MIT EARTH RESOURCES LABORATORY
ANNUAL FOUNDING MEMBERS MEETING 2018

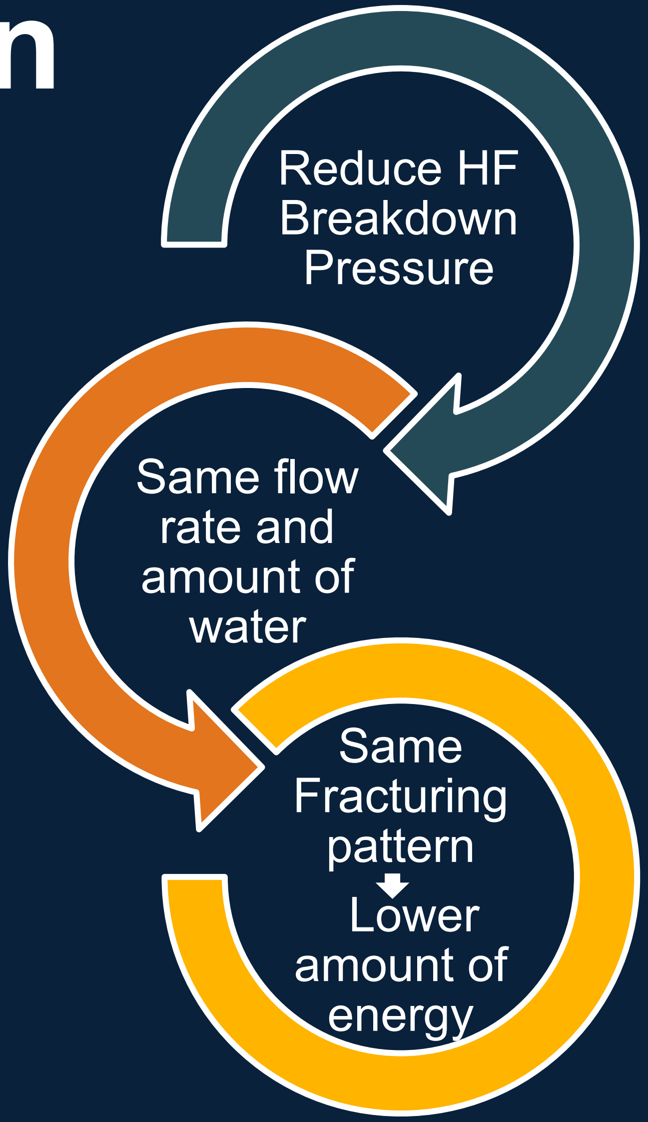
Reducing Breakdown Pressure in Hydraulic Fracturing Process

Effect of Flaw Shape and Penetration Fluids in Porous Material in Breakdown Pressure

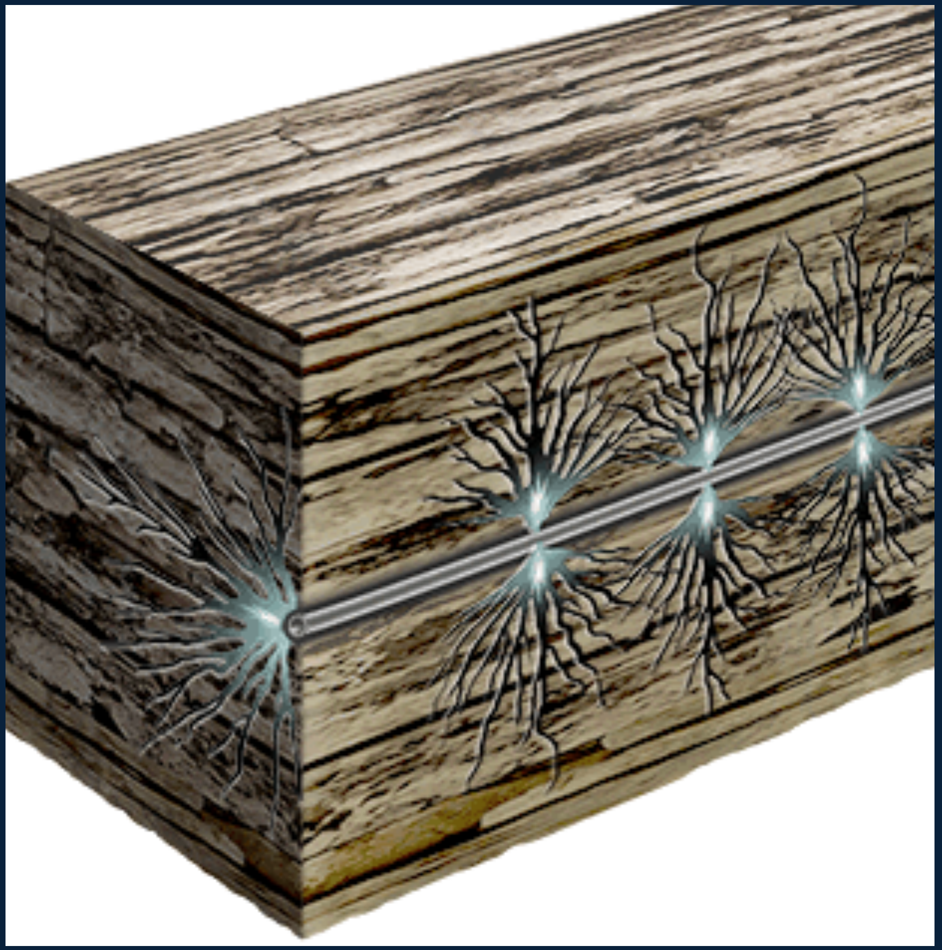
Ignacio M. Arzuaga García
MSC CANDIDATE [CIVIL AND ENVIRONMENTAL ENGINEERING]

Under supervision of Prof. Herbert Einstein

Motivation



Hydraulic Fracturing Process **MORE** energetically efficient



Key Points of the research

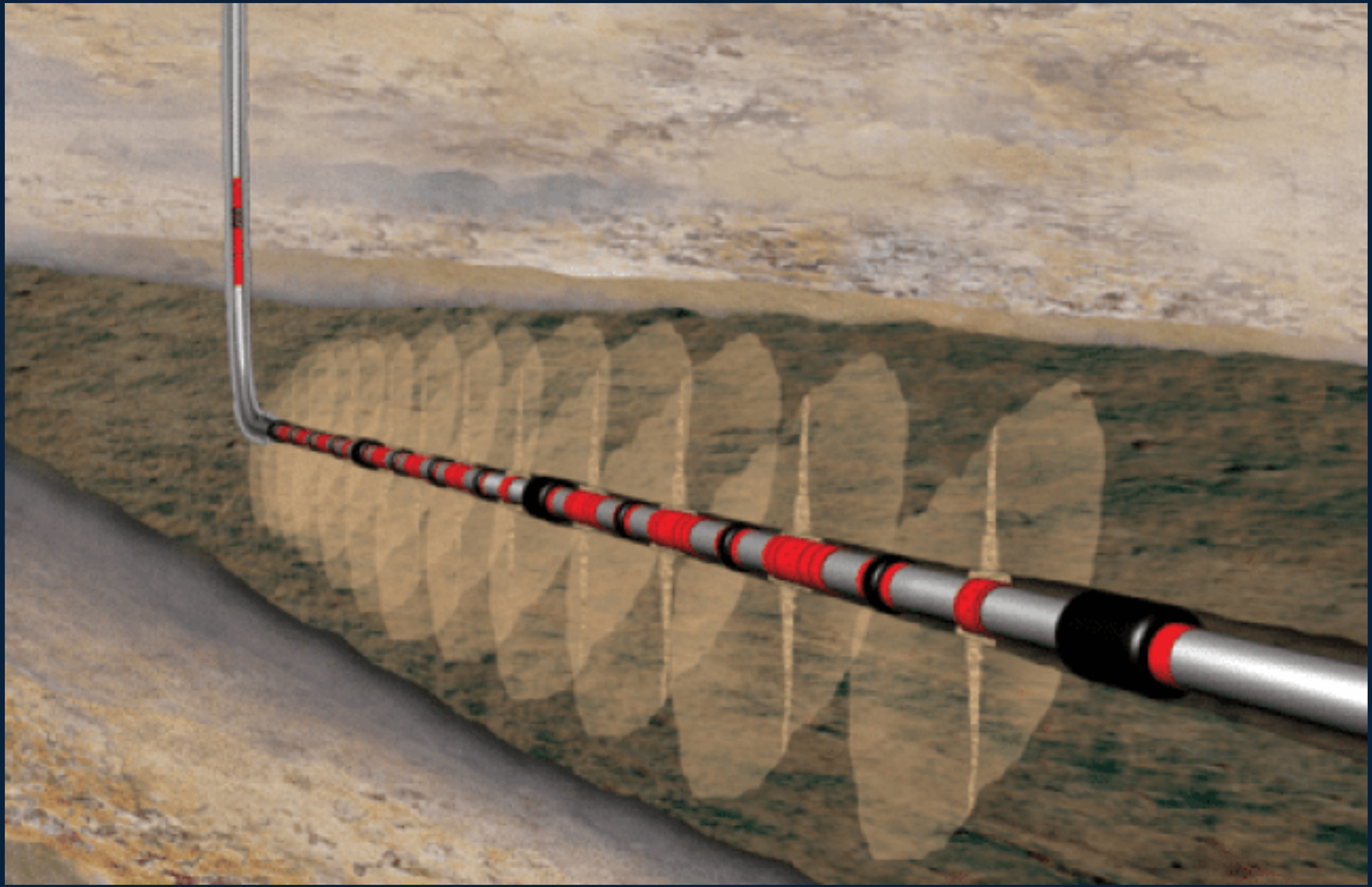
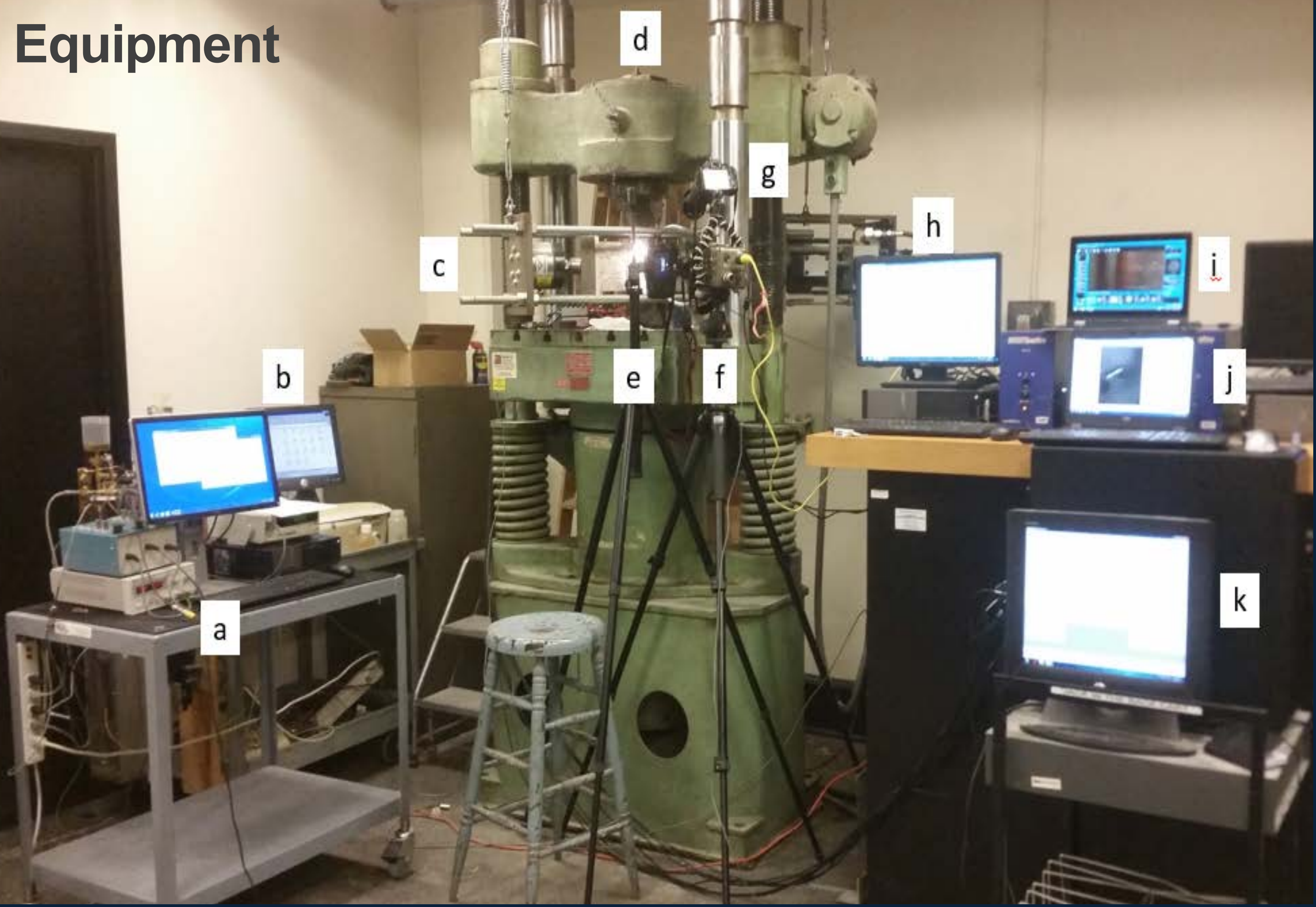


Image Credit: Halliburton

REDUCTION IN THE BREAKDOWN PRESSURE

1. Generating zones of stress concentration in the rock with the penetration gun (notches).
2. Increasing the seepage of injection fluid into the rock matrix.

Equipment

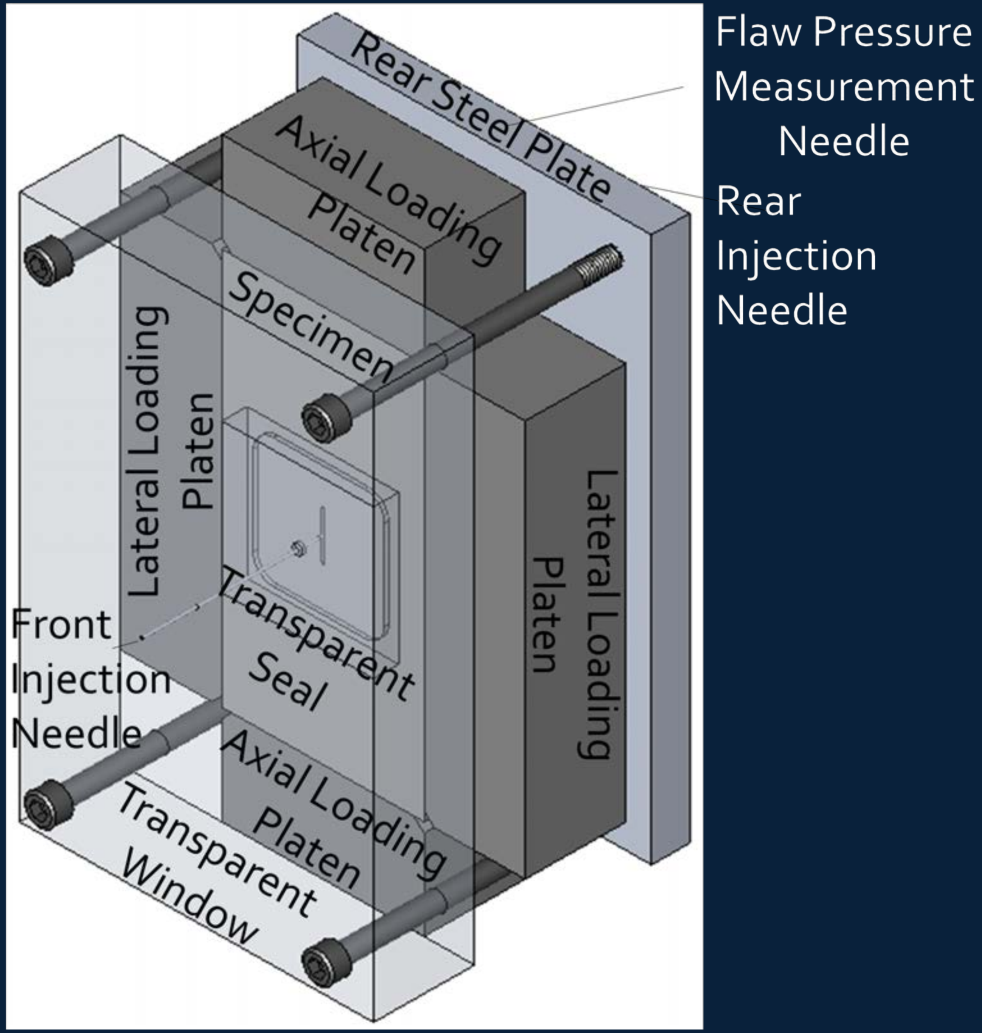


Our lab prioritizes the visualization of the fracturing process in real time

Hydraulic Fracturing Experimental Setup:

(a) Central data acquisition
(b) Hydraulic fracture apparatus (PVA, LVDT, Pressure Transducer)
(c) Lateral load
(d) Axial load
(e) High resolution images
(f) High speed video
(g) High resolution video
(h) Load frame computer
(i) High resolution camera computer
(j) High speed video computer
(k) Acoustic emissions system.

Detail of Baldwin Biaxial Loading Frame



Pressurization device
(Source: Omar Al-Dajani SM Thesis, 2017)

Equipment Details

The pressurization device, with Polycarbonate window and Transparent seals, allows us to track the fracturing process in real time

Research’s purpose

- Biaxial HF tests
  - Different shapes of the pressurized flaw in gypsum;
  - External Stresses:

4.5 MPa axially,

1 MPa laterally;

  - Constant flow rate of 0.015 cc/s.

- Gypsum
  - isotropic material;
  - easier to create specimens with different opening geometries.

- AE recorded but not yet analyzed.

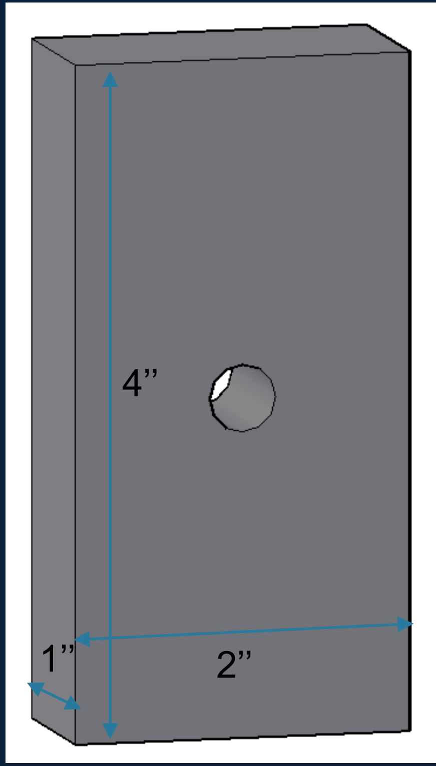


Figure 1: Specimen’s dimensions

A – Circle
B – Circle w/ short notch
C – Circle w/ long notch
D – Single vertical flaw

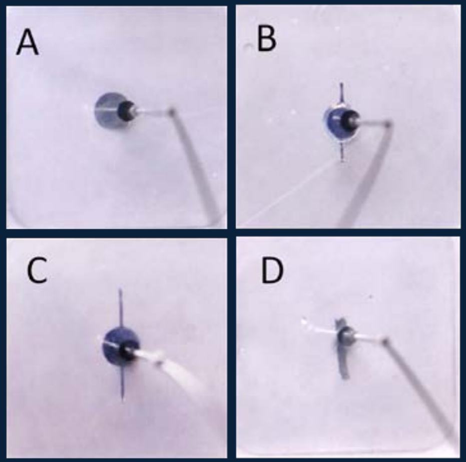


Figure 2: Four different shapes

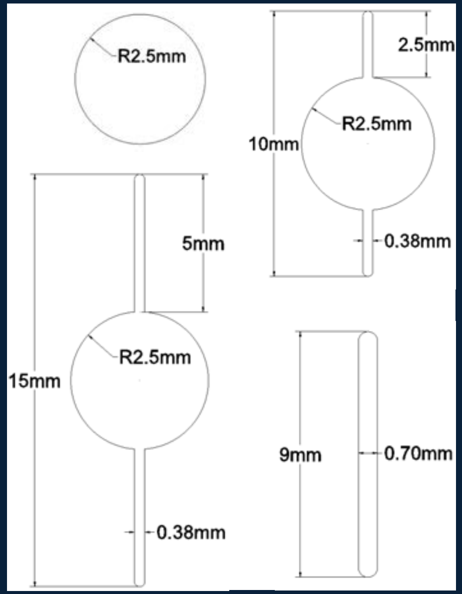


Figure 3: Shapes’ dimensions

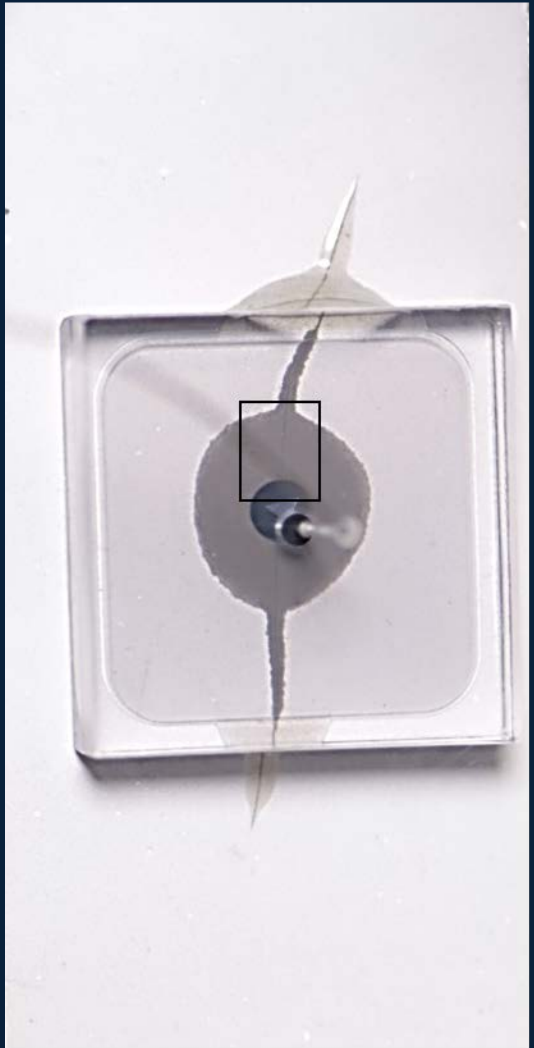
Earth Resources Laboratory

Effect of Flaw Shape in Breakdown Pressure

Experimental Results

CIRCULAR HOLE

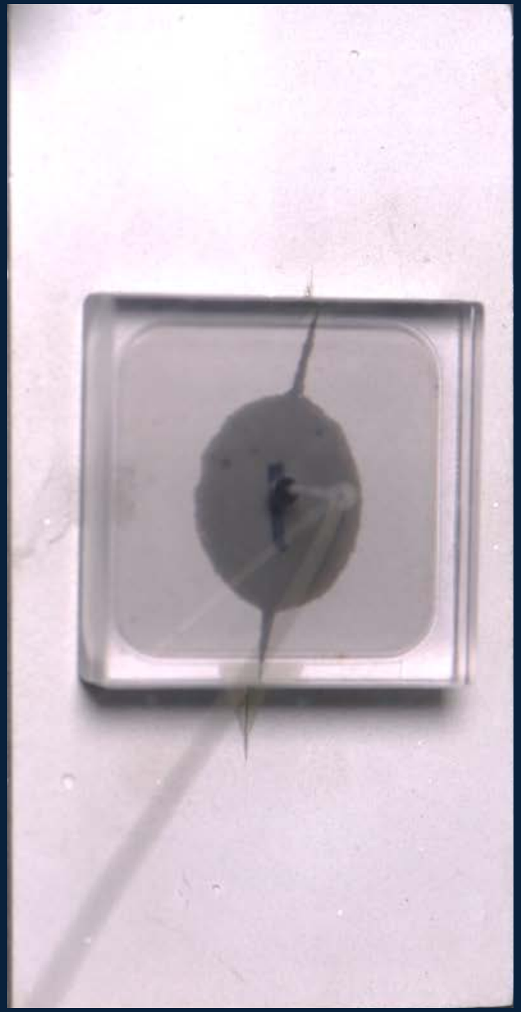
- Tensile fractures:
  - *Hydraulic fractures initiate at the top and bottom of the circle.*
  - *Quite straight near the opening, then it inclines when it reaches the boundary of the seal.*
- Crack tip moves faster than the front of the liquid.
- Oil seepage into matrix is observed before the cracks appear.
- Breakdown pressure: ~ 6.7 MPa



Experimental Results

SINGLE VERTICAL FLAW

- Tensile fractures:
  - *Hydraulic fractures initiate at the top and bottom of the circle.*
  - *Quite straight near the opening, then it inclines when it reaches the boundary of the seal.*
- Crack tip moves faster than the front of the liquid.
- Oil seepage into matrix is observed before the cracks appear.
- Breakdown pressure: ~ 6.5 MPa

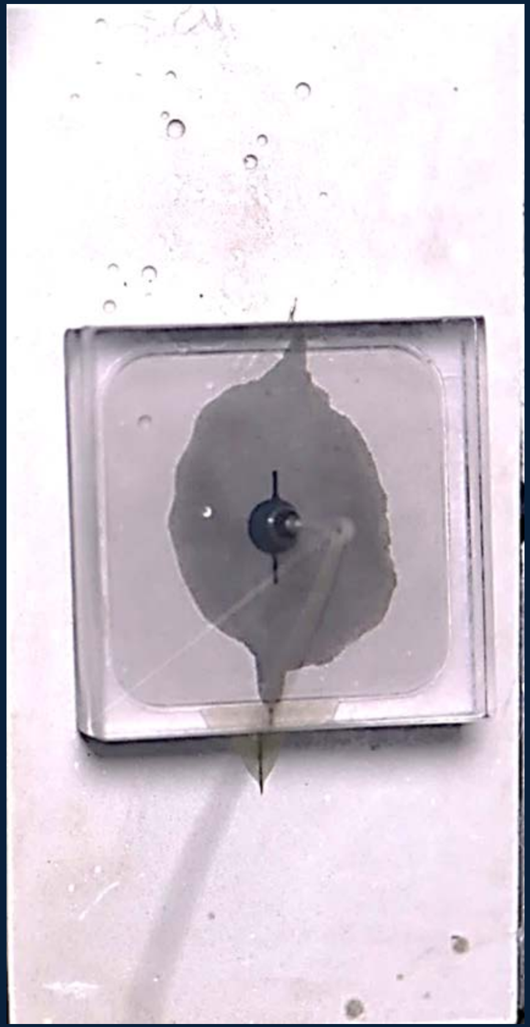


Experimental Results

CIRCULAR HOLE WITH SHORT NOTCH

- Tensile fractures:
  - *Hydraulic fractures initiate at the tip of the notch;*
  - *Quite straight near the notch;*
- Crack tip moves faster than the front of the liquid.
- Oil seepage into matrix is observed before the cracks appear.
- Breakdown pressure lower than in previous geometries:

  ~ 2.5 – 4.0 MPa

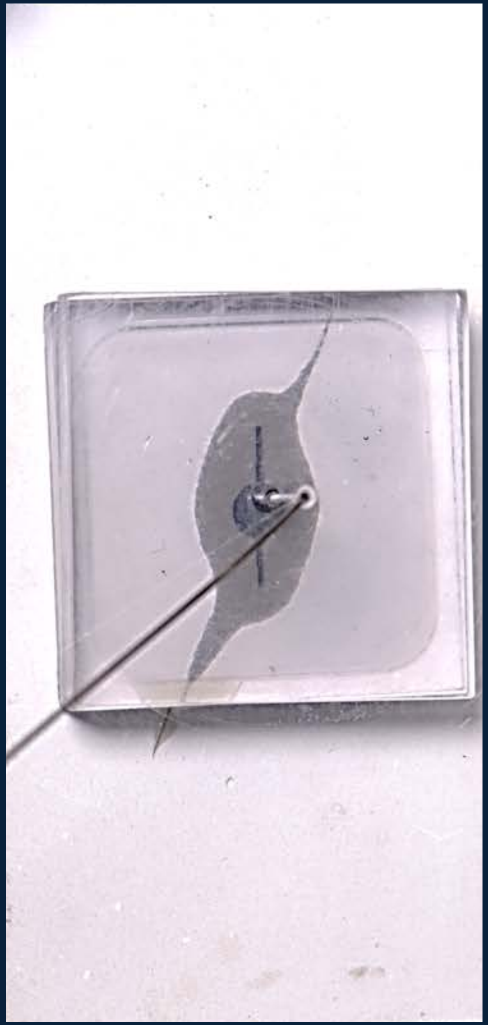


Experimental Results

CIRCULAR HOLE WITH LONG NOTCH

- Tensile fractures:
  - *Hydraulic fractures initiate at the tip of the notch;*
  - *Quite straight near the notch*
  - *In the case shown, the fracture at the bottom initiates at the corner between the circle and the notch.*
- Oil seepage into matrix is observed before the cracks appear.
- Breakdown pressure lower than in previous geometries:

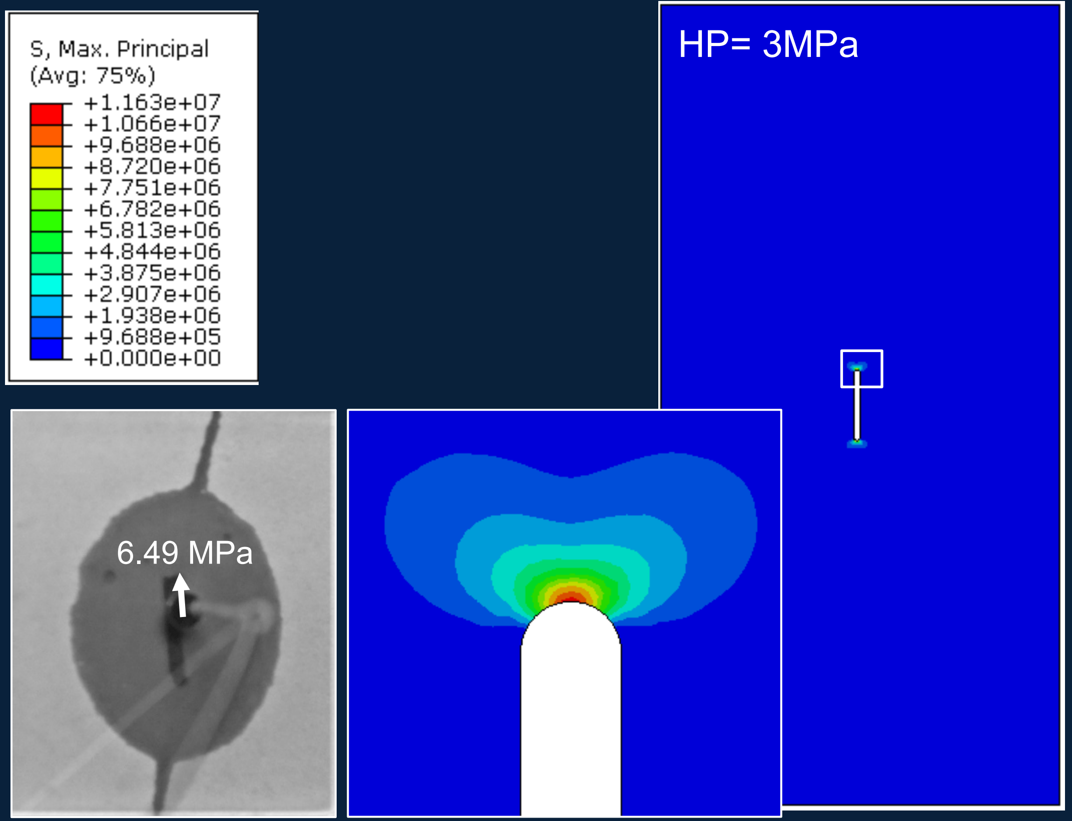
  ~ 2.5 – 3.8 MPa



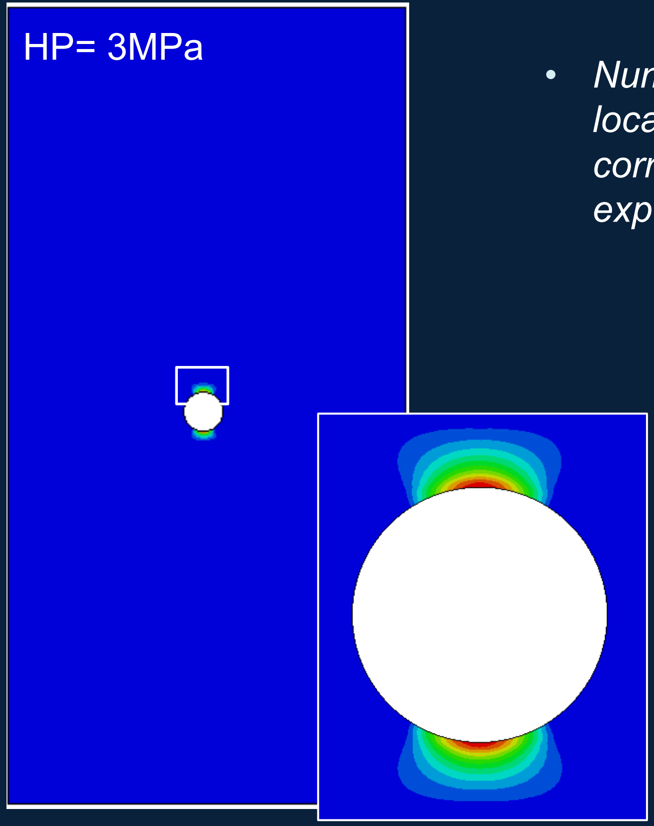
Numerical Model

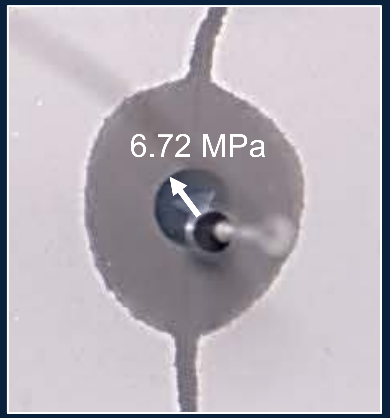
NUMERICAL (ABAQUS): ELASTIC MODEL – TO SHOW THAT STRESSES CONCENTRATION OCCURS WHERE HF INITIATES

SINGLE VERTICAL FLAW



CIRCULAR HOLE





- *Numerical results regarding location of hydraulic fracture correspond to the experimental ones.*

Analytical Model

KIRSCH + HP

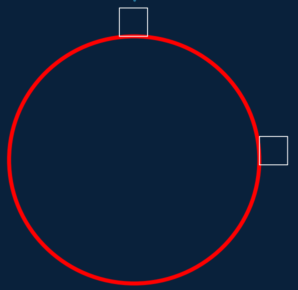
Min ppal: -2.86 MPa

Max ppal: +4.25 MPa

σ_{rr} = 0 MPa + HP = -3 MPa (*-2.86 MPa*)

$\sigma_{\theta\theta}$ = **(3 σ_h-σ_v) + HP**= +4.5MPa (*+4.25MPa*)

$\tau_{r\theta}$ = 0 MPa (*-0.14MPa*)

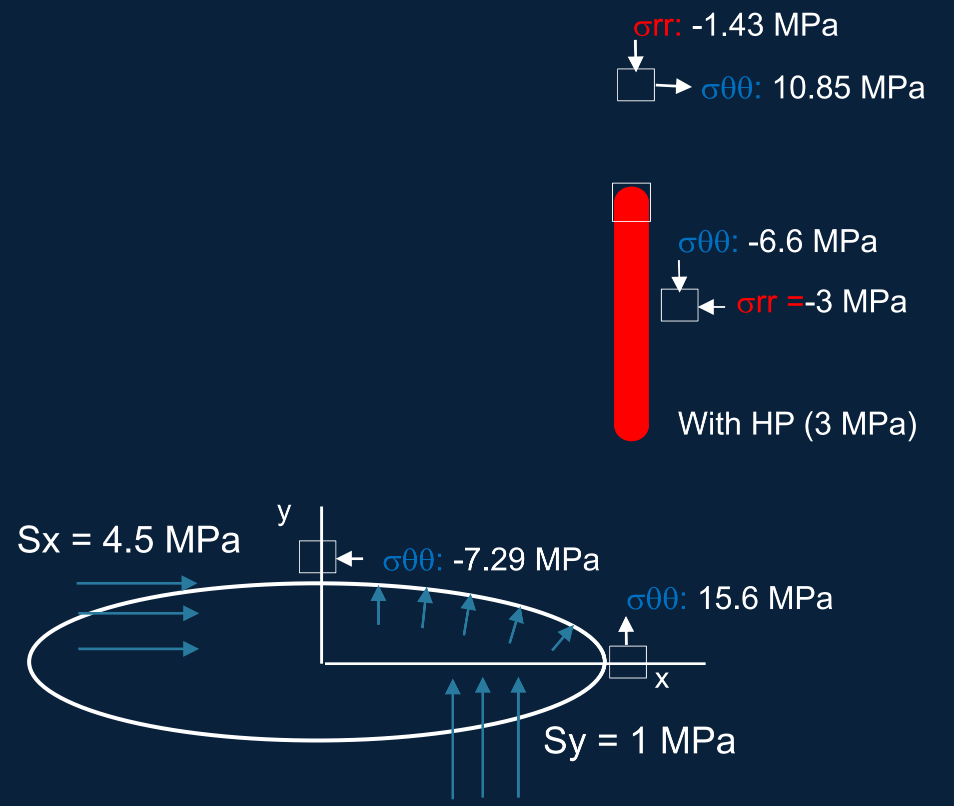


$\sigma_{\theta\theta}$ = **(3 σ_v-σ_h) + HP** = -9.5MPa (*-9.33MPa*)

σ_{rr} = 0 MPa + HP= -3MPa (*-3.09MPa*)

$\tau_{r\theta}$ = 0 MPa (*0.14MPa*)

JAEGER AND COOK (1979)



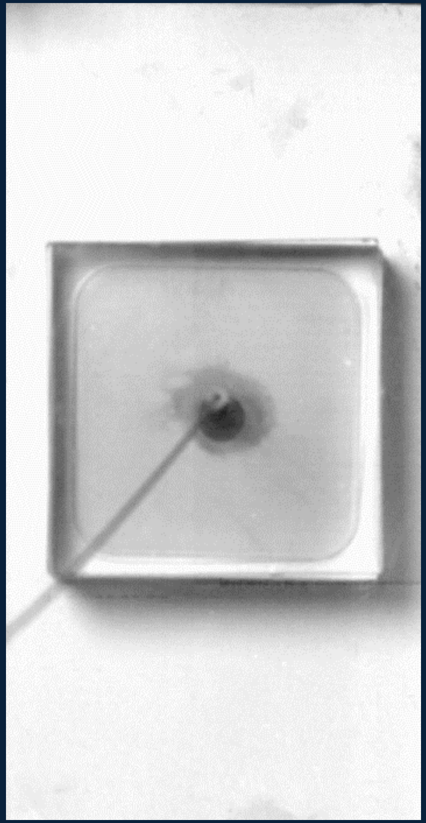
Effect of Penetration Fluids in Porous Material in Breakdown Pressure

Fracturing pressure using a penetrating fluid vs. non-penetrating fluid

BRIEF LITERATURE REVIEW

- Haimson and Fairhurst (1969)
  - *Stresses due to possible infiltration of the formation by the injected fluid may significantly affect the critical (breakdown) pressure (Haimson and Geertsma).*
  - *Laboratory tests show that in porous-permeable rock the breakdown pressure is lower than in an impermeable but otherwise identical formation.*
- Hubbert and Willis (1957)
  - *With a non-penetrating fluid in radial flow away from a well bore, a distributed force acts outward and its effect is to diminish the stress concentration at the face of the hole.*
  - *This in turn reduces the excess pressure that otherwise would be required to produce breakdown.*

Circular Hole

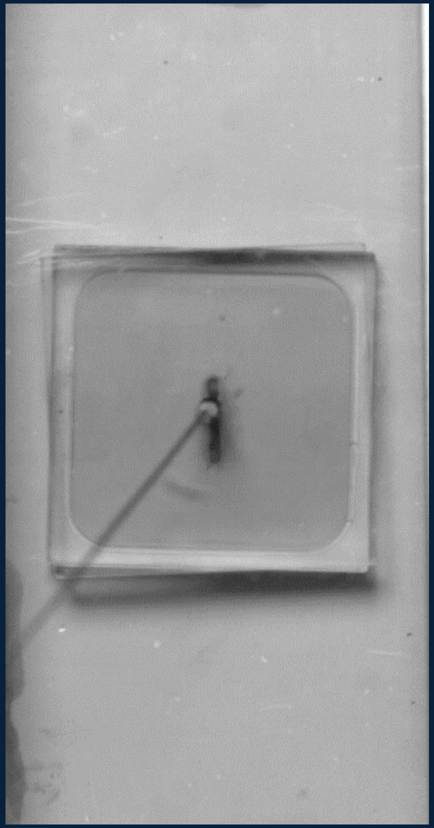
PENETRATING FLUID (PERMEABLE OPENING)	NON-PENETRATING FLUID (IMPERMEBLE WITH WAX)
 Breakdown pressure: ~ 6.7 MPa	 Breakdown pressure: ~ 9.0 MPa

Single Vertical Flaw

PENETRATING FLUID (PERMEABLE OPENING)

Breakdown pressure:
~ 6.5 MPa

NON-PENETRATING FLUID (IMPERMEBLE WITH WAX)



Breakdown pressure:
~ 10.0 MPa

Conclusions

FLAW (PREEXISTING OPENINGS) – SHAPE HAS:

- No effect on Fracture Patterns but introduces zone of stress concentration.
- Effect on Hydraulic breakdown pressure:
  - *Hydraulic pressure at fracture initiation is lower in cases with notch (concentration of stresses).*
- Experimental results can be related to results of elastic model.

THE PRESSURE AT THE HF WITH SEEPAGE INTO THE MATRIX IS MUCH LOWER THAN ALLOWING SEEPAGE.

- The experimental results are consistent with theory.
- Experiments have shown an increase in breakdown pressure between 30% - 50% from penetrating fluids to the non-penetrating fluids.