Effect of Elastic Properties and Confining Pressure on Damage Localization Mechanisms and Acoustic Emission Trends

Harsha Vora (hv6@rice.edu), Julia Morgan (morganj@rice.edu)
Department of Earth Science, Rice University, Houston, TX

Abstract

The objective of the study is to understand the control confining pressure and elastic properties of rock have on the deformation process in rocks. Discrete element modeling method is used to simulate particulate rock of defined grain size distribution. Biaxial tests are conducted on the virtual samples, and acoustic emission trends and deformation patterns are analyzed as the rock is taken to failure. We try to quantify and correlate the predicted seismicity to observed deformation patterns to build a predictive model.

Initial results show confining pressure being having largest control on brittle-ductile transition in deformation patterns, with elastic parameters dictating fracture energy and seismic magnitudes. At low confining pressures, we observe brittle deformation patterns and high seismic b-values. At high confining pressures, we observe diffuse deformation patterns and low seismic b-values. Elastic parameters have decreasing control over deformation patterns with increasing confining pressures.

The Discrete Element Method

•Construct geologic medium as assemblage of simple particles – disks or spheres

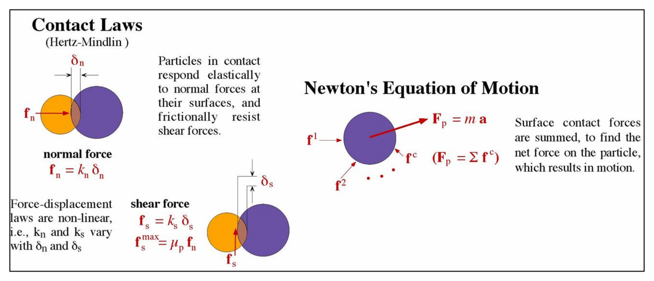
•Apply physical properties to particles:

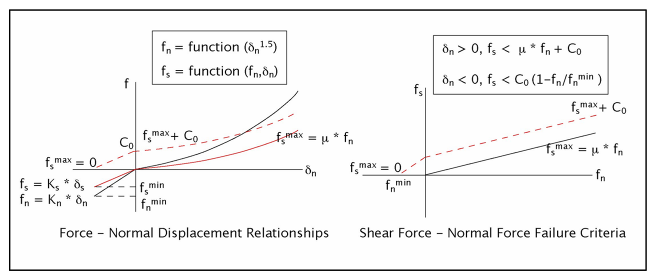
Contact friction, elastic particle deformation

Inter-particle bonds, normal, shear, and rotation

Pairwise interactions, no long-range interactions

•Resolve forces onto particles, track resultant motion





Methodology

• Particle sizes: 10E-5 m to 40E-5 m

• Pre-consolidation Stress: 10 MPa

•Calculate energy of micro-fractures generated

$$E_f = \left(\frac{1}{2C_f}\right)\sigma_{cf}^2 v_f$$

E_f : energy of micro-fracture
C_f :Young's Modulus
σ_{cf} : Peak strength of element
v_f : Volume of failed element

• Calculate Moment of events

$$M_e = \frac{2}{3}log_{10}E_s - 2.9$$

M_e : Moment
E_s : Energy of micro-fracture (N.m)

• Clump events for a defined spatial and temporal limit

• Evaluate b-value

$$log\ N(M) = a - bM$$

N: Number of earthquakes greater than magnitude M
b: slope of frequency-magnitude

Low b-value: Greater coalescence of micro-fractures, lower resistance to damage propagation

High b-value: Lower coalescence of micro-fractures, higher resistance to damage propagation

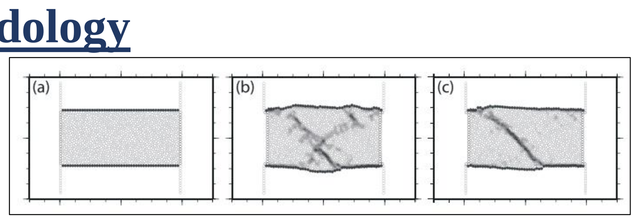
• Evaluate fractal nature of deformation using D-value

$$C(R) = \frac{2}{N(N-1)}N_{(r<R)}$$

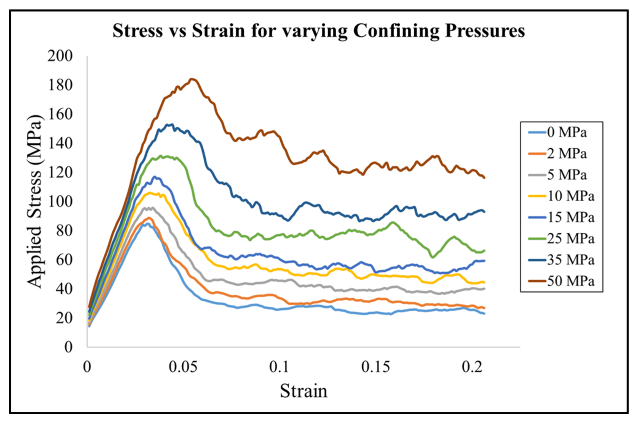
$$C(R)\ \alpha\ R^D$$

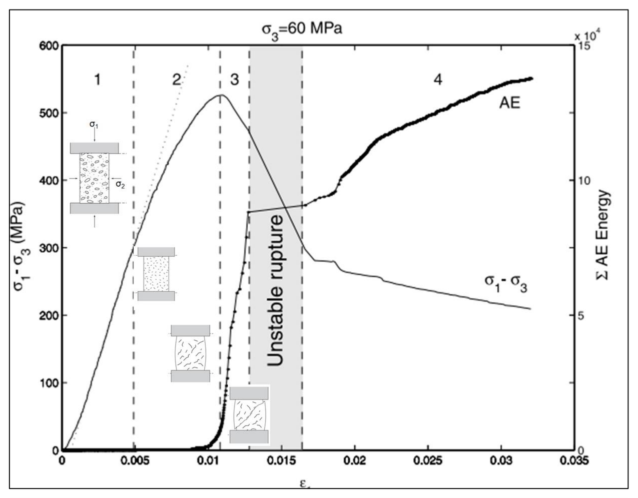
D: fractal dimension
N: number of event pairs
R: radius (m)

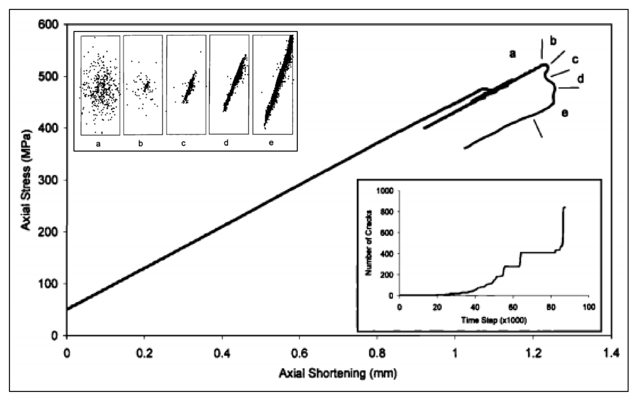
Low D-value: Localized Damage
High D-value: Diffused Damage

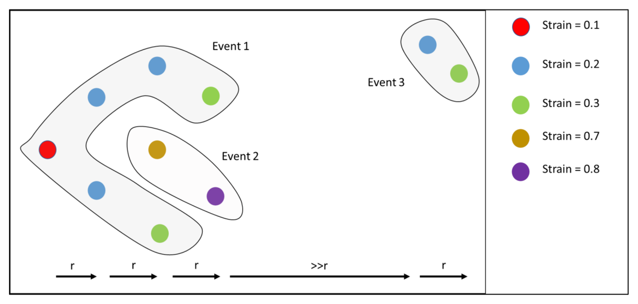


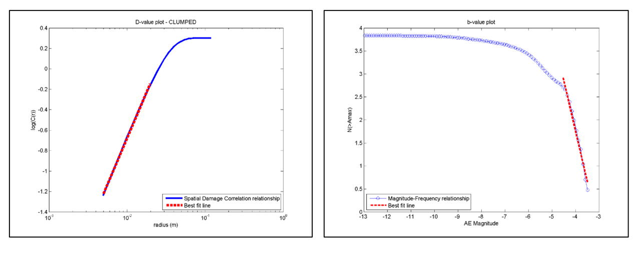
Bond Parameters	Value
Young's Modulus	2E08 Pa – 1E11 Pa
Shear Modulus	2E07 Pa – 2E09 Pa
Compressive Strength	8E07 Pa
Tensile Strength	4E07 Pa





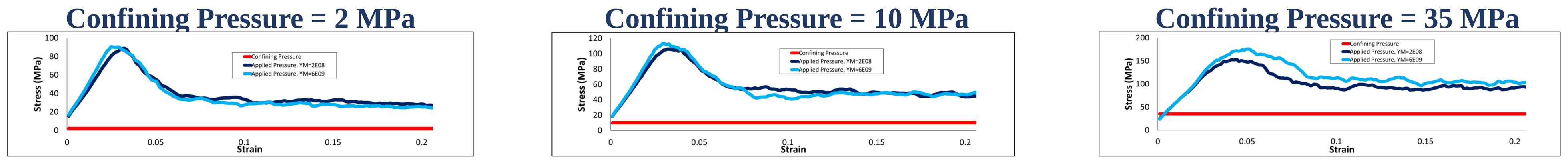




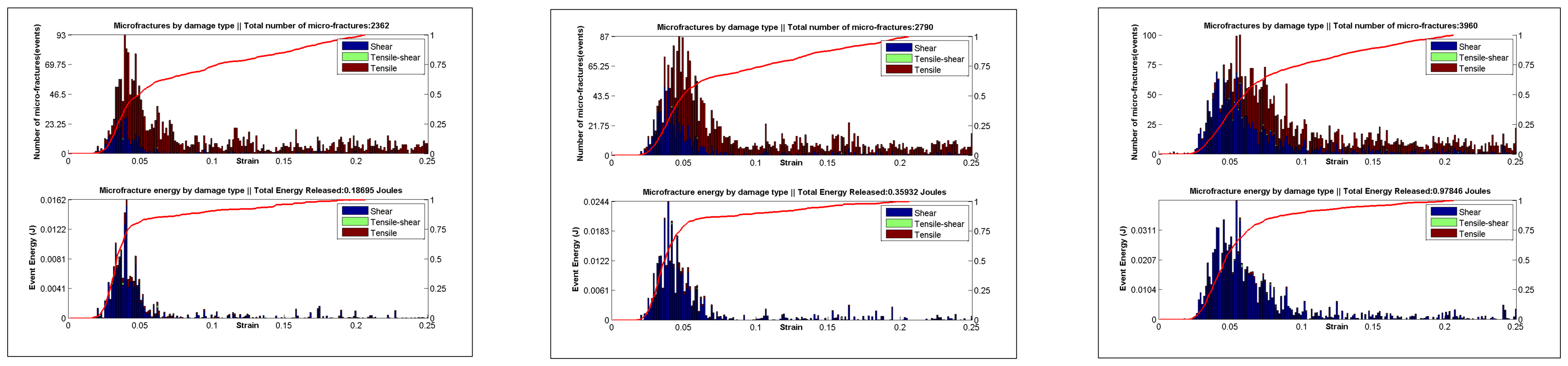


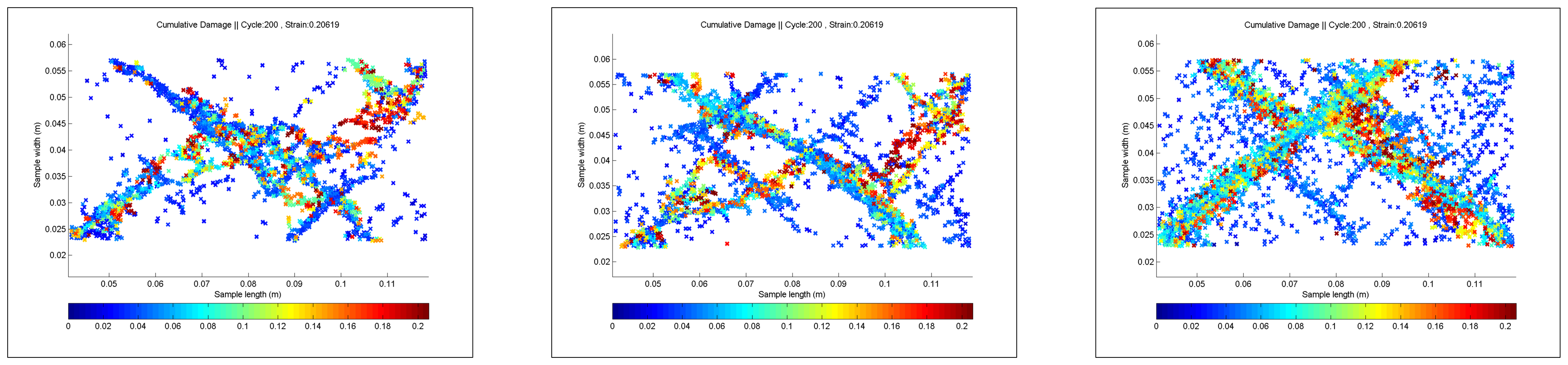
Effect of Young's Modulus and Confining Pressure on Rock Deformation

Confining Pressure = 2 MPa | Confining Pressure = 10 MPa | Confining Pressure = 35 MPa



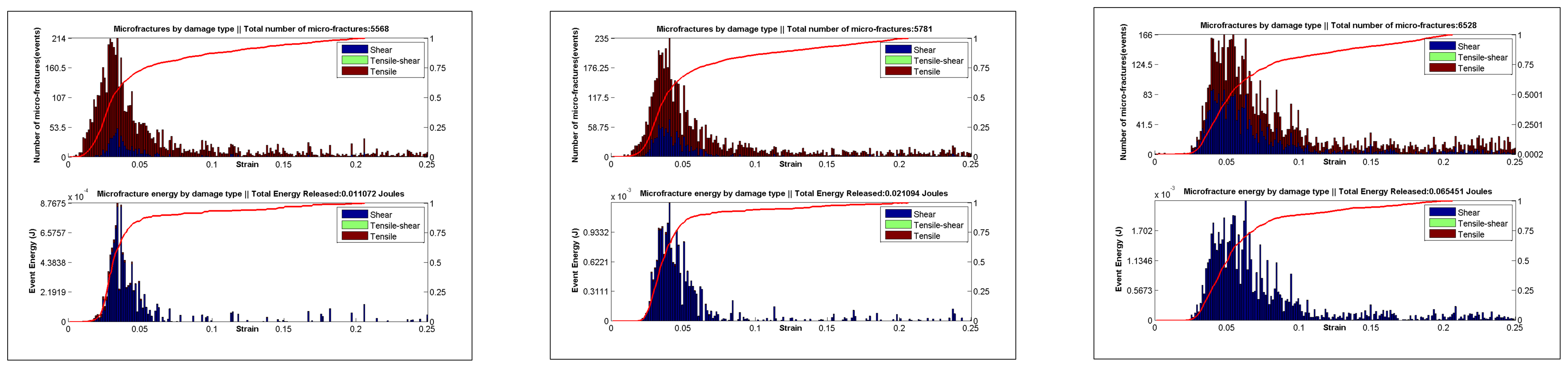
Young's Modulus = 2E08 Pa

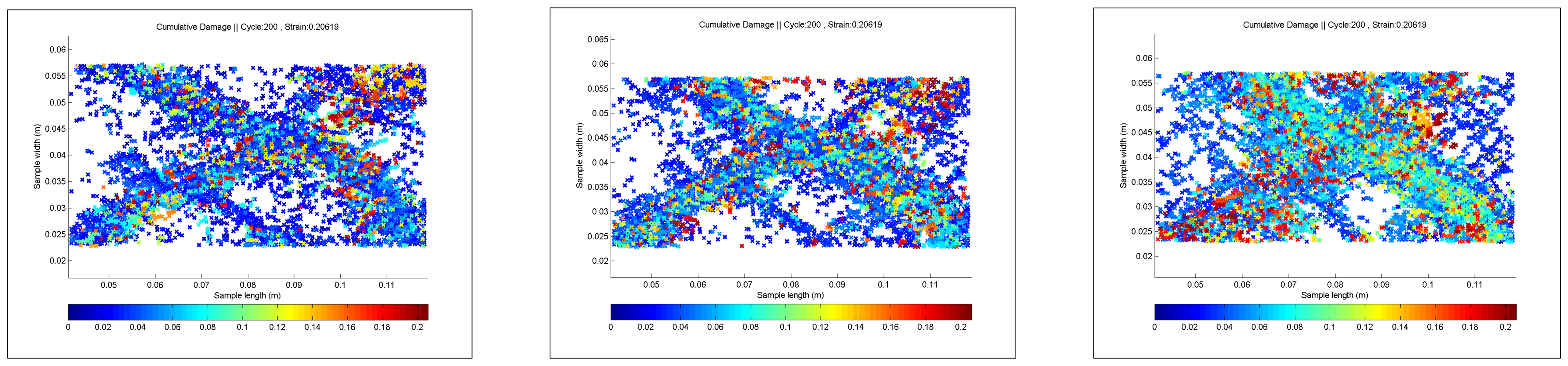




b-value: 1.6288 | b-value: 1.4012 | b-value: 1.0989
D-value: 1.5310 | D-value: 1.5513 | D-value: 1.6295

Young's Modulus = 6E09 Pa

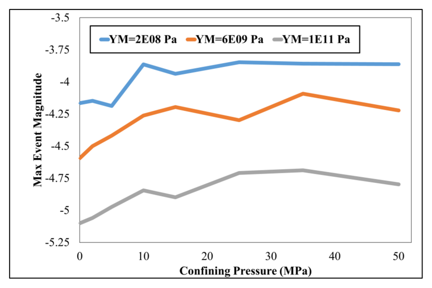


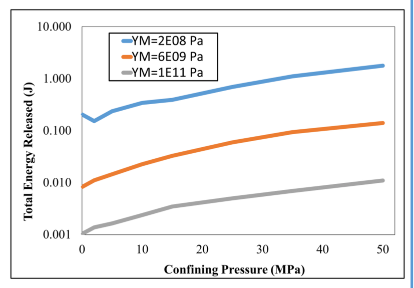


b-value: 1.4027 | b-value: 1.1848 | b-value: 1.1791
D-value: 1.6254 | D-value: 1.7207 | D-value: 1.7790

Important Observations

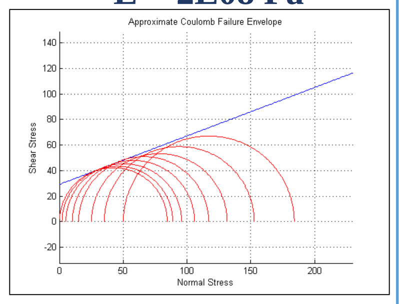
- Fracture energy and magnitude of events produced are inversely related to the Modulus of Elasticity. As confining pressure increases, magnitude of energy released also increases



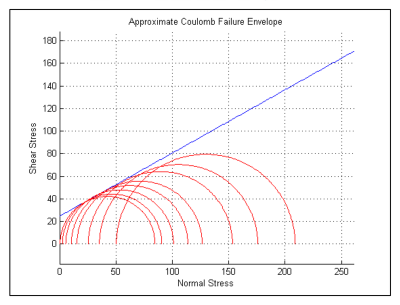


- As Young's Modulus increases, deviation from linear Mohr Coulomb behavior occurs at increasingly lower normal stresses

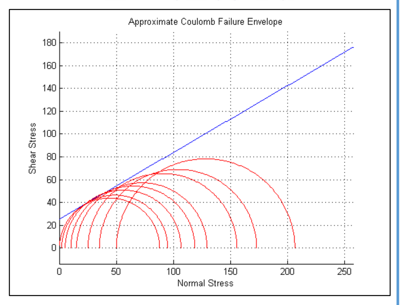
E = 2E08 Pa



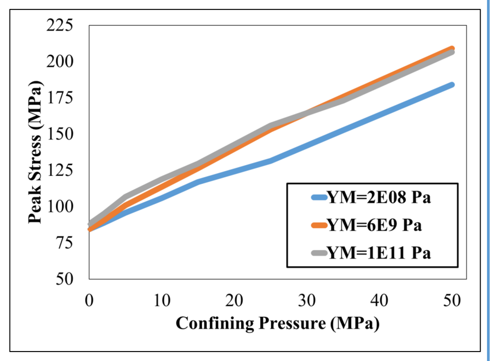
E = 1E11 Pa



E = 6E09 Pa

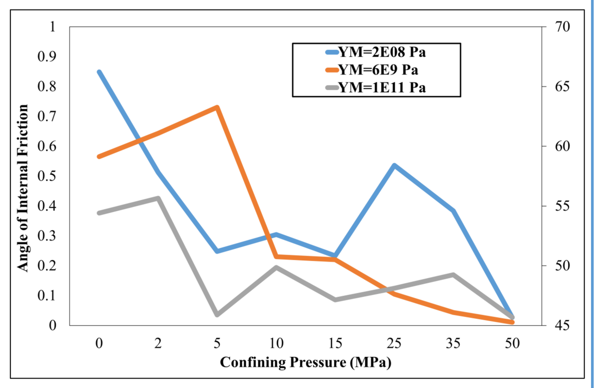


- Peak Strength and residual strength of rock increase with Confining Pressure



- Strain over which localization of macro-rupture takes place, or speed of fracture propagation, decreases with confining pressure.

- As Confining Stress increases, angle of macro-fracture (θ) decreases, and consequently angle of internal friction decreases



- Cumulative energy released from fracturing process increases with Confining Pressure

Results

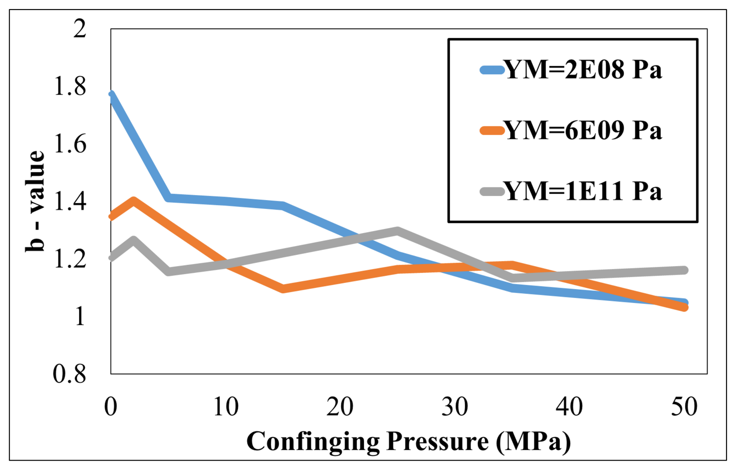
- Elastic properties of rock control magnitude of energy release, magnitude of acoustic emissions upon rock deformation.
  Energy released from deformation increases with increasing Shear Modulus and decreasing Young's Modulus.

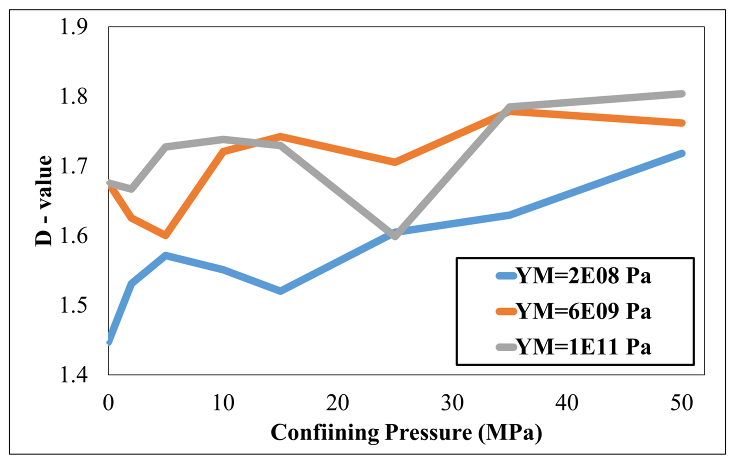
- At low Confining Pressure
  - Deformation is localized (Brittle)
  - High b-values
  - Low D-values
  - Elastic properties have some control over deformation patterns

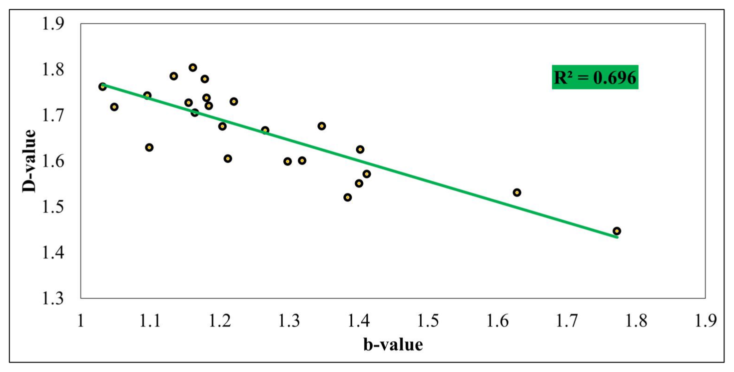
- At high Confining Pressure
  - Deformation is diffuse (Ductile)
  - Low b-values
  - High D-values
  - Effect of elastic properties is negligible as acoustic emission and deformation patterns seem to converge

- Seismic b-values and fractal nature of deformation (D-value) have a linear relationship

$$D = -0.4493 * b + 2.2304$$



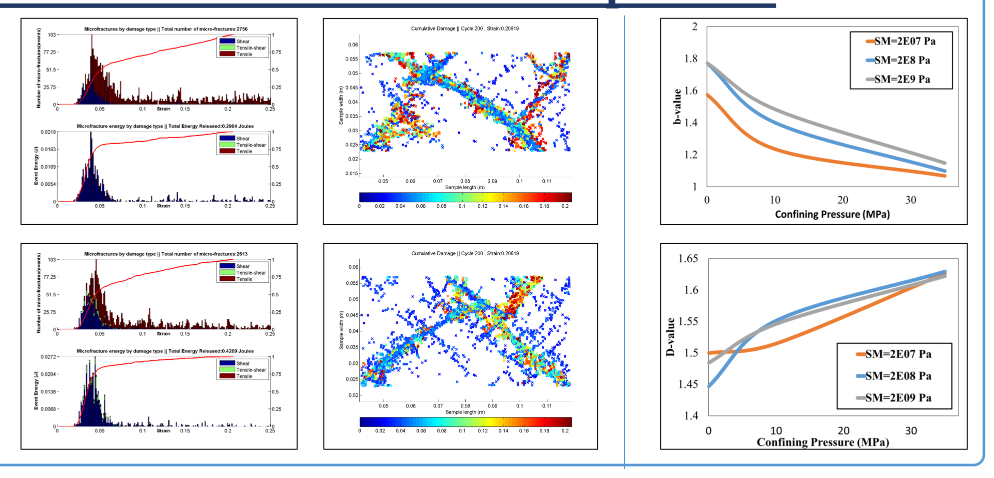




Effect of Shear Modulus on deformation patterns

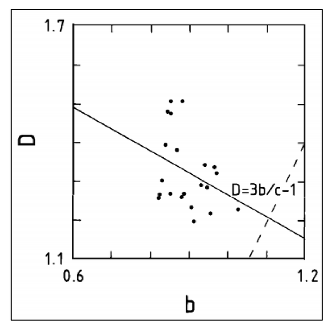
G = 2E07 Pa
Confining Pressure = 10 MPa
b-value: 1.2358
D-value: 1.515

G = 2E09 Pa
Confining Pressure = 10 MPa
b-value: 1.4842
D-value: 1.5462



Key Questions and Future Work

1. Is Confining Pressure the biggest control on brittle-ductile transition in deformation patterns ?
2. Are energy and speed of fracture propagation decoupled from the mechanism of deformation ?
3. Can we predict in situ deformation pattern from knowledge of stress state of rock and it's elastic properties ?
4. Can patterns of deformation and acoustic emissions from lab-scale samples be correlated to earthquakes ?



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