LA-UR-16-24463
Approved for public release; distribution is unlimited.

Title: FDEM for Borehole Fracture Initiation

Author(s): Rougier, Esteban
Lei, Zhou
Knight, Earl E.
Munjiza, Antonio

Intended for: Workshop on HydroFracture - 50th US Rock Mechanics/Geomechanics Symposium, 2016-06-24 (Houston, Texas, United States)

Issued: 2016-07-11 (rev.1)

FDEM for Borehole Fracture Initiation

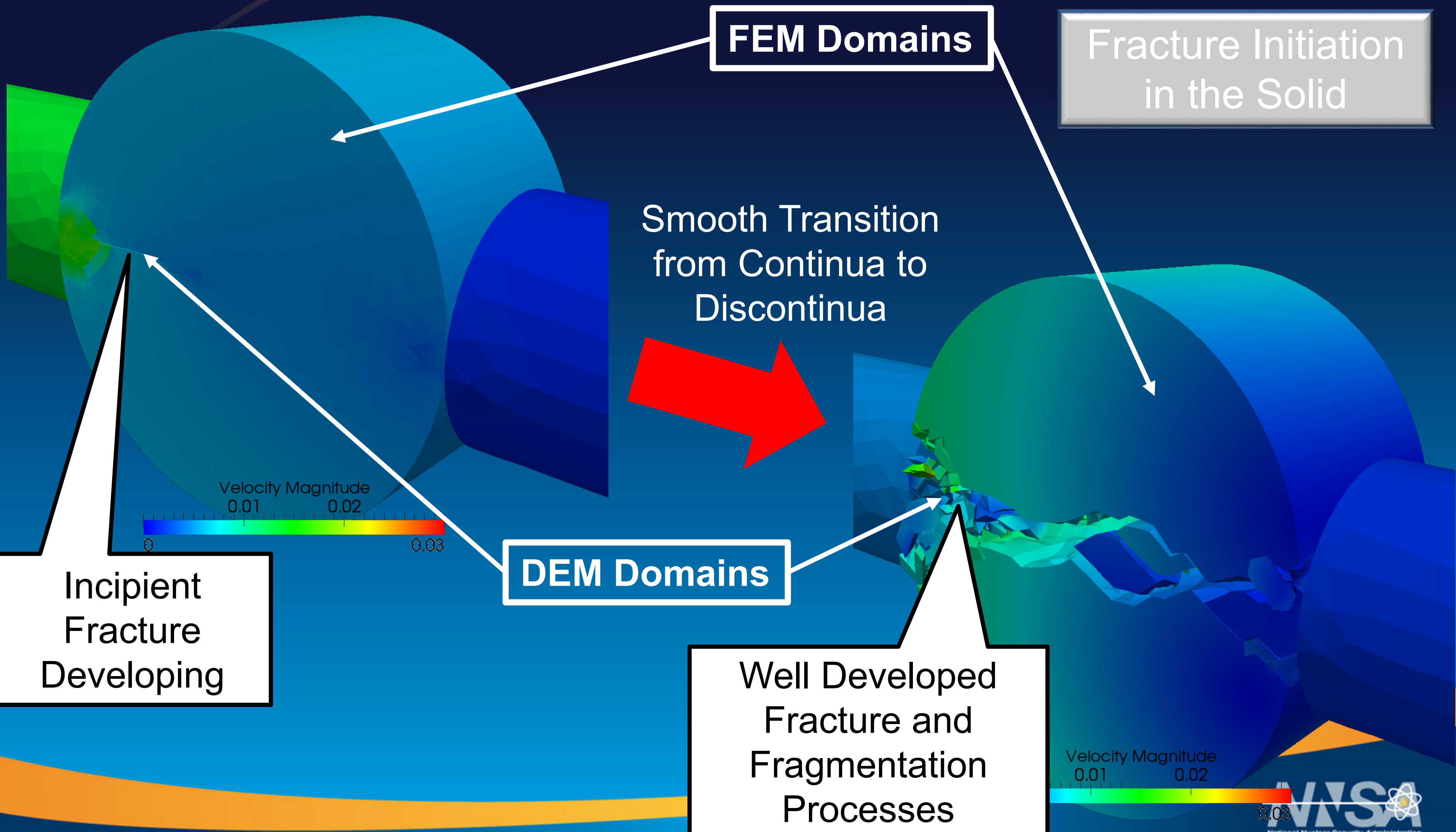
Esteban Rougier, Zhou Lei, Earl E. Knight, & Antonio Munjiza

EES-17 Geodynamics Team

Los Alamos National Laboratory

June 24, 2016

FDEM in a Nutshell
Hybrid Continua-Discontinua



HOSS
Hybrid Optimization Software Suite

Los Alamos NATIONAL LABORATORY EST.1943

HOSS-Solid

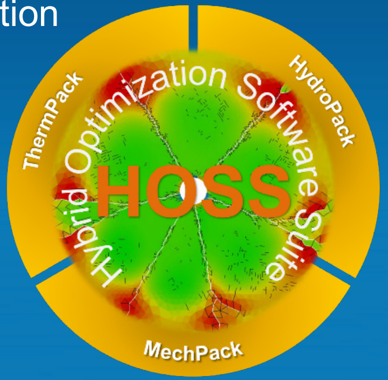
- The next generation FDEM technology
- Multiplicative decomposition-based large deformation
- Linkage to nonlinear material packages
- Incorporates material stochastic framework
- Non-locking finite elements
- Next generation fracture model
- State-of-the-art contact detection algorithms
- Latest generation discretized distributed smooth contact force based approach
- 2D/2.5D/3D general/irregular shapes of discrete elements
- Rock joint handling

HOSS-ISF

- Naturally integrates solid with all regimes of fluid flow at material point level
- Not a coupling approach
- Supports any explicit solid solver and any explicit fluid solver
- Resolves transient and steady state flow through crack manifolds as well as existing rock joint manifolds
- Resolves transient and steady state flow between crack/joint manifolds and rock matrix
- Resolves transient and steady state anisotropic flow through porous geo-material (seepage)

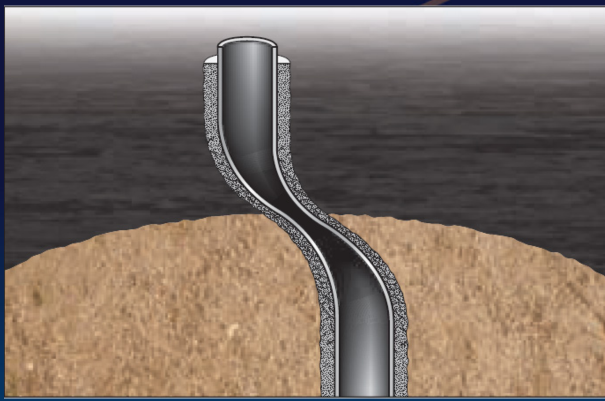
HOSS-Fluid

- Universal explicit CFD solver for all flow regime
- Suitable for both steady state and developing transient flow
- Stable for all flow regimes
- Combines all flow regimes in the same problem
- Material law is supplied separately through material packages
- Includes non-inertial Eulerian formulation

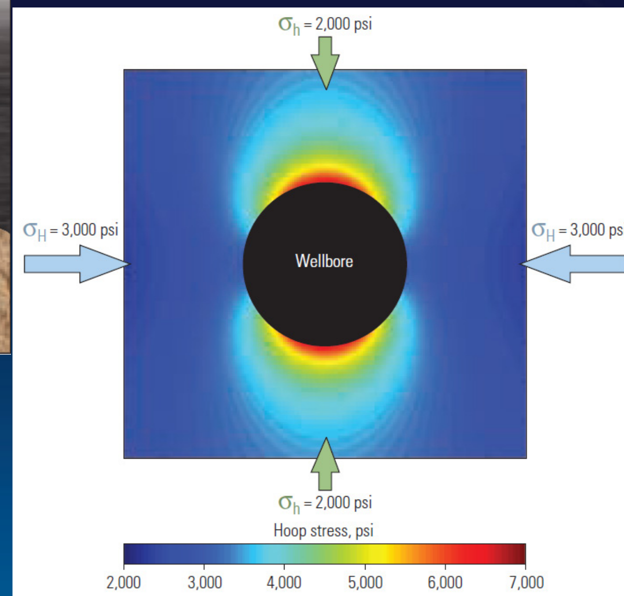


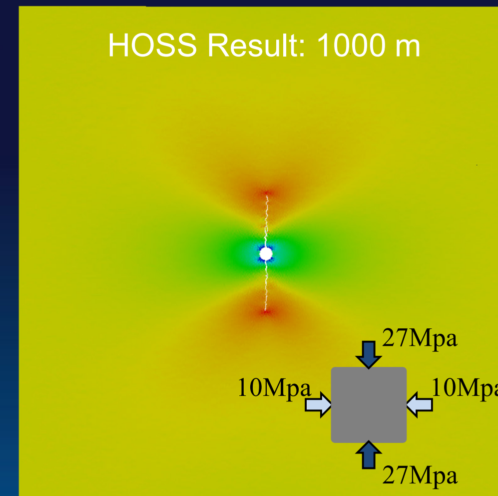
Initially developed for high strain rate analysis of underground explosive events

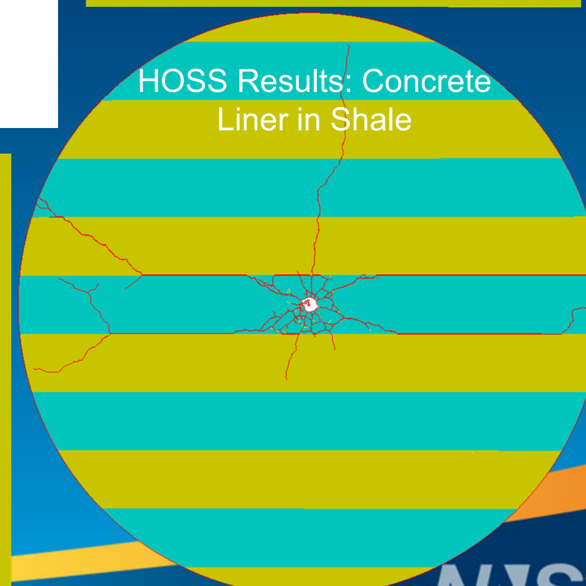
Previous Work on Fracking
Wellbore Stress

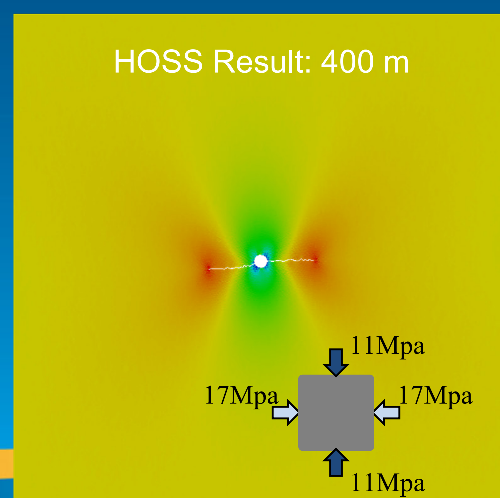


Pics from “Rocks Matter: Ground Truth in Geomechanics,” Cook et. al.





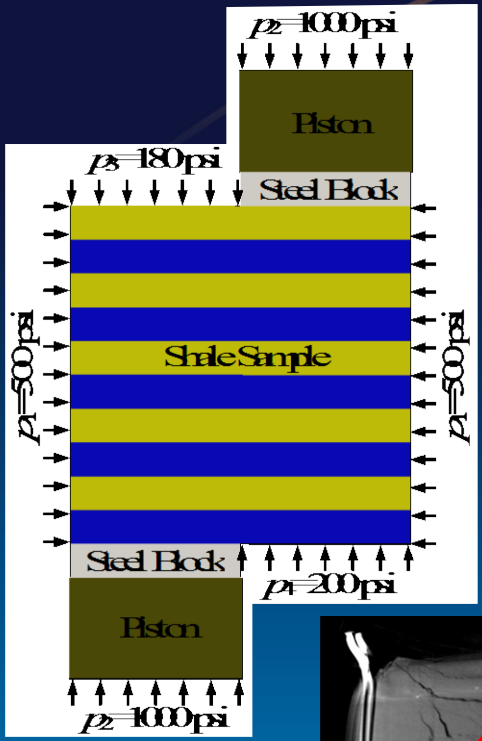


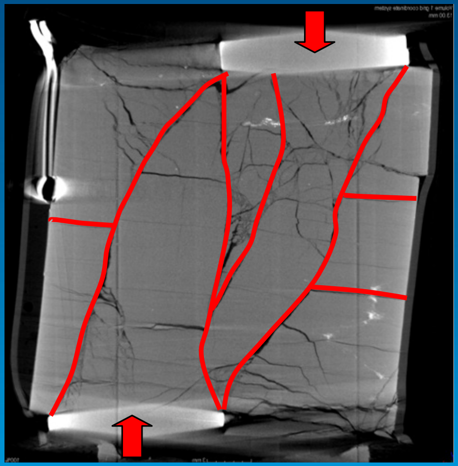


Wellbore Integrity and Drilling Technologies

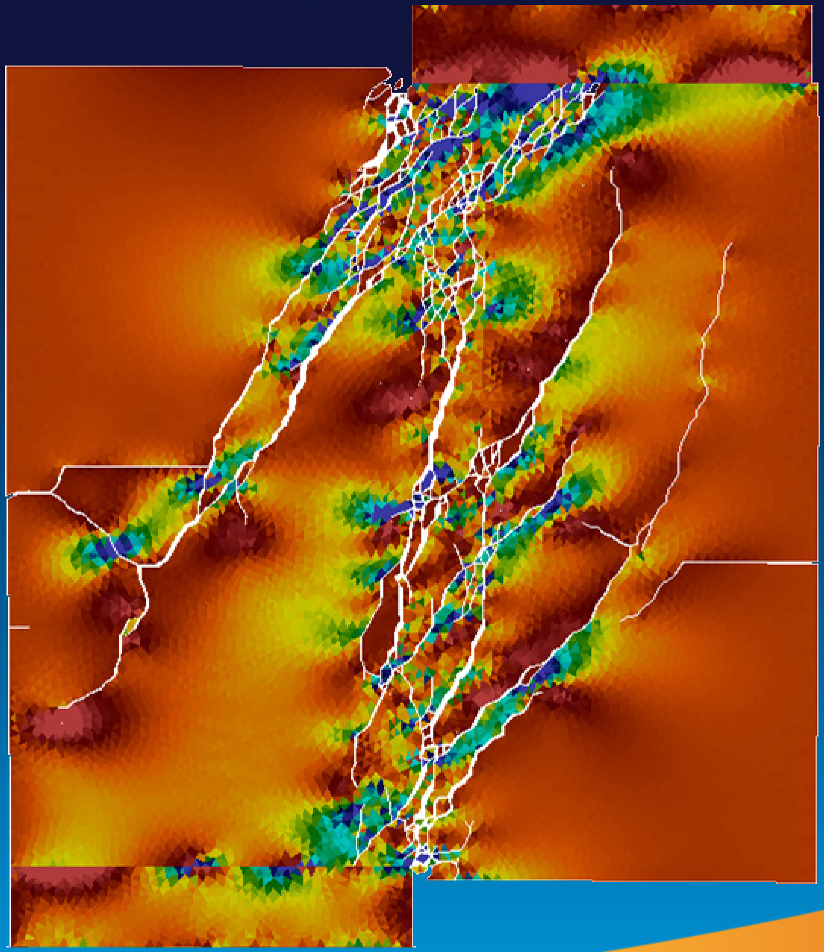
Previous Work on Fracking

Triaxial Core-Flood Experiment of Shale



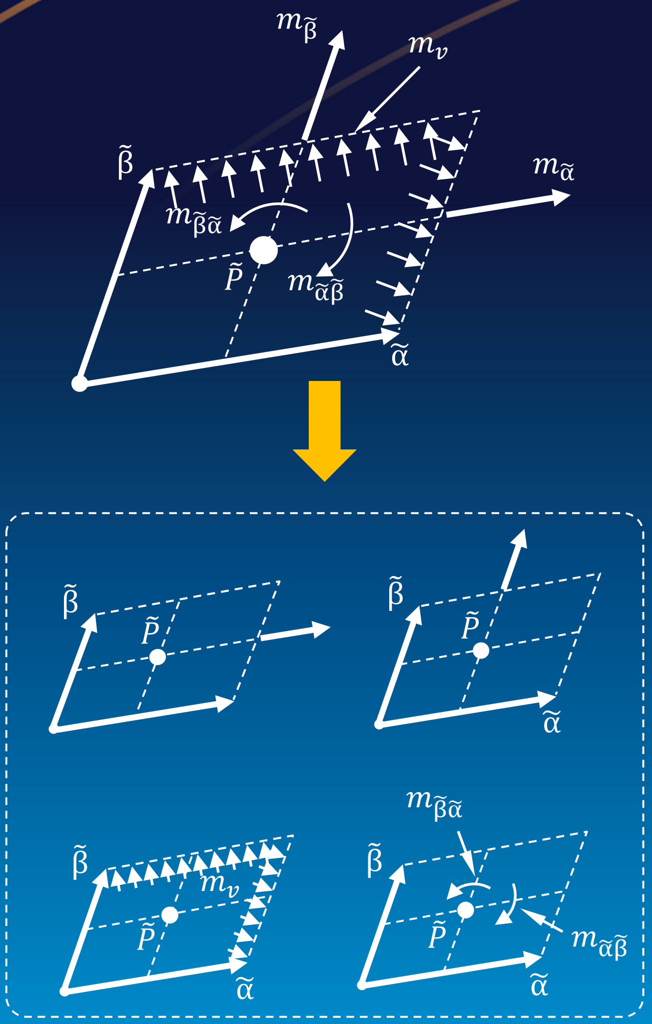


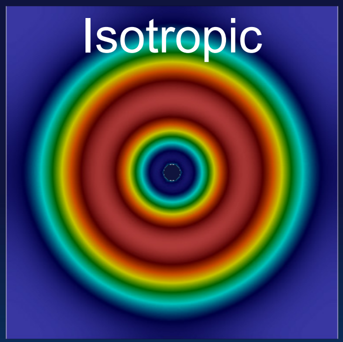
Animation of Shear Stress

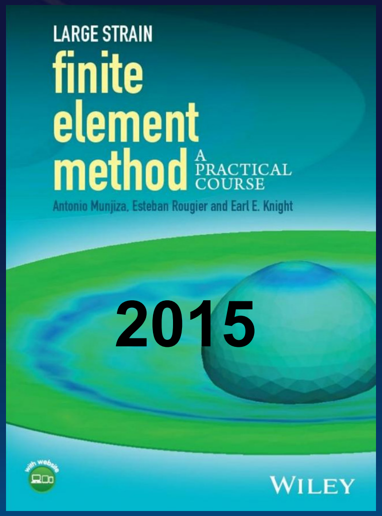


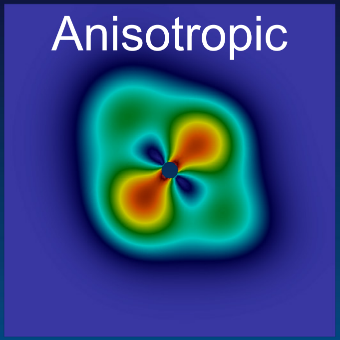
Advanced Developments under HOSS

Solid Material Model



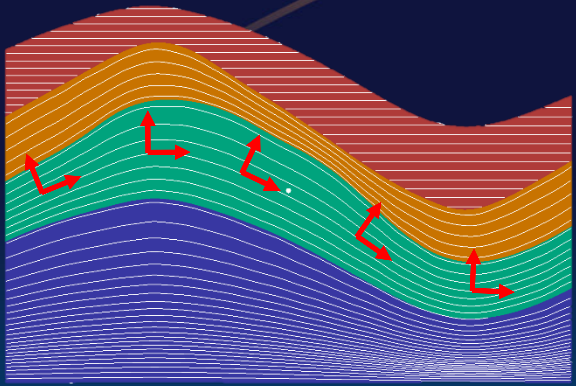




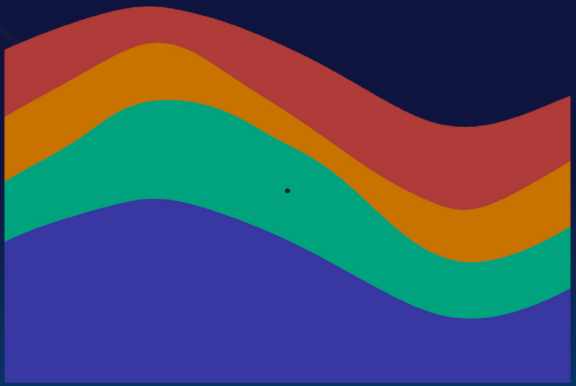


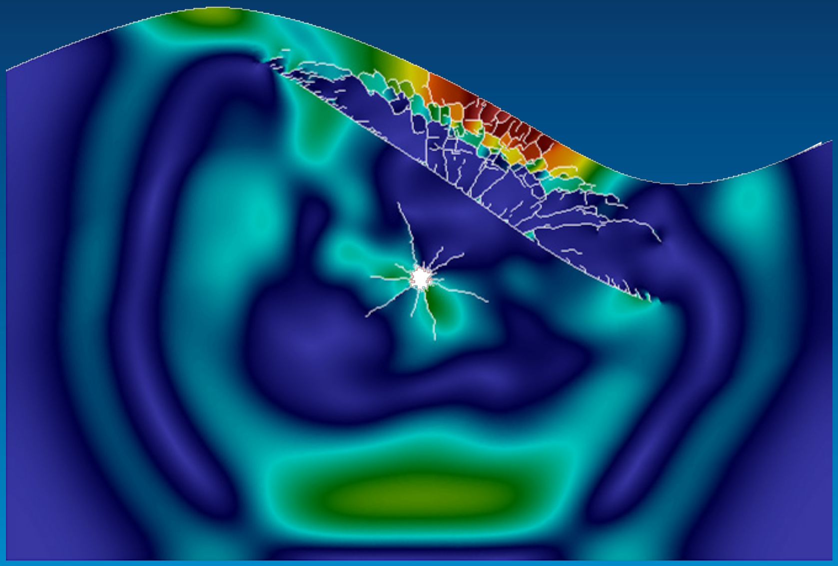
- Features a unified hypo-hyper approach with multiplicative decomposition based selective integration approach.
- Eliminates volumetric locking.
- Multiplicative decomposition allows for the linkage to nonlinear material packages.
- Anisotropic properties of the solid can be specified in a cell by cell basis.

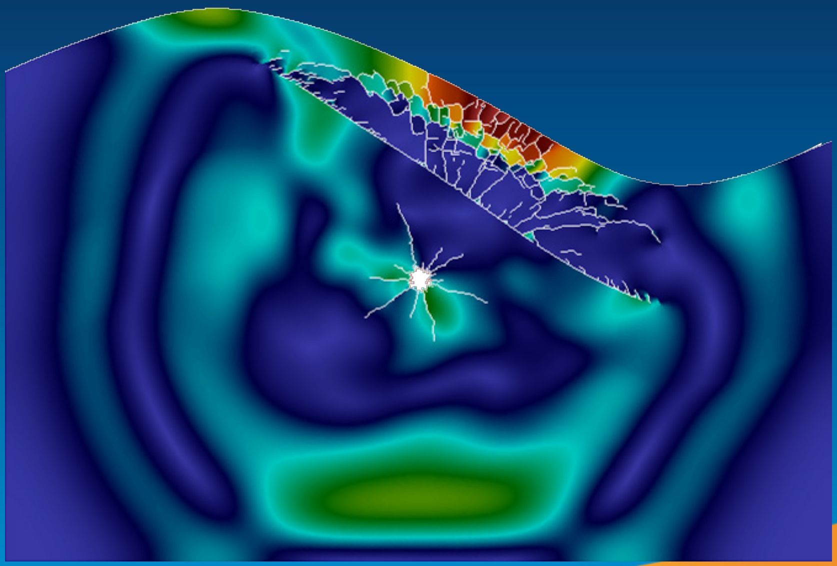
Advanced Developments under HOSS
Solid Material Model



Anisotropic vs. Isotropic

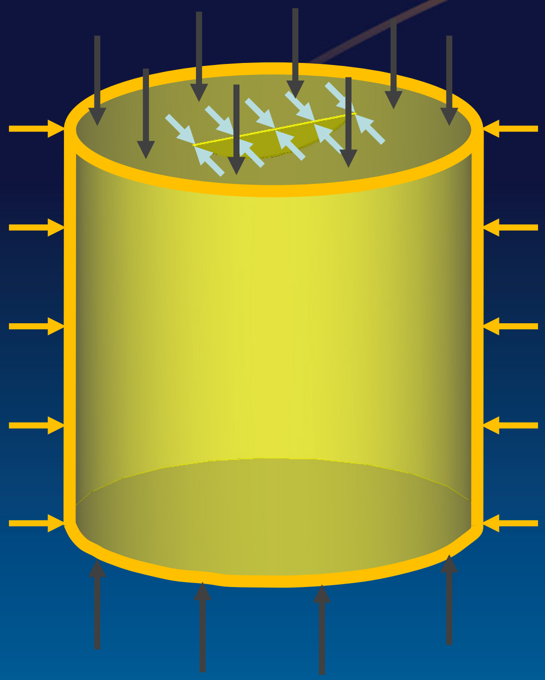


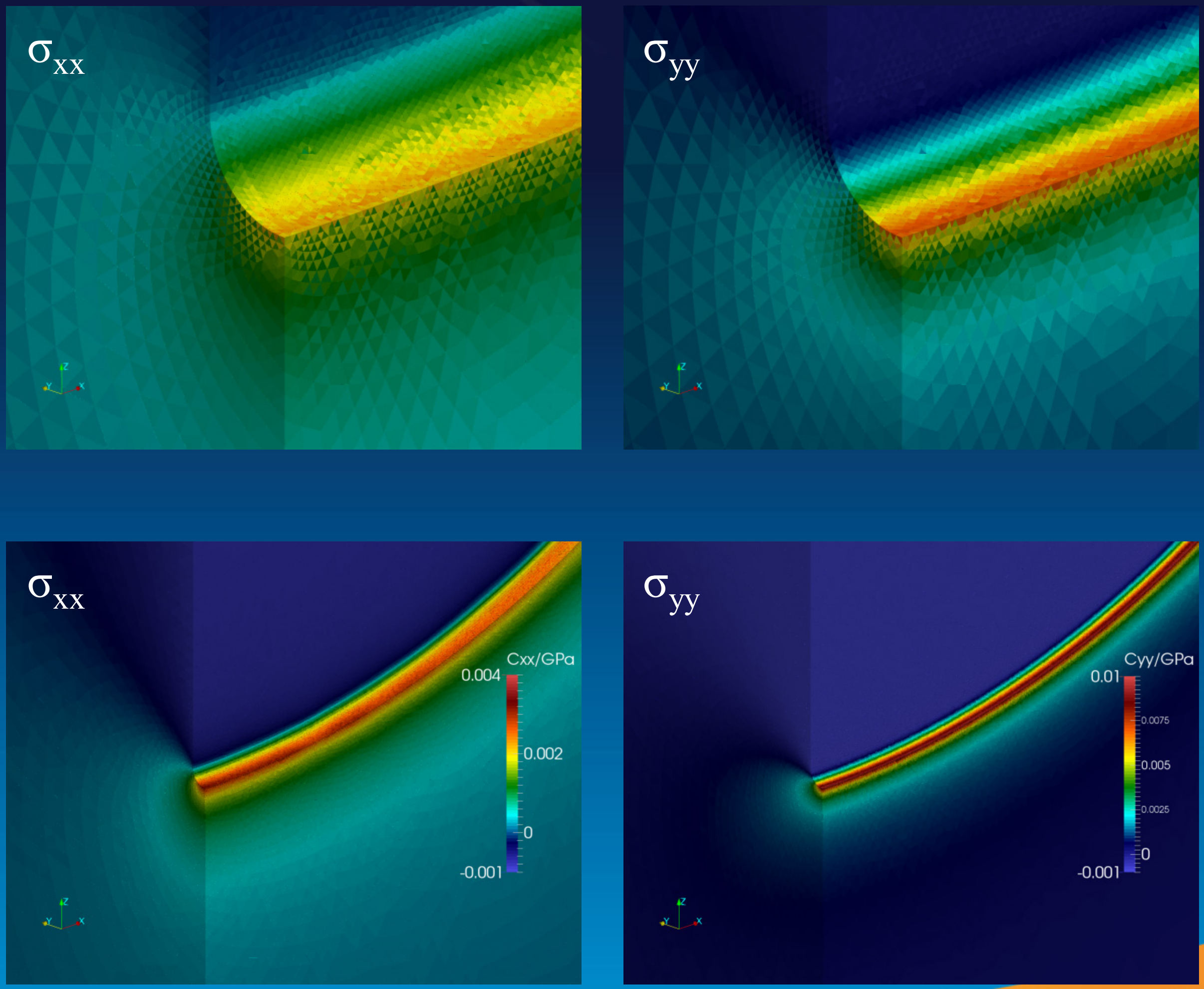




Advanced Developments under HOSS

Solid Material Model

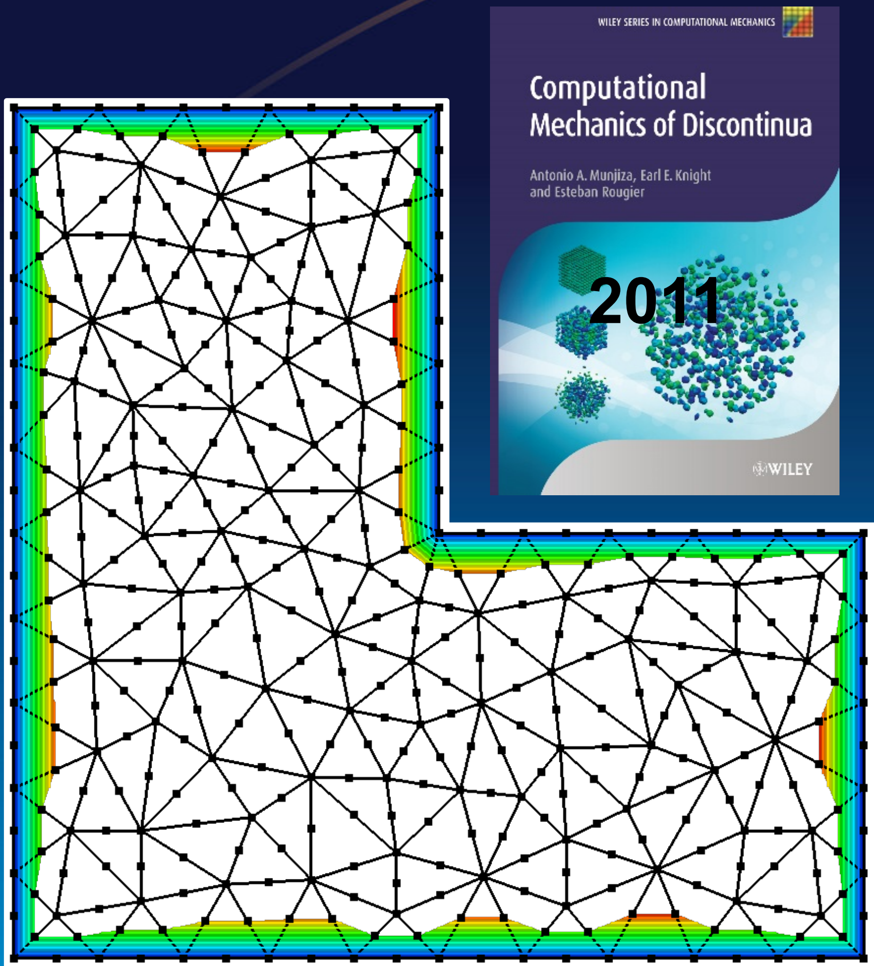




Constant Strain Tet.
vs.
Composite Tet.

In the composite elements selective integration of stresses is used in order to avoid locking problems

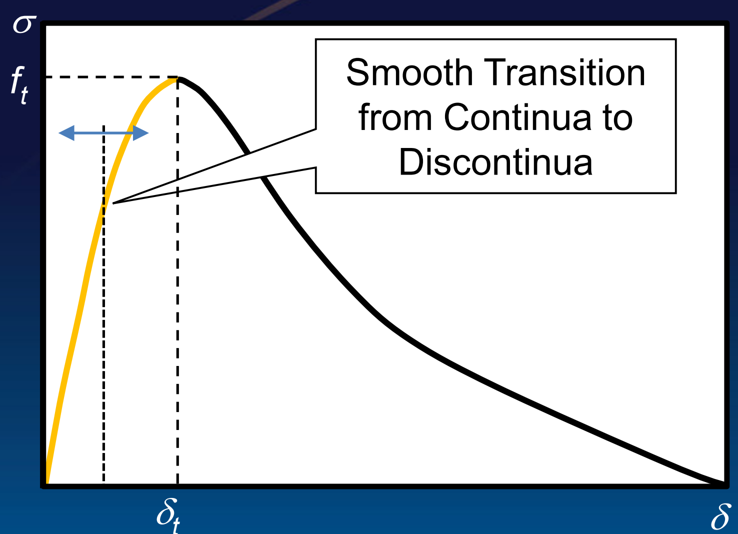
Advanced Developments under HOSS
Smooth Contact Algorithm

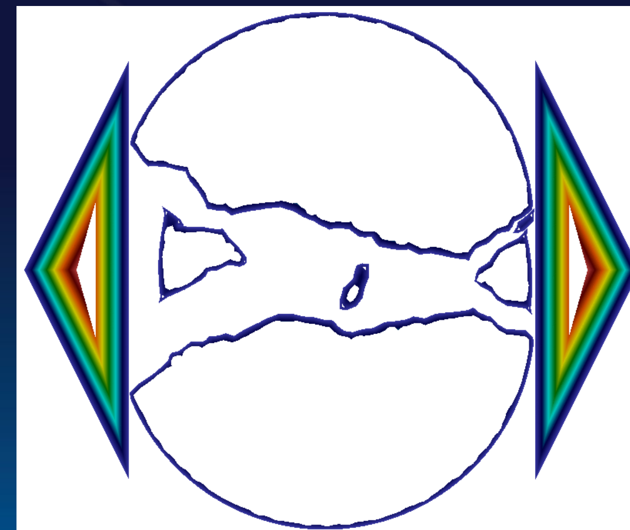


- A improved discretized distributed contact force based approach which exactly preserves the contact energy.
- A "triangle to point" approach greatly improves the computational efficiency in FDEM.
- The smooth approach greatly improves accuracy especially for dynamic fracture related simulations.
- A robust algorithm that overcomes the problems observed with existing contact enforcement approaches ("non-smooth contact forces" and "dead contact zones").

With this new algorithm the contact search and interaction is resolved only around the areas of interest, i.e., fractures

Advanced Developments under HOSS
Unified Cohesive Model





- Features a unified cohesive model, which incorporates most of the advantages from existing approaches.
- Automatically and dynamically inserts damaged surfaces into the material according to the stress state.
- Smoothly transits state variables from continua to discontinua.
- Incorporates the smooth contact algorithm which greatly improves both the efficiency and accuracy.

Advanced Developments under HOSS

1st Generation vs. Next Generation

1st Generation FDEM

- Combined Single Smeared Crack Model
- Discrete Element based Contact Algorithm
- Constant Strain Elements

Next Generation FDEM

- Non-locking Elements
- Smooth Contact Algorithm
- Unified Cohesive Model

Smoother Fracture Transition

Smoother Contact Force

Smoother Stress Field

Y-code based

Continua

Discontinua

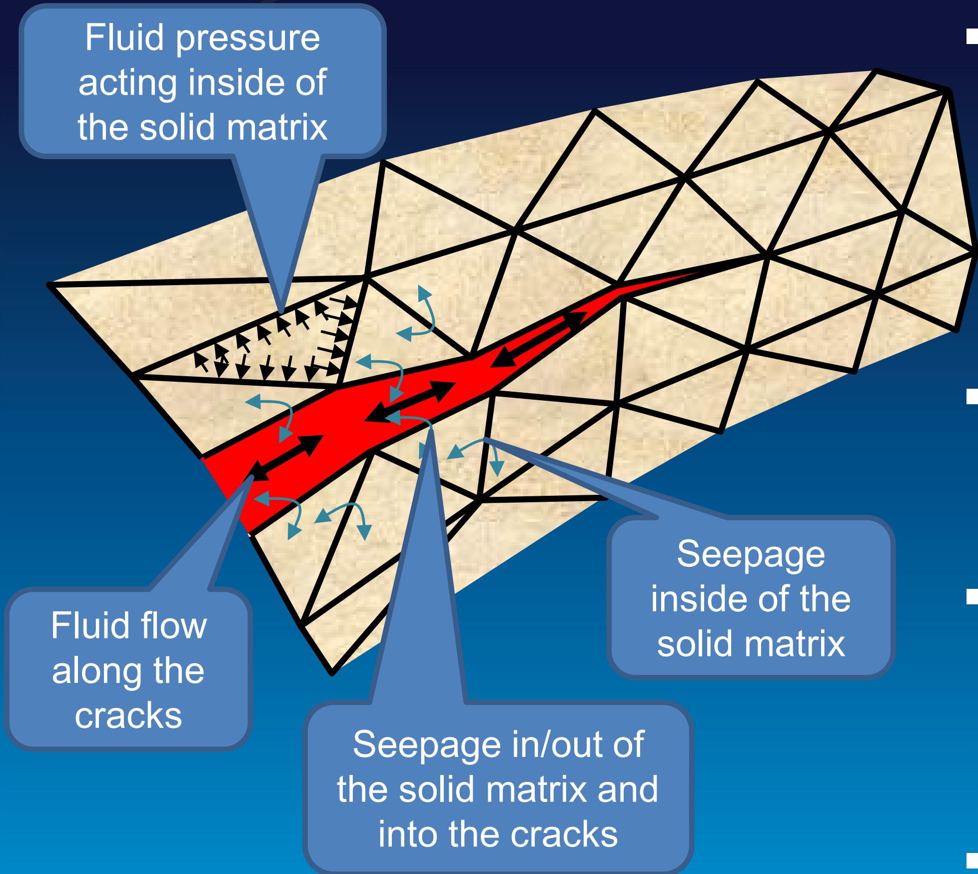
HOSS based

Continua

Discontinua

The Solver for Fracking

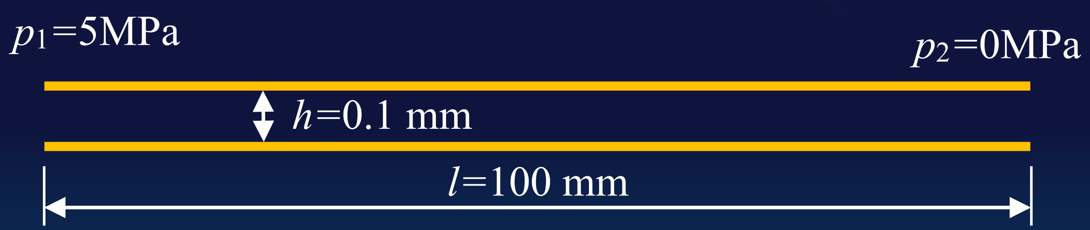
Integrated Solid-Fluid Solver (ISF)

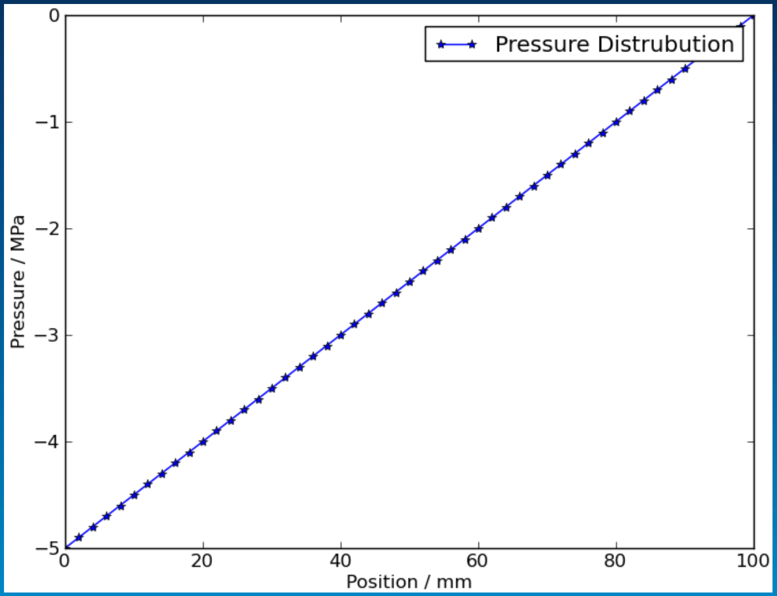


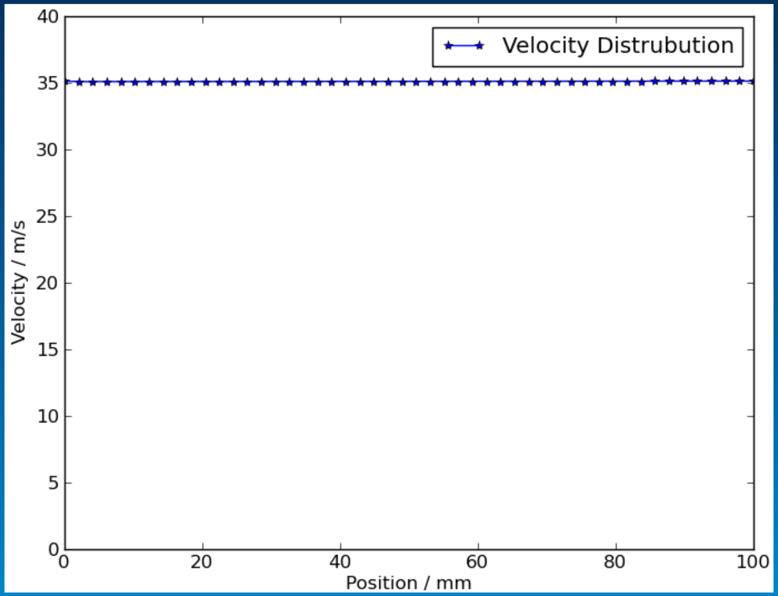
- Specially designed for modeling hydrofrac type of processes
- ISF accounts for:
  - Fluid flow through fracturing porous solid in 2D/3D
  - Fluid flow through crack manifolds
  - Pressure wave propagation through fluid
  - Fluid-solid interaction
- Fluid phase is described using the same grid of solid phase via a modified Eulerian formulation.
- Eliminates the need of continuously mapping physical variables between the fluid and solid domains.
- Explicit solver with an aperture independent time step

US Patent #US20150032427 A1

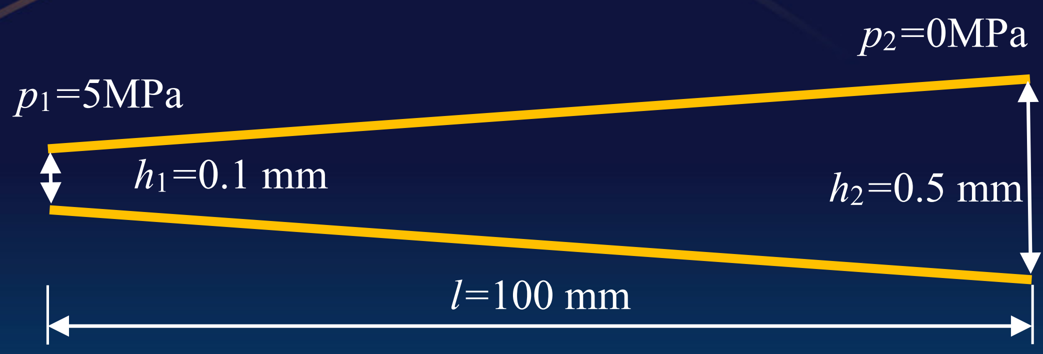
Integrated Solid-Fluid Solver (ISF)

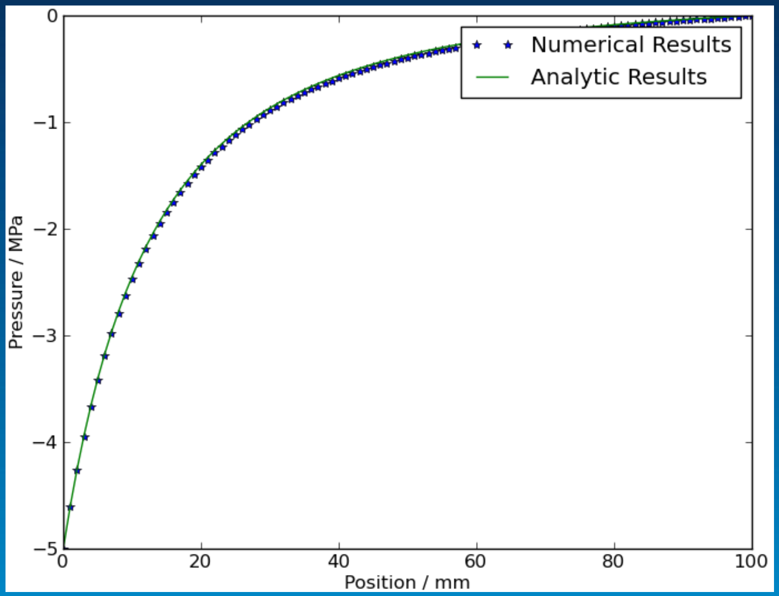


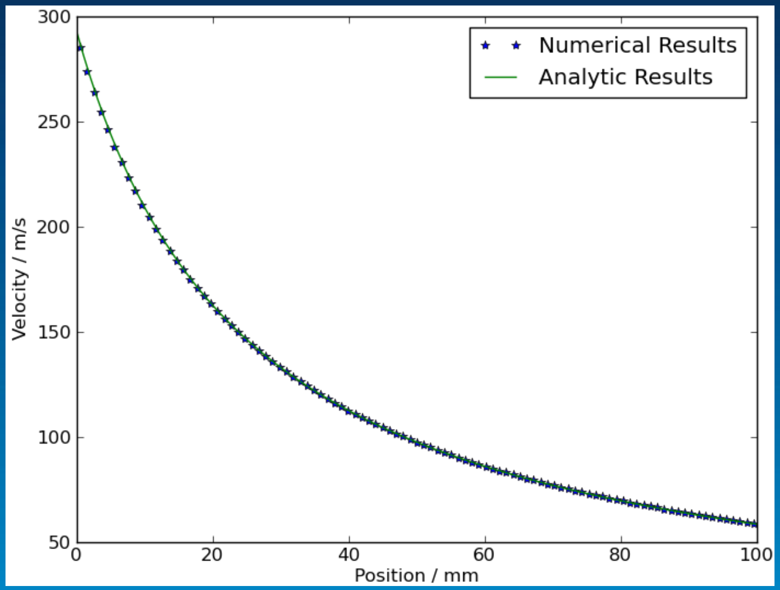




Integrated Solid-Fluid Solver (ISF)

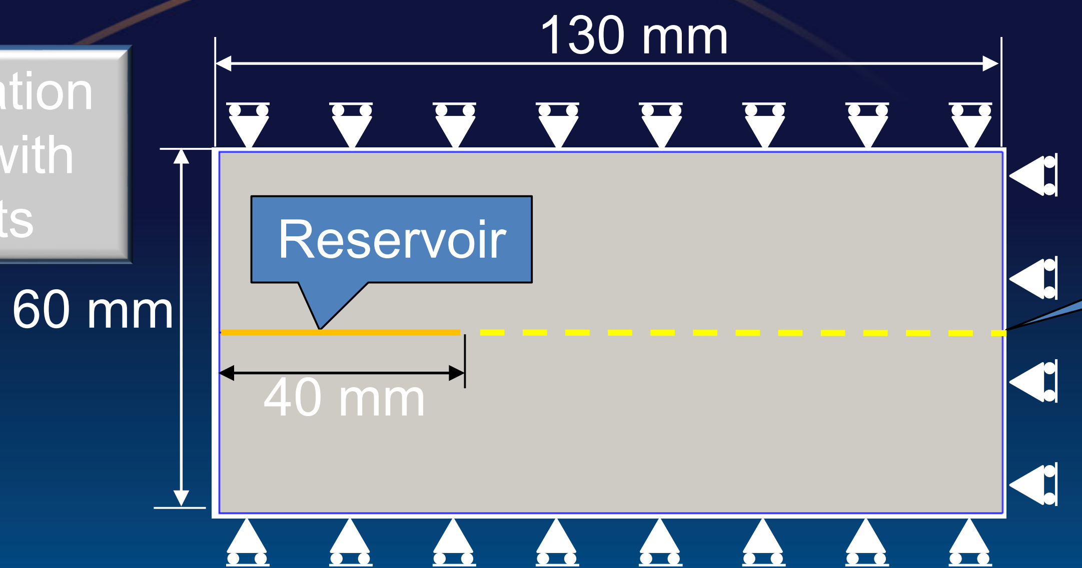


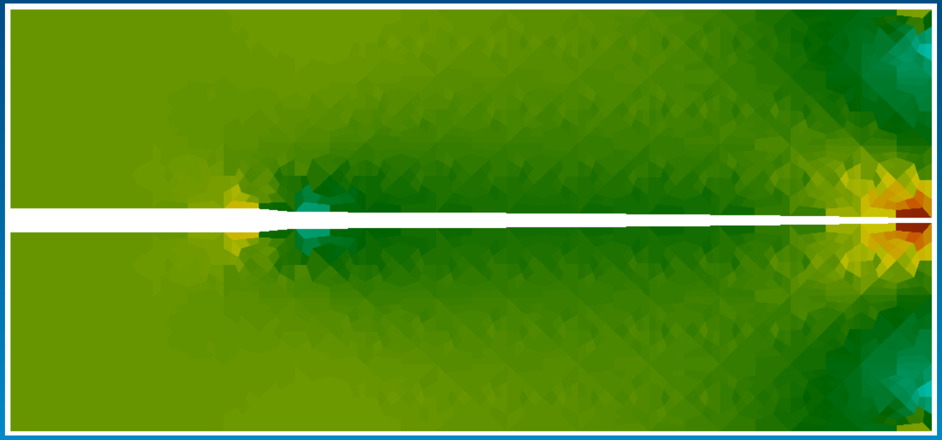




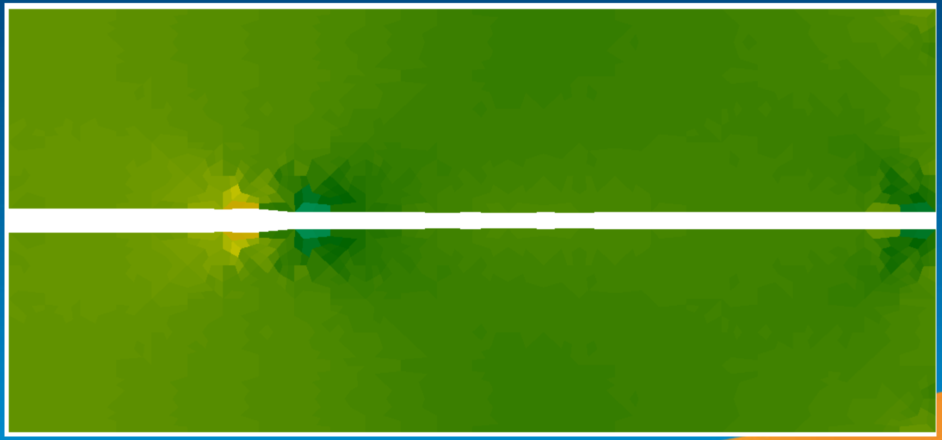
Integrated Solid-Fluid Solver (ISF)

Fracture Initiation in the Solid with Fluid Effects





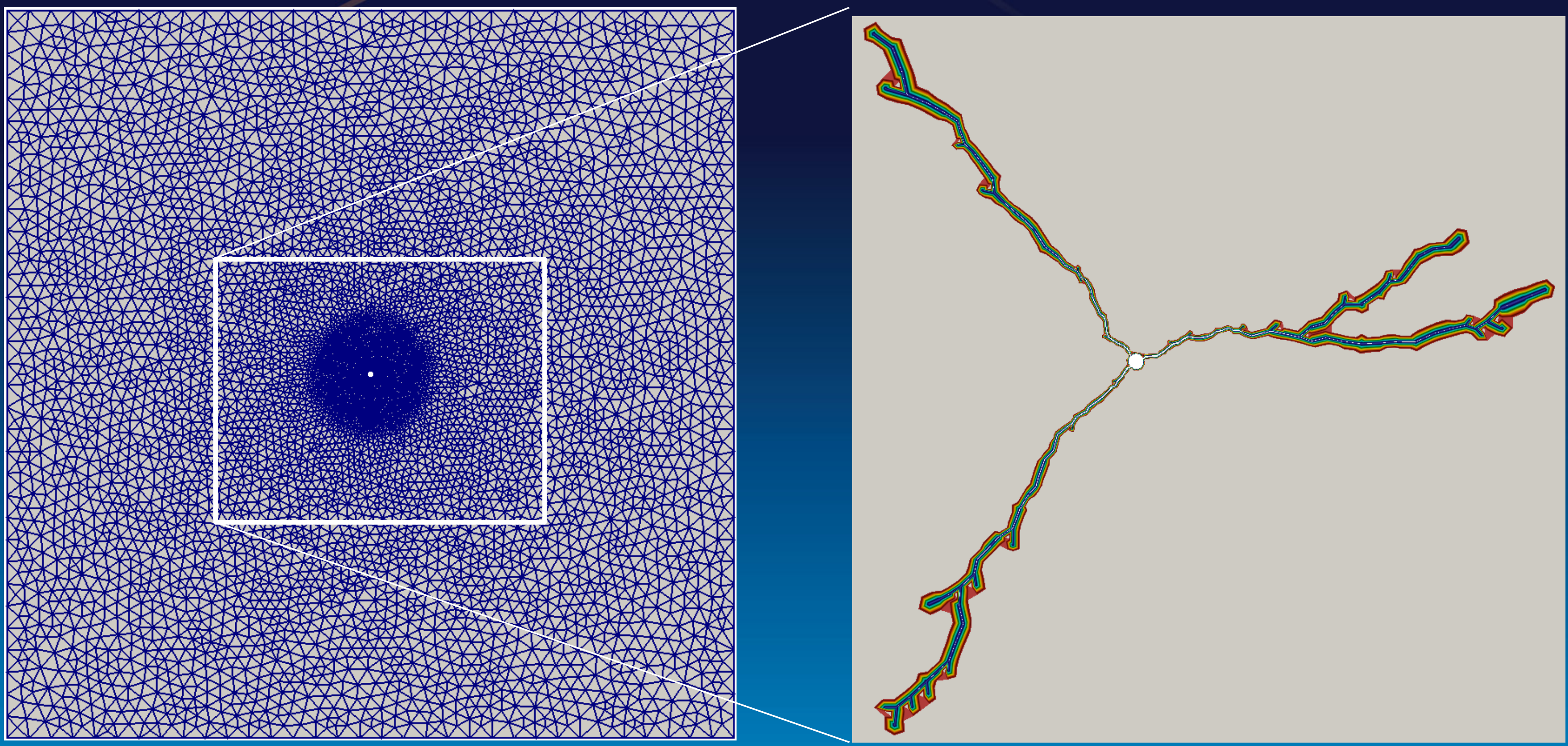
High Δp

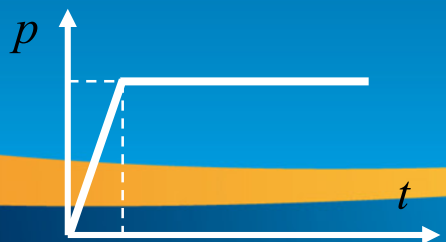


Low Δp

ISF Solver Applied to Hydrofracture

Around Borehole

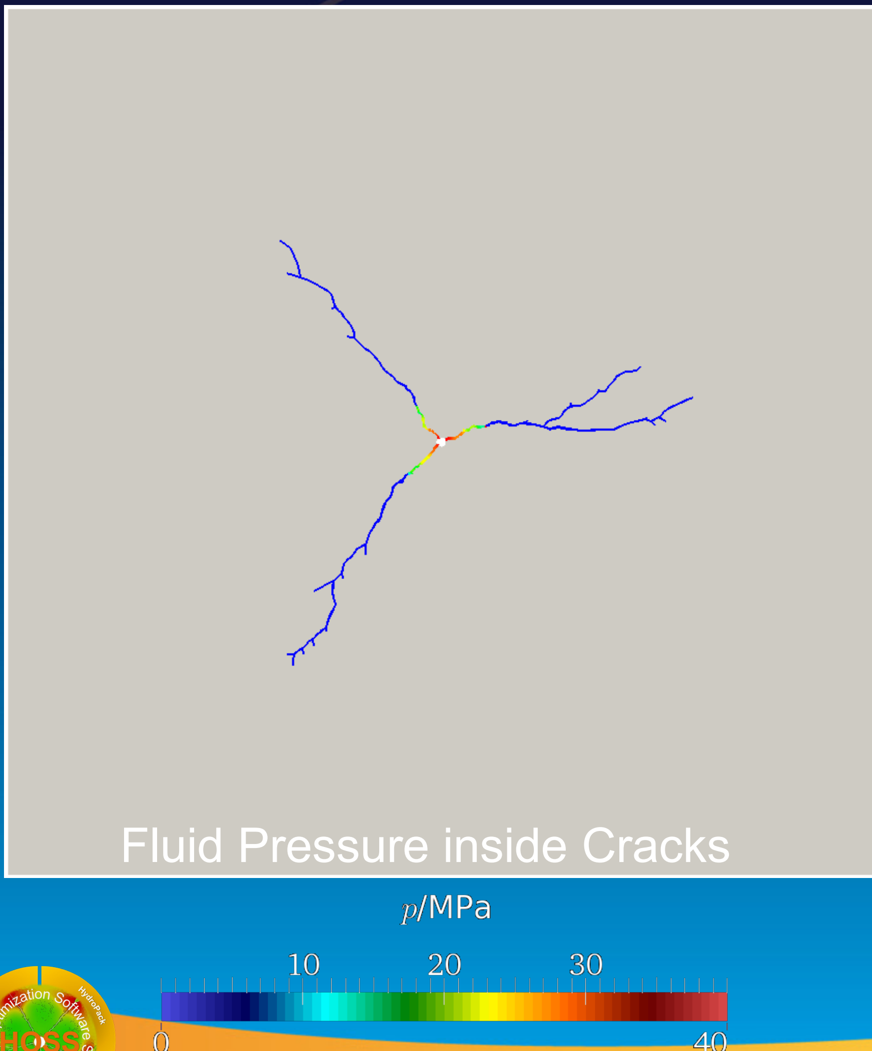




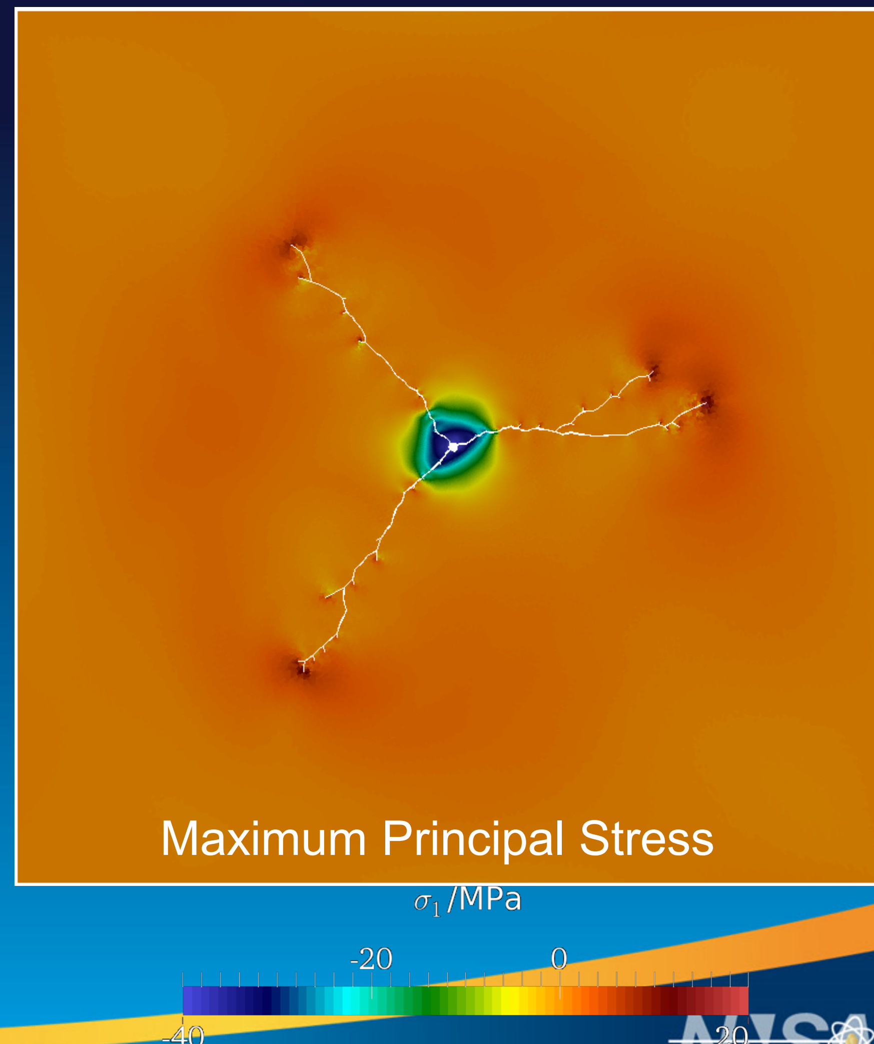
Dimension = 50 m × 50 m
Diameter of borehole = 0.5 m
Element size around borehole = 0.1 m
Total number of elements = 12560

ISF Solver Applied to Hydrofracture

Around Borehole



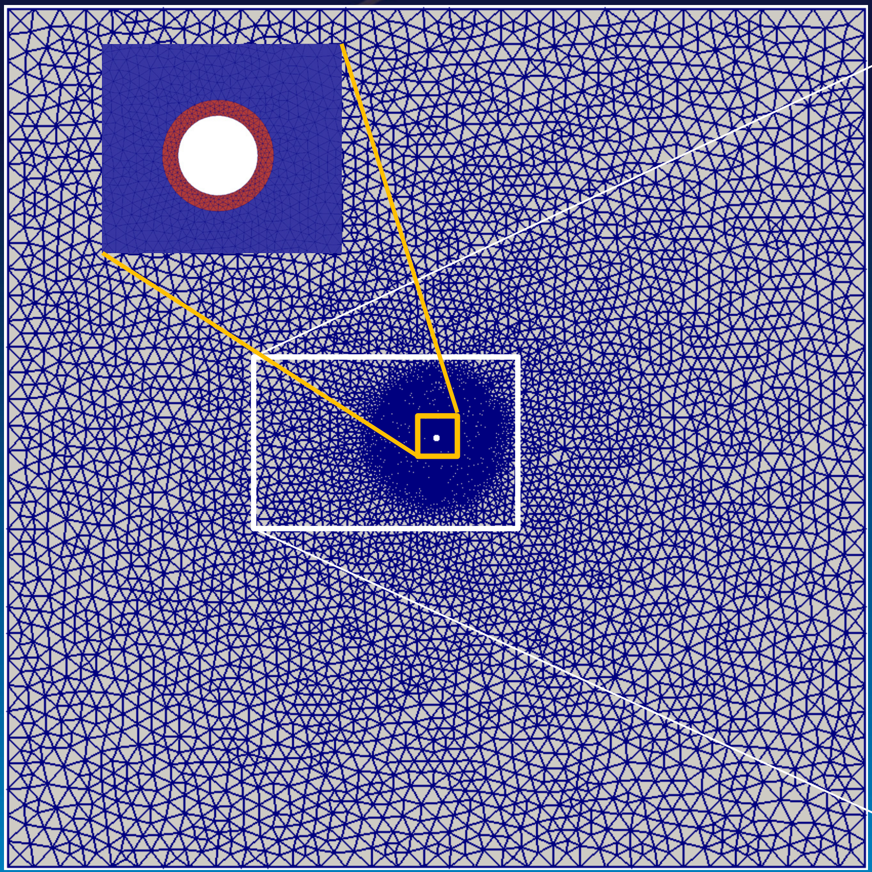
Fluid Pressure inside Cracks



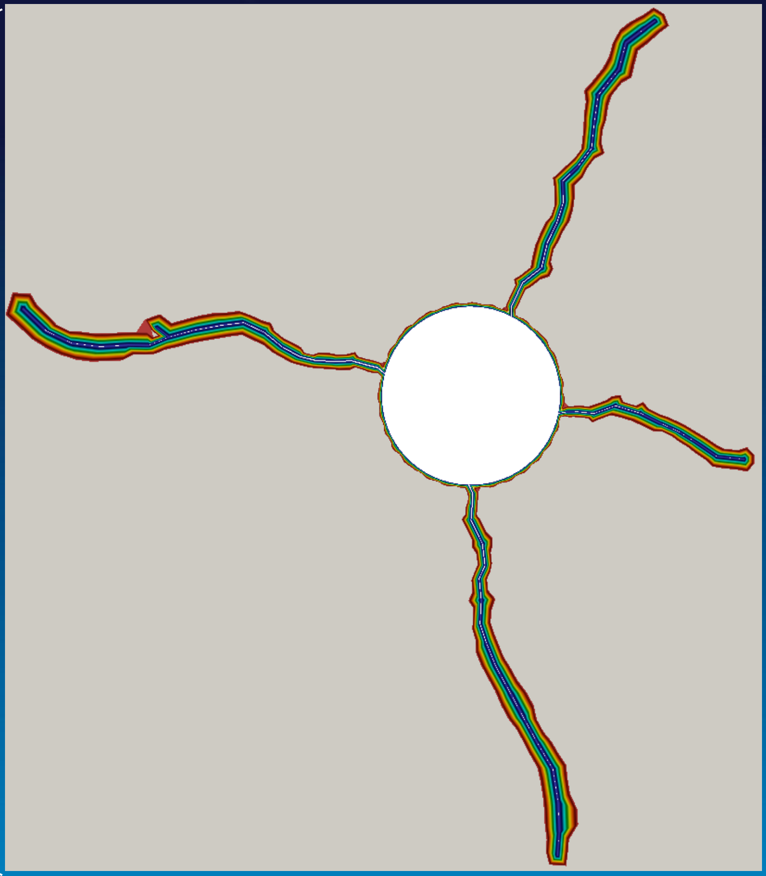
Maximum Principal Stress

ISF Solver Applied to Hydrofracture
Around Borehole – 20 MPa

Computational Model



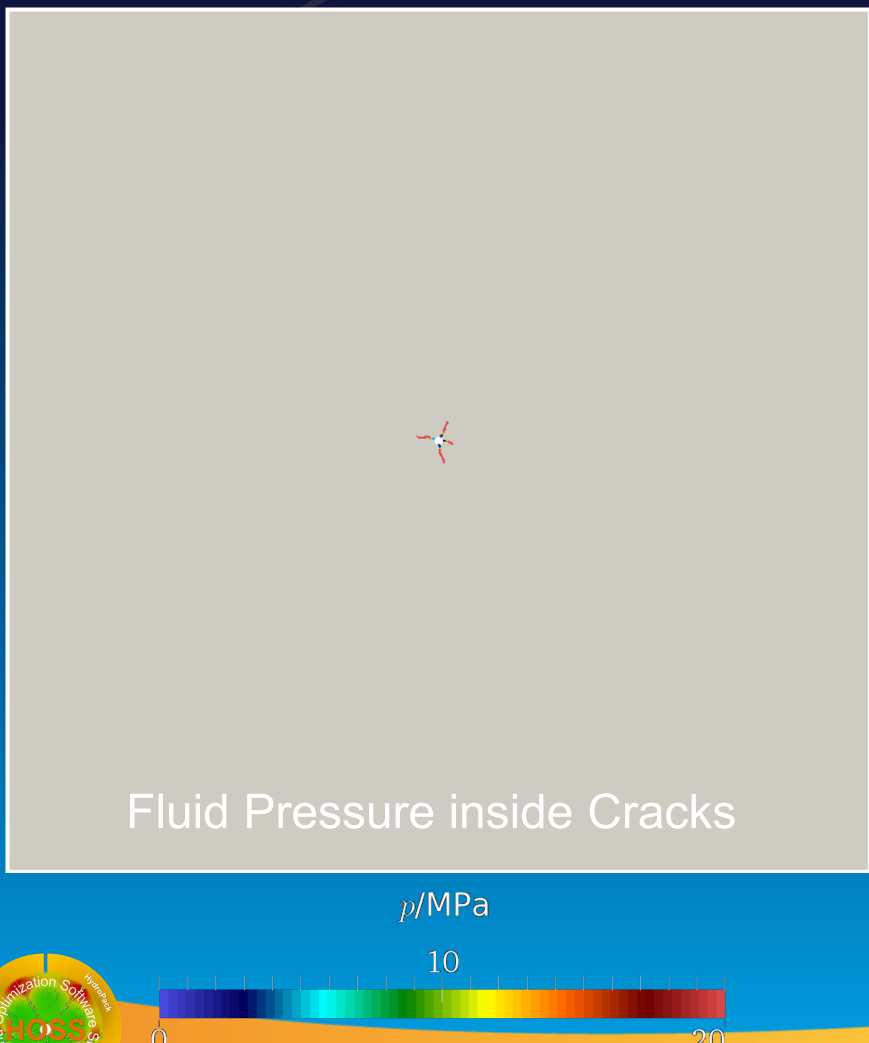
Smooth Contact Potential

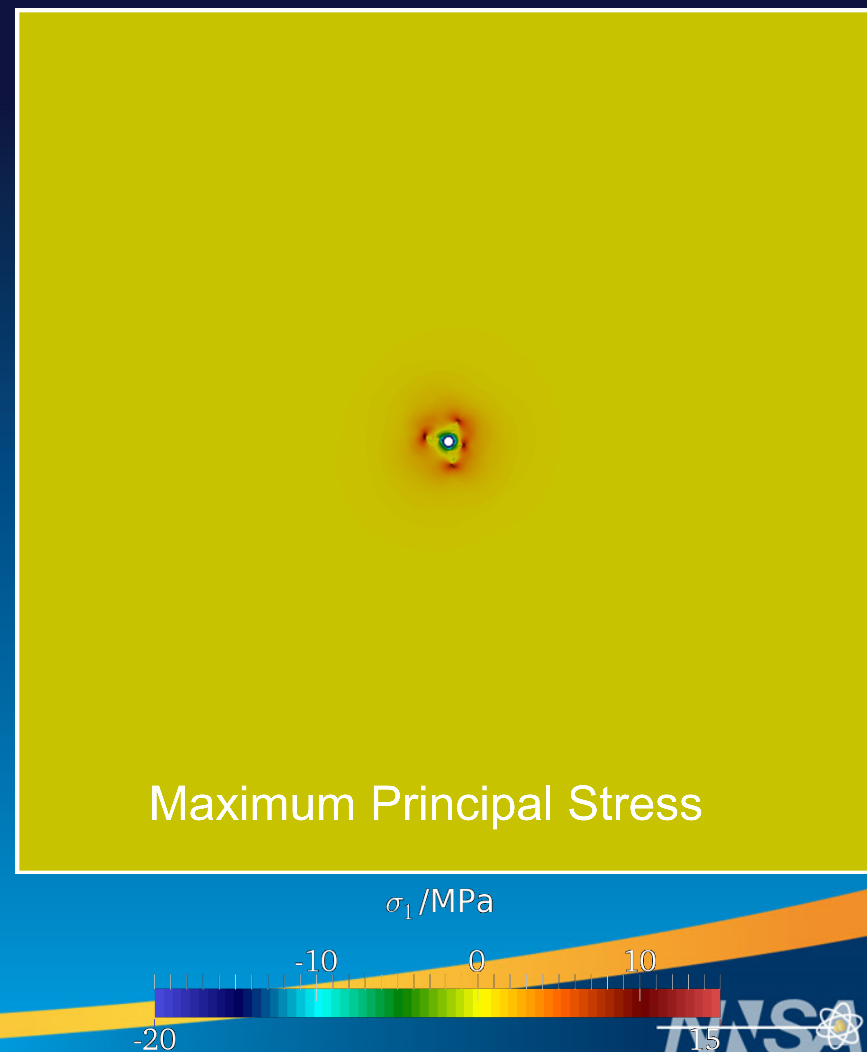


Dimension = 50 m × 50 m
Diameter of borehole = 0.5 m
Element size around borehole = 0.1 m
Total number of elements = 12560

ISF Solver Applied to Hydrofracture

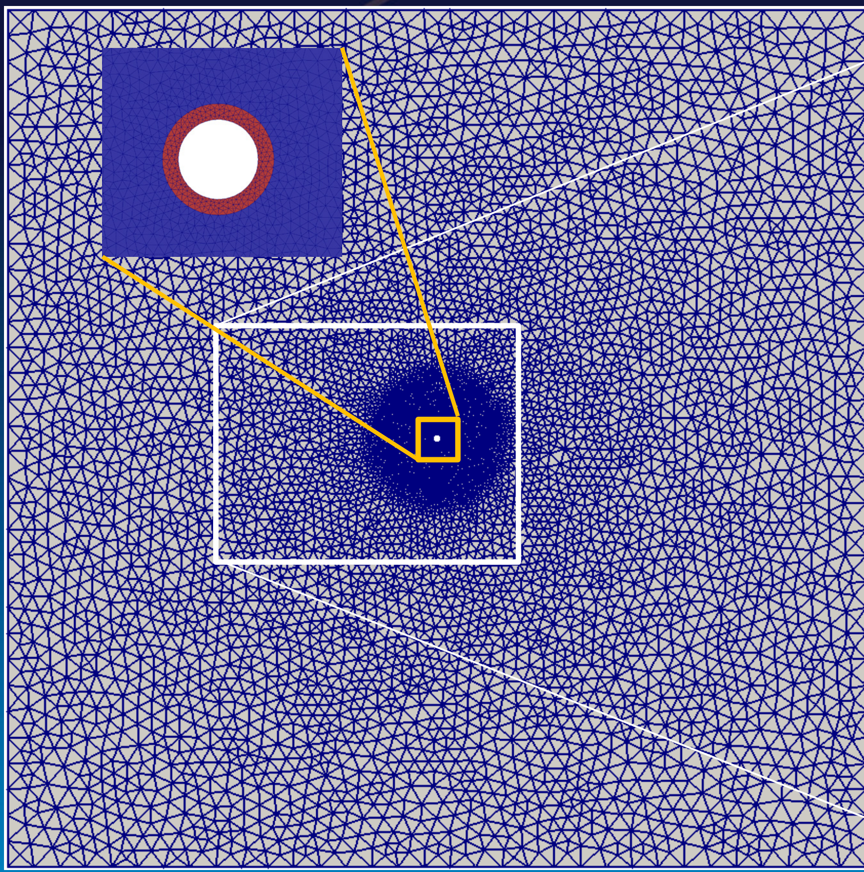
Around Borehole – 20 MPa



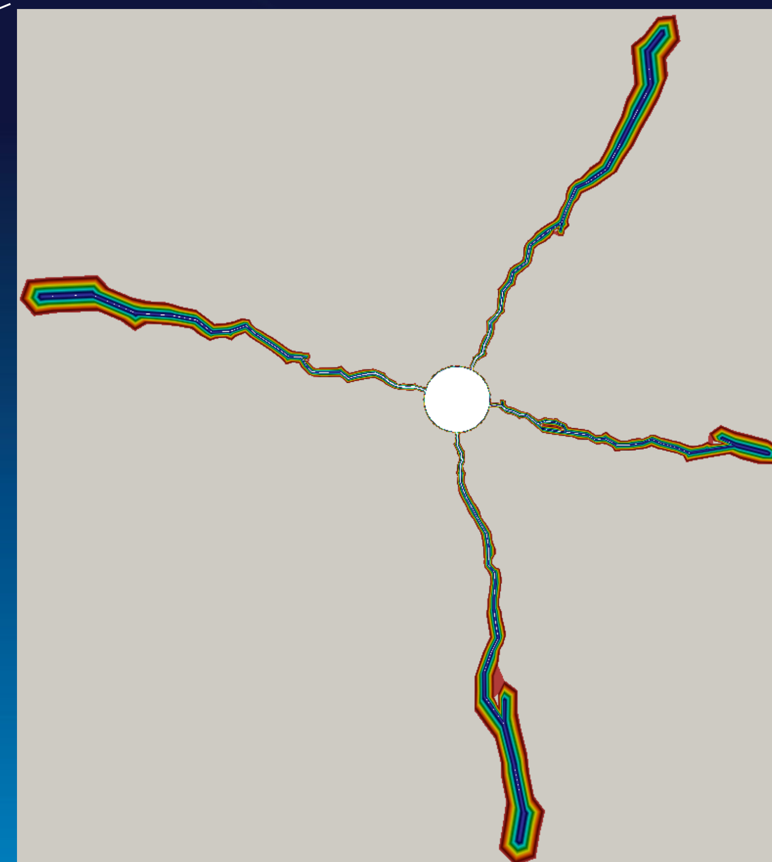


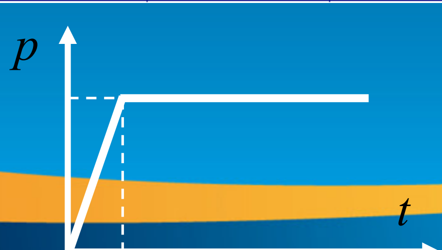
ISF Solver Applied to Hydrofracture
Around Borehole – 40 MPa

Computational Model



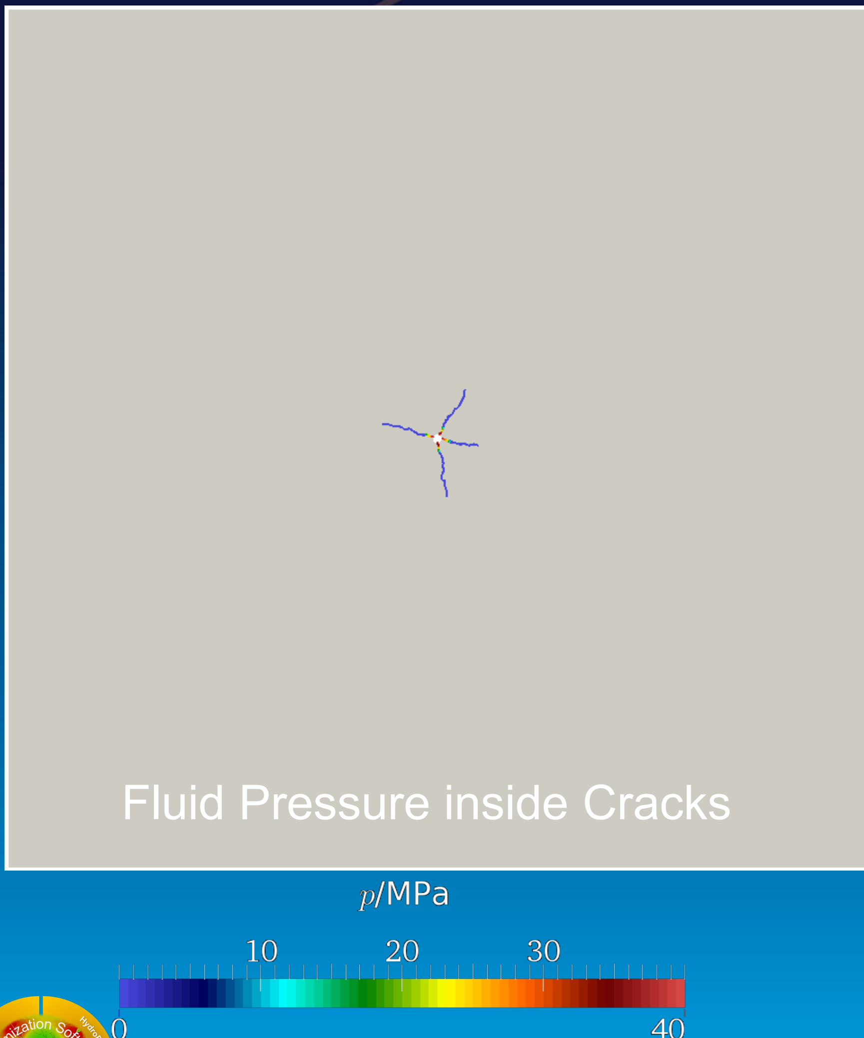
Smooth Contact Potential

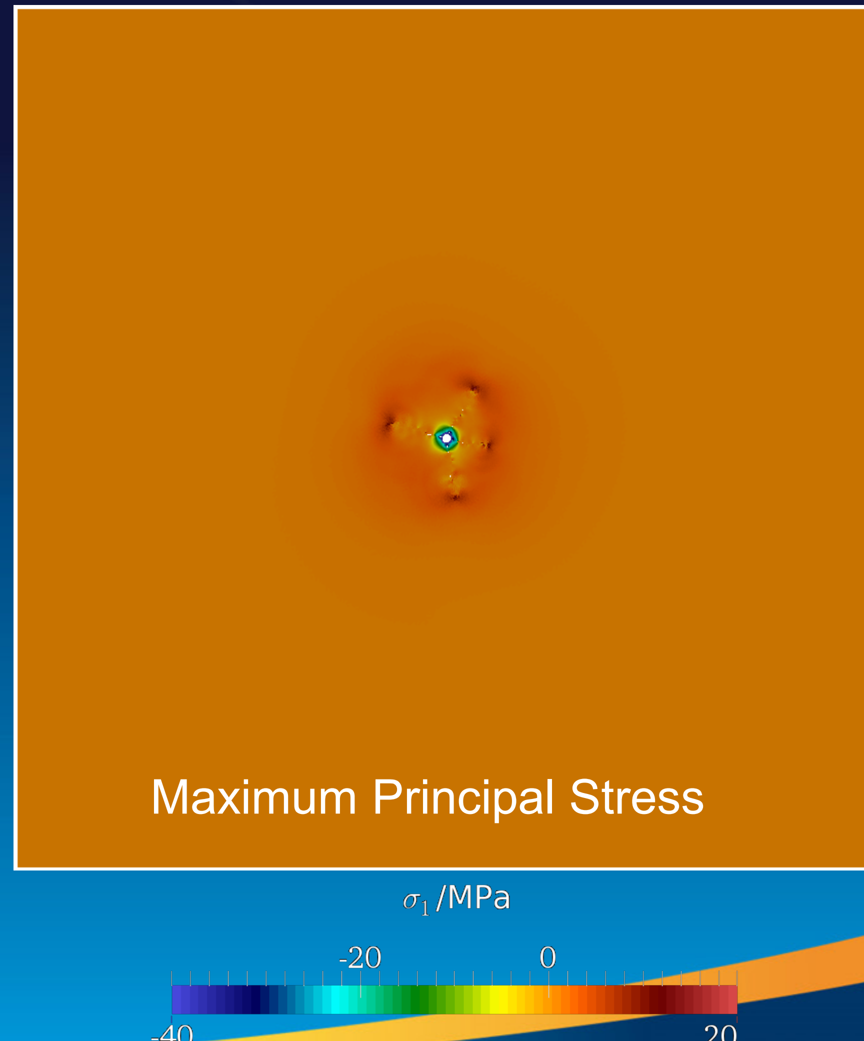




Dimension = 50 m × 50 m
Diameter of borehole = 0.5 m
Element size around borehole = 0.1 m
Total number of elements = 12560

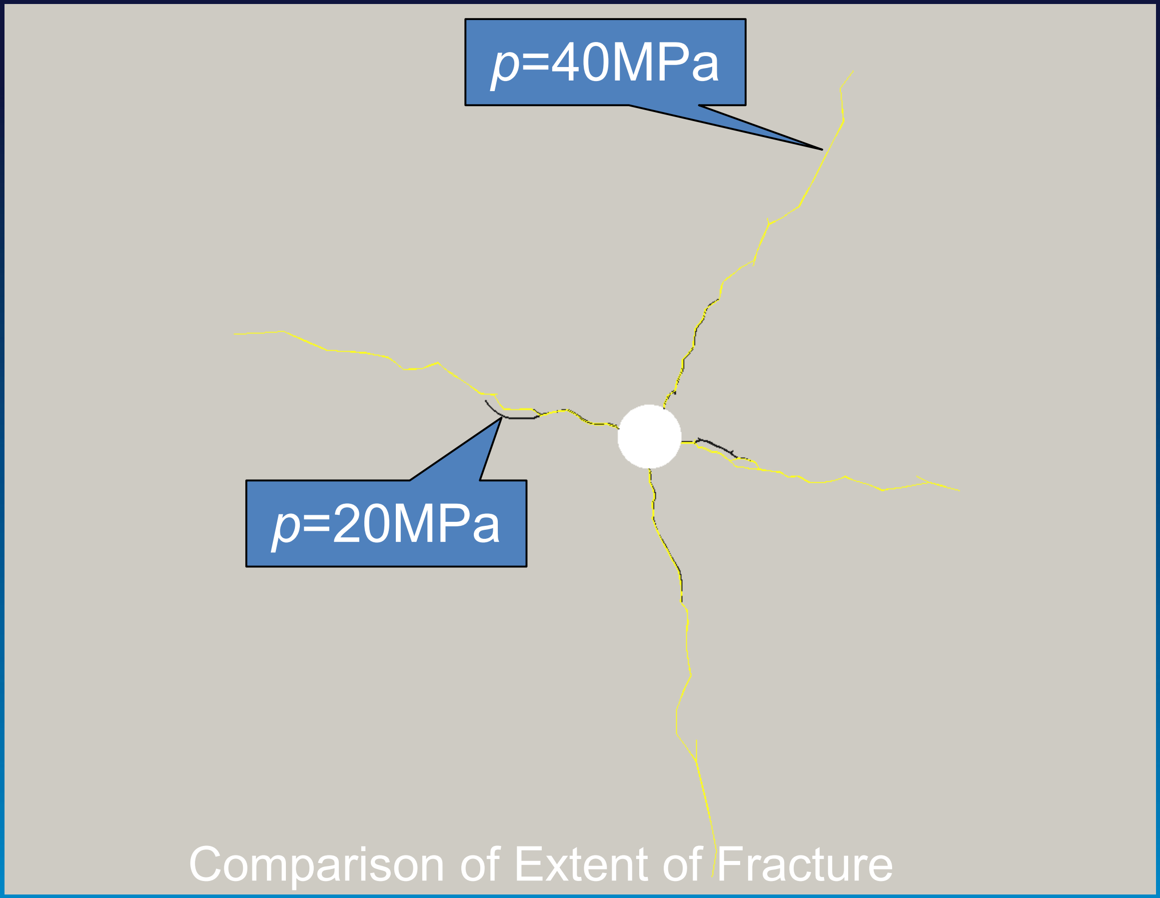
ISF Solver Applied to Hydrofracture
Around Borehole – 40 MPa





ISF Solver Applied to Hydrofracture
Around Borehole – 20 MPa vs 40 MPa

Los Alamos NATIONAL LABORATORY EST. 1943



Summary

- We are confident about ISF being applied to real world borehole problems
  - The time step in our approach is independent of the fracture aperture size
  - This enables us to use very fine meshes around the borehole without penalizing the computational cost as fractures develop and fluid flows through them. Several other approaches must use larger element size to compensate
- Current ISF projects:
  - Internal Los Alamos Laboratory project (LDRD-DR) – Novel Frac Fluids
  - Oil&Gas service company research project concerning energetic explosions down hole
- Will be applied to Basic Energy Science program on fracture propagation
- Next steps include: parallelization and implementation of a quasi-static solver

Los Alamos
NATIONAL LABORATORY
EST. 1943

Thank you for your attention!

POCs:

– Esteban Rougier, erougier@lanl.gov, 505-667-1733

– Zhou Lei, zlei@lanl.gov, 505-667-2632

– Earl E. Knight, knighte@lanl.gov, 505-667-5584