Nonlinear Acoustic Methods for the Detection and Monitoring of CO2/Brine Leakage Pathways in Wellbore Systems

Pierre-Yves Le Bas

Bill Carey, John Stormont,
Mahmoud Taha, Ed Matteo,
Harvey Goodman

Outline

- Benefits to the program
- Overview
- Nonlinear acoustics – background
- Application to wellbore leakage pathway detection
- First samples and results
- Synergies
- Expected Outcomes
- Summary

Benefit to the Program

- Develop and validate technologies to ensure 99 percent storage permanence (goal 1) by Identifying and characterizing wellbore leakage path (area of interest 2)

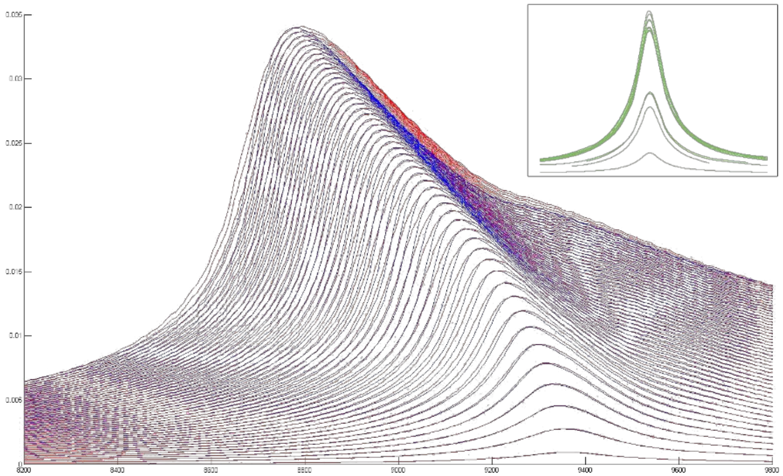
- This will lead to improved prediction, identification, and quantification of wellbore leakage risk.

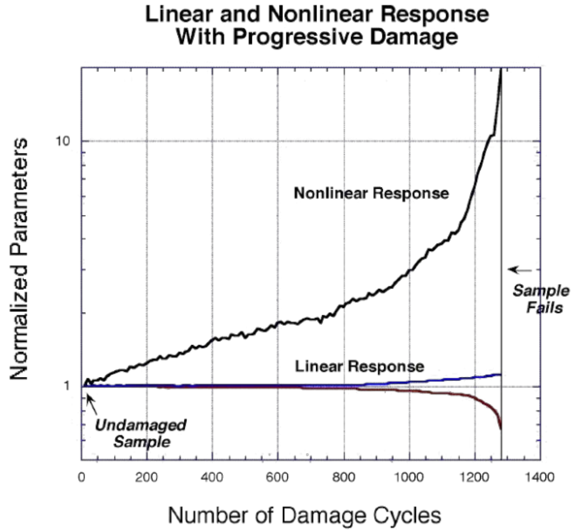
Project Overview: Goals and Objectives

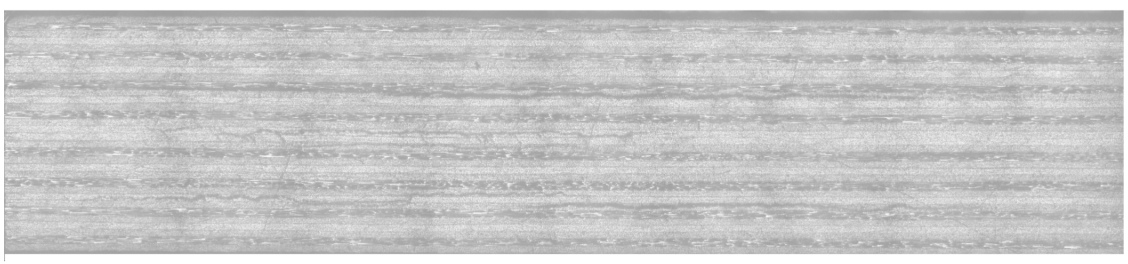
- **GOAL:** Improve detection of leakage path near well bore using a combination of nonlinear acoustics and time reversal

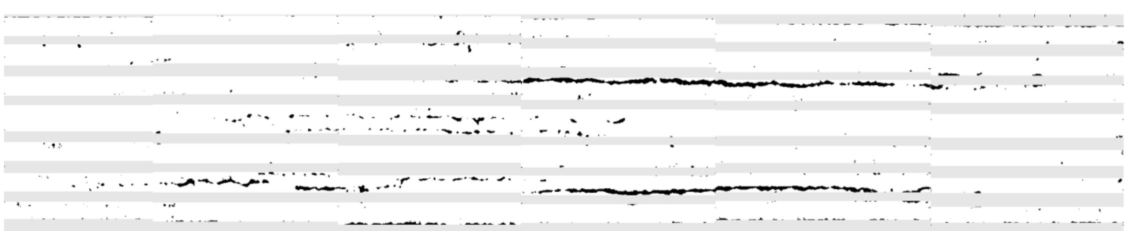
- **Objectives:**
  - development of a time-reversal acoustic probe,
  - testing on representative wellbore materials,
  - generating a variety of damaged wellbore materials and wellbore materials exposed to carbon dioxide (CO_2) for the experiments,
  - conducting *in situ* field measurements at the Mont Terri, Switzerland underground laboratory

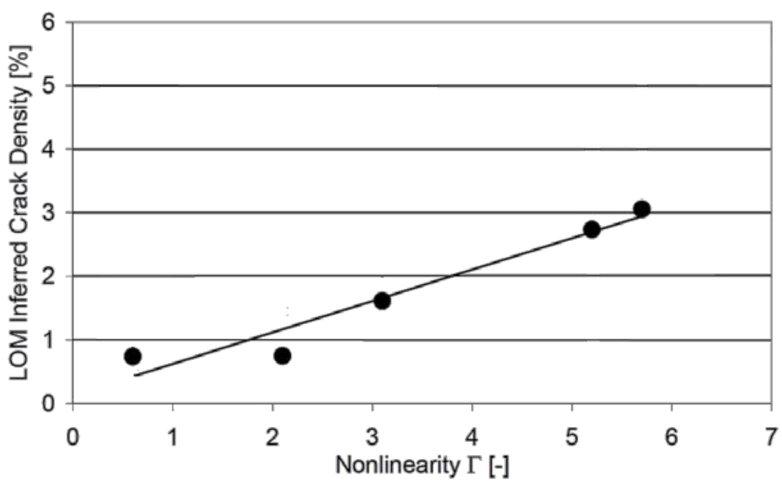
Methodology: Nonlinear Acoustics



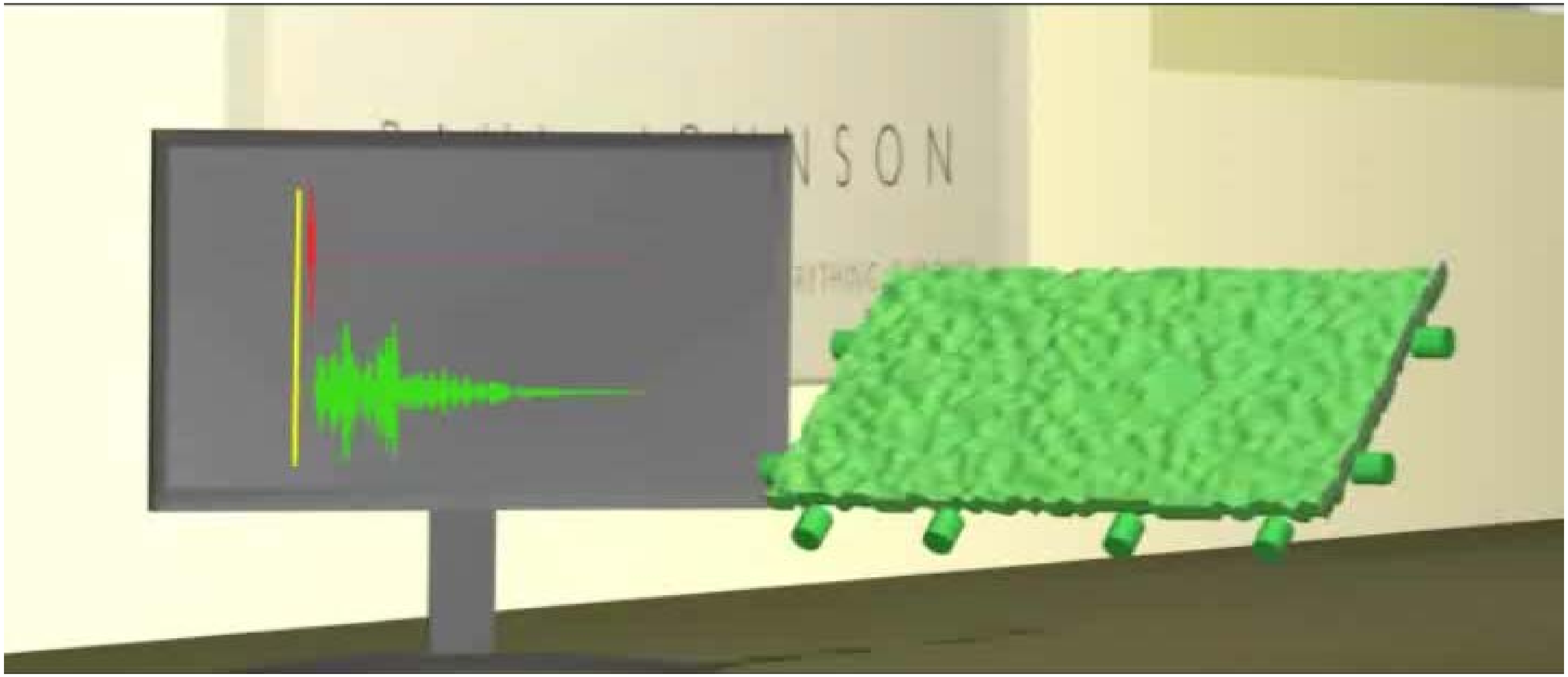




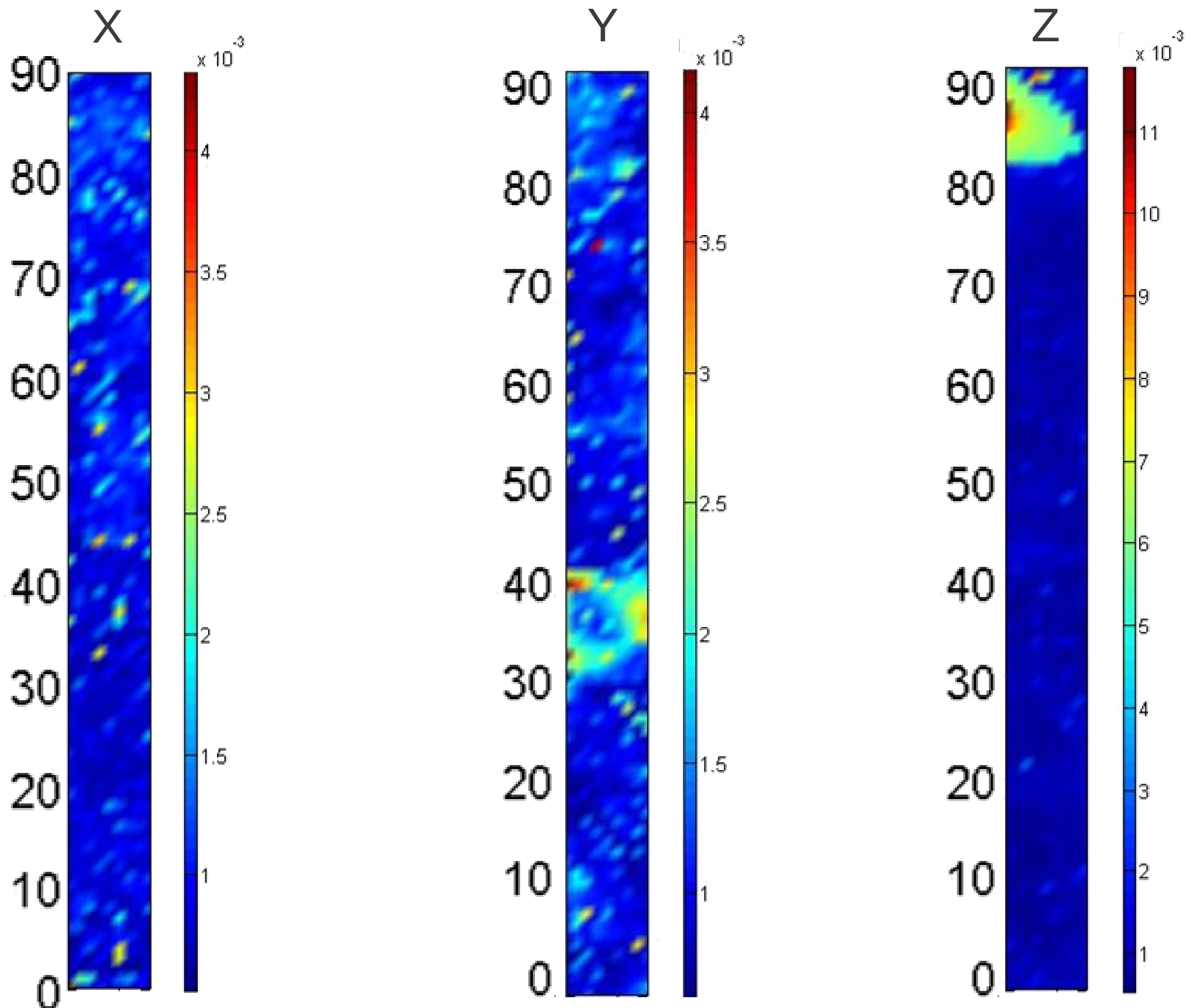


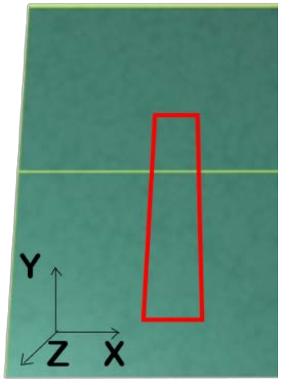


Methodology: Time Reversal

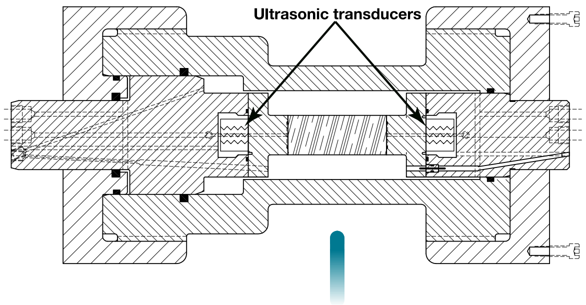


Methodology: Nonlinear Acoustics and Time Reversal



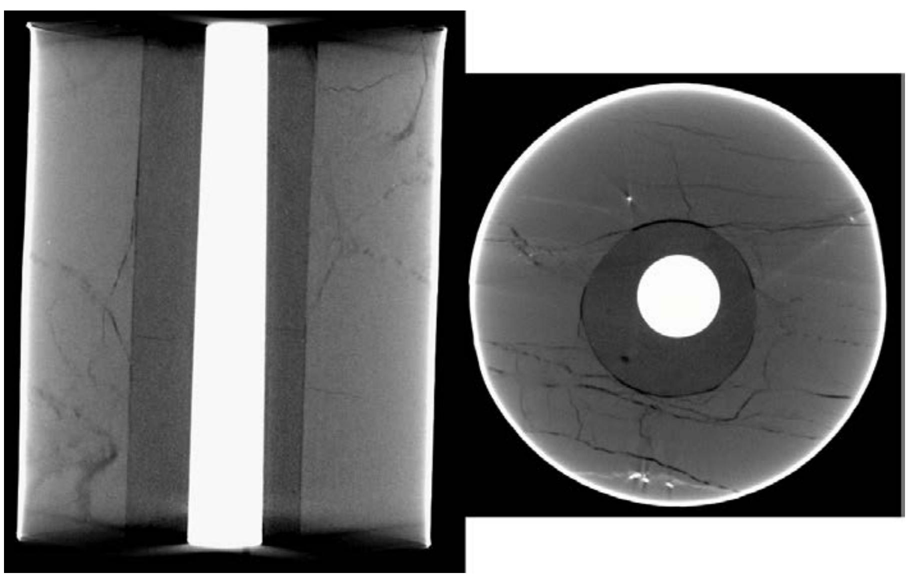


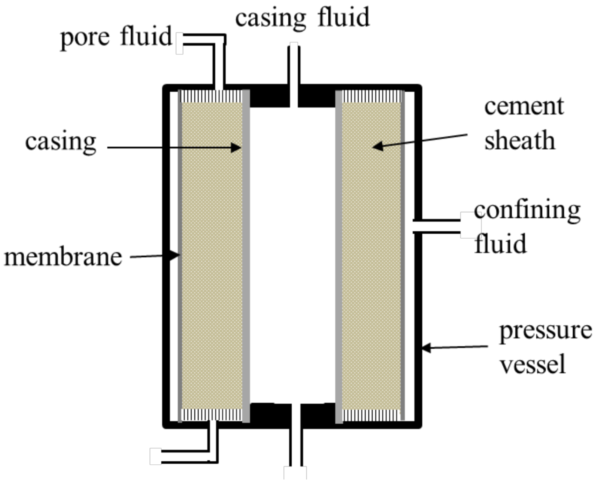
Methodology: Wellbore models



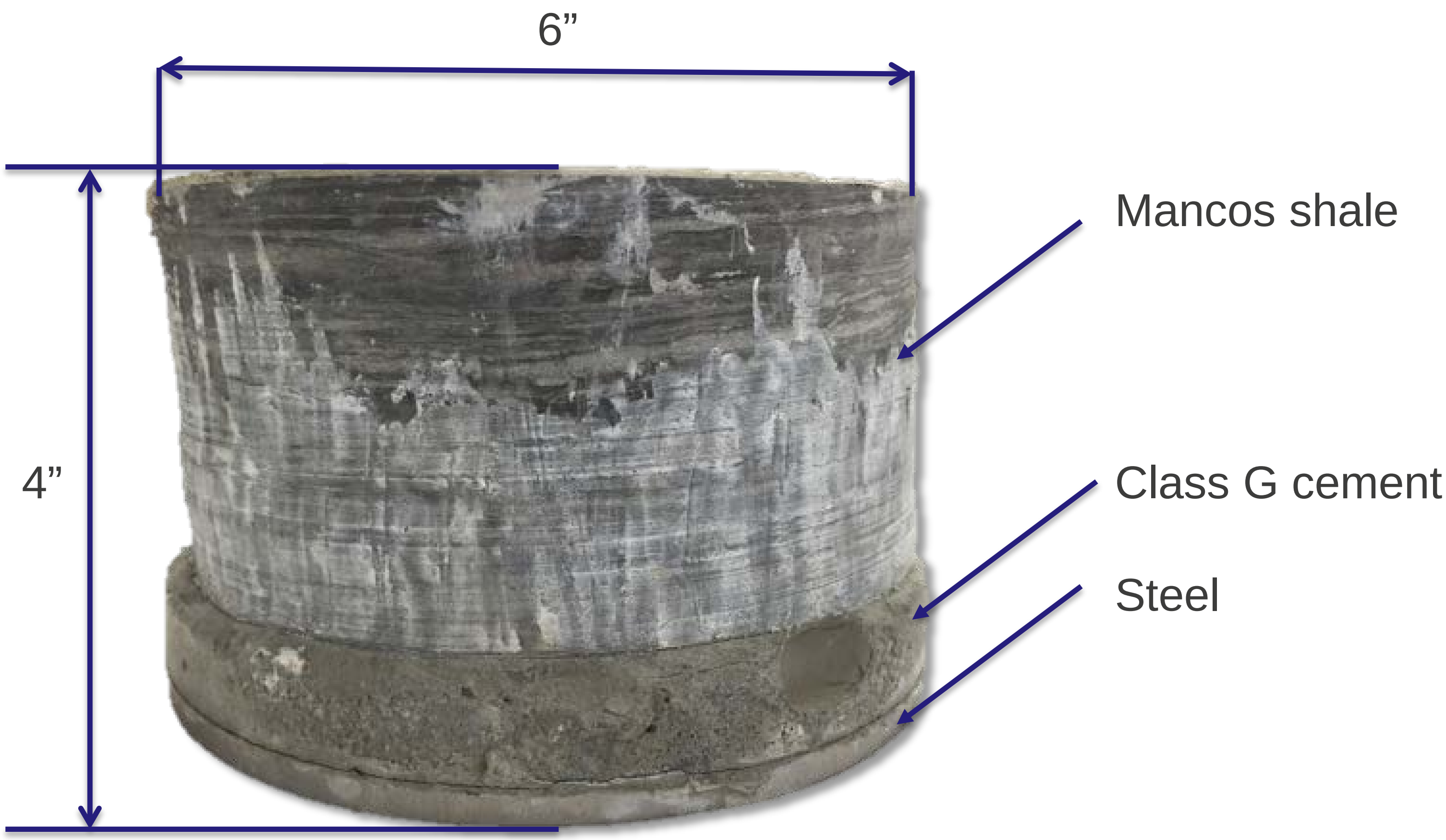
Fluids:
Supercritical CO_2
Brine
Oil
Simultaneous injection of two fluids

ples

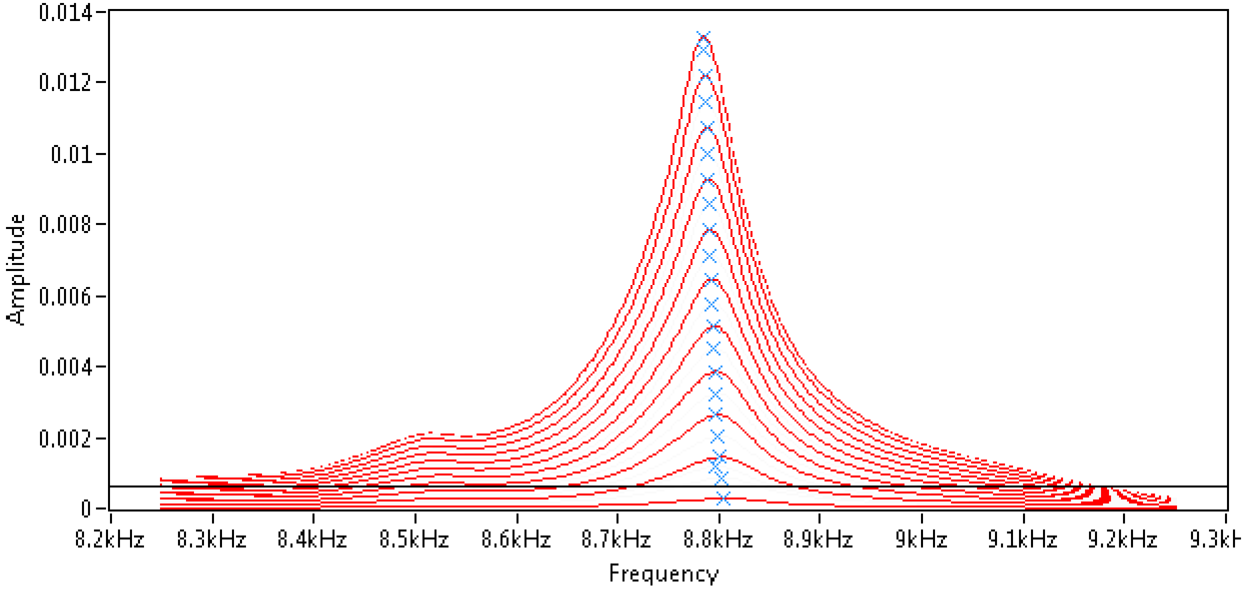




Samples

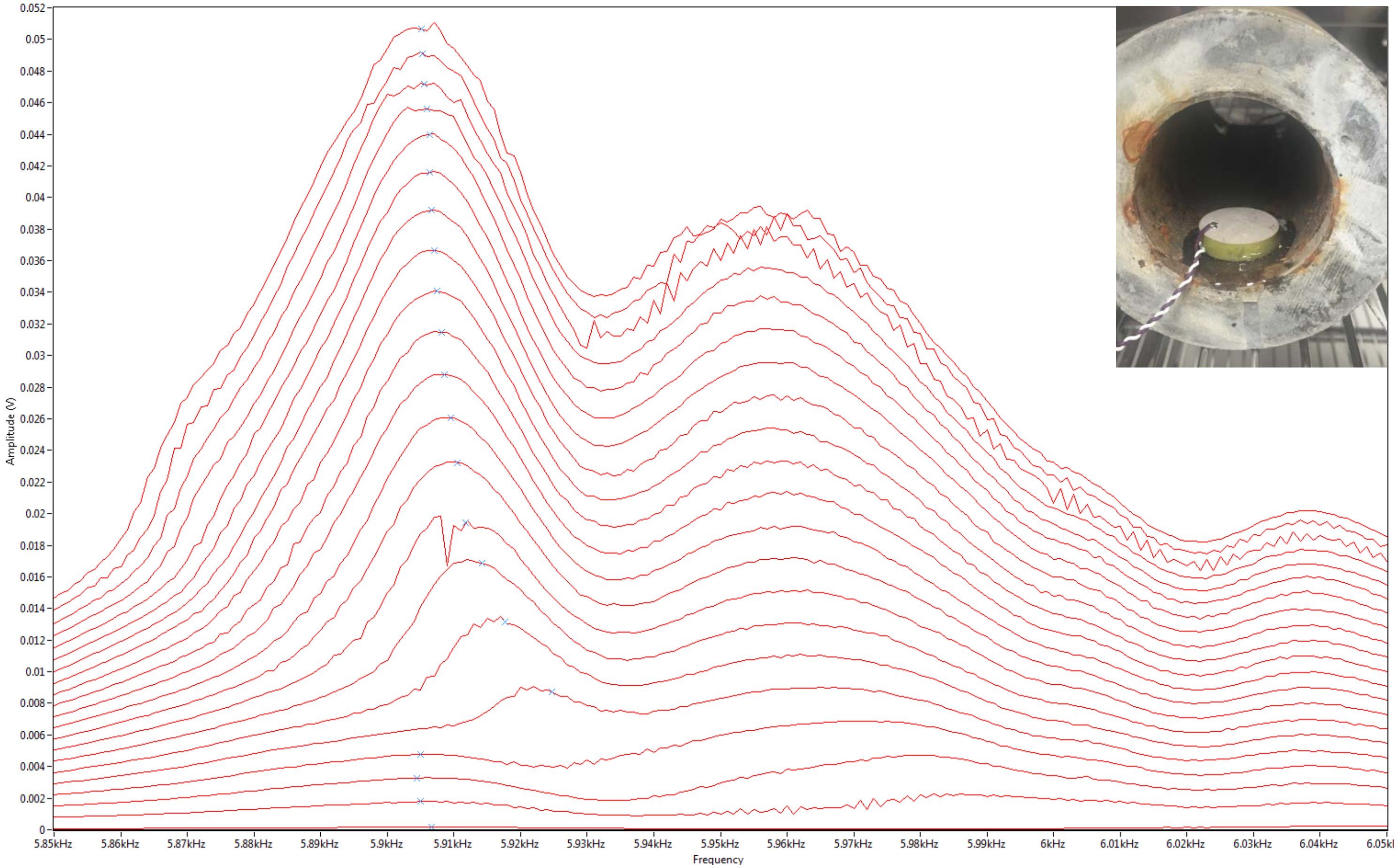


Baseline

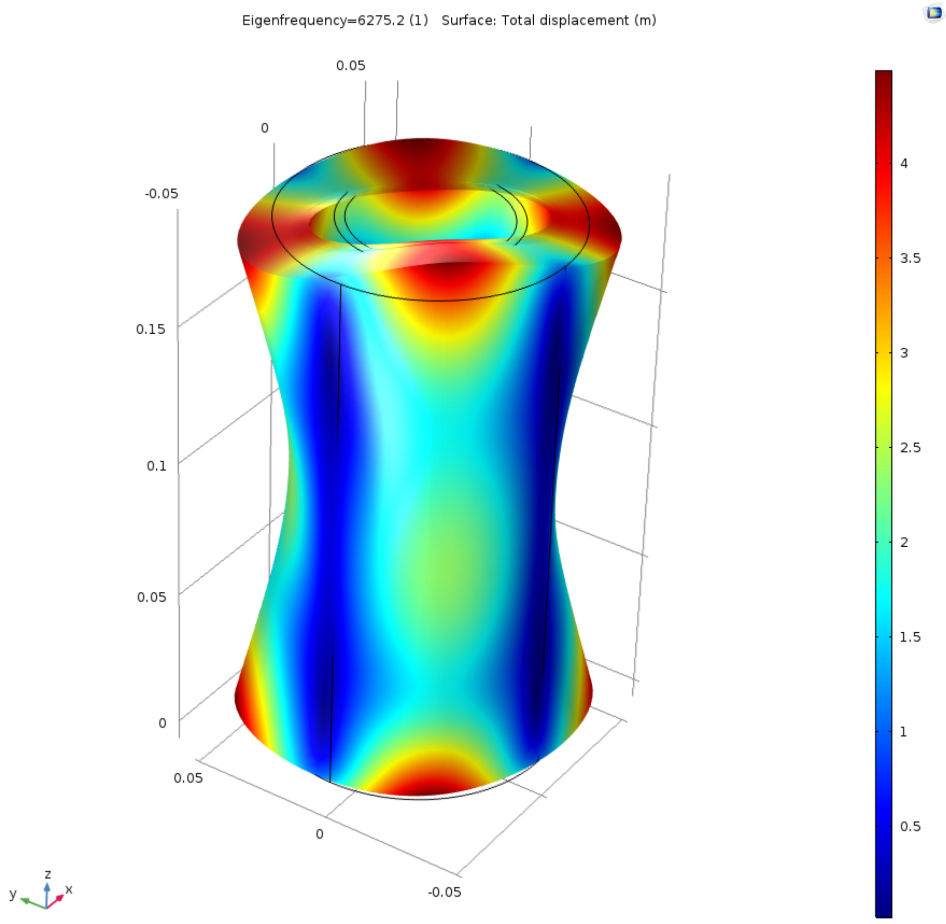

0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Amplitude
8.2kHz
8.3kHz
8.4kHz
8.5kHz
8.6kHz
8.7kHz
8.8kHz
8.9kHz
9kHz
9.1kHz
9.2kHz
Frequency

New samples

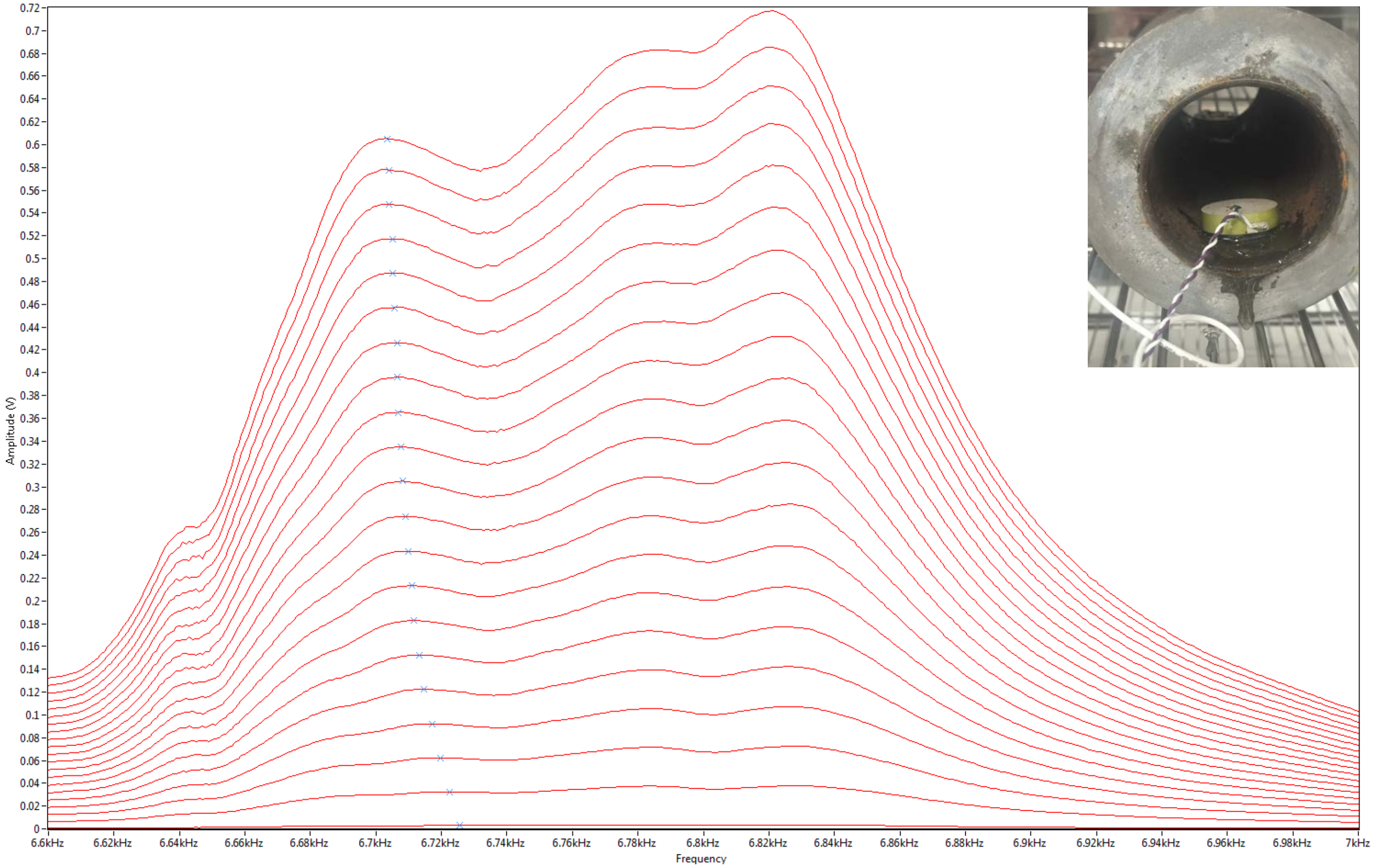
Intact sample



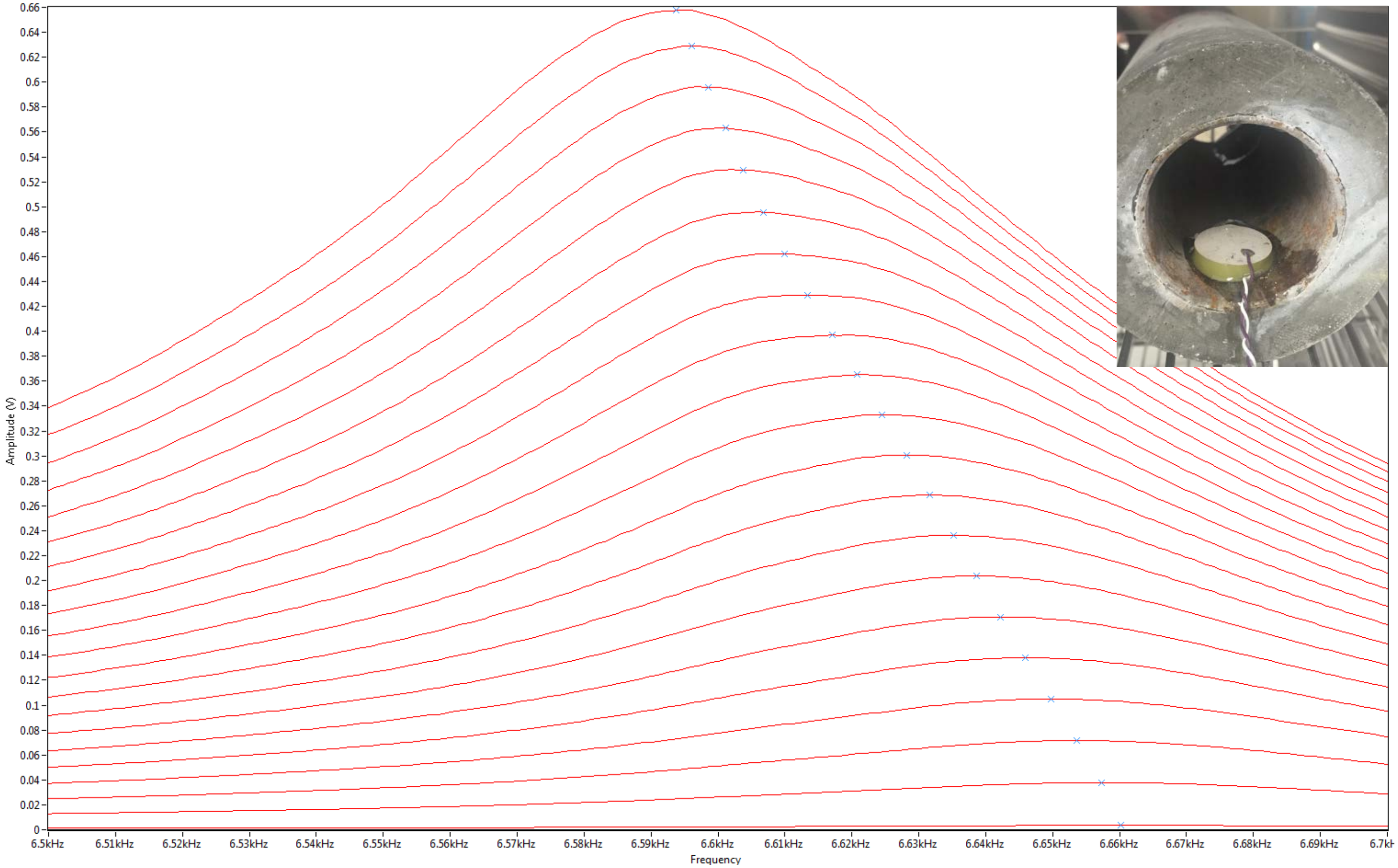
Mode shape


Eigenfrequency=6275.2 (1) Surface: Total displacement (m)
0.05
0
-0.05
0.15
0.1
0.05
0
0.05
0
-0.05
4
3.5
3
2.5
2
1.5
1
0.5
z
y
x

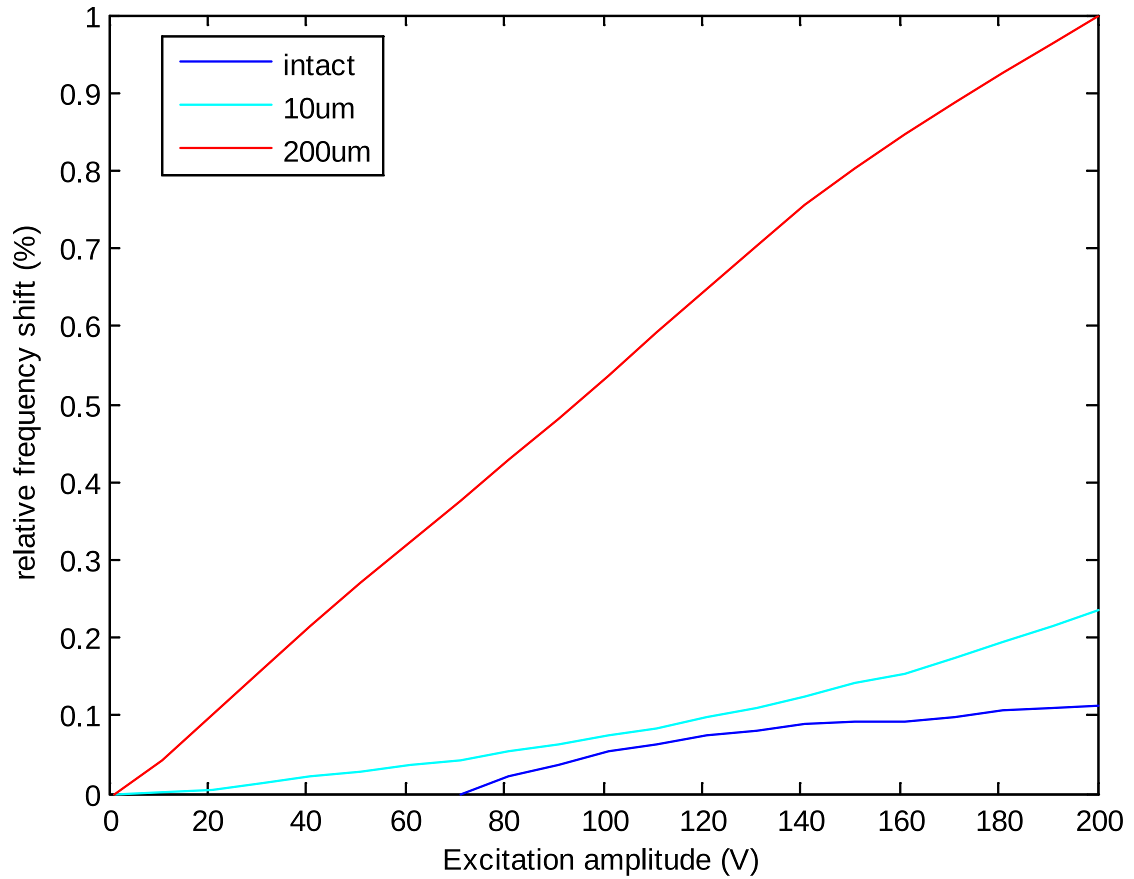
Thermally induced micro-annulus (~15μm)



Release film induced micro-annulus (~200μm)



Comparison

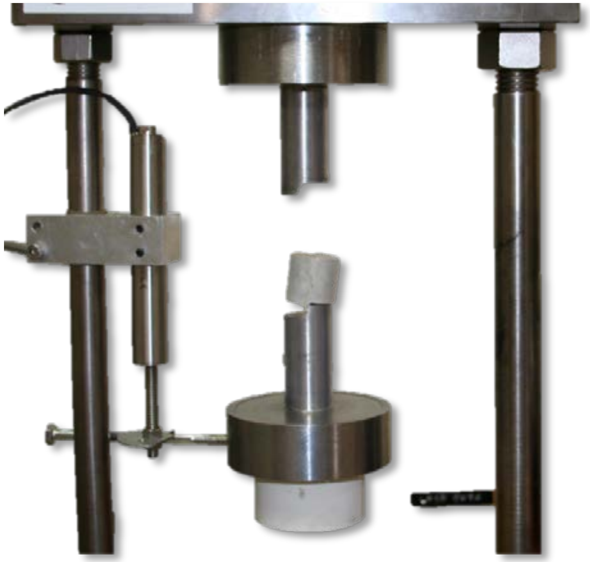


Sample	Slope
Intact	$8\ 10^{-4}$
10 um	$1\ 10^{-3}$
200um	$5\ 10^{-3}$

Experimental Measurement of Interface Strength and Permeability

Direct-Shear Apparatus

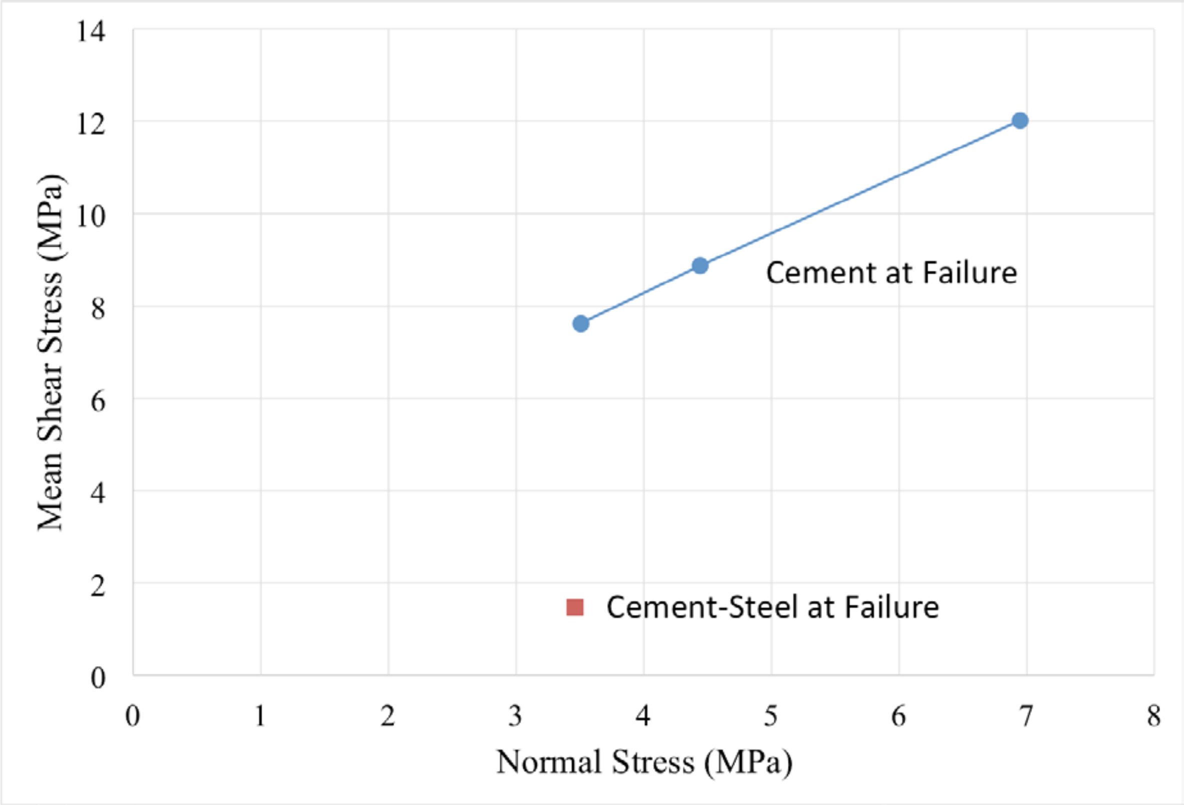
Illustrating LVDT, split pistons, and cement specimen



Cement-Steel Specimen

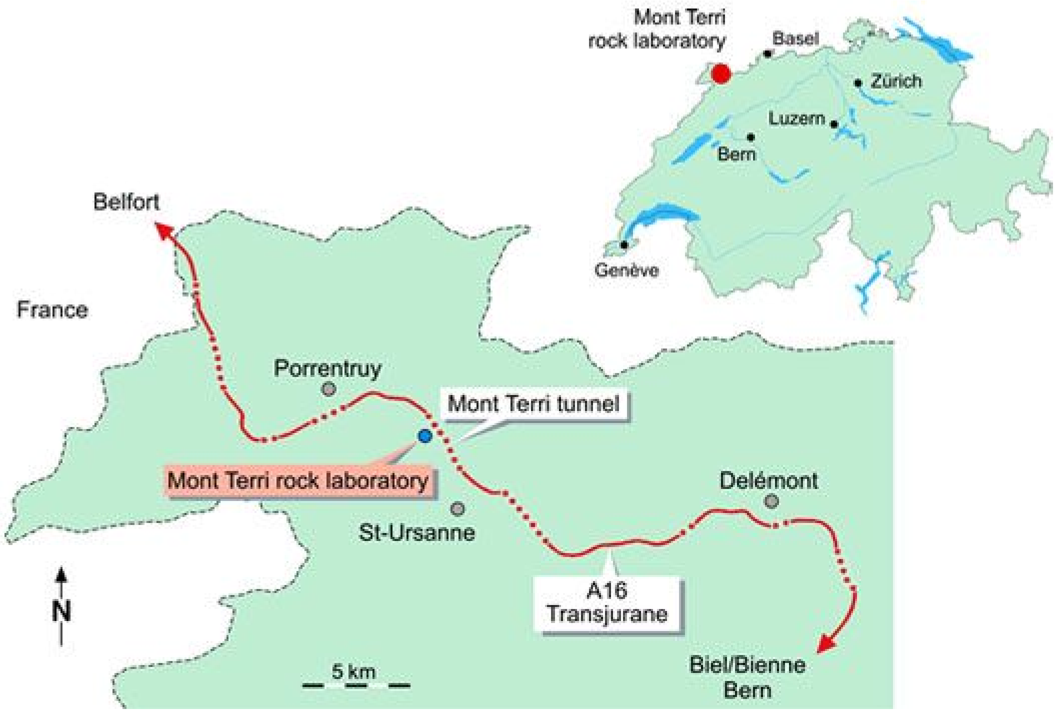
Hoek Cell for Confining Pressure

Strength Data for Cement and Cement-Steel Specimens

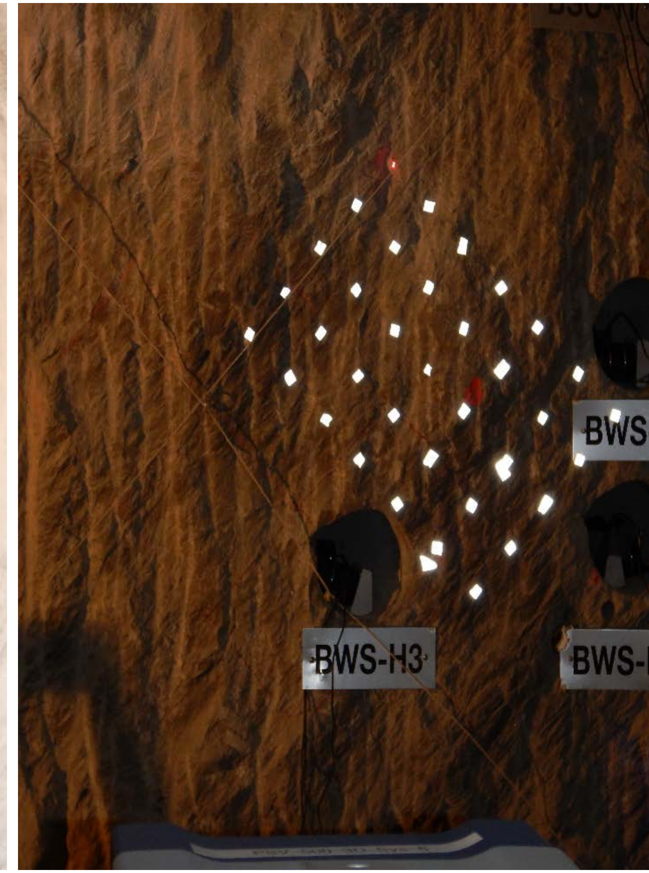


Synergy: Mont Terri

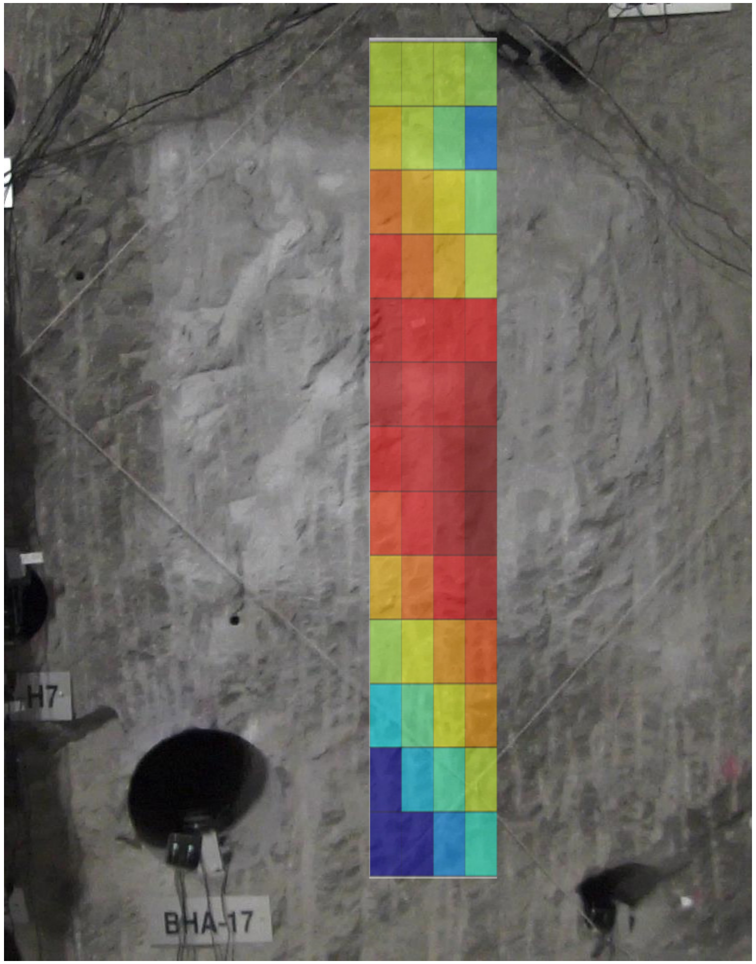
Another project involving Chevron shows potential for additional in-situ measurements

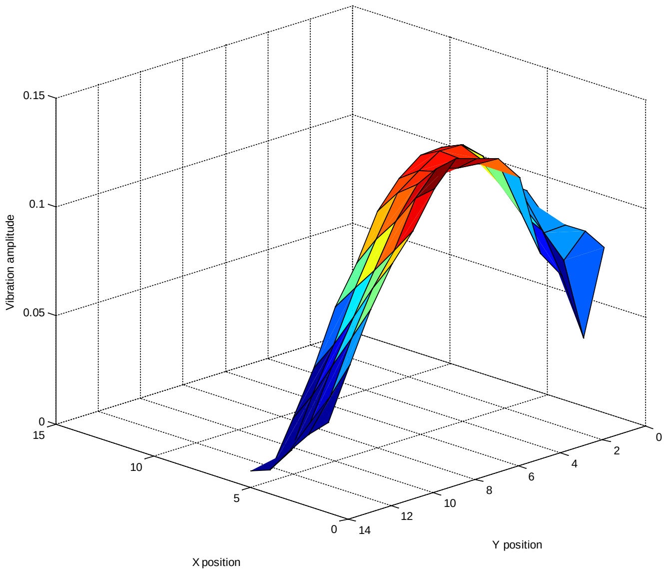


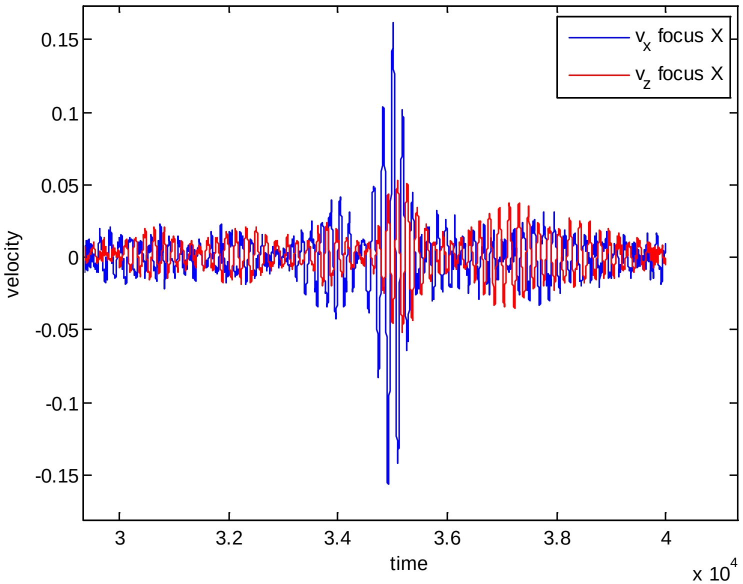
Setup



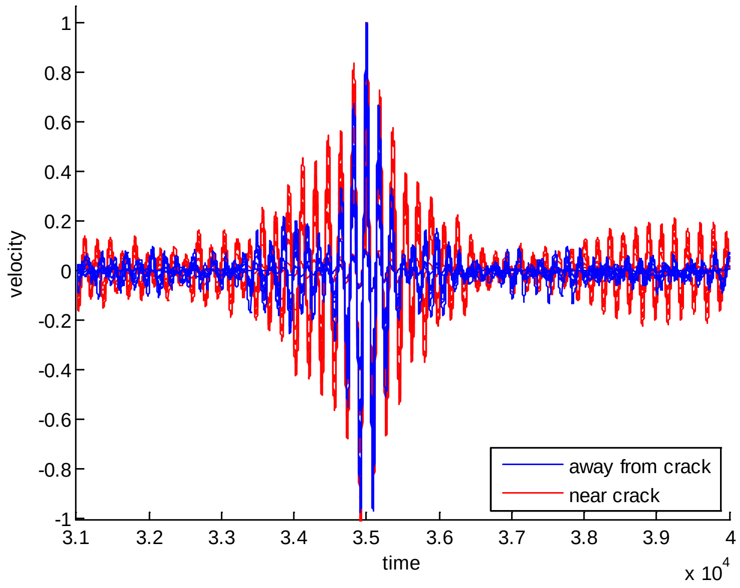
Results: Focus

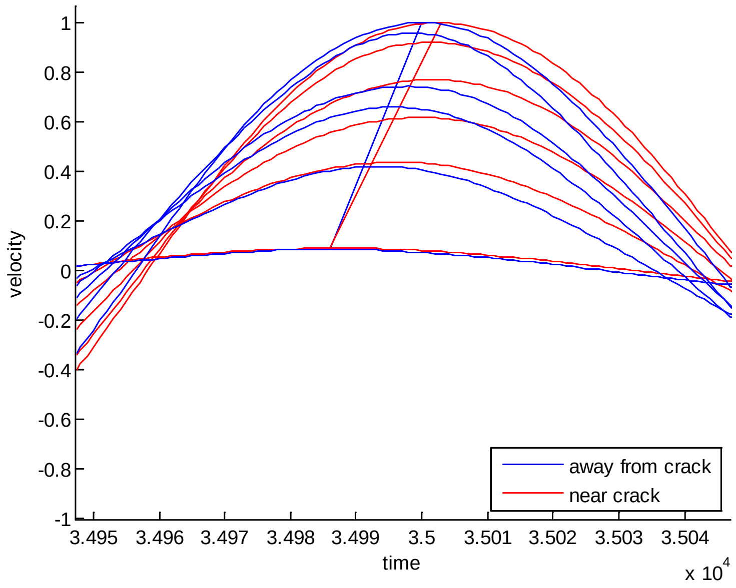






Results: Nonlinear Signature





Expected Outcomes

- A novel, field tested, method to detect and characterize cracks and leakage pathways near wellbore
- The technology developed within this will allow a better characterization of leakage path near wellbore, leading to a better monitoring and first assessment of potential leaks at CO_2 storage facilities

Summary

Project lead by LANL in collaboration with UNM and SNL. Chevron is cost share

Goal is to

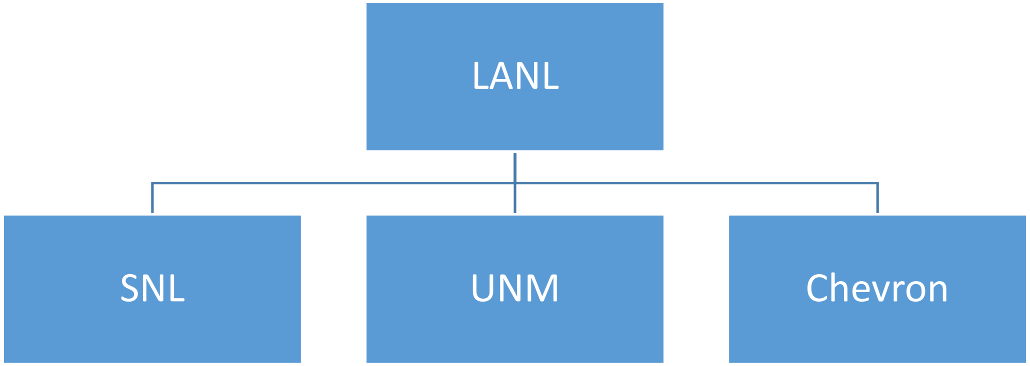
- Use of nonlinear acoustics to quantify cracks
- Use of time reversal with nonlinear acoustics to estimate the orientation of cracks
- Experiments first on well characterized intact samples that will then be damaged under controlled conditions
- Field experiments to validate the whole method

Currently,

- Samples have been created
- Baseline, nonlinear measurements have been done
- Nonlinear measurements on damage samples show the validity of nonlinear parameter to identify cracks

Organization Chart/ Communication Plan

- **Communication plan:**
  - Monthly progress meeting with all participants



Task/Subtask Breakdown

- **Task 1.0 – Project Management, Planning, and Reporting**
  - 1.1 PMP updates
  - 1.2 Meetings
  - 1.3 Reporting
  - 1.4 Project Management

- **Task 2.0 - Design Laboratory Wellbore Materials, Assemble, and Characterize Baseline Properties**
  - 2.1 Design Laboratory Wellbore Materials and Assemble

    Creation of rock samples with a metallic tube cemented inside to simulate wellbore
  - 2.2 Characterize Baseline Properties of Laboratory Wellbore Materials

    Characterization of the sample after creation, before damage:

    - X-Ray CT

    - Permeability

    - Linear and Nonlinear acoustics parameters

Task/Subtask Breakdown

- **Task 3.0 – Generate Thermal- and Mechanical-induced Damage to Wellbore Materials and Characterize**
  - Damage samples in a triaxial coreflood system to generate cracks in various directions
  - Characterize damage via X-Ray CT
- **Task 4.0 - Assemble Acoustic Probe and Perform Time-Reversal Characterization of the Nonlinear Behavior of Damaged Wellbore Materials at Laboratory Conditions**
  - 4.1 Assemble Acoustic Probe for Time-Reversal Measurements
  - 4.2 Perform assessment of the Nonlinear Behavior of Damaged Materials using Time Reversal techniques
    - Measure nonlinear parameters using time reversal on all damaged samples
- **Task 5.0 - Perform Time-Reversal Characterization of Wellbore Material Exposed to Carbon Dioxide to Measure Elastic Property Changes**

Task/Subtask Breakdown

- **Task 6.0 – Develop Analytical Framework for Three-dimensional (3D) Nonlinear Acoustic Behavior in Relationship to Known Fracture Distribution**

  Correlate measurement of task 4 with characterization of task 3 to infer crack density and orientation from acoustics measurements

- **Task 7.0 – Develop Pulse-echo Doppler Method to Acoustically Measure Flow Rates and Correlate with Direct Permeability Measurements in Wellbore Materials**

  Measure nonlinear parameters using time reversal on all damaged samples

- **Task 8.0 - Proof-of-Principle Time-Reversal Measurements at Laboratory Experimental Downhole Conditions and In situ at the Mont Terri, Switzerland Facility**
  - 8.1 lab experiments mimicking downhole conditions
  - 8.2 *in-situ* experiments
  - 8.3 Report on *in-situ* results

Deliverables / Milestones / Decision Points

completed

Budget Period	Task/ Subtask	Milestone ID/Description	Planned Completion	Verification Method[1,2]
1	1.0/1.1	A. Updated Project Management Plan	11/30/2015	Project Management Plan file
1	1.0	B. Kickoff Meeting	12/31/2015	Presentation file
1	**2.0/2.2**	**C. Quick-look report summarizing the results of the baseline characterization property measurements of the wellbore materials.**	**6/30/2016**	**Quick-look report**
1	3.0	D. Plan for the induced damage and characterization of the damaged wellbore material.	5/31/2016	Workplan
1	**3.0**	**E. Quick-look report summarizing the laboratory-induced damage experiments including the conditions of the damage events and characterization measurements of the damaged wellbore materials.**	**9/30/2016**	**Quick-look report**
2	**4.0/4.2**	**F. Plan for performing time-reversal measurements using the acoustic probe to characterize the damaged wellbore material.**	**12/31/2016**	**Workplan**
2	**4.0/4.2**	**G. Quick-look report summarizing the time-reversal acoustic probe measurements of the damaged wellbore materials.**	**5/31/2017**	**Quick-look report**
2	**5.0**	**H. Plan for performing time-reversal characterization of wellbore material exposed to carbon dioxide (CO_2) to measure elastic property changes.**	**1/31/2017**	**Workplan**
2	**5.0**	**I. Quick-look report summarizing the time-reversal acoustic probe measurements of the wellbore materials exposed to CO_2 in a controlled environment.**	**7/31/2017**	**Quick-look Report**
2	6.0	J. Plan for the experimental investigation of extracting wellbore material fracture density and orientation with the time-reversal acoustic probe method.	2/28/2017	Workplan

Deliverables / Milestones / Decision Points

Budget Period	Task/ Subtask	Milestone ID/Description	Planned Completion	Verification Method[1,2]
2	6.0	K. Quick-look report summarizing the experimental results of extracting wellbore material fracture density and orientation with the time-reversal acoustic probe method.	8/31/2017	Quick-look Report
3	7.0	L. Plan for the experimental investigation and development of a pulse-echo Doppler method to acoustically measure flow rates.	10/31/2017	Workplan
3	7.0	M. Quick-look report summarizing the experimental results of the pulse-echo Doppler method to acoustically measure flow rates in wellbore materials.	2/28/2018	Quick-look Report
3	8.0/8.1	N. Plan for performing the experiments and measurements in the laboratory at downhole conditions.	1/31/2018	Workplan
3	8.0/8.1	O. Quick-look report summarizing the results of the time-reversal measurements at laboratory experimental downhole conditions.	4/30/2018	Quick-look Report
3	8.0/8.2	P. Plan for performing the measurements *in situ* at the Mont Terri, Switzerland facility.	5/31/2018	Workplan
3	8.0/8.2	Q. Quick-look report summarizing the results of time-reversal measurements at experimental downhole conditions *in situ* at Mont Terri, Switzerland facility.	8/31/2018	Quick-look Report
3	8.0/8.3	R. Fact Sheet “Nonlinear Acoustic Probe for Wellbore Damage Detection” containing field operating conditions, performance, and cost for use.	9/30/2018	Fact Sheet

Risk Matrix

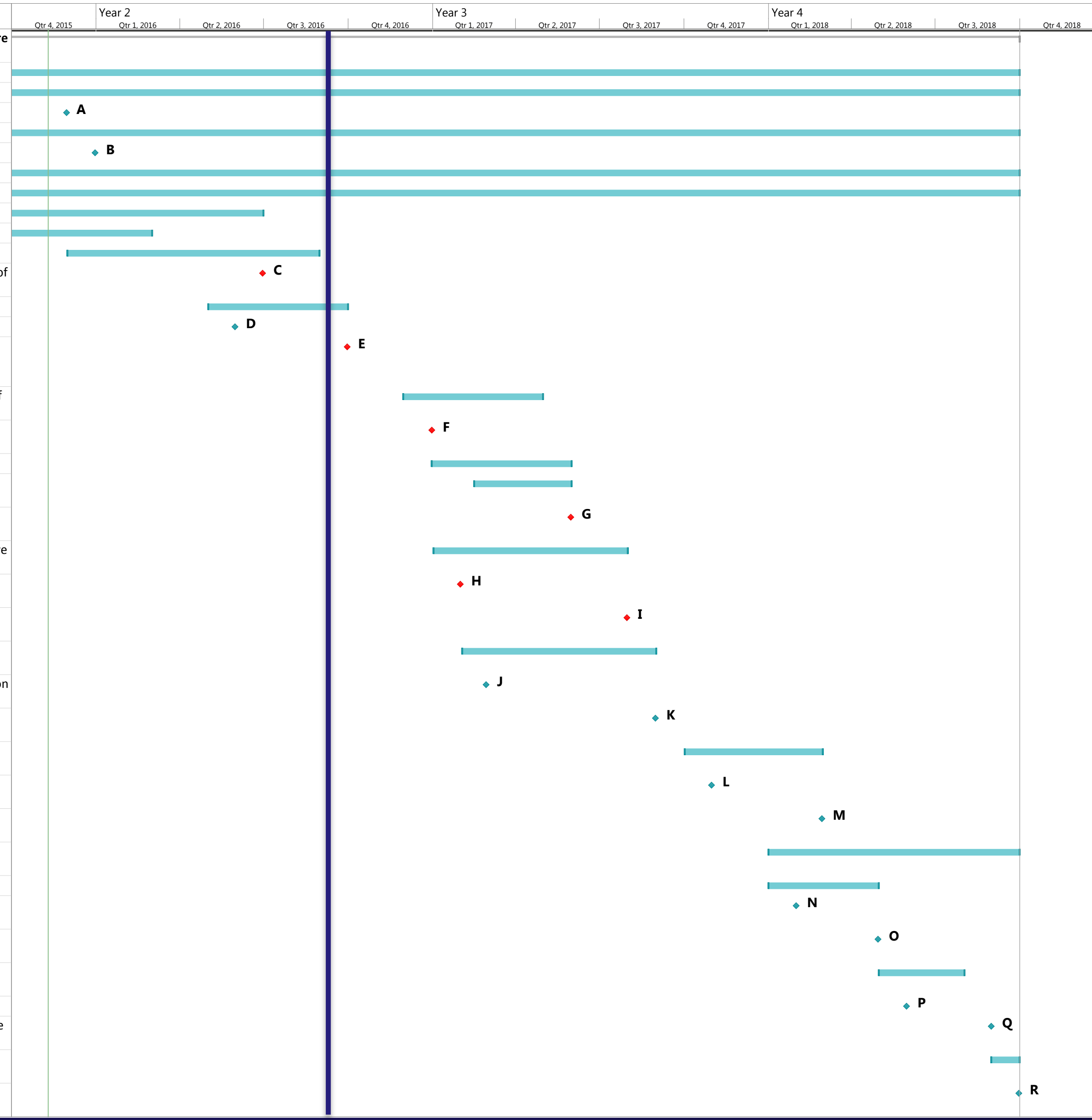
Description	Probability	Impact	Mitigation and Response Strategies
Technical Risks			
Flow rate might be too low for Doppler measurement	Moderate	Moderate	This will be tested early. If it happens to be true efforts will be redirected to the main objective, leakage pathways detection and characterization
Resource Risks			
1 Post-doc needs to be hired. A suitable candidate could take longer than anticipated to be found	Low	Moderate	Current staff will work on the project until an appropriate post-doc can be hired
Management Risks			
Contract with UNM will take longer than expected to be in place	Moderate	Low	UNM will leverage other projects to start

Proposed Schedule

ask Name

lonlinear Acoustics Methods for Detection and Monitoring of CO2/Brine Leakage Pathways in Wellbore ystems

1.0 Project Management Plan (PMP)
1.1 Project Management Plan (PMP)
A. Updated Project Management Plan
1.2 Meetings
B. Kickoff Meeting
1.3 Reportings
1.4 Project Management
2.0 Design Laboratory Wellbore Materials, Assemble, and Characterize Baseline Properties
2.1 Design Laboratory Wellbore Materials, Assemble
2.2 Characterize Baseline Properties of Laboratory Wellbore Materials
C. Quick-look report summarizing the results of the baseline characterization property measurements of the wellbore materials.
3.0 Generate Thermal- and Mechanical-induced Damage to Wellbore Materials and Characterize
D. Plan for the induced damage and characterization of the damaged wellbore material.
E. Quick-look report summarizing the laboratory-induced damage experiments including the conditions of the damage events and characterization measurements of the damaged wellbore materials.
4.0 Assemble Acoustics Probe and Perform Time-Reversal Characterization of the Nonlinear Behavior of Damaged Wellbore Materials at Laboratory Conditions
F. Plan for performing time-reversal measurements using the acoustic probe to characterize the damaged wellbore material.
4.1 Assemble Acoustics Probe for Time-Reversal Measurements
4.2 Perform Assessment of the Nonlinear Behavior of Damaged Materials using Time Reversal techniques
G. Quick-look report summarizing the time-reversal acoustic probe measurements of the damaged wellbore materials.
5.0 Perform Time-Reversal Caracterization of Wellbore Material Exposed to Carbone Dioxide to Measure Elastic Property Changes
H. Plan for performing time-reversal characterization of wellbore material exposed to carbon dioxide (CO2) to measure elastic property changes.
I. Quick-look report summarizing the time-reversal acoustic probe measurements of the wellbore materials exposed to CO2 in a controlled environment.
6.0 Develop Analytical Framework for Three-dimensional (3D) Nonlinear Acoustics Behavior in relationship to Known Fracture Distribution
J. Plan for the experimental investigation of extracting wellbore material fracture density and orientation with the time-reversal acoustic probe method.
K. Quick-look report summarizing the experimental results of extracting wellbore material fracture density and orientation with the time-reversal acoustic probe method.
7.0 Develop Pulse-Echo Doppler Method to Acoustically Measure Flow Rates and Correlate with Direct Permeability Measurements in Wellbore Materials
L. Plan for the experimental investigation and development of a pulse-echo Doppler method to acoustically measure flow rates.
M. Quick-look report summarizing the experimental results of the pulse-echo Doppler method to acoustically measure flow rates in wellbore materials.
8.0 Proof-of-Principle Time-Reversal Measurements at Laboratory Experimental Downhole Conditions and In Situ at the Mont Teri, Switzerland Facility
8.1 Time-Reversal Measurements at Laboratory Experimental Downhole Conditions
N. Plan for performing the experiments and measurements in the laboratory at downhole conditions.
O. Quick-look report summarizing the results of the time-reversal measurements at laboratory experimental downhole conditions.
8.2 Time-Reversal Measurements at Experimental Downhole Conditions In situ at Mont Terri, Switzerland Facility
P. Plan for performing the measurements in situ at the Mont Terri, Switzerland facility.
Q. Quick-look report summarizing the results of time-reversal measurements at experimental downhole conditions in situ at Mont Terri, Switzerland facility.
8.3 Summary of Field Operating Performance for Time-Reversal Acoustic Probe for Detection of Damaged Wellbore Materials
R. Fact Sheet “Nonlinear Acoustic Probe for Wellbore Damage Detection” containing field operating conditions, performance, and cost for use.



Appendix: Bibliography

N/A