DOE-ARRA Geologic Sequestration Training and Research 2011 Yearly Review Meeting

Project DE-FE0002020
Title: Geomechanical Simulation of Fluid-Driven Fractures

University of Minnesota

Dr. Joseph F. Labuz, Civil Engineering

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Project Participants

- **Faculty: Joe Labuz, PI; Sonia Mogilevskaya, co-PI; Emmanuel Detournay, co-PI**
- **Students, full-time on project: Roman Makhnenko, Ph.D. student; Dmitry Nikolski, Ph.D. student**
- **Students, part-time on project: Andrey Pyatigorets, Ph.D student; Jim Meyer, M.S. student**

Introduction

- **Devise rock characterization techniques related to testing of fluid-saturated rock**
- **Develop predictive models for simulation of fluid-driven fractures**
- **Establish educational frameworks for geomechanics issues**
- **Benefits: training of students, plane-strain experiments, BEM fracture code**

Project Objectives

- **Conduct experiments using a plane-strain apparatus with fluid-saturated rock**
- **Model fluid-driven fractures using a boundary element method**
- **Teach courses in experimental (AE), numerical (BEM), and analytical (poroelasticity) methods**

Project Funding

- **Total Project Cost: $299,568**
- **DOE Share: $299,568**
- **Non-DOE Cost Share: $0 (although faculty contribute time and UMN equipment)**
- **Cost Share Provider: (UMN)**

Highlights of Project to Date

- **Calibration and modification of plane-strain apparatus**
- **Development of 2D BEM code for simulation of fracture**
- **Course taught on BEM**

Tasks – Overview

Task No.	Task Description	Task Duration	Task Funding
1	Project Management and Planning	12/01/2009 – 11/30/2012	$0
2	Plane strain tests: drained and undrained	12/01/2009 – 12/31/2010	$112,079
3	Numerical modeling: BEM algorithm	12/01/2009 – 12/31/2010	$112,078
4	Course development	01/01/2011 – 12/31/2011	$0

Project Schedule

Activities	Time (1 block = 2 months)																	
	Year 1						Year 2						Year 3					
Task 1.0 Project management																		
Task 2.0 Experiments																		
2.1 System calibration																		
2.2.1 Undrained testing																		
2.2.2 Drained testing																		
2.3 AE/damage assessment																		
Task 3.0 Numerical modeling																		
3.1 Two-D BEM																		
3.2 Three-D BEM																		
3.3 Fluid coupling																		
Task 4.0 Course development																		
4.1 Experimental mechanics																		
4.2 Poro/thermal elasticity																		
4.3 Boundary element modeling																		

Discussion – Task 2

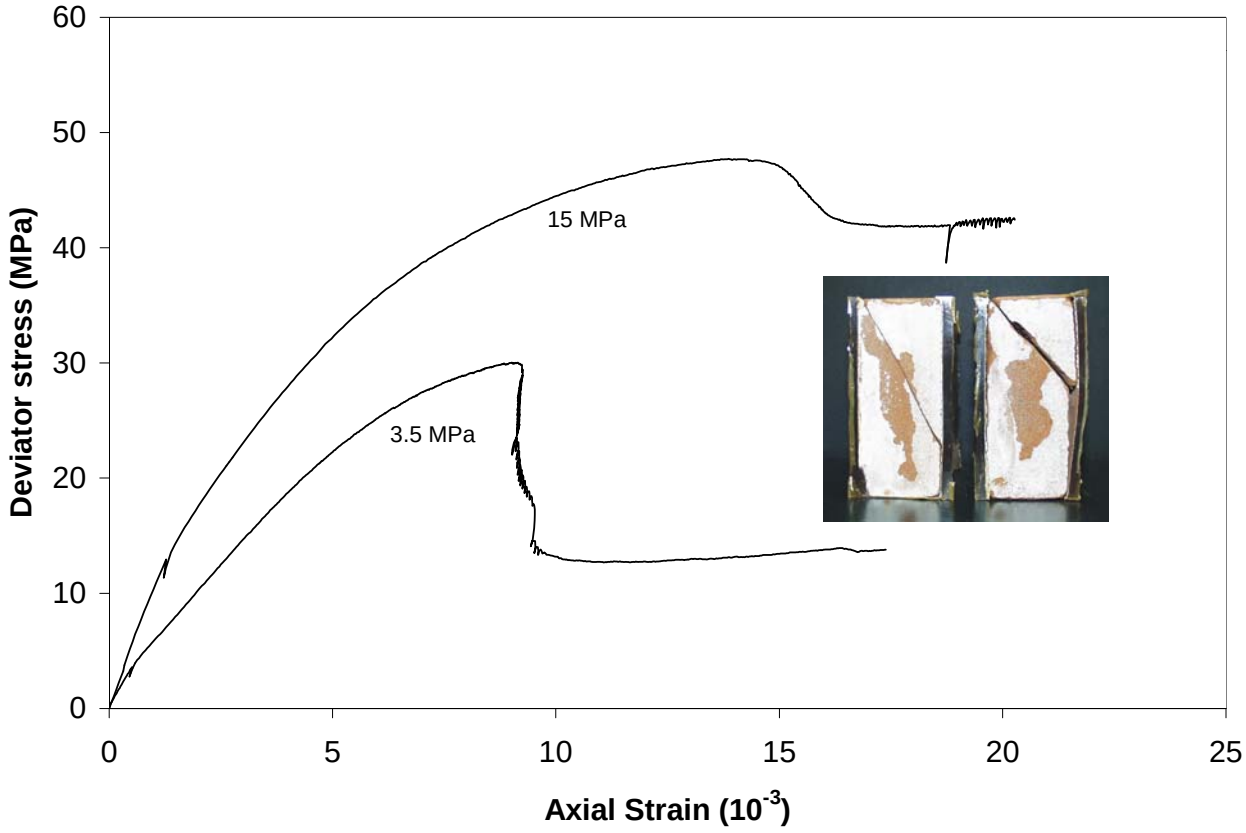
- Plane-strain tests/perform drained, undrained experiments
- Subtasks: 2.1 Calibration, 2.2 Experiments, 2.3 Constitutive modeling, damage assess
- J. Labuz, R. Makhnenko
- Task Status: 33% complete

Discussion – Task 2

- **Major accomplishments: calibration of transducers, upgrade of controller, modification of feedback signal**
- **Major issues/problems: R. Makhnenko passed Ph.D. written prelim exam; still needs to pass oral prelim**

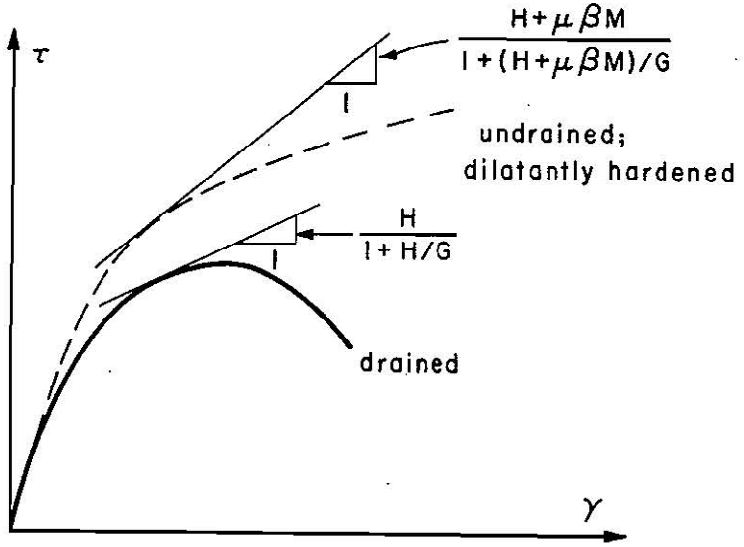
Experiments

Rock is pressure sensitive (frictional), cohesive, dilatant; measure properties under plane-strain & analyze failure (localization, softening)



Dilatant hardening

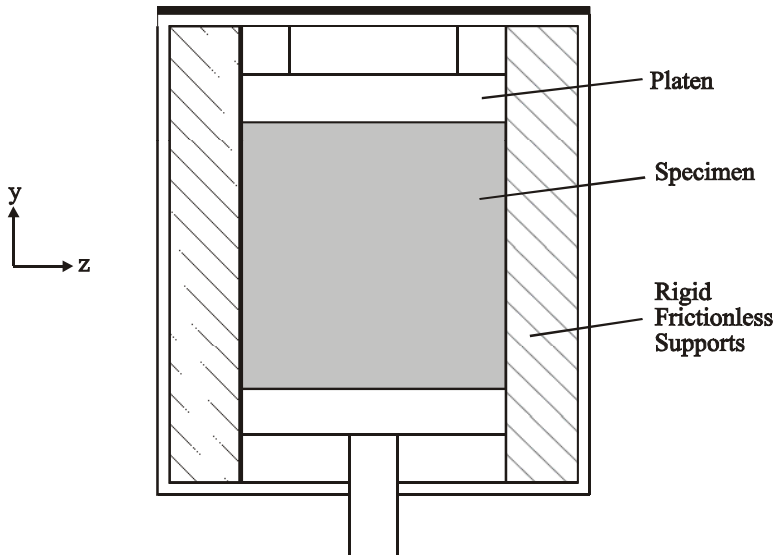
Fluid-saturated rock: lab test allows evaluation of hardening effect, poroelastic parameters, damage (AE) monitoring



(Rice 1975)

Plane-strain testing

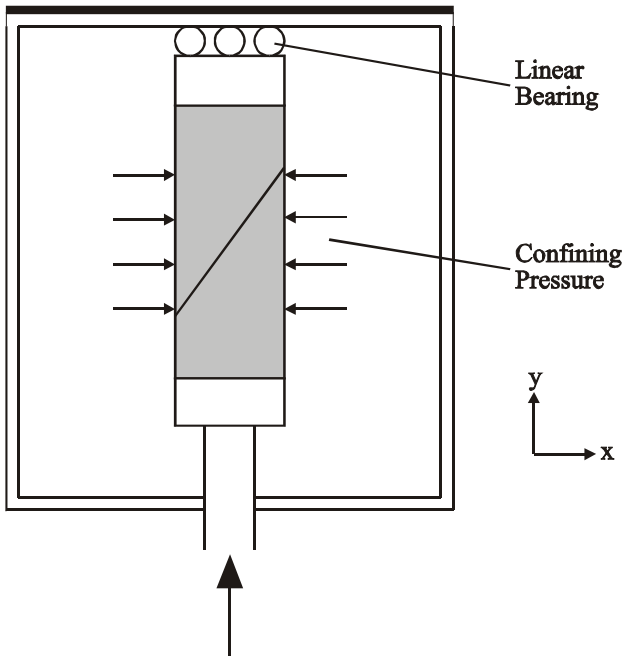
- Duncan & Seed (1966) – Berkeley: ASCE, 81-104
- Dickey, Ladd & Rixner (1968) – MIT: WES report
- Al-Hussaini (1968) – GTech: Ph.D. thesis & WES report
- Rock: Stavropoulou (1982) – South Africa; Wawersik (1990) – Sandia Labs; Ord et al. (1991) – CSIRO



Plane-strain testing

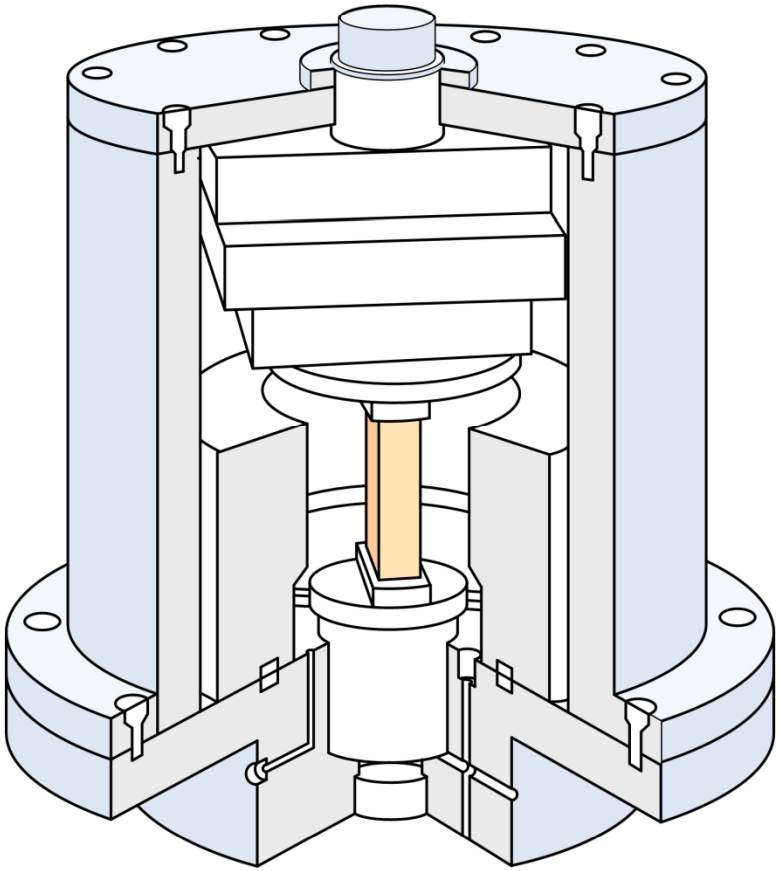
- **Vardoulakis & Goldscheider (1981) – Karlsruhe: proceedings**
- **Vardoulakis & Drescher (1986) – Minnesota: U.S. patent**
- **Drescher, Vardoulakis & Han (1990) – Minnesota: GTJ ASTM, 226-34**
- **Labuz, Vardoulakis & Drescher (1991) – Minnesota: U.S. patent**

No kinematic constraint! (VG device)

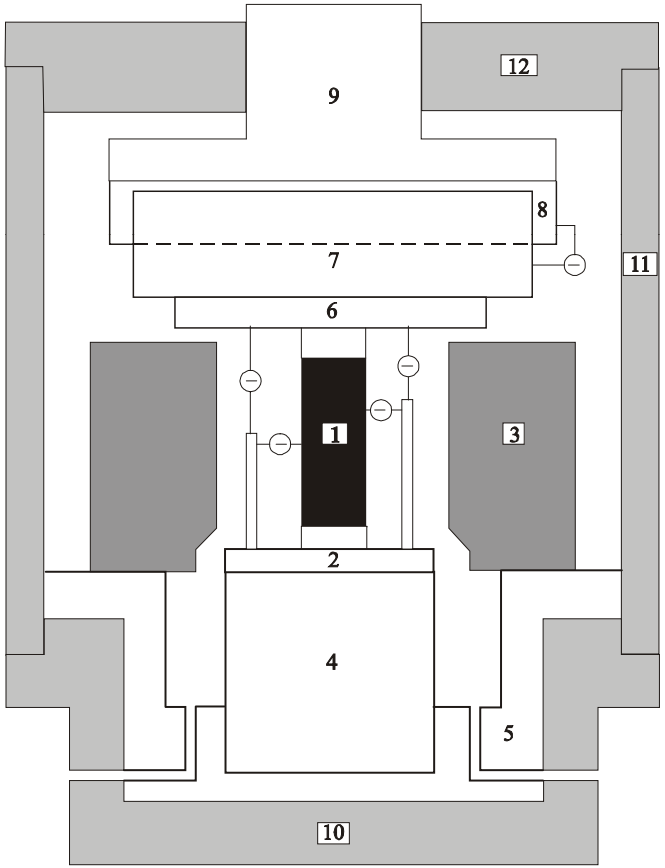


UMN Plane-strain apparatus

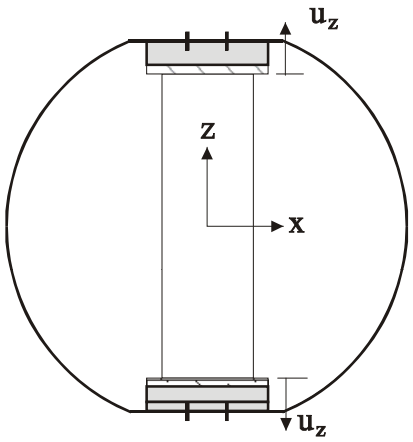
- passive restraint w/ biaxial frame
- wedge assembly to seat specimen
- stearic acid lubricant
- linear bearing to allow translation
- internal sensors: displacements, AE

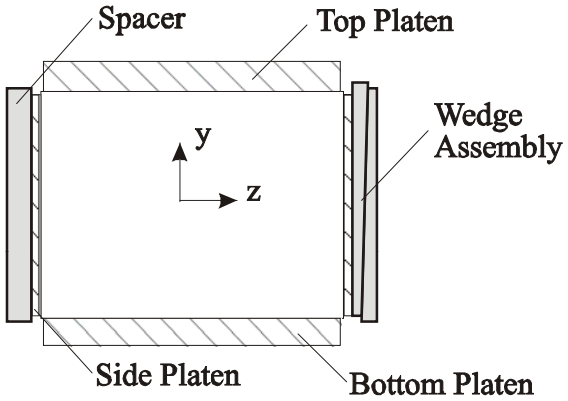


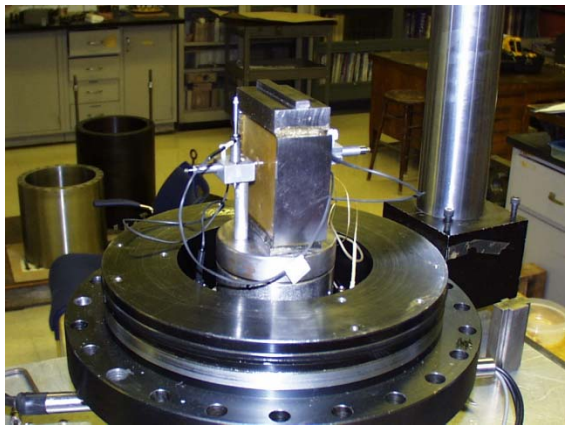
Plane-strain apparatus



Biaxial frame







- **Percent Plane Strain (σ_{xx}= 0): *PPS = 1 – R/*ν**

$$R = -\frac{\varepsilon_{zz}}{\varepsilon_{yy}} \qquad R = \frac{\nu\left(\sigma_{xx} + \sigma_{yy}\right)}{\sigma_{yy} - \nu\sigma_{xx} + f\left(E^*\right)}$$

- **Measure ε_{zz}, $\varepsilon_{\theta\theta}^{f}$; evaluate *PPS* and σ_{zz}**

Biaxial frame

- **Calibrate system w/ aluminum (E = 70 GPa), plexiglass (E = 3 GPa) specimens (σ_3/σ_1 = 0, 1)**

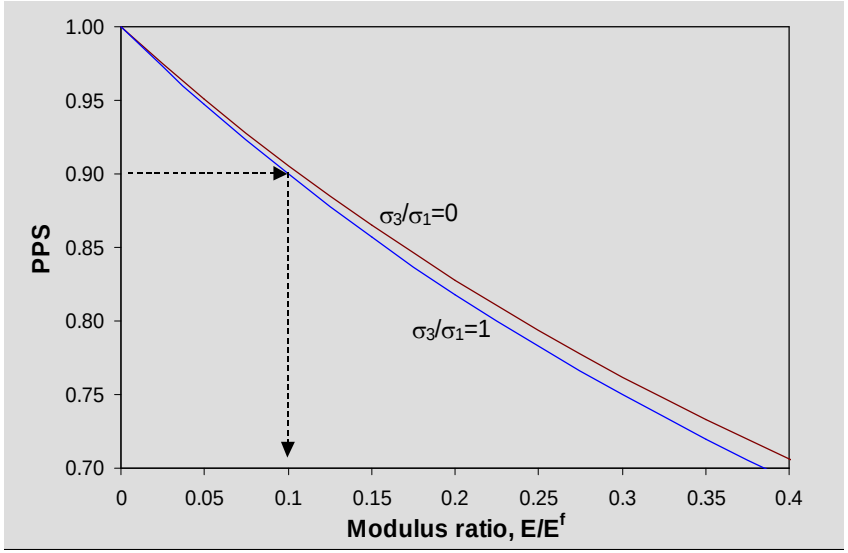
$$PPS = \frac{1 + f_1(\nu)}{E^* + f_2(\nu)} \qquad E^* = \frac{E}{E^f} \qquad E^f = \frac{k^f w}{A}$$

Example:

E = 14 GPa

E^f = 140 GPa

PPS = 90%



Discussion – Task 3

- **Numerical modeling/BEM code**
- **3.1 Two-D BE code, 3.2 Three-D BEM code, 3.3 Fluid coupling**
- **S. Mogilevskaya, D. Nikolski**
- **Task Status: 33% complete**

Discussion – Task 3

- **Major accomplishments: 2D BEM algorithm for fracture analysis**
- **Major issues/problems: D. Nikolski needs to pass both written and oral Ph.D. prelim exams**

Numerical modeling

Complex hyper-singular boundary integral equation (CHSIE)

- **Obtain from complex Somigliana's identity**
- **Connect displacements ($u = u_x + iu_y$) and tractions on the boundaries of inhomogeneities to far field stress (and boreholes pressures)**
- **Sum CHSIEs written for each homogeneous part of a piecewise homogeneous medium results in CHSIE in terms of displacement discontinuities Δu**

$$\int_S \Delta u \cdot F(t,\tau) d\tau = G(p,\sigma,\sigma^{\infty})$$

Numerical modeling

$$\int_S \Delta u \cdot F(t,\tau) d\tau = G(p,\sigma,\sigma^{\infty}) \qquad (1)$$

Δu – displacement discontinuity on crack contour S

$F(t,\tau)$ – function of geometric parameters

t – point of interest

G – function of elastic properties plus following

p – pressure at borehole(s)

σ – tractions at point t

σ^{∞} – far field stress

Displacement discontinuity is found by the numerical solution of equation (1) based on BEM technique

Discussion – Task 4

- Course development/teach 3 courses
- 4.1 Experimental geomechanics, 4.2 Poroelasticity, 4.3 Boundary element method
- J. Labuz, E. Detournay, S. Mogilevskaya
- Task Status: 33% complete
- Major accomplishments: 1 course taught

Project Milestones

(Include HQ and project milestones)

Milestone	Planned Completion Date	Actual Completion Date
Project kick-off meeting	03/09/2010	03/09/2010
Educational program	O6/30/2010	08/31/2010
Plane-strain experiments: drained and undrained	08/31/2012	
Numerical modeling: BEM algorithm	08/31/2012	

Anticipated Efforts for the Coming Year (2011)

- 1. Characterize mechanical properties of selected rock
- 2. Modify back-pressure system and related plumbing
- 3. Perform drained and undrained plane strain tests with AE monitoring
- 4. Evaluate 2D BEM code with analytical crack problems
- 5. Develop 3D BEM code for crack problems

PI Contact Information

- **If you have any questions or would be interested in collaboration please contact**
- **jlabuz@umn.edu**