SAND2015-1021PE

Wellbore Seal Repair

Ed Matteo, *Sandia National Labs*

BNL Cement SubTER Workshop

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SAND #

Sandia National Laboratories

Acknowledgements

Wellbore Seal Repair Using Nanocomposite Materials

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UNM

Sandia National Laboratories

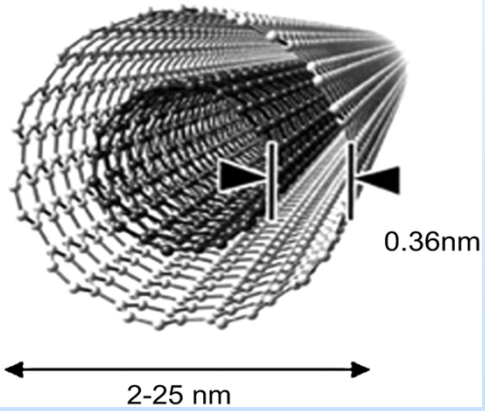
Topics

- Repair material development
- Flow through damaged and repaired wellbore systems
- Alteration of damaged wellbore systems
- Numerical modeling
- Developments with nanocomposites for wellbore applications

Repair material development

Nanocomposites - addition of small amounts of nano-scale materials can dramatically alter properties of materials such as polymers, composites, and cements.

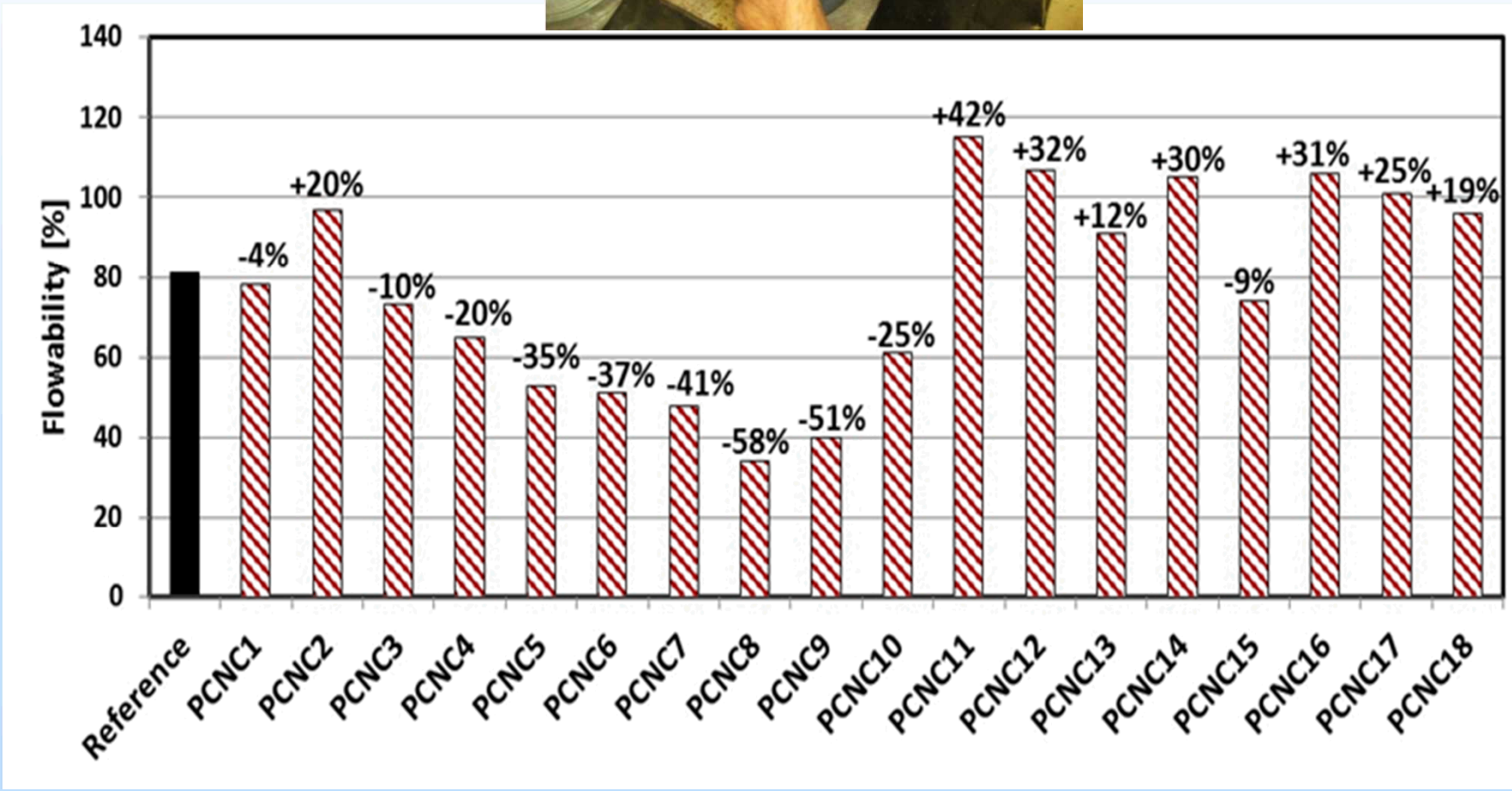
- Strength
- Ductility
- Reduce shrinkage
- Thermal stability
- Resistance to degradation



Materials

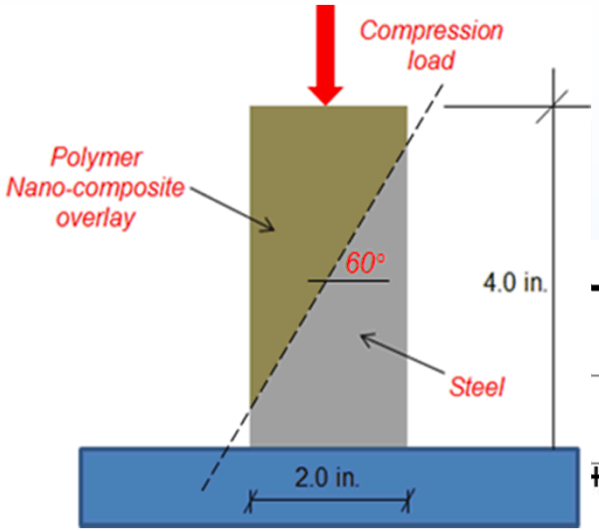
Material Abbreviation	Base material	Nano-material	Nano content
Reference	Microfine cement	None	---
PCNC1	Microfine cement + 5%SBR latex	None	---
PCNC2	Microfine cement + 15%SBR latex	None	---
PCNC3	Microfine cement + 5%SBR latex	MWCNTs	0.5%
PCNC4	Polysulfide siloxane epoxy	None	---
PCNC5	Polysulfide siloxane epoxy	MWCNTs	0.5%
PCNC6	Polysulfide siloxane epoxy	MWCNTs	1.0%
PCNC7	Polysulfide siloxane epoxy	MWCNTs	1.5%
PCNC8	Polysulfide siloxane epoxy	Nanoclay	4%
PCNC9	Polysulfide siloxane epoxy	Nanosilica	1%
PCNC10	Polysulfide siloxane epoxy	Nanoalumina	2%
PCNC11	Novolac epoxy	None	---
PCNC12	Novolac epoxy	MWCNTs	0.5%
PCNC13	Novolac epoxy	Nanosilica	1%
PCNC14	Novolac epoxy	Nanoalumina	2%
PCNC15	Polysulfide siloxane epoxy	NF-MWCNTs	0.5%
PCNC16	Novolac epoxy	MWCNTs	1.0%
PCNC17	Novolac epoxy	MWCNTs	1.5%
PCNC18	Novolac epoxy	Nanoclay	4%

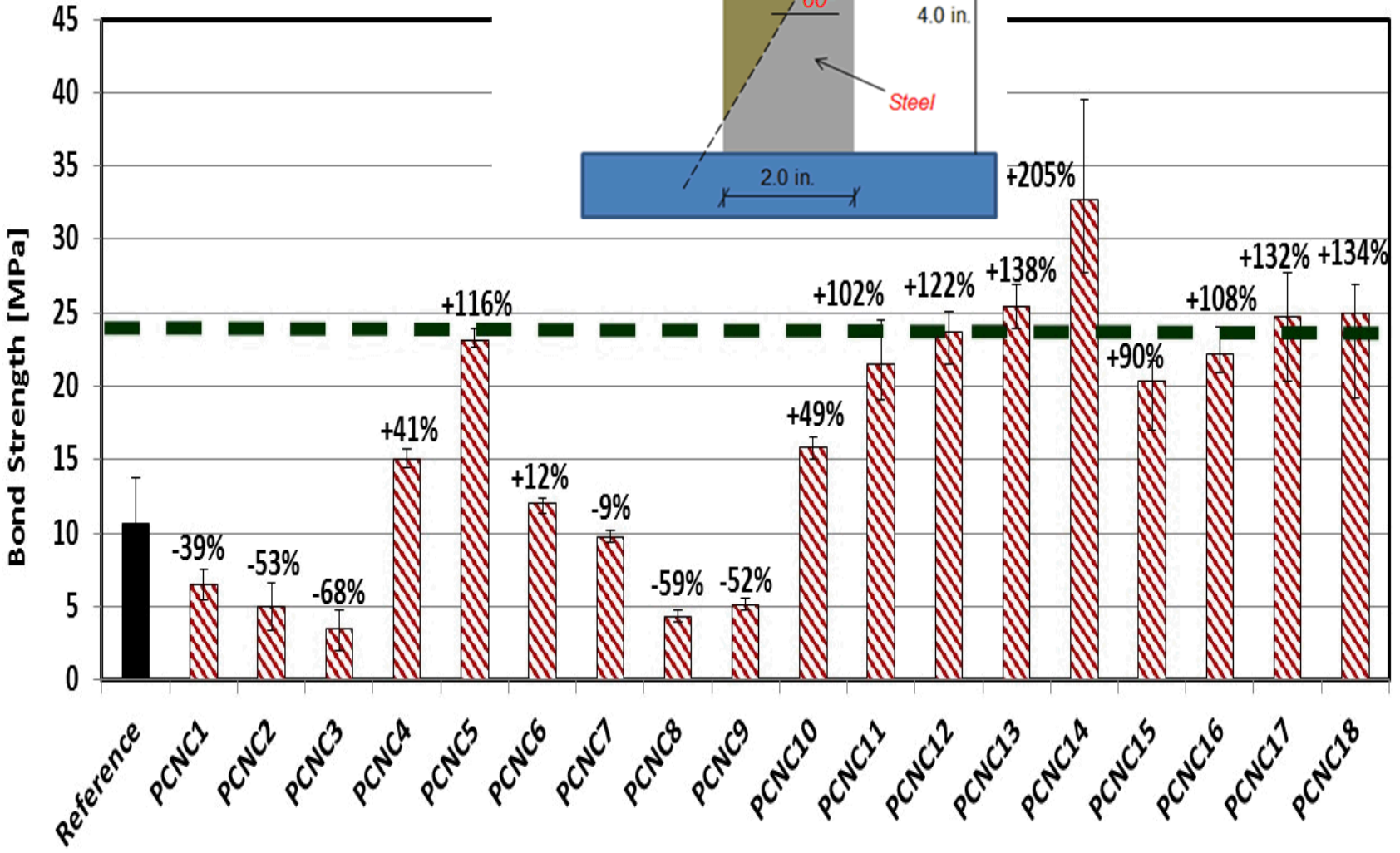
Flowability of PCNC



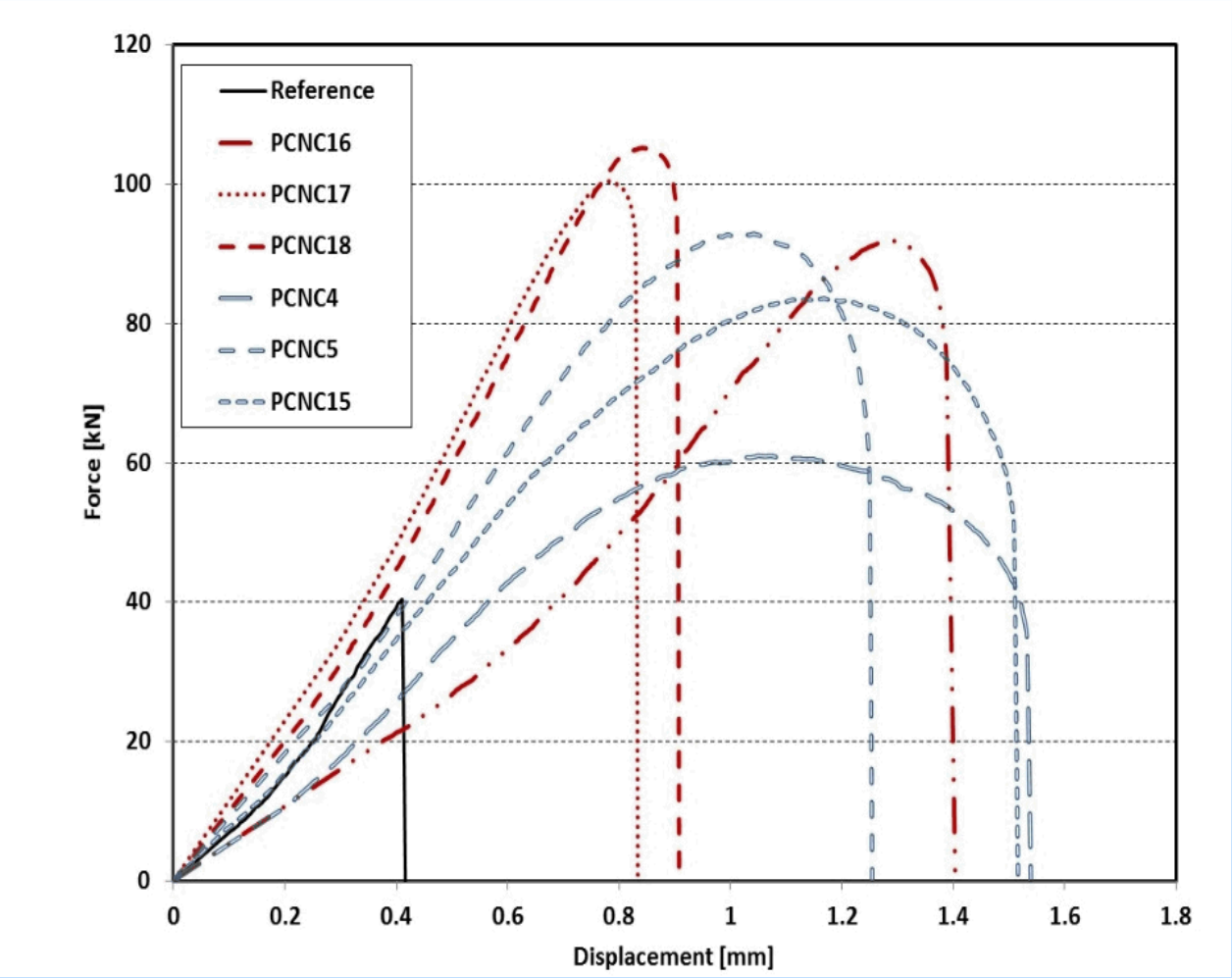
Bond Strength of PCNC and Steel

Slant shear test

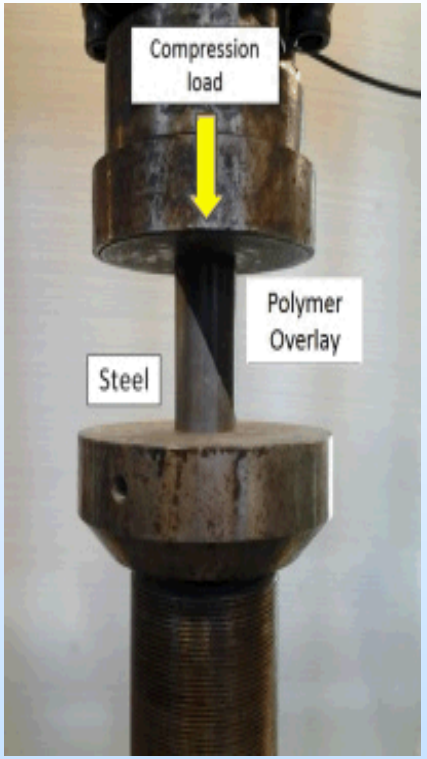




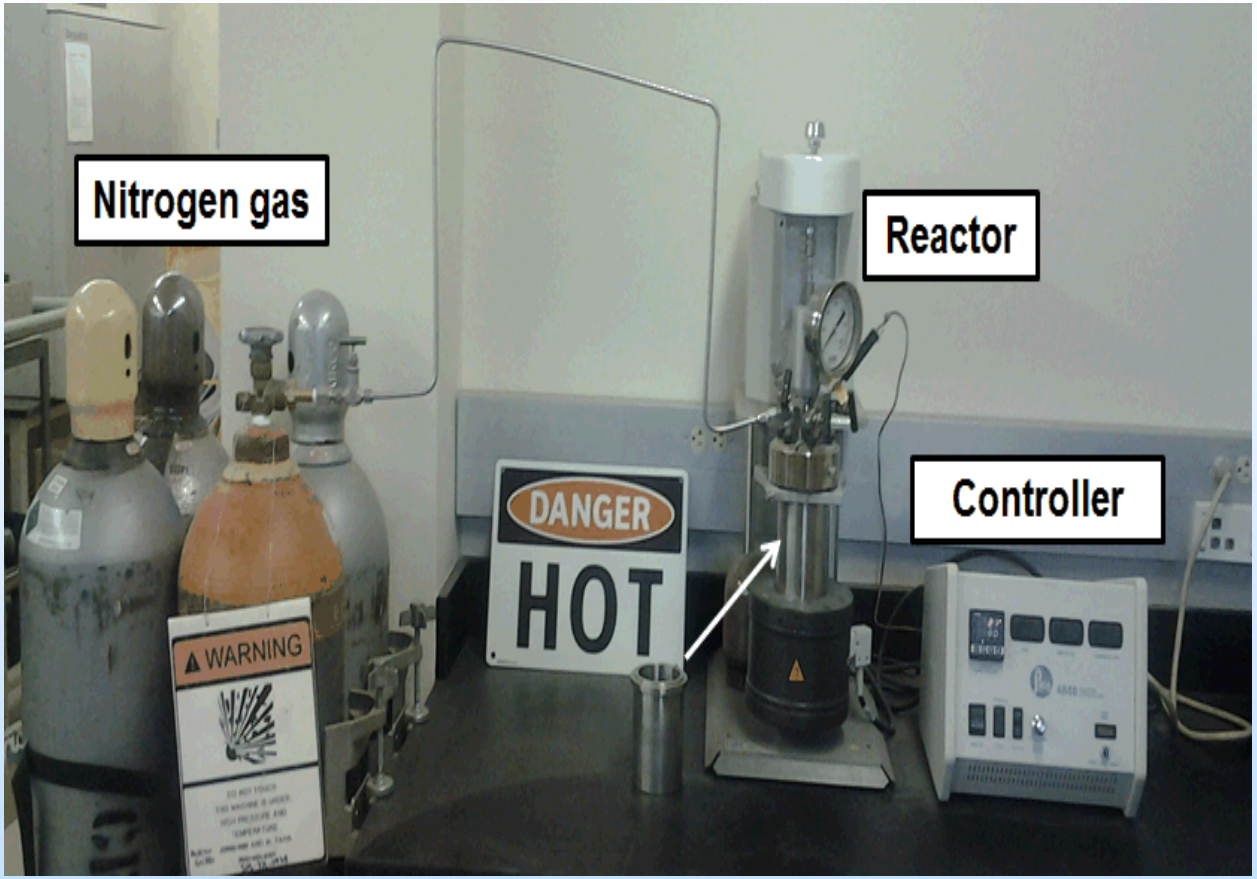
PCNC – Steel slant shear behavior

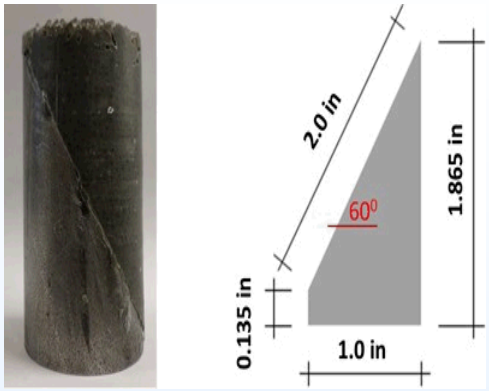


Slant shear test

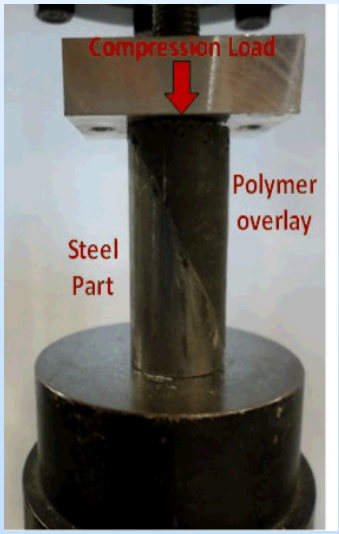


Examining the effect of high temperature and pressure



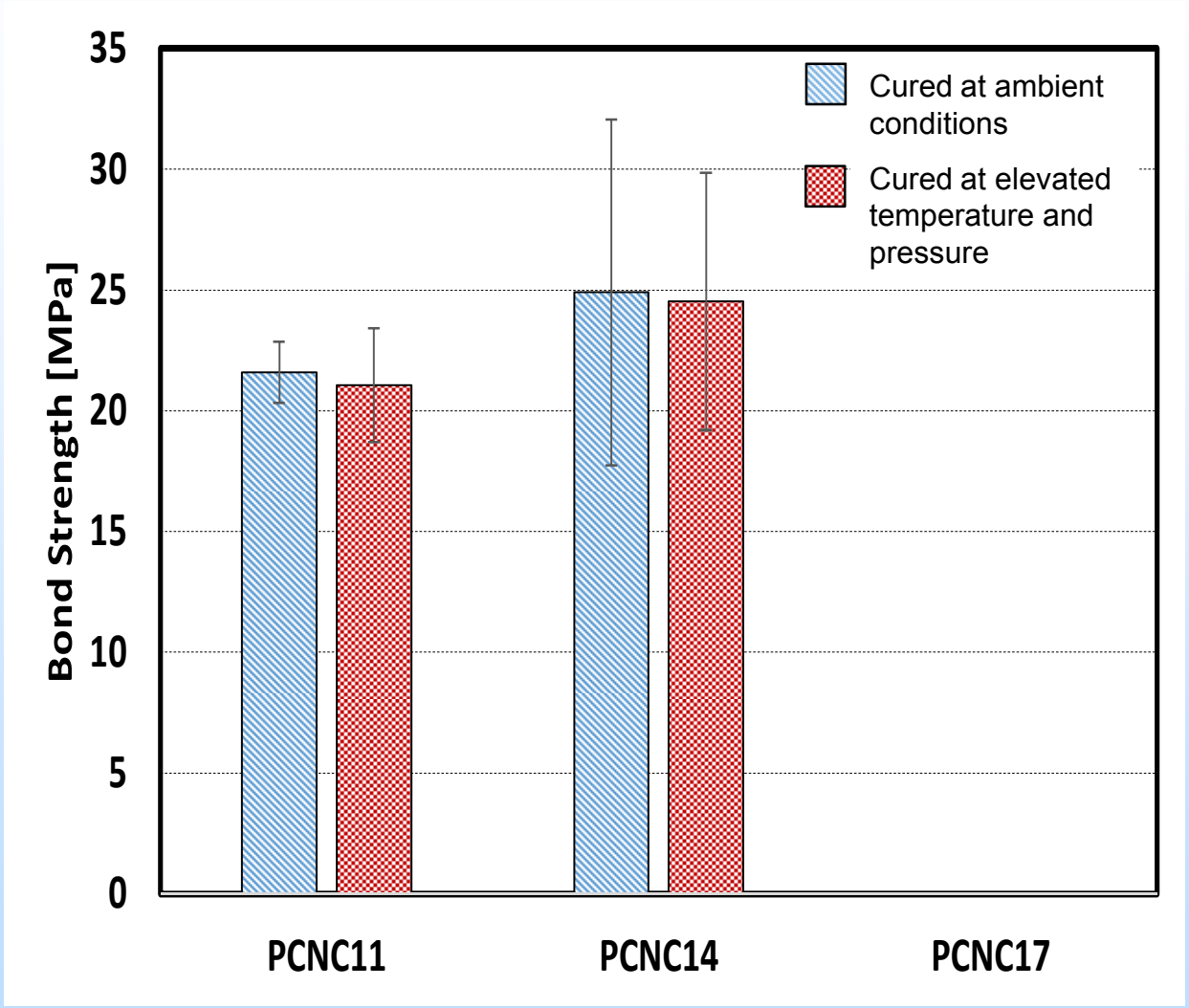


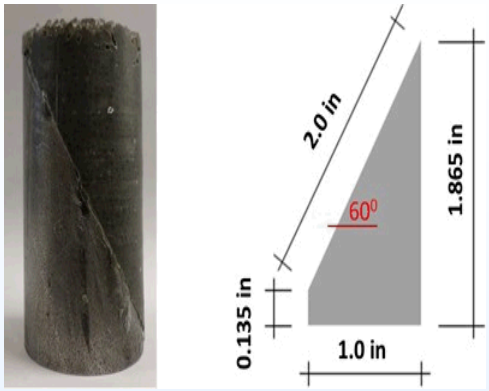
Scaled specimens



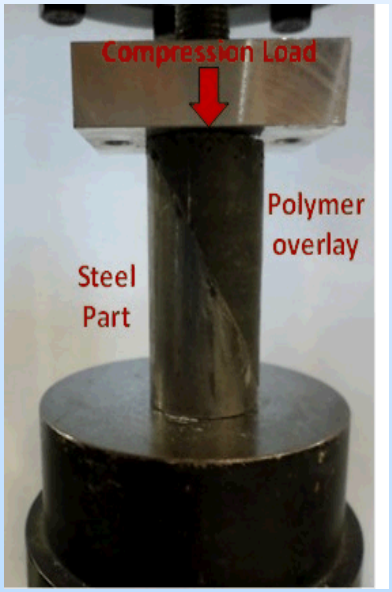
Temp: 80 °C
Pressure: 1500 psi
Conditions similar to 1000 m in oil well

No effect of elevated temperature and pressure

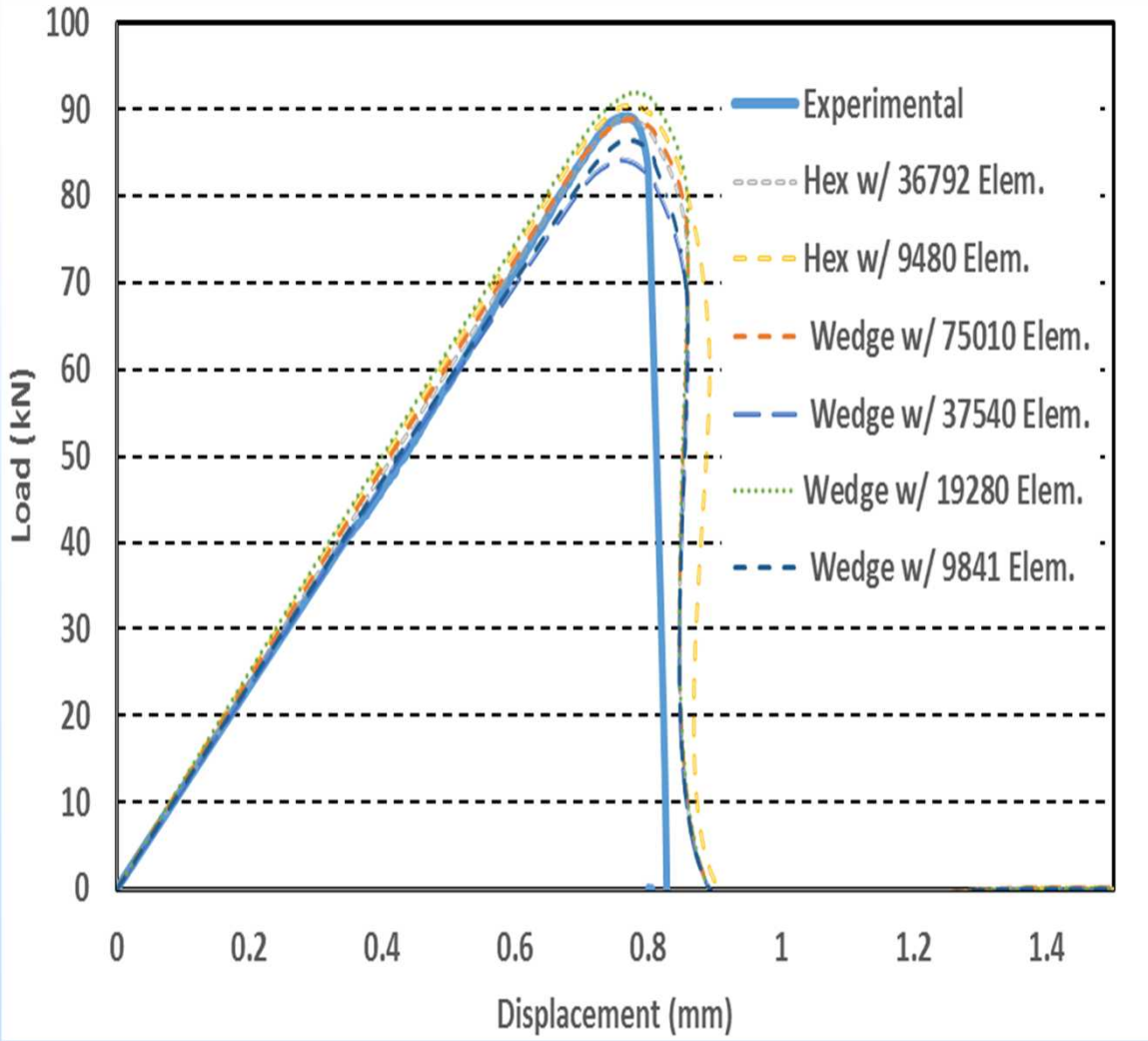


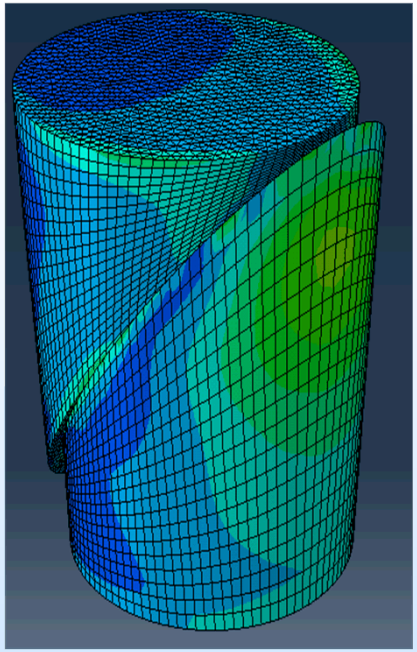


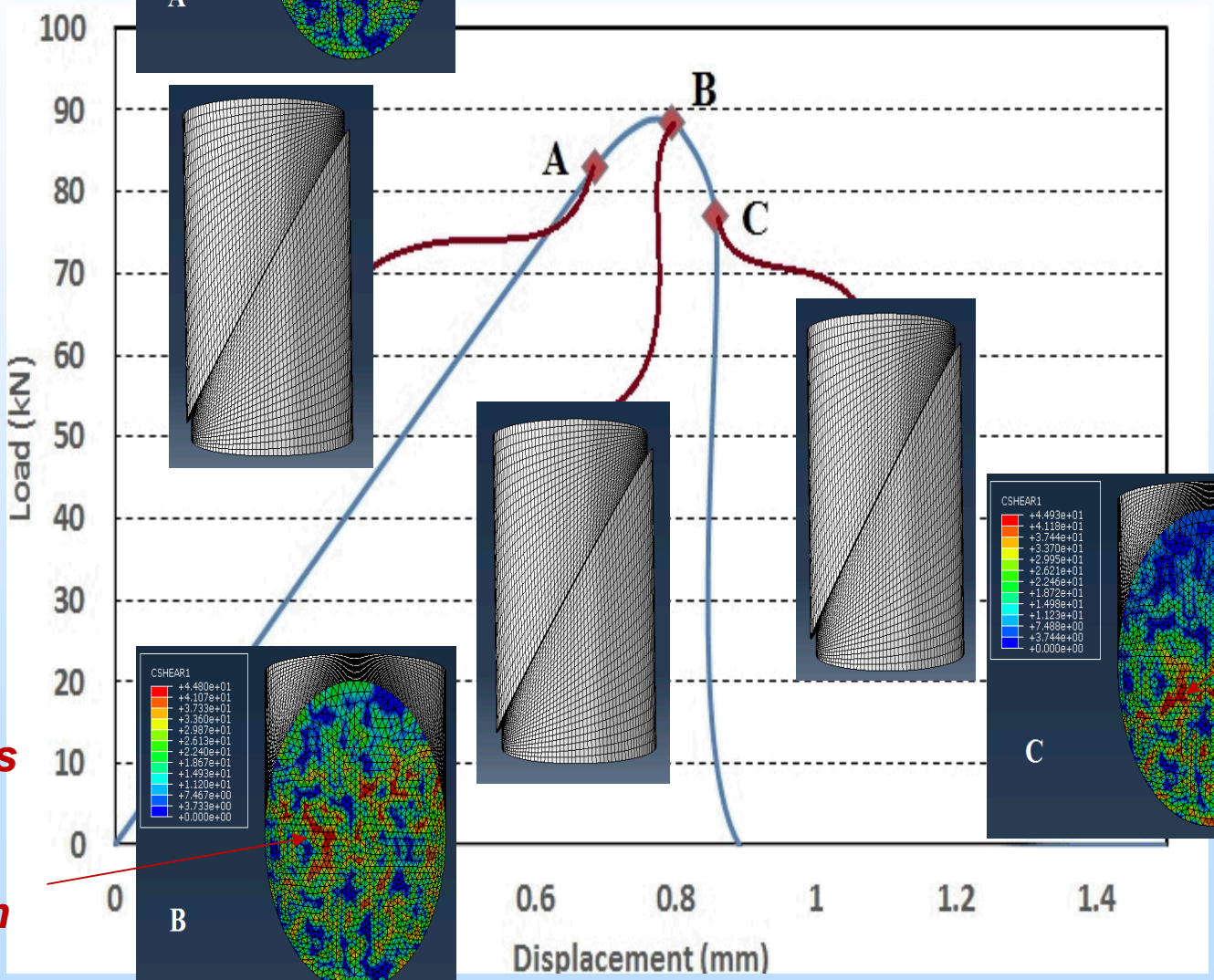
Scaled specimens



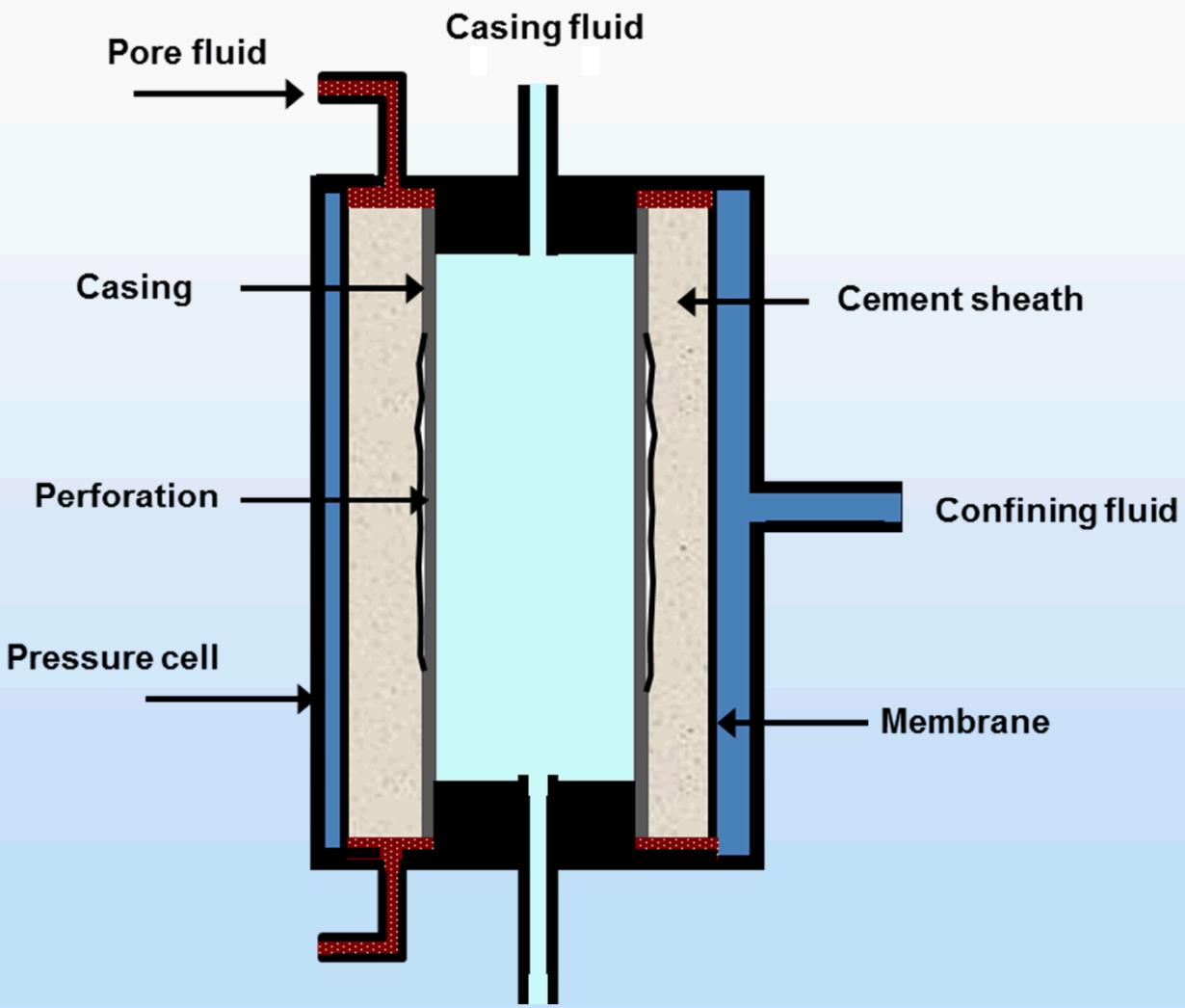
Numerical simulation of slant shear



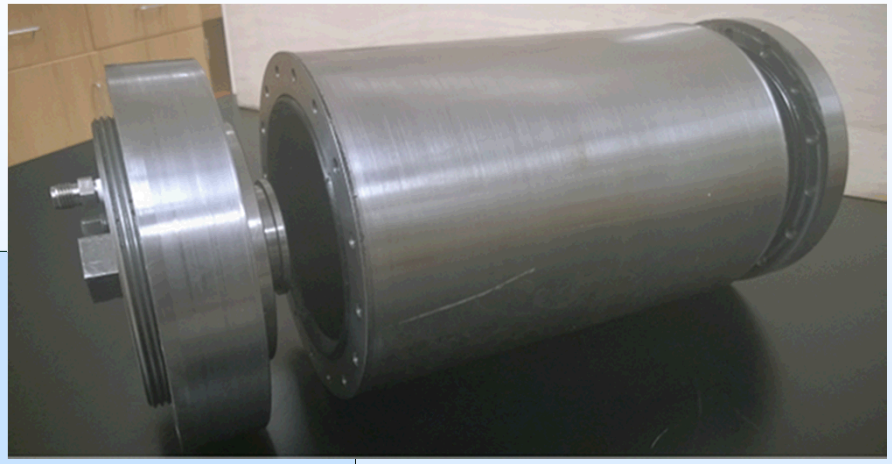


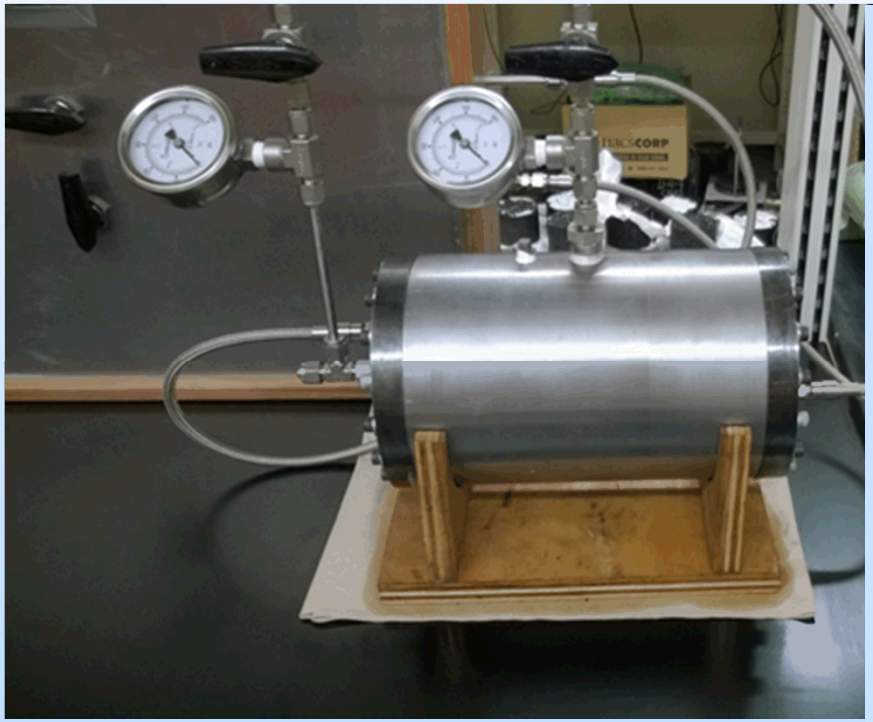

Red spots indicate reaching maximum stress
A
B
C
Load (kN)
Displacement (mm)
0
10
20
30
40
50
60
70
80
90
100
0.6
0.8
1
1.2
1.4
Red spots indicate reaching maximum stress
Red spots indicate reaching maximum stress

Flow through damaged and repaired wellbore systems


Pore fluid
Casing fluid
Casing
Cement sheath
Perforation
Confining fluid
Pressure cell
Membrane

Pressure vessel





Independent control of confining pressure to 30 MPa and casing pressure to 20 MPa.

Gas Permeameter

Gas pressures to 14 MPa.
Permeability range $>10^{-12}$ to $<10^{-21}$ m^2

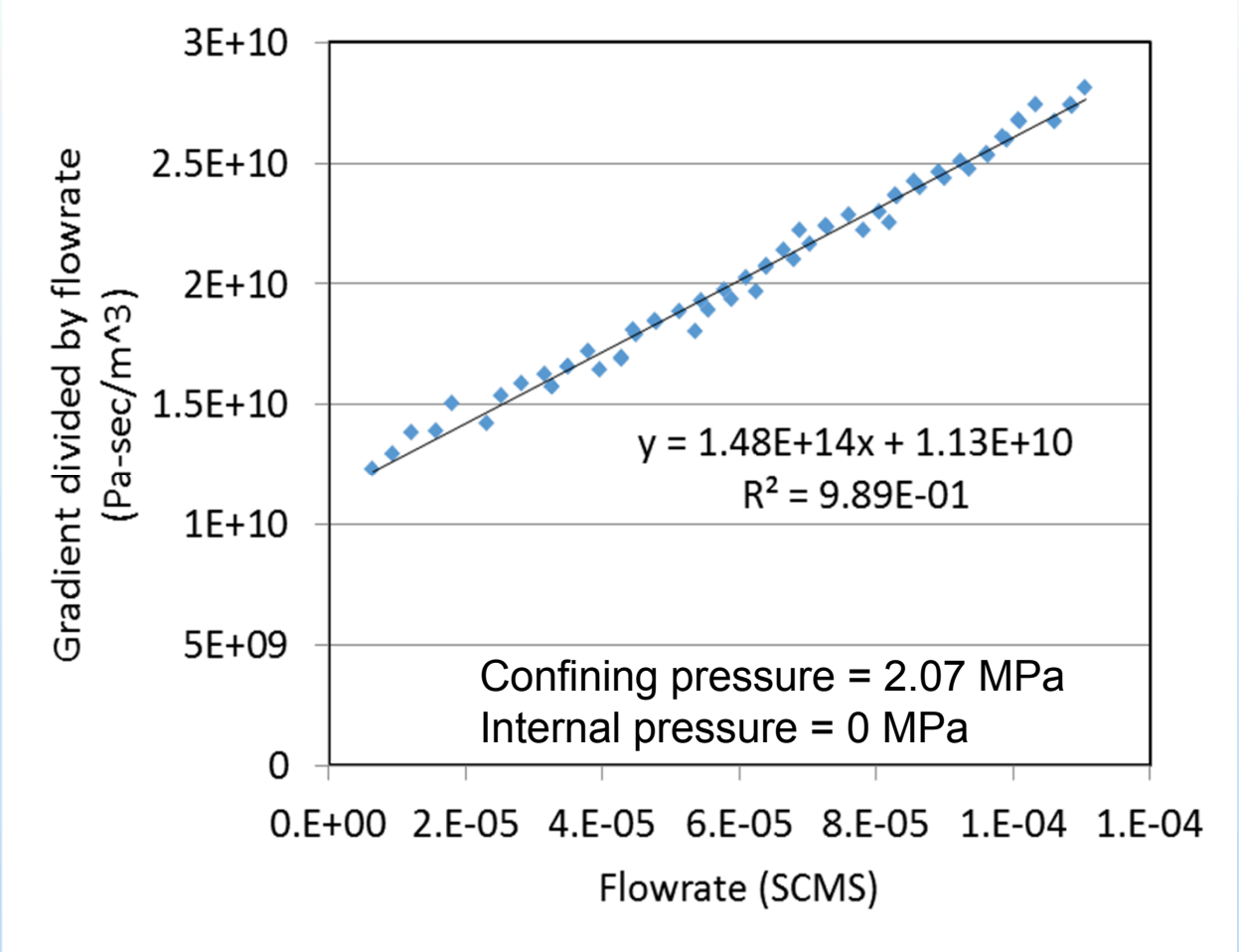
Specimen preparation

- Microannulus
  - Large
  - Small
- Cement fracture

Analysis of non-linear flow

$$-\frac{\nabla P}{Q} = \frac{\mu}{k\,A} + \frac{\beta\,\rho}{A^2}\,Q$$

Forchheimer's equation



Gas-slip (Klinkenberg) effects

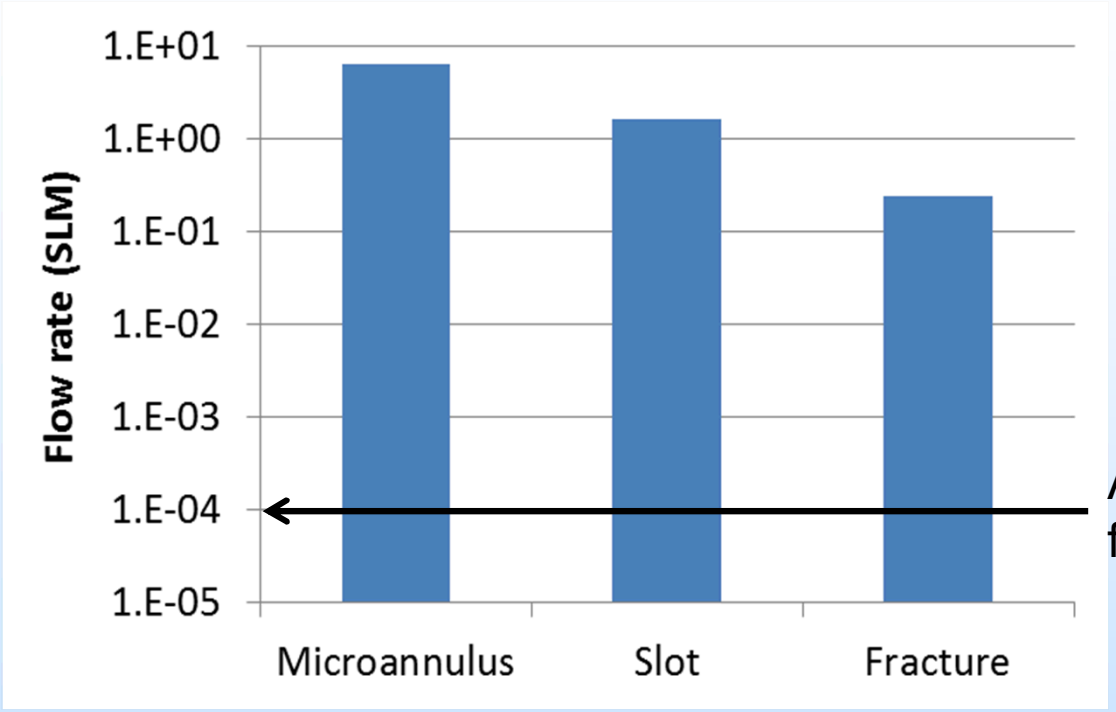
Conventional method – vary gas pressure

$$k = k_i \left(1 + \frac{b}{P_m}\right)$$

Alternative method – vary gas type

$$k = k_i \left(1 + \frac{d\,\mu}{\sqrt{M}}\right)$$

Flow dominated by flaws

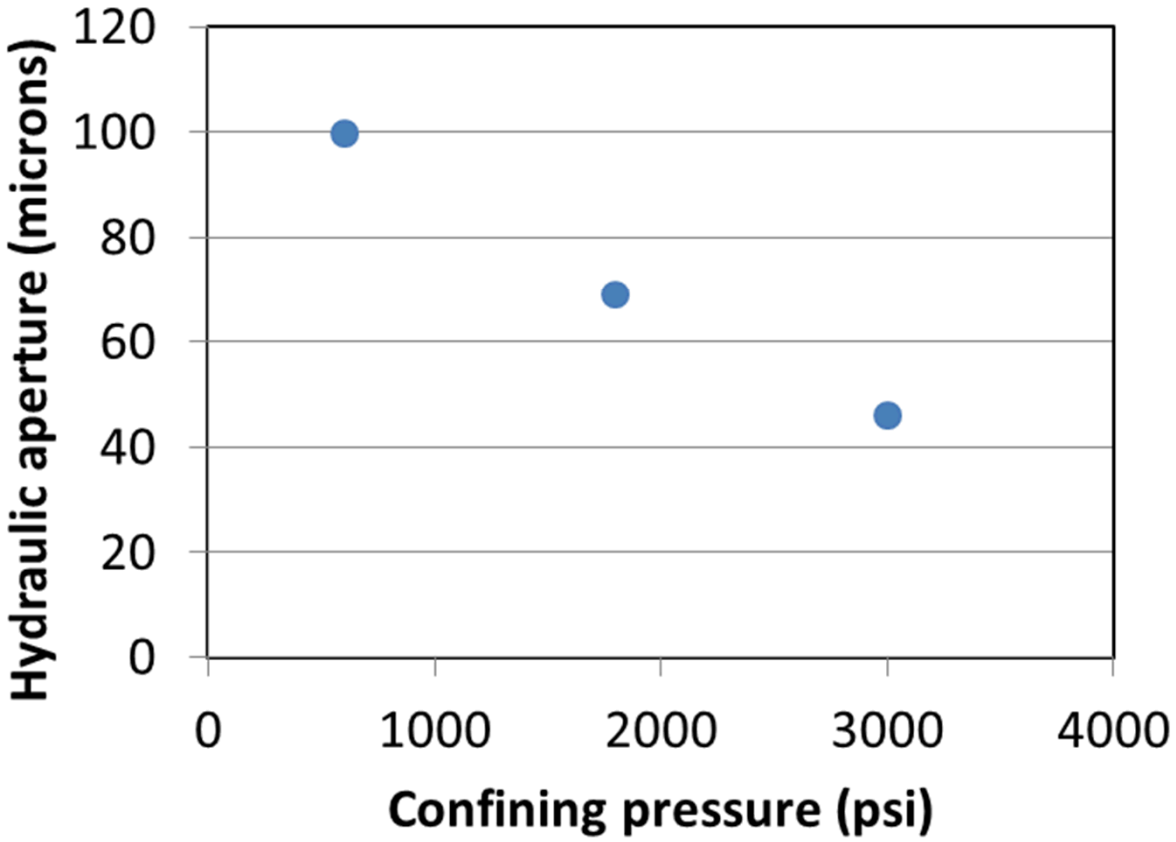


Approximate flow rate for intact specimen

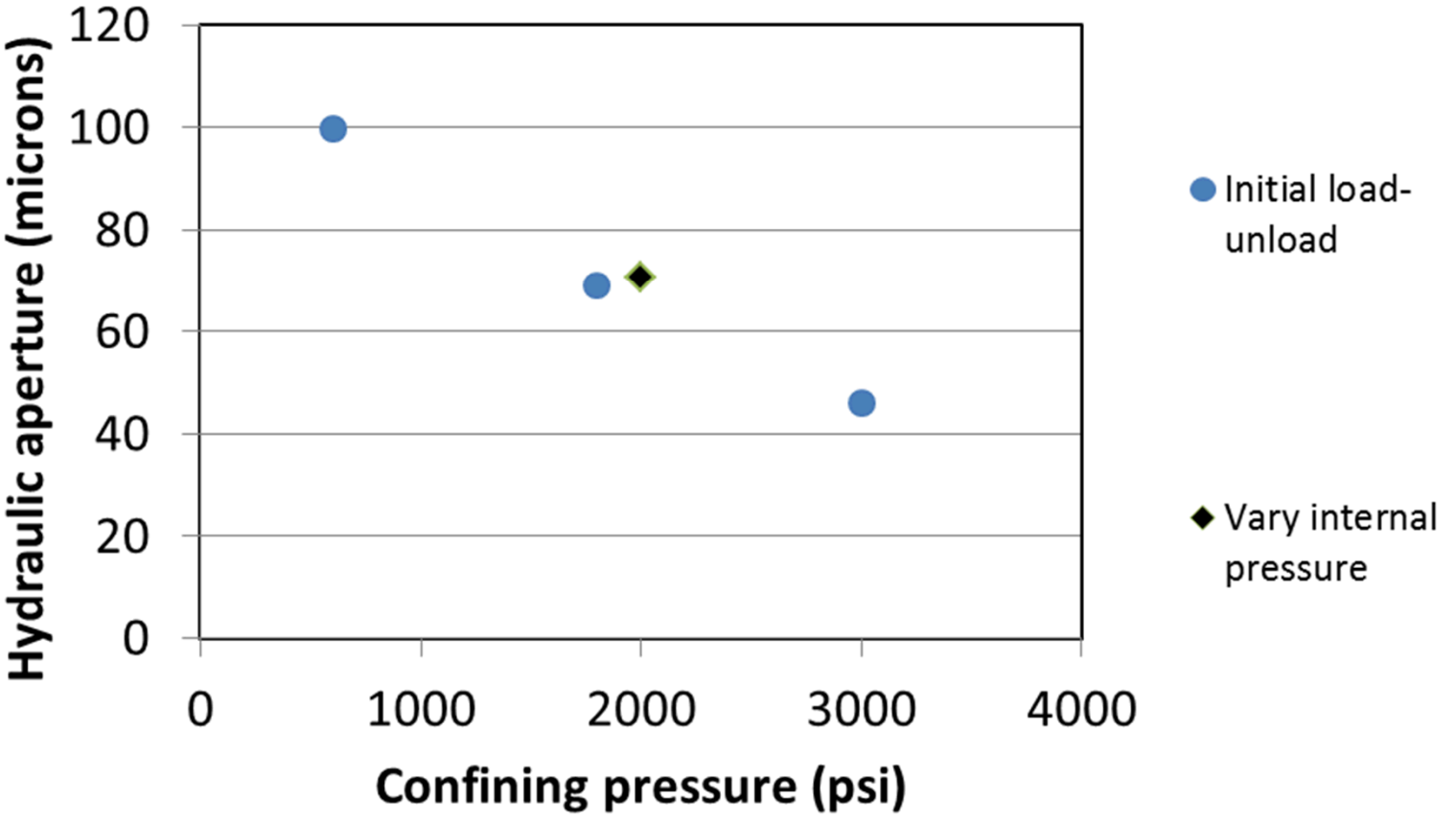
Cubic law for hydraulic aperture

$$h^3 = \frac{12\ k\ A}{w}$$

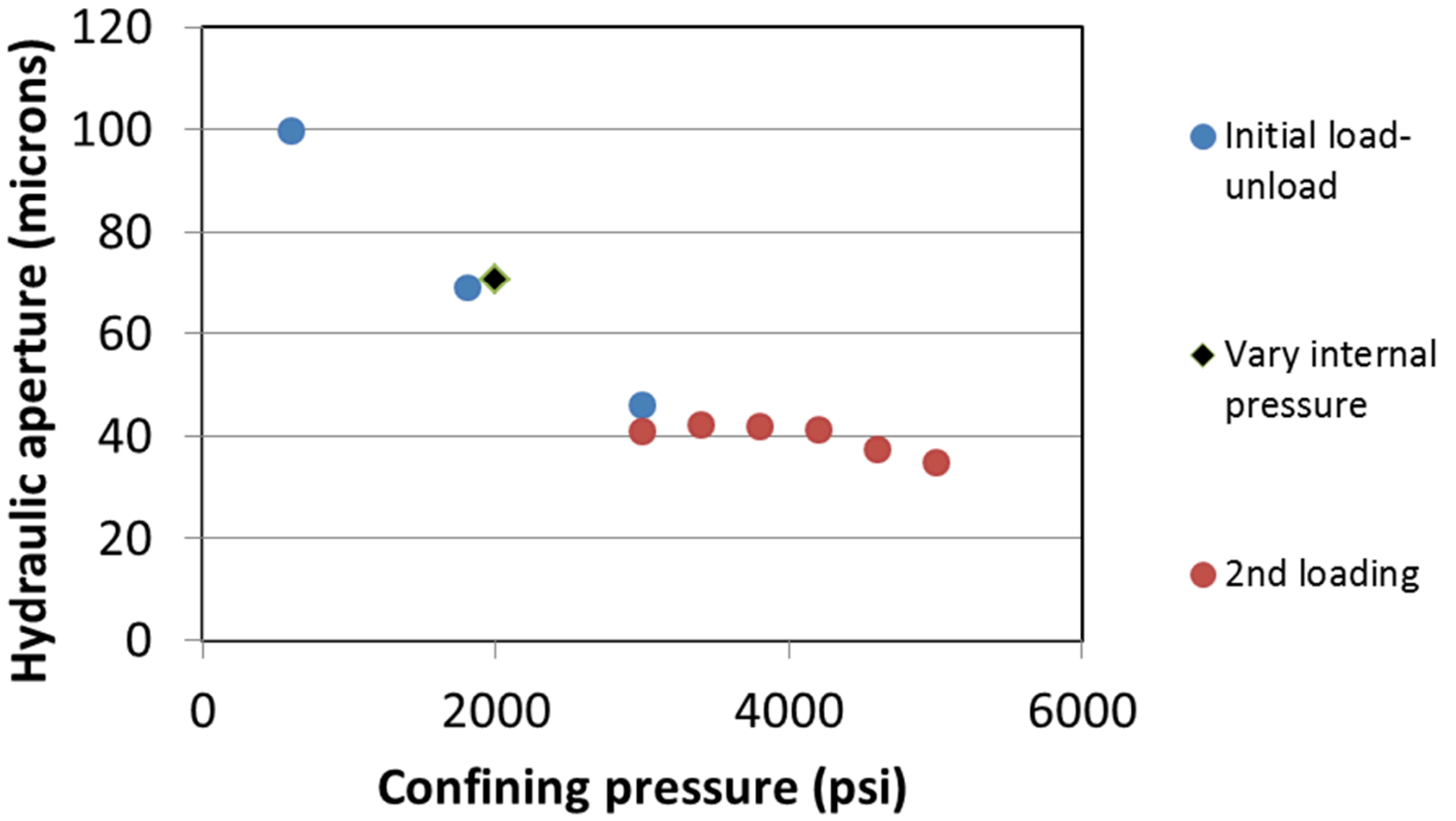
Large microannulus



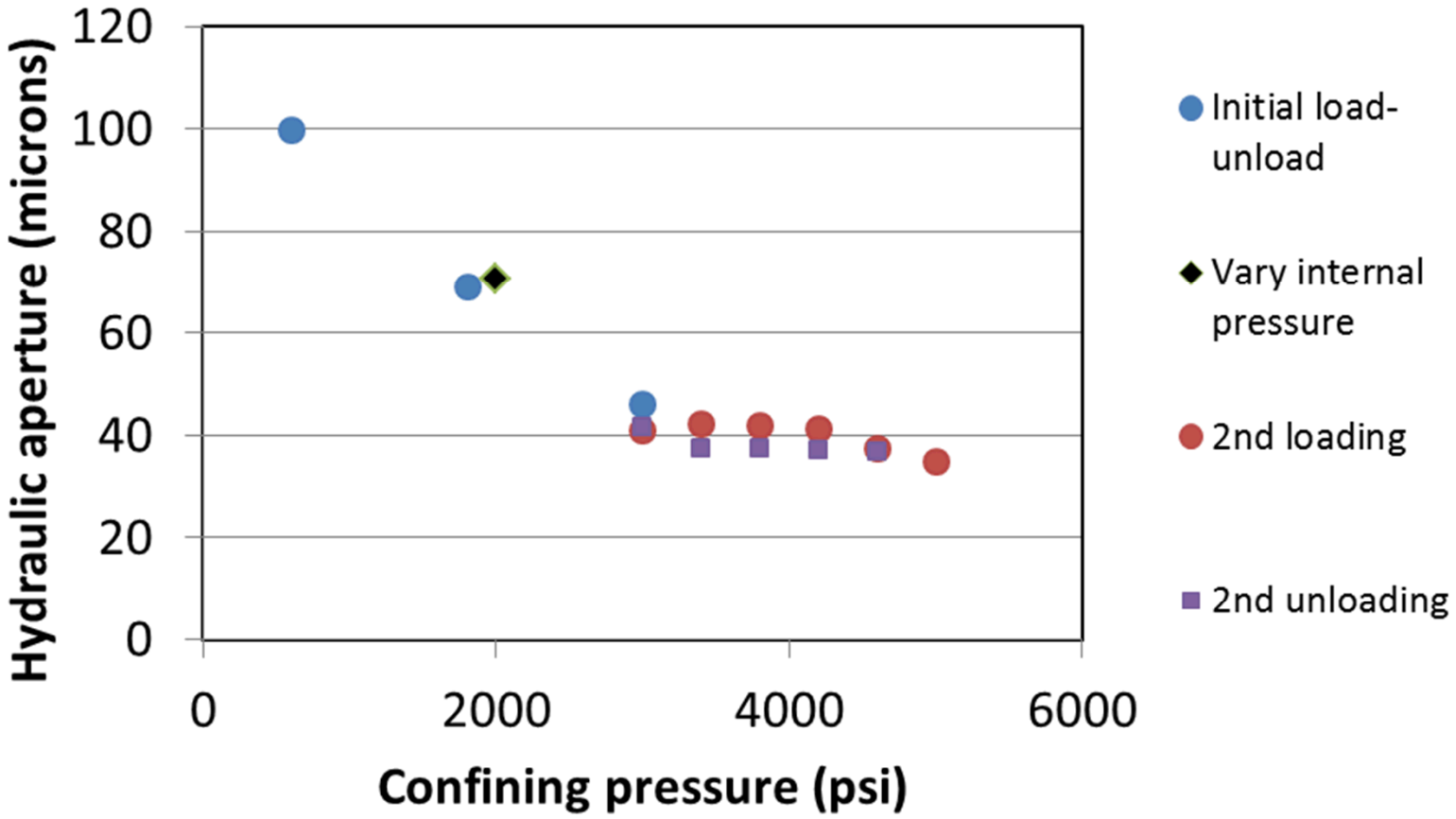
Large microannulus



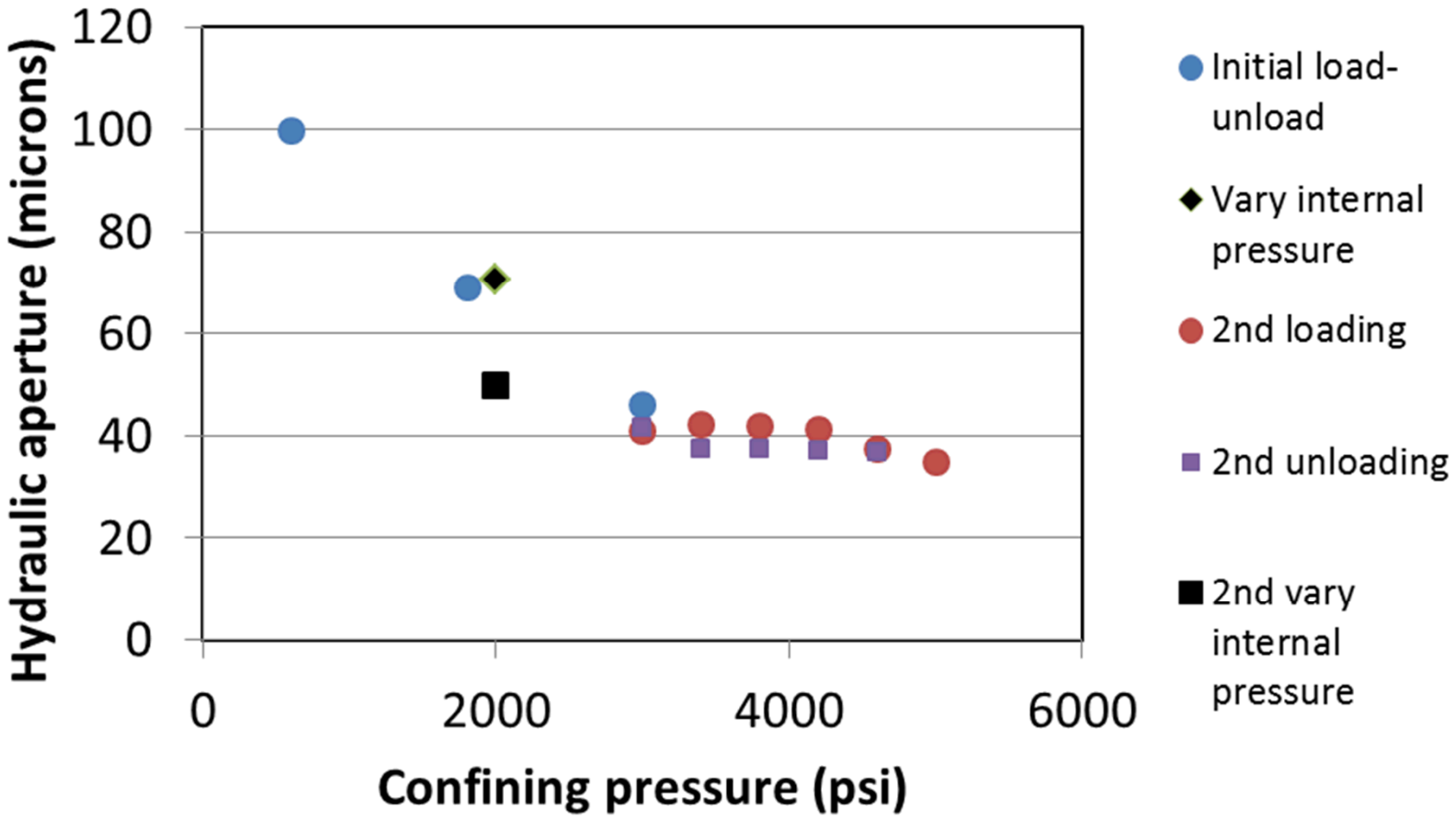
Large microannulus



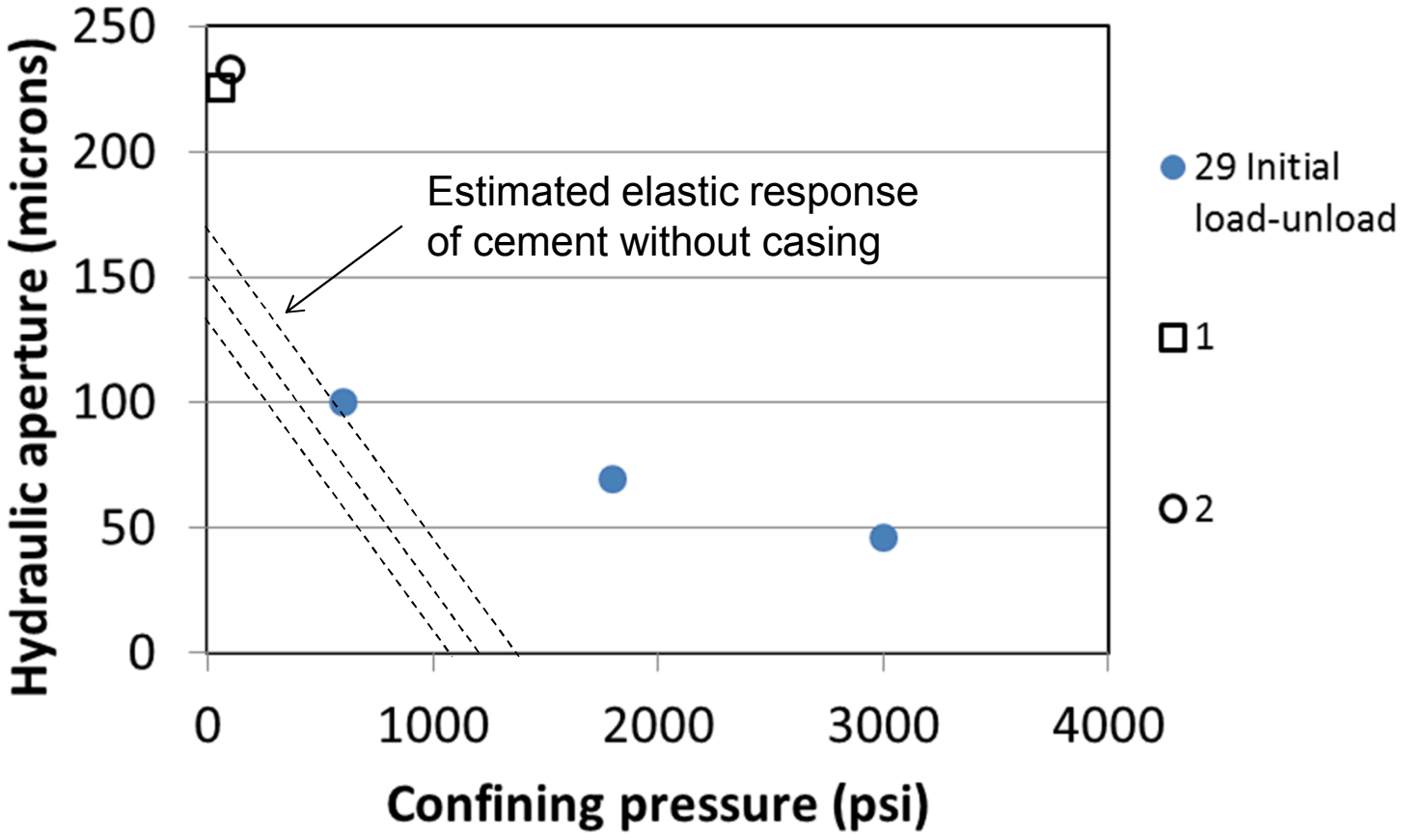
Large microannulus



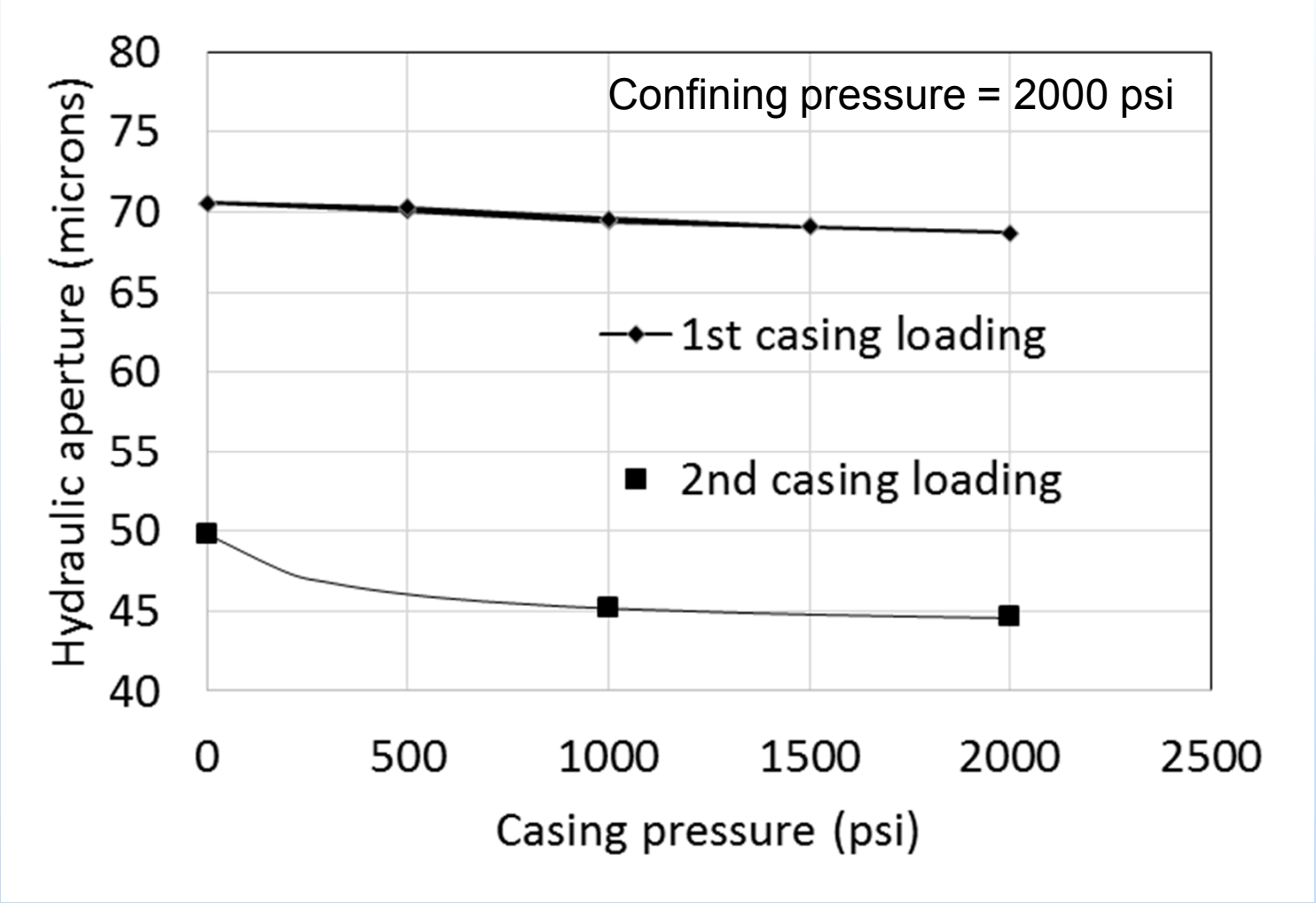
Large microannulus



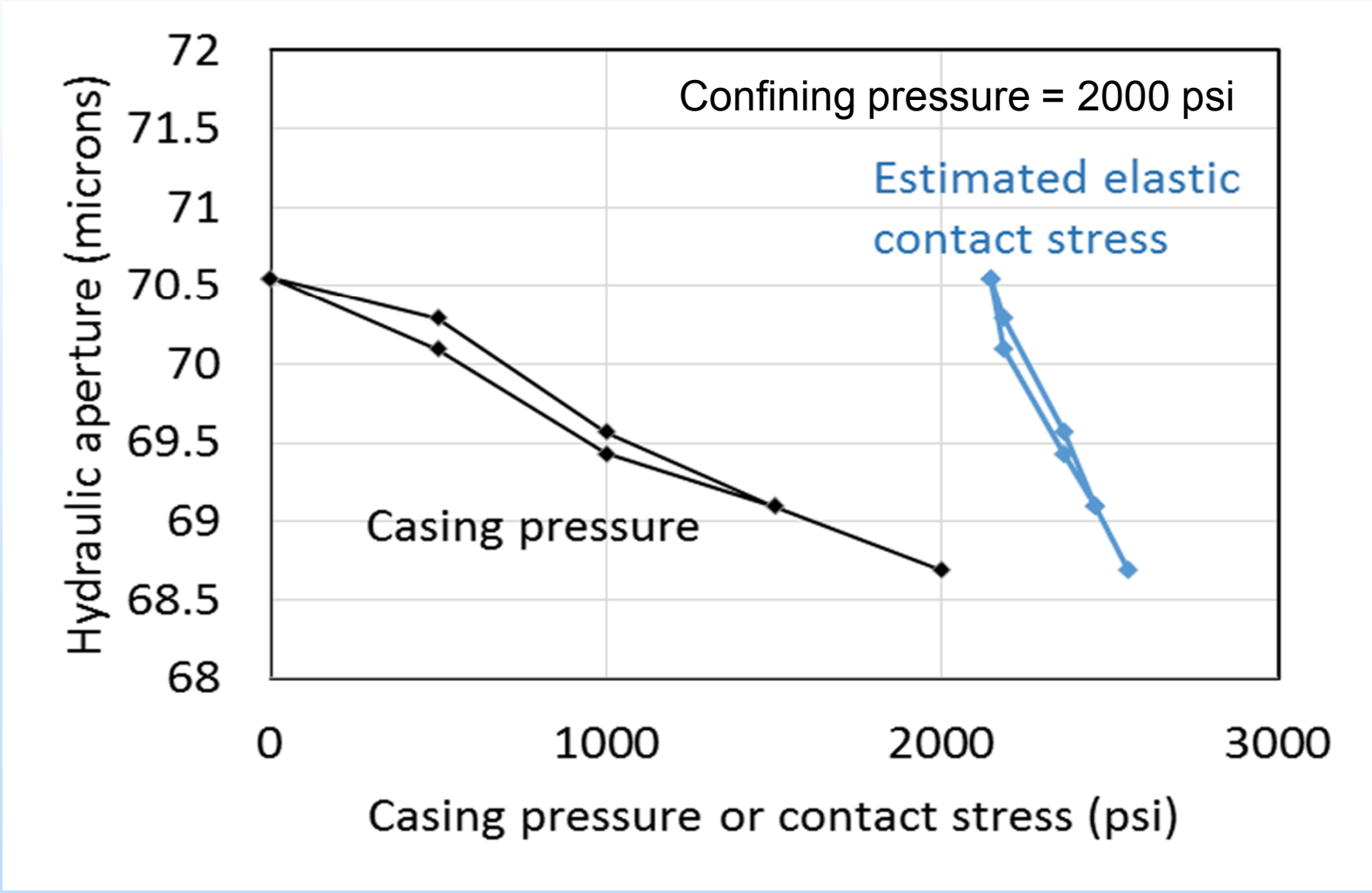
Large microannulus



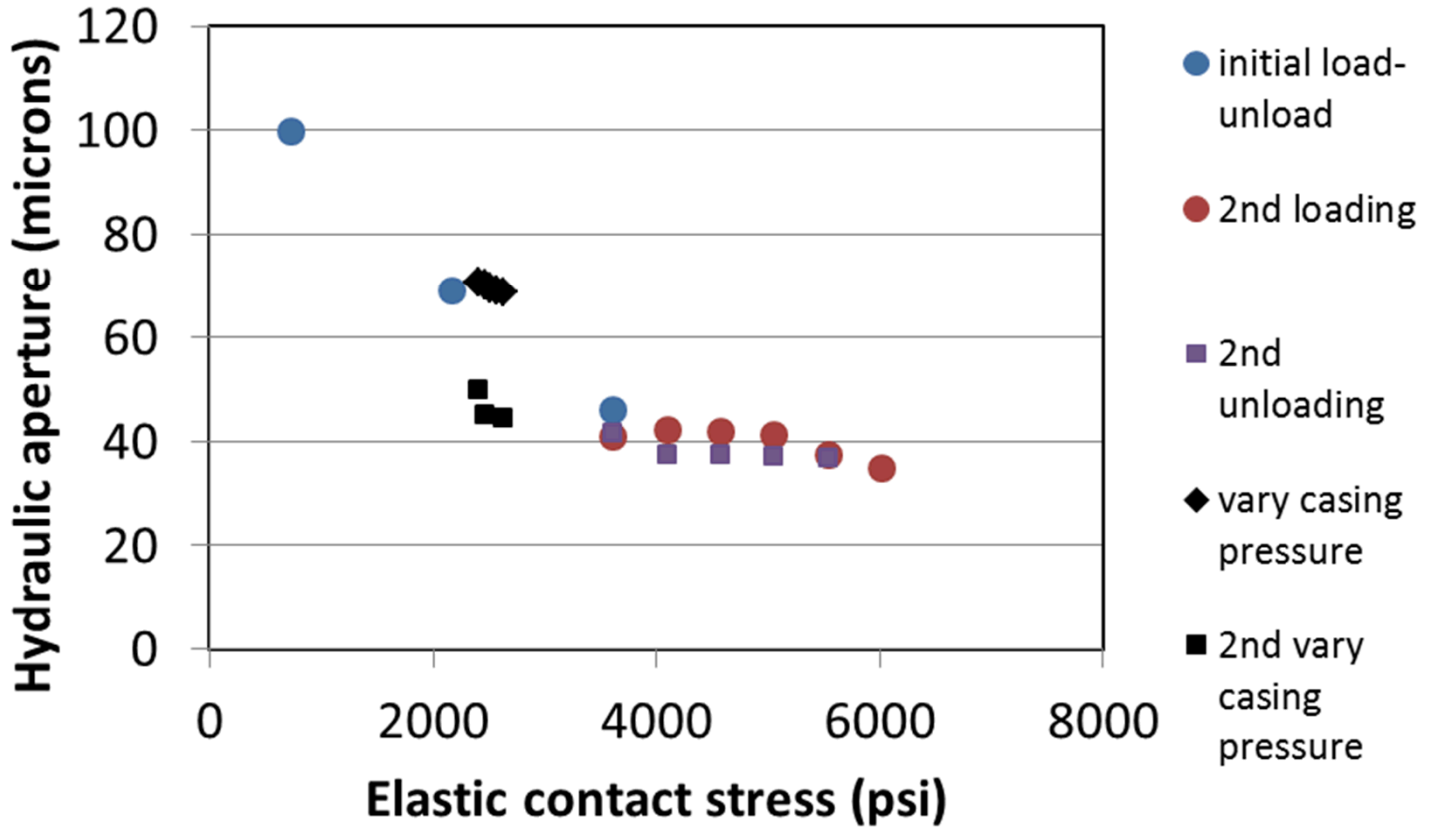
Vary casing pressure – Large microannulus



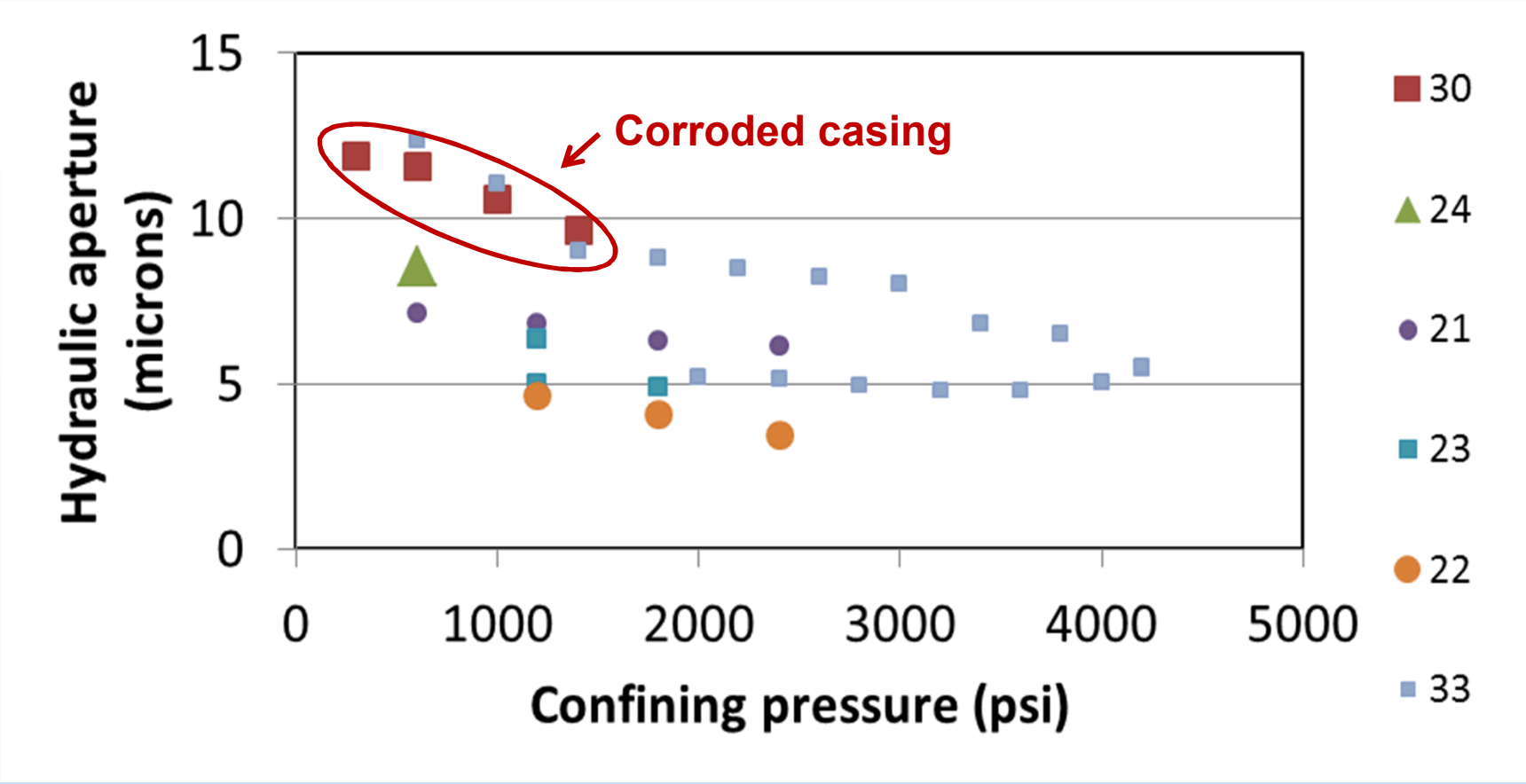
Vary casing pressure - Large microannulus



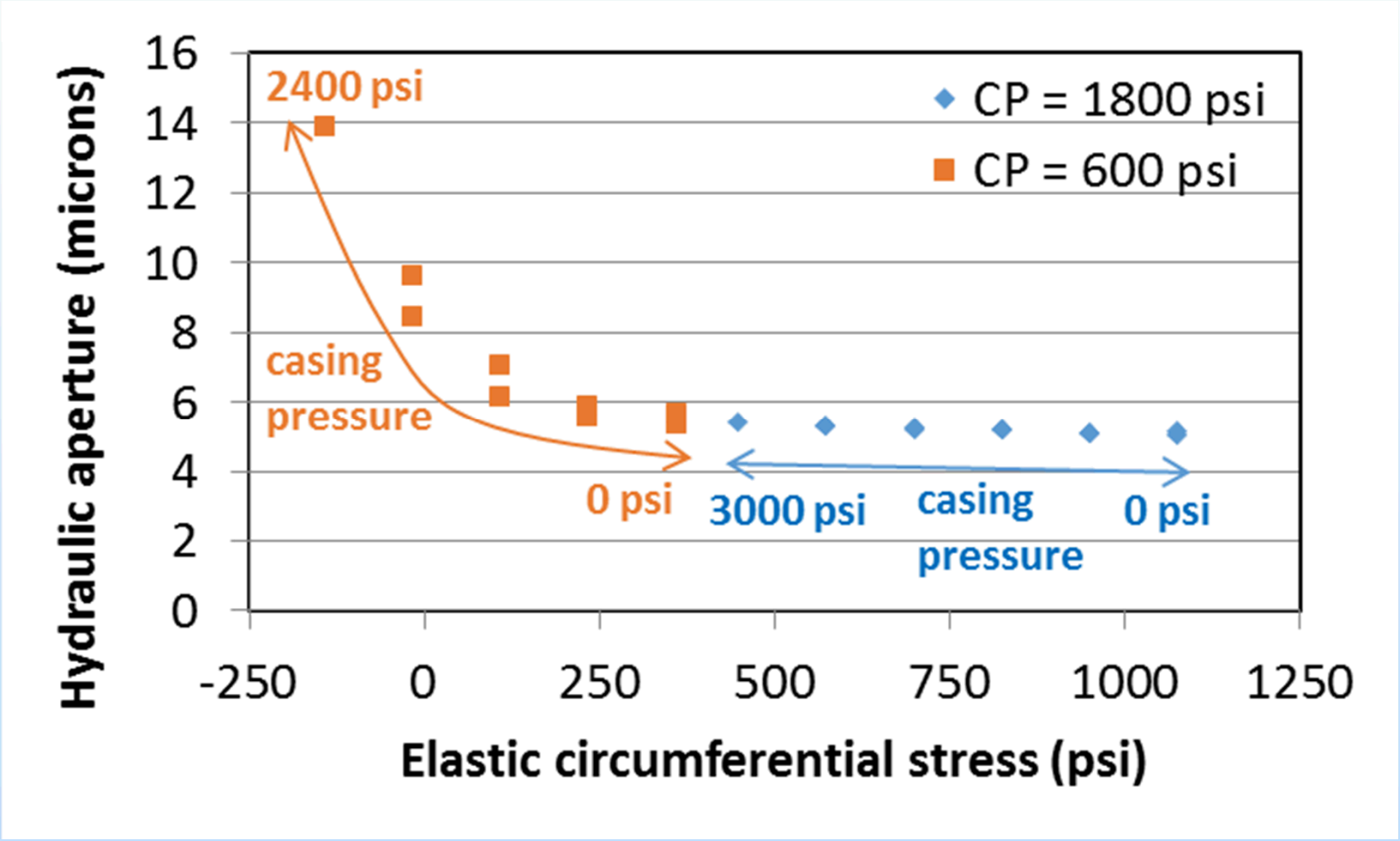
Large microannulus



Small microannulus

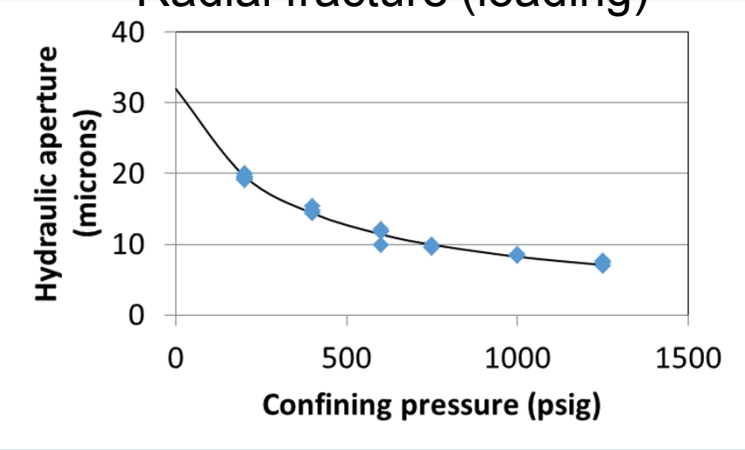


Internal casing pressure – small microannulus



Fit response to hyperbolic function

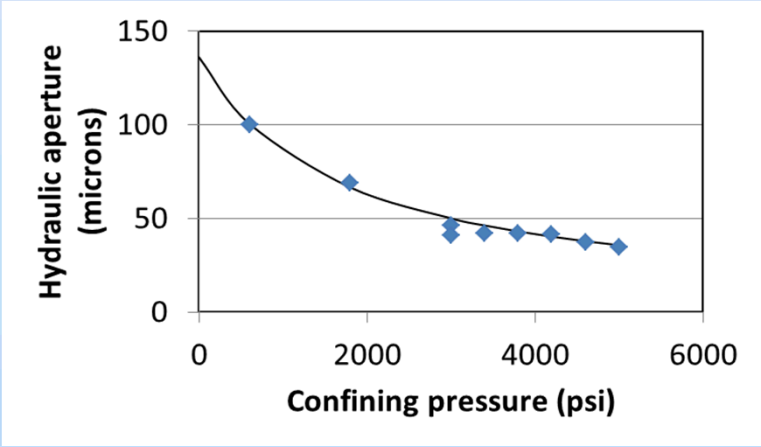
Radial fracture (loading)



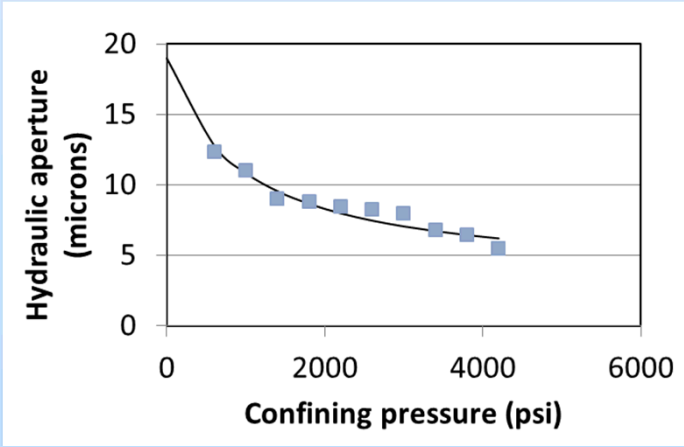
$$\sigma = \frac{-\Delta h}{a + b\,\Delta h}$$

Modified from Bandis et al., 1983

Large microannulus (loading)

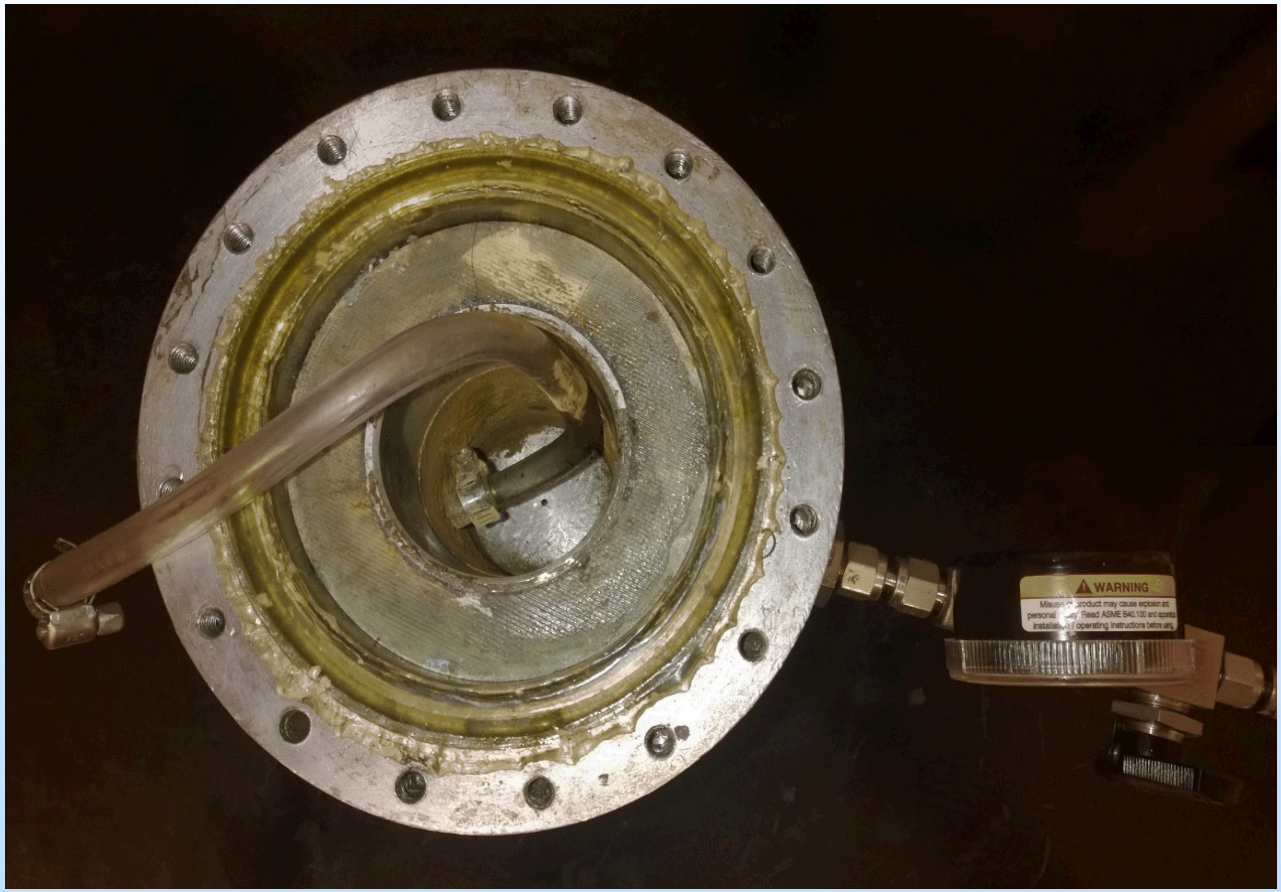


Small microannulus (loading)

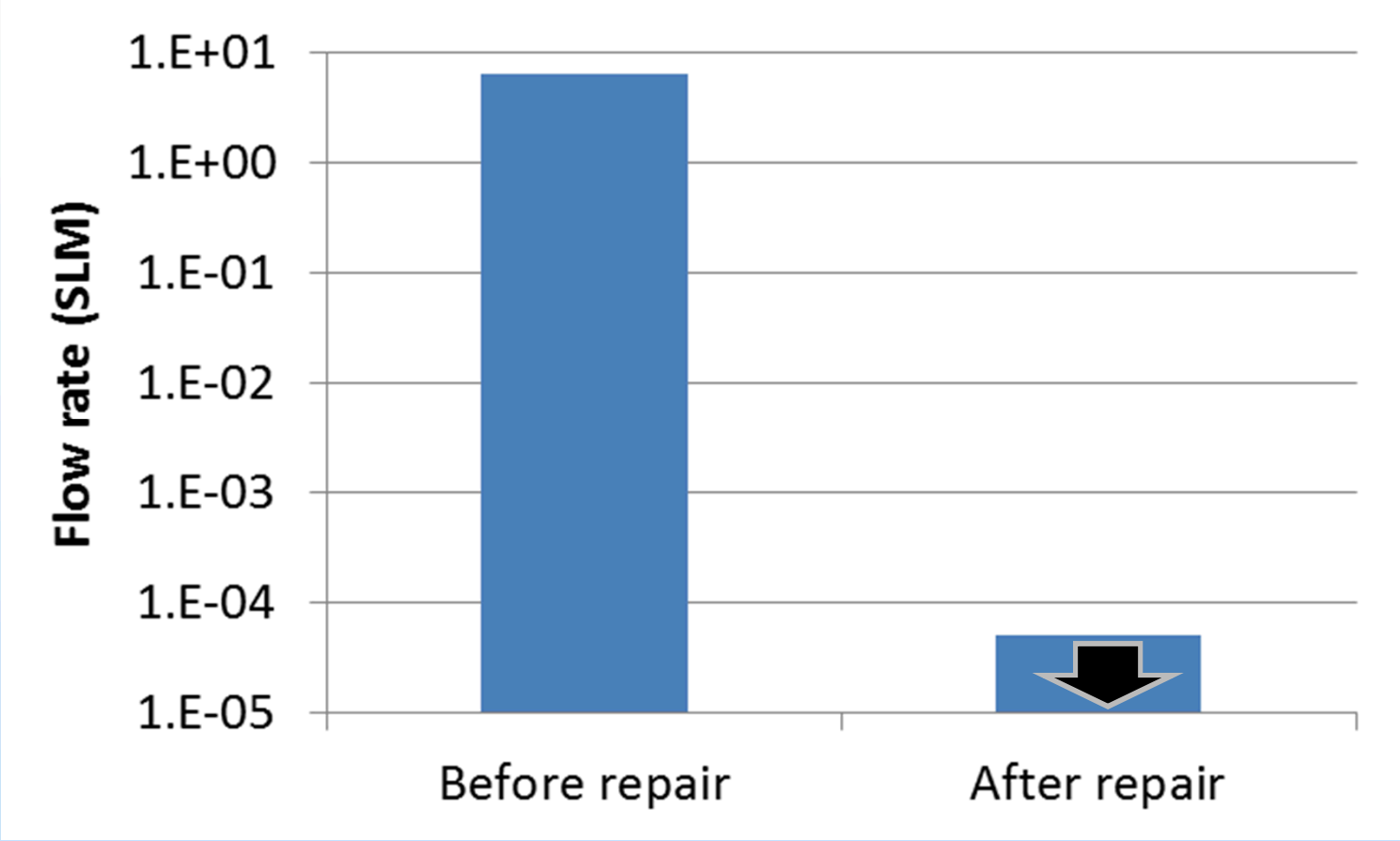


Repair of damaged wellbores

Repair of damaged wellbores

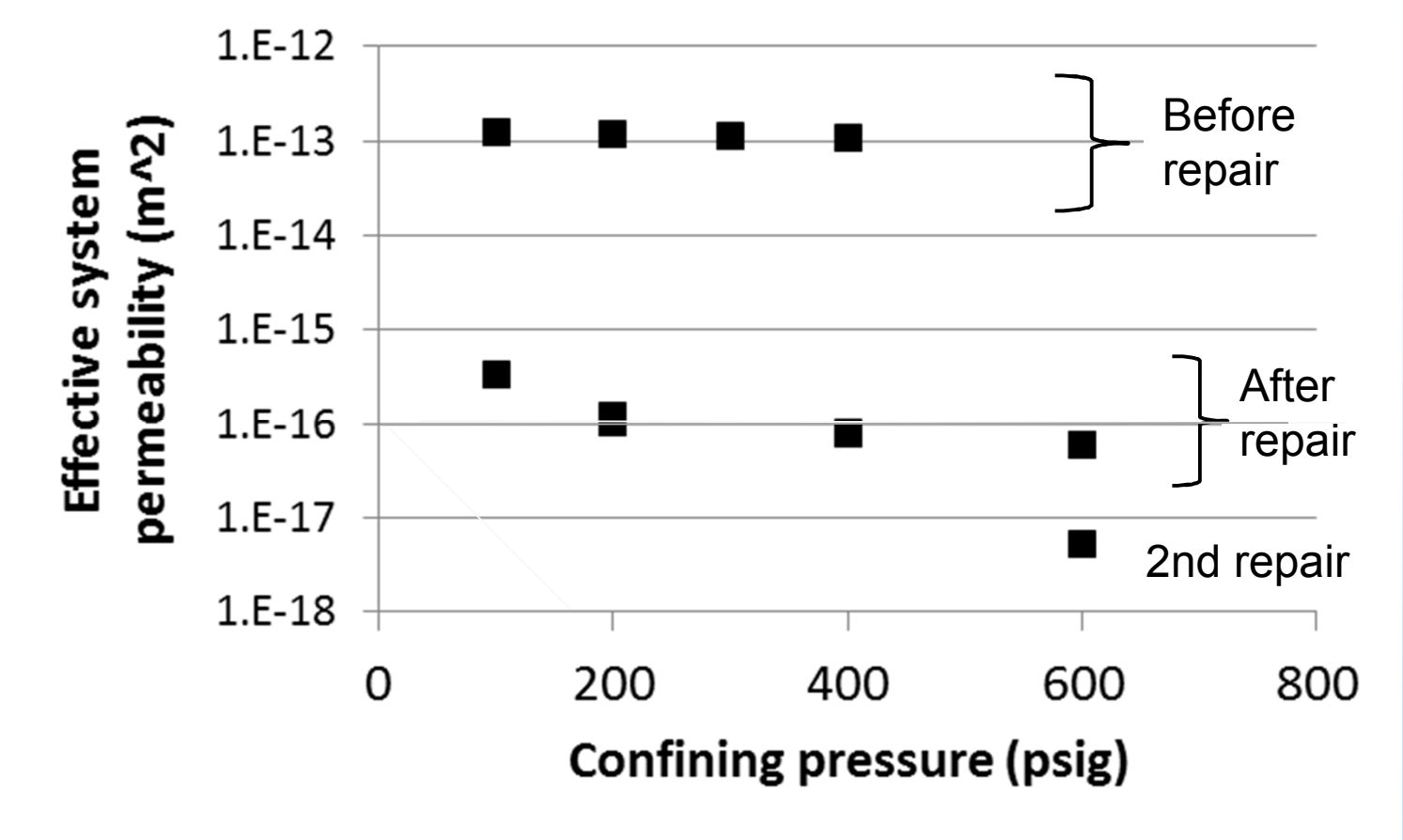


Large microannulus repair



Confining pressure = 200 psig
Internal pressure = 200 psig
Pore pressure = 100 psig

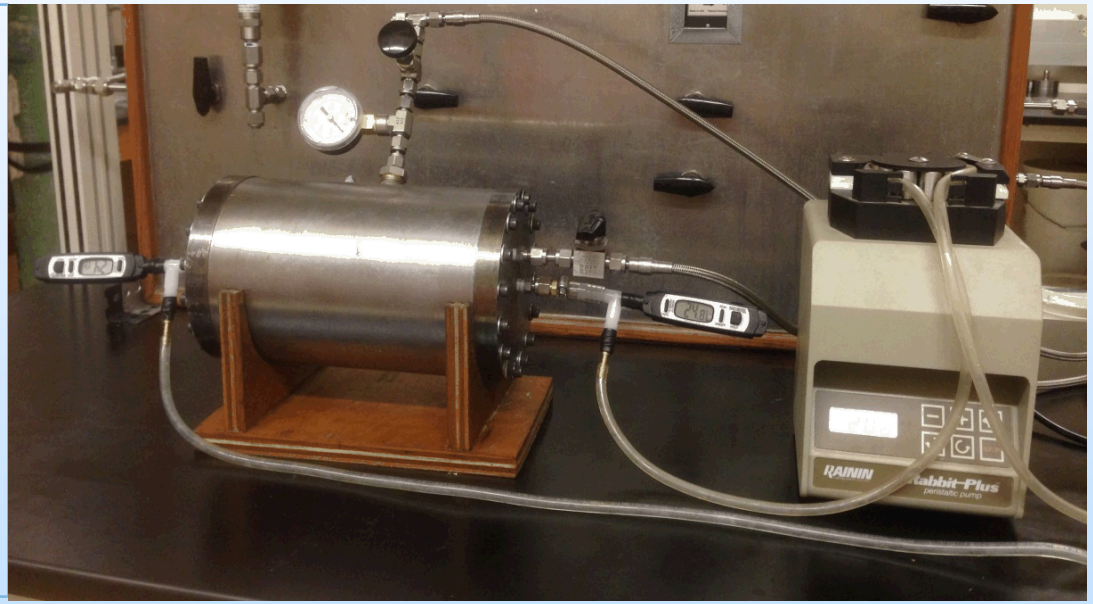
Cement fracture repair



Internal pressure = confining pressure
Gas pressure = 50 psig

In development for evaluating repair

- Change casing temperatures to induce casing expansion and contraction



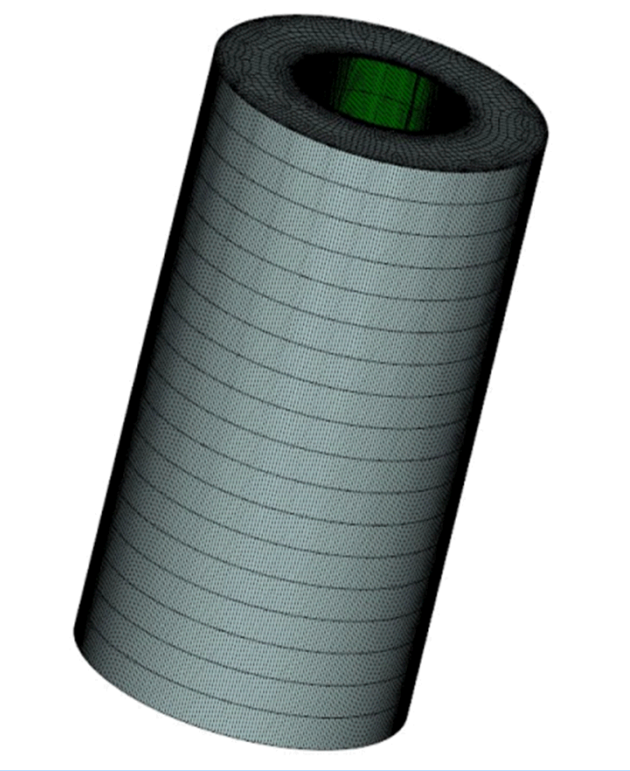
Numerical modeling

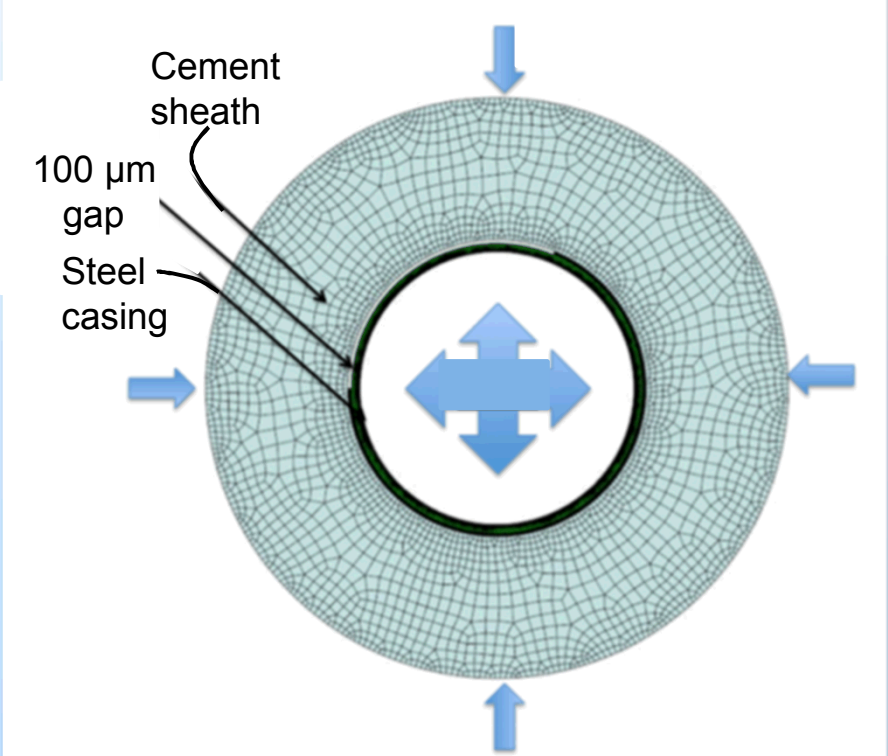
Numerical simulations

Model of pressure vessel system

Estimate stress and strains repair material will be subject to

Correlate stress conditions to permeability values





Wellbore Seal Repair Project

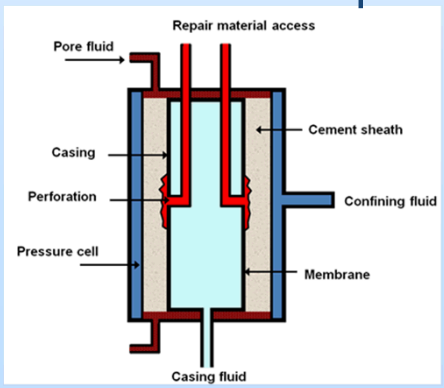
DOE NETL funded in collaboration with UNM

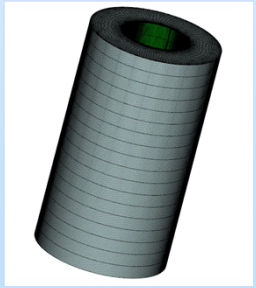
Novel Materials Development Test Matrix

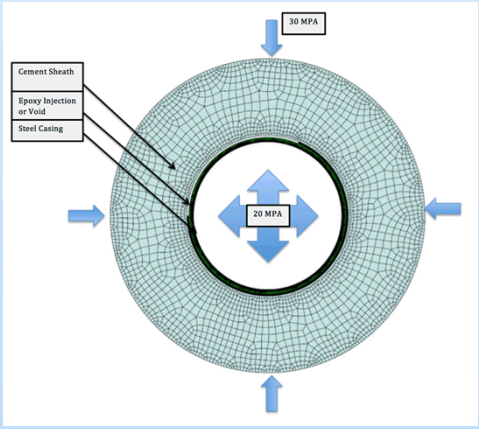
Polymers	Nanomaterials					
	Neat	CNTs	Nanoclay	Nanosilica	Nanoalumina	Graphene NP
Polysulfide siloxane epoxy	C	C	C	C	C	U
Novolac epoxy	C	C	U	C	C	U
Siloxane epoxy	P	P	P	P	P	P
SBR latex/cement	P	P	P	P	P	P
Reference repair material (Microfine cement)	P (without nanomaterials)					

C: Completed testing **U: Undergoing testing** **P: Planned testing in coming quarter**

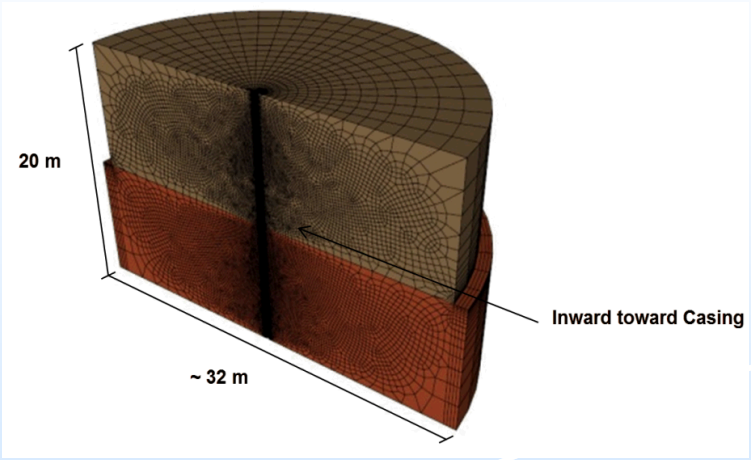
Wellbore Mock-up Bench-scale Testing

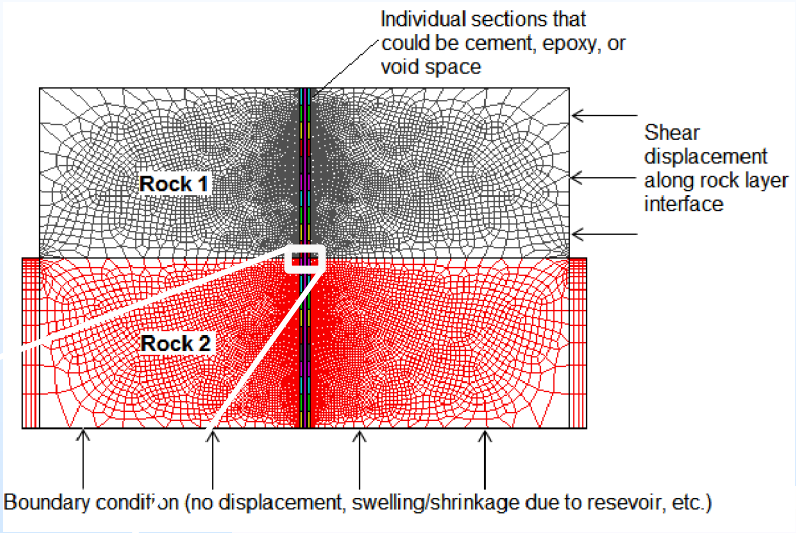


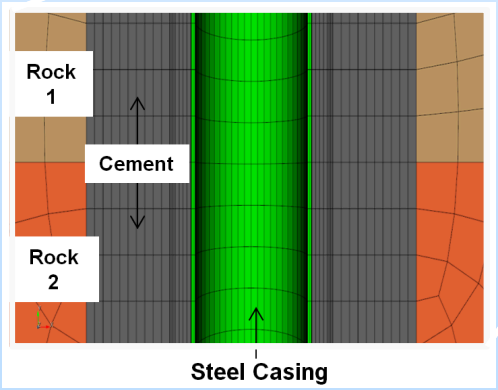


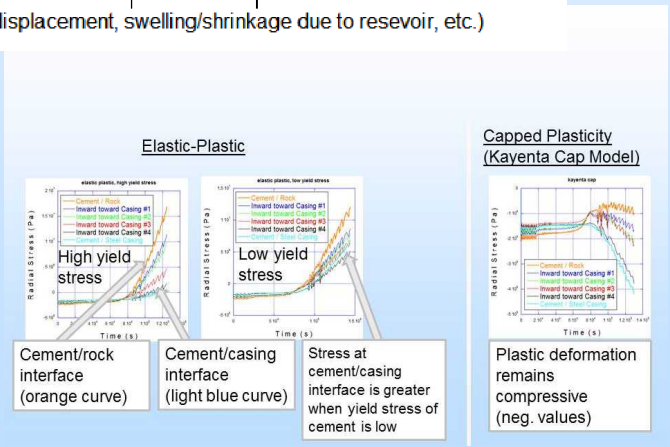


3D Geomechanical Wellbore Modelling

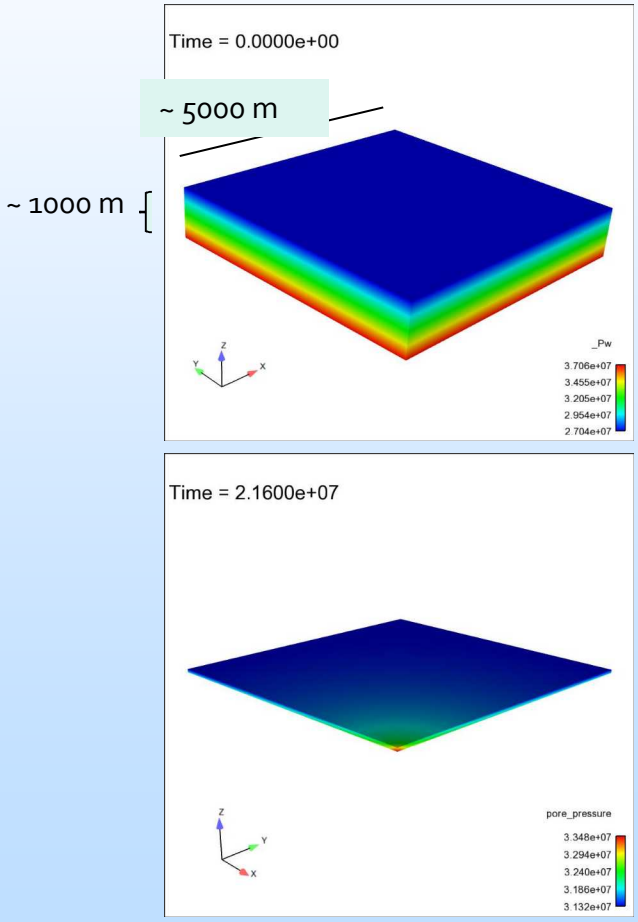


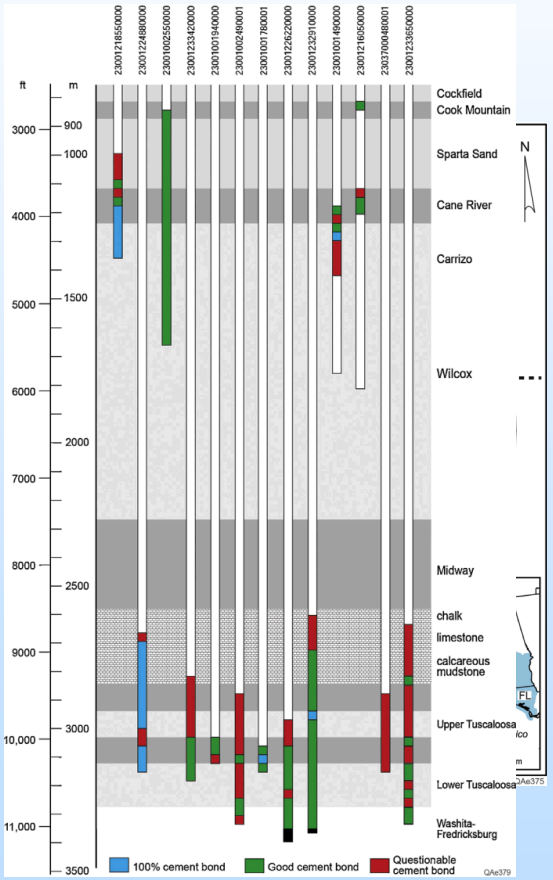






Intregrating Wellbore Modeling with Field Scale Modeling

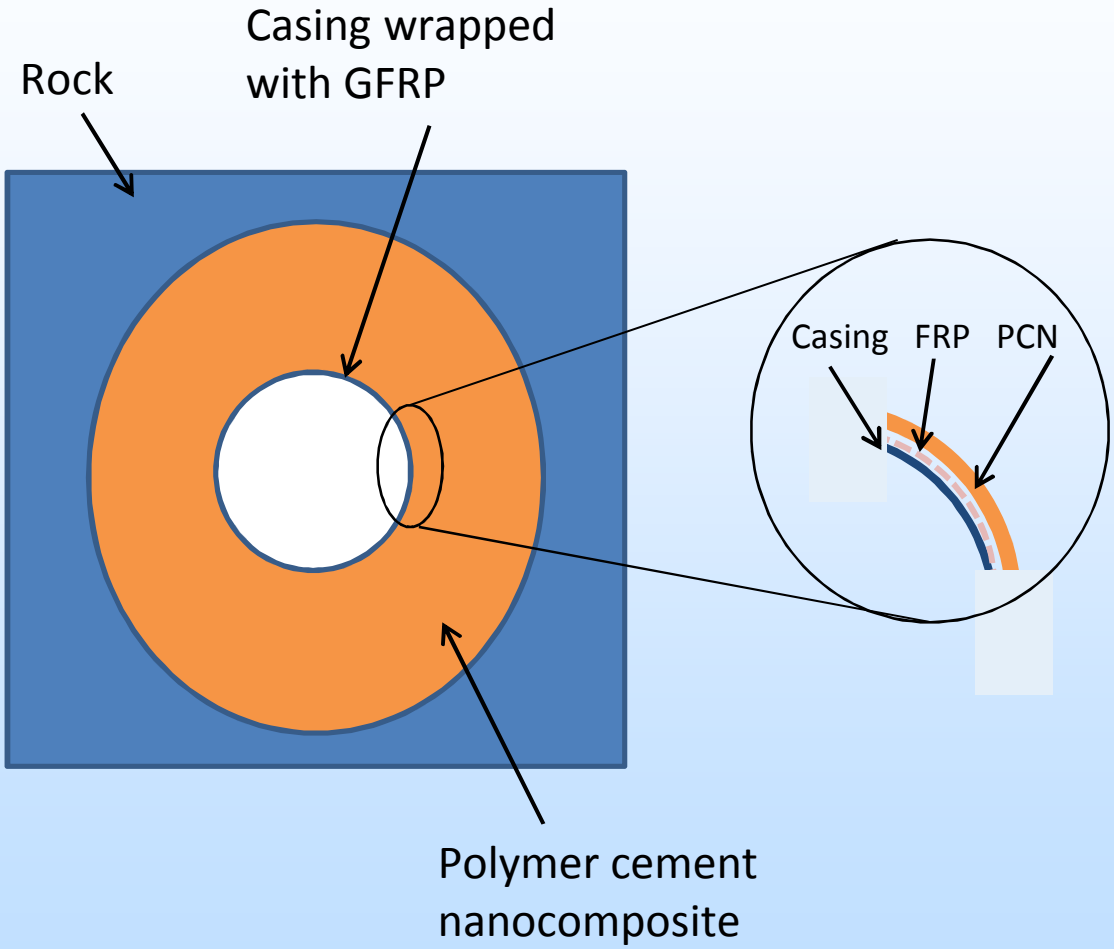




Nicot et al., *IJGGC, 18, 2013*

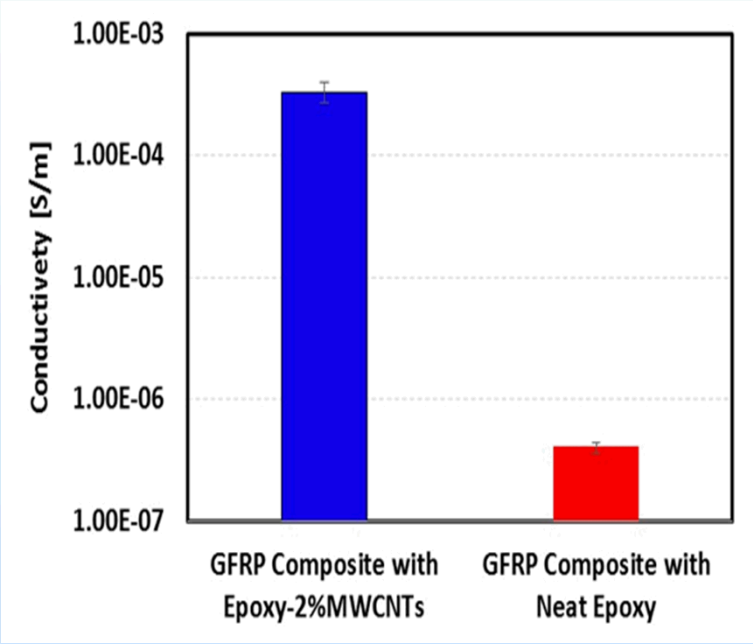
Developments with nanocomposites for wellbore applications

Bond to casing

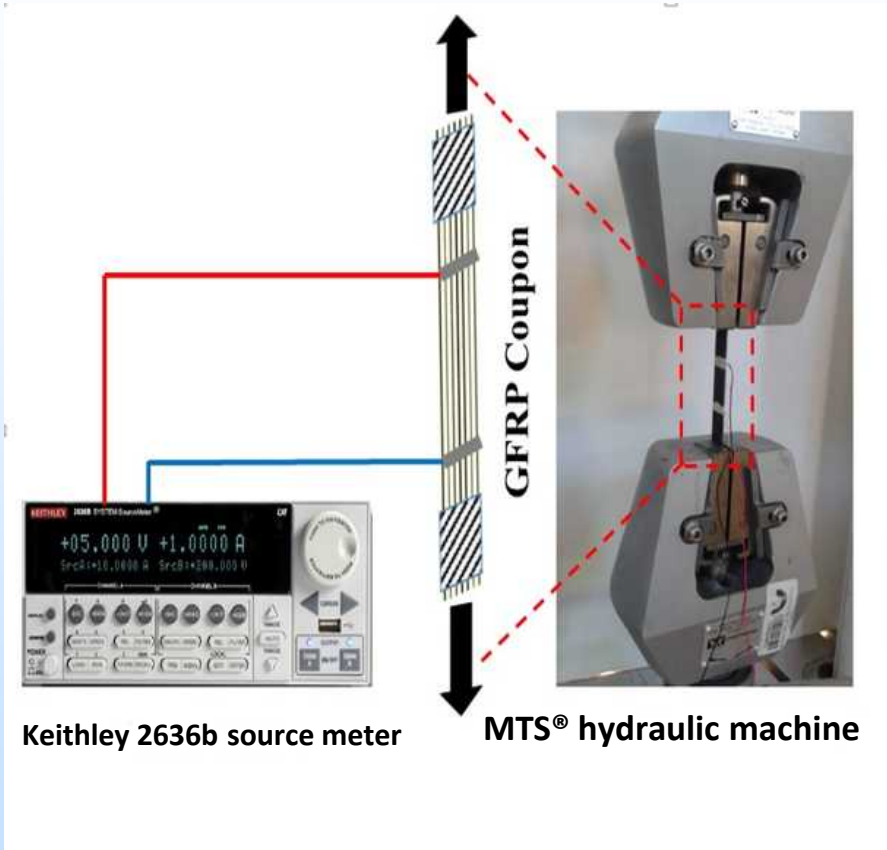


Sensing damage

Electrical conductivity increased with MWCNTs



Electromechanical testing

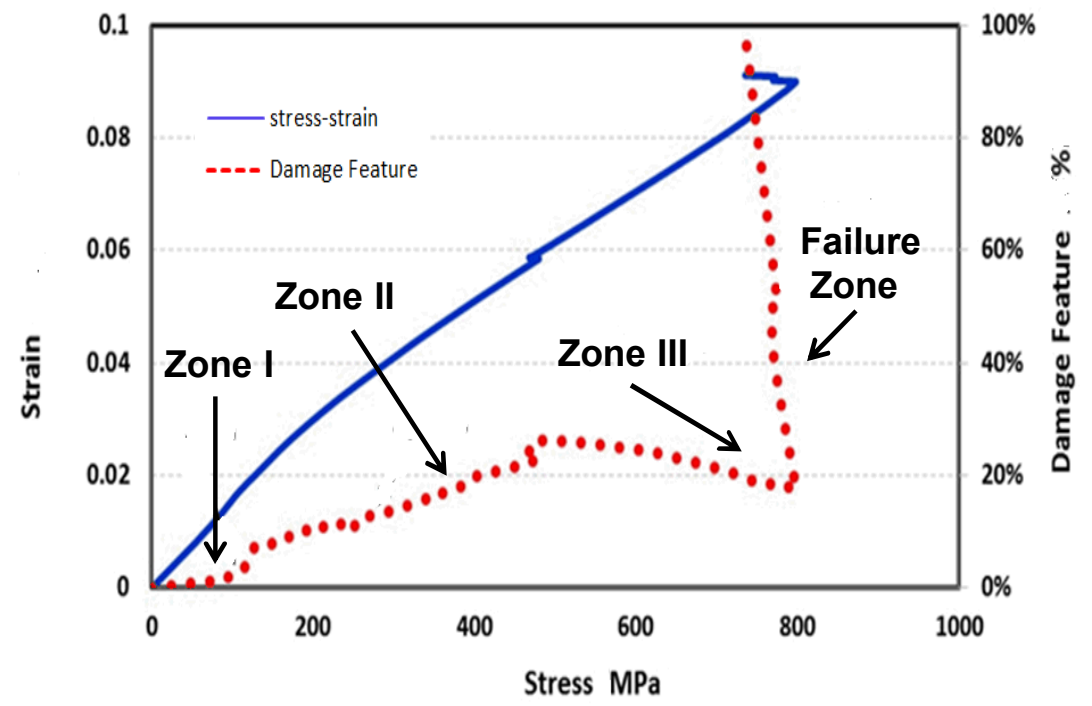


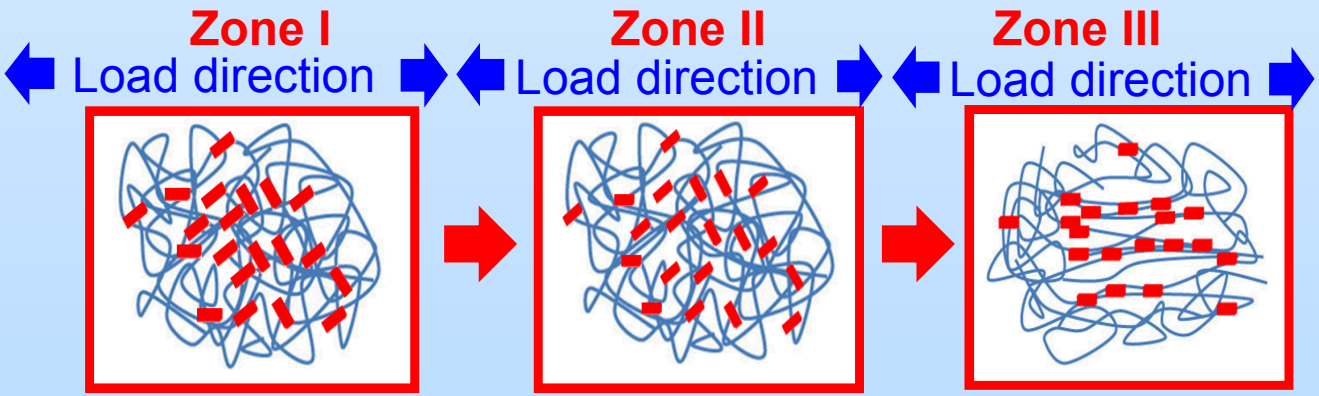
The damage function $\lambda(t)$:

$$\lambda(t) = \frac{R(t) - R(t_0)}{R(t_0)}$$

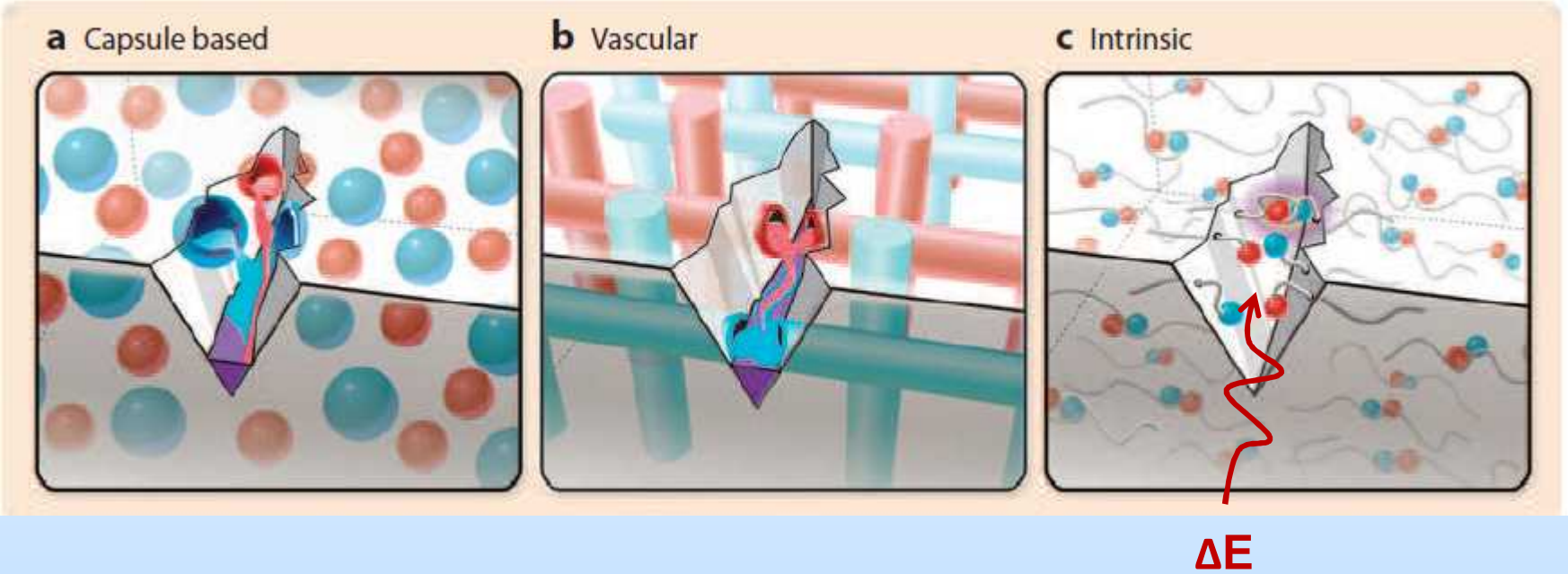
Electromechanical test

On-Axis Static Tension Test



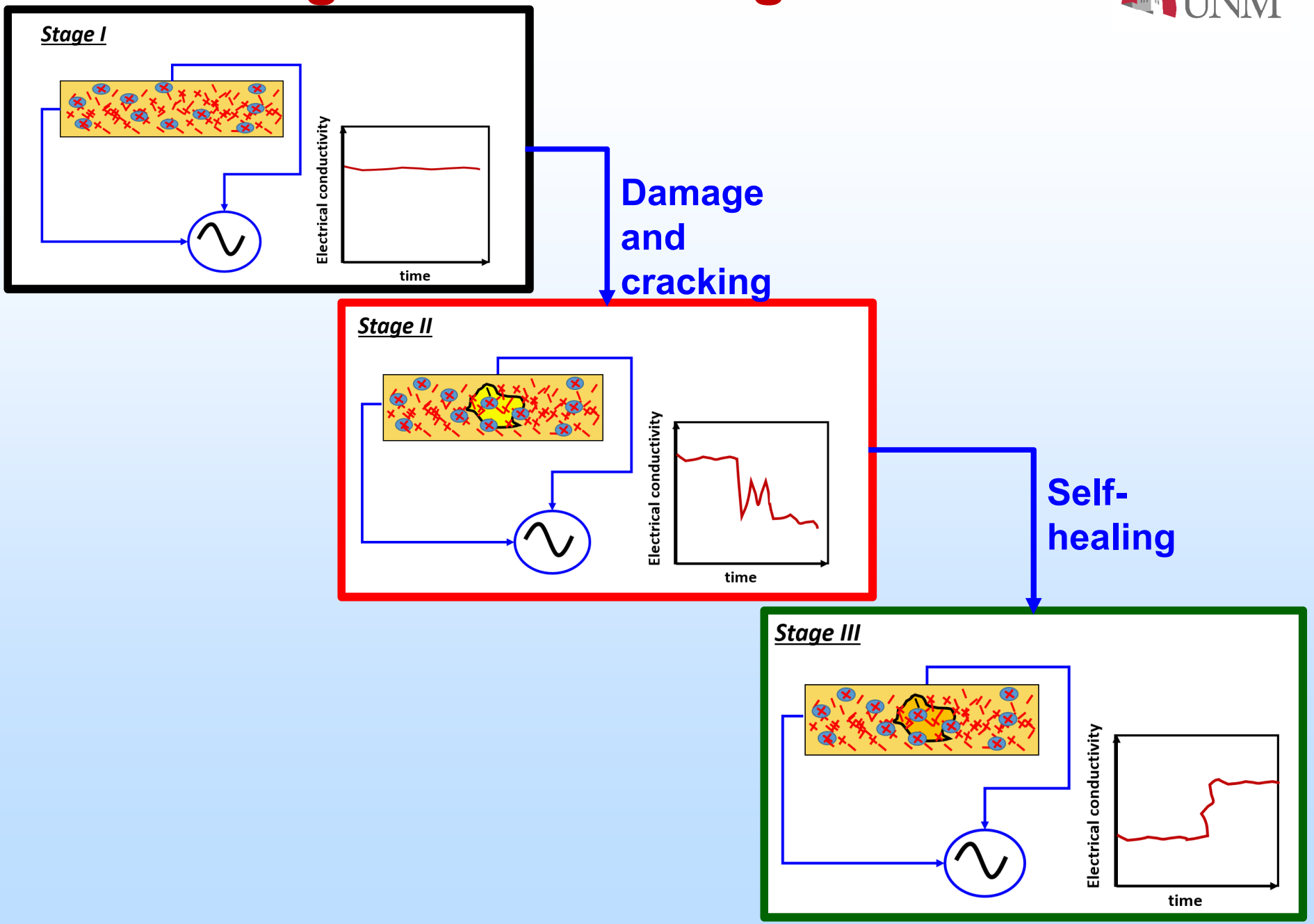


Self-healing composites



Blaiszik et al. 2010, Annual Review of Materials Research

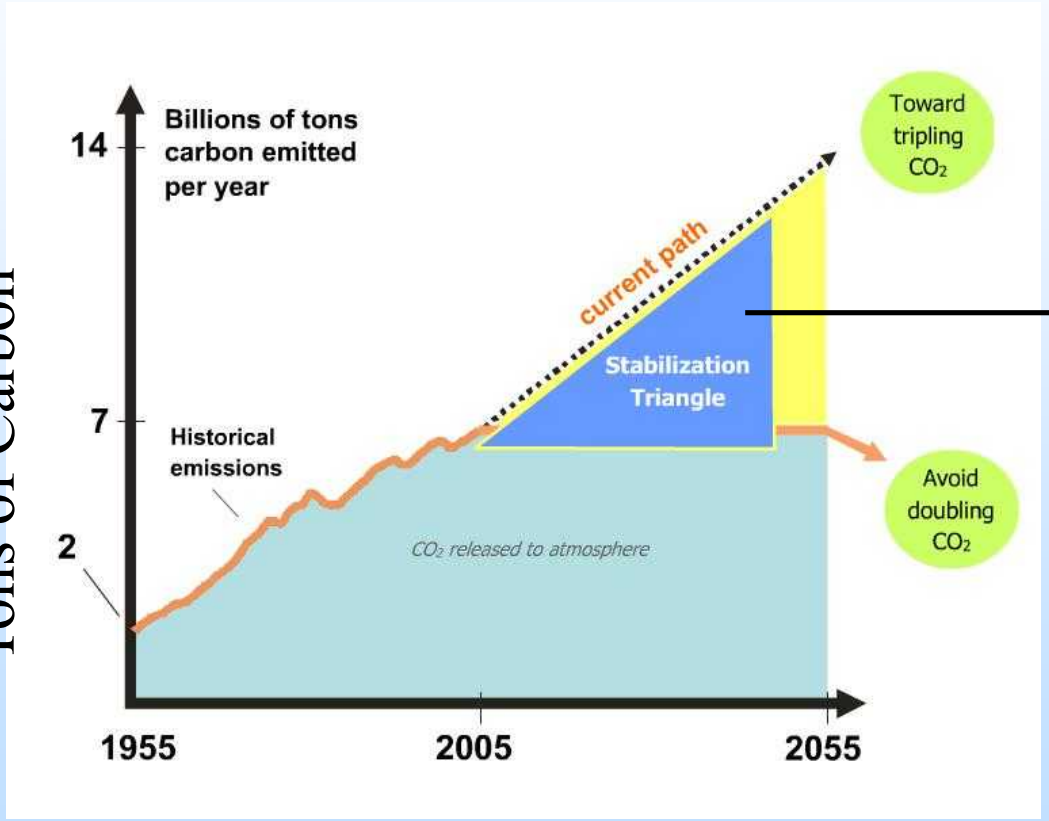
Self-healing and monitoring

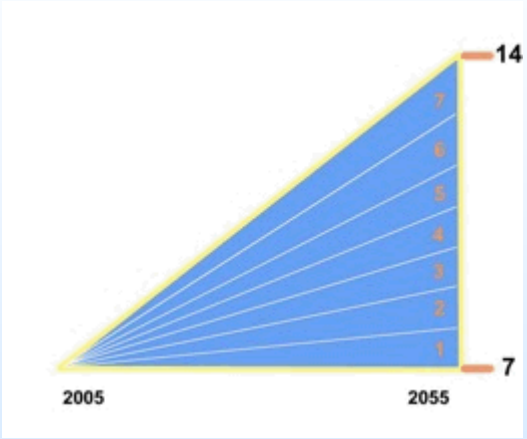


Thank you!

Back-up Slides

An Appreciable Reduction in Carbon Emissions is a "Heavy Lift"





7 Wedges = 1.3 Tt CO2

1 wedge ~ 186 GtCO2

= 4X increase in natural gas

S. Pacala and R. Socolow. *Science*, **305**(5686), p.968-972, 2004

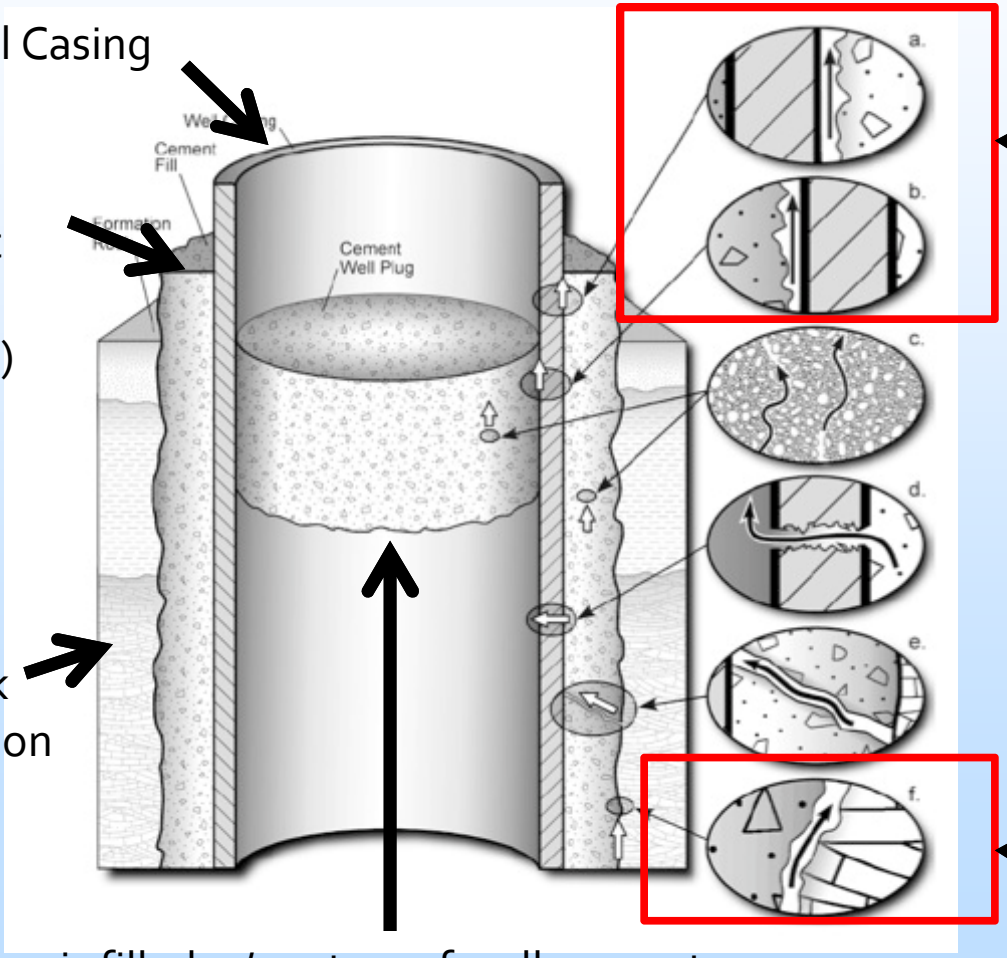
Anatomy of an Abandoned Wellbore

Interfaces between well cement / caprock and well cement/wellbore have high potential as leakage pathways

Well Casing

Well Cement (outer annulus)

Caprock Formation



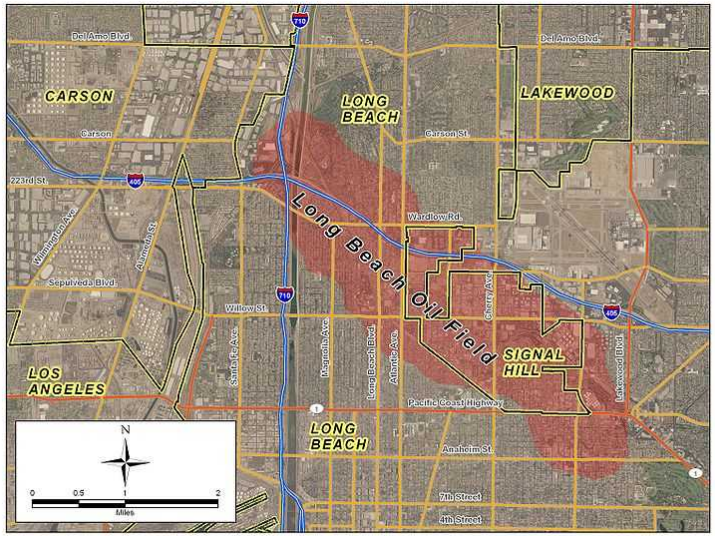
Well cement / wellbore interface

Well cement caprock interface

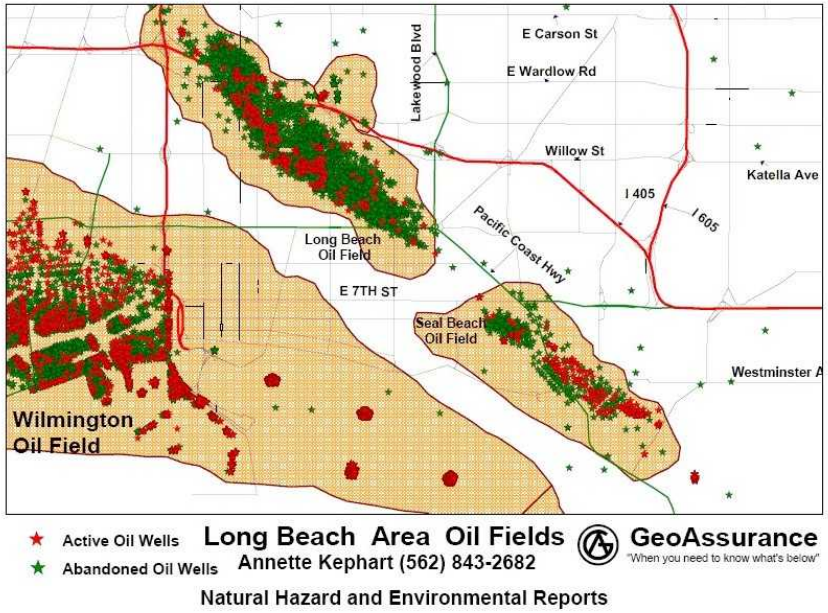
Well Casing is filled w/ meters of well cement

Gasda et al., 2008

- Typically, there are thousands of (known) abandoned wells in a field
- Re-completion is prohibitively expensive



http://en.wikipedia.org/wiki/Long_Beach_Oil_Field



http://en.wikipedia.org/wiki/Long_Beach_Oil_Field

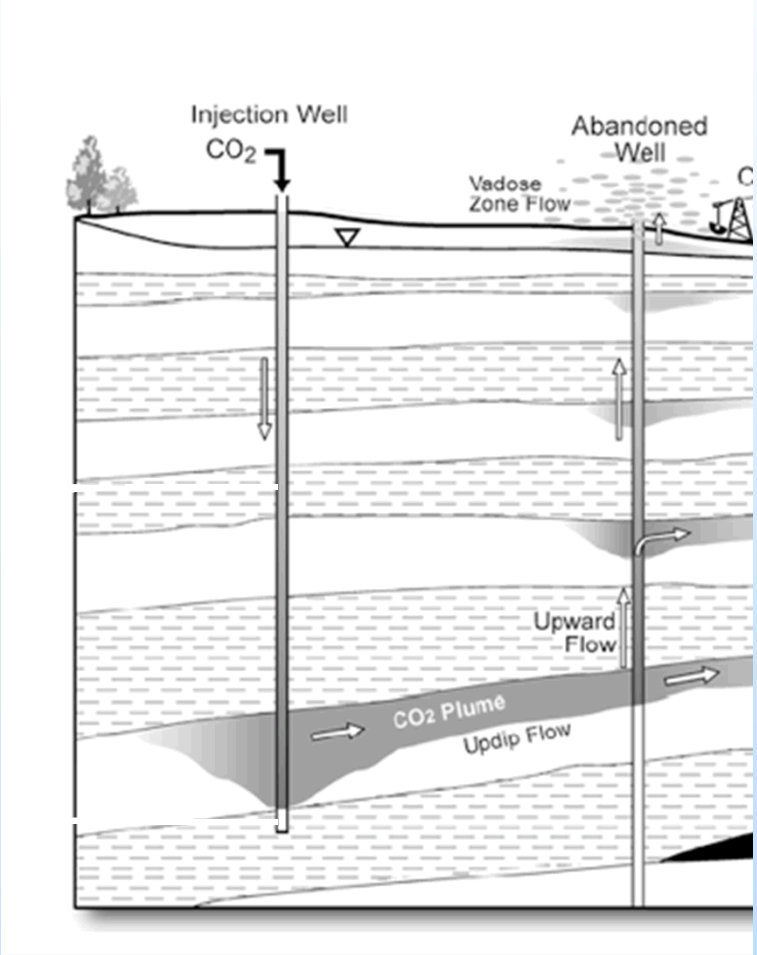
Verticality Matters!

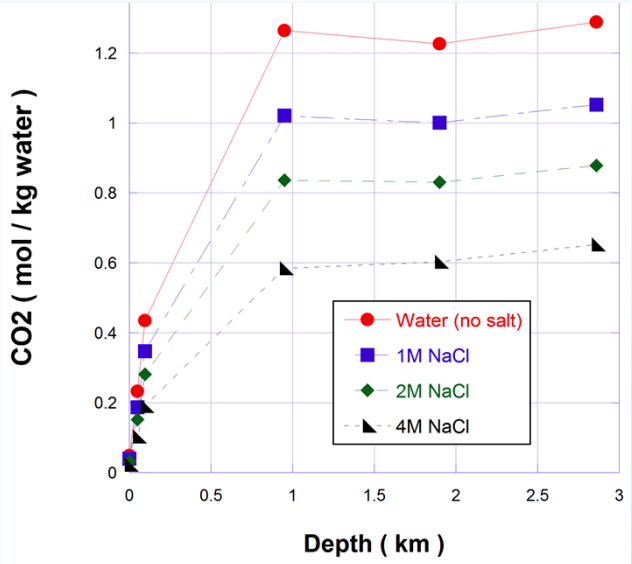
- T, P will effect cement curing
  - Permeability, porosity
- Solubility of CO_2 varies w.r.t. T, P, and brine concentration
- Phase of CO_2 varies with T, P
- Also can affecting mineral wetting properties

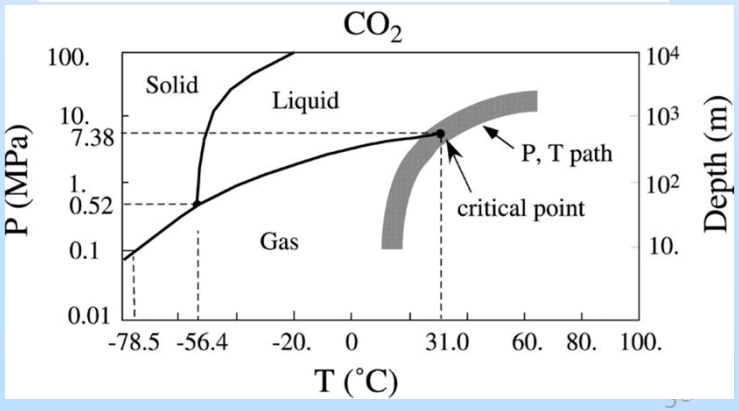
“Verticality” illustrated …

0.5 km
T= 37.5 C
P=5.25 MPa

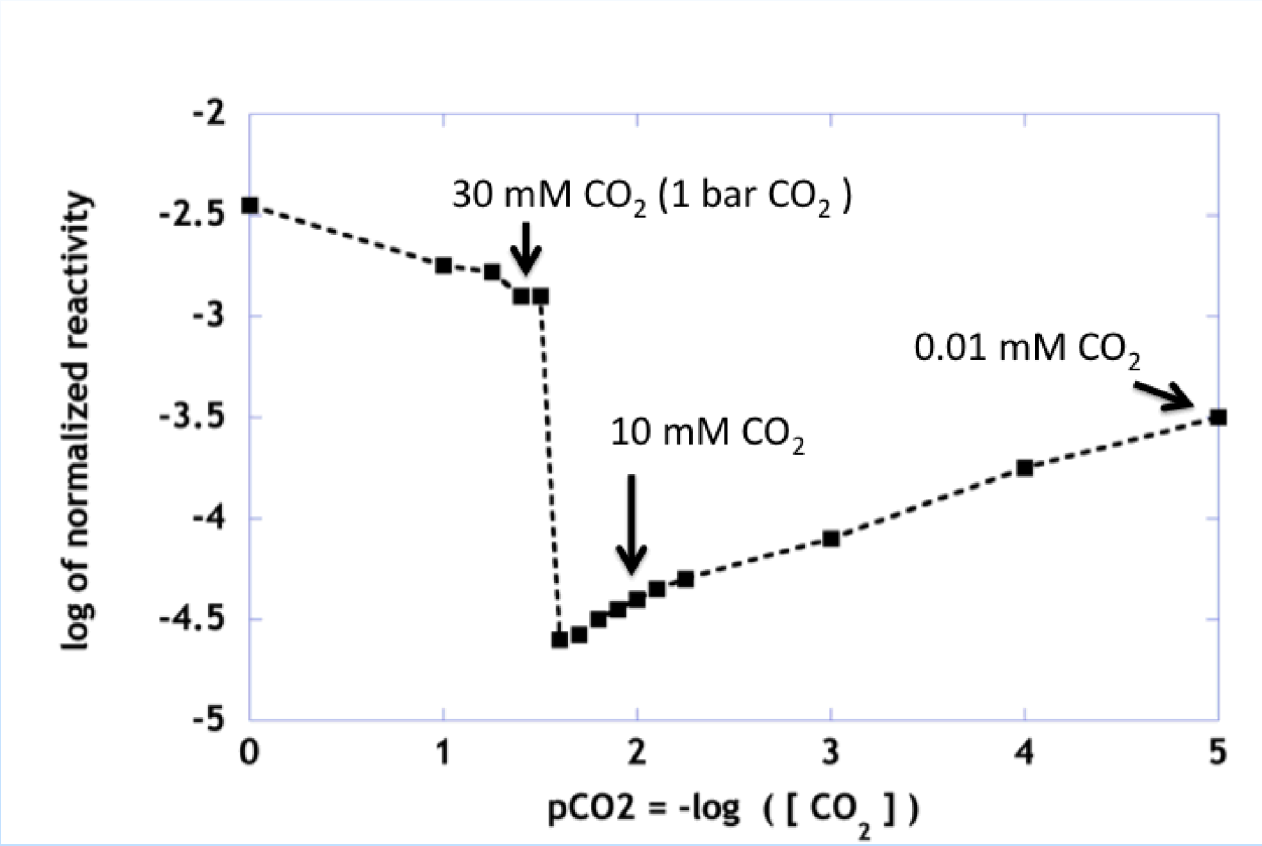
1 km
T= 50 C
P=10.5 MPa







Simulations imply possible kinetic slow-down due to self-sealing



Data courtesy of Dr. Bruno Huet, Lafarge

Pore-Plugging Experiments