THREE DECADES OF ITASCA SOFTWARE

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Itasca Consulting Group, Inc.

3rd International FLAC/DEM Symposium
Hangzhou, China, 22-24 October 2013

Summary

- History of Itasca code releases
- International distribution and IEP support
- Range of applications and organizations
- Examples of the wide spectrum of uses
- The future

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History

The six main Itasca codes started to be distributed in the following years:

UDEC	1983	2D angular block DEM
FLAC	1985	2D continuum
3DEC	1989	3D angular block DEM
FLAC3D	1994	3D continuum
PFC2D	1994	2D circular particle DEM
PFC3D	1995	3D circular particle DEM

International distribution

Itasca's codes have been shipped to **86 countries**, from Algeria to Zimbabwe.

These code sales are from ***1998 onwards***

FLAC	4242
FLAC3D	2764
UDEC	1326
PFC2D	1150
PFC3D	970
3DEC	572
TOTAL	**11,024**

(There were several thousand code sales ***before 1998*** – e.g., 1000 copies of *FLAC* alone were shipped by 1994)

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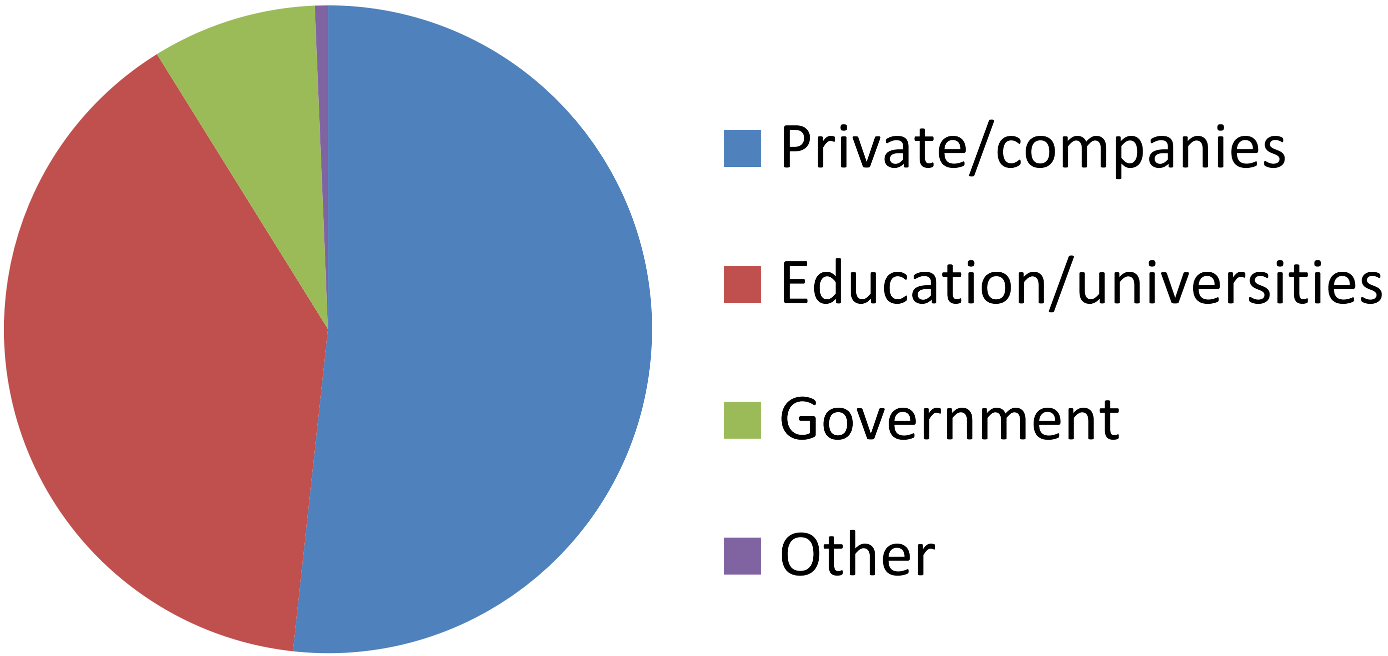
Organizations that use Itasca codes



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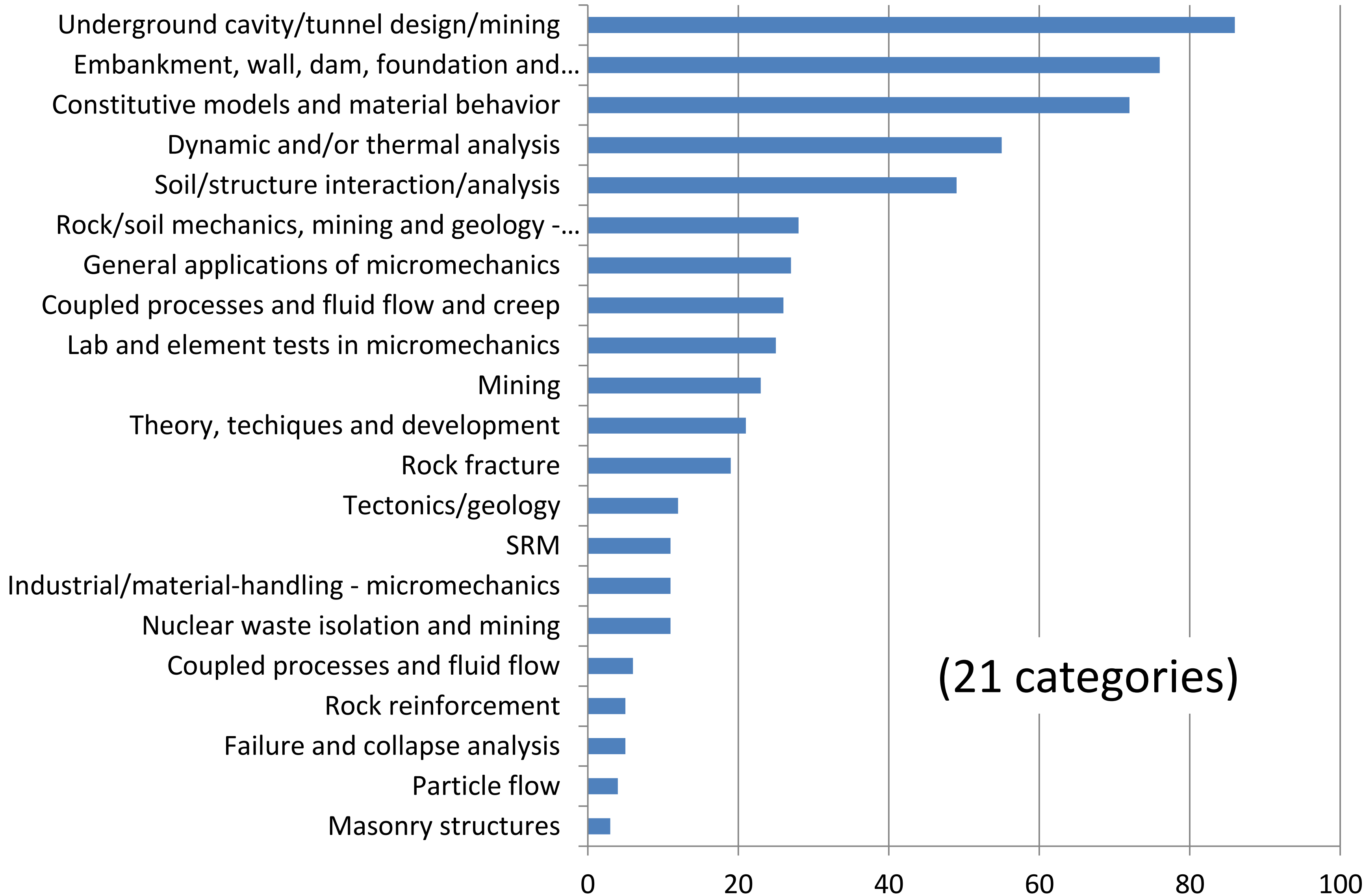
Applications

There were 575 papers in the ten International Itasca Symposia (including this one).

The following chart shows the wide variety of topics covered:


Underground cavity/tunnel design/mining
Embankment, wall, dam, foundation and…
Constitutive models and material behavior
Dynamic and/or thermal analysis
Soil/structure interaction/analysis
Rock/soil mechanics, mining and geology -…
General applications of micromechanics
Coupled processes and fluid flow and creep
Lab and element tests in micromechanics
Mining
Theory, techiques and development
Rock fracture
Tectonics/geology
SRM
Industrial/material-handling - micromechanics
Nuclear waste isolation and mining
Coupled processes and fluid flow
Rock reinforcement
Failure and collapse analysis
Particle flow
Masonry structures
0
20
40
60
80
100
(21 categories)

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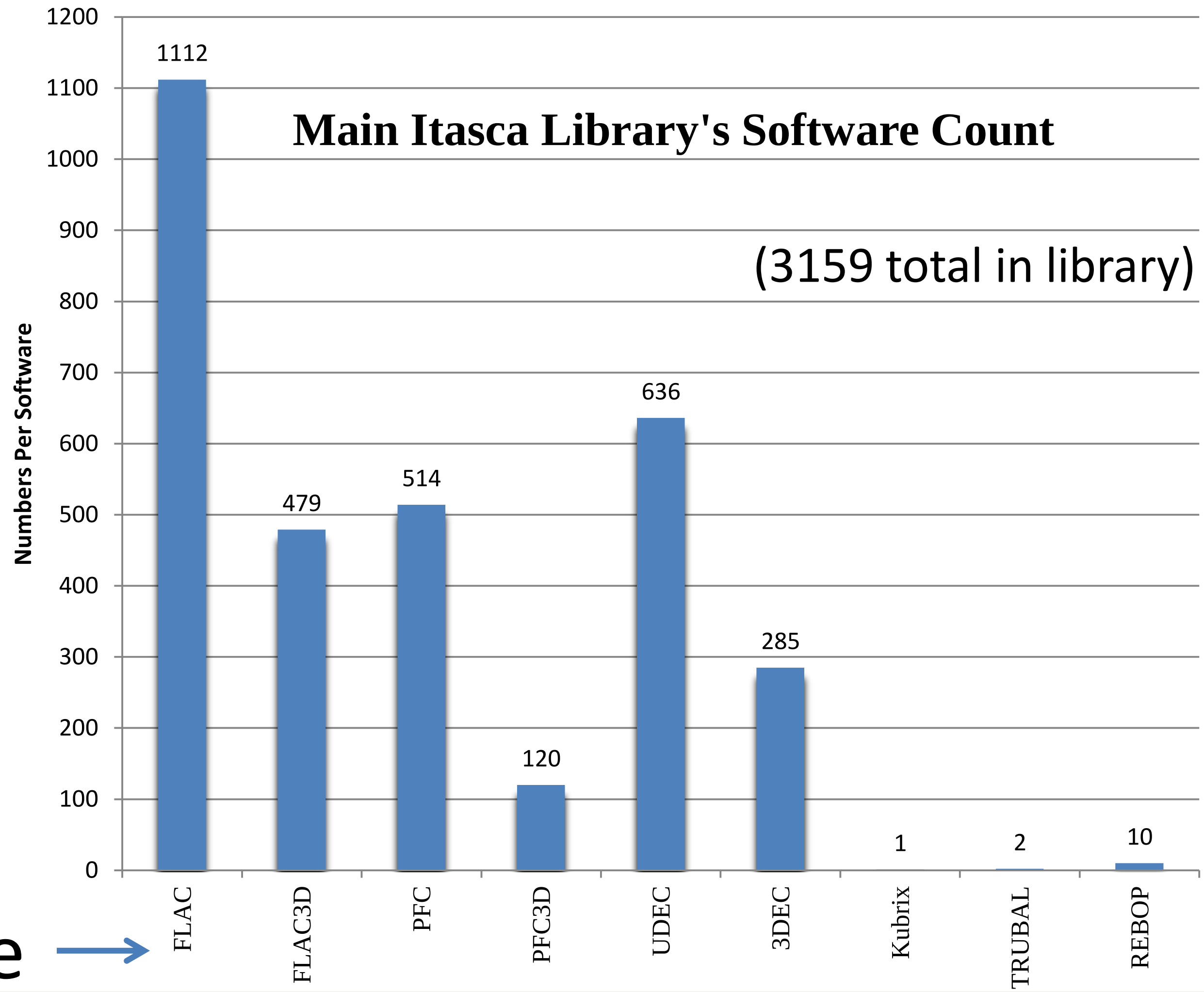
General papers

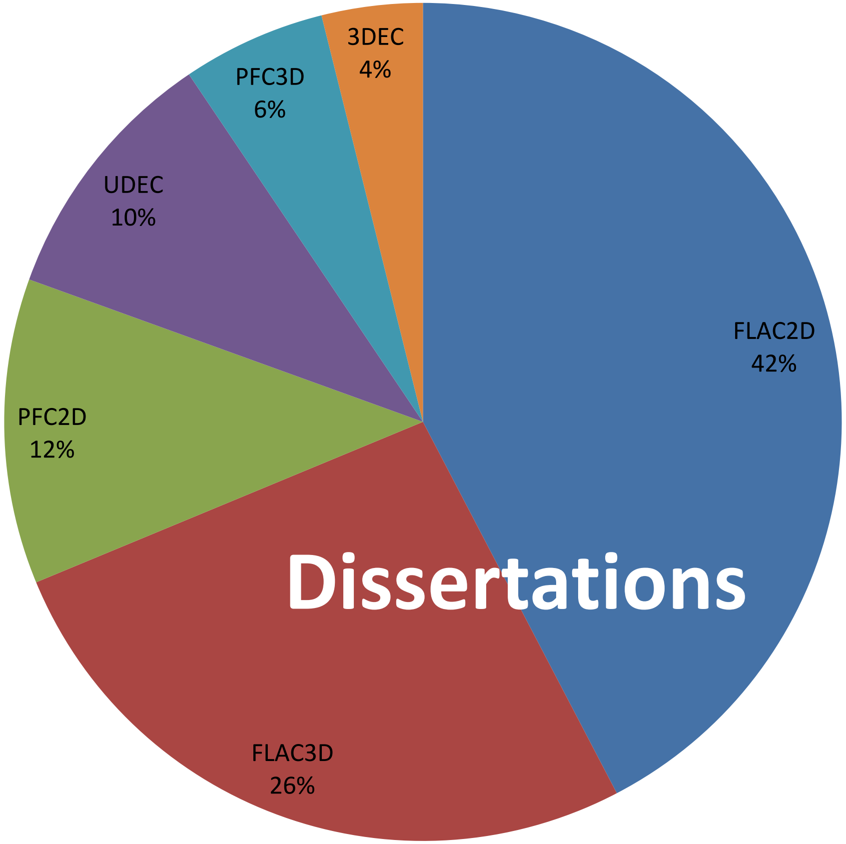
It is almost impossible to know the total number of papers that have been written about Itasca code applications – we have several thousand in the Itasca library, but there are probably many more.



Code →

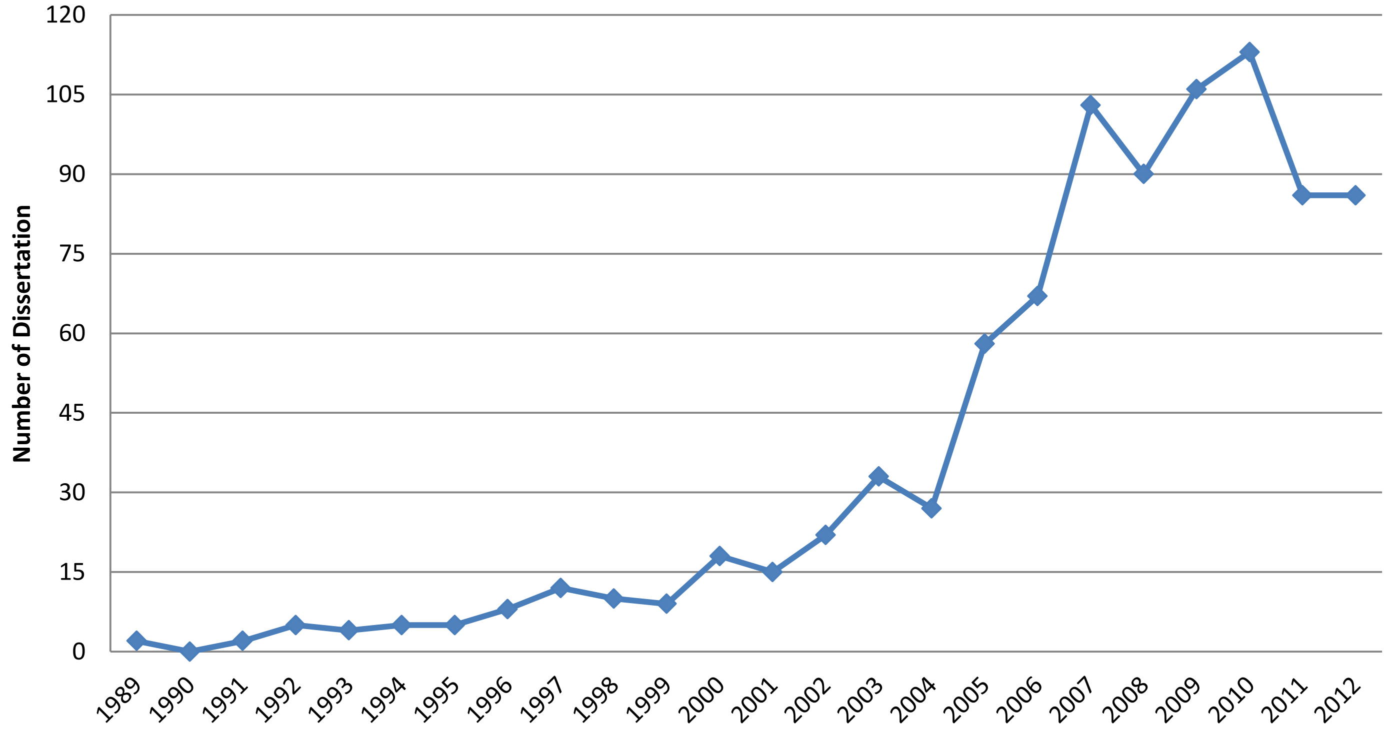
In addition, many **dissertations** have been written – we have records of **over 900** dissertations (most of them Ph.Ds), but there is evidence to suggest that there are many more.

We are particularly pleased about the large number of dissertations, because an extensive use of the codes in research reassures us that the physics is rigorous, the solutions robust and that documentation and access are good.



Percentage of code usage in dissertations

Dissertation Per Year



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Itasca Educational Partnership (IEP)

Itasca has supported students with free software, research grants and mentorship programs since 2007. Many significant papers and advances in science and engineering have resulted from this international collaboration with academic institutions.

IEP Participating Universities

53 Professors from **41** Different Institutions

- Budapest University of Technology
- Center for Excellence in Mining Innovation (CEMI)
- Centre de Geosciences – Ecole des Mines ParisTech
- Colorado School of Mines
- Ecole Centrale de Lyon
- Ecole et Observatoire des Sciences de la Terre
- Imperial College
- Institut National des Sciences Appliquées de Toulouse
- Institute of Geotechnical Engineering (Institut für Geotechnik)
- Kandilli Observatory and Earthquake Research Institute
- National Technical University of Athens (NTUA)
- Pontificia Universidade Catolica do Rio de Janeiro
- Robert Gordon University
- Ruhr-University Bochum
- Saint Louis University
- Southern Illinois University, Carbondale
- Texas A&M University
- Texas Tech University
- TU Braunschweig-Institut für Grundbau und Bodenmechanik
- Universidad de Chile
- Universidad Nacional de Colombia
- Universidad Técnica Federico Santa Maria
- Université de Mons – Faculté Polytechnique
- Université Laval
- Université Paris EST
- University College Dublin
- University of British Columbia
- University of Chicago
- University of Cologne
- University of Göttingen
- University of Illinois, Urbana Champaign
- University of Minnesota
- University of Nevada, Reno
- University of Rijeka
- University of São Paulo
- University of Stuttgart
- University of Toronto
- University of Utah
- University of Washington
- University of Waterloo
- University of Witwatersrand, School of Mining Engineering

The spectrum of code usage

Itasca software has been applied over wide ranges of size, time, stress-levels, importance to economy & safety and levels of fundamental knowledge:

- *Size scale from molecules to mountains*
- *Time scale from microseconds to millenia*
- *Stress scale from Pascals to giga-Pascals*
- *From nuclear repository design to falling apples*
- *From geological mechanisms to constitutive behavior of an element*

We illustrate *a few* diverse applications …

First, large-scale projects in Civil Engineering …

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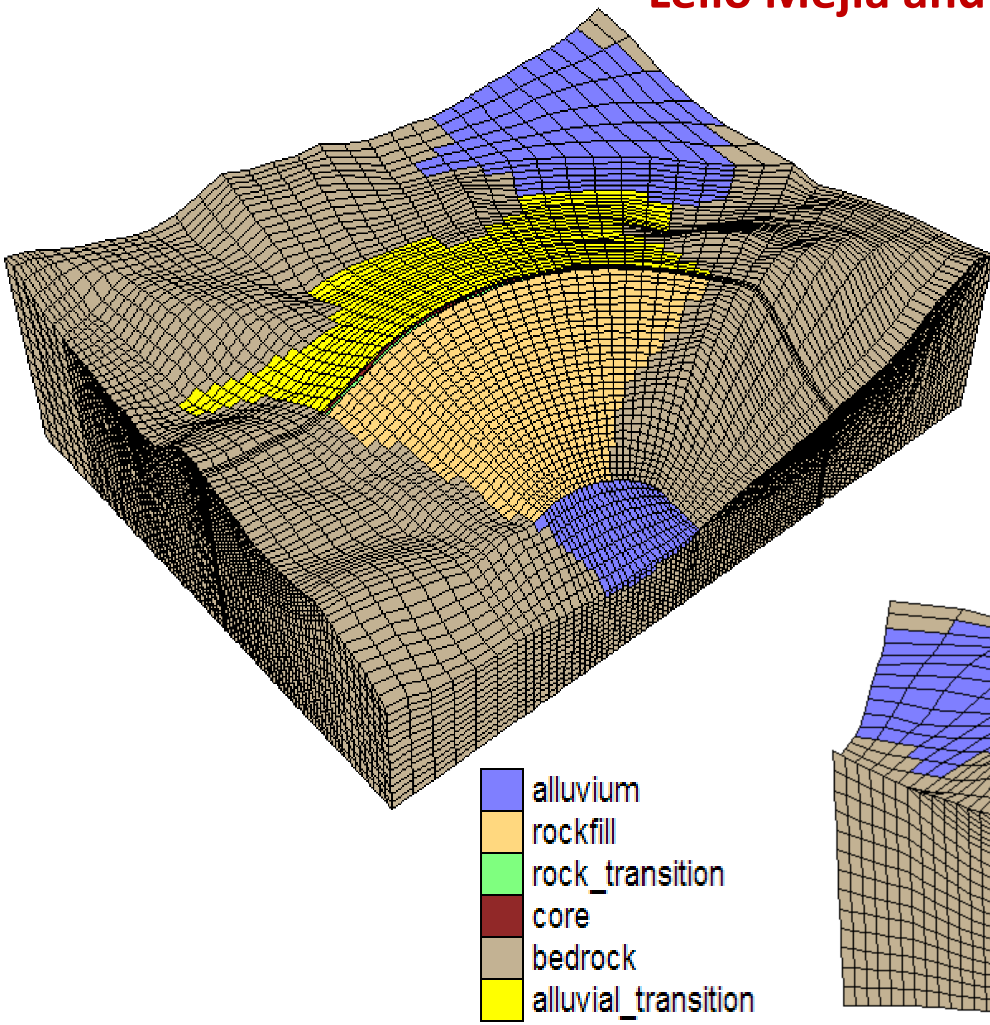
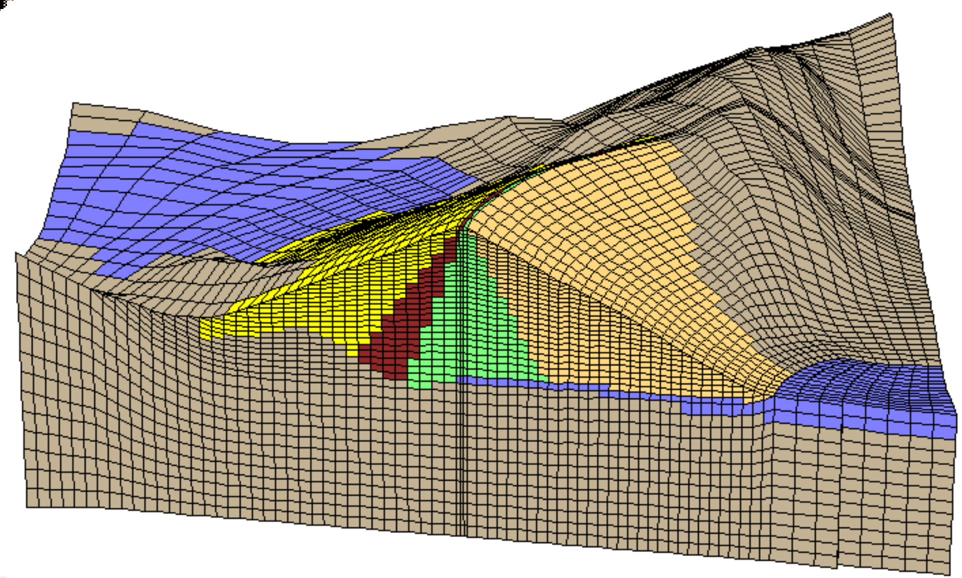
3D ANALYSIS OF THE SEISMIC RESPONSE OF SEVEN OAKS DAM

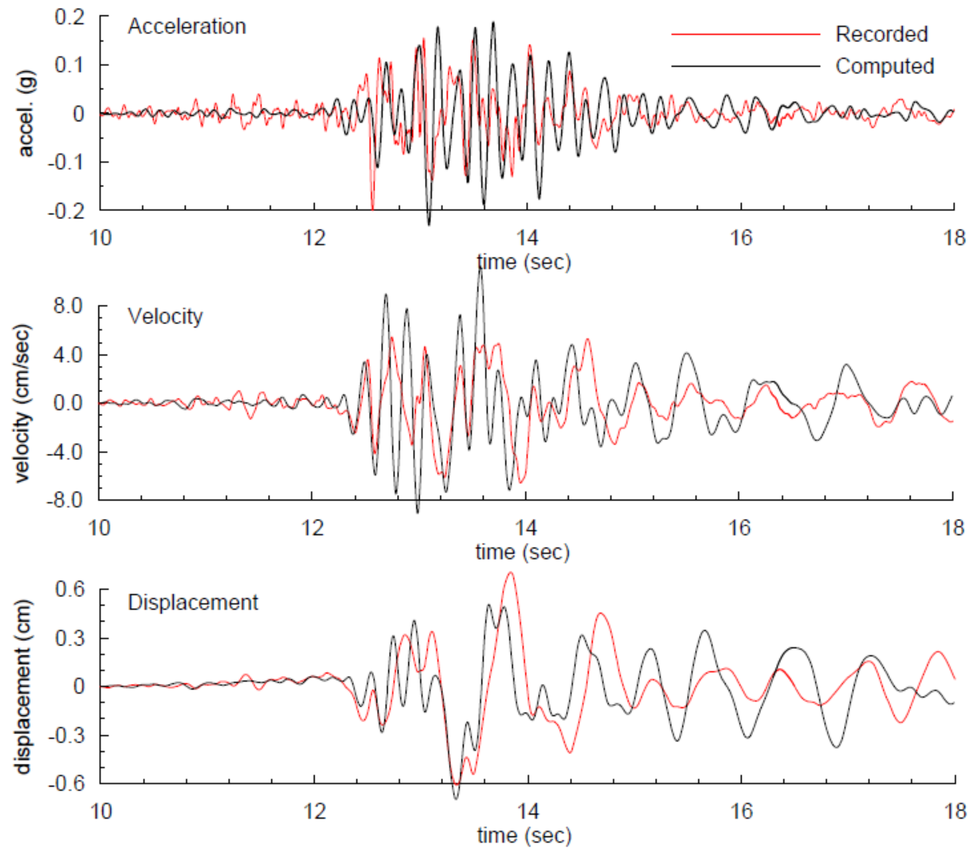
Lelio Mejia and Ethan Dawson, May 2010

Full 3D seismic simulation of a large dam and abutments with FLAC3D. Dynamic results were compared with measurements of motion in the field, for the Yucaipa earthquake.





Example of comparison between recorded motion (red) and computed motion (black), for N-S histories.



The authors note -

"The results of the analyses indicate that available 3-D analysis procedures are capable of simulating the recorded response of the dam during the Yucaipa and Big Bear Lake earthquakes reasonably well. However, the results suggest that considerable uncertainties are associated with the assumed analysis inputs."

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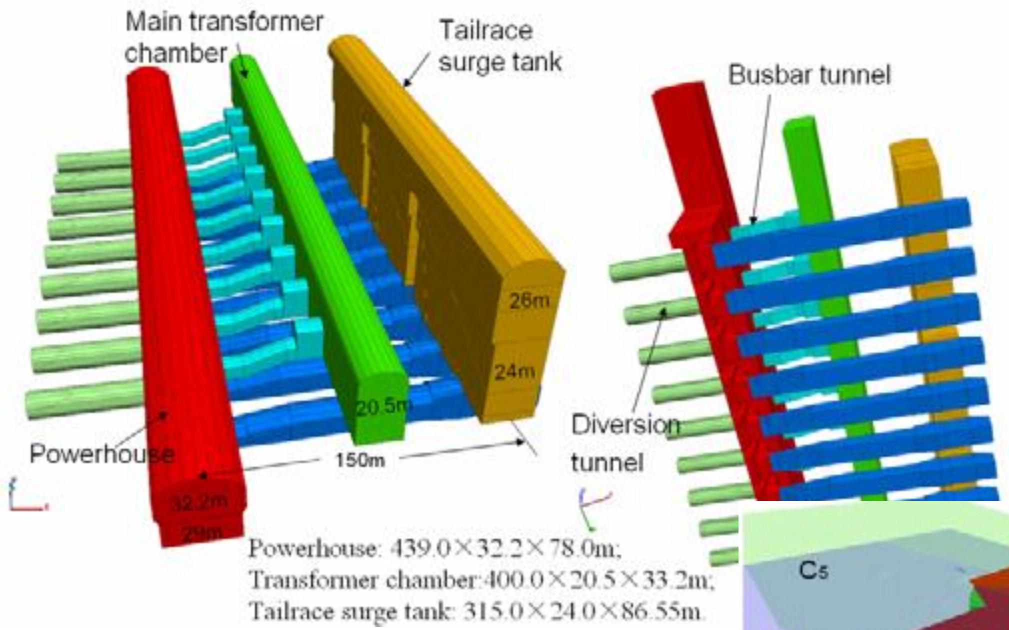
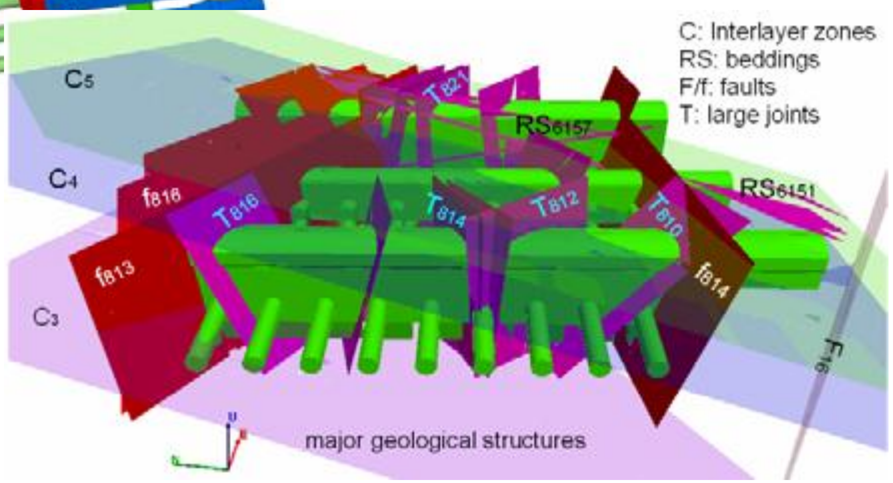
Numerical evaluation of cavern layout design for the Baihetan Hydropower Project in China, 2010 by Jiang, Y.L. and Xu, J.Q. Meng, G. T., Zhu, H.C., and Li, H.

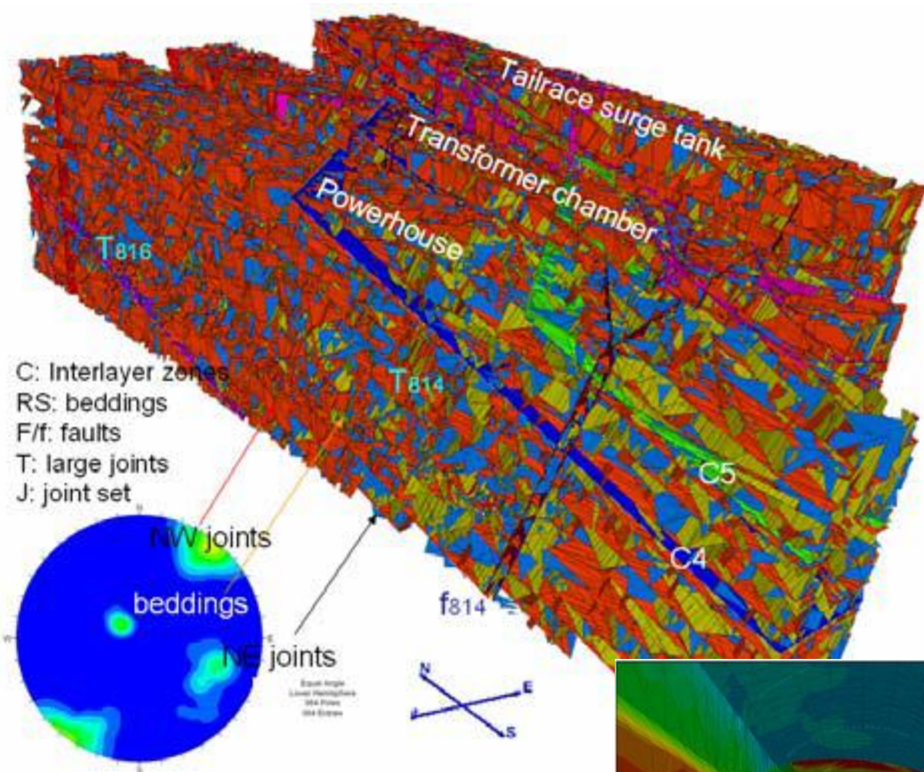


3DEC model of underground powerhouse

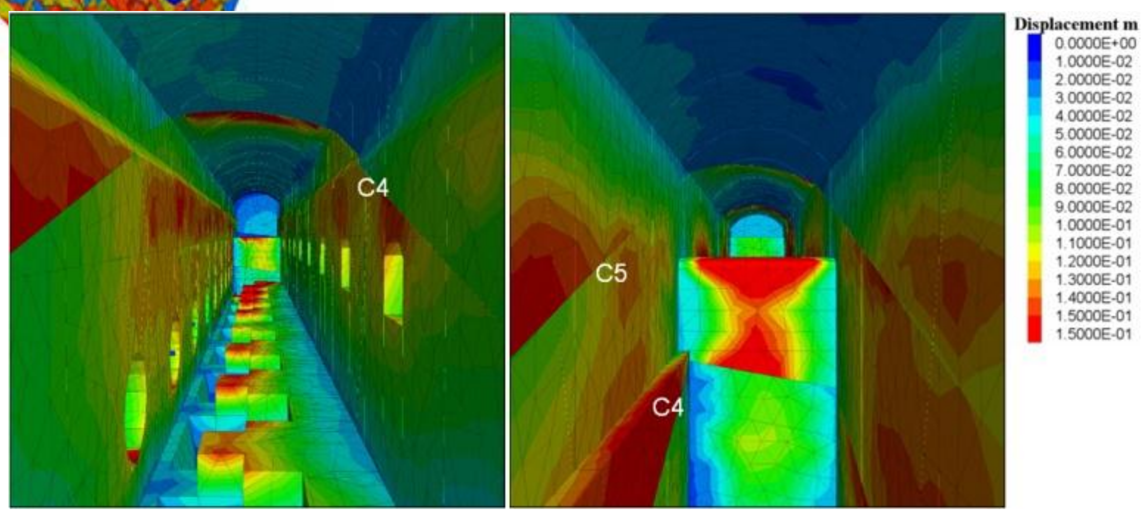
Geological structures in rock mass surrounding cavern in the right bank



Blocks formed by major structures and joint sets in *3DEC* model



Displacement contours in rock mass surrounding opening – *3DEC* simulation



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Innovative integration of modeling and field measurements …

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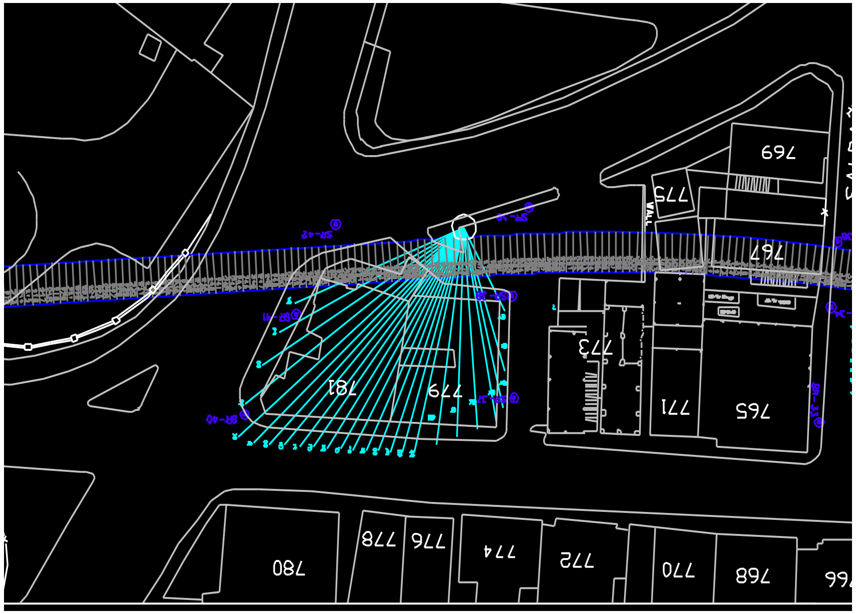
Real-time modeling of tunneling and compensation grouting at Rio Piedras, San Juan, Puerto Rico

by G. Buchet and A. Van Cotthem, 2001

– 8-storey building in Puerto Rico to be protected

– double track EPBM tunnel for rail line :



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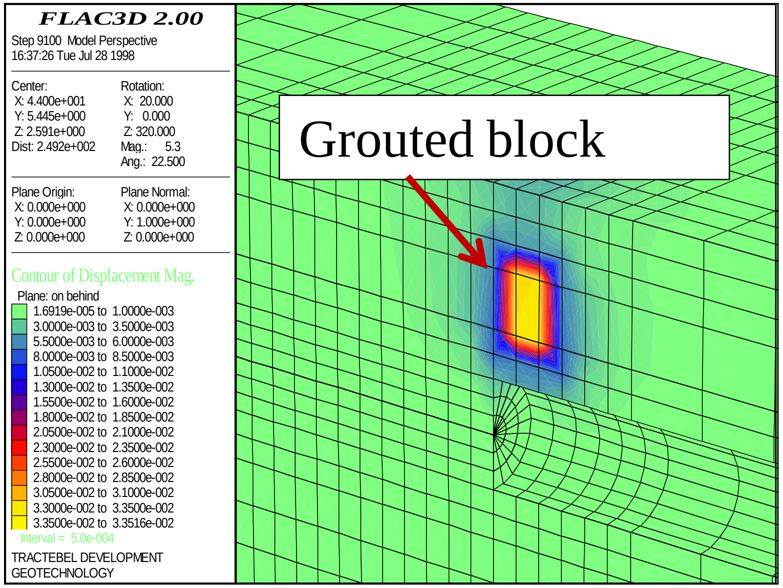
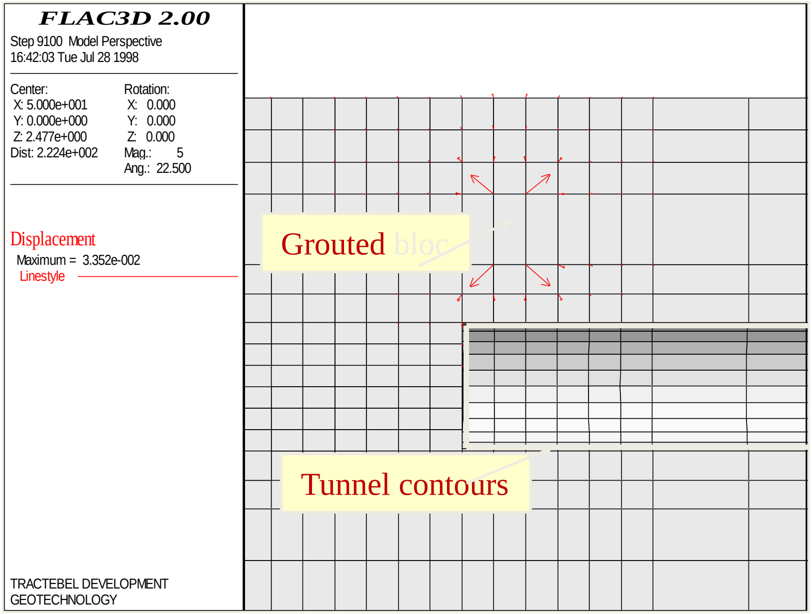
A *FLAC3D* model was used, in which grout injection was simulated by adding strain components to selected material regions. The moving tunnel face was represented by a technique of shifting state variables rather than re-gridding.





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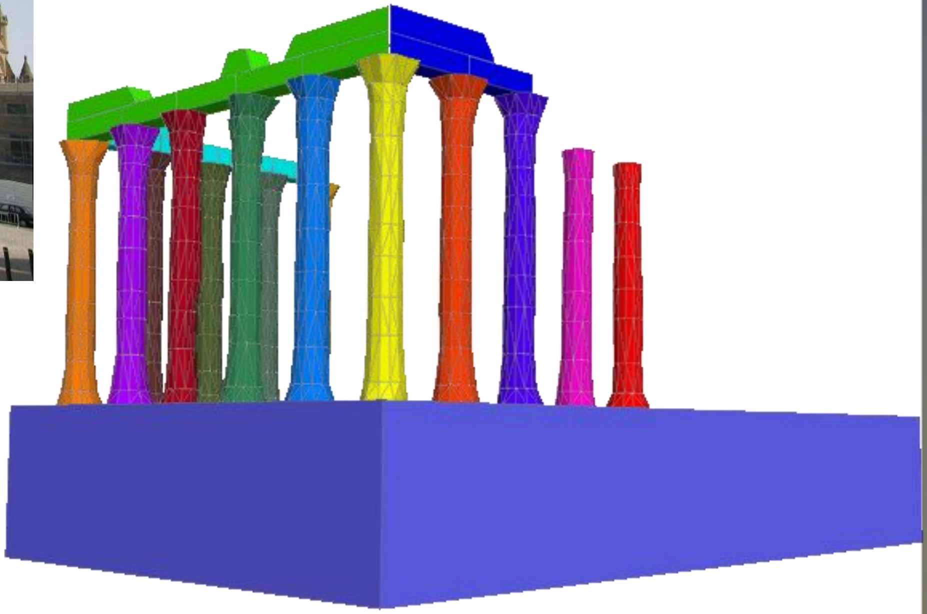
- Real-time modeling as construction proceeds
- 2 alternating teams working ..
  - on site (Puerto Rico) : site monitoring and compensation grouting control
  - home office (Europe) : numerical analyses and technical support
- Daily process: (use of Internet communications)

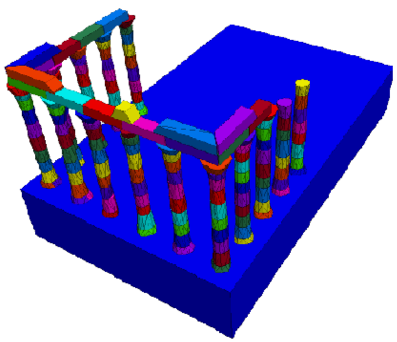
DAY	PUERTO RICO	EUROPE	ACTION
N-1	End of the day	Night	PR sends data on settlement, grouting, excavation progress + assumption for excavation progress day N
N	1 :00	7 :00	EU receives data from PR
N	1 :00-7 :00	7 :00-13 :00	EU : numerical analyses and results processing
N	7 :00	13 :00	EU sends to PR settlement profile computed by FLAC + the grouting program as prediction for the day
N	8 :00-20 :00		PR : grouting works
N	End of the day	Night	PR sends data on settlement, grouting, excavation progress + assumption for excavation progress day N+1

Unusual applications …

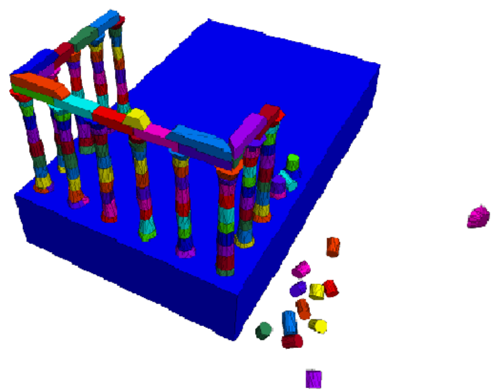
Roman temple, Évora, Portugal
Seismic analyis with 3DEC model (Nayeri 2012 and Jose Lemos)



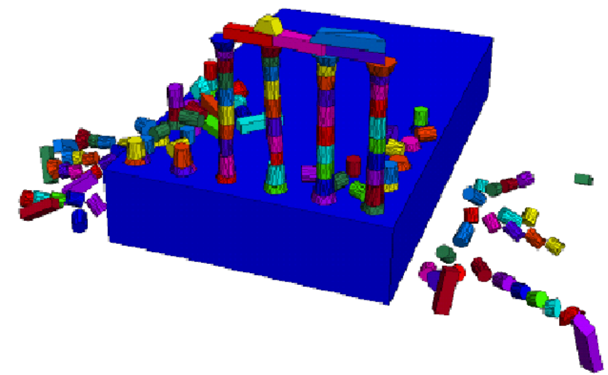
Collapse under various earthquake motions



Static run

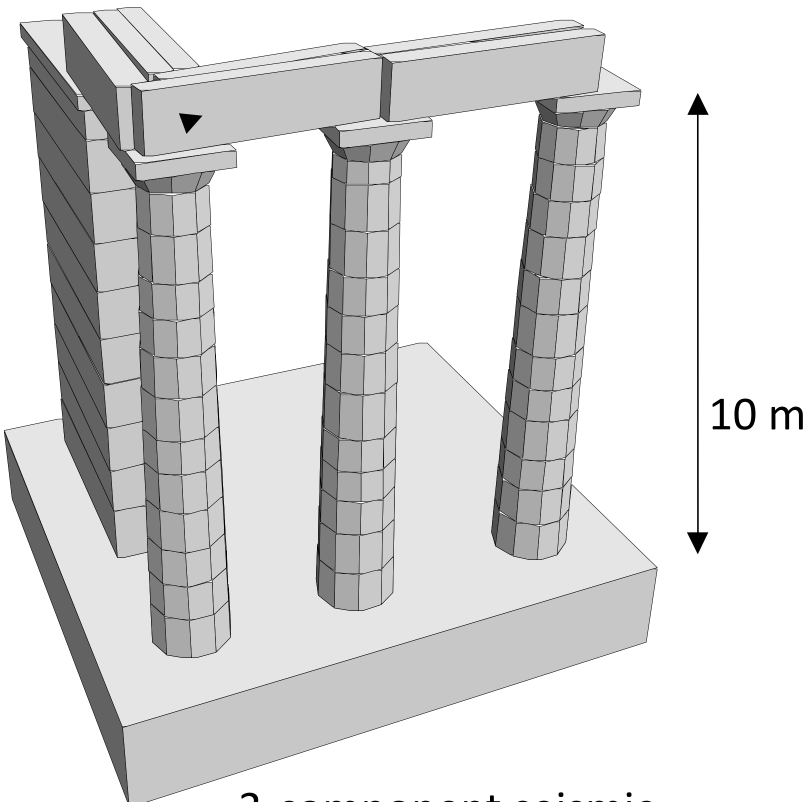


Near-field earthquake in longitudinal direction: PGA = 0.4 g

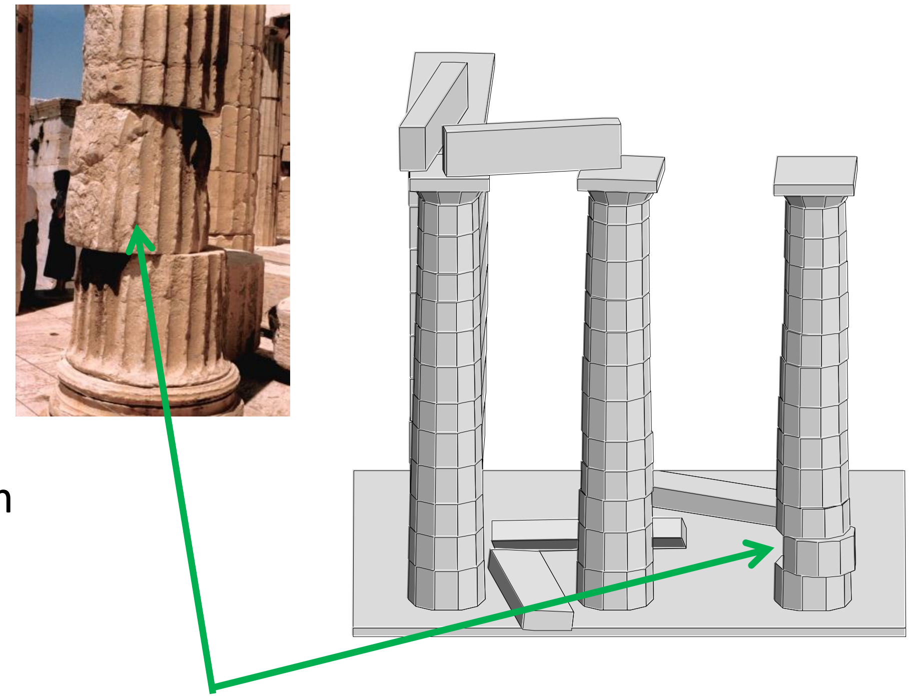


Far-field earthquake in transverse direction: PGA = 0.44 g

3DEC Rigid block model: seismic analysis of the Parthenon Pronaos (Psycharis et al 2003, and Jose Lemos)



3-component seismic input applied at base



The puzzling observation of displaced blocks is explained by large rocking motions in opposite directions

(Psycharis et al. 2003)

Fundamental science …

Martin Schöpfer (Department for Geodynamics and Sedimentology, University of Vienna) has done much innovative work on understanding geological mechanisms. One example is illustrated here …

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Fundamental mechanisms have been revealed by this study that were unknown before.

Moving from geological time to microseconds …

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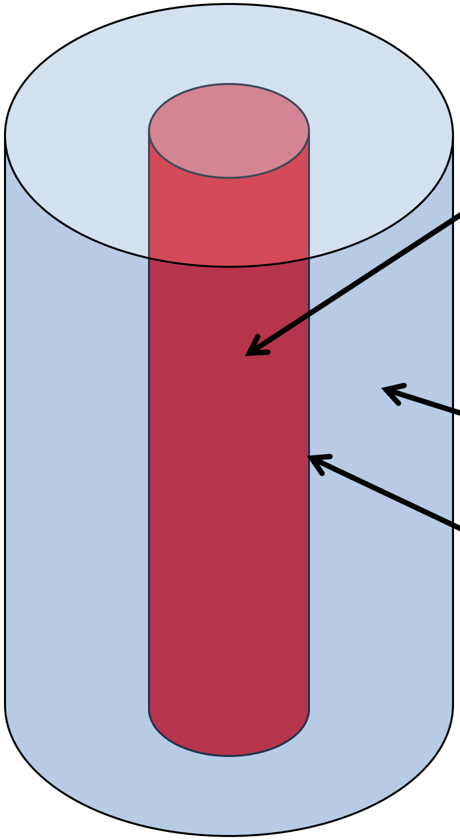
Modeling shock and detonation waves with *FLAC*, Cundall and Detournay, 2008



Explosive (ideal equation of state)

$$V_{\text{IDEAL}} = 4796\, m/s$$

Rock (elastoplastic)

Frictionless interface

Detonation is initiated at the bottom of the explosive column, using an axisymmetric *FLAC* grid in large-strain mode

The following equation of state is used, with energy *Q* released by the explosive:

$$e = \frac{p}{(\gamma - 1)\rho} - Q\lambda$$

Release (burn) rate is a function of pressure and burn fraction, λ:

$$\frac{d\lambda}{dt} = \frac{1}{\tau}\left(\frac{p}{p_{\mathrm{ref}}}\right)^{1.5}(1-\lambda)$$

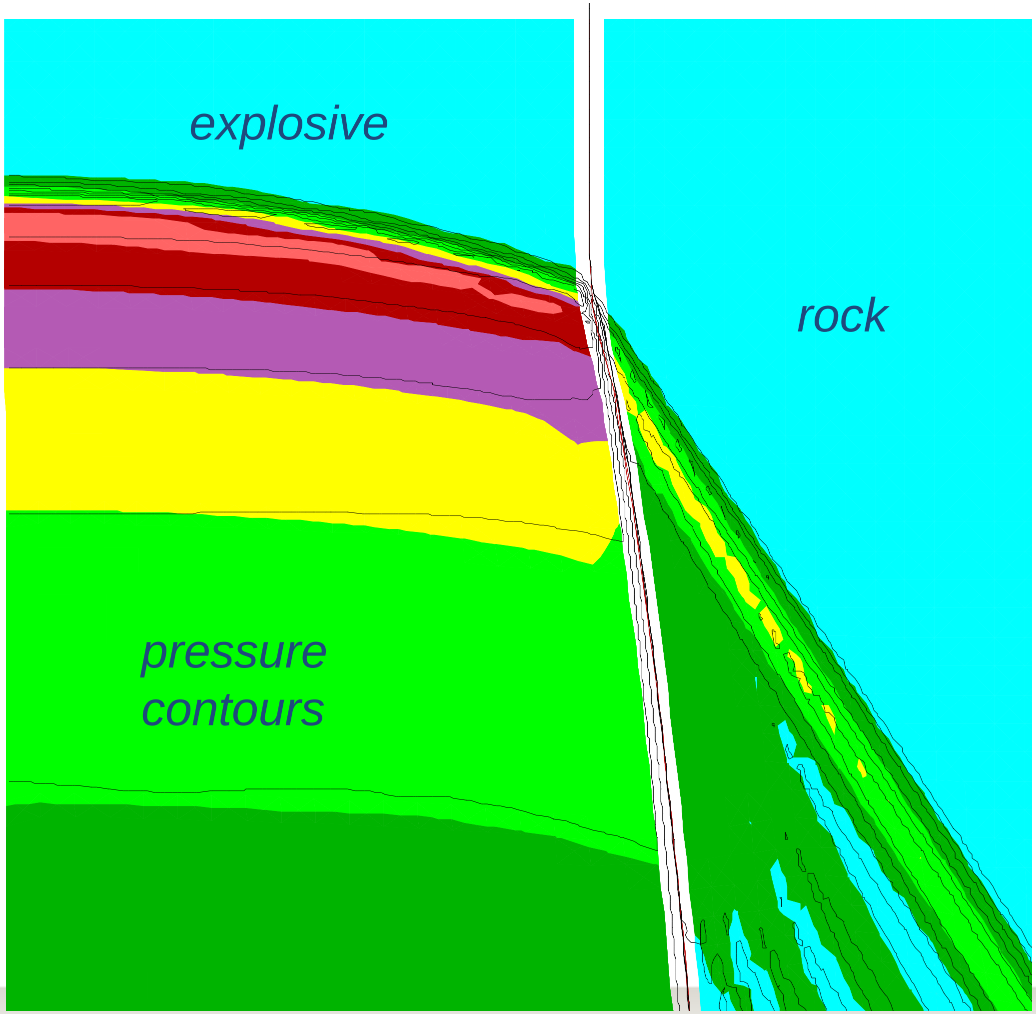
Note that peak pressures are in the order of **10 GPa**, and shock-front rise-times are fractions of a microsecond.

The equations are coded in *FLAC* (using *FISH)*, and the burn is initiated by injection of pressure at the base of the borehole. A snapshot of the shock wave is shown …

This case is "non-ideal" in two aspects: (a) the confinement is not rigid, so the shock front becomes curved, and (b) the energy release is spread out over a finite region.

Snapshot at a time of 0.2 ms, showing contours of pressure and the deformed shape of the interface (not magnified).

The color contours are for a zone size of 2.5 mm, while the black contour lines are for a zone size of 1.25 mm. (The initial explosive radius is 50 mm)



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Hydro-mechanical coupling …

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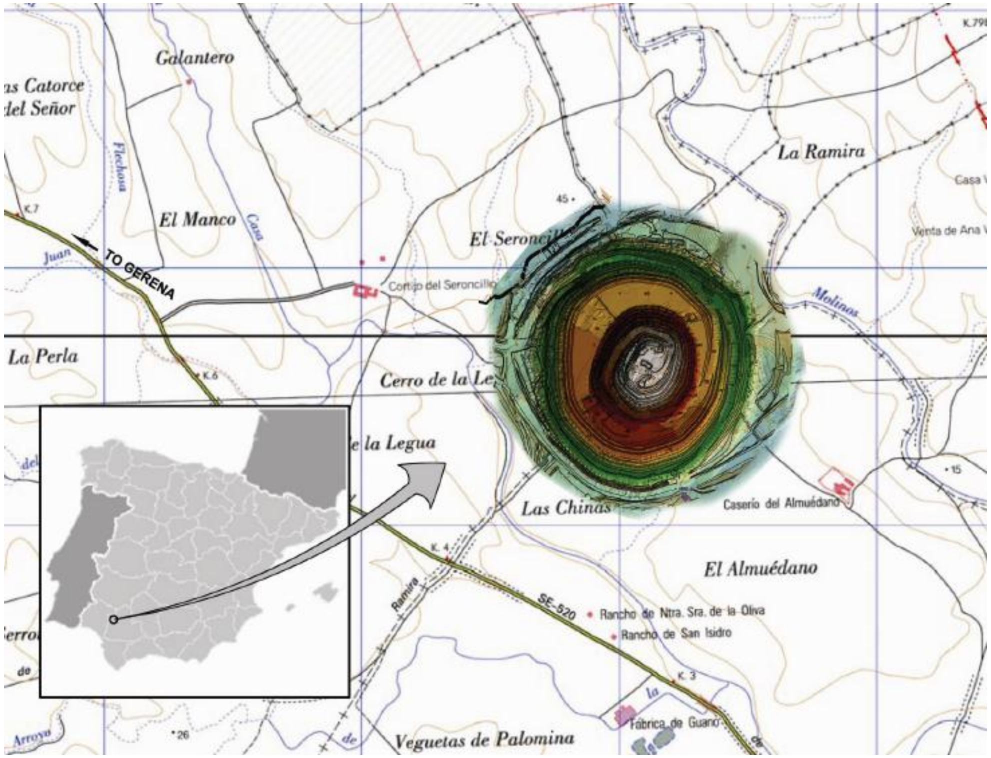
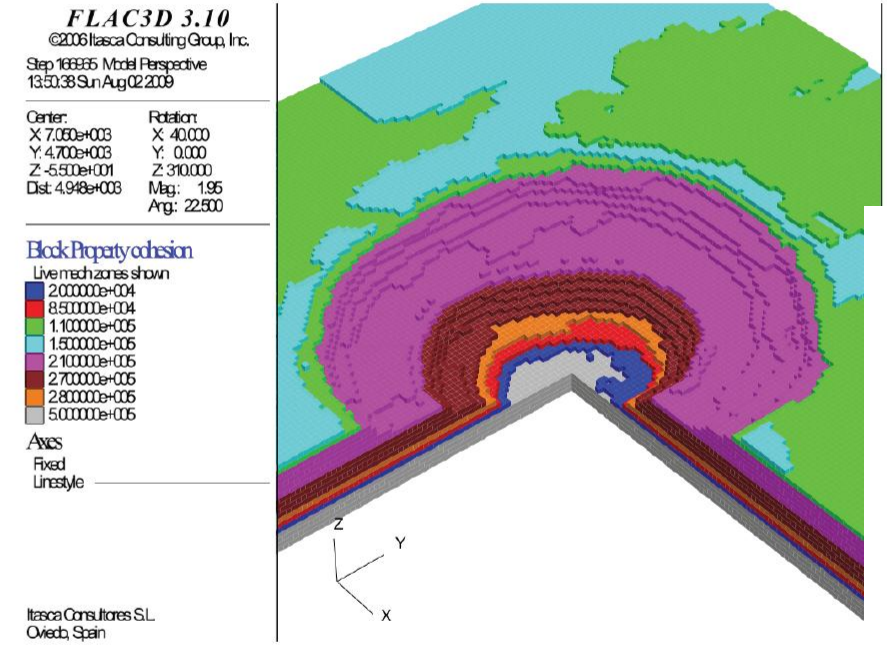
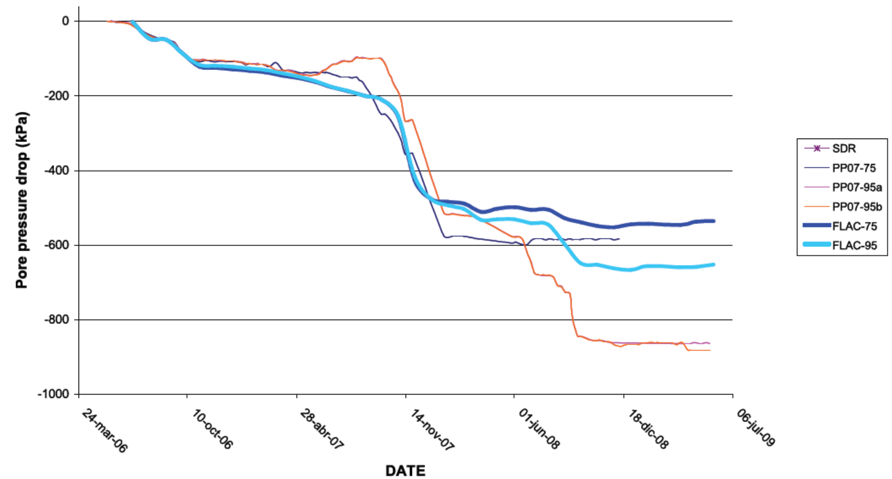
Coupled hydromechanical analysis of Cobre Las Cruces open pit
J.M. Galera, J. Montero, C. Perez, L. Vega and P. Varona, 2009



Plan view of open pit in southern Spain



Sector of 3D model and pore pressure response – measured and predicted



As the authors' say -

"A coupled hydromechanic analysis predicts a significant pore pressure drop due to the volumetric expansion associated with the excavation of the pit. This lower pore pressure distribution allows for a more aggressive and economical slope design."

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Thousands more example could be shown, but not today!

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A note about access and documentation

While not strictly “open-source,” Itasca codes allow the user a high degree of access to the internal workings:

1. All equations and algorithms are fully documented
2. There is access to almost all internal variables via the *FISH* embedded language.
3. The source code of **all** constitutive models is available to users (arguably the most important code components).
4. Users may write their own constitutive models, and may modify, or add to, most of the built-in algorithms.
5. There is a large repository of worked examples and validations.

The future

There is a vigorous program of updating **existing** codes, but there are several new developments coming up:

1. *PFC 5.0*, which is a completely new code that is capable of embodying the features of **all** the other codes.

1. The “lattice” codes – *BloUp*, *Slope Model* and *HF*.

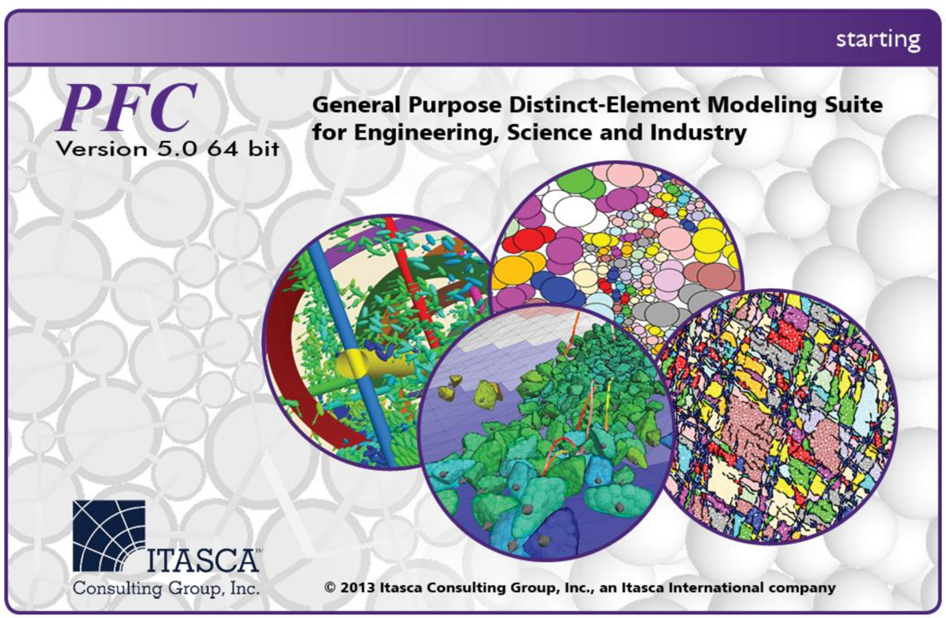
These will be discussed briefly

Note also that other Itasca codes – *KUBRIX*, *MINEDW* and *REBOP*– are not discussed here.

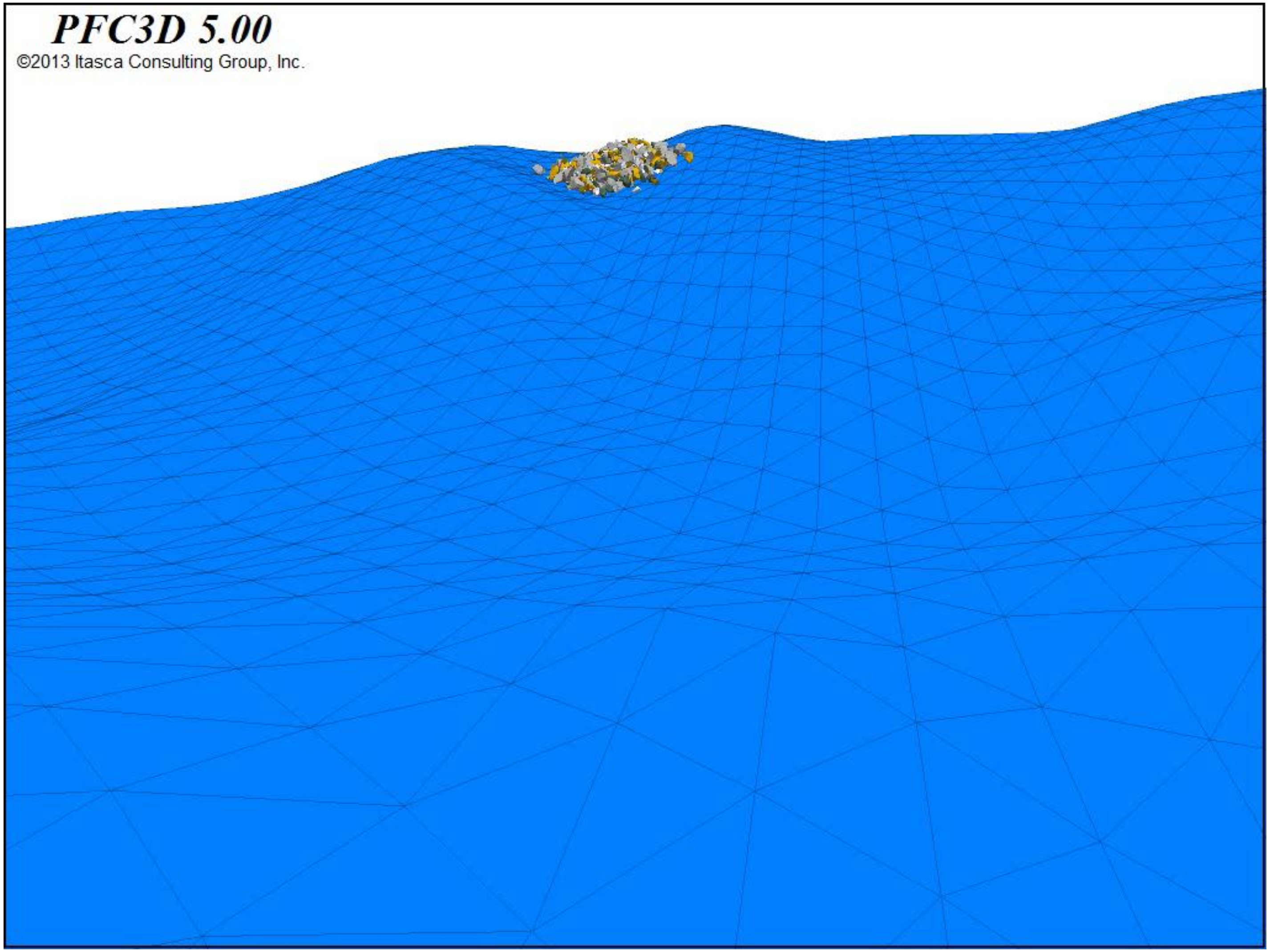
PFC 5.0

This is a new code that is structured in a ***completely different*** way from previous *PFC* versions. It is ***modular***, and will thus allow disparate objects and fields to interact, such as

continuum regions;
clumps; **b**alls;
angular blocks;
structural elements;
lattice regions;
analytically-defined objects;
user-specified objects;
fluid, **m**agnetic and **t**hermal fields; etc



An example of a *PFC 5.0* simulation – angular rocks on rough terrain



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PFC 5.0 takes advantage of multi-core machines, so the code runs much faster on current and planned machines.

The “interaction distance” may be specified, so that long-range interactions (such as molecular potentials) may be modeled.

Adaptive cell-space logic is used, so that proximity between disparate objects is detected very rapidly.

Note *PFC 5.0* is the first modular code; it is planned that all other calculation entities in existing codes will be modules that can be assembled into a fully-interacting code.

Lattice codes

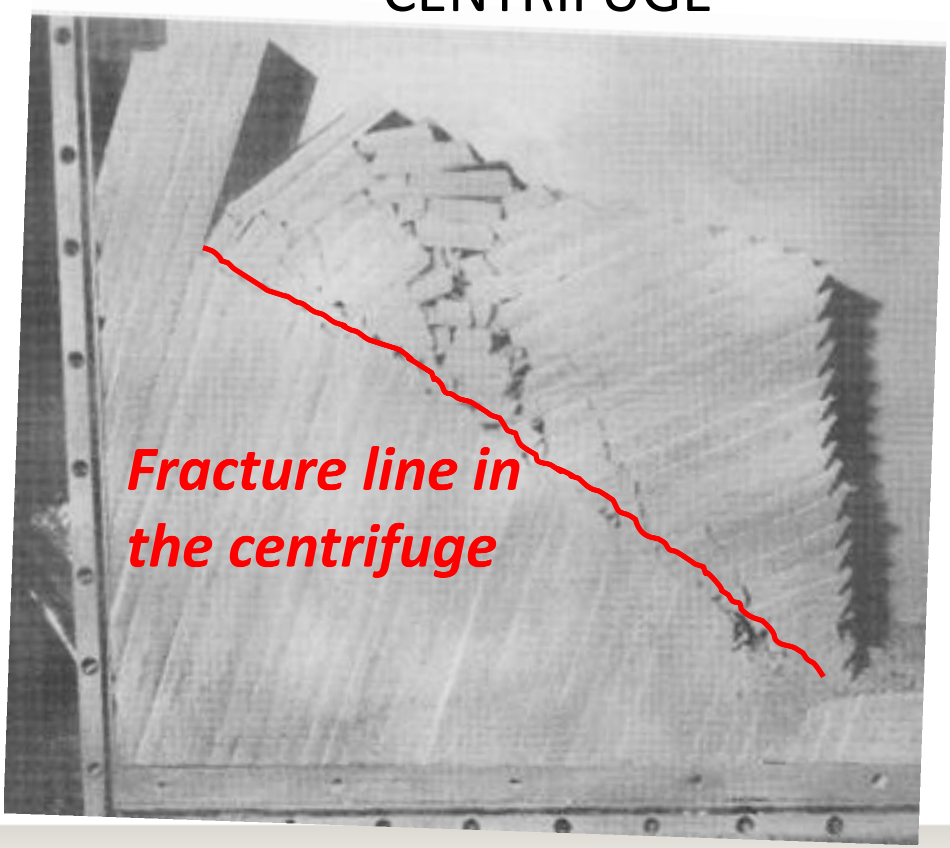
If we replace discrete particles with point masses and particle interactions with springs, we derive a much more efficient scheme for some applications. Springs may break, corresponding to micro-cracks in a brittle rock mass.

There are currently three codes that use the lattice formulation:

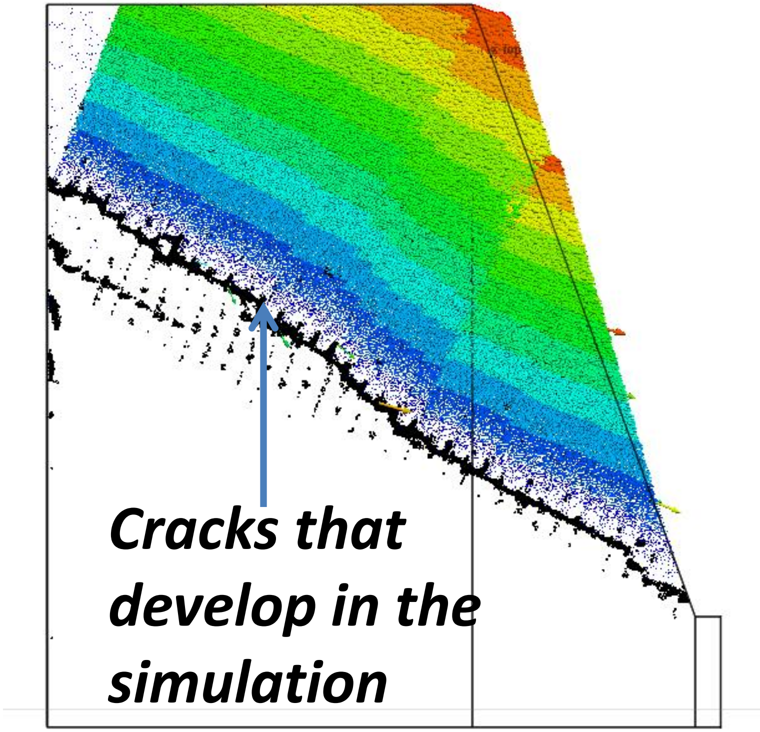
1. *Slope Model*: a quasi-static model with fluid coupling for brittle rock slopes;
2. *BloUp*: a model for the complete simulation of explosive rock breakage and muck-pile formation;
3. *HF*: a model for hydrofracturing from injection of fluid into a jointed rock mass.

Example of a *Slope Model* validation – flexural toppling in a centrifuge model (*Adhikary et al, 1997).* The model has joints dipping into the slope face. In order to fail, a line of cracks must develop.

CENTRIFUGE



SIMULATION



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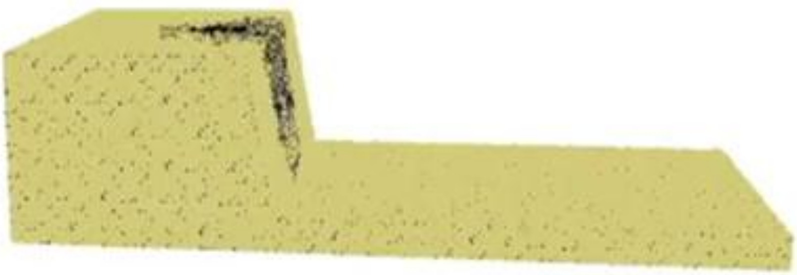
Example of bench blast simulated with lattice code *BloUp*



Conclusion: **Itasca software is already used extensively by the international community, and the future for the software is evolving rapidly, given the commitment to development, and the imagination of users.**

Thank you!

谢谢！

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