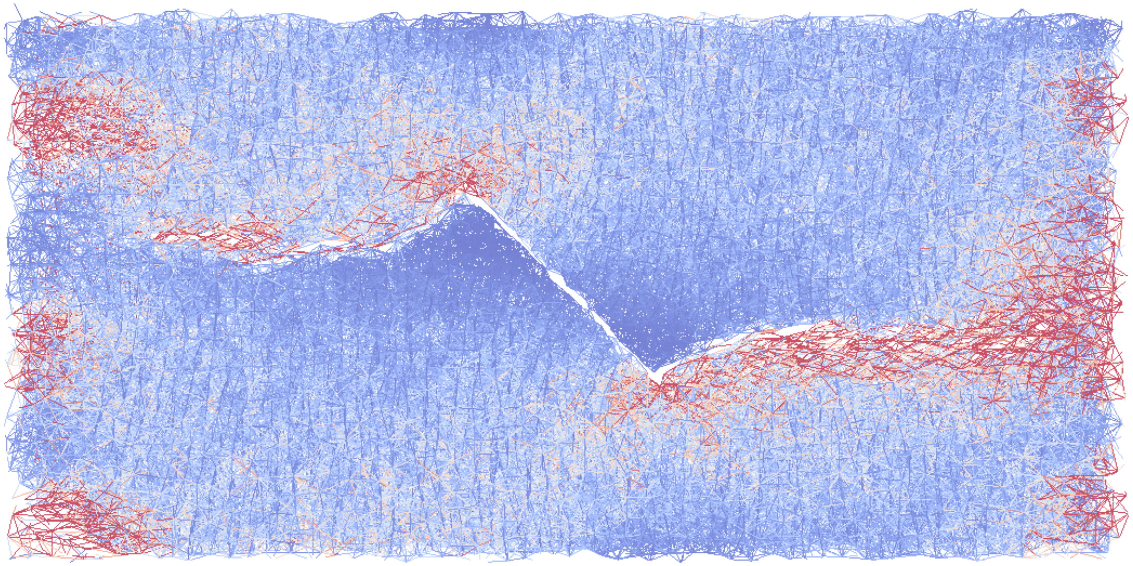

Discrete Element Based Hydraulic Fracture Model

Test Case 3: Single fracture in homogenous poroelastic, thermo elastic media

(a) Newtonian fluid without proppant in a poroelastic media

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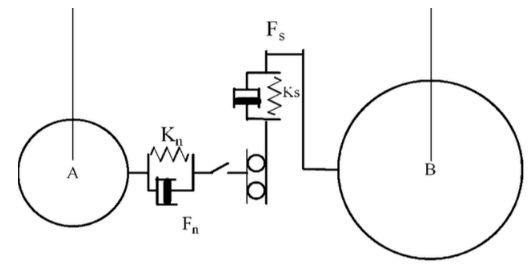
Discrete Element Method

1. Discrete element tracking (Yade): Newton's 2nd Law: $\ddot{u} = F/m$



2. Determination of forces (particle interactions):

$$k_n = \frac{E_1 r_1 E_2 r_2}{E_1 r + E_2 r_2} \ \& \ k_s = \upsilon k_n \mid F_n = k_n \Delta D \ \& \ F_s = F_{s,prev} + k_s \Delta u_S$$

3. Failure criteria (Scholtes and Donze 2012):

$$F_{n_{max}} = -tA_{int} \ \& \ F_{s_{\max}} = F_n \tan\varphi + cA_{int}$$

4. Fluid coupling (Yade, Chareyre et al. 2012):

$$[\boldsymbol{G}]\{\boldsymbol{P}\} = [\boldsymbol{E}]\{\dot{\boldsymbol{X}}\} + \boldsymbol{Q_q}$$

5. Triangulation created using particles as nodes

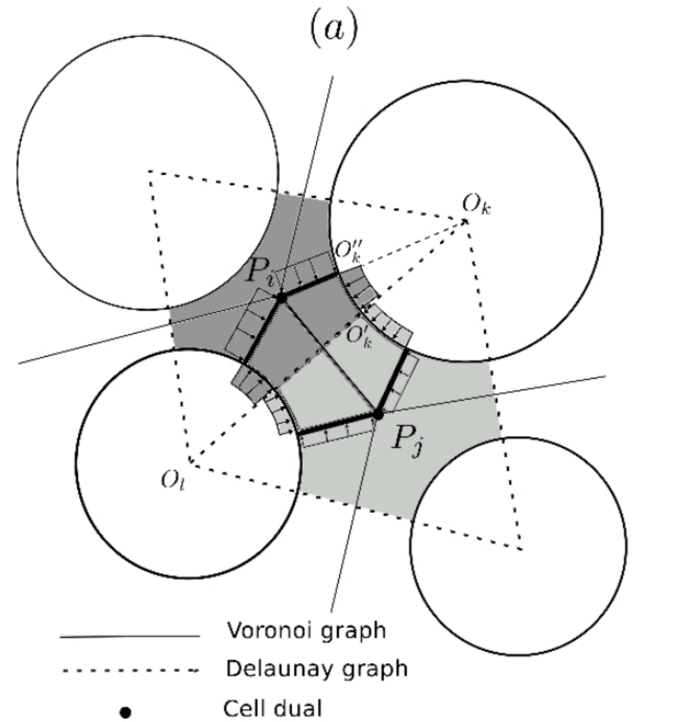
6. Conductance governed by Poiseuille's law (Papachristos, 2017):

non fractured, $k = \alpha \frac{A_{ij} {R_{ij}^{h}}^{2}}{\mu}$ & fractured, $k = \frac{h^3}{12\mu}$

7. Pressure and viscous forces on particles:

$$F_p = A_p(p_i - p_j)\boldsymbol{n} \ \& \ F_{v_{total}} = A_f(p_i - p_j)\boldsymbol{n}$$

$$F_{v,p} = F_{v,total}\,\gamma \ \& \ \gamma = A_p/A_{total}$$



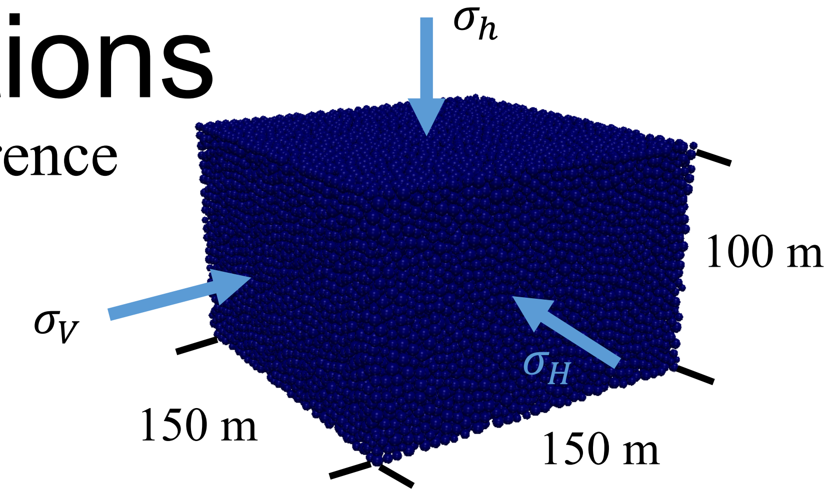
A_f=pore throat cross section, p = pore pressure

* $\boldsymbol{G}$ = conductance matrix, $\boldsymbol{E\dot{X}}$ = rate of volume change

$\boldsymbol{P}$ = pore pressures, F = force m = mass, $\ddot{u}$ = acceleration

Numerical Methods and Assumptions

- Particle position - explicit finite difference
- Fluid flow – pore finite volume

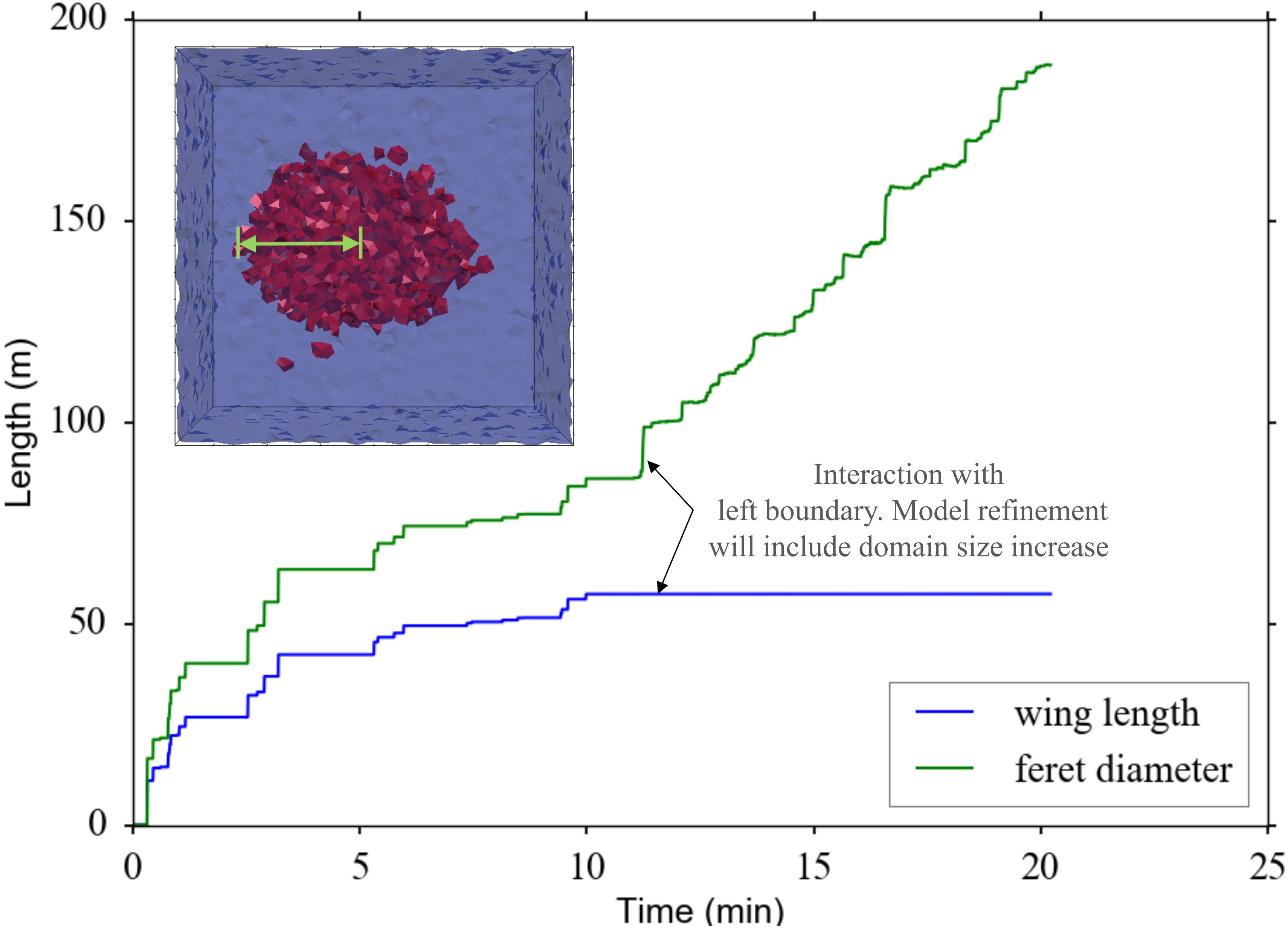


Model Assumptions:

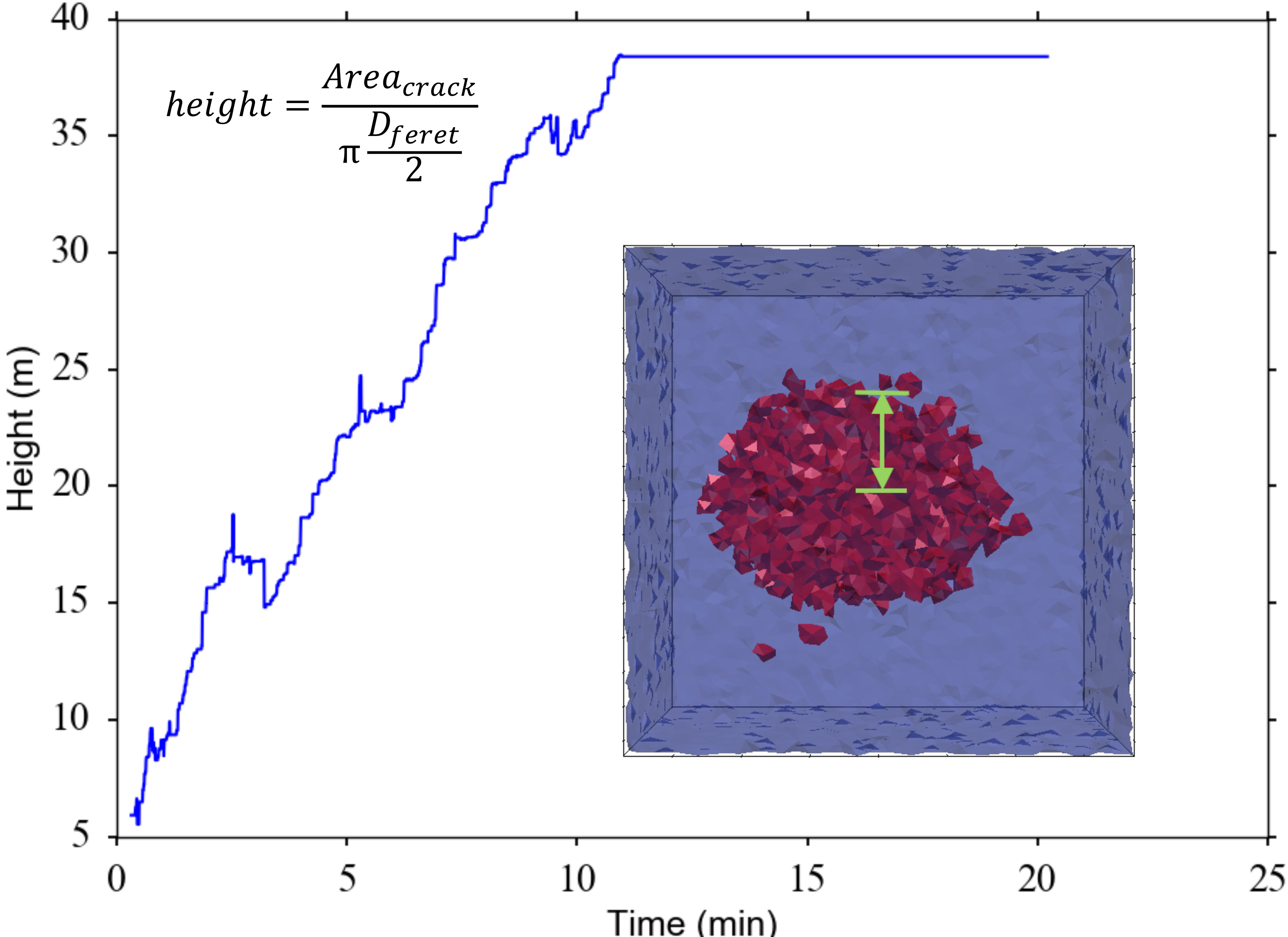
- Matrix permeability – Poiseuille's law
- Fracture permeability – parallel plate approximation
- Mohr-coulomb failure criteria based on particle size
- Broken bonds contain a residual fracture width
- Calibrated micro-parameters yield emergent behaviors according to specified macro parameters
- 10 cm perforation depth
- Constant pressure and stress boundary conditions

Micro parameter	Value (DEM)	Description
E_i	32 (GPa)	Young's modulus
k_s/k_n	0.05	Stiffness ratio
ϕ	25^o	friction angle
c	15 MPa	cohesion
t	2.3 MPa	tensile strength
γ_{int}	1.329	interaction range
r	1 m $\pm$ 0.25	particle radii
ρ	5000 kg/m^3	particle density
n	0.38	pack porosity
P_p	27 MPa	reservoir pressure
k_{factor}	9e-16	permeability factor
K_{fluid}	2.2 GPa	fluid bulk modulus
μ	0.001 Pa*s	viscosity
$h_{residual}$	1e-6 m	residual aperture

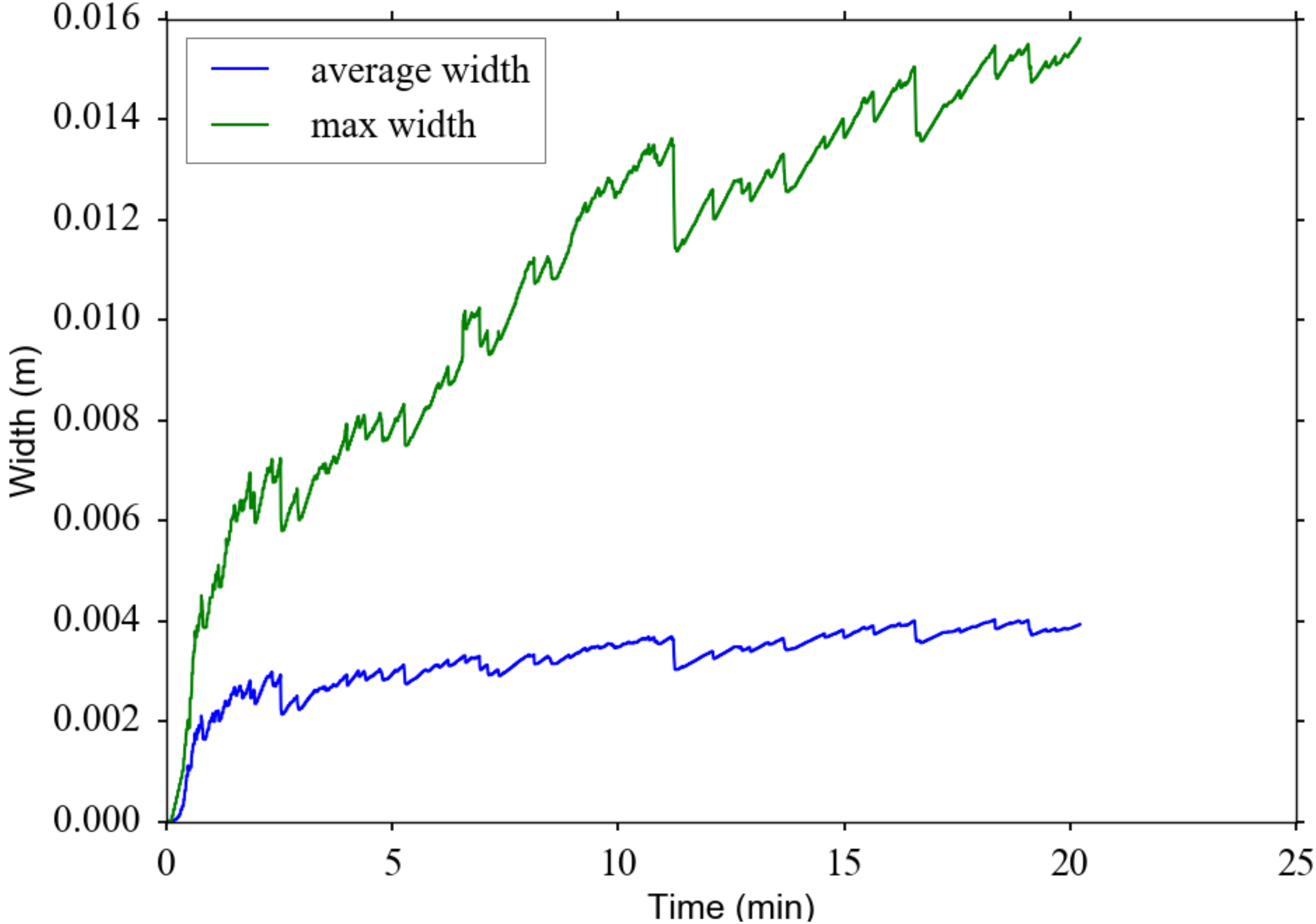
Fracture Length



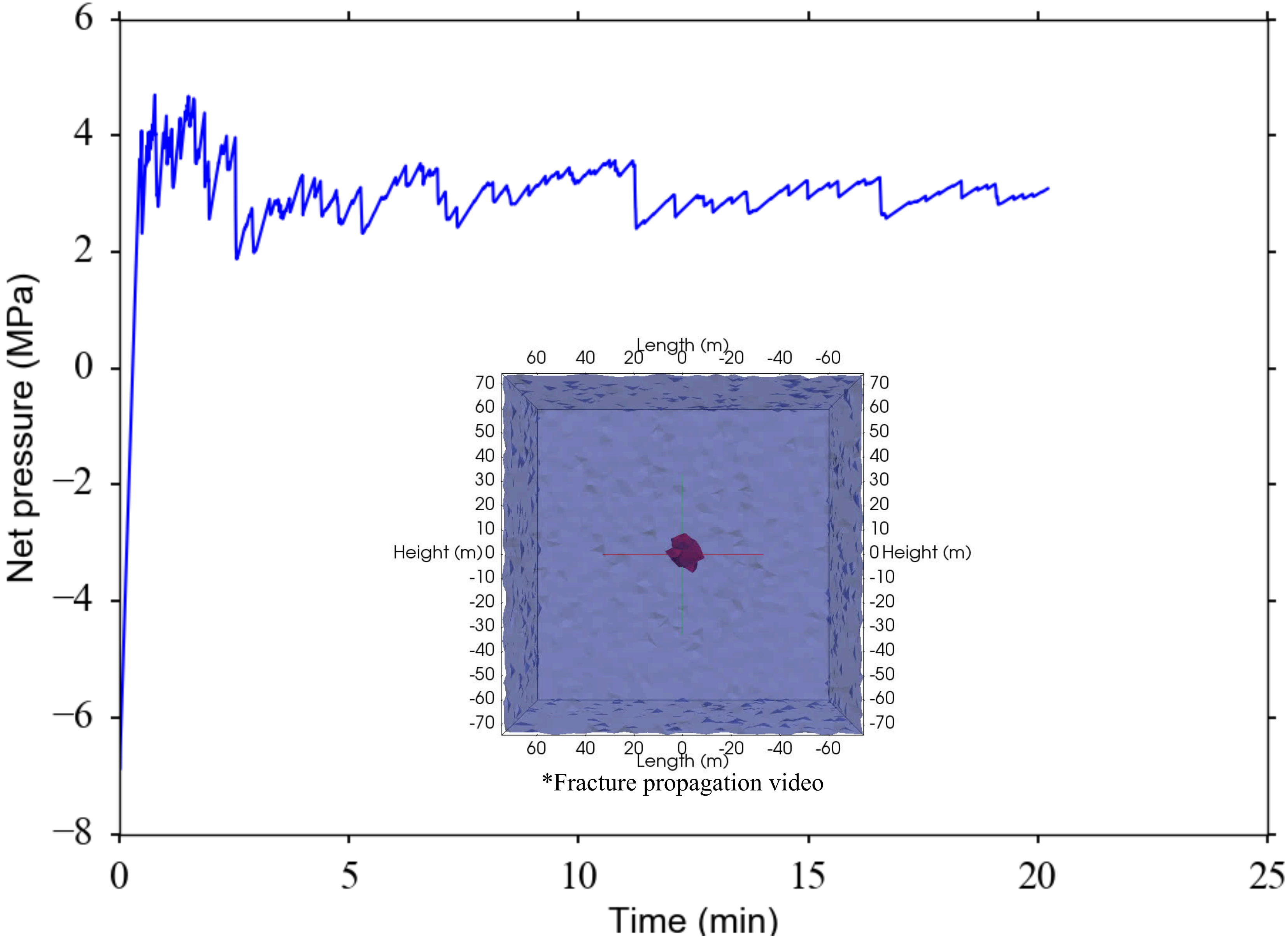
Fracture Height



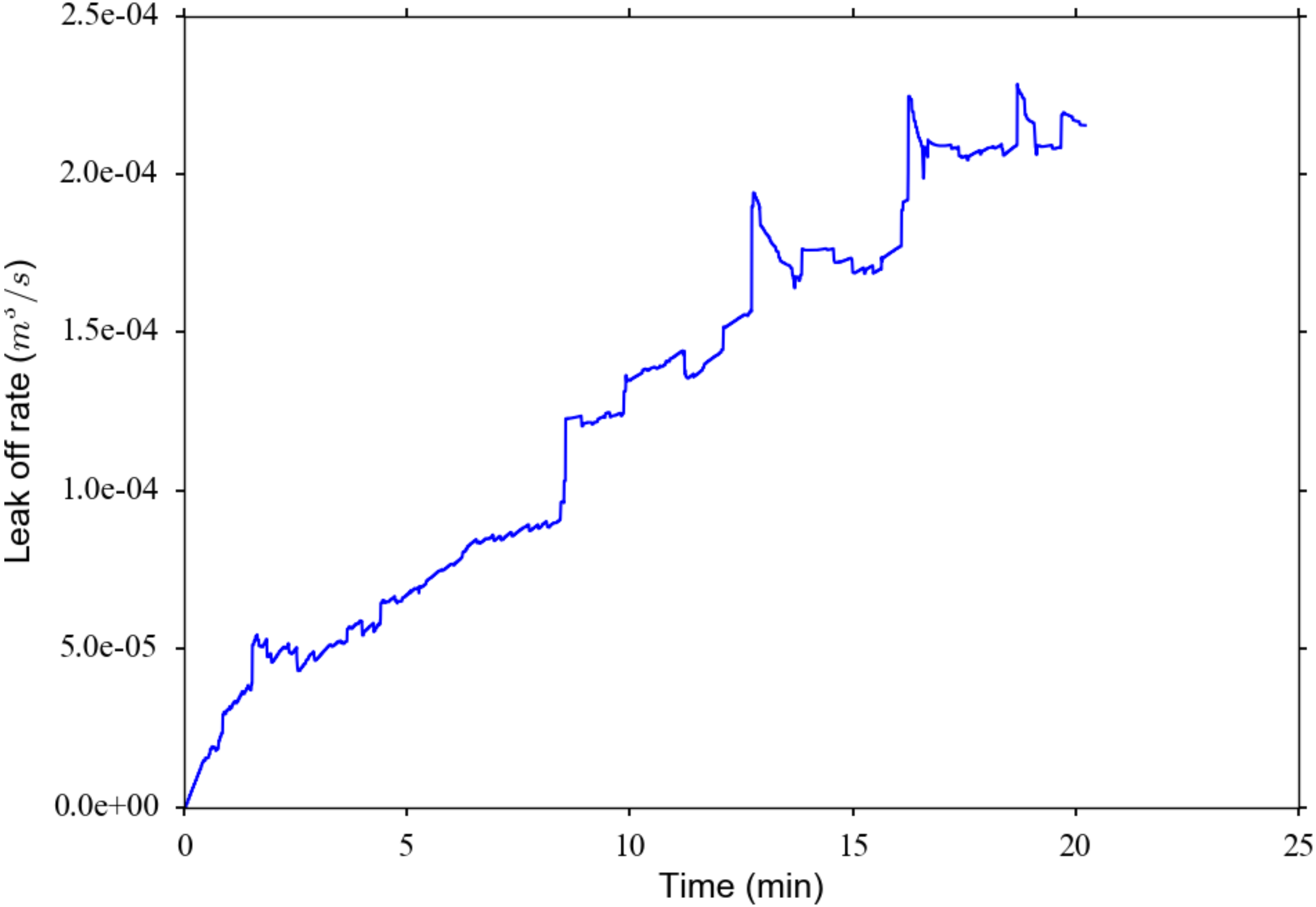
Fracture Width



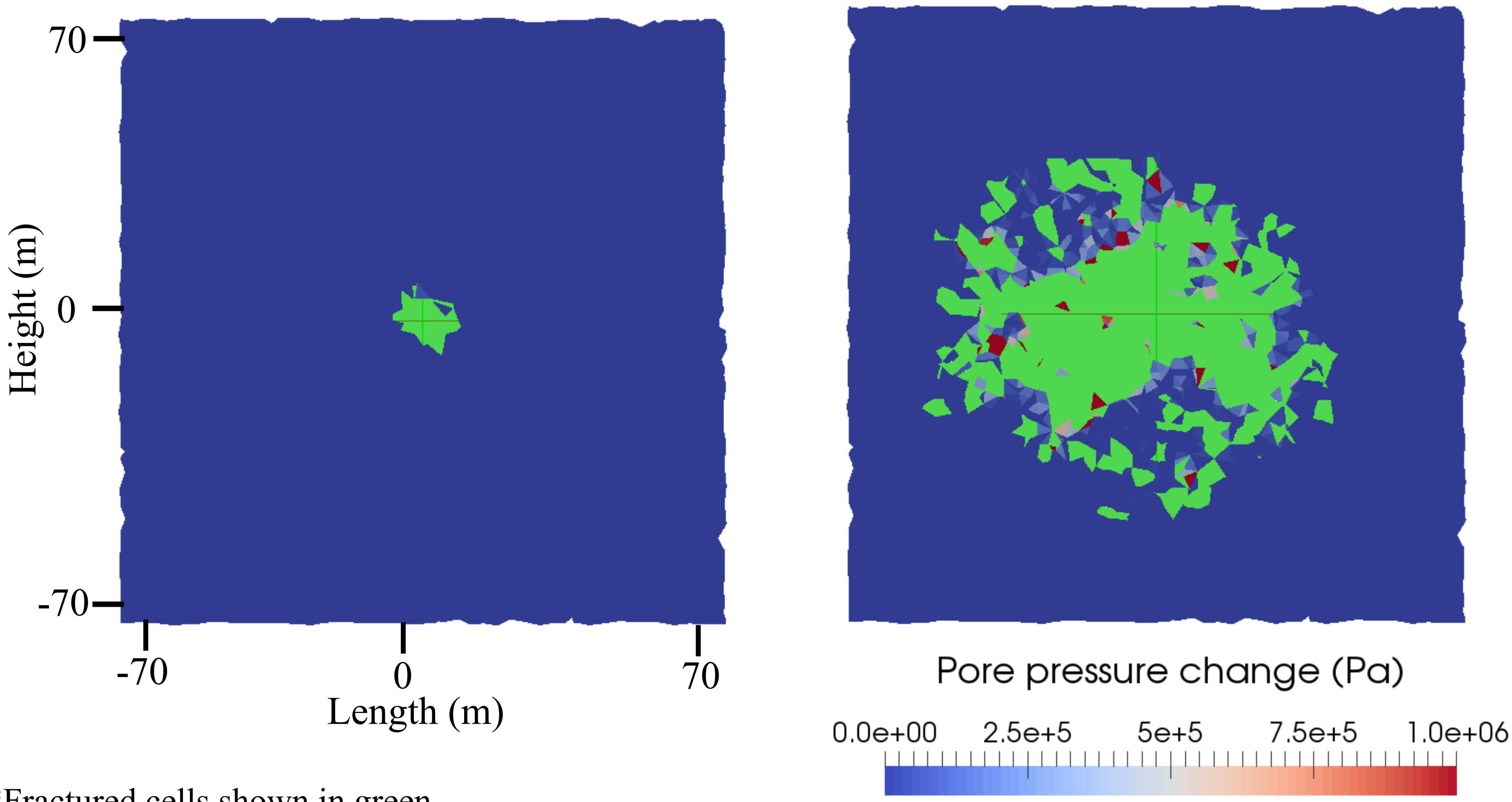
Net Pressure



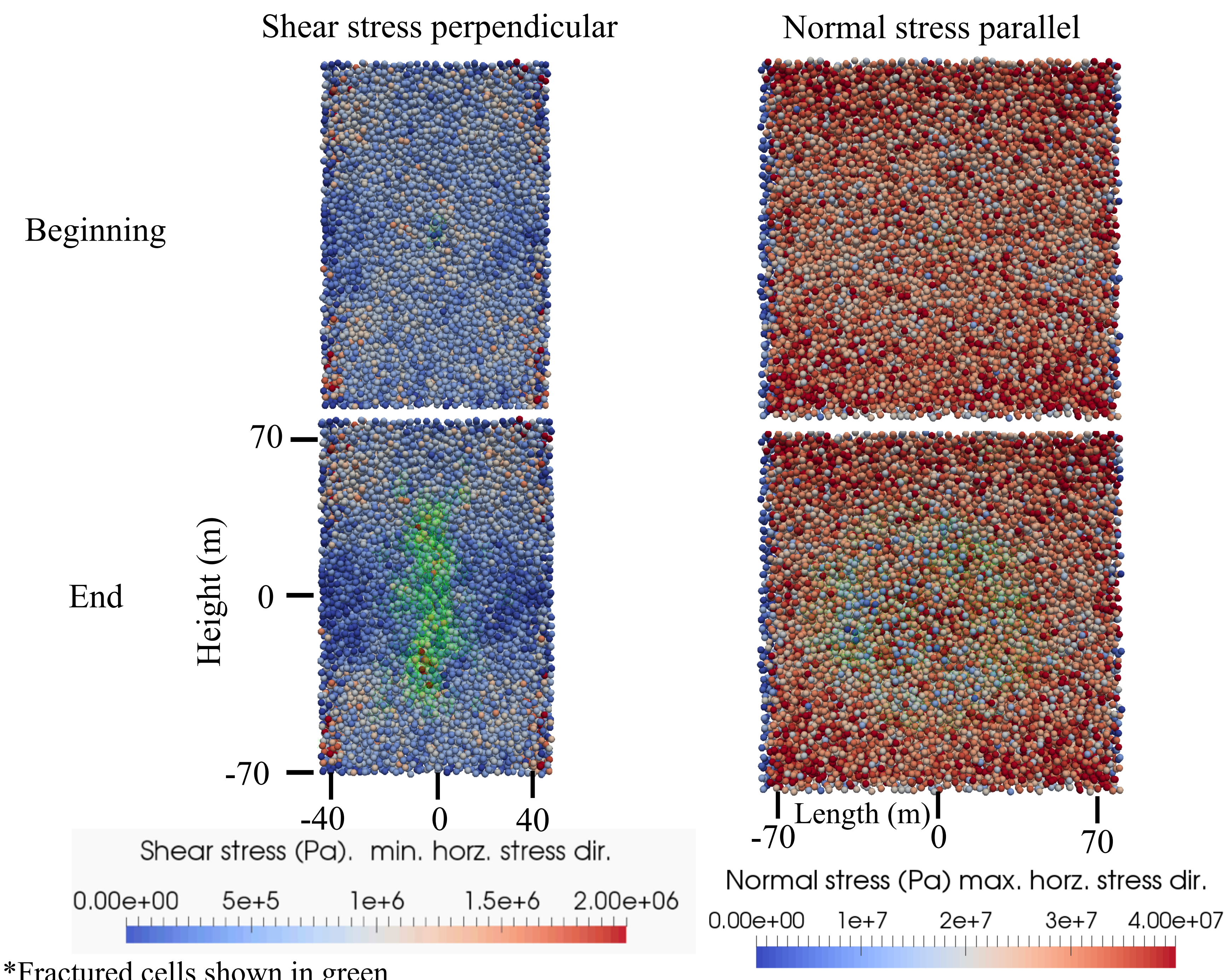
Leak-off Rate



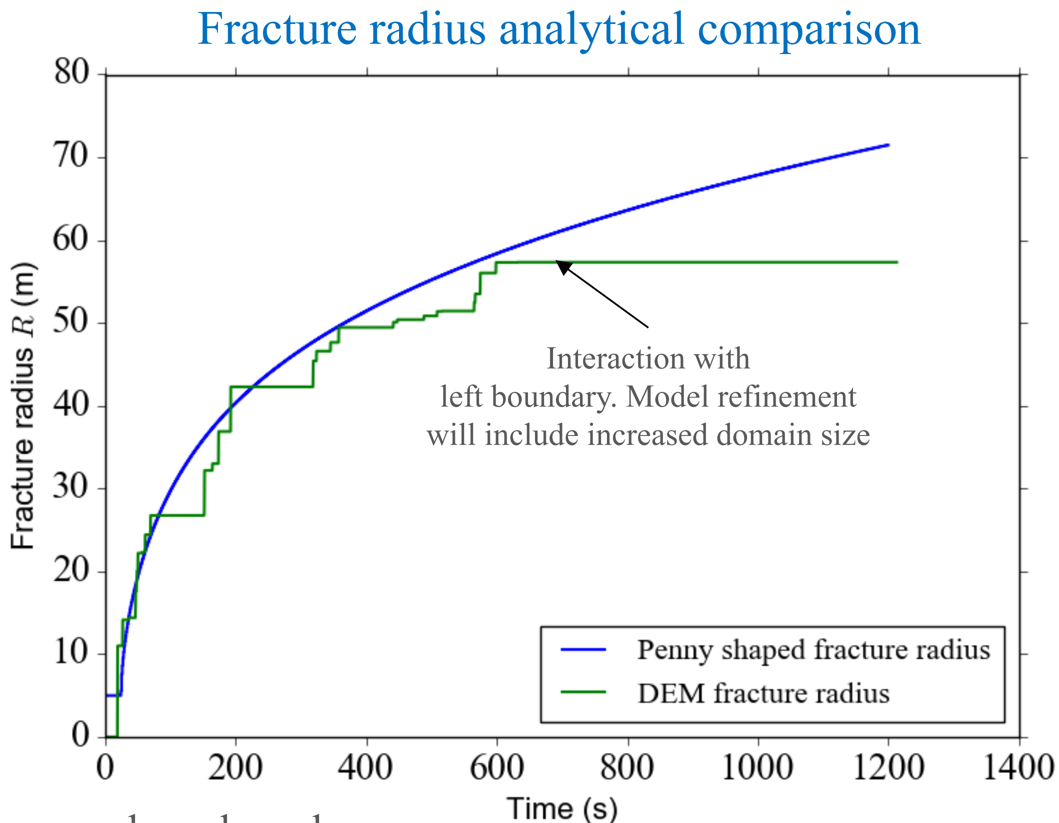
Pore Pressure



*Fractured cells shown in green


Shear stress perpendicular
Normal stress parallel
Beginning
End
Height (m)
70
0
-70
-40
0
40
Length (m)
-70
0
70
Shear stress (Pa). min. horz. stress dir.
0.00e+00
5e+5
1e+6
1.5e+6
2.00e+06
Normal stress (Pa) max. horz. stress dir.
0.00e+00
1e+7
2e+7
3e+7
4.00e+07
*Fractured cells shown in green

Extra Plots



Width of pressurized penny shaped crack (Sneddon and Elliot 1946)

$$w(r) = \frac{8p_{net}R}{\pi E'}\sqrt{1-(r/R)^2}$$

Propagation presure (Perkins and Kern 1961):

$$p_{net,c} = \left(\frac{2\pi^3\gamma_F E'^2}{3V}\right)^{1/5}$$

Conservation of volume:

$$\Delta V_f = q_i \Delta t_p - V_L$$

* V_L=leak off volume, q_i = injection flow rate
w = fracture width, p_{net} = net pressure
E' = Young's modulus γ_F = fracture energy ,R = fracture radius