01/08/2018

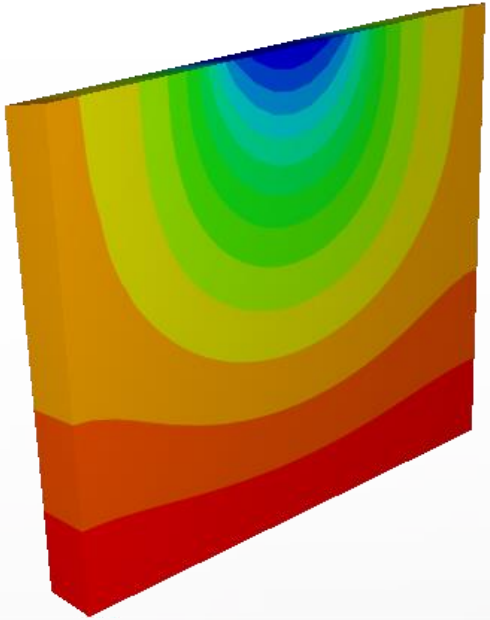
GeMA – Dual Porosity 3D Example

Version 1.0

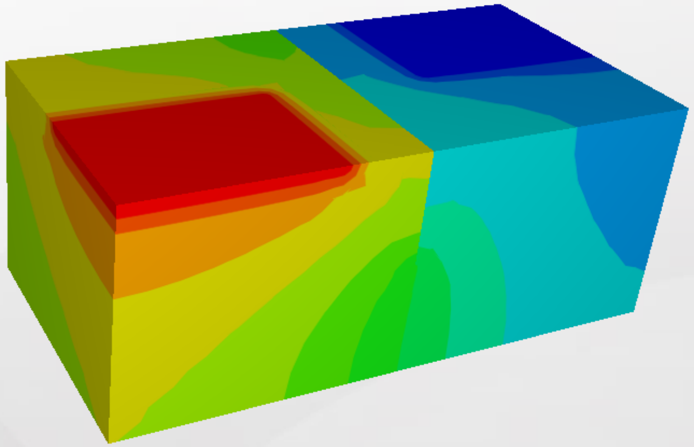
The example set

- This example set presents two 3D coupled hydro-mechanical simulations using the dual porosity, dual permeability model to represent a naturally fractured media.

- Only singular points are highlighted on this presentation. See the model files for additional details.



Example 1 - 3D Flow on a fractured Media

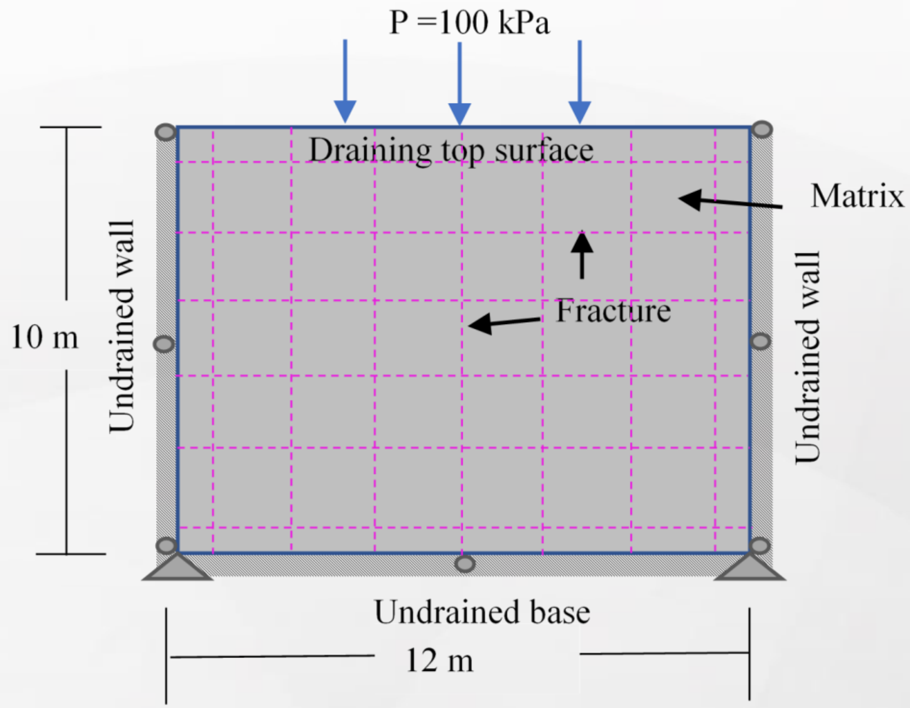


Example 2 – Dam seepage

1 – 3D FLOW ON A FRACTURED MEDIA

The Problem

- In this problem, a saturated poroelastic rectangle is compressed by applying uniform pressure at a region of 4 m * 1 m on the top of the model. The base is constrained in the *y*-direction and the left and right sides are constrained in the *x*-direction, beside front and back sides are constrained in *z*-direction to emulate the 2D problem. Natural fractures are represented by the dual porosity / dual permeability model.



Parameters	Values
Young's modulus, E(kPa)	1.00E+05
Possion's ratio, υ	0.2
Normal stiffness of fracture, k_n (kPa/m)	2.00E+04
Tangencial stiffness of fracture, k_s(kPa/m)	1.00E+04
Hydraulic permeability of the matrix, k_m(m/s)	1.00E-11
Fracture aperture, bx=by(m)	4.9e-4
Relative compressibility, $\beta_{fr} = \beta_m$(1/kPa)	0
Fluid viscocity, μ (cp)	1
Fracture spacing, s(m)	1
Specific weight of water, γ_w(kN/m^3)	10
Analysis time, t(s)	1.00E+09

Simulation file: DPDP-PTop.lua

Dual porosity Dual Permeability

- The dual porosity, dual permeability concept consists in the superposition of two porous systems with different characteristics. In fractured reservoirs, the primary porosity of the matrix and the secondary porosity of the fracture network are physically overlapped in space and time. The transfer of fluid occurs according to the potential of fluids between both, fracture and matrix media.

$$\nabla(D_{mfr}:\varepsilon - D_{mfr}:C_m:\alpha_m p_m - D_{mfr}:C_{fr}:\alpha_{fr} p_{fr}) + f = 0$$

$$\frac{k_m}{\mu}\nabla^2 p_m + D_{mfr}:C_m:\alpha_m:\frac{\partial \varepsilon}{\partial t} + \beta_m \frac{\partial p_m}{\partial t} + \omega\left(p_m - p_{fr}\right) + q_m = 0$$

$$\frac{k_{fr}}{\mu}\nabla^2 p_{fr} + D_{mfr}:C_{fr}:\alpha_{fr}:\frac{\partial \varepsilon}{\partial t} + \beta_{fr} \frac{\partial p_{fr}}{\partial t} - \omega\left(p_m - p_{fr}\right) + q_{fr} = 0$$

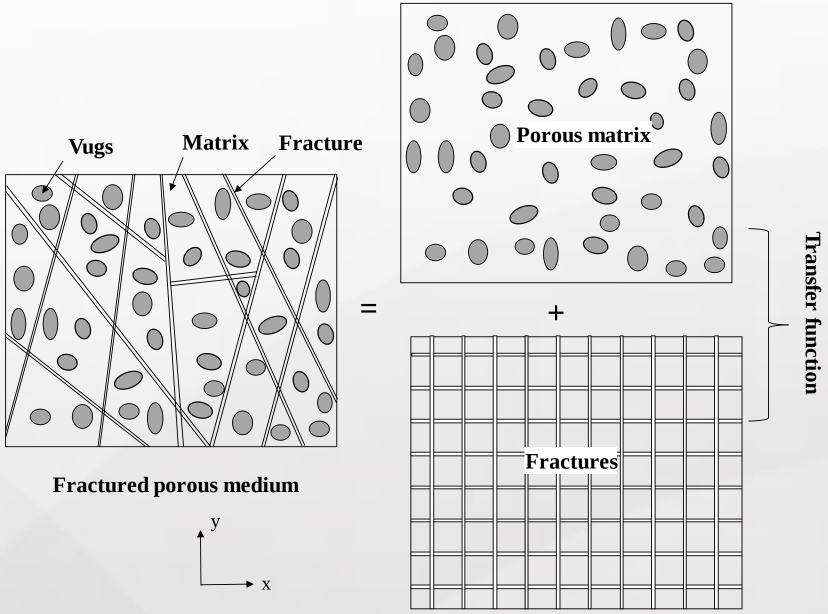


Fig. 1. Idealization of naturally fractured system with dual porosity model.

Model file: State variable

For a coupled Hydro-Mechanical, dual porosity simulation, the needed state variables are the displacement, the pore pressure and the fracture pore pressure:

```
-- State variables
StateVar{id = 'u', dim = 3, description = 'Displacements in the X, Y and Z directions', unit = 'm',
         format = '8.4f', groupName = 'mechanic'}

StateVar{id = 'P',  description = 'Pore pressure', unit = 'kPa',
         format = '8.4f', groupName = 'hydraulic'}

StateVar{id = 'Pf', description = 'Fracture pore pressure', unit = 'kPa',
         format = '8.4f', groupName = 'hydraulic'}
```

The group name is used by the fem solver to group types of state variables and to define tolerances for each one

Model file: Material properties

```
PropertySet
{
  id          = 'MatProp',
  typeName    = 'GemaPropertySet',
  description = 'Material properties',
  properties  = {
    {id = 'E',   description = 'Elasticity modulus',                 unit = 'kPa'},
    {id = 'nu',  description = 'Poisson ratio'},
    {id = 'K',   description = 'Hydraulic permeability in x',        unit = 'm/s'},
    {id = 'gw',  description = 'Specific weight of water',           unit = 'kN/m^3'},
    {id = 'Kww', description = 'Bulk modulus of water',              unit = 'kPa'},
    {id = 'Pht', description = 'Porosity'},
    {id = 'Bp',  description = 'Pore compressibility',               unit = 'kPa^-1'},
    {id = 'Knf', description = 'Normal elastic stiffness',           unit = 'kPa/m'},
    {id = 'Ksf', description = 'Shear elastic stiffness',            unit = 'kPa/m'},
    {id = 'Ktf', description = 'Tangential elastic stiffness',       unit = 'kPa/m'},
    {id = 'Bpf', description = 'Pore compressibility of fracture',   unit = 'kPa^-1'},
    {id = 'uff', description = 'Fracture dynamic visosity',          unit = 'kPa*s'},
    {id = 'Sx',  description = 'Fracture spacing along x',           unit = 'm'},
    {id = 'bx',  description = 'Fracture aperture along x',          unit = 'm'},
    {id = 'Sy',  description = 'Fracture spacing along y',           unit = 'm'},
    {id = 'by',  description = 'Fracture aperture along y',          unit = 'm'},
    {id = 'shpFacType', description = 'Shape factor type',           constMap = constants.HydroFemPhysics.shapeFactorModel},
    {id = 'materialHM',   description = 'HydroMechanical material type',  constMap = constants.CoupledHMFemPhysics.materialModels},
    {id = 'h',          description = 'Element thickness',           unit = 'm'},  },
```

HM Coupled Dual porosity properties

A map with the supported transfer function names

A map with the supported material names

… continues on the next slide

Model file: Material properties

```
values = {
   {E = 1.00e+05,  nu   = 0.2,          Knf = 2.00e+4,  Ksf = 1.00e+4,     Ktf = 1.00e+04,  K   = 1.00e-11, Kww = 2.20e+6,
    gw = 1.00e+01, Pht  = 0.1,          Bp  = 1.44e-6,  Bpf = 0,           uff = 1.00e-06,
    Sx = 1.00e+00, bx   = 0.00004933,   Sy  = 1.00e+00, by  = 0.00004933,  shpFacType = 'kazemi',
    materialHM = 'coupledDualPorosity', h = 1.000},
  }
}
```

A material type from `constants.CoupledHMFemPhysics.materialModels`
See the plugin docs for other available materials

A transfer function from `constants.HydroFemPhysics.shapeFactorModel`
See the plugin docs for other functions

Material was renamed to MaterialHM in the property set to avoid problems when we have materials with different physics.

Parameters	Values
Young's modulus, E(kPa)	1.00E+05
Possion's ratio, υ	0.2
Normal stiffness of fracture, k_n(kPa/m)	2.00E+04
Tangencial stiffness of fracture, k_s(kPa/m)	1.00E+04
Hydraulic permeability of the matrix, k_m(m/s)	1.00E-11
Fracture aperture, $bx=by$(m)	4.9e-4
Relative compressibility, $\beta_{fr} = \beta_m$(1/kPa)	0
Fluid viscocity, μ (cp)	1
Fracture spacing, s(m)	1
Specific weight of water, γ_w(kN/m^3)	10
Analysis time, t(s)	1.00E+09

Model file: Boundary conditions

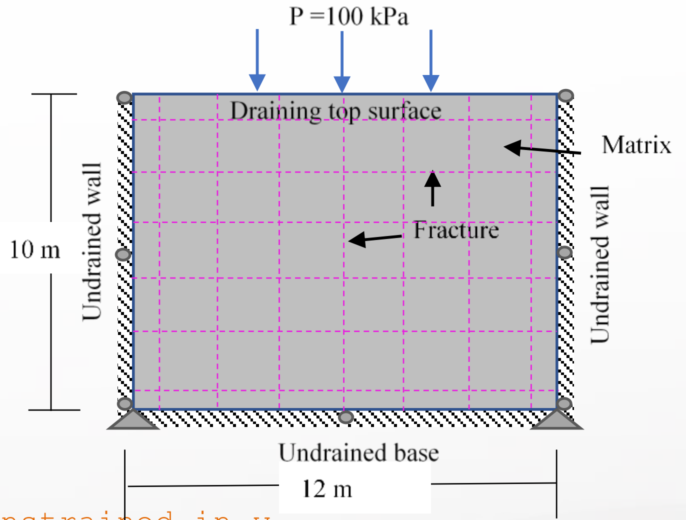
```
-- Pressure applied on the center nodes at the model top
BoundaryCondition {
  id   = 'cload',
  type = 'node concentrated forces',
  mesh = 'mesh',
  properties  = {
    {id = 'f',  description = 'External force applied on the node', unit = 'kN', dim = 3},
  },
  nodeValues = {
   {     168 ,     {     0.000,    -6.2500,      0.000}},
   {     172 ,     {     0.000,    -12.500,      0.000}},    ...
  }
}
```

Boundary condition type for prescribed forces values

Force dimensions

Node number

Nodal concentrated forces {Fx, Fy,Fz}




```
-- Constrained displacements. Sides are constrained in the x direction while the base is constrained in y.
-- Bottom corner nodes are constrained in both directions. Front and back sides are constrained in z.
BoundaryCondition {
  id   = 'bc',
  type = 'node displacement',
  mesh = 'mesh',
  properties  = {
    {id = 'ux',  description = 'Fixed node displacement in the X direction', unit = 'm', defVal = -9999},
    {id = 'uy',  description = 'Fixed node displacement in the Y direction', unit = 'm', defVal = -9999},
    {id = 'uz',  description = 'Fixed node displacement in the z direction', unit = 'm', defVal = -9999},
  },
  nodeValues = {
    {       1,   0.0000e+00,         nil,  0.0000e+00 },    ...
  }
}
```

Boundary condition type for prescribed displacements

A default value different from 0.0 is needed so that free nodes in one direction are not misinterpreted as a 0.0 displacement.

Prescribed displacement in *x*-

free Node in *y*-

Prescribed displacement in *z*-

… see model files for fixed pore pressure conditions

Solution file: Physics

The dual porosity model for a coupled HM problem is available through the DualPorosity object from the CoupledHMFemPhysics plugin.

```
PhysicalMethod {
  id       = 'DualPorosity',
  typeName = 'CoupledHMFemPhysics.DualPorosity',
  type     = 'fem',

  mesh                 = 'mesh',
  elementGroups        = {'HUPPF_1'},
  materials            = 'coupledDualPorosity',
  boundaryConditions = {'cload', 'bpm', 'bpf', 'bc'},
  ruleSet              = 1,

  properties = { material = 'materialHM' },

  permeabilityUpdate = true,
  penaltyStiffness   = false,
}
```

Since the Material was renamed to MaterialHM in the property set, the physics must be warned about this change by a translation map that tells it that the expected property Material will be given by property MaterialHM.

Solution file: Orchestration

```
local solverOptions = {
   type                 = 'transient automatic time step',
   timeMax              = 1.000E+09,
   timeInitIncrement    = 0.01,
   timeMinIncrement     = 0.01,
   timeMaxIncrement     = 1e8,
   iterationsMax        = 15,
   tolerance            = { mechanic = 1.0e-05, hydraulic = 1.0e-5 },
}
```

- type: Variable time step, transient, non-linear solver
- timeMax: Maximum time for the simulation
- timeInitIncrement: Size of the increment
- timeMinIncrement: Minimum increment
- timeMaxIncrement: Maximum increment
- iterationsMax: Maximum number of interactions
- tolerance: Associates a tolerance with each physics type

```
function ProcessScript()
   -- Create the solver model
   local solver = fem.init({'DualPorosity'}, 'solver', solverOptions)

   -- Prepare the file where results will be saved
   local file = io.prepareMeshFile('mesh', '$SIMULATIONDIR/out/DPDP-PTop', 'nf', {'u','P','Pf'},
                                   {'S', 'E'}, {split = true, saveDisplacements = true})

   -- Saves initial state to the file
   io.addResultToMeshFile(file, 0.0)
```

{'S', 'E'}: Save stresses and strains

… continues on the next slide

Solution file: Orchestration

```
-- Flow loop
local dt        = solverOptions.timeInitIncrement
local FinalTime = solverOptions.timeMax
local Time      = dt
local OldTime   = 0.0
local LastStep  = false

while (Time <= FinalTime) do
  print('------------------')
  print(tr('Flow iteration - time = %1 s'):num(Time))
  print('------------------')

  -- Run transient analysis.  Solver returns a suggested
  -- time-step for the next iteration
  dt = fem.step(solver, dt)

  -- If we are later on the simulation, lets ignore the
  -- suggested time step and use an increment that is 5%
  -- greater than the previous one
  if(Time >=1e6) then
    dt = (Time - OldTime) * 1.05
  end
```

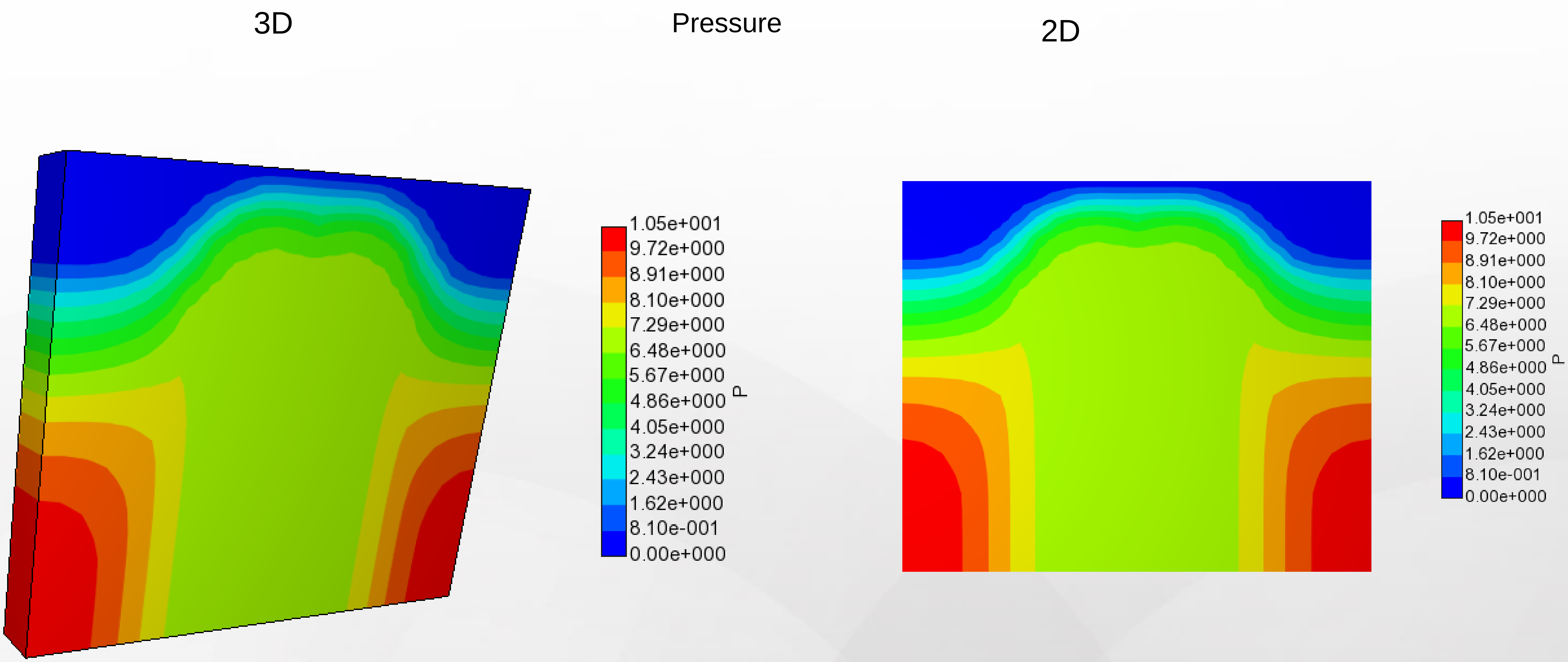
```
  -- Save results
  io.addResultToMeshFile(file, Time)
  print(tr('Flow iteration - Dtime = %1 s'):num(dt))

  -- Adjust time to guarantee that the last iteration
  -- will be on the requested final simulation time
  OldTime = Time
  if (Time + dt >= FinalTime and not LastStep) then
    dt   = FinalTime - Time
    Time = FinalTime
    LastStep = true
    -- Test special case when Time == FinalTime
    if equal(dt, 0.0) then break end else
    Time = Time + dt
  end

  print('Time = ' .. Time)
 end

 -- Closes the result file
 io.closeMeshFile(file)
end
```

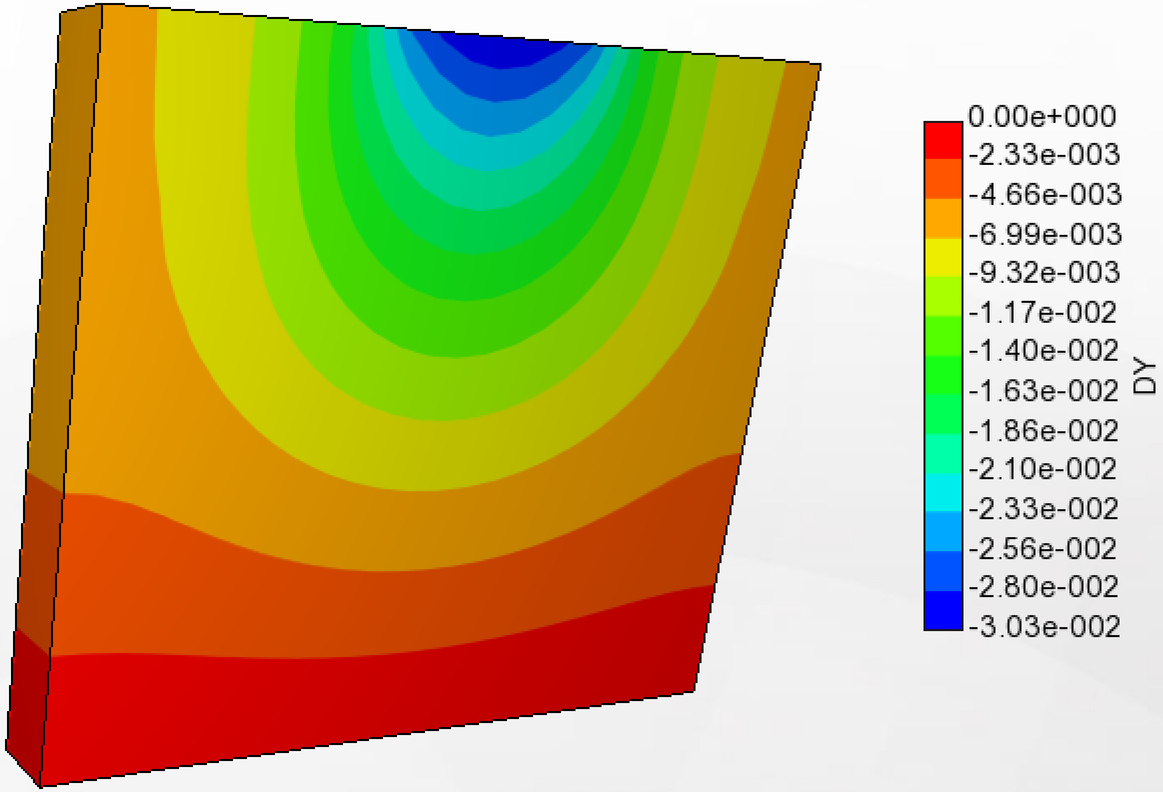
Results at t = 1.0E9 s



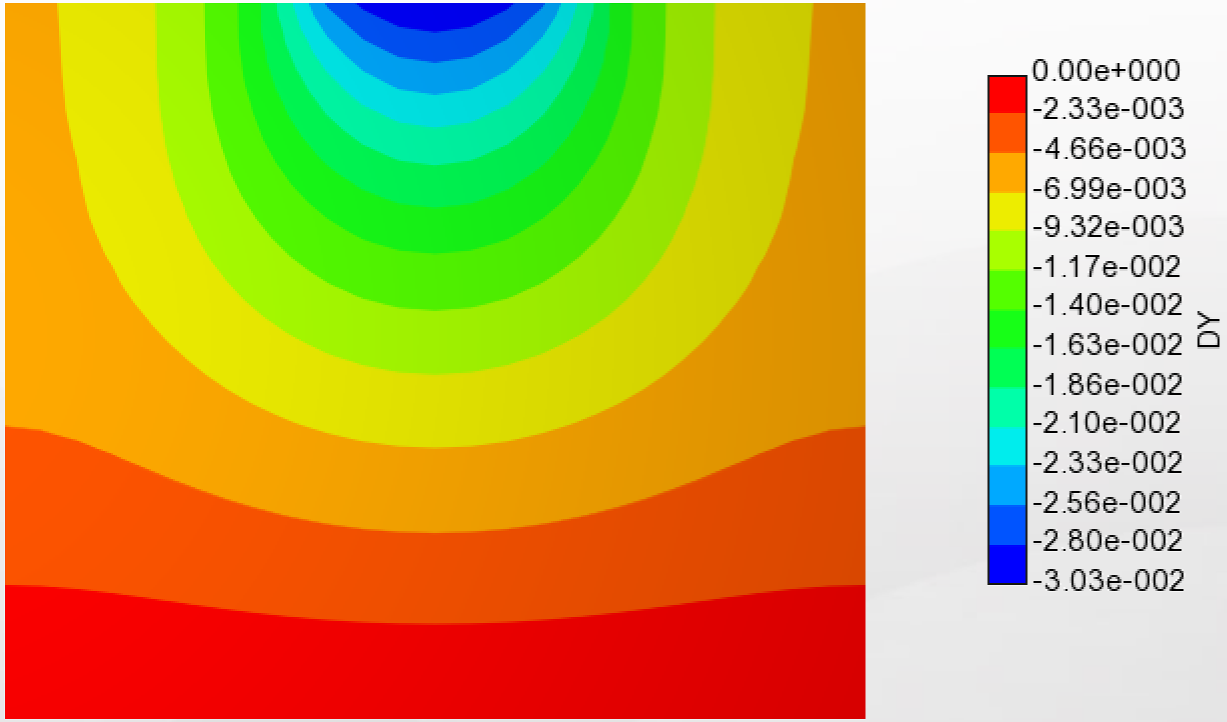
Results at t = 1.0e9 s

3D

Final Y Displacement



2D

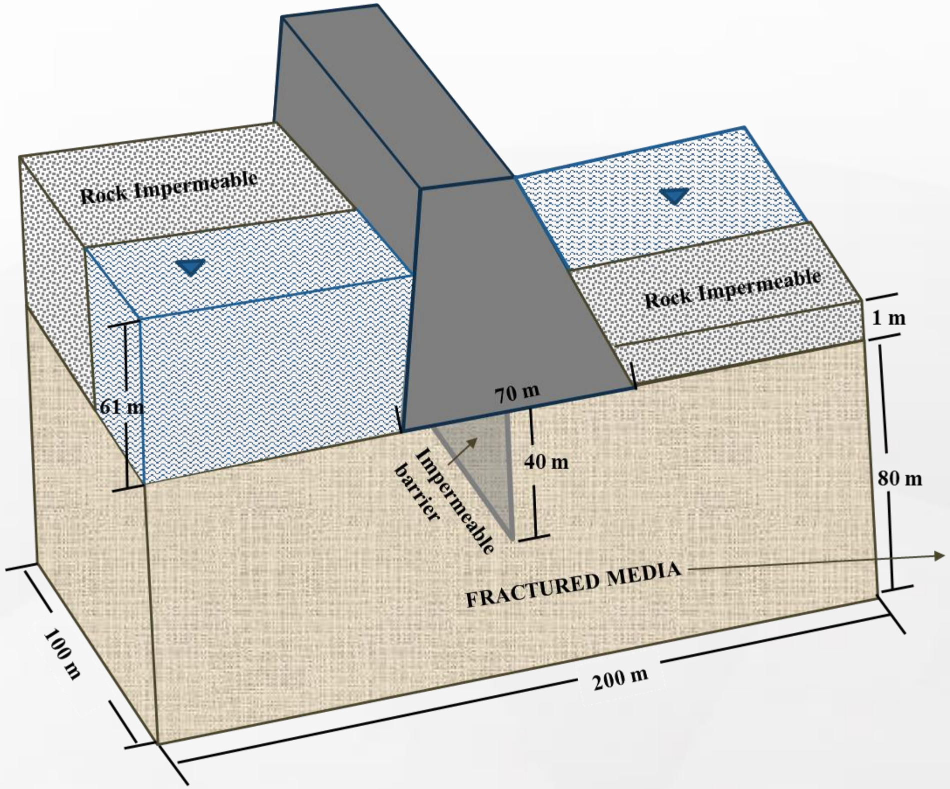


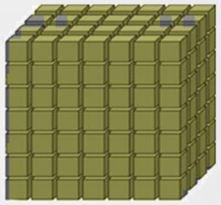
2 – DAM-SEEPAGE PROBLEM

The problem

- In the following example, a dam-seepage 3D problem, transient flow results from the pressure differences between the right and left sides of the dam. The analysis procedure assumes the surrounding region is impermeable. There is also an impermeable barrier with 40 m deep.
- Natural fractures are represented by the dual porosity / dual permeability model. The barrier is modeled using interface elements.

Parameters	Values
Young's modulus, E(kPa)	1.00E+07
Possion's ratio, υ	0.2
Normal stiffness of fracture, k_n (kPa/m)	1.00E+08
Tangencial stiffness of fractures, k_s, k_t(kPa/m)	1.00E+08
Hydraulic permeability of the matrix, k_m(m/s)	1.00E-8
Fracture aperture, $bx=by=bz$ (m)	1e-3
Relative compressibility, β_{fr} = β_m(1/kPa)	0
Fluid viscocity, μ (cp)	1
Fracture spacing, $Sx=Sy=Sz$(m)	10
Specific weight of water, γ_w(kN/m^3)	10
Analysis time, t(s)	1.00E+09





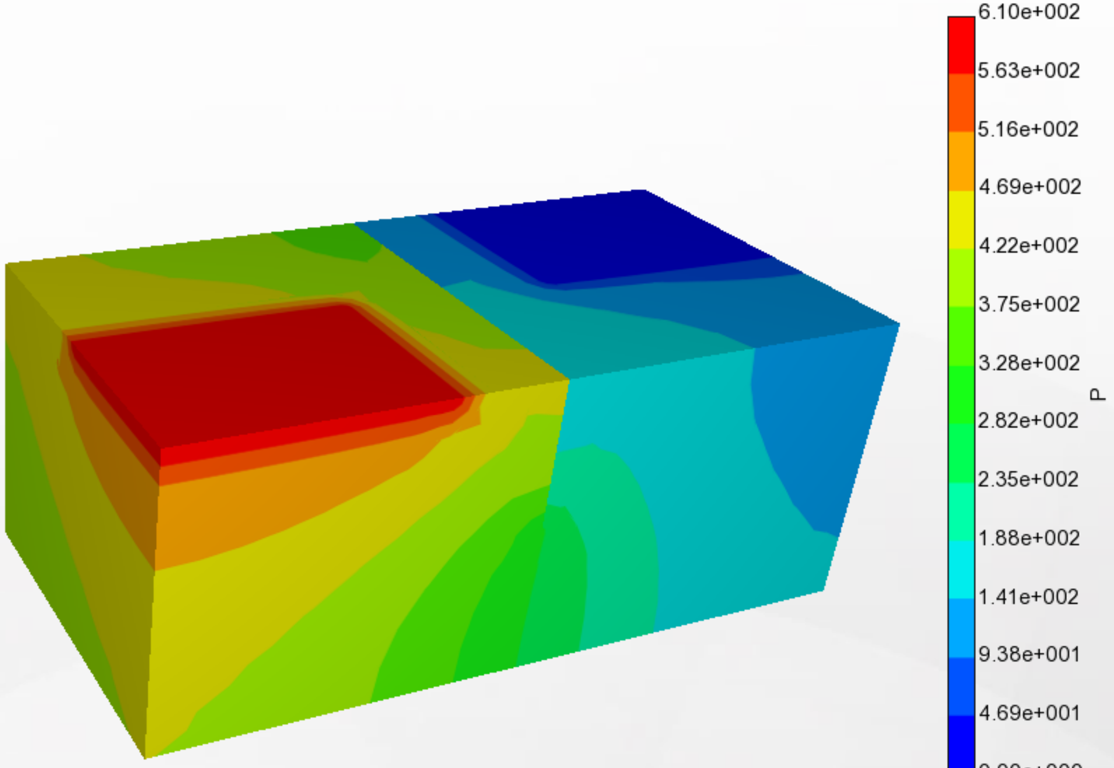
Fractured media representation

Simulation file: DAM-DPP-DFN.lua

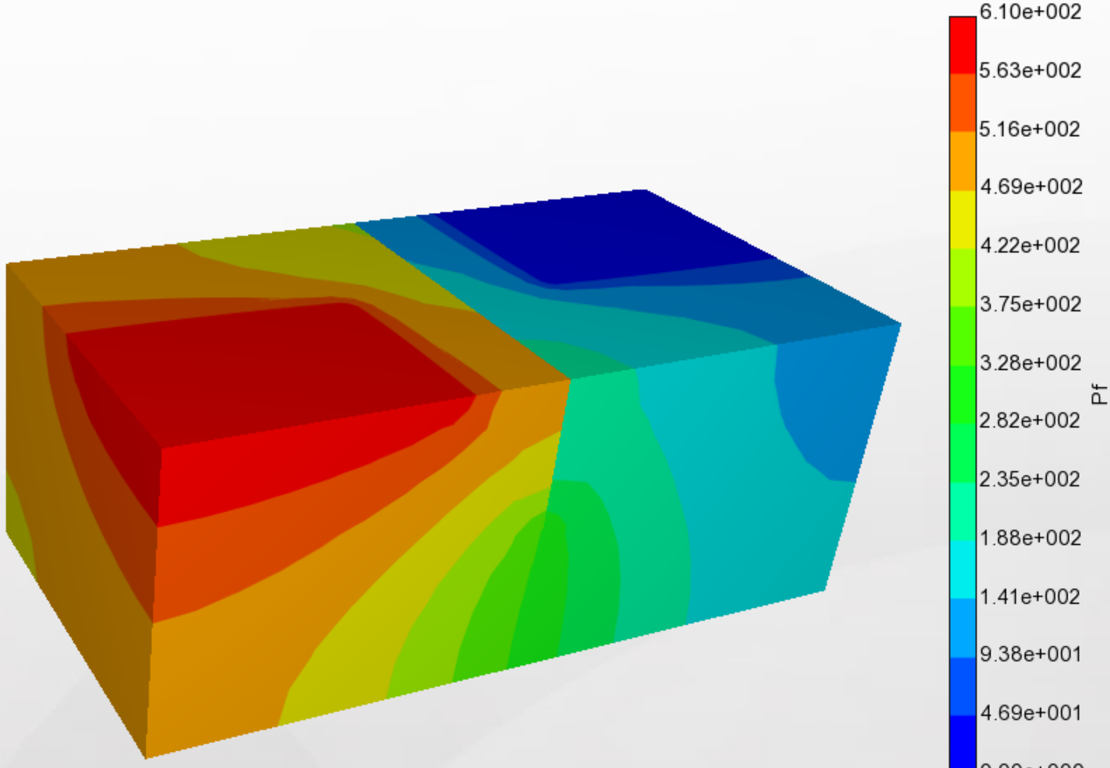
The model file and the orchestration script for this example follows the same principles used on the previous one. See the simulation files for details.

Results at t = 3600 s

Matrix Pressure

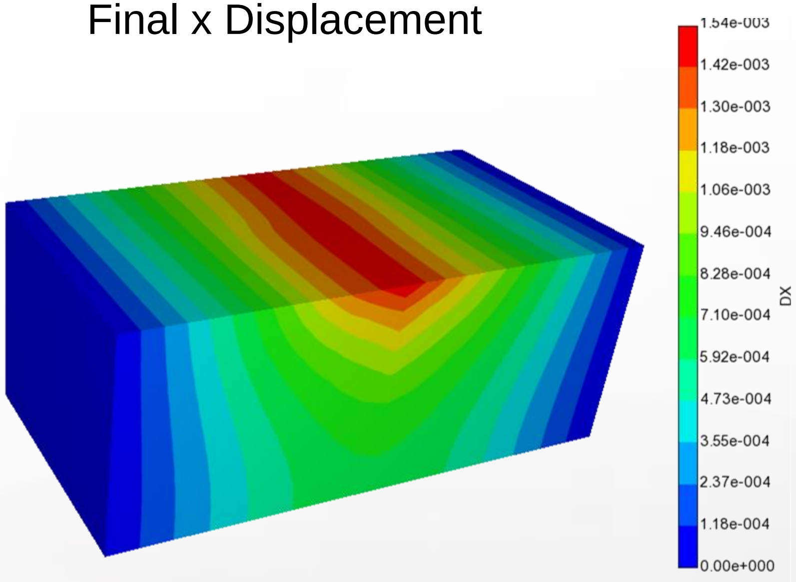


Fracture Pressure

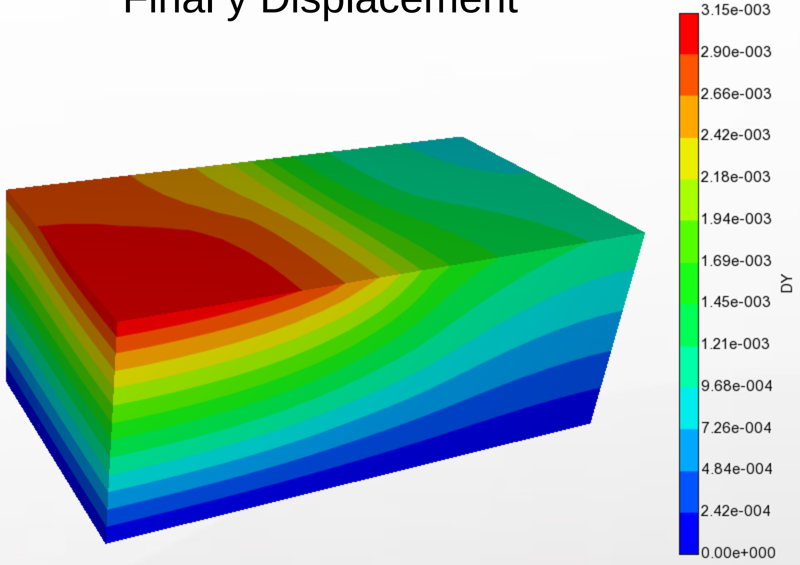


Results at t = 3600 s

Final x Displacement



Final y Displacement



Final z Displacement