Plastic Deformation and Resulting Enhancement in Caprock Failure Limit

Yidi Wu[1], Amin Mehrabian[1], Sheng-Li Chen[2], Younane Abousleiman[3]

1. The Pennsylvania State University, 2. Louisiana State University, 3. University of Oklahoma

1. INTRODUCTION

CO2 Geological Storage Projects

Caprock integrity concerns arise when injecting fluid into a reservoir, e.g., during CO2 geo-sequestration or withdrawing fluid from the same, e.g., during oil and gas production.

Most of major Carbon Capture and Storage (CCS) projects are terminated cause of concerns of leakage problem caused by compromised caprock integrity, e.g., In Salah CCS project. (Wang, 2021)

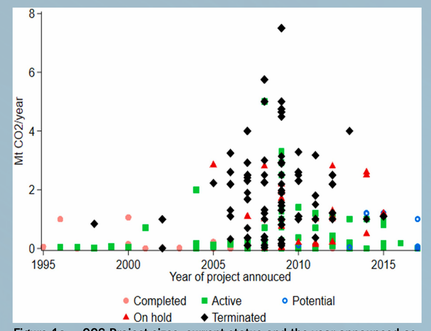

Figure 1a — CCS Project sizes, current status and the year announced as of 2021 (Wang, 2021).

Leakage Mechanisms

- ❑ *Intact Rock Failure:*
  - Shear failure
  - Tensile failure
- ❑ *Fault Reactivation:*
  - Fault reactivation
  - Reactivation of the pre-existing cracks
- ❑ *Operation Flaws:*
  - Leakage via the injection well
- ❑ *Reservoir Flow Related:*
  - Capillary seal pressure exceeded

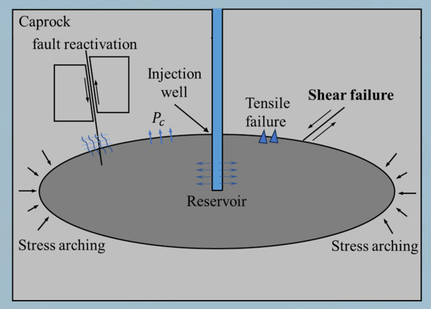

Figure 1b — Schematic of CO2 injection and its induced leakage problems.

Plasticity vs Elasticity

In unconfined uniaxial compression test, elastic response is observed all the way up until elastic yield, where current integrity analysis conclude complete failure.

However, experimental results have shown that plastic deformation beyond elastic yield will occur before complete failure. That final failure is usually characterized by a presumed total plastic strain allowance as shown here.

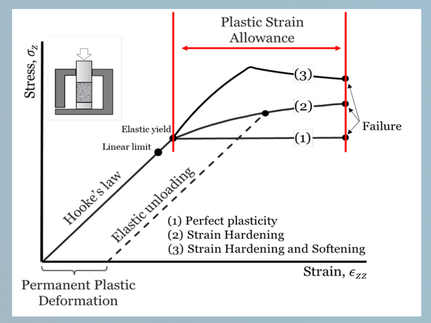

Figure 1c — Stress-strain plot from

2. OBJECTIVE

- ❑ To assess the enhancement in caprock integrity by considering a plastic strain allowance.
- ❑ To obtain the extent by which caprock plastic deformation allows for and enables more CO2 injection in the reservoir without causing caprock shear failure.

3. METHODS

Reservoir and Caprock Model

The injection of CO2 is causing reservoir to grow, which leads to the expansion of the interface between reservoir and caprock. As the interface expands, caprock initially undergoes elastic deformation, but after enough volume of injection, plastic deformation is expected to occur.

- ❑ Spherically symmetric model
- ❑ CO2 injection into embedded poroelastic reservoir
- ❑ *Drained* or *Undrained* elastoplastic caprock

Boundary Conditions:

- ❑ Far-field:
  - ❑ Isotropic stress state (σ_0)
- ❑ Center point:
  - ❑ CO2 injection (q_f)
- ❑ Interface between reservoir and caprock
  - ❑ Continuity of radial stress
  - ❑ Continuity of radial displacement
  - ❑ No-flow interface

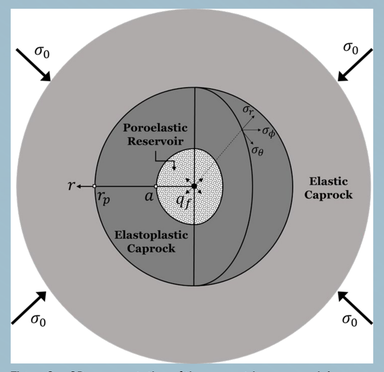

Figure 3 — 3D representation of the symmetric proxy model.

4. RESULTS

The mean-deviatoric effective stress paths are illustrated for a material point at the reservoir-caprock interface with different values of plastic strain-hardening parameter, m, representing different rock types and with caprock under drained or undrained conditions.

The stress paths are color-coded based on the pore volume injected (PVI) of CO2 and a failure criterion in terms of the maximum allowable total strain (ϵ) as represented by dashed lines from 1% to 5% with 0.5% increments.

Findings indicate that a 2% plastic strain allowance in the undrained caprock total elastoplastic strain results in more than twofold increase in the embedded reservoir injectivity compared to it at the elastic yield limit of the caprock.

- ❑ Mean effective normal stress: $P' = (\sigma'_r + \sigma'_\theta + \sigma'_\varphi)/3$
- ❑ Deviatoric stress: $q = \sqrt{2}/2\left[(\sigma'_r - \sigma'_\theta)^2 + (\sigma'_\theta - \sigma'_\varphi)^2 + (\sigma'_r - \sigma'_\varphi)^2\right]^{1/2}$

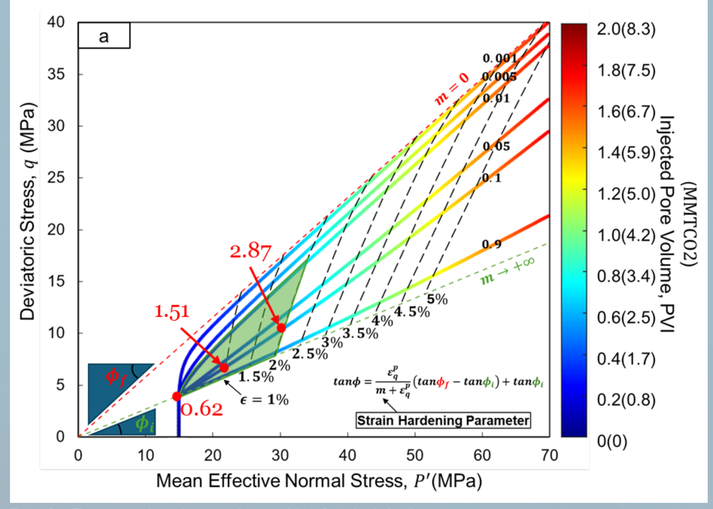

Figure 4a —The stress paths at the reservoir-caprock interface. (undrained)

4. RESULTS (cont.)

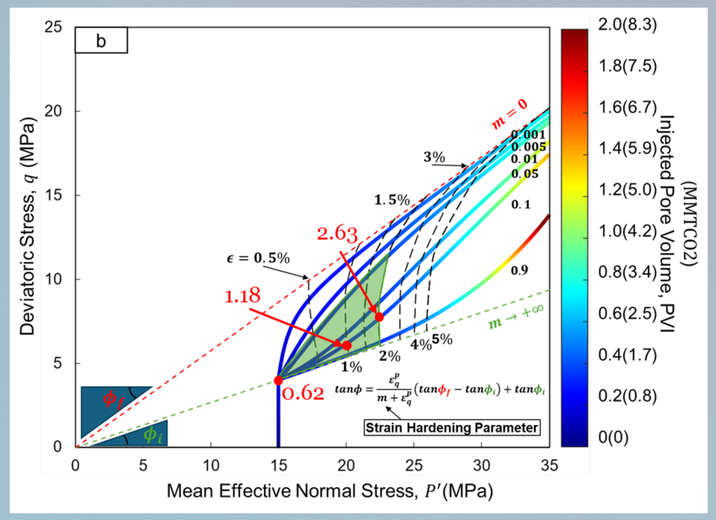

Figure 4b —The stress paths at the reservoir-caprock interface. (drained)

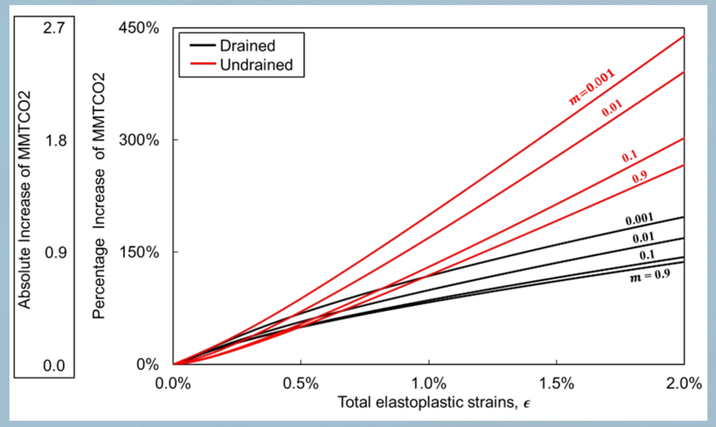

Fig. 4c— Percentage increase and absolute increase in million metric tons of injected supercritical CO2 (MMTCO2) compared to elastic limit vs allowable total elastoplastic strains for both drained and undrained cases.

5. REFERENCE

- ❑ Wu, Y., Mehrabian, A., Chen, S.L. and Abousleiman, Y., 2024. Plastic Deformation and Resulting Enhancement in Caprock Failure Limit. In *SPE Annual Technical Conference and Exhibition*, p.D031S046R001. SPE. https://doi.org/10.2118/220695-MS
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- ❑ Wang, N., 2021. What went wrong? Learning from three decades of carbon capture, utilization and sequestration (CCUS) pilot and demonstration projects. *Energy Policy*, *158*, p.112546. https://doi.org/10.1016/j.enpol.2021.112546

PennState College of Earth and Mineral Sciences | John and Willie Leone Family Department of Energy and Mineral Engineering