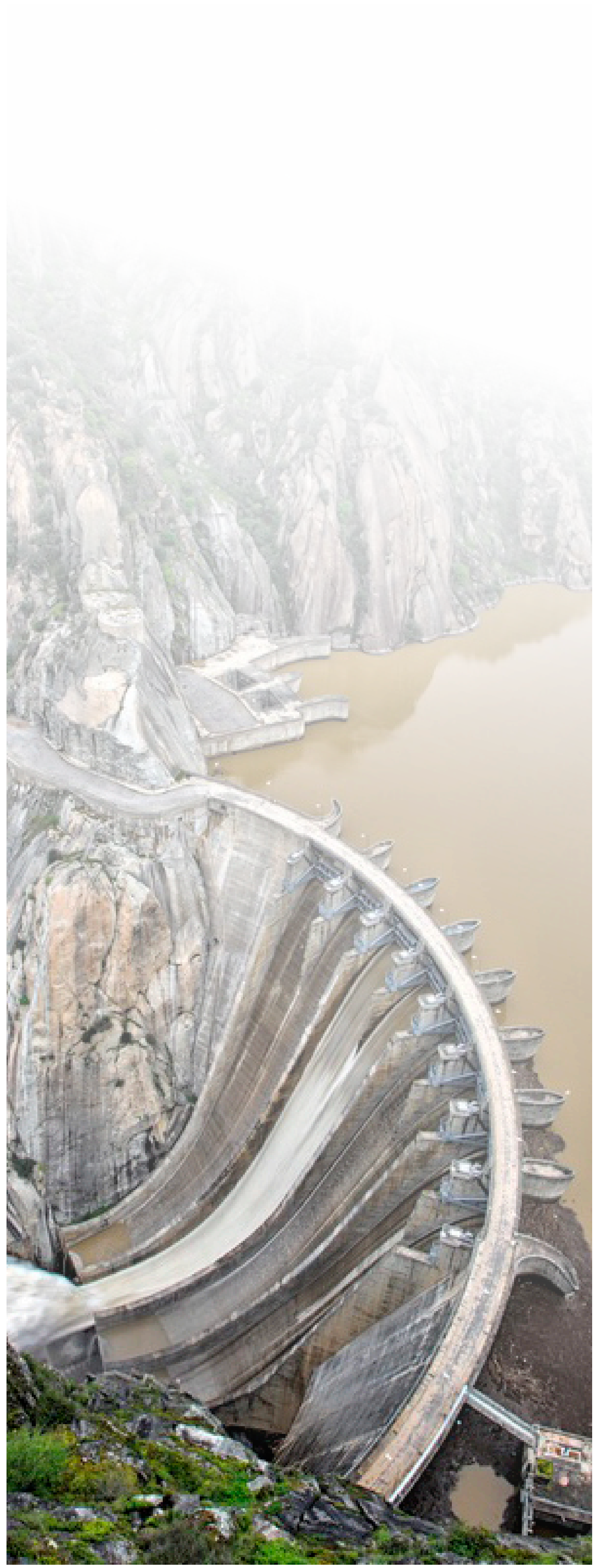
Lucas de Melo
Geosyntec Consultants
10220 Old Columbia Road, Suite 200,
Columbia, Maryland 21046 USA
Email: ldemelo@geosyntec.com)
Phone: (410) 381-4333

Gary Person
Geotechnical Office
Minnesota Department of Transportation (MnDOT)
1400 Gervais Avenue
Maplewood, MN 55109 USA
Email: gary.person@state.mn.us
Phone: (651) 366-5598

Adrien Saitta
Geotechnical Expert
EGIS Tunnels
Les Pléïades N° 35Park Nord
La Bouvarde
74373 Pringy
Email: adrien.saitta@egis.fr

Pierre Wyniecki
Scientific Director
Nuvia
L'Archimède - 85 av Archimède
13857 - AIX EN PROVENCE Cedex 3
Email: pierre.wyniecki@nuvia.fr
Phone: 06-80-13-18-50

Pierre-Yves Vecchio
Project Manager
CONFLUENCE ING. GEOTECHNIQUE
2 rue de Port
01360 – LOYETTES
Email: py.vecchio@beconfluence.fr
Phone: 04-72-05-88-03



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Contact us at:

Itasca International Inc.
111 3rd Avenue South, Suite 450
Minneapolis, Minnesota 55401 USA

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

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