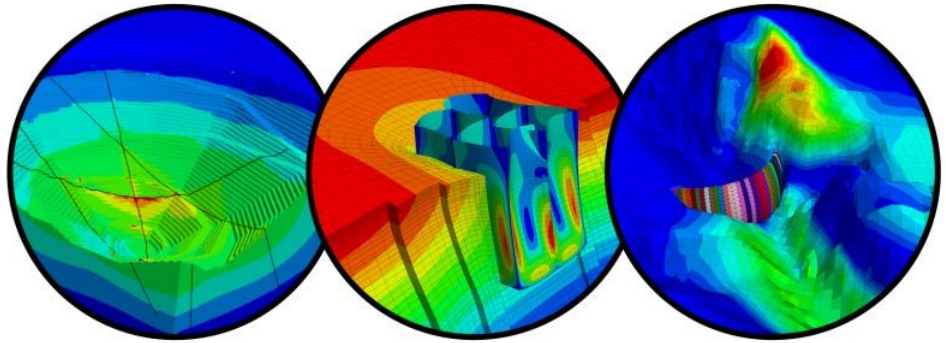
ITASCA™



New Features in *FLAC3D* Version 9

Itasca Consulting Group, Inc.

May 09, 2023

Zhāo Chéng

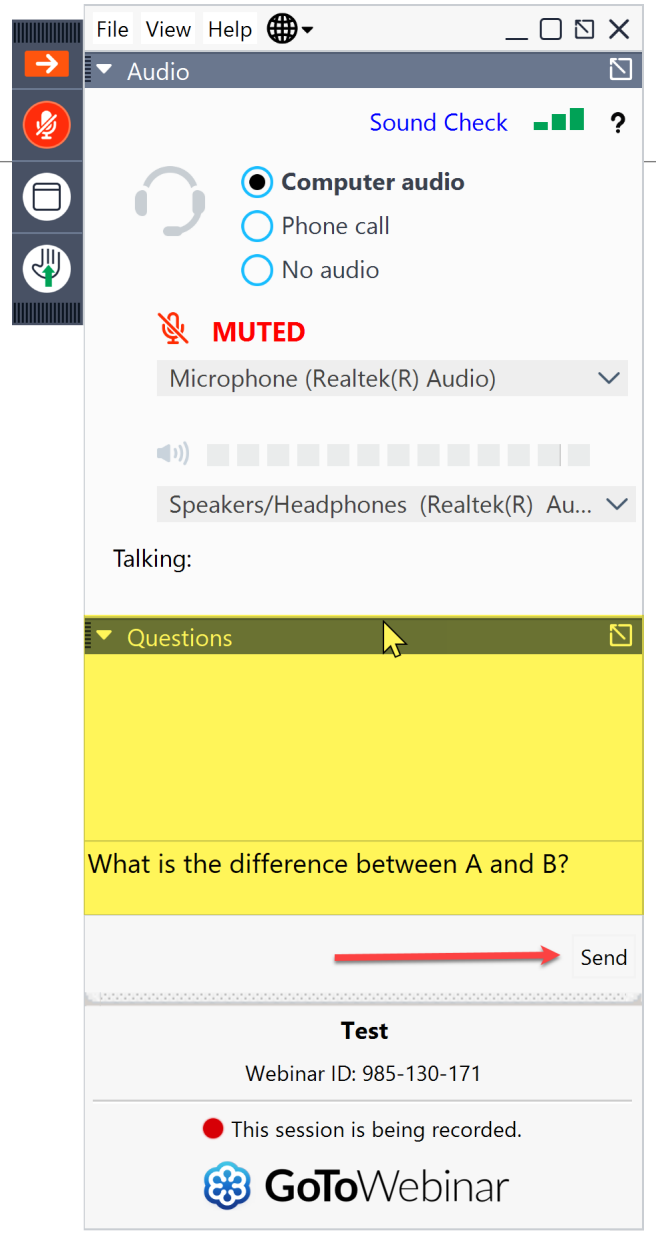
Jim Hazzard

David DeGagné

Questions

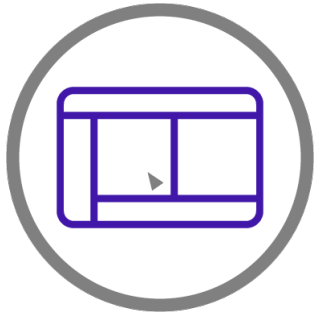
To type your questions, please use **Questions** dialog in the **GoTo**Webinar window.

Questions will be answered at the end of the webinar.

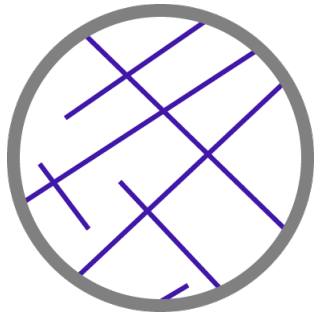


Outline

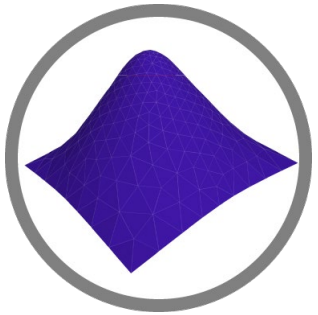
SERIOUSLY FASTER



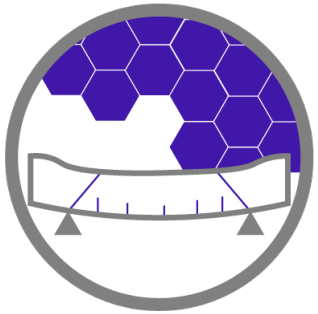
HIGHSPEED DYNAMICS



ZONE JOINTS

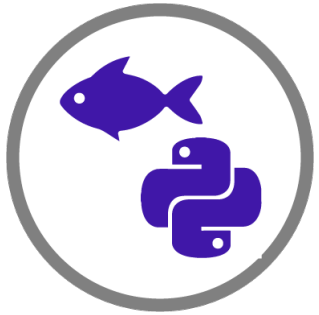


NON-LINEAR STRUCTURES

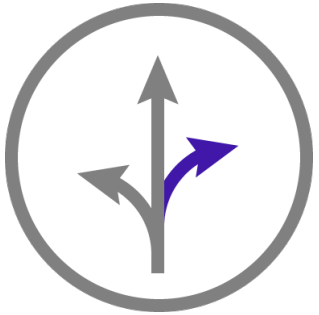


NEW & IMPROVED CONSTITUTIVE MODELS

IMPROVED USER INTERFACE



POWERFUL SCRIPTING

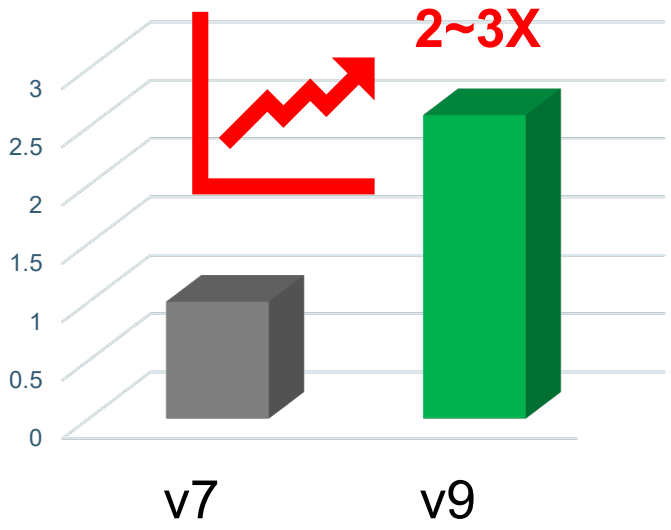


VERY FLEXIBLE

Seriously Faster

- Static and dynamic analyses in general
- Saturated fluid/thermal calculation
- Maxwell damping for dynamic analysis
- Plotting
- Multi-threaded apply
- Save and restore models
- *FISH* splitting

Faster Performance – In General

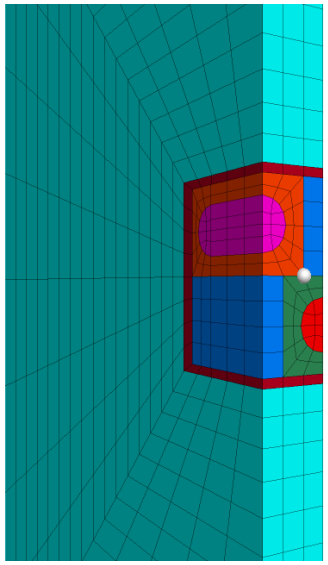


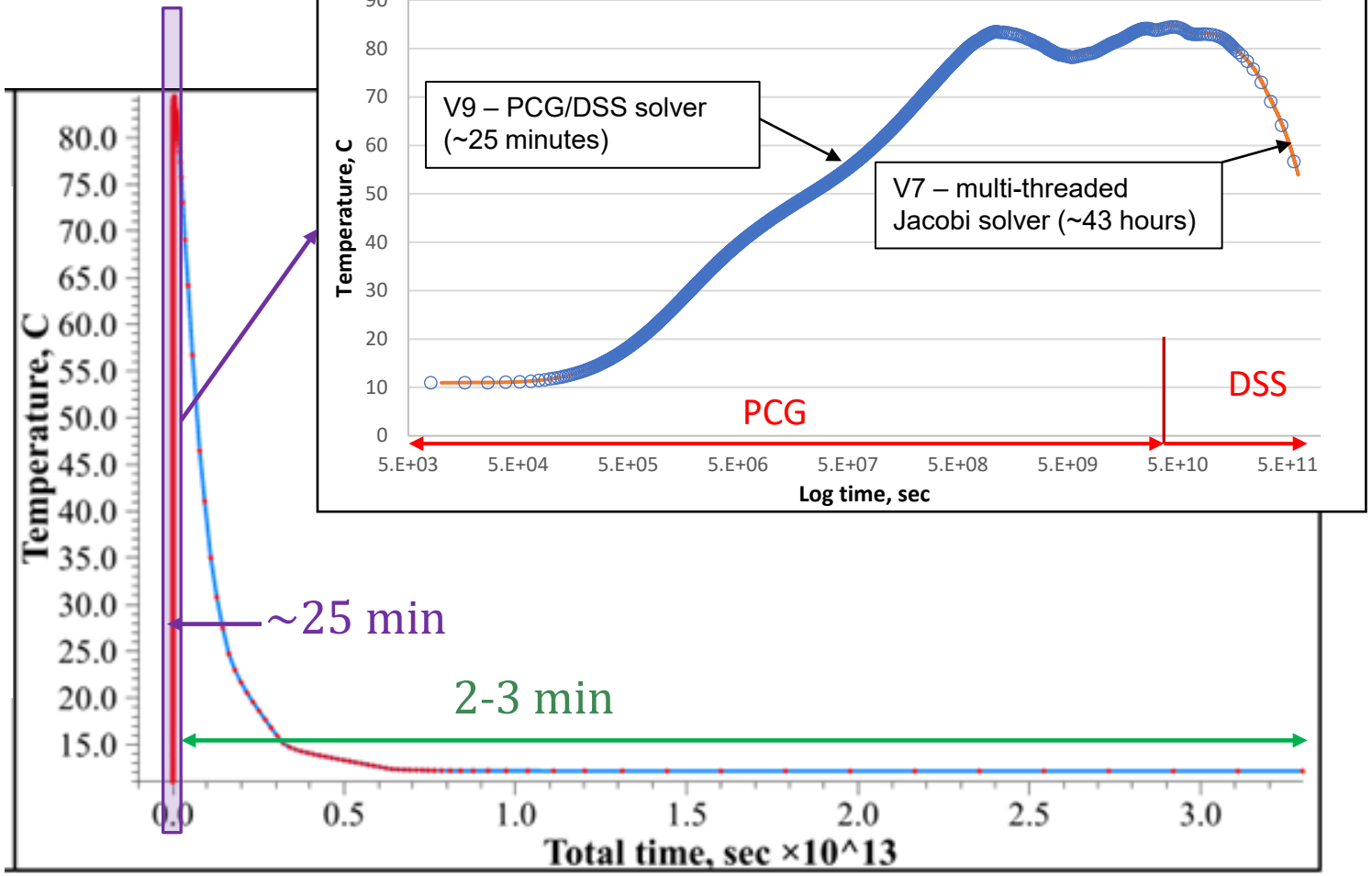
An optimization to zone stiffness stability calculations has been made so that the calculation is faster compared with older versions.

- This results in zones converging to a ***static*** solution in roughly **40%** of the steps required previously, combined with a change in the default damping for static analysis.
- The stable ***dynamic*** timestep is now **2.6** times larger than it was before *for zones* (structural elements and links may be the limiting factor).

Faster Performance – New Implicit Algorithms

Improved implicit saturated-fluid/thermal solver





SERIOUSLY FASTER

Faster Performance – Plotting and Others

Up to 10X

- Zone plotitem generation speed improvements.
- Remove ZGROUP plot item, integrated capability into the main zone plotitem. More than **10x** faster to generate.

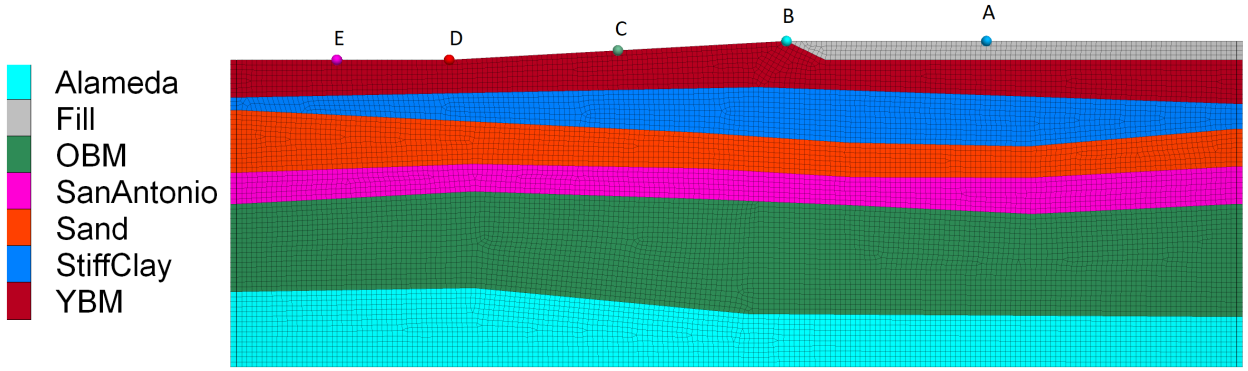
Up to 10X

- Multi-threaded apply.
- Improved algorithm to save/restore models with many slots/groups.
- *FISH* splitting.

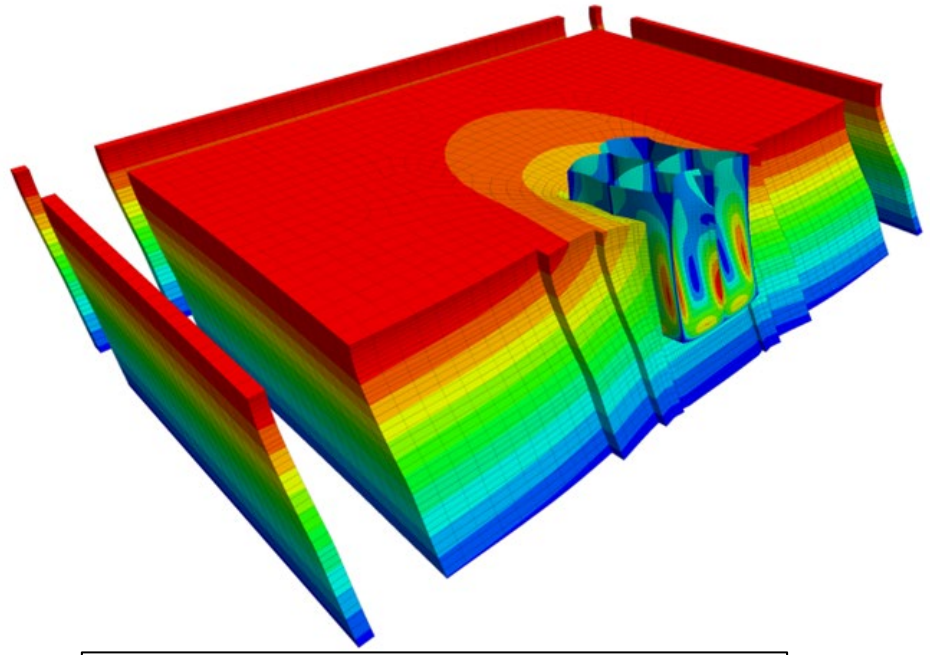
Faster Performance – Dynamic Analyses

Up to 10~200X

For dynamic analysis, using Maxwell damping vs Rayleigh damping, for zones and structures.



2D Site Response, 13.3X

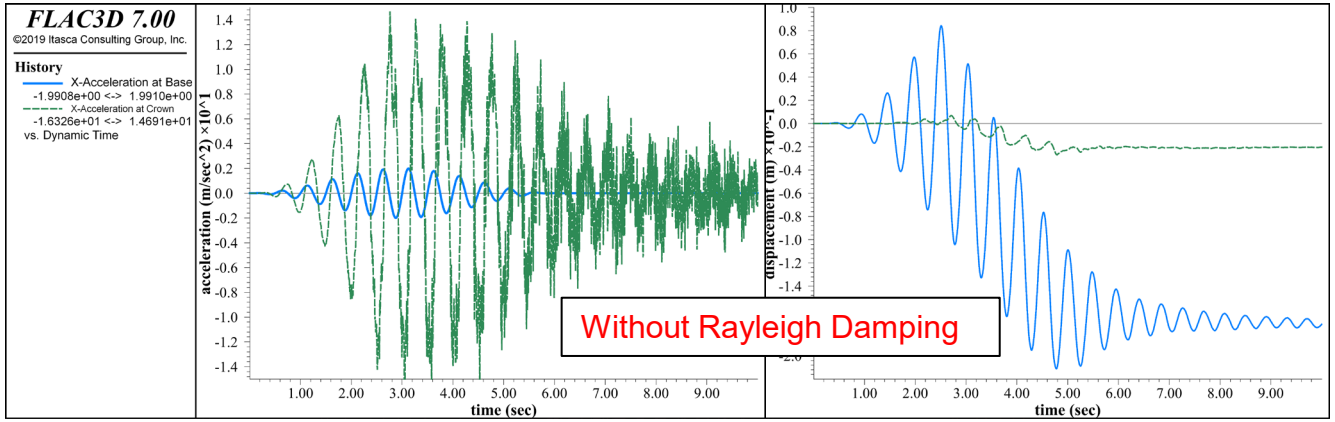


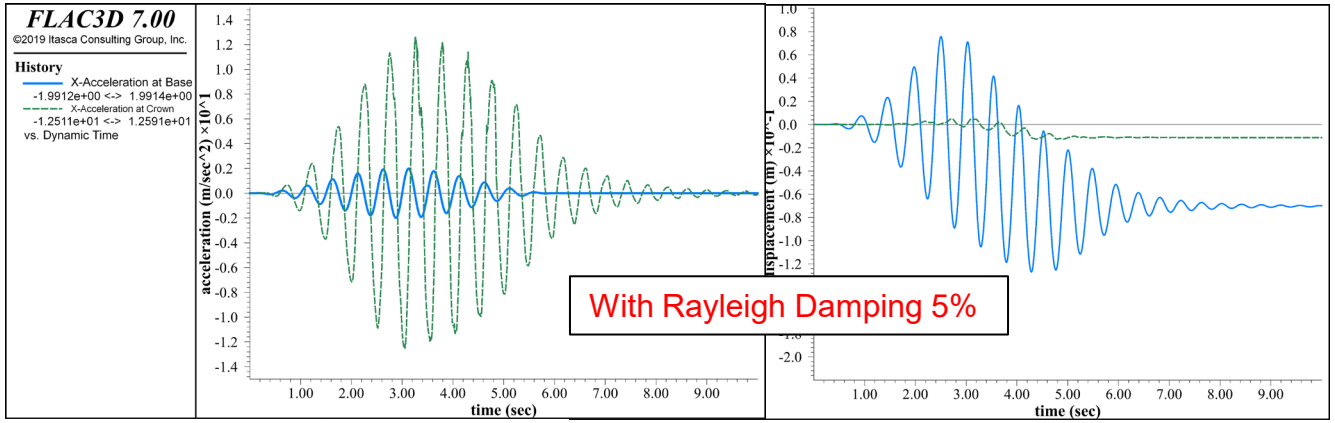
3D Soil-Structure Interaction, 120X

SERIOUSLY FASTER

Maxwell Damping

- In very large *FLAC3D* simulations, stiffness-proportional (Rayleigh) damping can be impractical as it significantly reduces the dynamic time step.
- But without stiffness-proportional damping, high frequencies are noises (undamped), and analysis results are questionable.

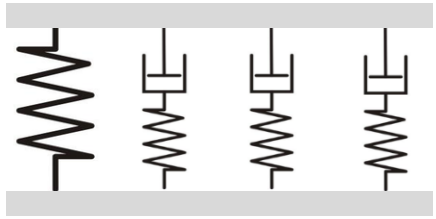




Maxwell Damping

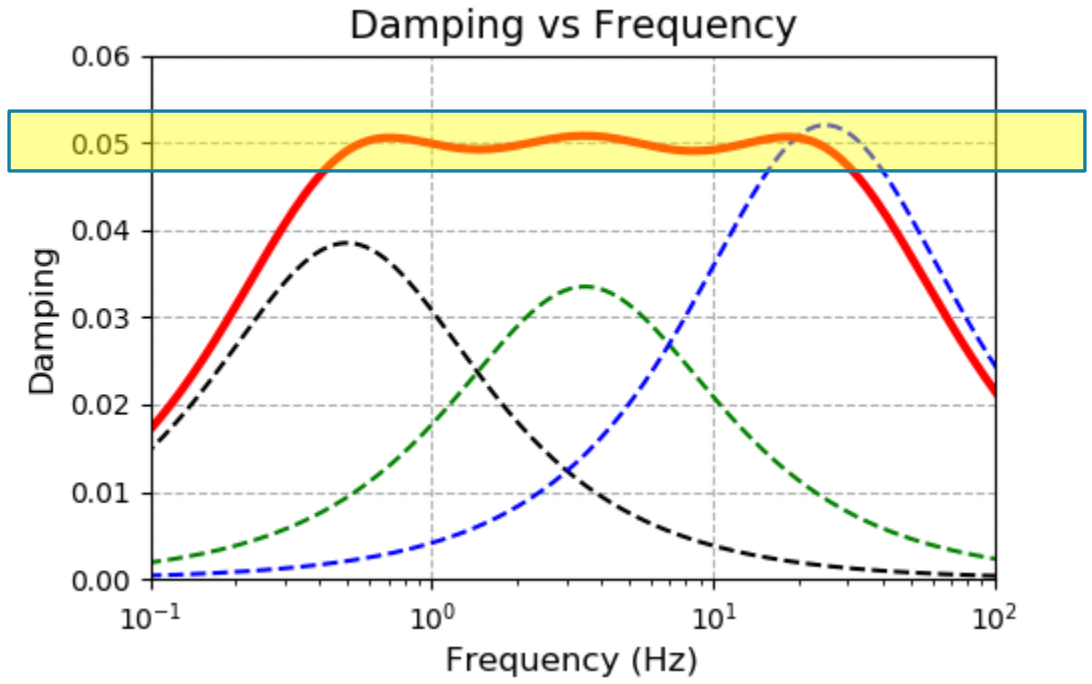
Maxwell damping:

By using more than one Maxwell components, parallel to the constitutive model, a frequency range with **relatively constant** damping can be obtained.

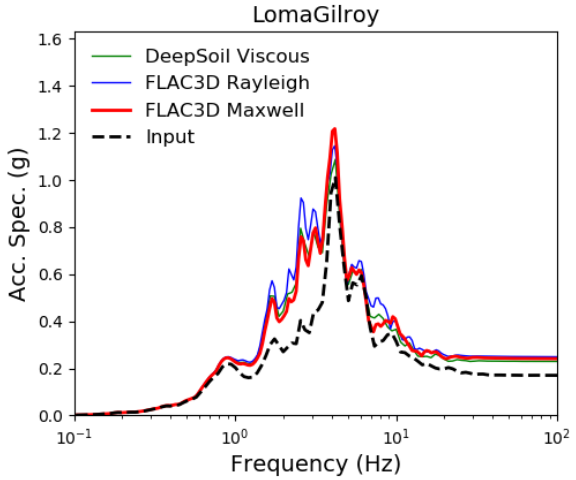


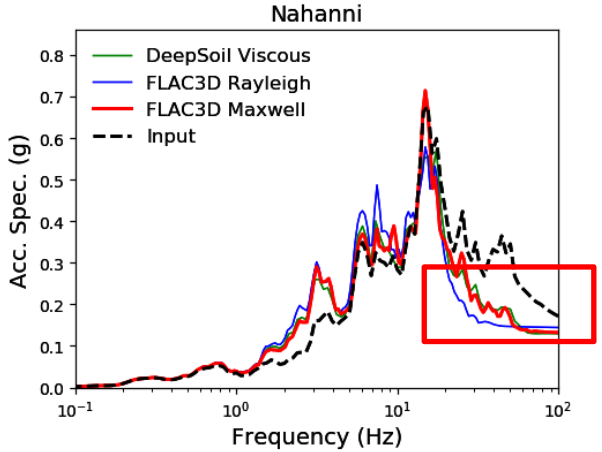
Implemented in *FLAC3D* v9:

- Zones
- Structure Elements
- Deformable Structure Links



Maxwell Damping





zone dynamic damping maxwell (0.0039 0.5) (0.0029 3.5) (0.0041 25.0)

- Response performance is as well as Rayleigh damping.
- Overcome Rayleigh damping shortcomings:
  - Dramatically reduced time step;
  - Overdamping for high frequencies.

$$\frac{\Delta t(Maxwell)}{\Delta t\ (Rayleigh)} = 10\sim200$$

New & Improved Constitutive Models

Improved

- Plastic-Hardening (PH) model
- Ubiquitous-Anisotropic model

Added

- Columnar-Basalt (COMBA) model
- Plastic-damage concrete model
- Von-Mises model with kinematic hardening

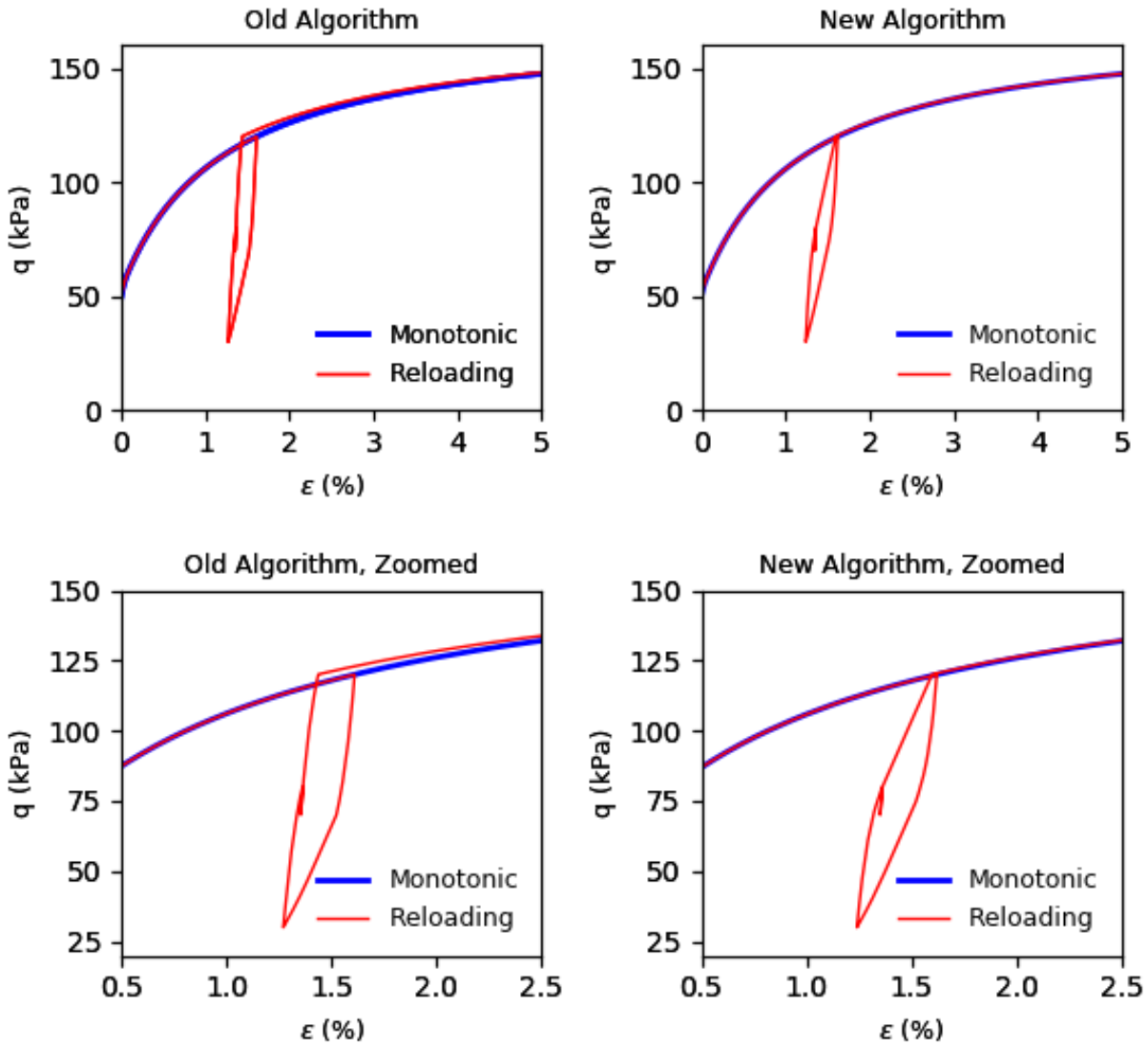
FLAC3D now has

38 mechanical constitutive models (**11** creep models) + many UDMs

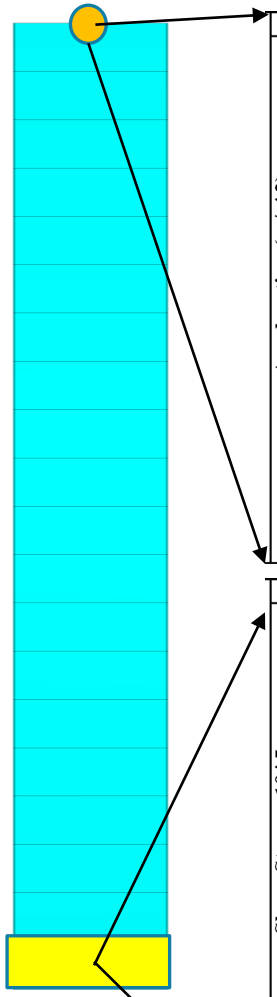
PH Model: Improvement

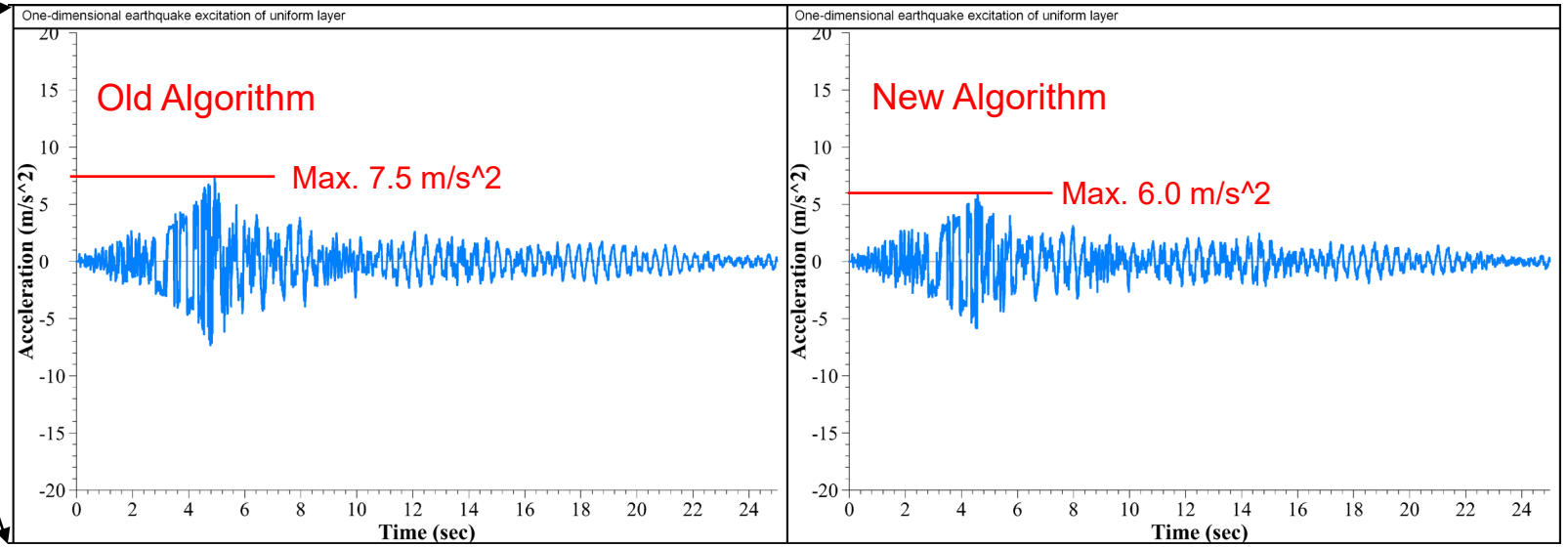
- V7 based on the old Benz (2007) algorithm on small-strain hysteretic loop.
- V9 based on the new '**brick**' algorithm (Cudny and Truty, 2020).
- The previous (v7) limitation note on over-shooting of the PH model no longer holds and can thus be removed in v9.
- This update enables PH with small-strain flag a more practical dynamic model.

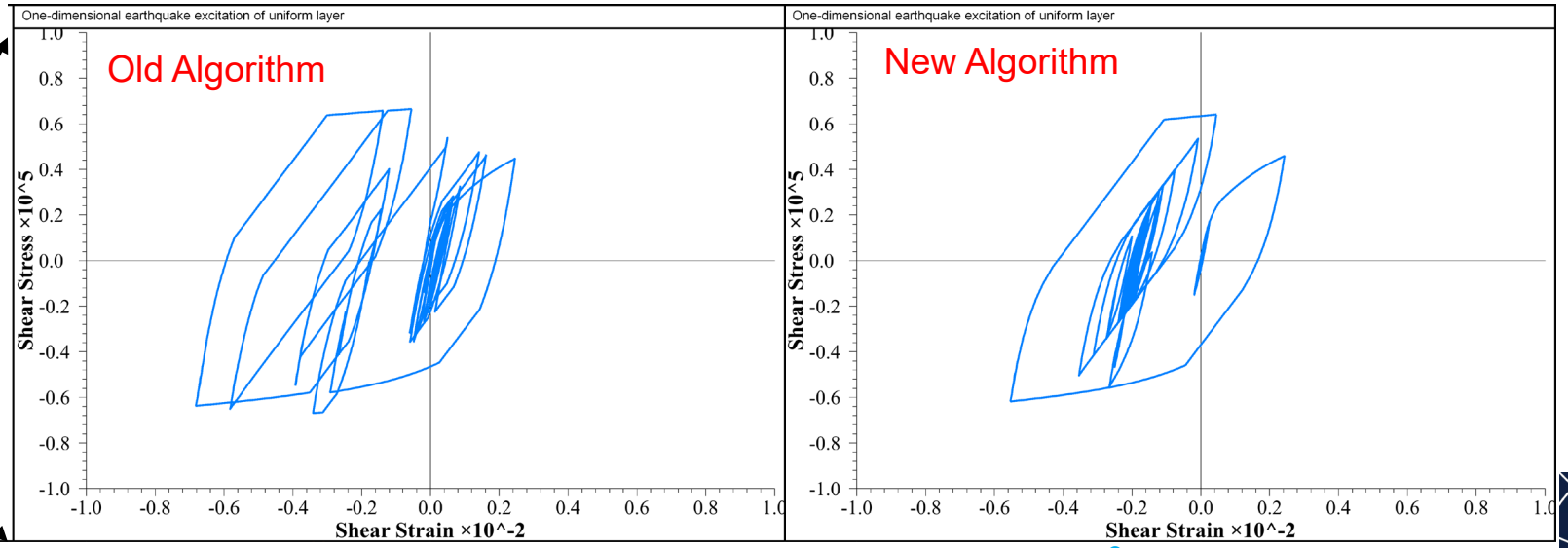
PH Model: Improved Performance



PH Model: Stress-strain Results







NEW & IMPROVED
CONSTITUTIVE MODELS

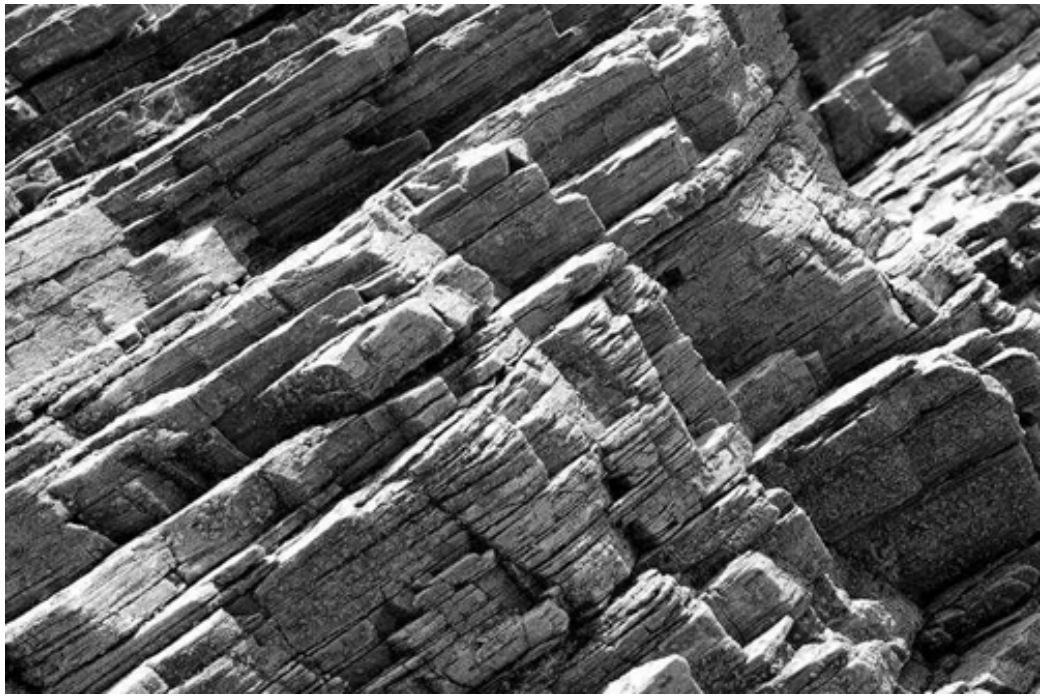
Ubiquitous-Anisotropic Model: Improvement

- V7:

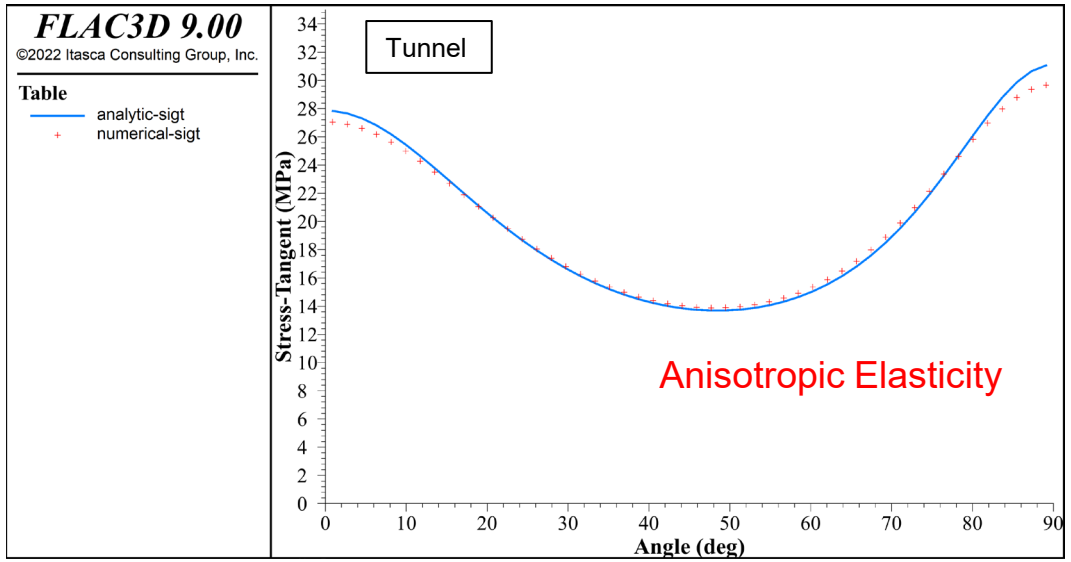
Matrix – anisotropic elasticity
Joint – Mohr-Coulomb law

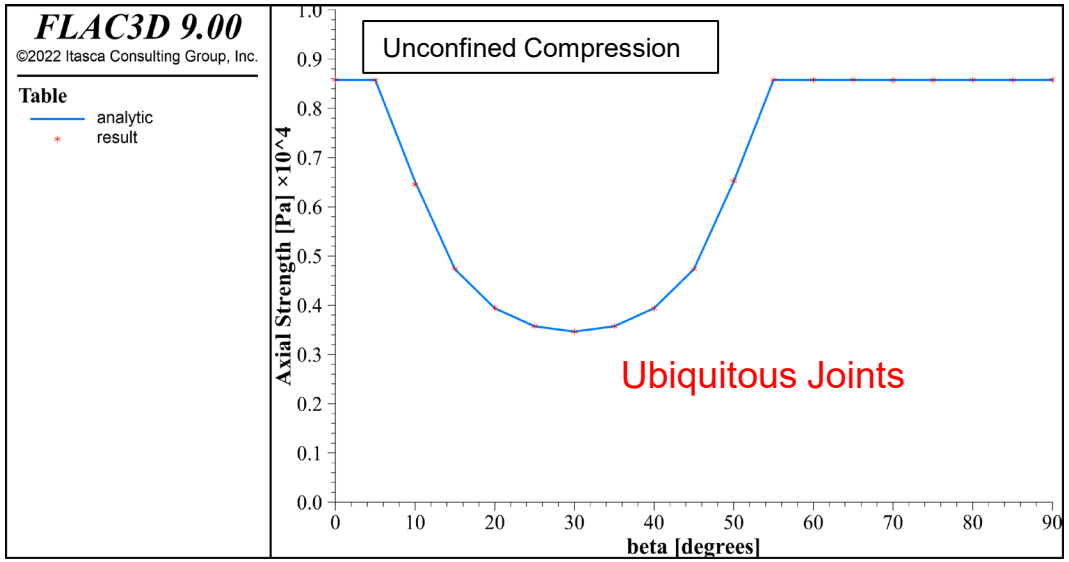
- V9:

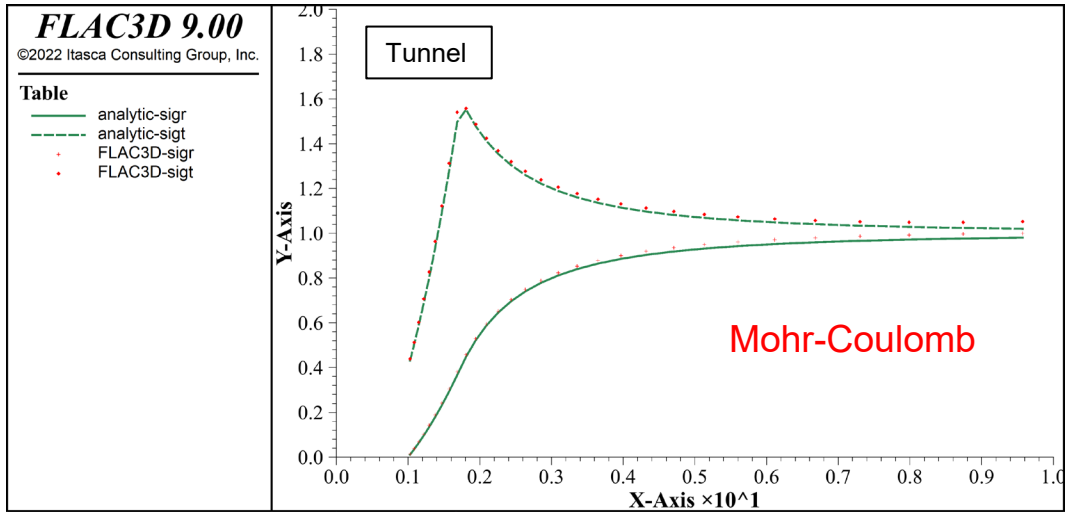
Matrix – anisotropic elasticity & Mohr-Coulomb law
Joint – Mohr-Coulomb law

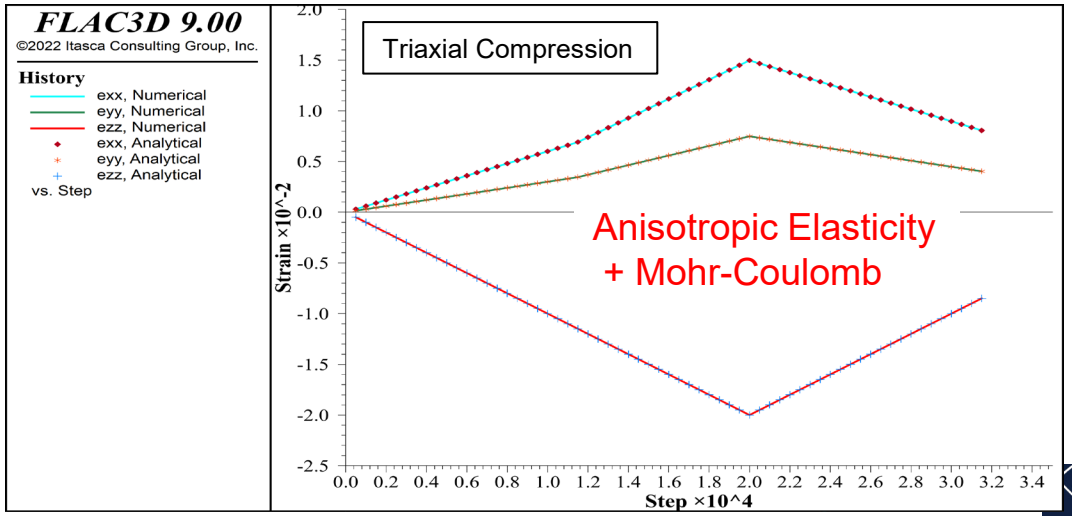


Ubiquitous-Anisotropic Model: Verifications







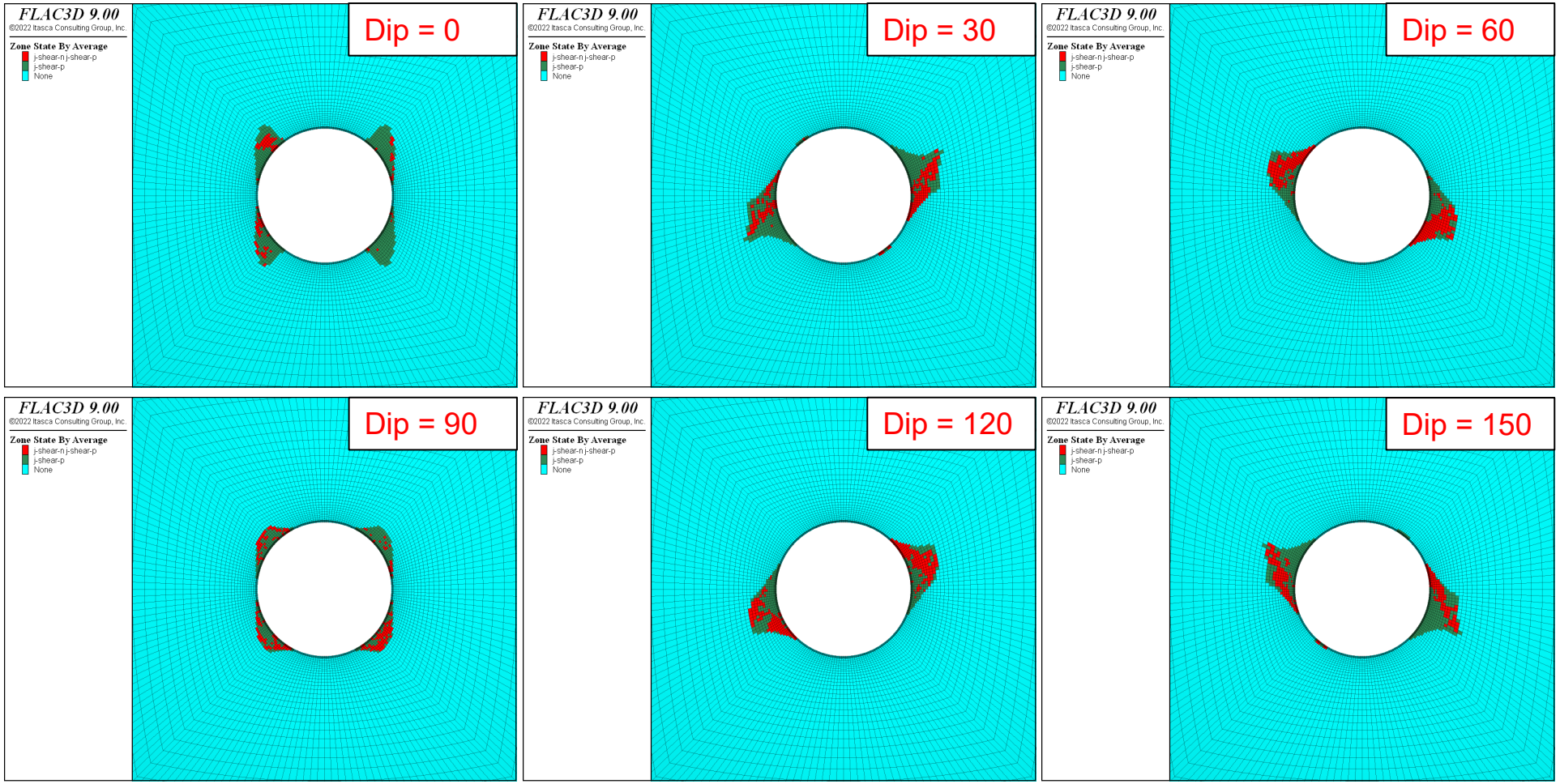


Columnar-Basalt (COMBA) Model:

- **Up to four** arbitrary orientations of weakness (ubiquitous joint).
- Anisotropic elastic matrix.
- Strain hardening/softening Mohr-Coulomb envelope with tension cutoff for matrix.
- Strain hardening/softening can be specified for joints.
- An amplification factor can be applied to joint dilation that depends on the angle between a set direction.
- **Creep** option on weak planes.
- **For multi-jointed rockmsss, e.g., columnar-basalt**.

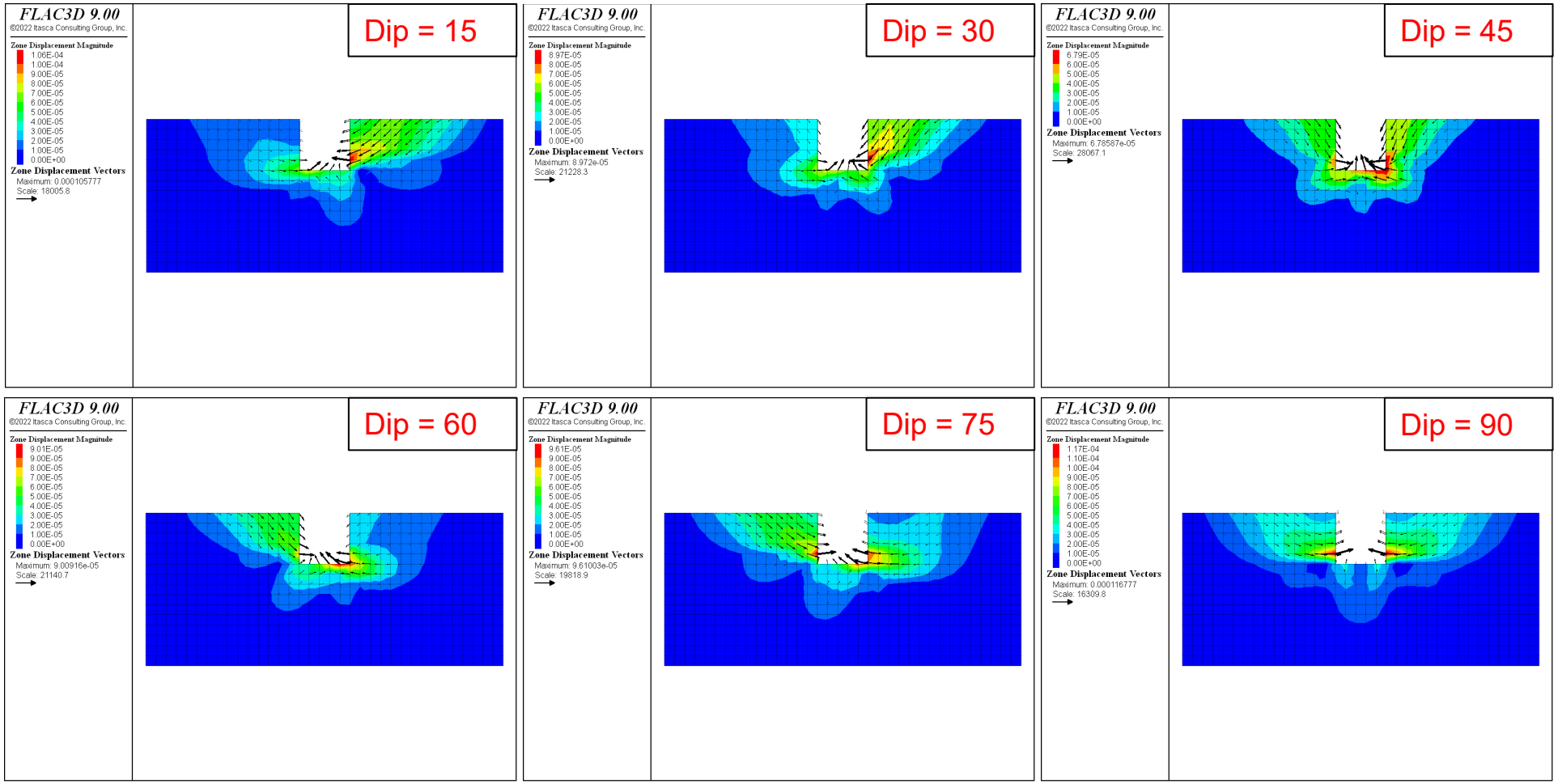
(Detournay et al 2016, Meng et al 2020)

Columnar-Basalt (COMBA) Model:



Three Sets of joints:
dip3 = dip
dip1 = dip3 + 90°

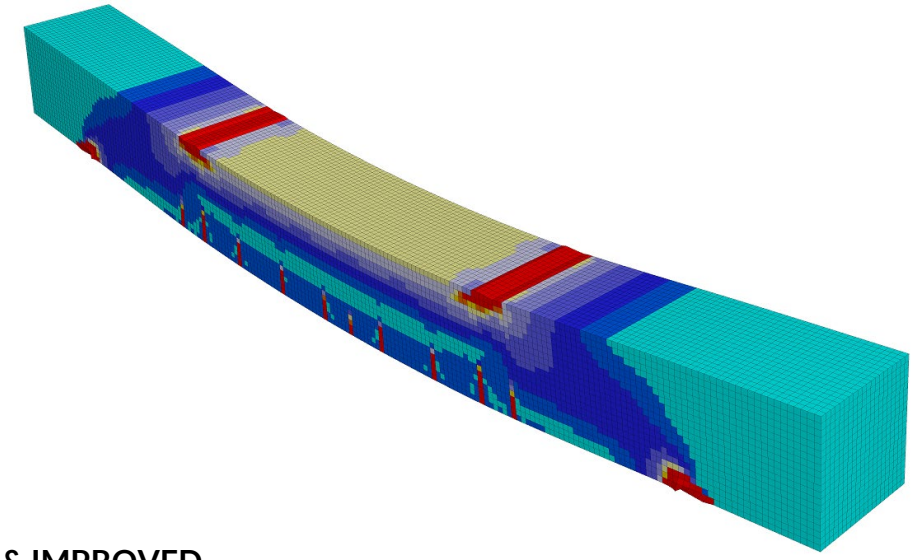
Columnar-Basalt (COMBA) Model:



One set of joints:
Creep effect

Plastic-damage Concrete Model:

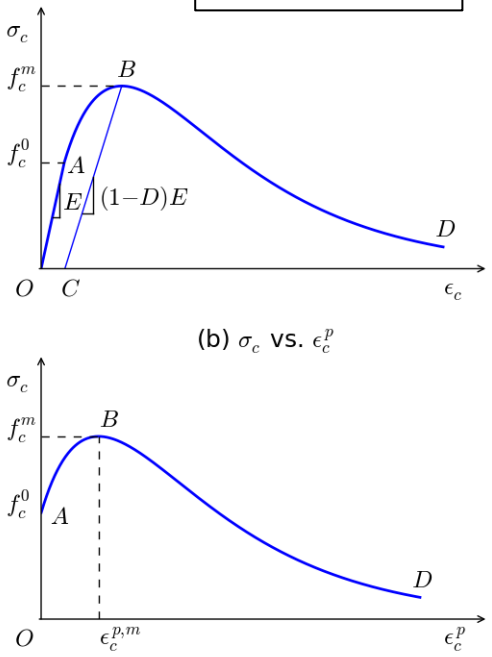
- A plastic-damage model.
- Damage in both extension and compression.
- Damage based on fracture-energy.
- Modulus degradation in continuum damage mechanics.
- Compatible to Mohr-Coulomb yielding criteria.



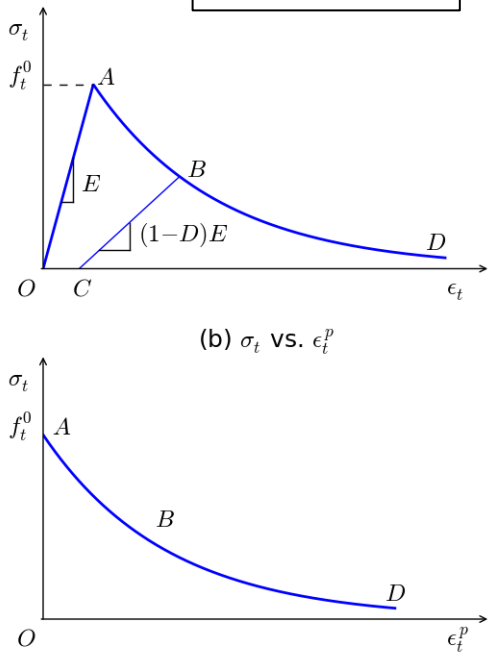
(Modified from Lublinear et al, 1989 and Lee & Fenvas, 1998)

Plastic-damage Concrete Model:

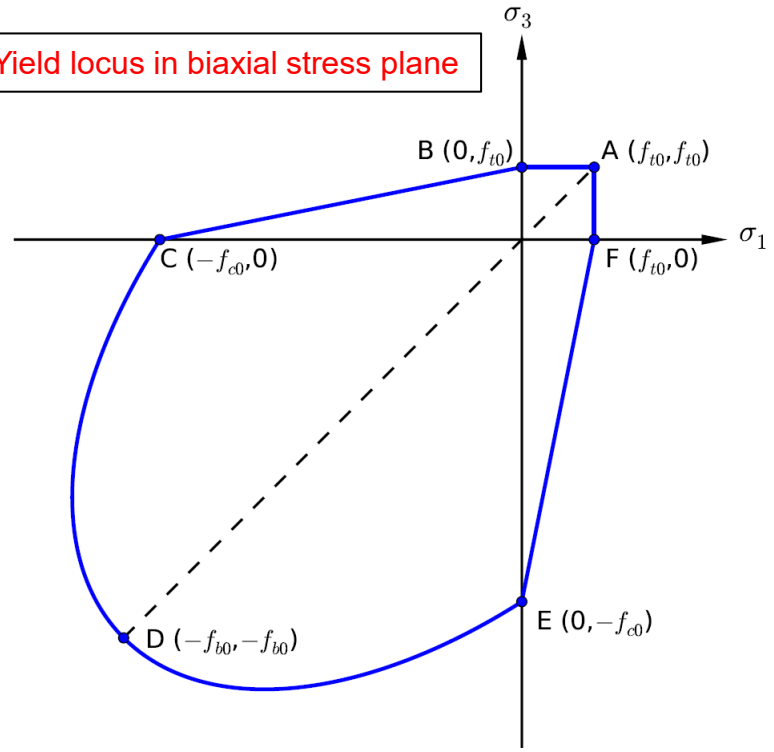
Compression

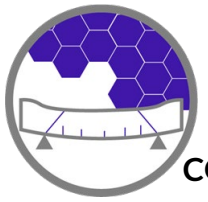


Extension



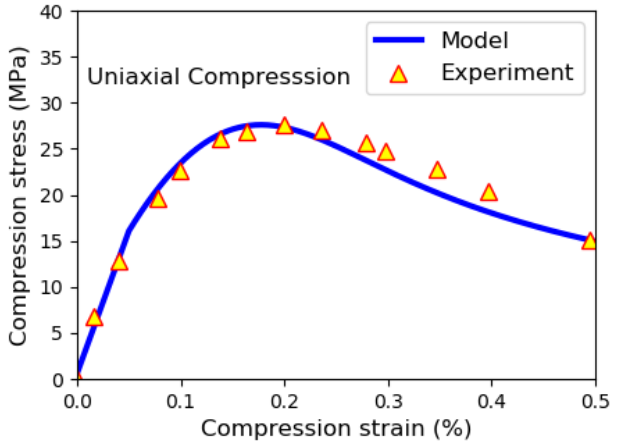
Yield locus in biaxial stress plane

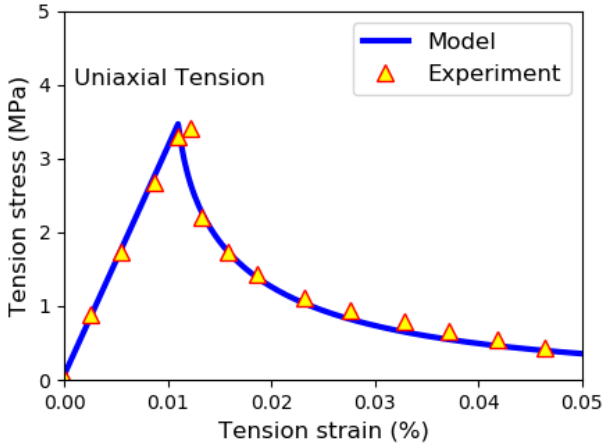


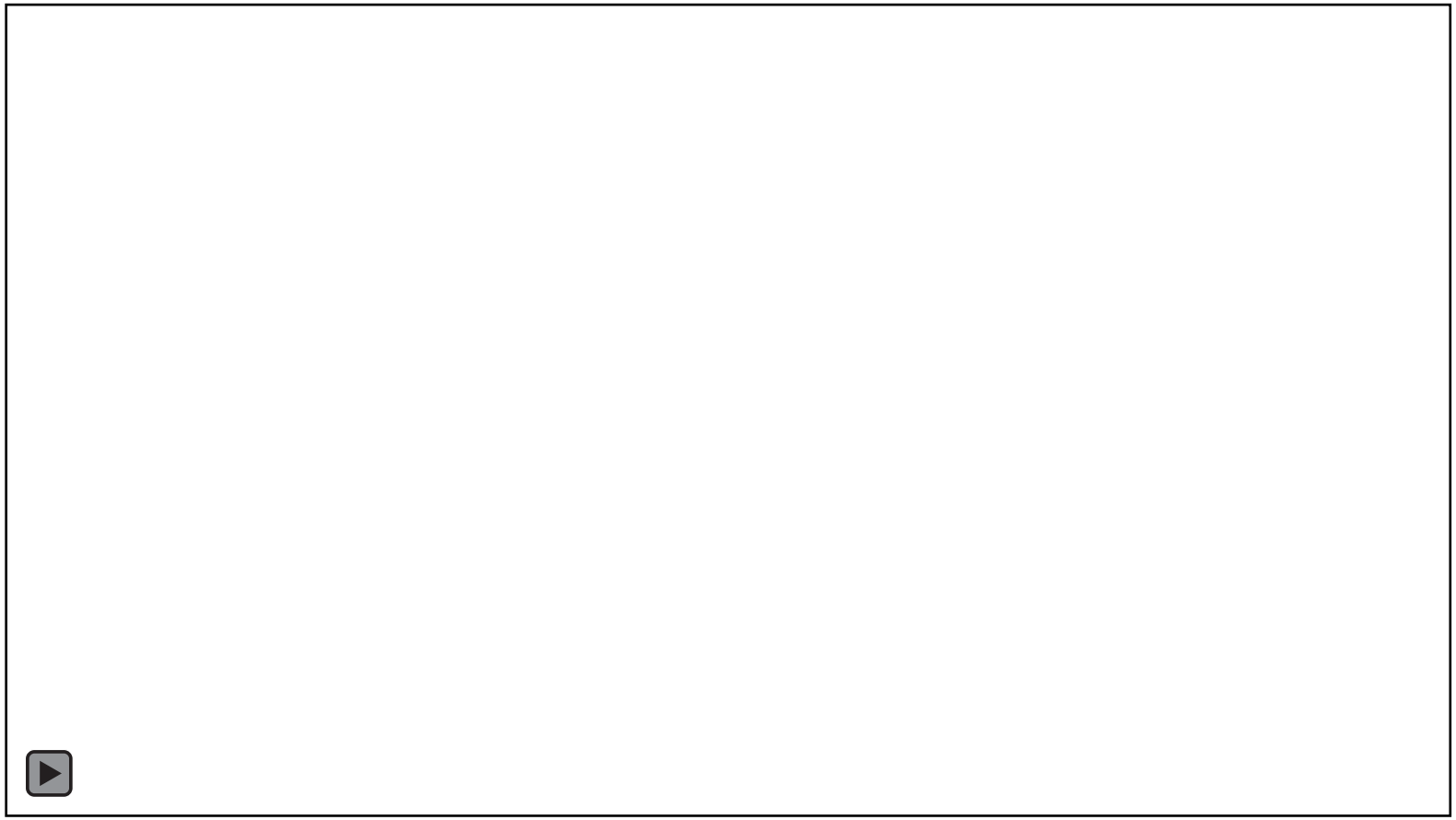


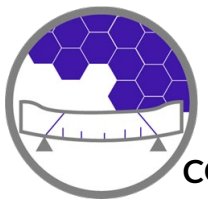
NEW & IMPROVED
CONSTITUTIVE MODELS

Plastic-damage Concrete Model:





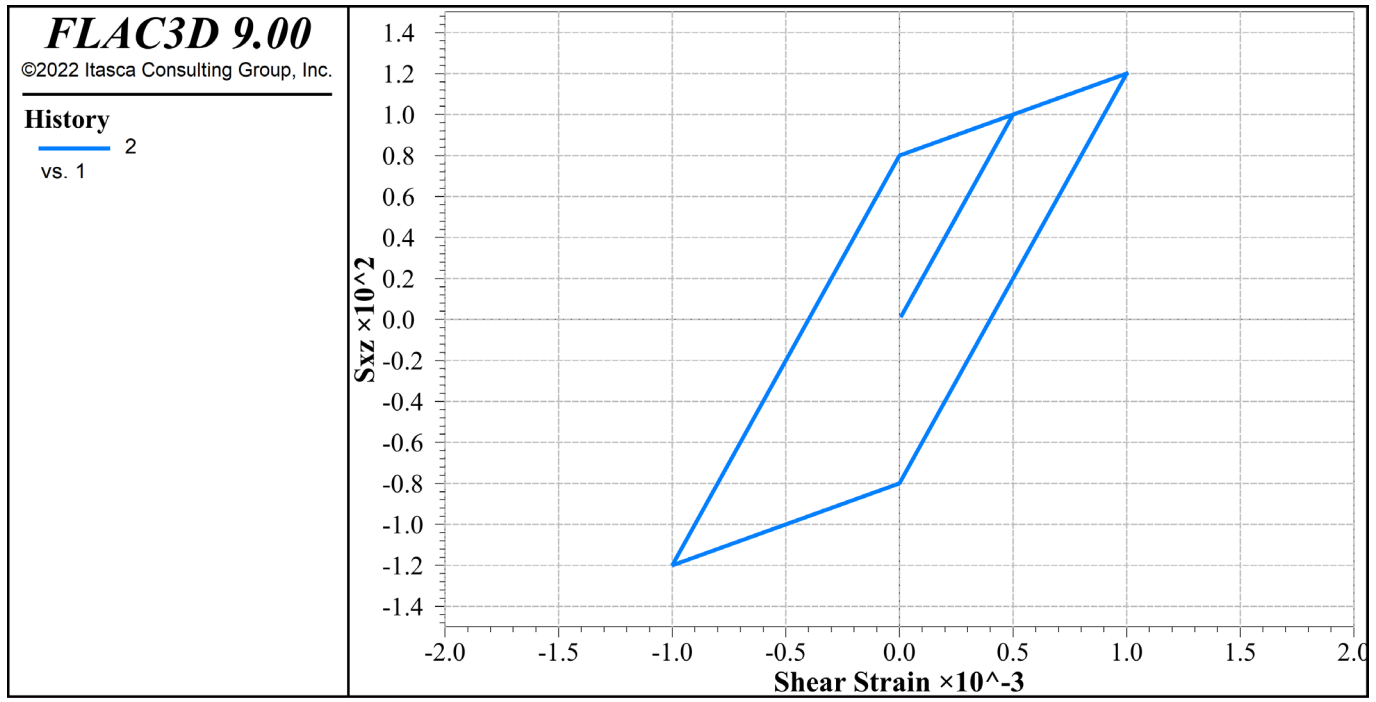




NEW & IMPROVED
CONSTITUTIVE MODELS

Von-Mises Model :

- Von-Mises law.
- Optional kinematic hardening.
- For metal-like materials, used by **non-linear structures**.



Non-linear Structures

Constitutive laws at integration points

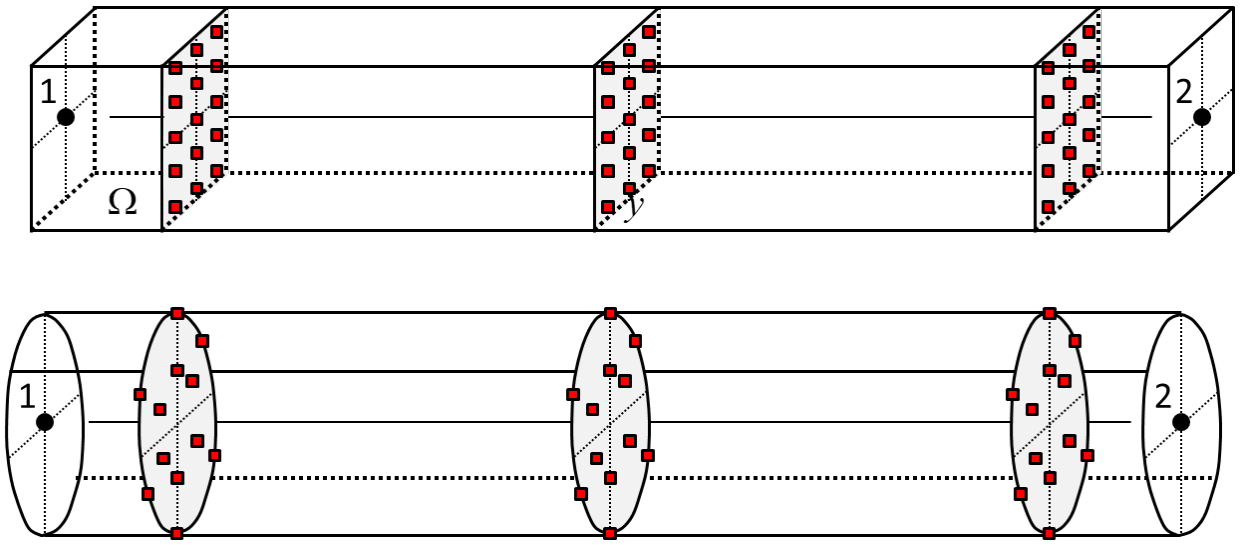
Implemented non-linear models for structures:

- Von-Mises
- Mohr-Coulomb
- Strain-Softening

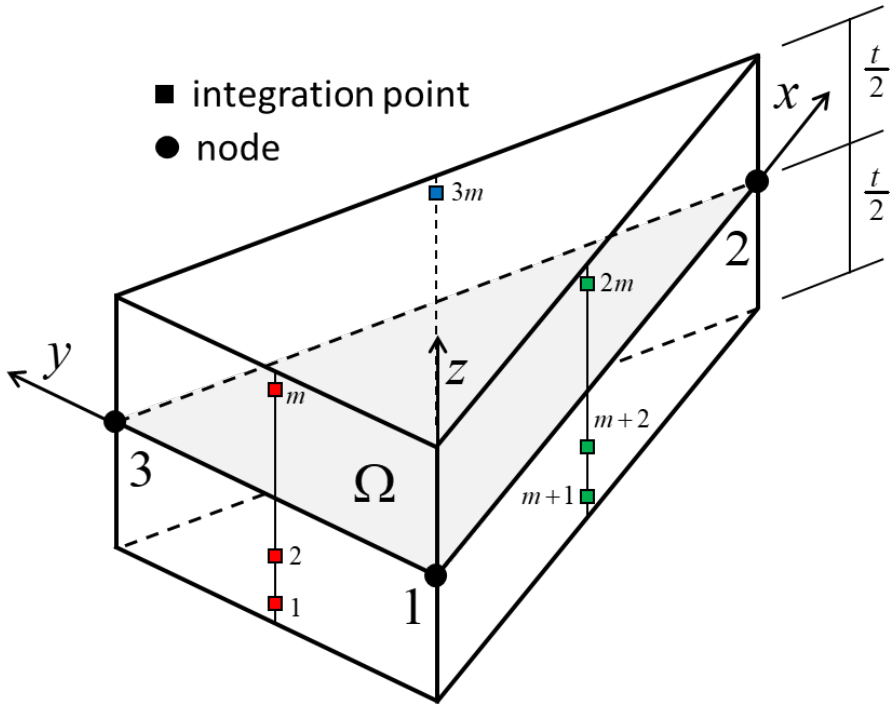
```
struct beam cmodel assign von-mises
struct beam cmodel plastic-integration rectangular cross-section rectangular layout 3 5 3 ; for element shown here
struct beam property direction-y (0,1,0) . . .
                              young 68e9 poisson 0.33 strength-yield 270e6 modulus-plastic 0.0; 6061-T6 aluminum alloy
```

Non-linear Structures:

Beam Element (rectangular or circular)



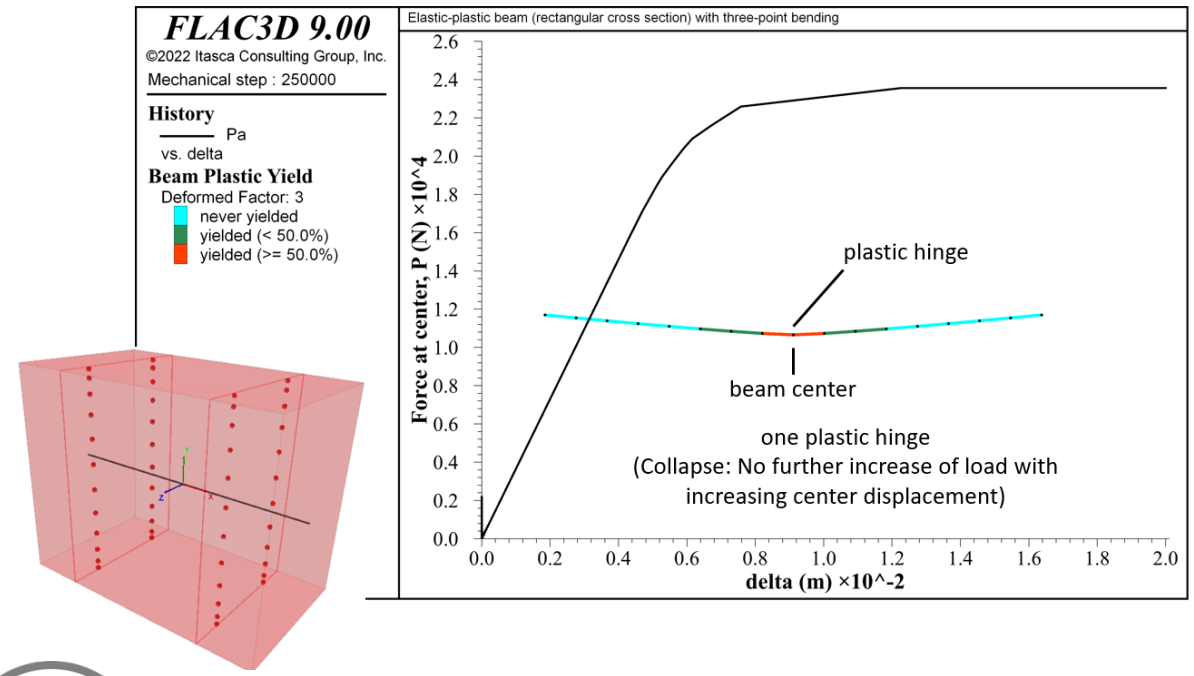
Shell Element

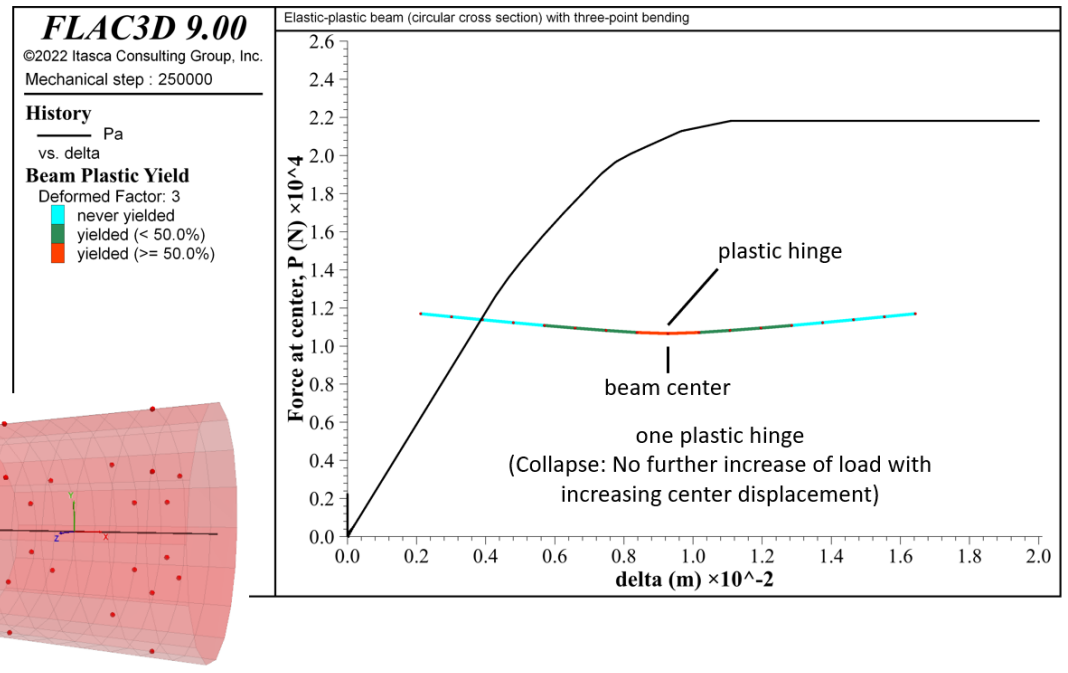


Non-linear Structures:

Elastic-plastic beam with three-point bending

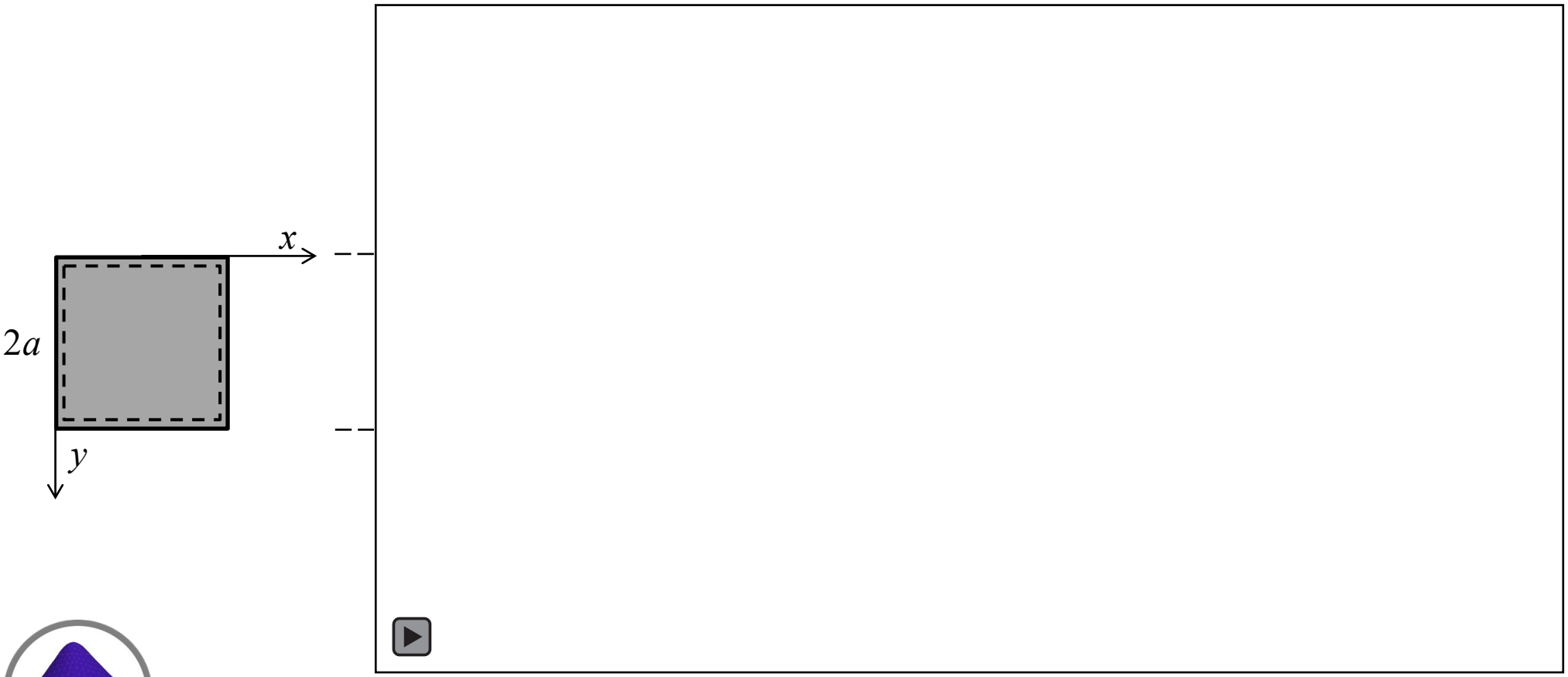
(**ThreePointBending-plastic**; analytical yield and limit loads; plastic hinge at collapse; rectangular and circular cross sections)





Non-linear Structures:

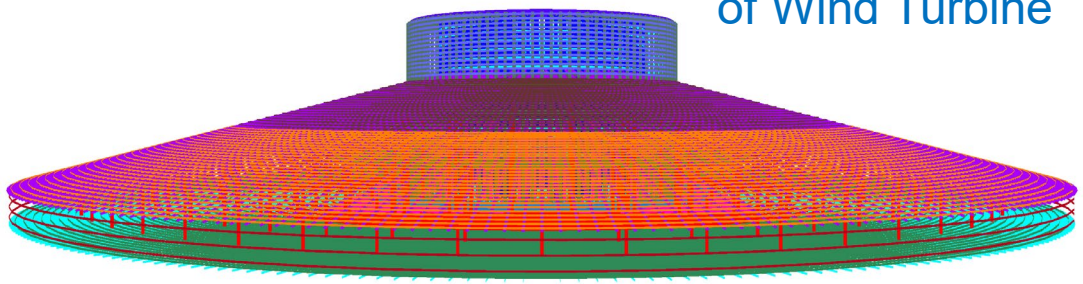
Elastic-plastic plate with uniform load (square plate, simply supported)



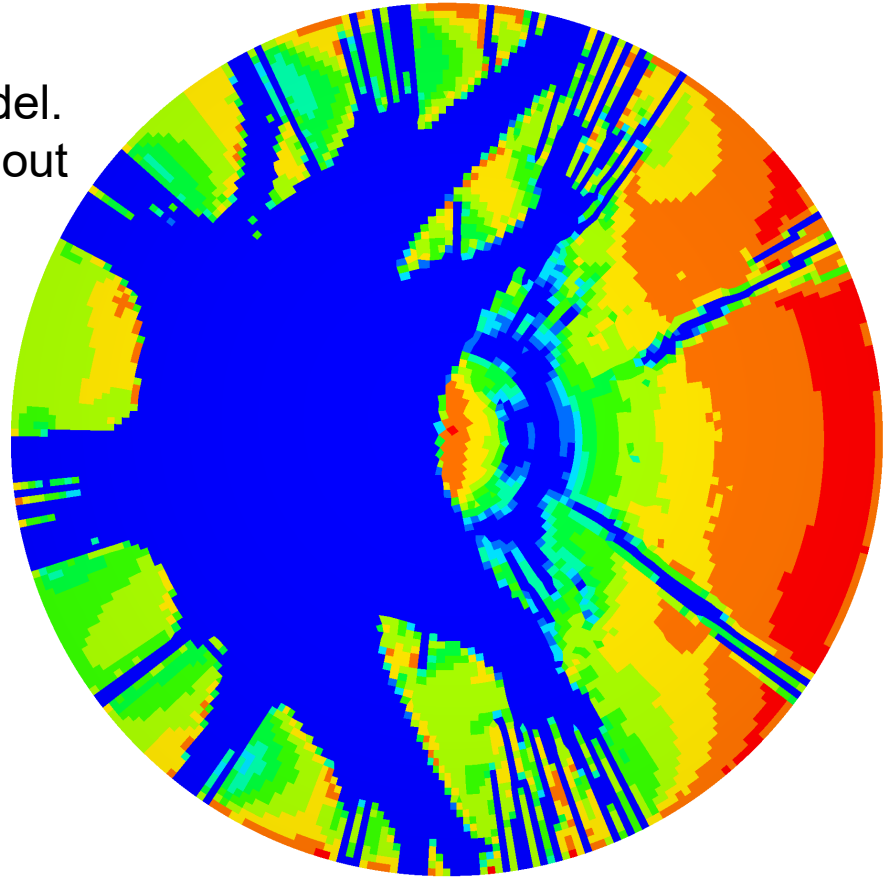
Reinforced Concrete

Now, it is easy to analyze the behavior of **reinforced concrete** in *FLAC3D* v9:

- **Concrete** modeling by **zones** with the **concrete** model.
- **Bars** modeling by **beams/piles** using the nonlinear **von-Mises** model.
- The **nodes** of the beams/piles can be located **at any position**, without requiring them to be coordinated with gridpoints.



Reinforced Concrete Foundation of Wind Turbine



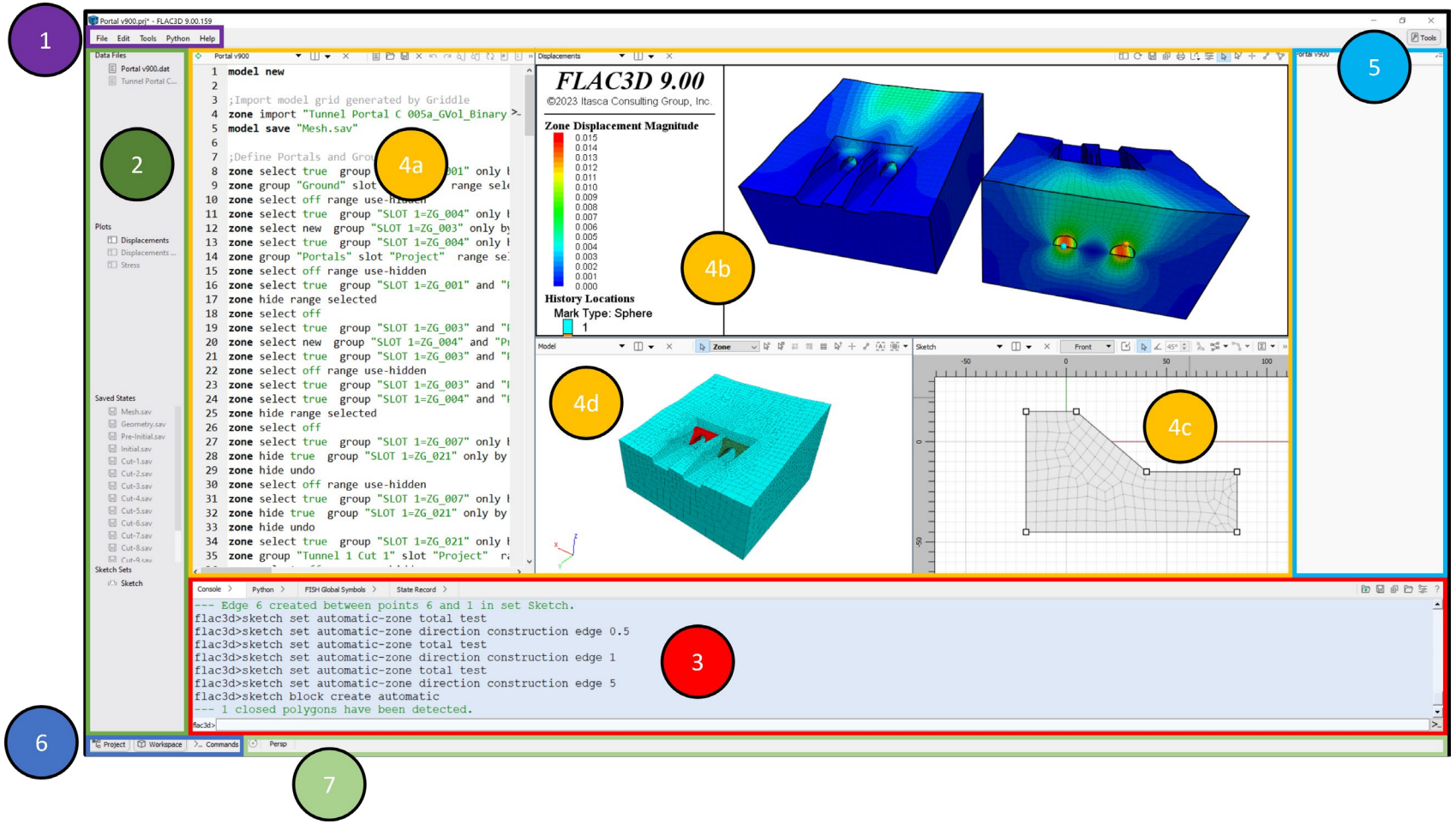
(Figure Courtesy: Augusto Lucarelli)

NON-LINEAR STRUCTURES

New User Interface

- Reorganize user interface
- More flexible
- **Splitting new windows**

1.Main Menu
2.Project pane
3.Command Console
4.Content Workspace
5.Contextual Tools/Help panel
6.Layout Toggles to hide
7.Status bar

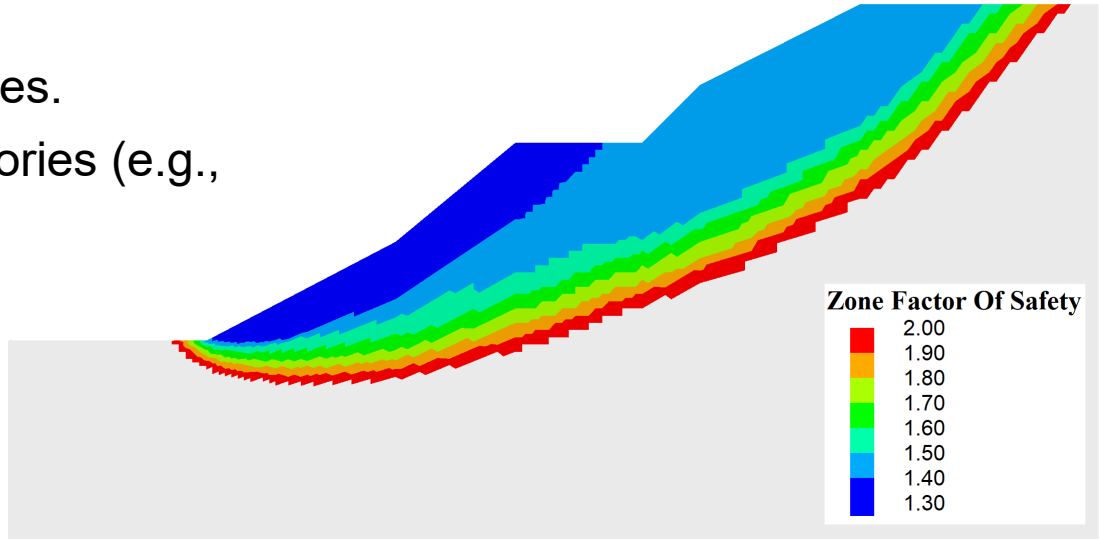


IMPROVED USER INTERFACE

Many Plot Item Improvements

For examples:

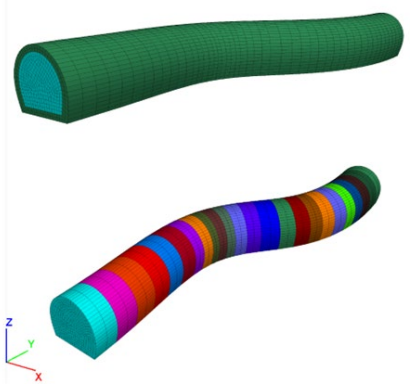
- More attributes of contour plot including **user-defined contour ramp**.
- **Format** and **precision** of the contour legends can be specified.
- Add option to **swap axes** for table and profile charts.
- Add option to add **minor gridlines** to charts.
- Improved **logarithmic scale** for charts.
- Option to **omit "past" states** when plotting yield states.
- **More** plots of contours (e.g., fos, fluid-head) and histories (e.g., structure node acceleration).

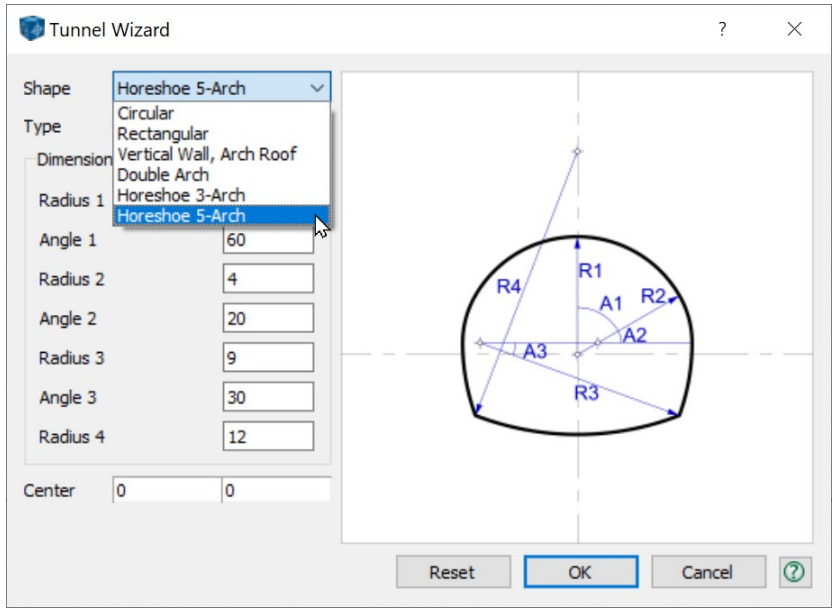


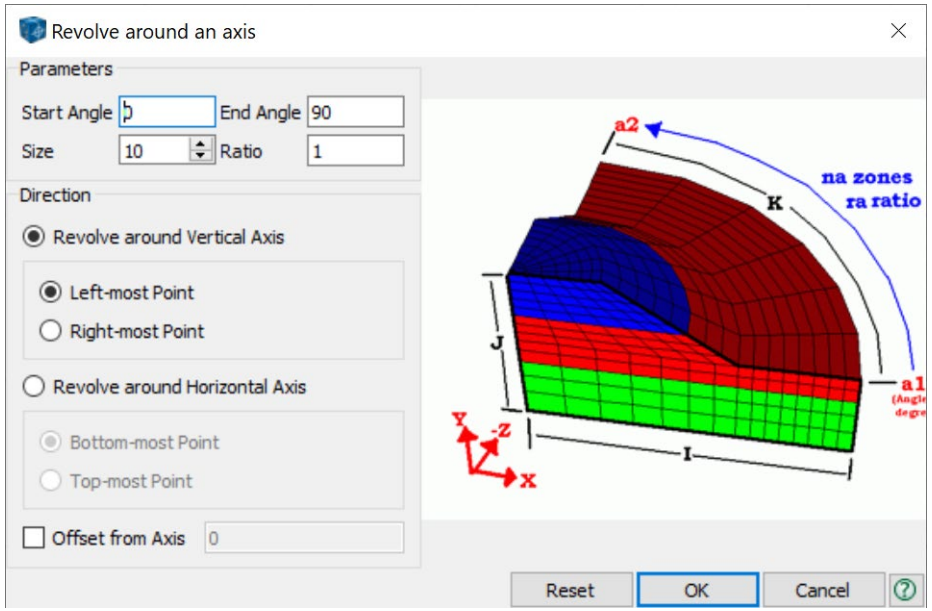
IMPROVED
USER INTERFACE

Improved Sketch (Extruder)

- The pane “Extrusion” in v7 renamed to “Sketch” in v9.
- Ruler/Background grid
- Slope/Tunnel wizard
- Revolve a 2D sketch along a vertical or horizontal axis
- Along curved path

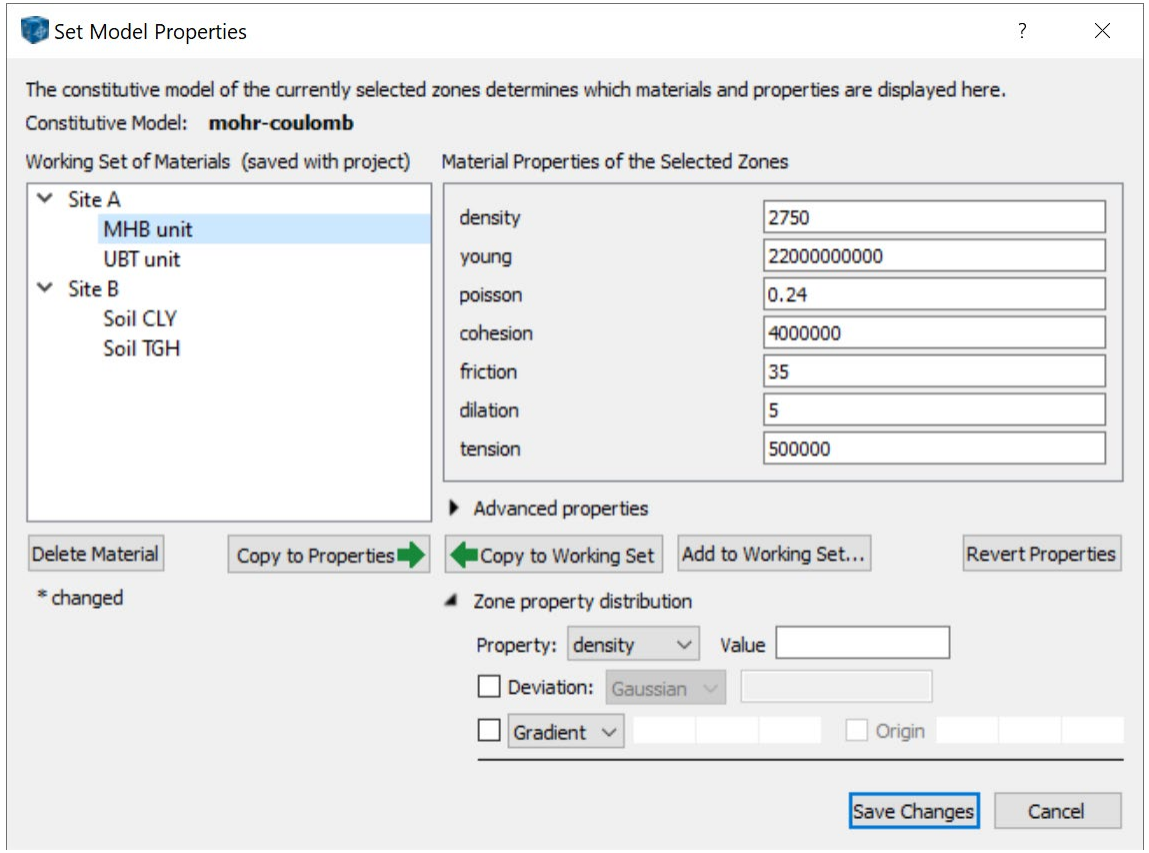




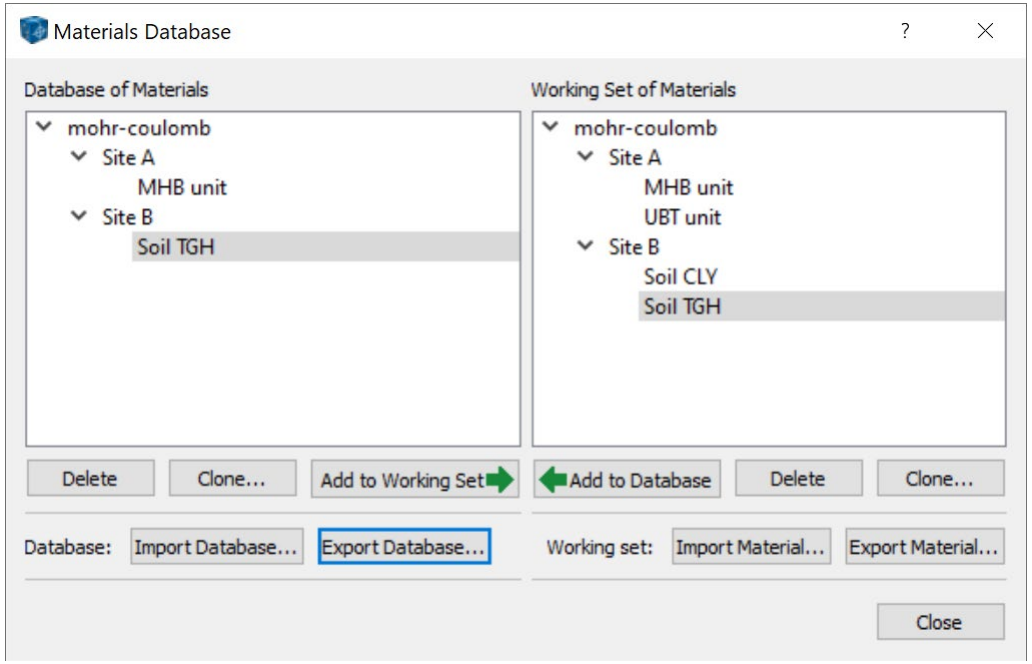


IMPROVED
USER INTERFACE

Material Dialog



- Define and interactively specify material properties
- Create, then import/export material properties in a built-in properties database



IMPROVED USER INTERFACE

Embedded Python

- **Updated to version 3.10.5.**
- Include *numpy*, *scipy*, *pyside*, *openpyxl*, *matplotlib* et al.
- Super easy for parametric study.
- Optional post-processing using Python.

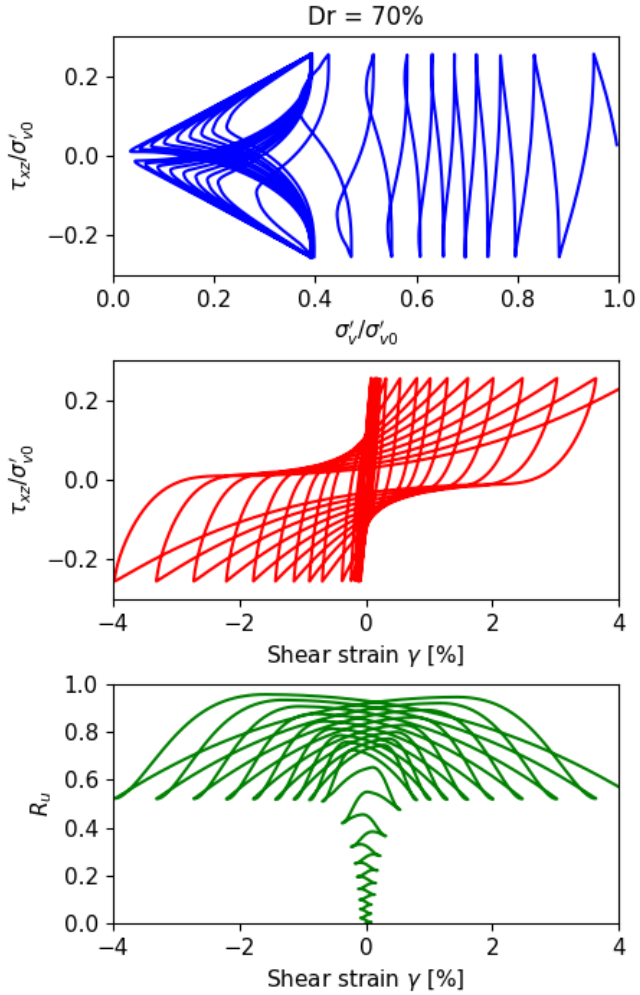
```
1  import itasca as it
2  it.command("python-reset-state false")
3
4  # Dr and CSR
5  DrDic = {0.30 : 0.071,
6           0.50 : 0.129,
7           0.70 : 0.255}
8  outfile = 'dss-cyc-ud-'
9  for dr0, csr in DrDic.items() :
10     it.command("model new")
11     it.fish.set('dr0', dr0)
12     it.fish.set('csr', csr)
13     it.command("program call 'CyclicUndrainedDirectSimpleShear.dat' ")
```

Multiple Cases

Loop

Python variables to FISH variables

Parametric Study



Plotted by Python

POWERFUL SCRIPTING

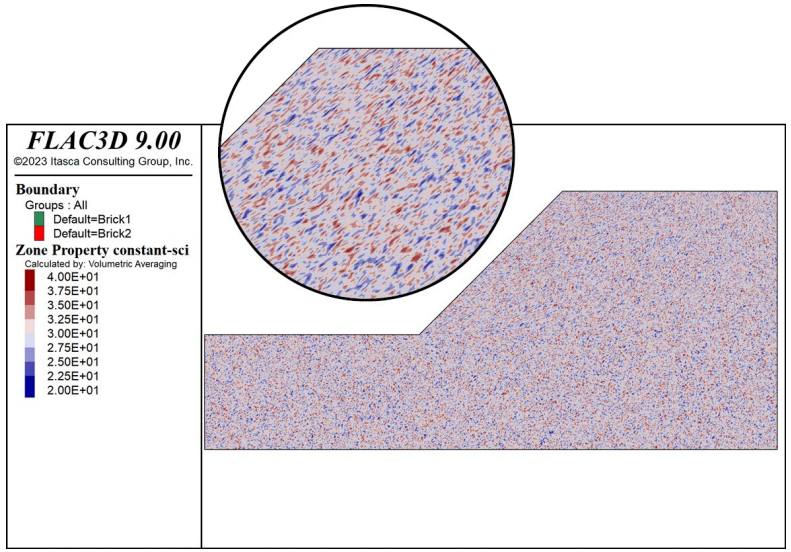
Multithreaded *FISH*

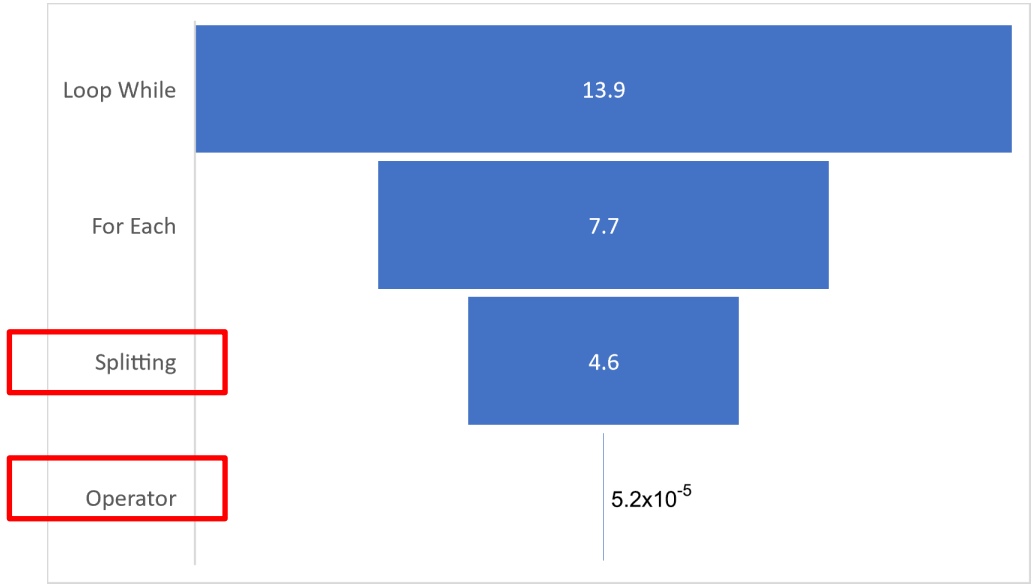
- *FISH* splitting

```
fish define random_Sci_LIST
    zone.prop(::zone.list,'constant-sci') ::= 20. + 20.*(math.random.uniform(list.size(zone.list)))
end
[random_Sci_LIST]
```

- *FISH* operator

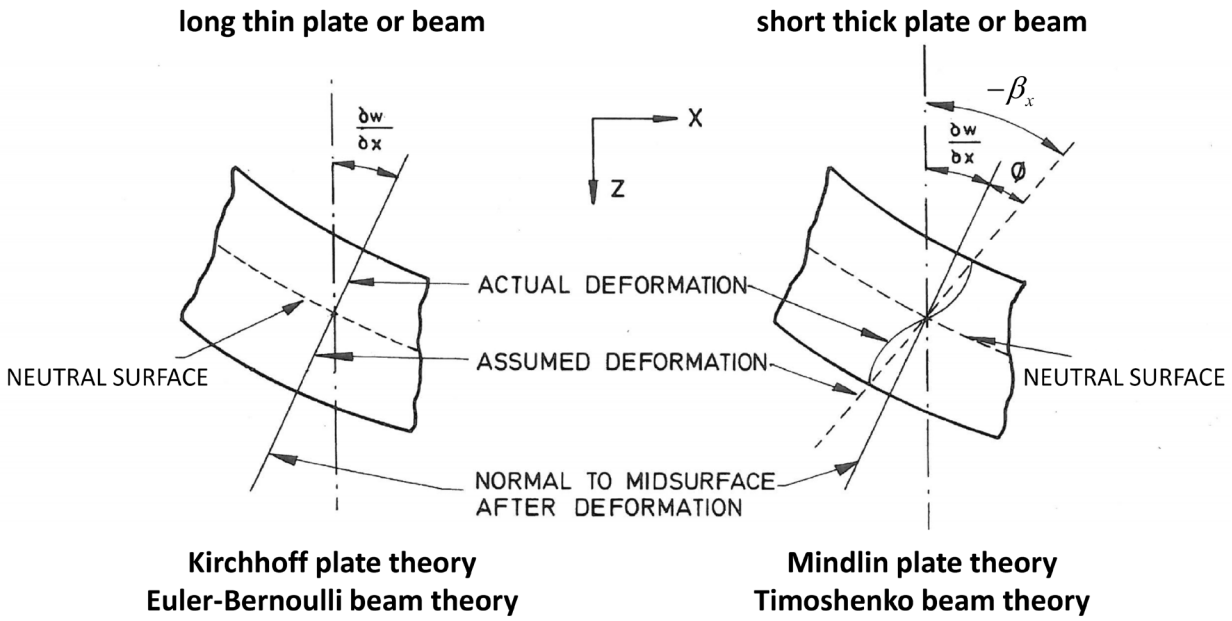
```
fish operator random_Sci_LIST(fred)
    zone.prop(fred,'constant-sci') = (20. + 20.*(math.random.uniform()))
end
[random_Sci_LIST(::zone.list)]
```

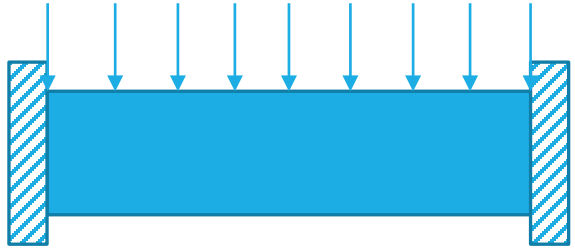


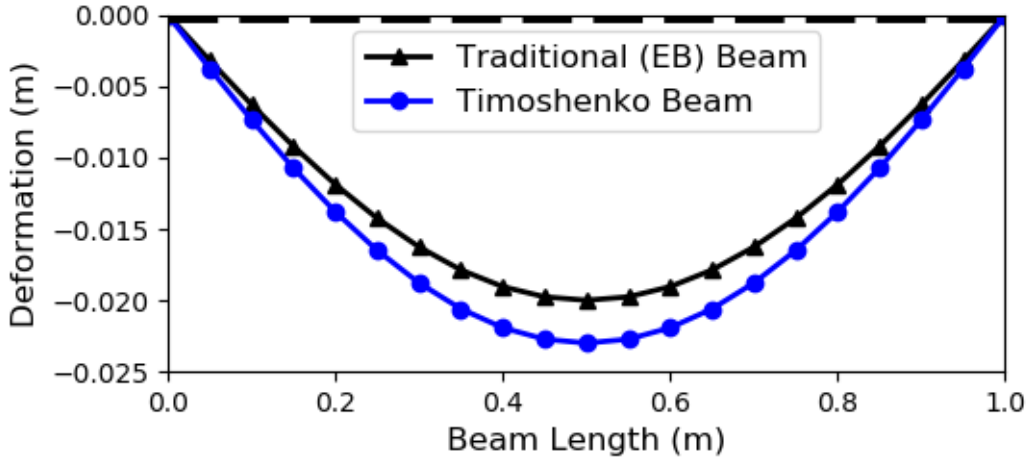


POWERFUL SCRIPTING

Timoshenko Beam:





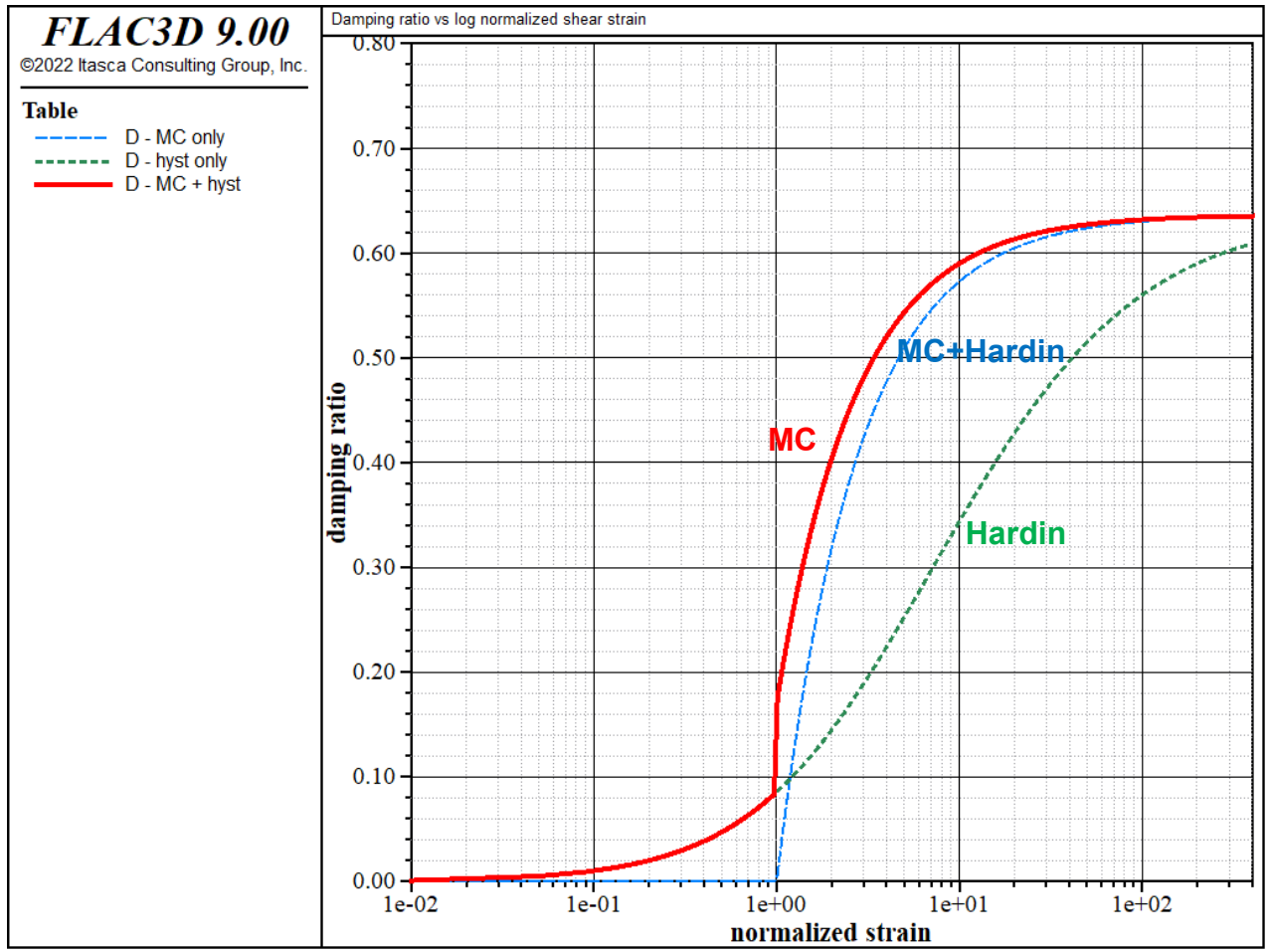


struct beam create by-line … element-type timoshenko

FLAC3D 9

MORE NEW FEATURES

Ramberg-Osgood Hysteretic Damping Model:



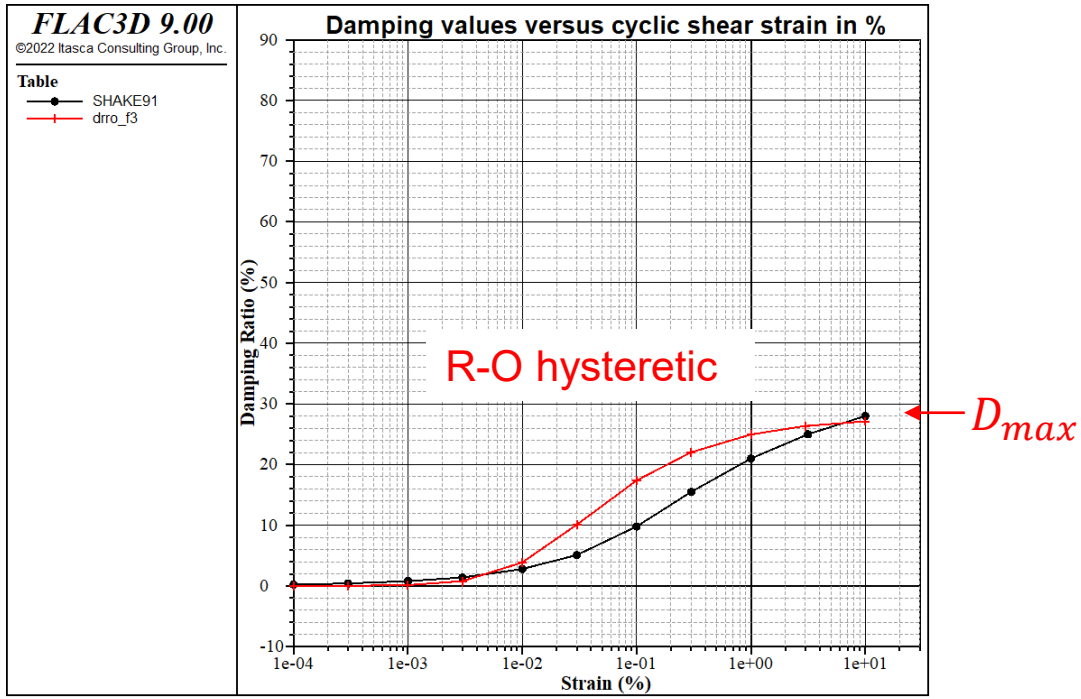
Drawback of current constitutive and hysteretic damping:

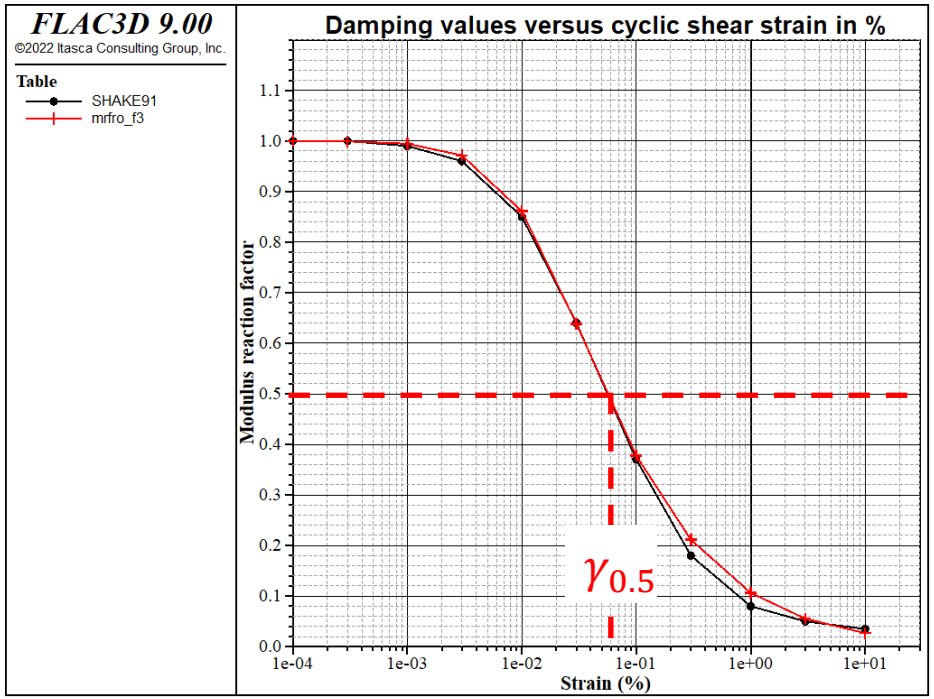
Damping at high shear strain is close to $2/\pi$ = 63.7%.

Experiment data is usually between 20~35%.

MORE NEW FEATURES

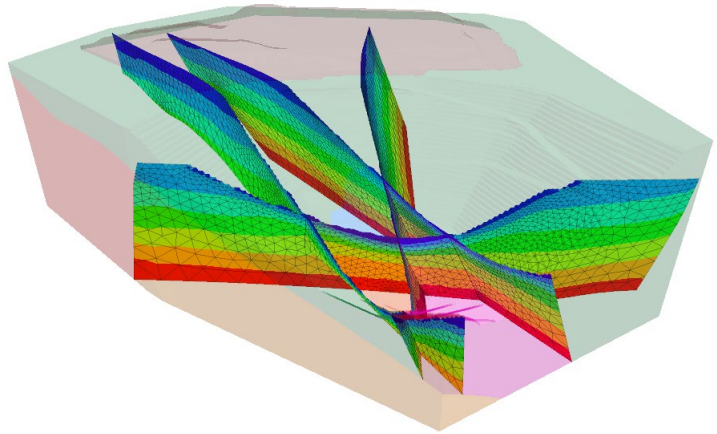
Ramberg-Osgood Hysteretic Damping Model:

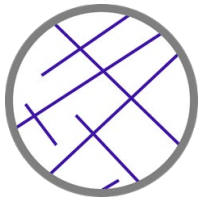




Zone Joints

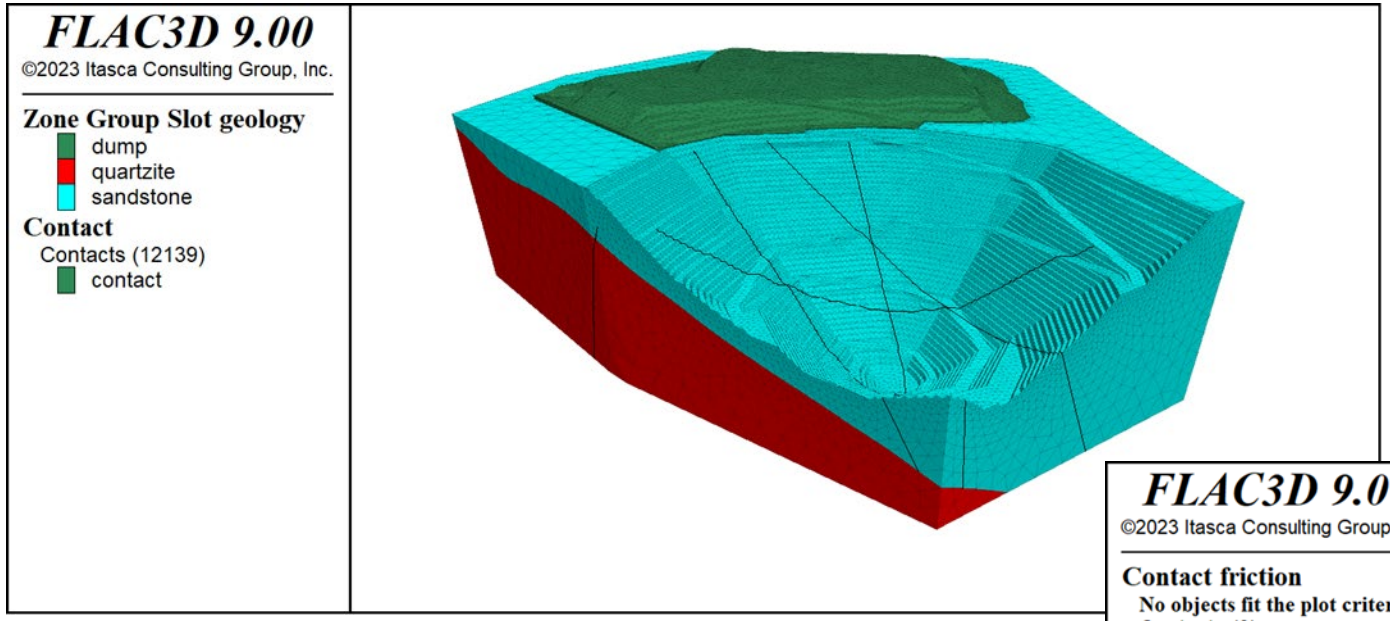
- Similar to *3DEC* and *PFC* joints, Zone Joints are an alternative to *FLAC3D* interfaces.
- Two-sided interfaces.
- Incremental formulation.
- Better performances for multiple intersecting joints.
- Small-strain mode.
- Cutting can be from *Griddle* or *3DEC*.

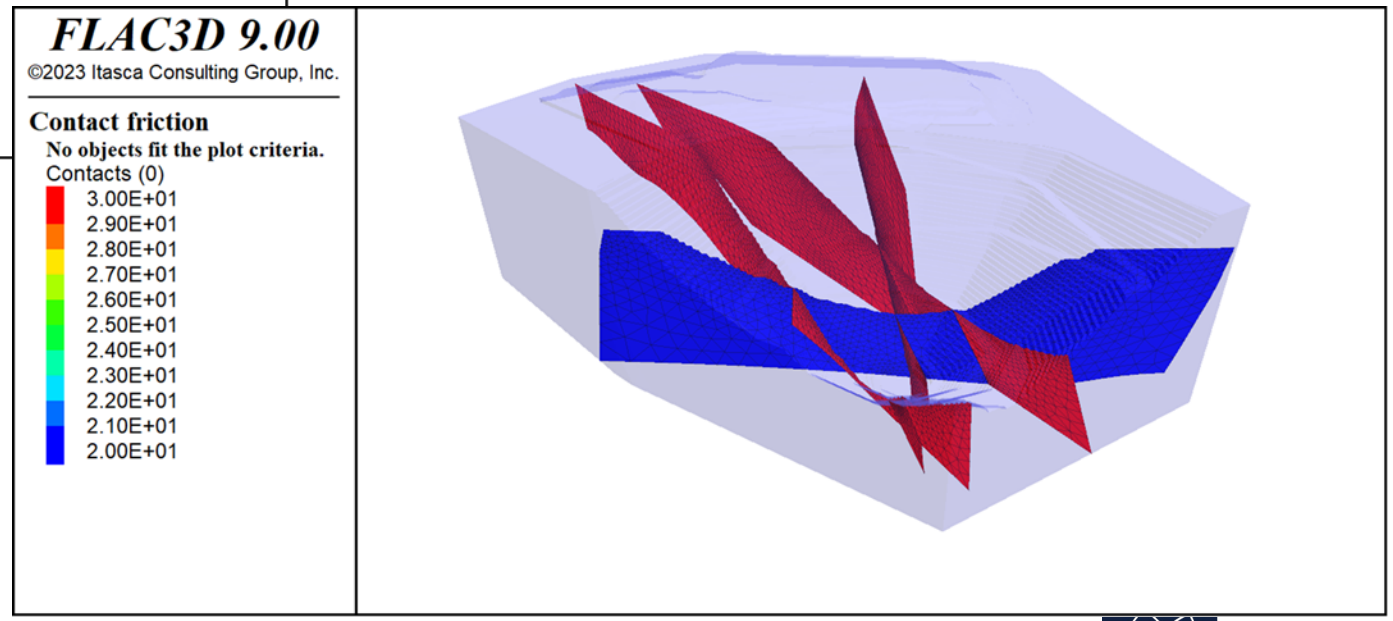


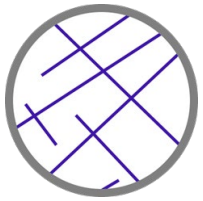


ZONE
JOINTS

Zone Joints

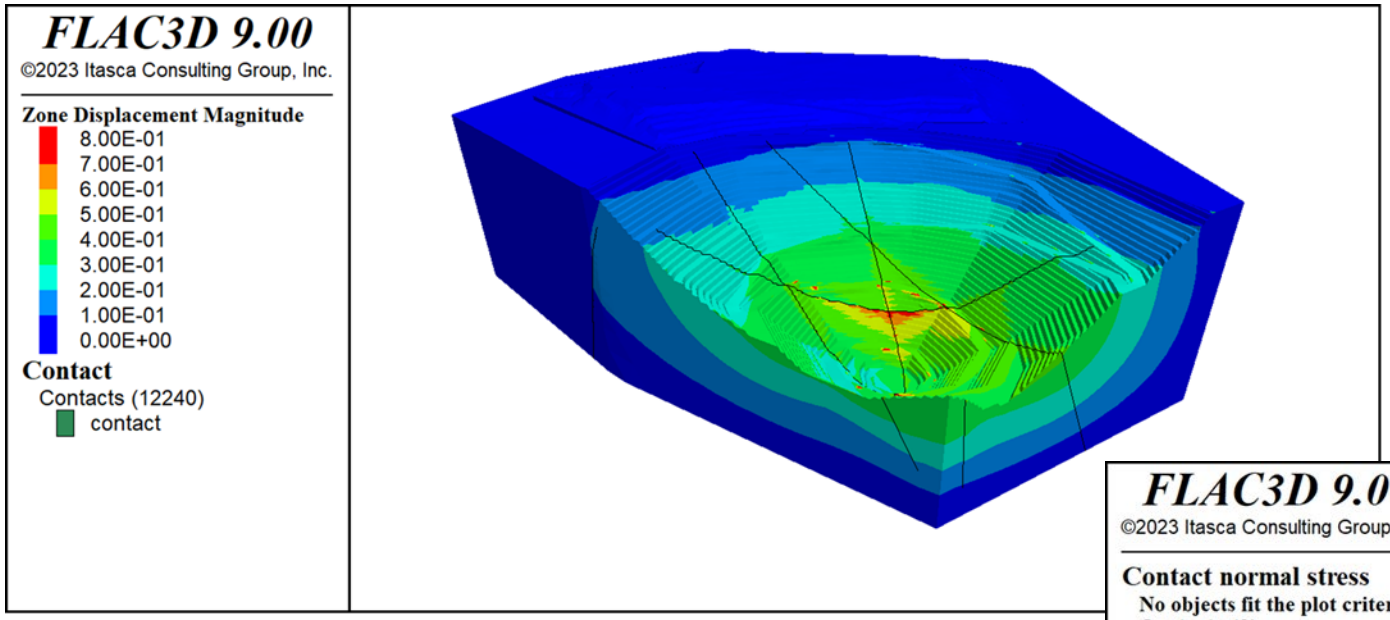


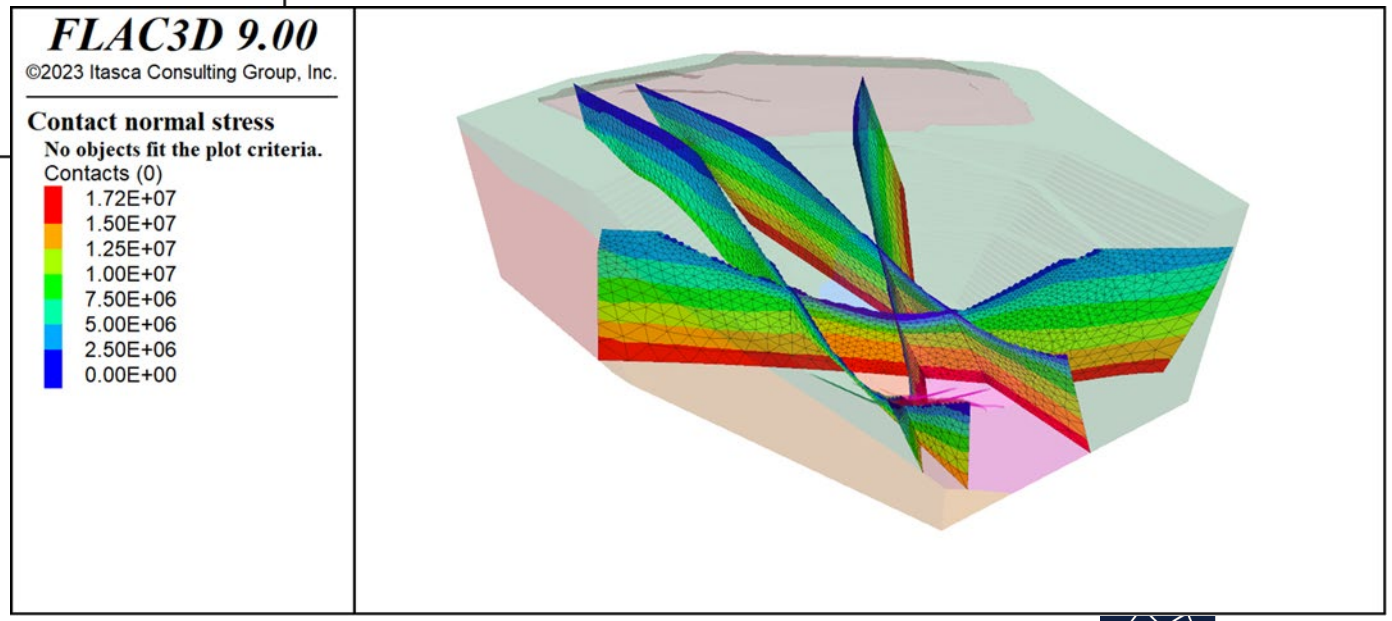


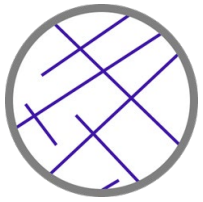


ZONE
JOINTS

Zone Joints:







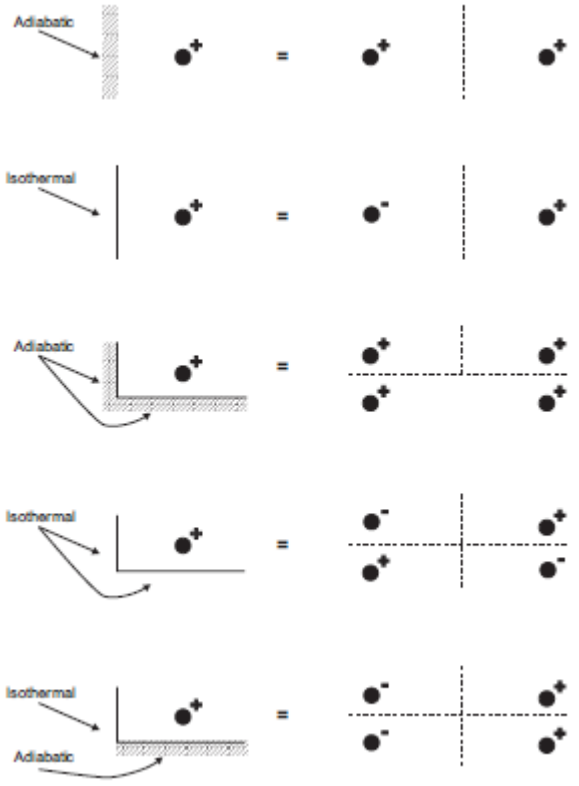
ZONE
JOINTS

Fast Analytical Temperature Calculation for Specified Sources:

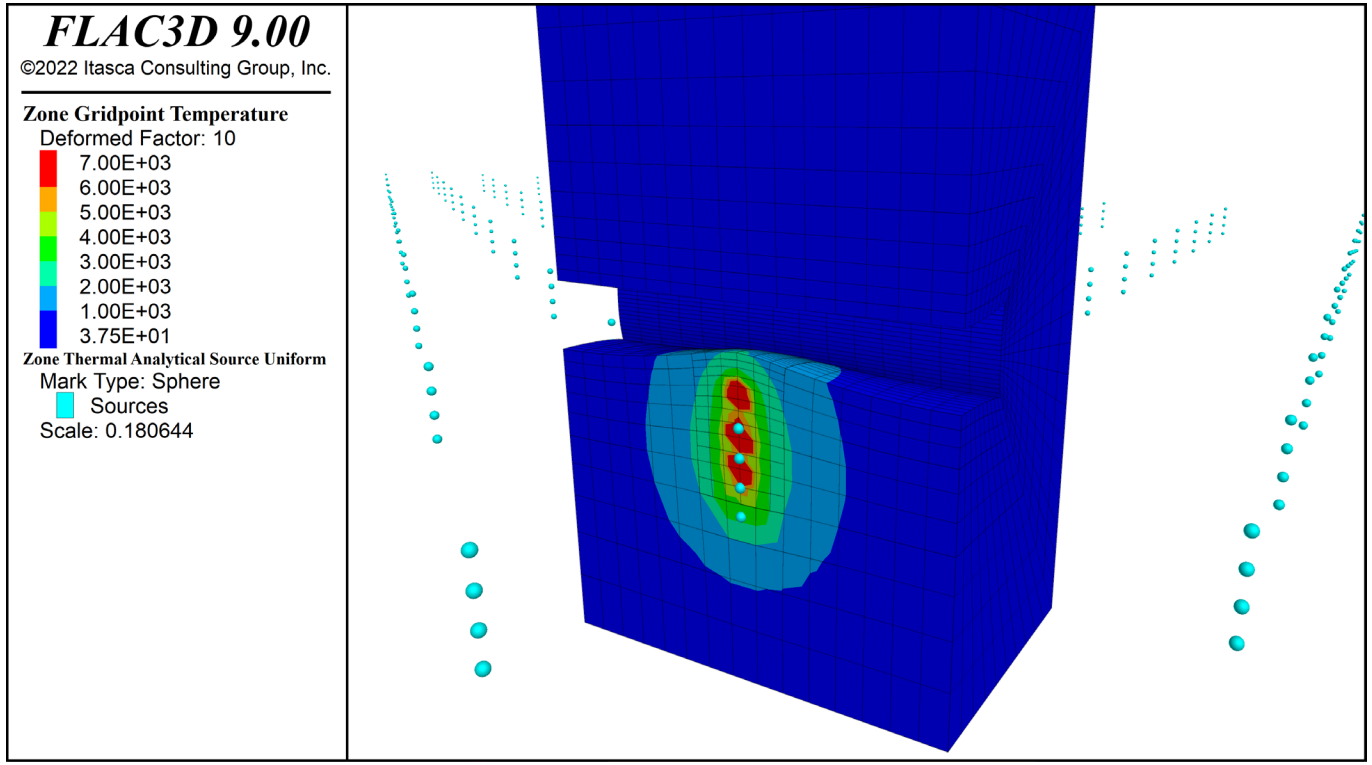
- Point heat sources are placed either individually, or in lines and grids, to represent point, line or plane sources.
- Specifically oriented to solving design problems associated with **nuclear waste disposal**.

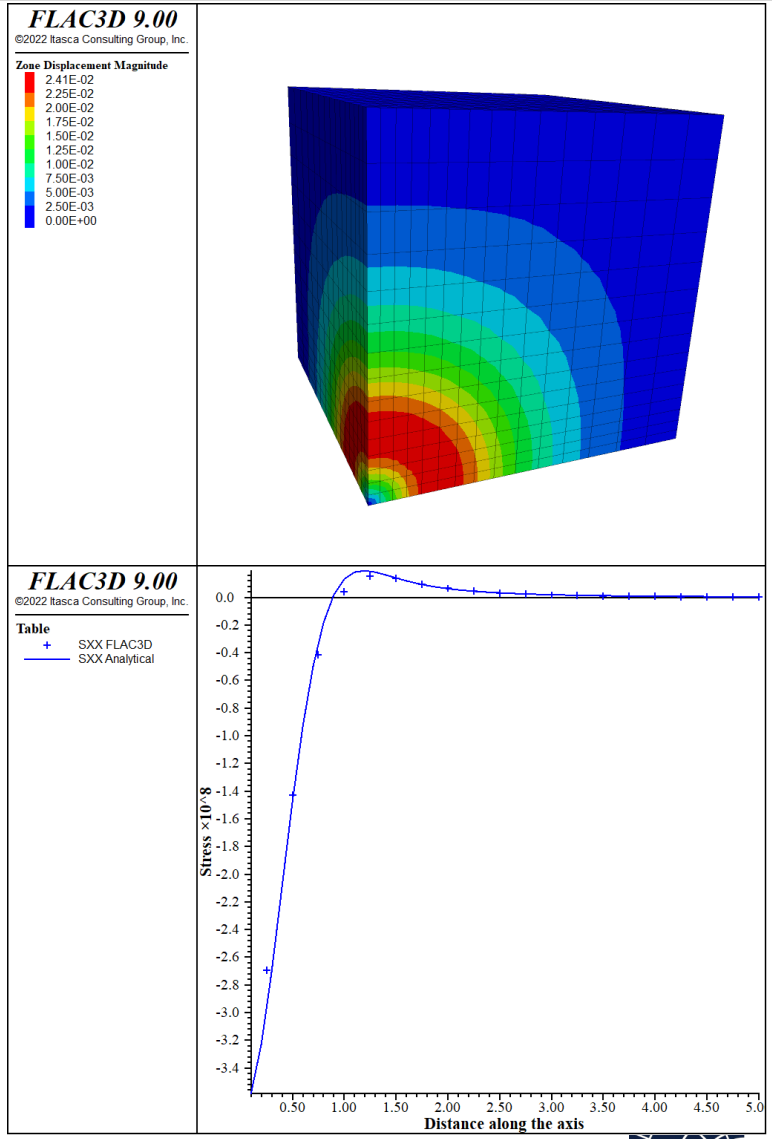
Advantages:
- Infinite thermal boundary is automatically incorporated.
- Calculation is extremely quick.
- Calculation is independent of the temperature at previous times.
- Mechanical B.C. can be applied correctly.
- Inhomogeneous and anisotropic mechanical properties.

Limitations:
- Thermally homogeneous and isotropic with constant properties.
- For only a few restricted thermal B.C. (i.e., adiabatic and isothermal planes).



Fast Analytical Temperature Calculation for Specified Sources:

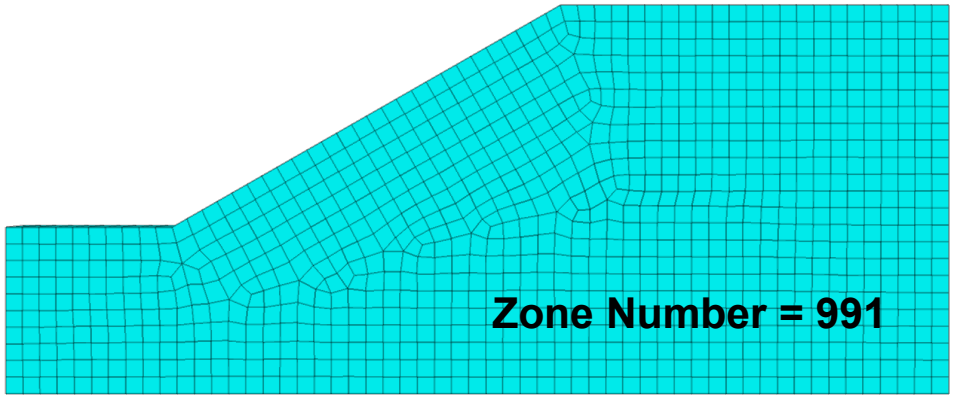


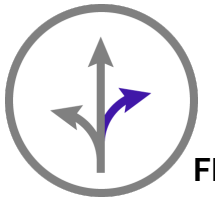


MORE NEW FEATURES

Very Flexible

- DEMO version (Windows & Linux) now allows **1000** zones.
- **All** license types now allow **two** instances per license.
- User-interface can now detect if GPU support is enabled in Remote Desktop connections and stop forcing ANGLE mode which removes all plots.

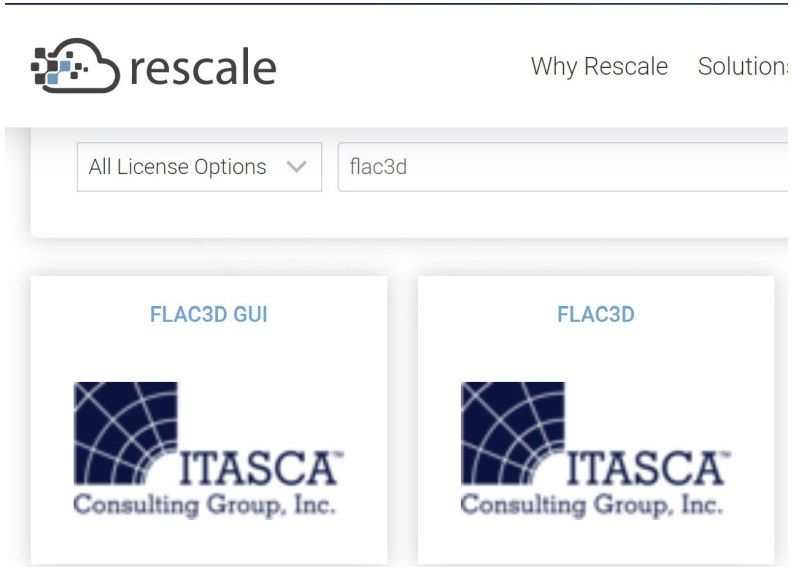


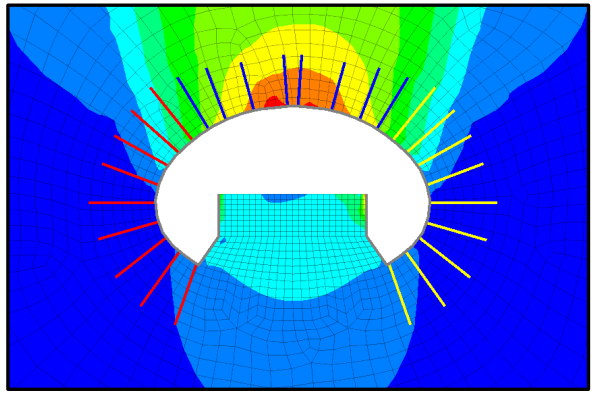


VERY
FLAXIBLE

Coming Soon

- Overhauled fluid flow calculations
  - Easier and faster
  - Implicit solutions even for partially saturated flow
  - Different permeability-suction relationships possible
- Cloud computing with Rescale
  - Easy running of *FLAC3D* on the cloud through Rescale
  - Linux version significantly cheaper than Windows. Save files are compatible.
- *FLAC2D* to be released in June
  - 2D version of *FLAC3D*.





Thank you!

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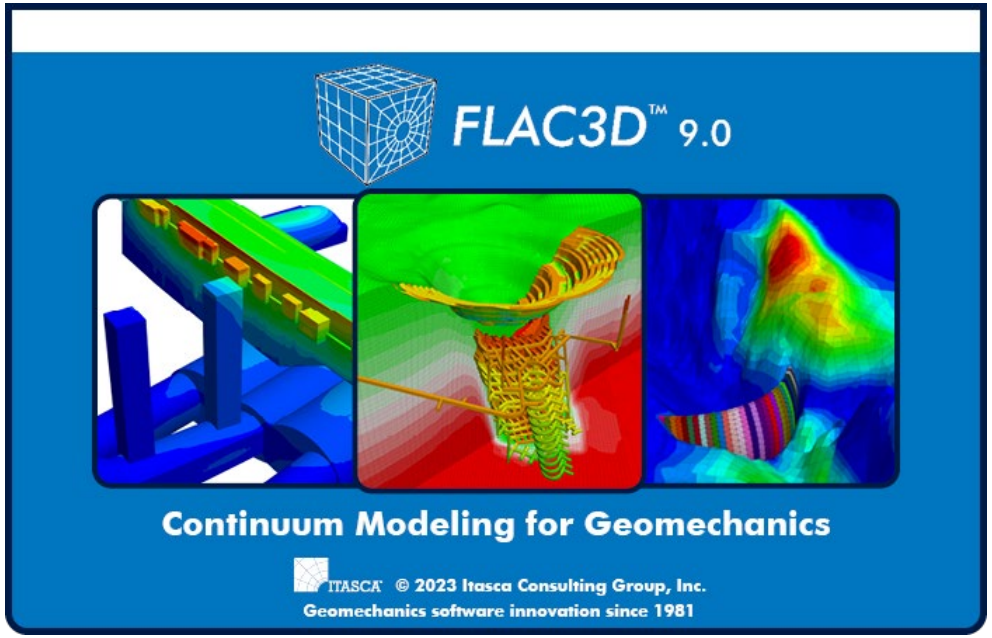
FLAC3D Technical Support
https://www.itascacg.com/contact-itasca/sw-tech-support-flac3d



For the Q&A session,
please refer to:
https://bit.ly/3pM2iYZ