Emergence of Delamination Fractures around the Casing during Wellbore Stimulation

Arash Dahi Taleghani
Louisiana State University

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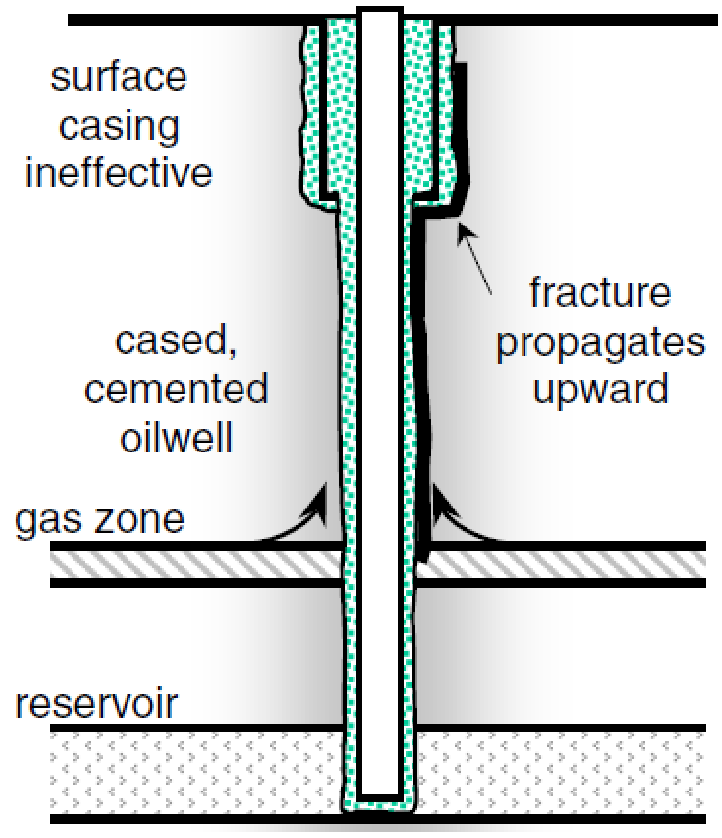
Delamination Fractures

- Hydraulic fracturing a common practice for economic production in many plays
- Excessive fluid pressure cause rock cracking may induce cracks along the casing i.e. delamination cracks
- Delamination crack provide hydraulic communication with shallower zones

Failure Development Mechanism

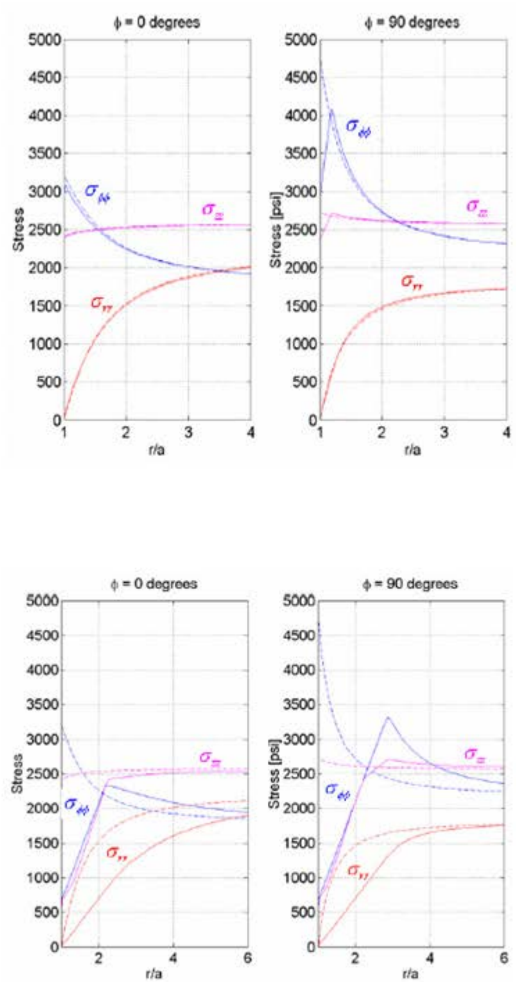
- Failure in cement
- Delamination (detachment) of casing/ cements or cement/rock
- Fracturing surrounding rock
- Stress analysis of wellbore casing delamination crack

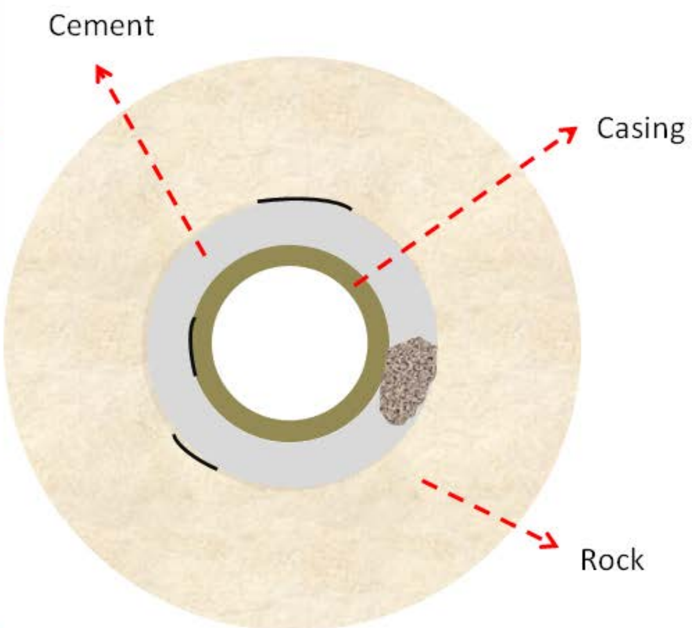


Aftermaths

- The cement sheath failure poses serious challenges to wellbore integrity, which is potential to cause underground venting along the well with large damaging consequences (Nesheli, 2006)
  - Pollute the environment
  - Cause reservoir depletion and hydrocarbon reserves losses
  - Damage or abandon the well
  - Cause water coning (in bottom-water reservoirs)
  - Induce safety risk due to the flow of dangerous formation fluids
  - Cause large financial losses
  - Hurt and kill the personnel

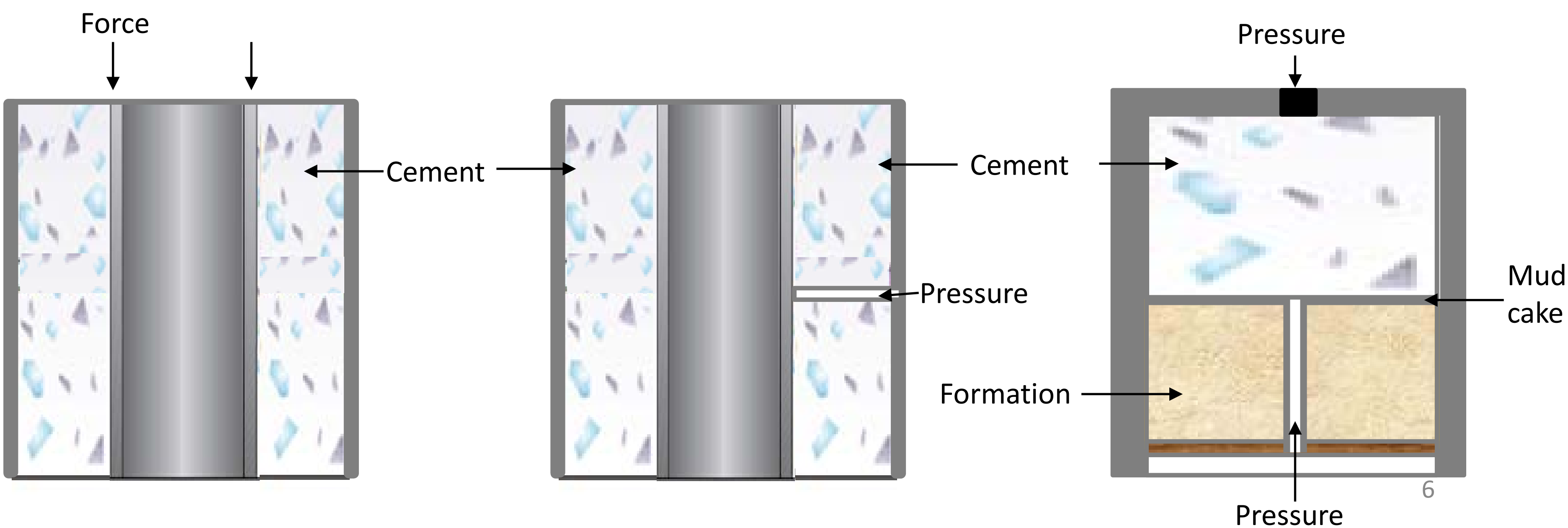
Initiation Scenario





Shear and Hydraulic Bond Lab Test

Carter and Evans (1964) presented the lab method to test shear/hydraulic bond of cement to formation (or casing).



A
Shear bond test

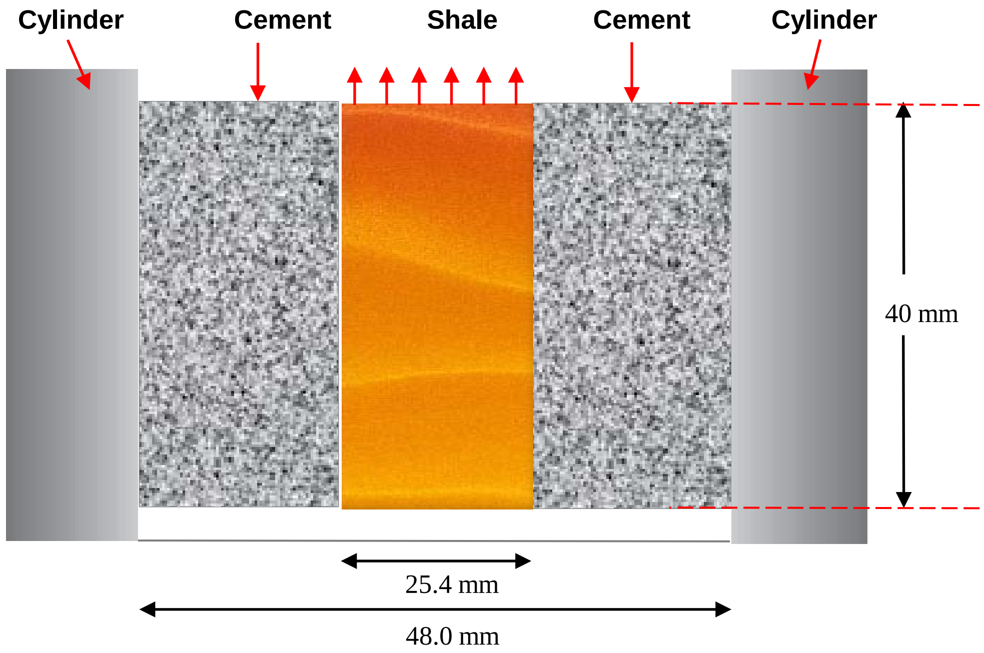
B
Hydraulic bond test to pipe

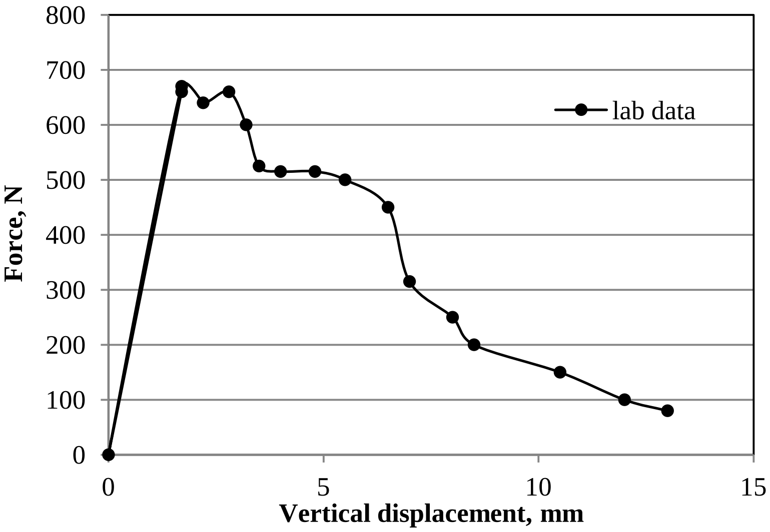
C
Hydraulic bond test to formation

Evans and Carter (1962)

Pulling Out Lab Test

Ladva (2005) presented a pulling out test to measure the cement and shale interface parameters and its mechanical failure process.





Cement Bond Log

Cement bond logs(CBMs) and variable density logs (VDLs)
(Bellabarba, 2008)

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Sonic logging tool

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Measure signal amplitude or attenuation

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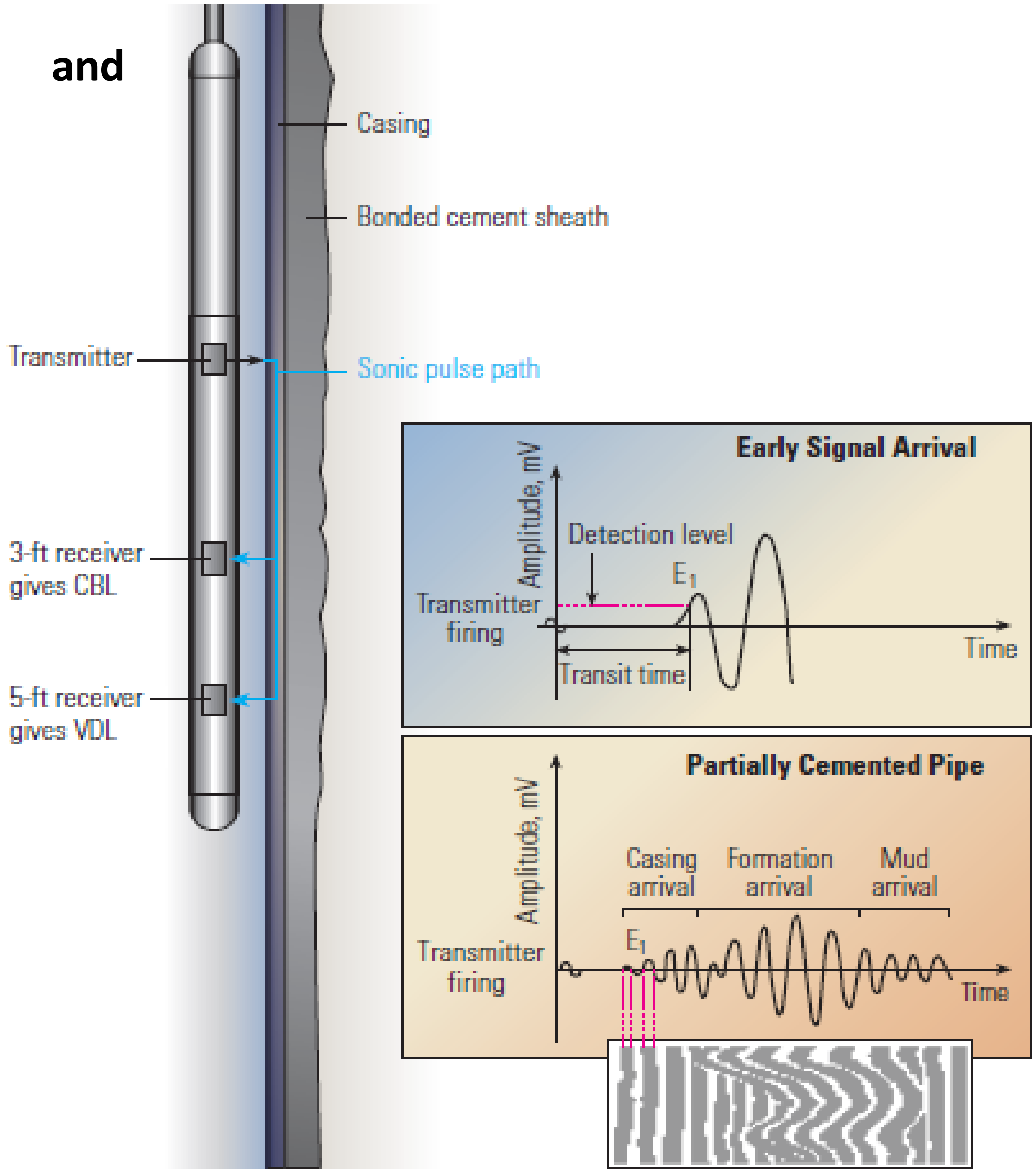
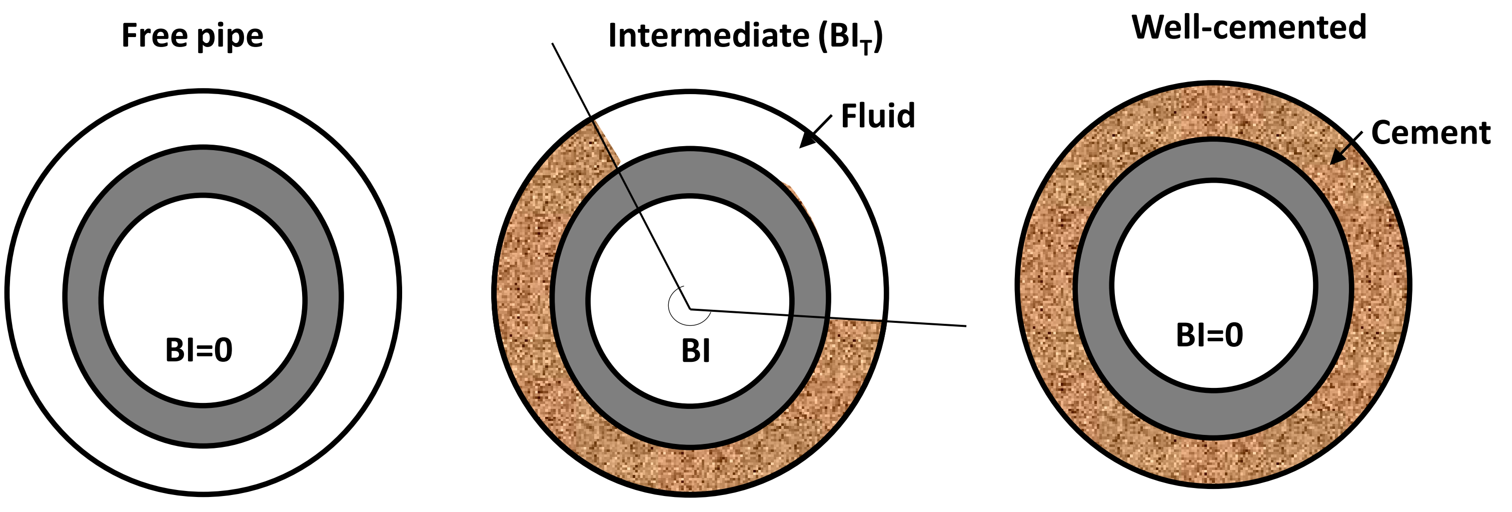
transmitter emitting a 10 to 20 kHz acoustic wave after it has traveled through a section of the casing as an extensional model



- **Ultrasonic imaging tools (Schlumberger USI UltraSonic Imager)**
  - using a rotating transducer
  - Excite a casing resonance mode at a frequency
    - casing thickness
    - the acoustic impedances of the media on either side of the casing.
- **The cement acoustic impedance is then classified as gas, liquid, cement.**
- **The Bond Index (BI) (Pistre, 2005)**



The Strength and Weakness of ultrasonic logging tool

Strength:

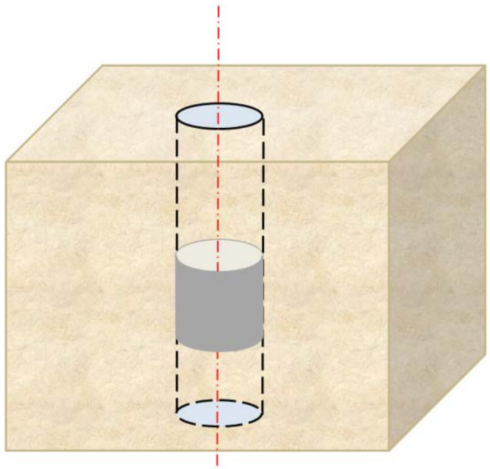
Provide radial or azimuthal information to differentiate among channels, contaminated cement, microannuli and tool eccentricity.

Weakness:

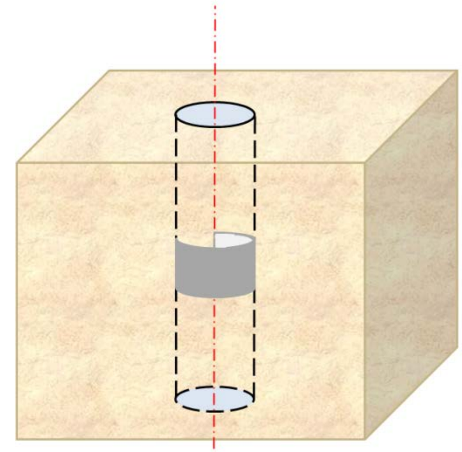
- Ultrasonic imaging tools that are based on the pulse-echo techniques are limited when logging in highly attenuative muds because of low signal-to-noise ratios

- The pulse-echo technique has difficulty differentiating between a drilling fluid and a lightweight or mud-contaminated cement of similar acoustic impedance.

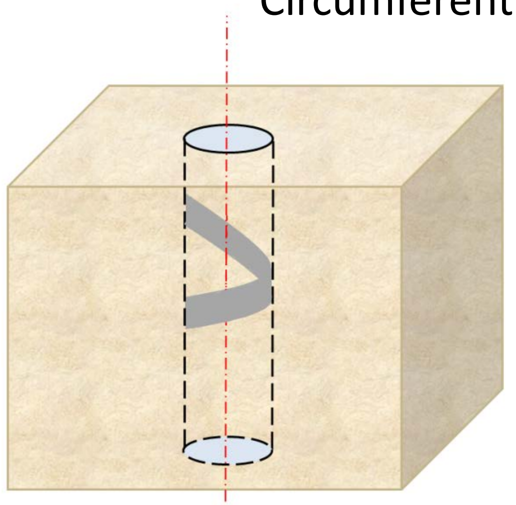
Modes of Failure



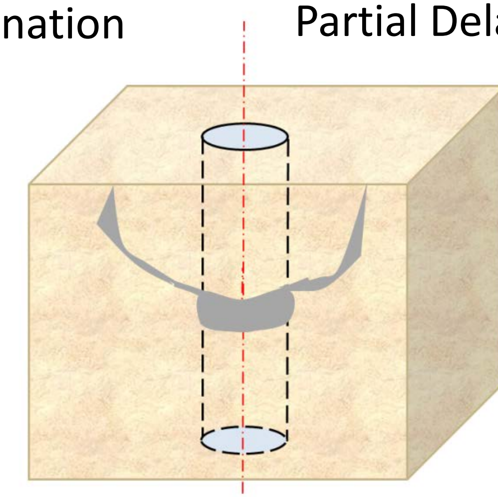
Circumferential Delamination



Partial Delamination



Spiral Delamination



Bowl-shaped failure


SOLUTIONS

Modeling Cement Failure

Multi-physics Governing Equations

- **Darcy's Law**

$$v_i = -\frac{k_{ij}}{\mu} \nabla p_j$$

- **Force Equilibrium Equation**

$$S_{ij,j} = 0$$

- **Mass Conservation Equation**

$$\frac{\partial \varsigma}{\partial t} + q_{i,j} = 0$$

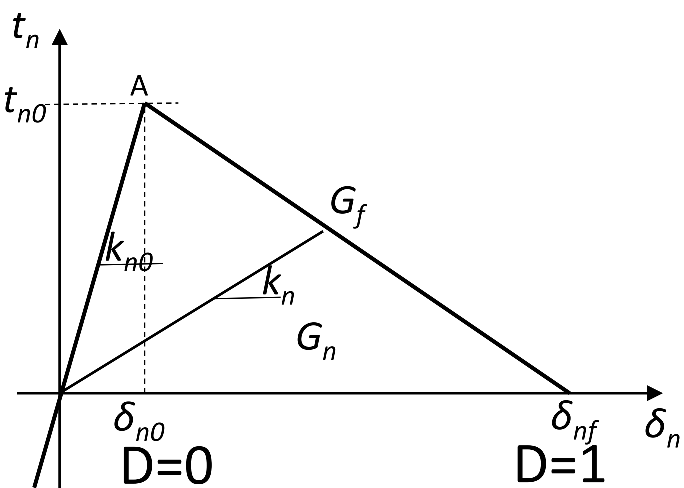
- **Constitutive Relations**

$$\begin{cases} 2Ge_{ij} = \sigma_{ij} - v\sigma_{kk}\delta_{ij} + \alpha(1-2v)\delta_{ij}P + \beta\delta_{ij}T \\ 2G\varsigma = \alpha(1-2v)\sigma_{kk} + \dfrac{\alpha^2(1-2v)^2}{v_u - v} p - 2G\beta_f T \end{cases}$$

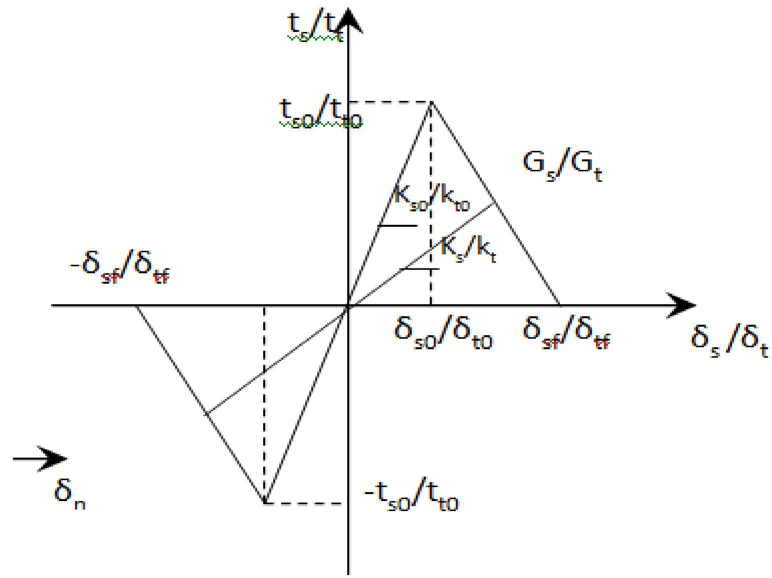
- **Energy Conservation Equation**

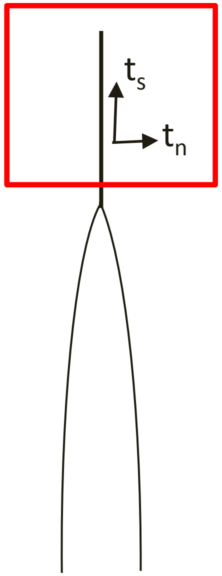
$$\rho C_v \frac{\partial T}{\partial t} = -(\rho_f C_v q) \cdot \nabla T + \nabla \cdot (-\lambda \nabla T)$$

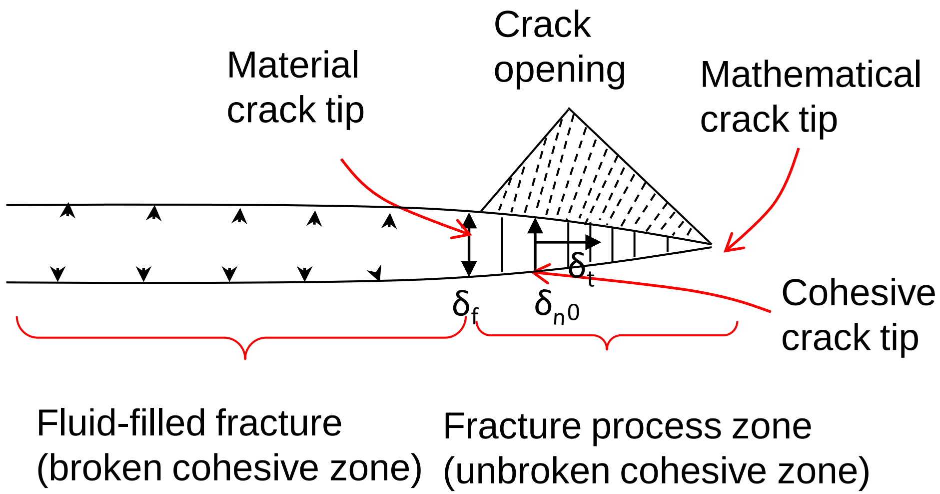
Theory of Methodology



(a) t_n-δ_n curve in normal direction







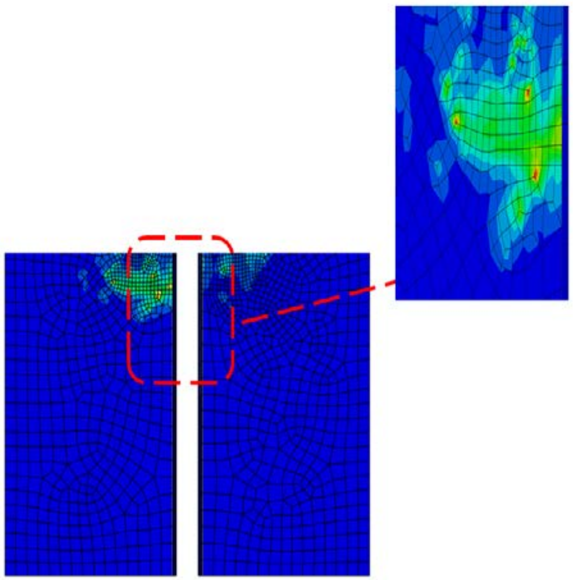
- A scalar damage degree variable, *D*

$$D = \frac{\delta_{mf}\left(\delta_{m,\max} - \delta_{m0}\right)}{\delta_{m,\max}\left(\delta_{mf} - \delta_{m0}\right)}$$

$$\delta_m = \sqrt{\langle \delta_n \rangle^2 + \delta_s^{\,2}}$$

Numerical Modeling

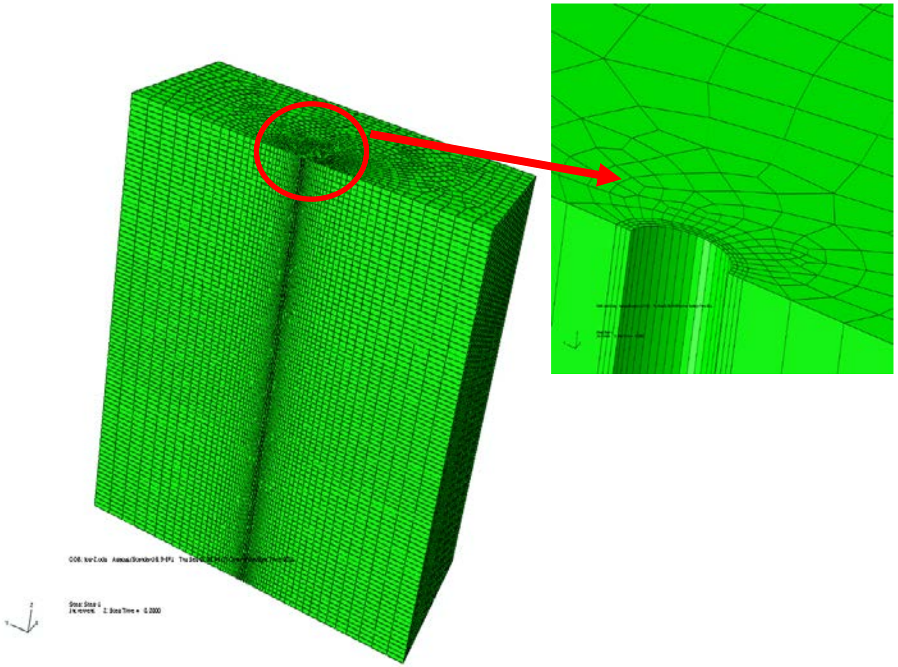
- Analytical solution are limited to simple geometries and simple rock behavior
    - Benchmark for numerical models
- Numerical Modeling
    - Two dimensional
        - Limited
        - Bowl shape
        - Circumferential
    - Three dimensional



A poroelastic model for liquefaction at the seafloor. This problem has some three-dimensional characteristics.

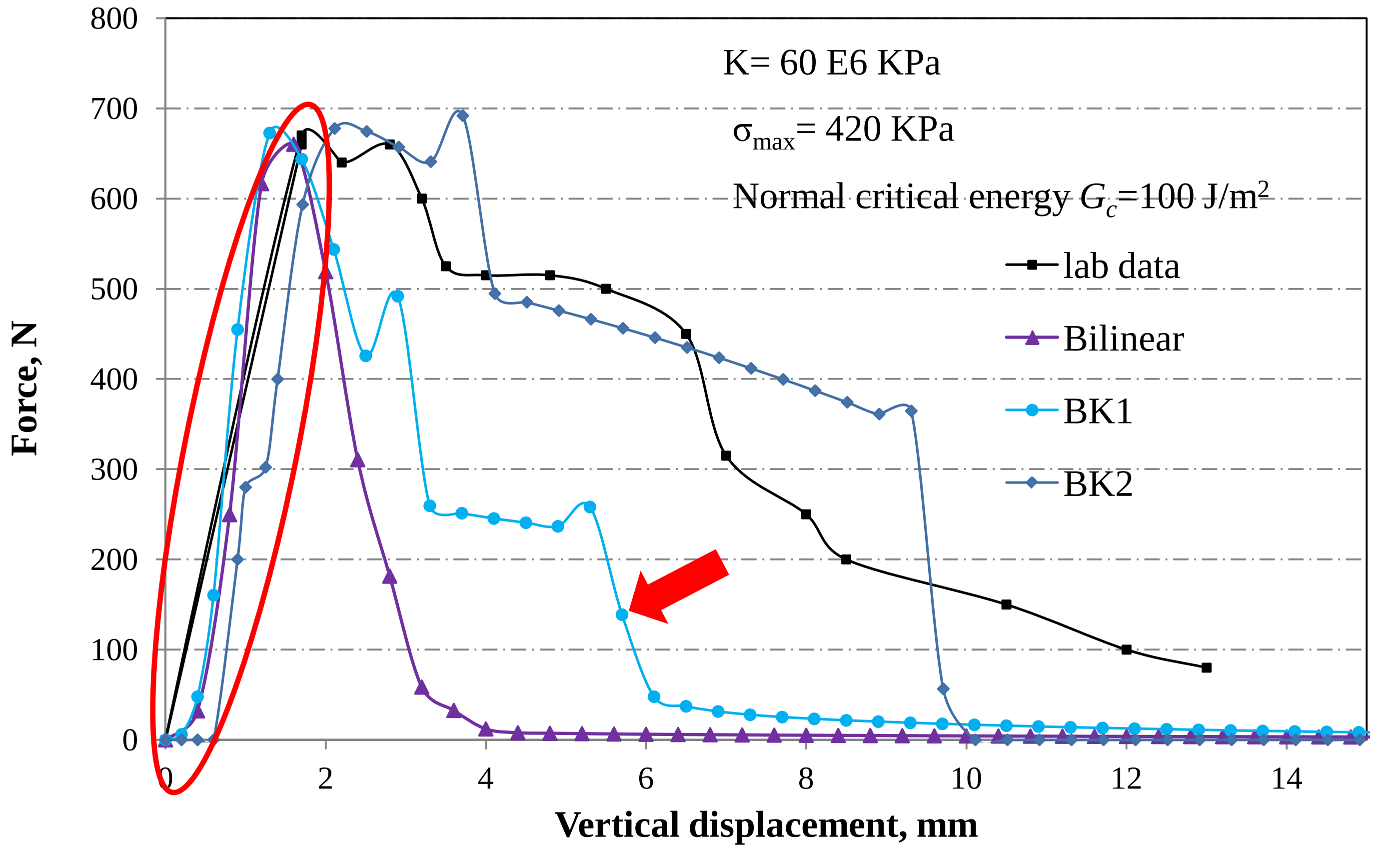
Numerical Modeling

- 3D still has geometric limitation for failure path
  - Level Set
    - Sand production
  - Partition of unity methods
- Model delamination
  - Cohesive zone
  - Pore pressure is incorporated in Cz



Measuring Cement Interface Properties

- Using classical loading test with more sophisticated constitutive equation for cement interface leads to determination of cohesive parameters.



Concluding Remarks

- Current approach for modeling cement behavior is very simplistic to catch many effects leads to failure.
- There is a need to define more realistic criteria to assess and design well cements.
- New research project should be defined aiming at a better understanding the risk of underground venting.
- Results and approach can also be directly applied to other environmental issues like well leakage problems in abandoned well or CO_2 sequestration.

Thanks!