Cohesive Model Applied to Fracture Propagation in Indiana Limestone

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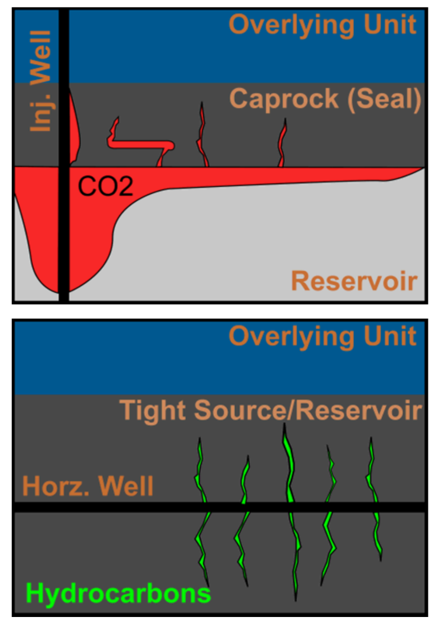
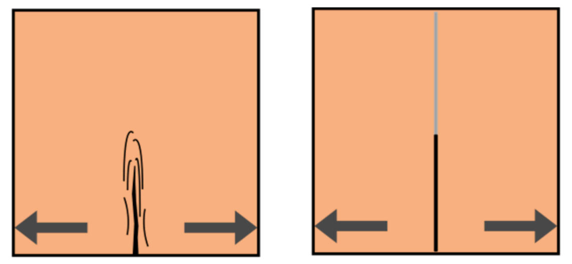
Introduction

Goal 1: Test if linear softening cohesive fracture model (LCFM) can be used to predict fracture propagation in different geometries for geomaterials.

Goal 2: Understand fracture propagation in Indiana Limestone through lens of combined numerical modeling and experiment.

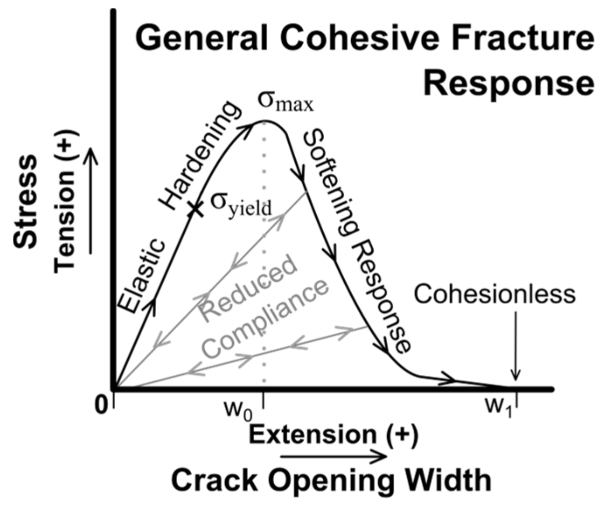


Modeling and process understanding of opening-mode fracture propagation in geomaterials is critical to viability of CO_2 capture and storage, unconventional hydrocarbon extraction, and waste repository design. Fractures provide possible preferential leakage and extraction pathways.

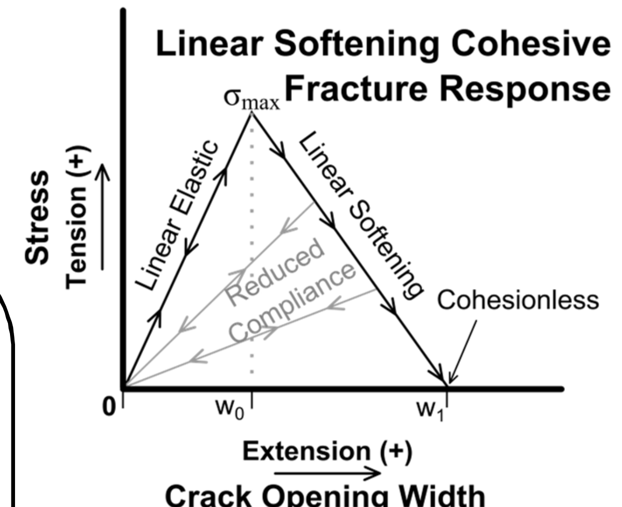


'Real' Fracture w/ Complex Damage and Geometry

Cohesive Fracture w/ Finite Defined Zone of Damage



Cohesive fracture models idealize the actual fracture processes into a plane between continuum media (Bažant and Plañas, 1907).



Each 'segment' of fracture responds elastically initially, then may have different formulations of yield and softening. We use the LCFM that has been used to simulate generic Mode I and hydraulic fractures (Yao, 2012)

Workflow

Fix σ_{max} with Brazil tests, Young's mod. (E) with UCS.

↓

Calibrate w_1 and E of LCFM in short-rod geometry.

↓

Confirm model in notched 3-point bend (N3PB) geometry.

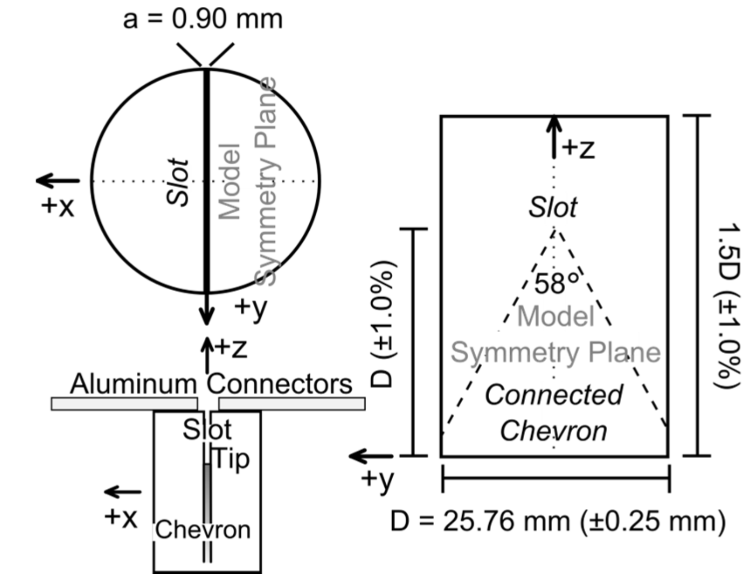
↓

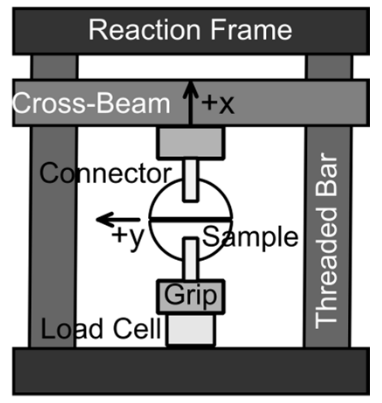
Propose hypotheses for deviations.

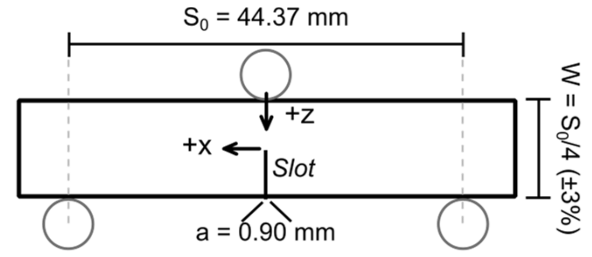
Methods

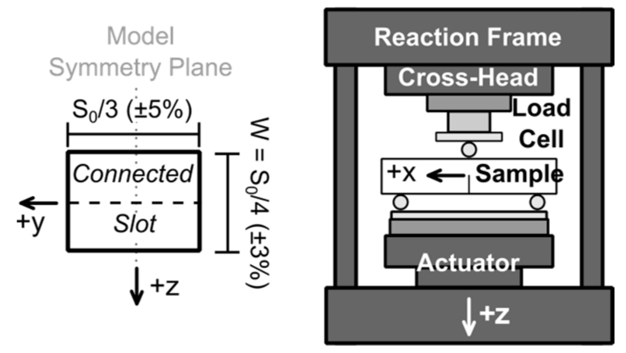
Experimental Set-up

Short-rod samples prepared from Indiana Limestone in accord with Ouchterleny (1989,1990), with force and displacement measured in a MTI SEMTester 1000. Tested at 0.001 mm/s





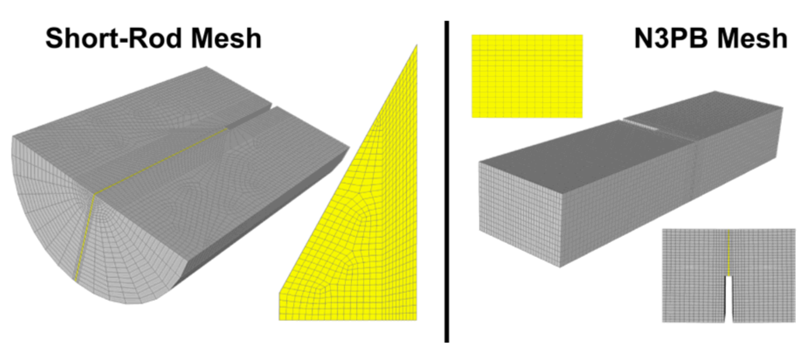




N3PB tests in accord with ASTM C1421-10 (2011), were tested in a MTS 220-kip frame using frame dispalcement, and Honeywell 1112.5 N load cell. Tested at 0.001 mm/s.

Brazilian and UCS tests were performed in the MTS 220 kip frame in conformance with ASTM D3967-08 (2008) and ASTM D7012 -3 (2013). UCS-test strains were measured with 0.125 universal-T strain gages.

Numerical Model



Cohesive zone 0.2 of notch width. Meshing performed in Cubit. Used 8-node hexahedron elements. Yellow elements were linear softening cohesive elements. Gray were linear elastic elements.

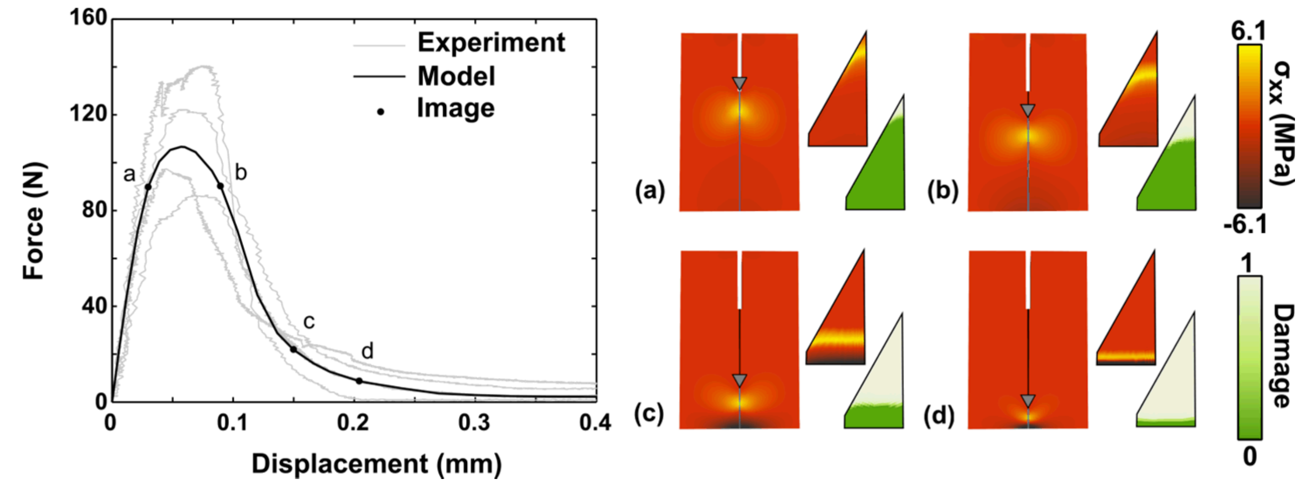
LCFM-finite element simulations performed in Abaqus Standard 13.1 (**ref**). Displacement boundary conditions enforced on top surface (shor-rod) and outer edges (N3PB). Resultant forces found on same nodesets. Symmetry plane (y=0) used.

Initial Params. (Brazil, UCS Tests)

σ_{max} = 5.9 MPa (fixed in simulations). +/- 15%.
E = 39.5 GPa (subs. calibrated). +/- 10%

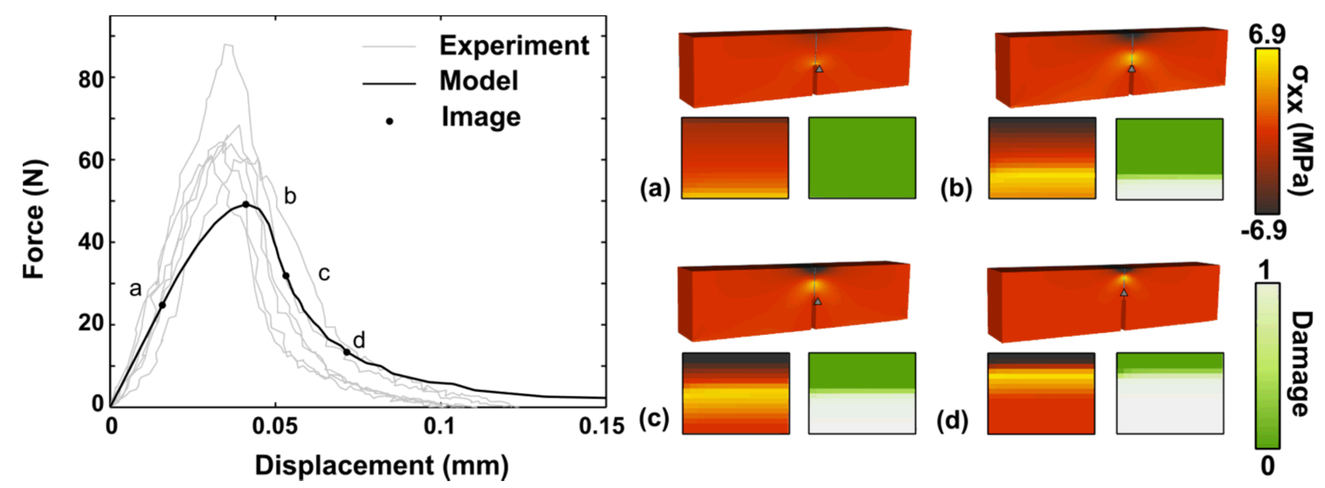
Results

Short-rod Calibrations



- Calibrated successfully.
  - E_{cal} = 7 GPa << 40 Gpa
  - w_1 = 0.0115 mm.
- Pre-peak yield similar in test and simulation.
- Matched both initial and late softening behavior.
- Observed piece-wise failure similar to qualitative simulated failure pattern.
- Simulation does not match very late behavior (d), (cannot account for compressive damage).

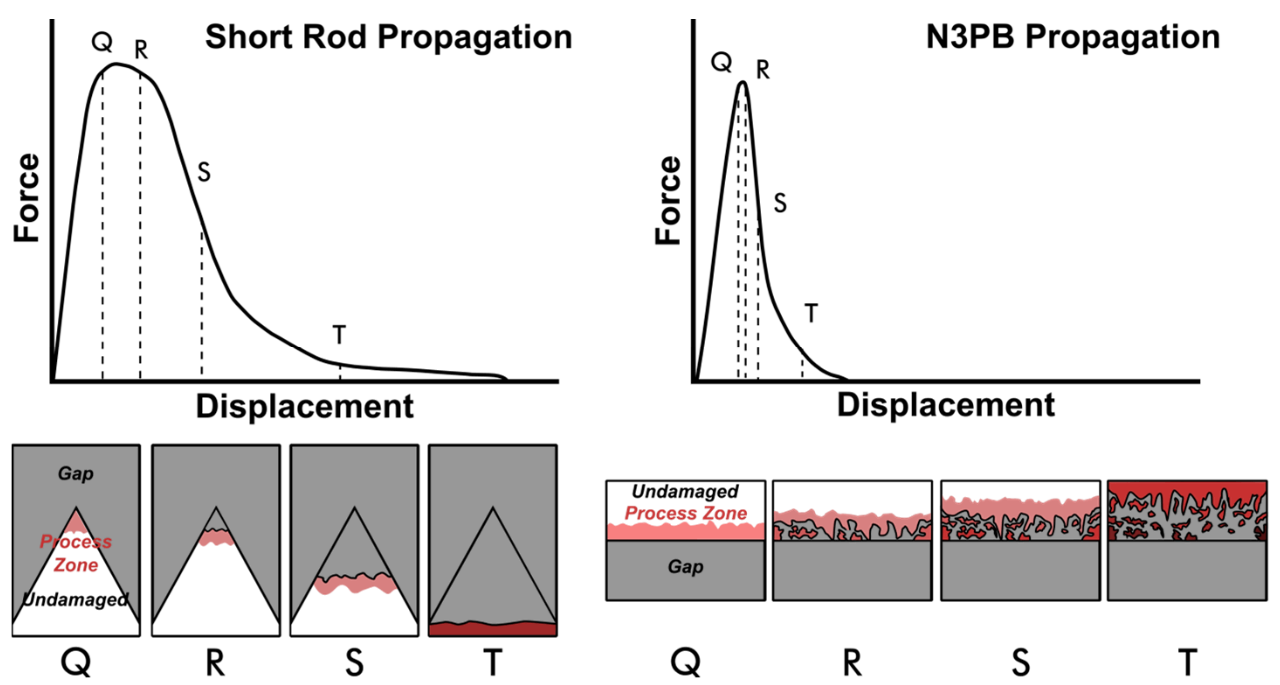
N3PB Confirmation



- Simulated peak force 80% of minimum observed force.
- Simulated yield proportional to peak force begins much earlier than observed.
- Simulated elastic response more compliant (lower slope) than observed.
- Simulation overshoots observed late softening behavior.
- Observed fracture is diffuse through >99% of softening, with coherent unstable fracture forming just before complete failure.
- Simulation has discrete fracture progression sequentially.

Conclusions

Conceptual Model



- LCFM can be reasonably used in different geometry and loading configurations.
- Volumetric proportion of stress in tensile, shear and compressive states control continuum elastic response.
- LCFM assumes uniform fracture process through all of propagation.
- N3PB has 2-stage failure, with stiff and strong shear elements stiffening sample and shielding weak tensile portions.

Acknowledgements

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