Applied Numerical Modeling in Geomechanics – 2020 – Billaux, Hazzard, Nelson & Schöpfer (eds.) Paper: 18-01

Future plans for Itasca software

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1 INTRODUCTION

UDEC Version 1.0 was released in February of 1983. Over the last 35 years, the Itasca geomechanics codes have evolved and grown coinciding with the explosion in personal computer power. The evolution includes the addition of graphical user interfaces, new continuum and discontinuum programs, multi-threaded computations and the mainstream acceptance of 3D modeling in geomechanics consulting. Recent advances in computer architecture, easy access to massive processing power (cloud computing) and new numerical modeling techniques mean that the software is continuing to adapt and change to meet the modern day demands of consultants and researchers. This paper describes some of these recent developments and future plans.

2 THE NEAR FUTURE

2.1 *Common Framework*

Most of the Itasca programs have evolved somewhat independently over the last 30 years. This has resulted in programs with similar functionality but different look and feel – and sometimes different commands and *FISH* to do the same things (*FLAC* and *FLAC3D* are a good example of this). One priority for Itasca is therefore to bring all codes together into one coherent framework. This will not only make life easier for our users when using multiple programs, but it will also make development more efficient.

With Version 7 of *FLAC3D*, *PFC* and *3DEC*, all components may coexist in the same program. It is possible to create, manipulate and visualize balls, blocks, zones and structural elements in the same model (see Fig. 1). In addition, documentation for all programs is included in one package of HTML pages, with command/*FISH* help more tightly integrated with the graphical user interface.

The ability to load all the components into a single model also enables easy coupling between components. It is already possible to couple *PFC* balls, clumps and rigid blocks to *FLAC3D* zones or structural elements. Currently under development is coupling between *3DEC* blocks and *FLAC3D* structural elements, and eventually coupling between *3DEC* flow planes and *FLAC3D* zones and/or *PFC* balls.

Bringing the codes together under the common framework also means consistency between 2D and 3D. A 2D version of *FLAC3D* is currently under development that will work equivalently to *FLAC3D* – including the ability to create and solve unstructured meshes (Fig. 2), and also to couple with *PFC2D* (Fig. 3). Similarly, *UDEC* now uses the same GUI as the other programs and has the same command and *FISH* structure as the forthcoming *3DEC* release (*3DEC* 7).

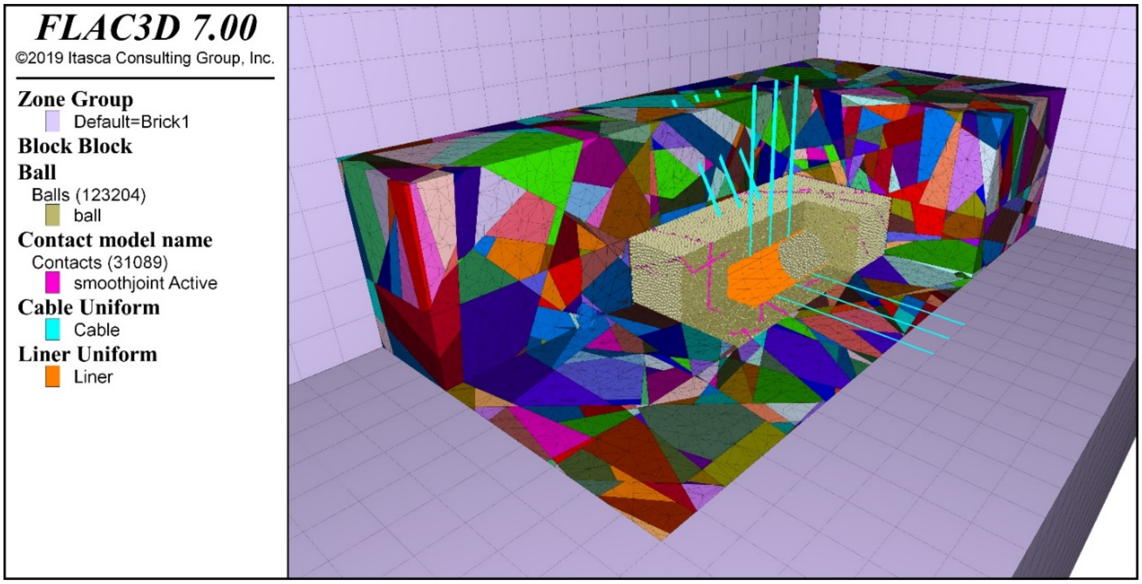

Figure 1. Model showing *FLAC3D* zones, *3DEC* blocks and *PFC* balls as part of the same model. A discrete fracture network is used to cut the blocks and set up smooth joint contacts in the *PFC* model. Cables and liners are also shown.

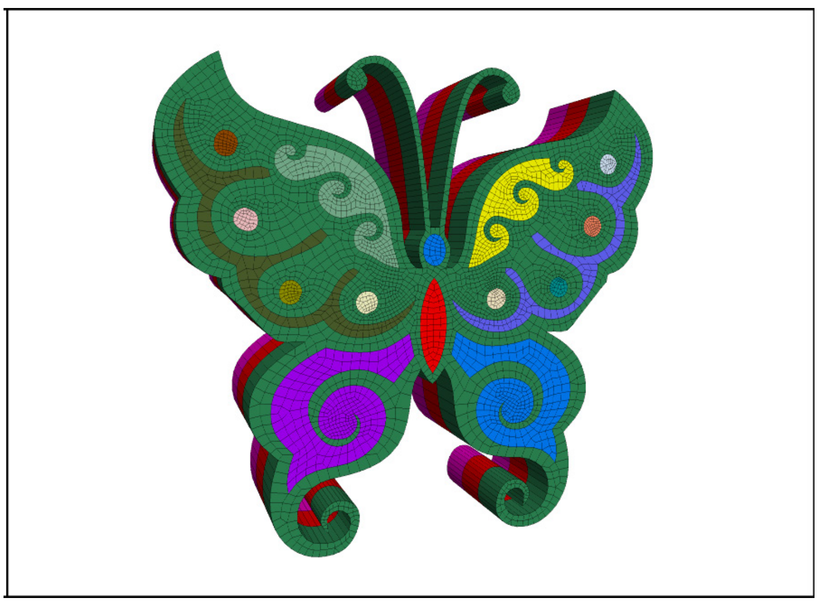

Figure 2. Unstructured *2D* mesh extruded to create a 3D model.

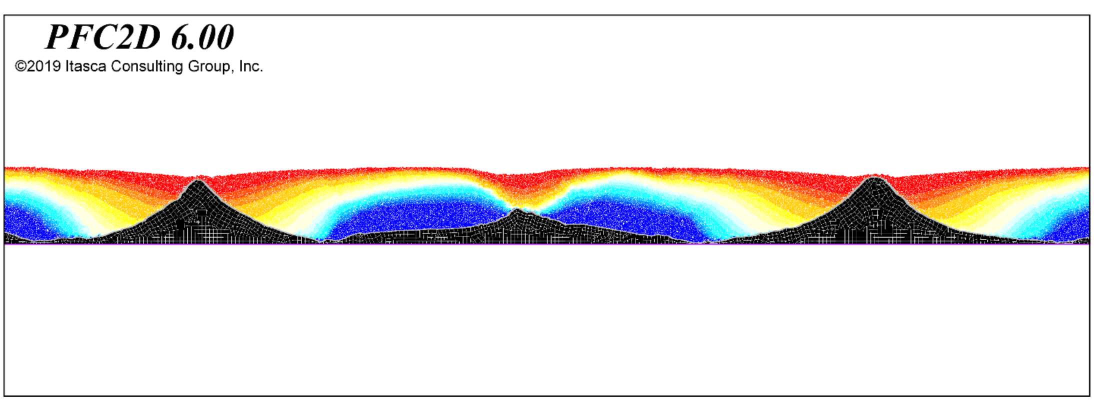

Figure 3. *FLAC2D* zones (black) coupled with *PFC* balls (contoured) simulating horizontal extension of a 20 × 1 km rock layer. Figure courtesy of Martin Schöpfer.

2.2 *Speed*

By far the most requested improvement for Itasca 3D programs is shorter run times. Changes made to *FLAC3D* 7 sped up some models by a factor of 2 compared with *FLAC3D* 6. Recent multithreading of *FISH* has also improved *FISH* intensive model runtimes, in some cases by a factor of 10. However, what users really want is 10 to 100 times shorter run times for all models. This type of performance would enable:

- Running of much larger models that include more detail and/or larger volumes
- Turning around model results more quickly to help with prediction and design
- Probabilistic analysis as an alternative to factor of safety calculations
- Parameter studies and Monte-Carlo simulations – even for large 3D models.

To achieve this type of performance improvement, significant changes in algorithms and/or architecture are required. On the algorithmic side, a new, robust implicit solver has recently been implemented for thermal calculations (see Pyatigorets, this proceedings). Depending on the model, speedups of 1000x can be achieved compared to the existing methods. The same logic will be extended to fluid calculations. Another example is the addition of rigid polyhedral blocks and *FLAC3D* coupling, allowing one to model similar *3DEC* bonded-block models 2.5-3.5 times faster (see Purvance, this proceedings).

What about architectural improvements? All Itasca programs are already multi-threaded, meaning that the code will use all processors on a single CPU, however there are limitations to how many processors can exist on a single CPU and how fast data transfer can occur. Graphical Processing Units (GPUs) potentially offer improved processing speed but the interactive nature of Itasca Software makes it difficult to take advantage of this power. Given these concerns, and the rapid rise of cloud computing capabilities, it has been decided to parallelize the 3D codes for use on massive, distributed memory computer clusters.

With distributed memory clusters, there is theoretically no limit to the size of computer that can be used (at the time of writing, the world's largest supercomputer at the Oak Ridge National Lab has over 2 million cores). Most engineers do not have access to this kind of hardware, but with cloud computing services (e.g. Amazon Web Services or Microsoft Azure Service) it is conceivable that 50 or even 100 cores could be used for large models. Because of communication overhead, 10 cores will not run 10x faster than 1 core, however initial testing has shown efficiencies of 70% may be achievable, meaning a 7x speedup for 10 cores with preliminary MPI versions of *FLAC3D* and *PFC*. This equates to turning a one-week simulation into a one-day job, and could especially impact the use of DEM for large-scale modeling efforts. Itasca is also developing an easy-to-use web portal for AWS that will enable users to easily spin up virtual machines with Itasca software pre-loaded.

Another initiative related to this is the porting of Itasca programs to the Linux operating system. All 3D programs use Qt libraries for the GUI interface (https://www.qt.io/). This means that the programs are not tied to a specific operating system and creating a Linux version is possible. Work has already started on this. Since most distributed memory clusters use Linux, and Linux cloud resources are substantially less expensive, this will be very desirable when the MPI capabilities are available.

2.3 *Mining Module*

The numerical modeling of caving operations is particularly challenging due to the very large-strains involved, fragmentation, mixing, changing rock mass properties and other complexities. Discrete element models (e.g. *PFC* or *3DEC*) could potentially capture the mechanics of the problem, but to perform a mine-scale simulation with these programs is computationally prohibitive. Pierce (2010) describes a cave-scale simulator (REBOP) based on behavior observed in *PFC3D* and models. The method encodes behavior laws derived based on flow patterns observed in *PFC3D* and *FLAC* simulations. In this way the important physics are captured but a full discrete element model does not need to be executed.

The method described in Pierce (2010) is currently being incorporated as a module within *FLAC3D*. In this way it will be possible to easily perform simulations of caving coupled to the outlying continuum, which will be modeled by *FLAC3D* zones (Fig. 4).

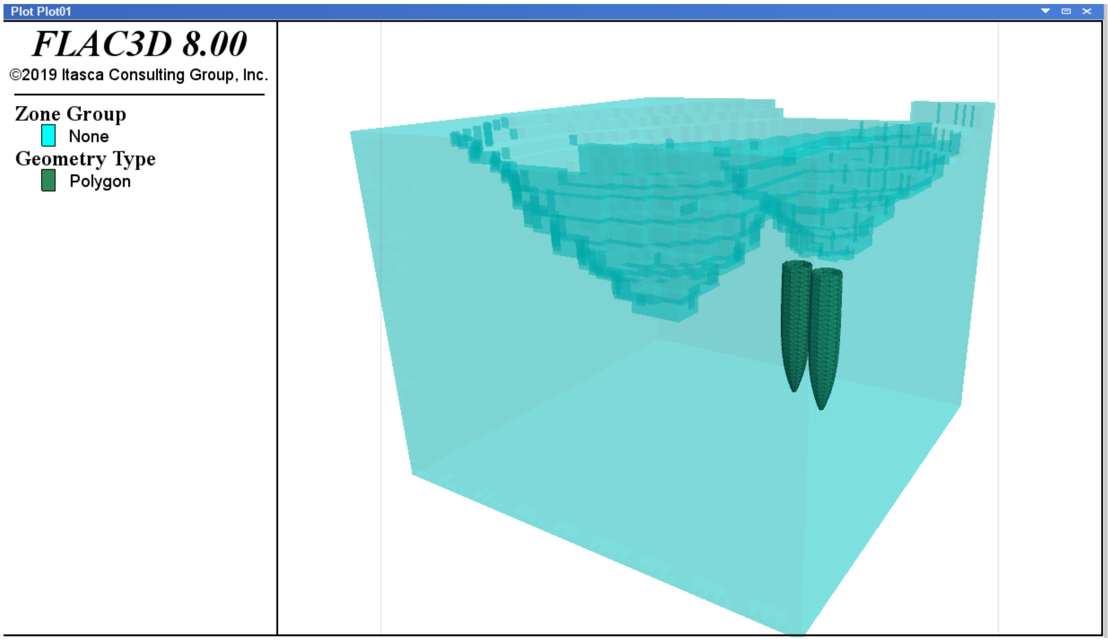

Figure 4. Caving model showing Isolated Movement Zones developing from two drawpoints under an open pit.

In some cases, it is sufficient to model cave mining with a continuum – as long as the correct mechanics are being approximated. The simulation needs to consider the progressive failure and disintegration of the rock mass from an intact/jointed to a caved material and draw-induced bulking and associated modulus softening. Itasca Constitutive Model for Advanced Strain Softening (IMASS) constitutive model has been developed to represent the rock-mass response to stress changes (i.e., rock-mass yield, modulus softening, density adjustment, dilation, dilation shutoff, scaling of properties to zone size, cohesion weakening, tension weakening, and frictional strengthening). This constitutive model was developed using strain-softening material models, with strain-dependent properties adjusted to reflect the impacts of dilation and bulking as a result of induced stress changes. The model has already been successfully applied to several mining projects.

The current plan is to incorporate these new technologies, and possibly other useful algorithms into a special mining module for use with *FLAC3D*.

2.4 *Meshing*

The second-most requested improvement is to make meshing easier and more robust. Two main avenues are being explored to help reduce the burden of meshing and improve model speed and accuracy:

- Improved tetrahedral elements for more accurate plasticity calculations (and consequently easier meshing)
- Remeshing for models undergoing severe mesh distortion. This is potentially important for liquefaction problems, simulations of slope runout and other large strain problems. We will also be investigating ALE (Arbitrary Lagrangian-Eulerian) adaptive meshing techniques for these types of problems.

2.5 *Other*

Other current and planned developments include:

- Non-linear structural elements (the ability for liners to cracks and fail)
- Simpler and faster fluid calculations for partially saturated material
- Multi-grid or multi-scale explicit static solution algorithm to decrease communication overhead between near and far field
- Stiffness based loose coupling in static mechanical mode – to speed convergence times of models dominated by stiffness differences

- Embedding the Python programming language in Itasca software. Python brings the Itasca software many powerful scientific computing libraries and improves flexibly via interoperation with other software, support for many data formats, and by enabling internet communication.
- Improved logic for interfaces between zones (essentially bringing *3DEC* contact mechanics into *FLAC3D*)
- Improved coupling capabilities between different numerical strategies

3 THE FAR FUTURE

3.1 *New Modeling Methods*

Itasca software currently offers users the ability to simulate a spectrum of behaviors from small-strain, psuedo-static continua to large-strain, dynamic discontinua. The new rigid block capabilities in *PFC* have recently added to the range of possible solutions available. Challenges remain with respect to meshing and calculation times – especially in discontinuum modeling. The lattice approach, in which the rock mass is represented by a network of springs and masses, offers significantly faster runtimes than a true discontinuum model, but still offers the ability to generate complicated geometries and fracture networks without the need to generate a mesh. This technology is currently incorporated into *XSite*, the commercially available program for hydraulic fracture simulation (https://www.itascacg.com/software/XSite). Similar application-specific programs exist for modeling rock slopes and blasting, but these programs are not currently commercially available. The long-term plan is to incorporate the lattice technology into the common framework to enable use for "general purpose" modeling and coupling with other components (zones, blocks, balls, clumps, rigid blocks and walls).

Other "meshless" methods such as the material-point method (Gracia 2018) or Smoothed-Particle Hydrodynamics (Liu & Lui 2003) will also be explored in a continuing effort to efficiently solve difficult problems in geomechanics and other related fields.

3.2 *New Applications*

Itasca programs have been used in a very wide range of applications from modeling shaving of human hair to bruising of apples (Scheffler et al. 2018). However, the target applications are generally civil, mining and petroleum engineering. The potential increase in speed through distributed memory computing, and the easy access to computer resources through the cloud, could potentially revolutionize the way in which Itasca programs are used in these industries. Where currently models are created to examine mechanics of past events or make predictions far into the future, significantly faster computation could produce almost real-time feedback, allowing geo-engineers to observe model results, make modifications and recommendations as engineering works are ongoing.

As a next step, field data such as prisms, inclinometers, strain gauges, smart bolts, radar could feed into the models and the models could intelligently recalibrate themselves to improve the data match and make better predictions. The emerging field of machine learning shows potential promise toward making models smarter faster and more accurate.

4 SUMMARY

Itasca pioneered the use of numerical modeling for solving geomechanics problems in the 80s and 90s. Since then, the field has exploded and engineers have a plethora of possible numerical solutions to choose from; both in 2D and more recently in 3D. Itasca has always tried to differentiate itself by allowing the most flexibility and power – enabling users to solve their most challenging problems. With the addition of Python scripting, multi-threaded *FISH*, and other developments, Itasca continues to be at the forefront of code flexibility. The challenge for 2020 and beyond is to harness new technologies and the power of cloud computing to enable faster, larger, and more complex modeling scenarios, while keeping the modeling workflow and model analysis and interpretation as easy as possible.

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