The value of sensing for performance-based earthquake engineering assessment of natural gas pipelines and facility systems

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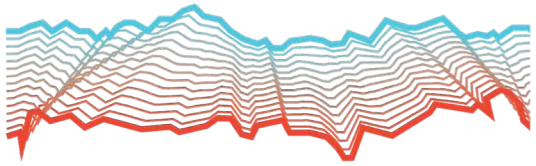

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Background

- Recent advances in sensor & communication technologies improve the monitoring methods for infrastructure assessment
- Advanced risk models are being developed
- However, Infrastructure owners slow at adopting these new technologies due to
  - *Up-front costs*
  - *Change to the original operations*
  - *Uncertainty of the parameters for simulation tools*

Purpose

- Selected emerging sensing & monitoring technologies review
  - *Continuous monitoring – distributed fiber optic sensor (DFOS) & wireless sensor network (WSN)*
  - *Remote sensing – LiDAR, InSAR & structure from motion (SfM)*
  - *Leakage detections – flow & gas sensing*
  - *In-line inspection (ILI) method – smart PIG*
- Reduce the uncertainty in the simulation tools
  - *Update the inputs and verify the intermediate and final outputs*
- Enhance confidence of using the selected technologies
  - *Demonstrations of using emerging sensing technologies*

Example Technology Evaluation and Testing

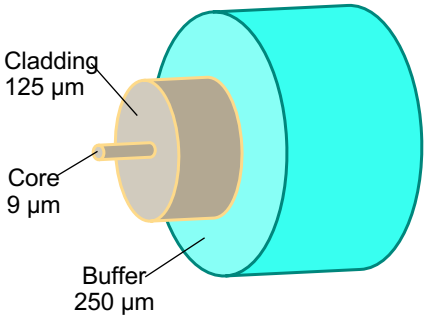
Distributed Fiber Optic Strain Sensing

Three Phases:

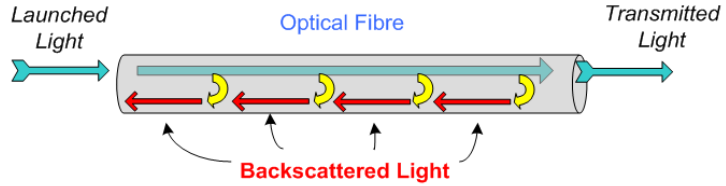
1. ***State-of-the-art review***
2. ***Laboratory testing***
3. ***Field testing (requires utility cooperation)***

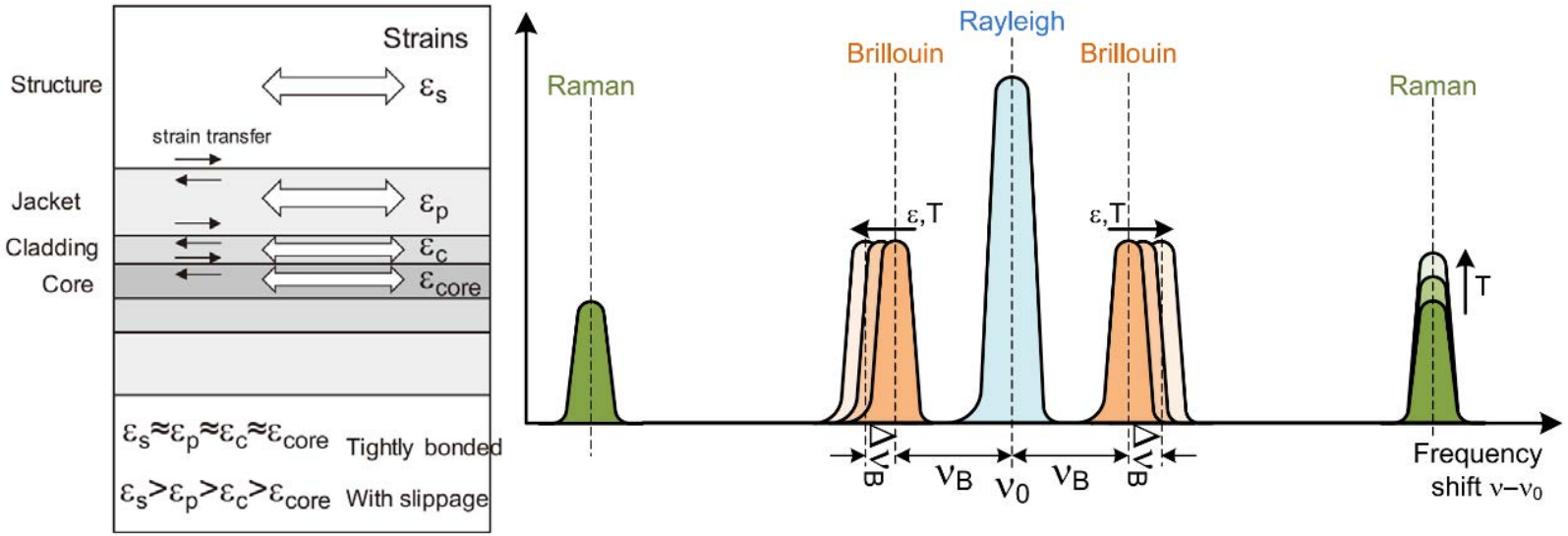
Phase 1: State-of-the-art Review

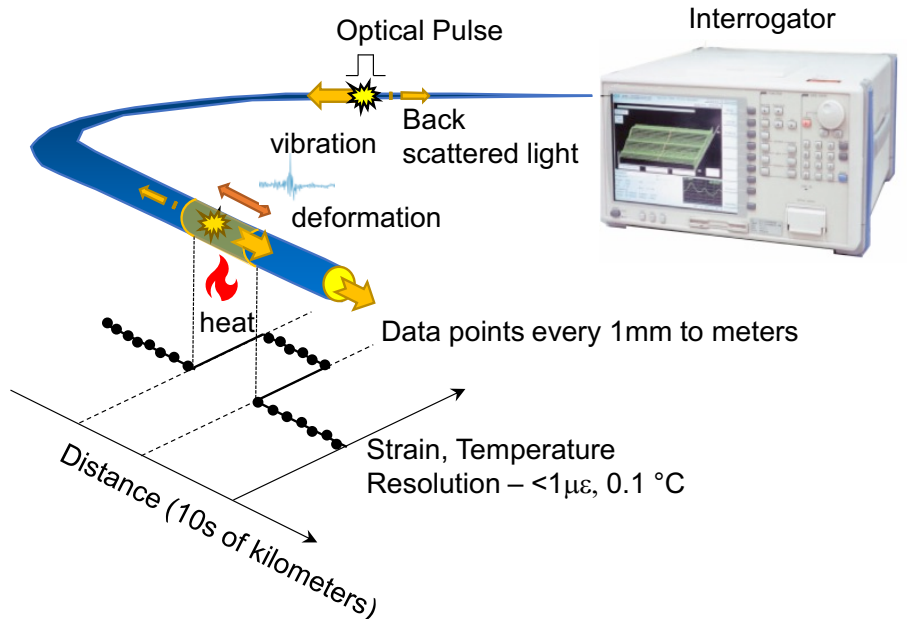
Distributed Fiber Optic Sensing (DFOS)



- Light signal propagation & back-scattering mechanism
- Back-scatter modes & detection techniques
  - *Distributed Strain & Temperature Sensing (DSTS)*
  - *Distributed Temperature Sensing (DTS)*
  - *Distributed Acoustic Sensing (DAS)*
- Strain transfer mechanism







Soga and Luo, 2018

2022

Distributed Fiber Optic Sensing Commercial Review

- Selected commercial analyzers & cables specification

Distributed Strain & Temperature Sensing Analyzers

TYPES	BRAND & MODEL	MAX. DISTANCE	MIN. READ-OUT	MIN. SPATIAL RESOLUTION	ACCURACY	MIN. SAMPLE FREQUENCY
OTDR OTDA	Neubrex NBX-7031	27km	10mm	20mm	20nε/ 0.001°C	0.2Hz
OFDR	Luna ODiSI 6100	50m	0.65mm	-	<±1με/ -	10Hz
OFDR	Semicon OSI-S	100m	1mm	1mm	±1με/ ±0.1°C	4Hz

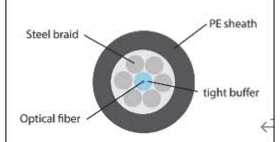
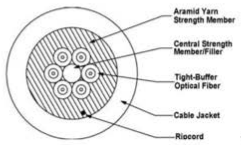
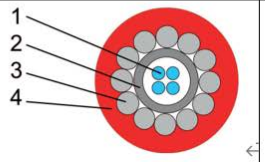
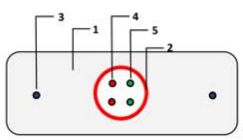
Distributed Temperature Sensing Analyzers

BRAND & MODEL	MAX. DISTANCE	MIN. READ-OUT	MIN. SPATIAL RESOLUTION	ACCURACY	MIN. SAMPLE RATE
Sensornet HALO-DTS	4km	2m	-	0.45°C	15sec
NKT Photonics LIOS EN.SURE OTS4	80km	0.25m	1m	2°C	60sec
Sensornet Sentinel DTS-XR SM	30km	1m	1m	-	10sec
OZ Optics ForeSight-BDTS	10km	-	1m	0.3°C	24sec

Distributed Acoustic Sensing Analyzers

TYPES	BRAND & MODEL	MAX. DISTANCE	READ-OUT	MIN. SPATIAL RESOLUTION	FREQUENCY	
					RANGE	MAX. SAMPLE
φ- OTDR	Optasense ODH-4	10km	-	1.3m	-	200kHz
φ- OTDR	Silixa iDAS	40km	>25cm	1m	0.01Hz ~ 50kHz	100kHz
OFDR	Neubrex NBX-S4000	50km	20cm	2.8m	1Hz ~ 2.5kHz	5kHz

Sensors

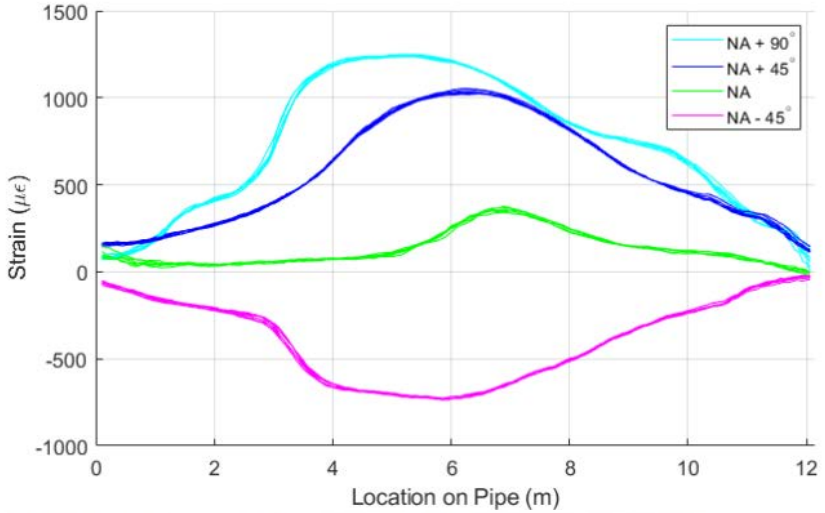
COMPANY	NanZee Sensing	Smartec	Solifos	Smartec
MODEL	NZS-DSS-C02	Hydro & Geo	3_50_1_001	SMARTProfile II
BUFFER	Tight	Tight	Loose	Hybrid
TARGETS	Strain	Strain & temperature	Temperature	Strain & temperature
DIMENSION	ϕ5mm	ϕ6mm	ϕ3.8mm	8mm x 4mm
DIAGRAM				

Phase 2: Laboratory Testing

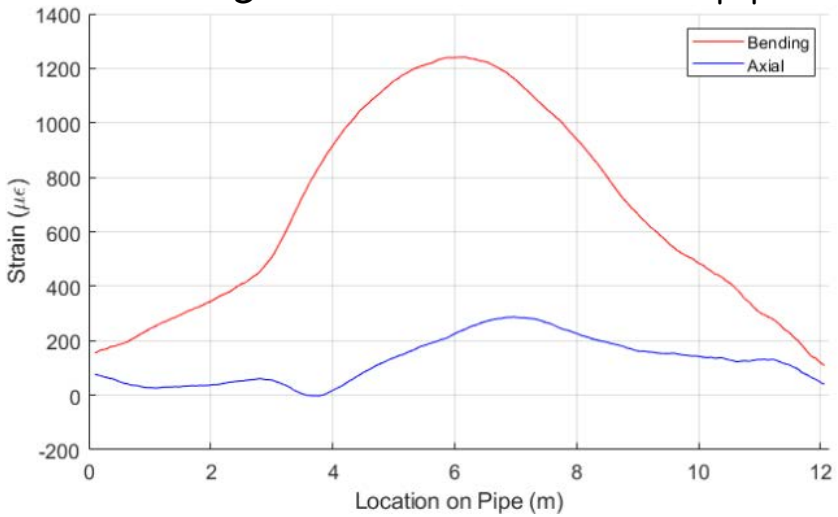
HDPE Pipeline Bending Test – DFOS Distributed Strain & Temperature Sensing (DSTS)

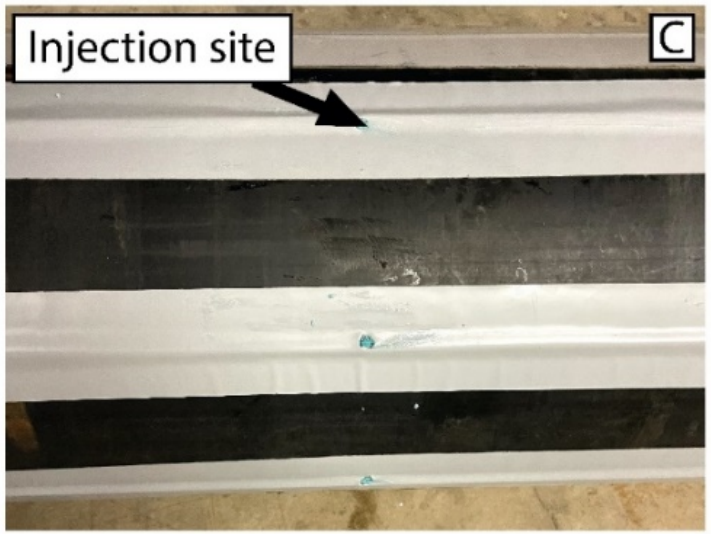
2022

Strain of the pipe

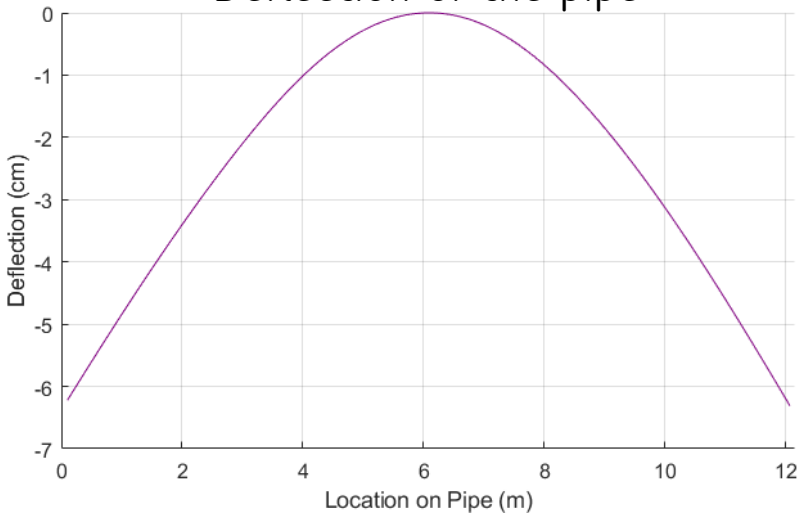


Bending and axial strain of the pipe

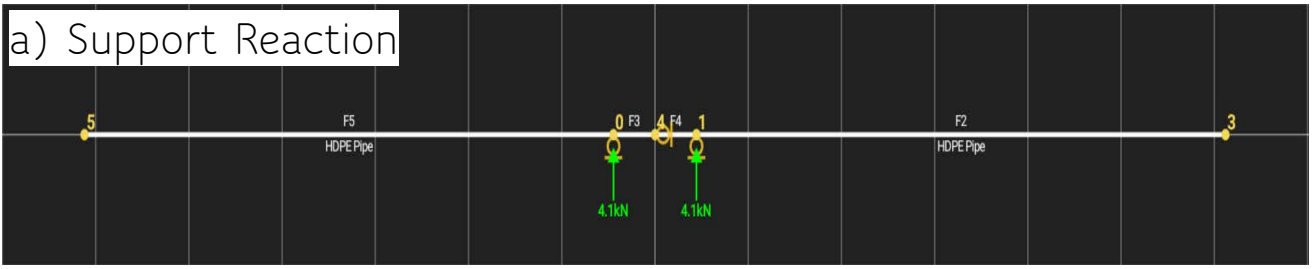


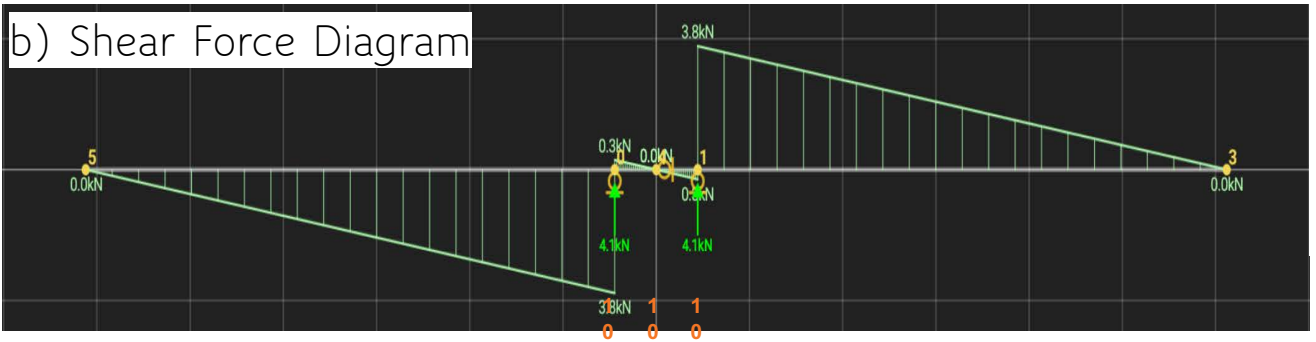


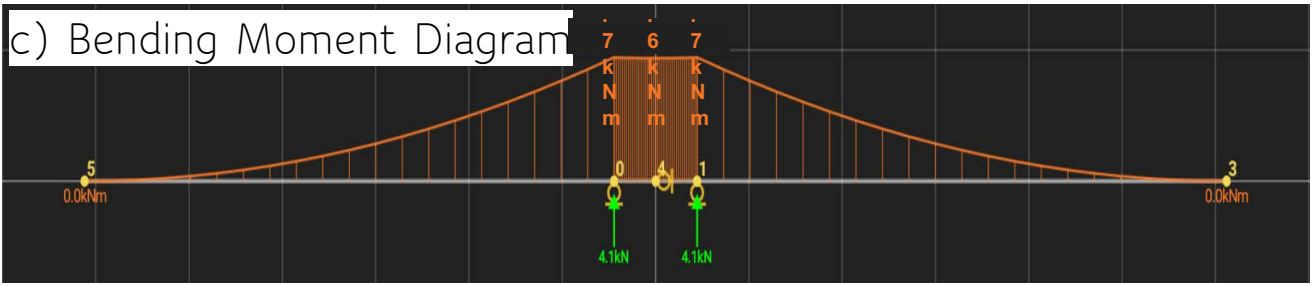
Deflection of the pipe

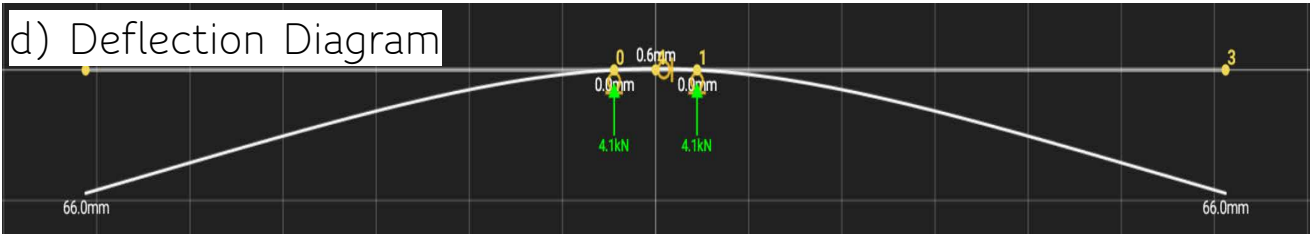


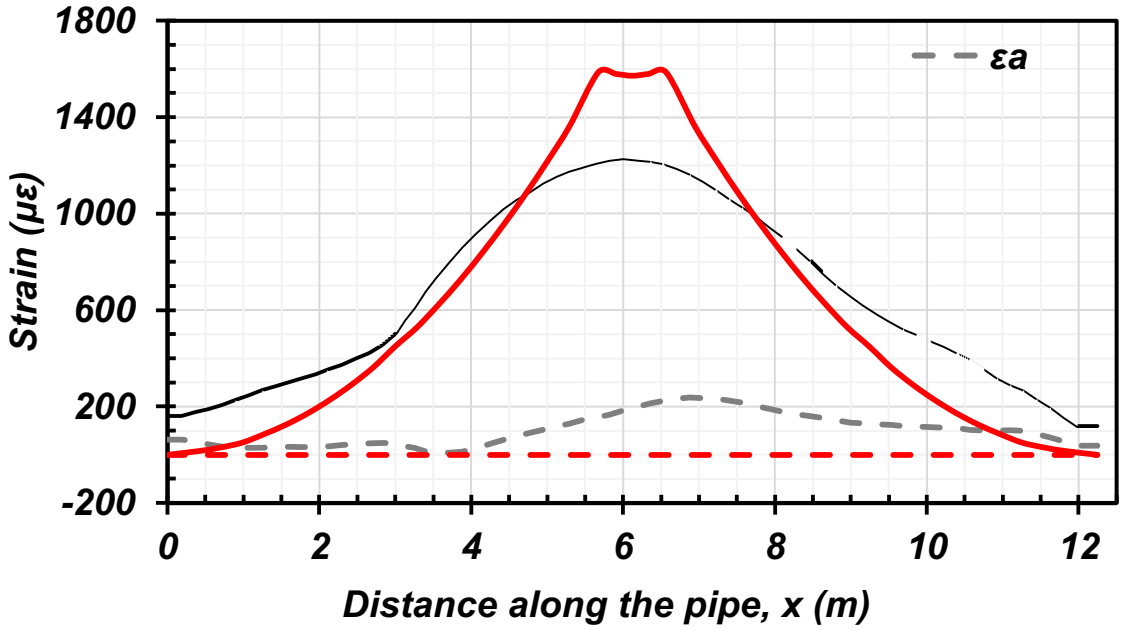
HDPE Pipeline Bending Test – Analytical Comparison

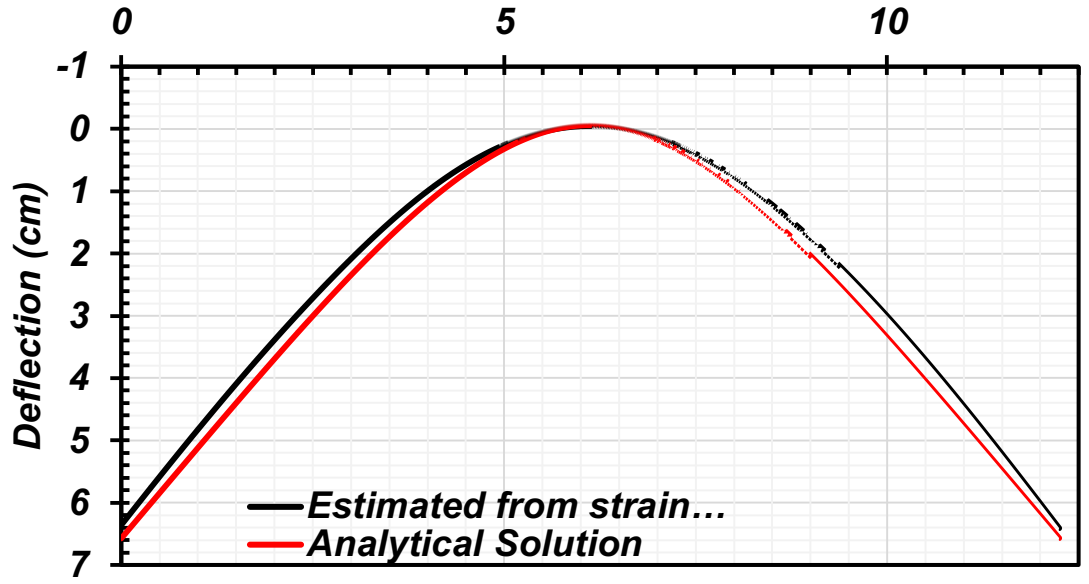












Pressurized Steel Pipeline Bending Test – DFOS Distributed Strain & Temperature Sensing (DSTS)

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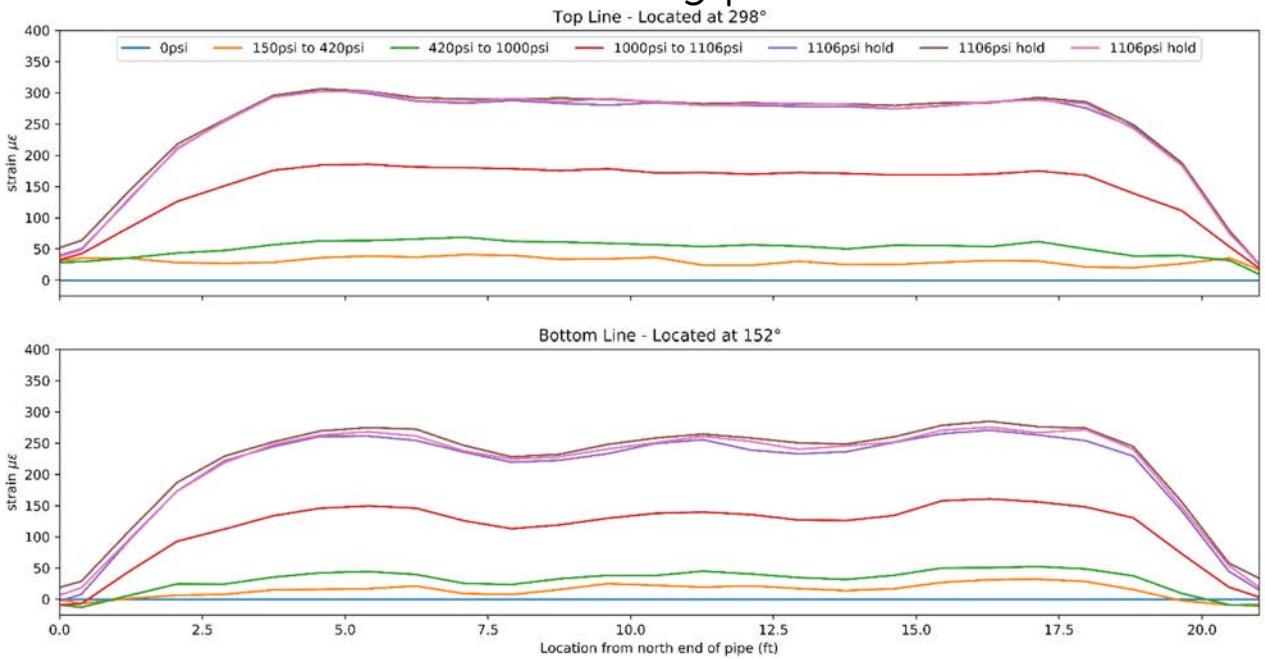
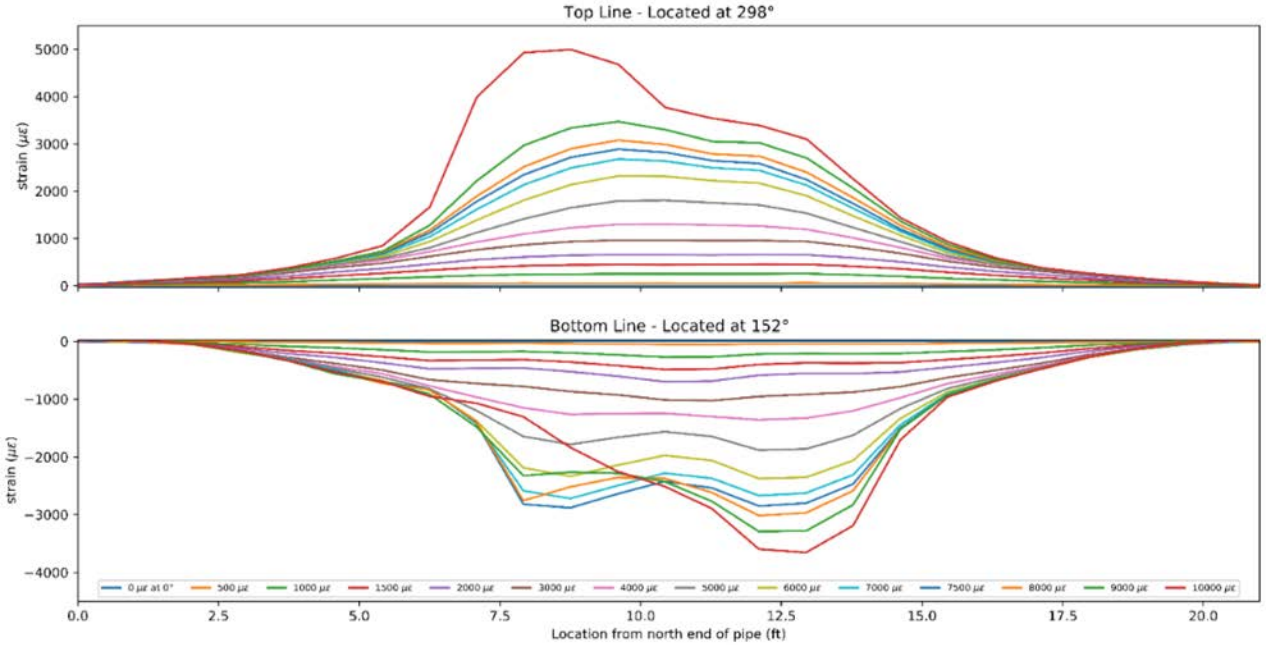
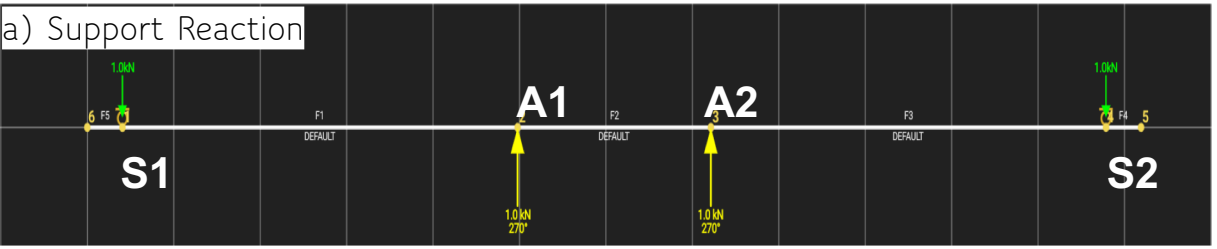
Strain measurement during pressurization test

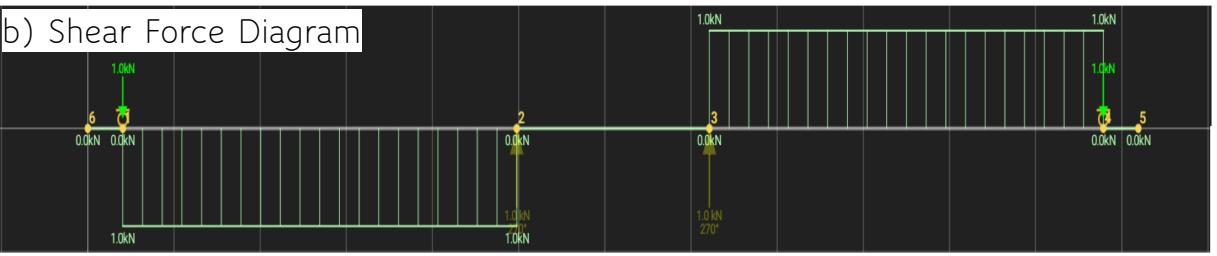


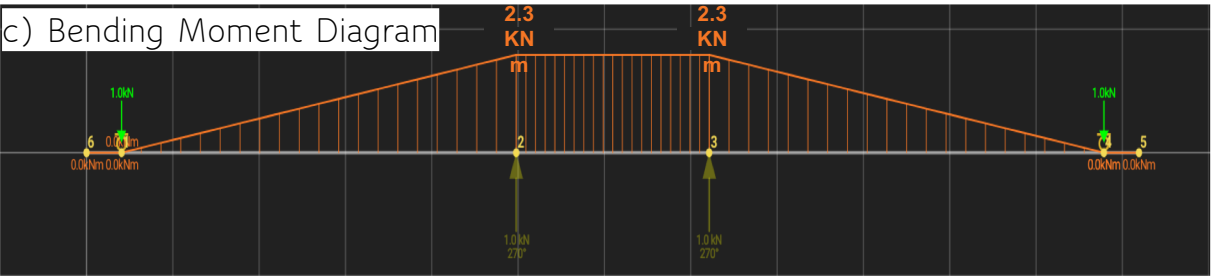
Strain measurement during bending test

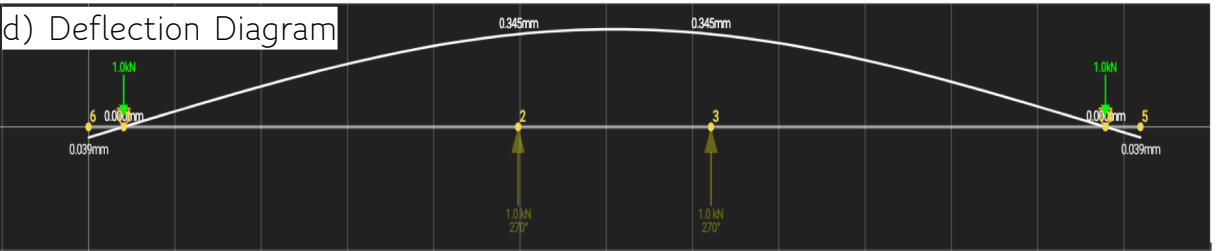


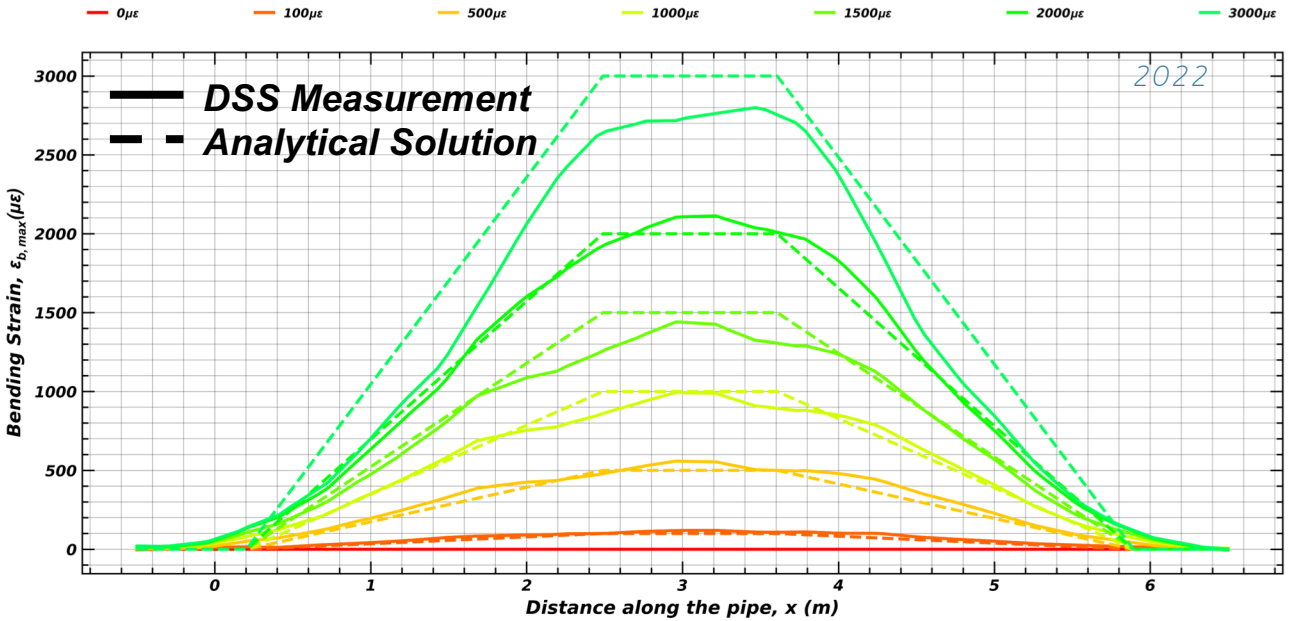
Pressurized Steel Pipeline Bending Test – Analytical Comparison

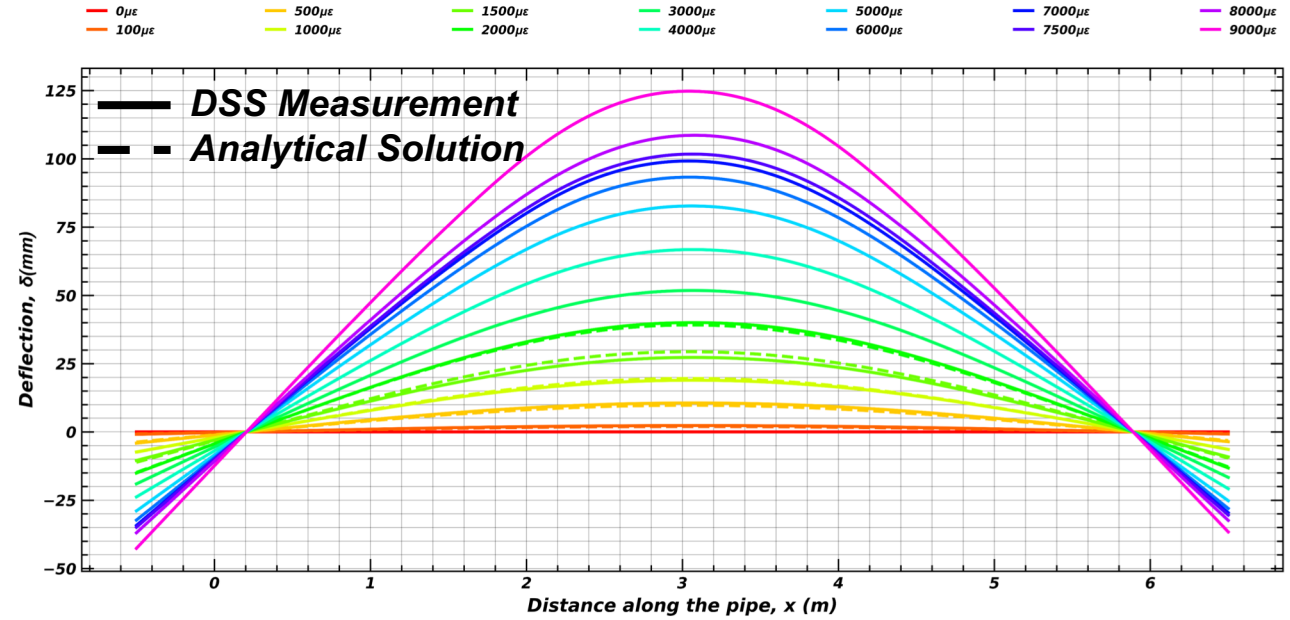






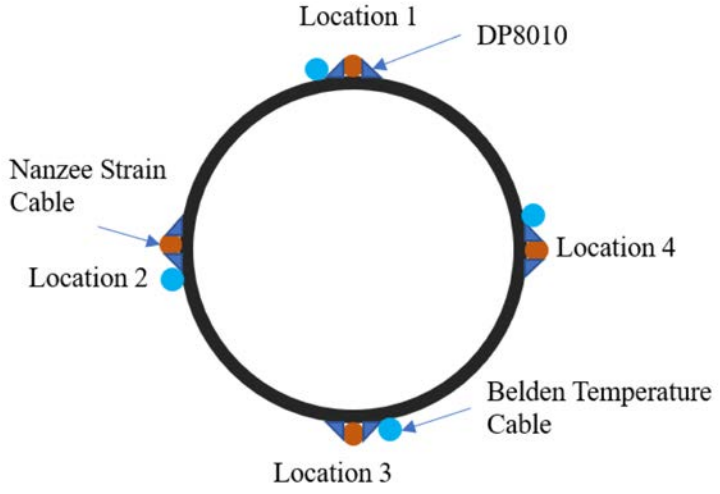




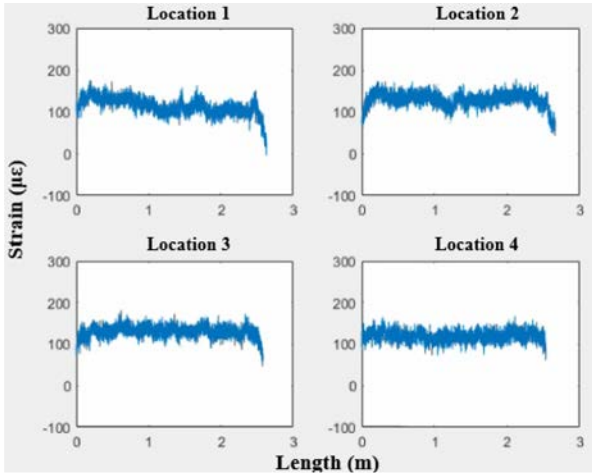


Gas Well Tubing Pressure Test – DFOS Distributed Strain & Temperature Sensing (DSTS)

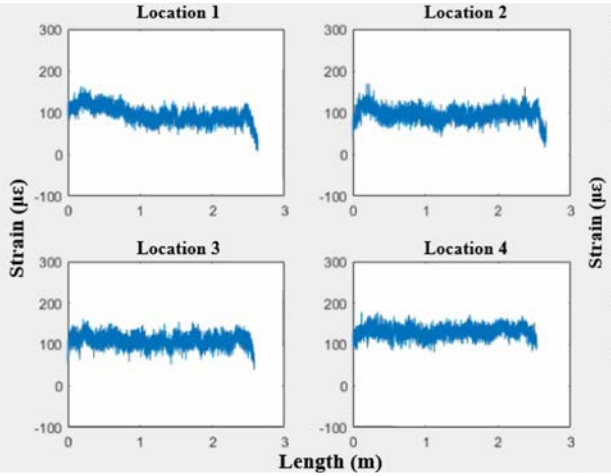
2022



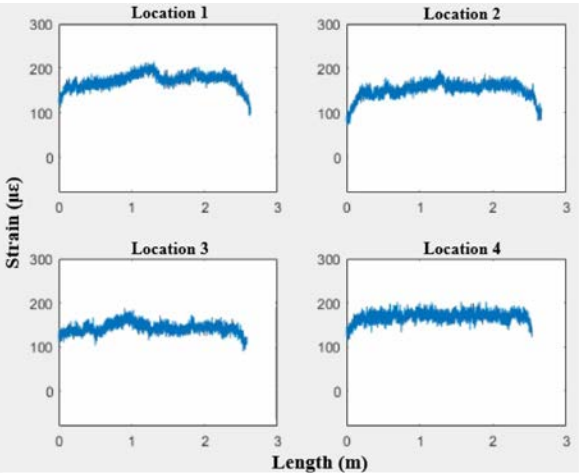
Without defect
Pressure=1600psi



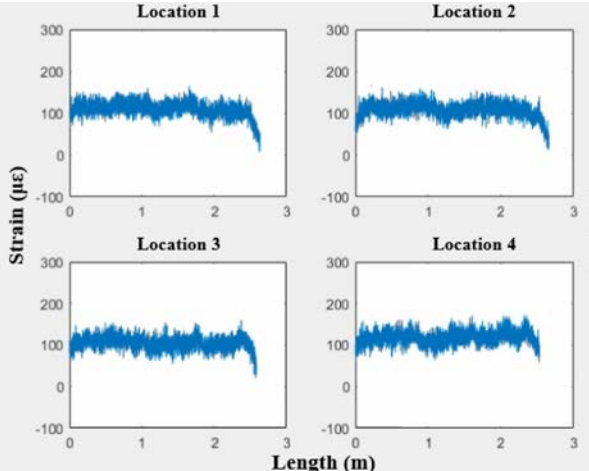
Defect: A=2"x1", d=1/8"
Pressure=1600psi



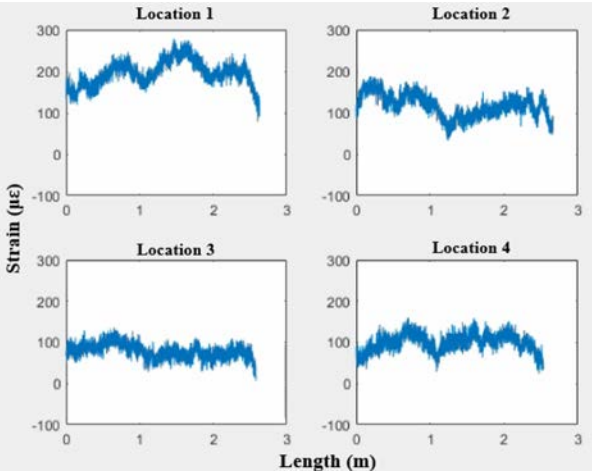
Defect: A=2"x2", d=3/16"
Pressure=1600psi



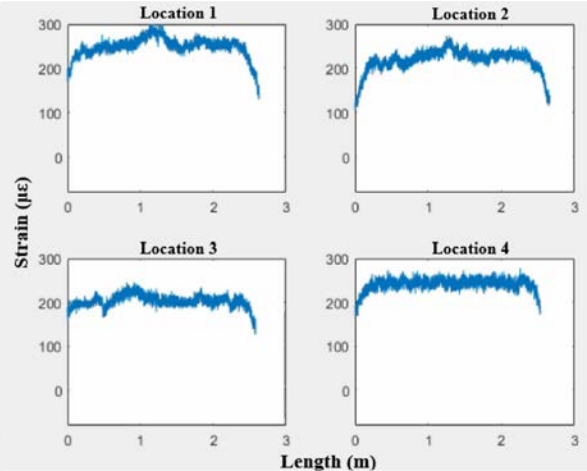
Defect: A=2"x1", d=1/16"
Pressure=1600psi



Defect: A=2"x2", d=1/8"
Pressure=1600psi



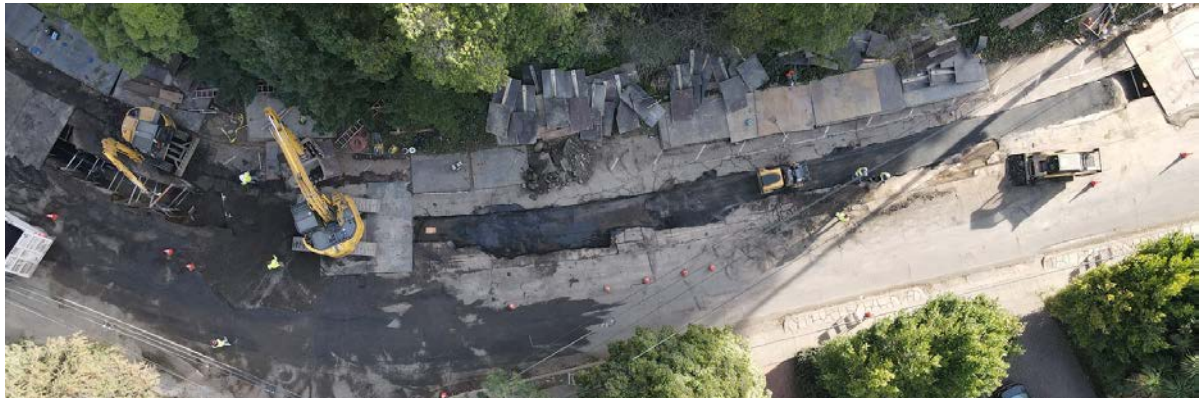
Defect: A=2"x2", d=3/16"
Pressure=2300psi

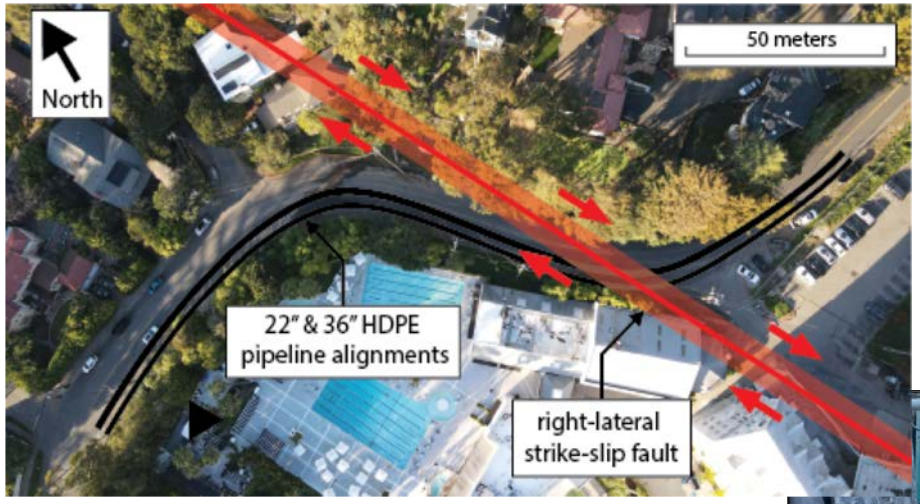


Phase 3: Field Testing

Field Deployments of DFOS

- 1500’ of critical HDPE water pipeline owned by EBMUD
  - Crosses the Hayward fault in Oakland, CA
  - Instrumented using DFOS strain sensing
  - Sensing technology, installation specs and data analysis performed by Soga Research Group

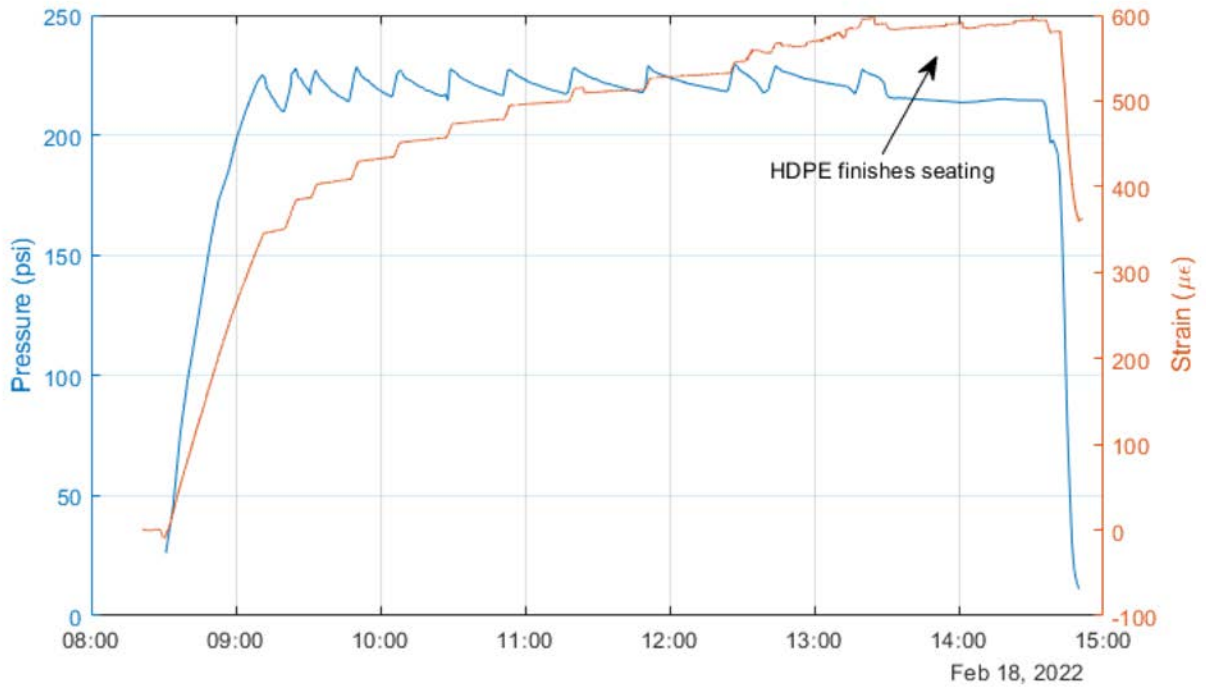


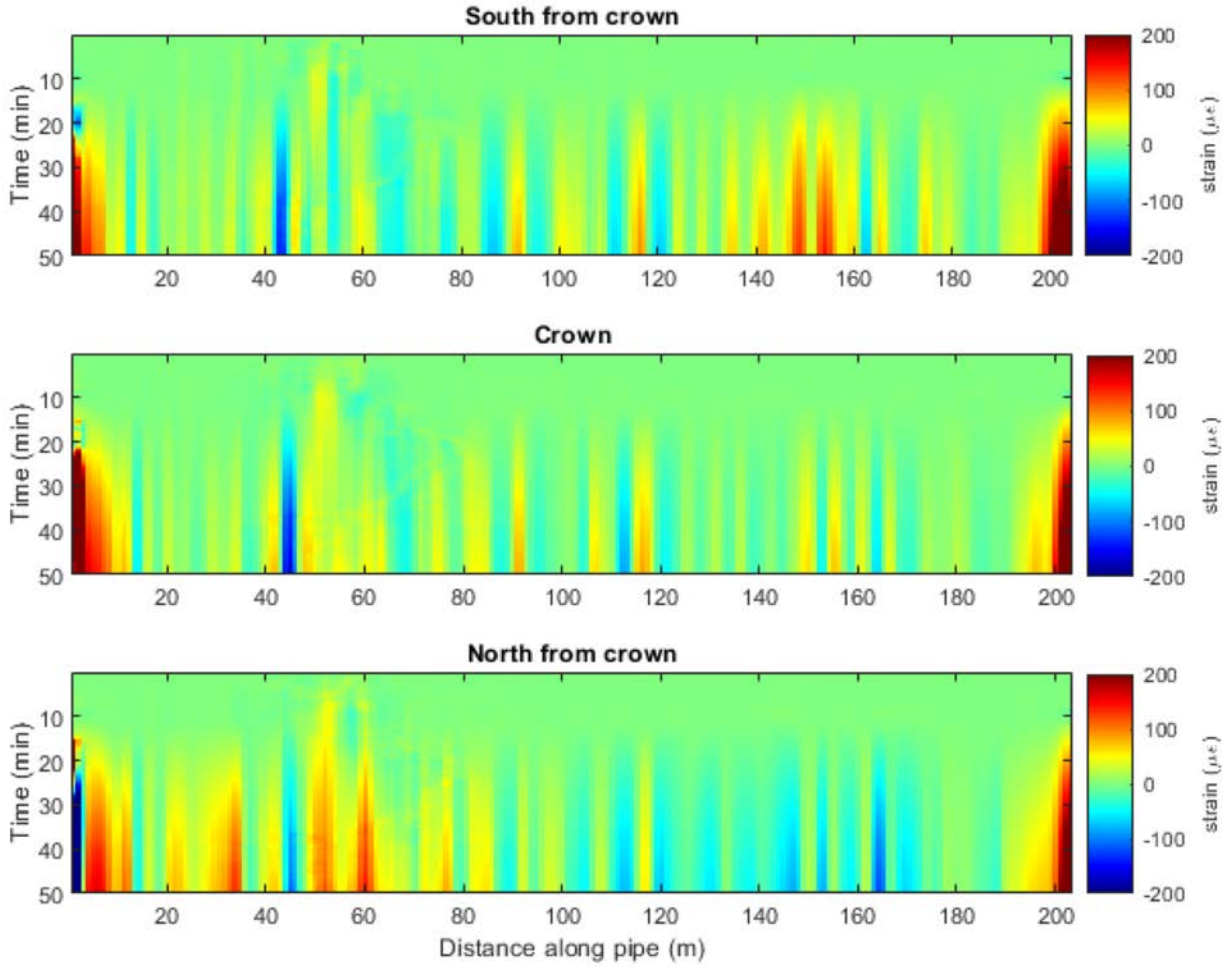


Installed optical fiber

HDPE Pipe Pressurization

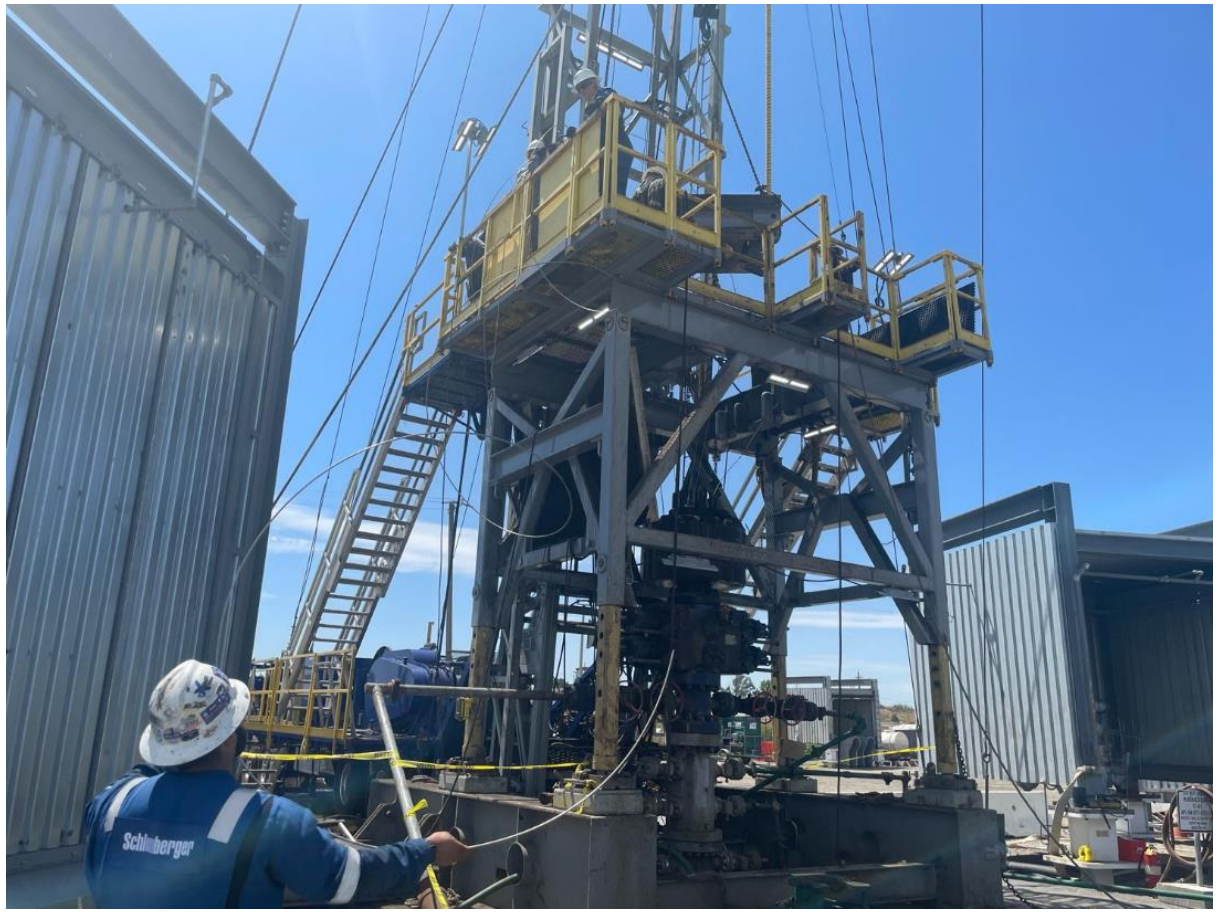
Strain can be used to verify when HDPE expansion has stopped

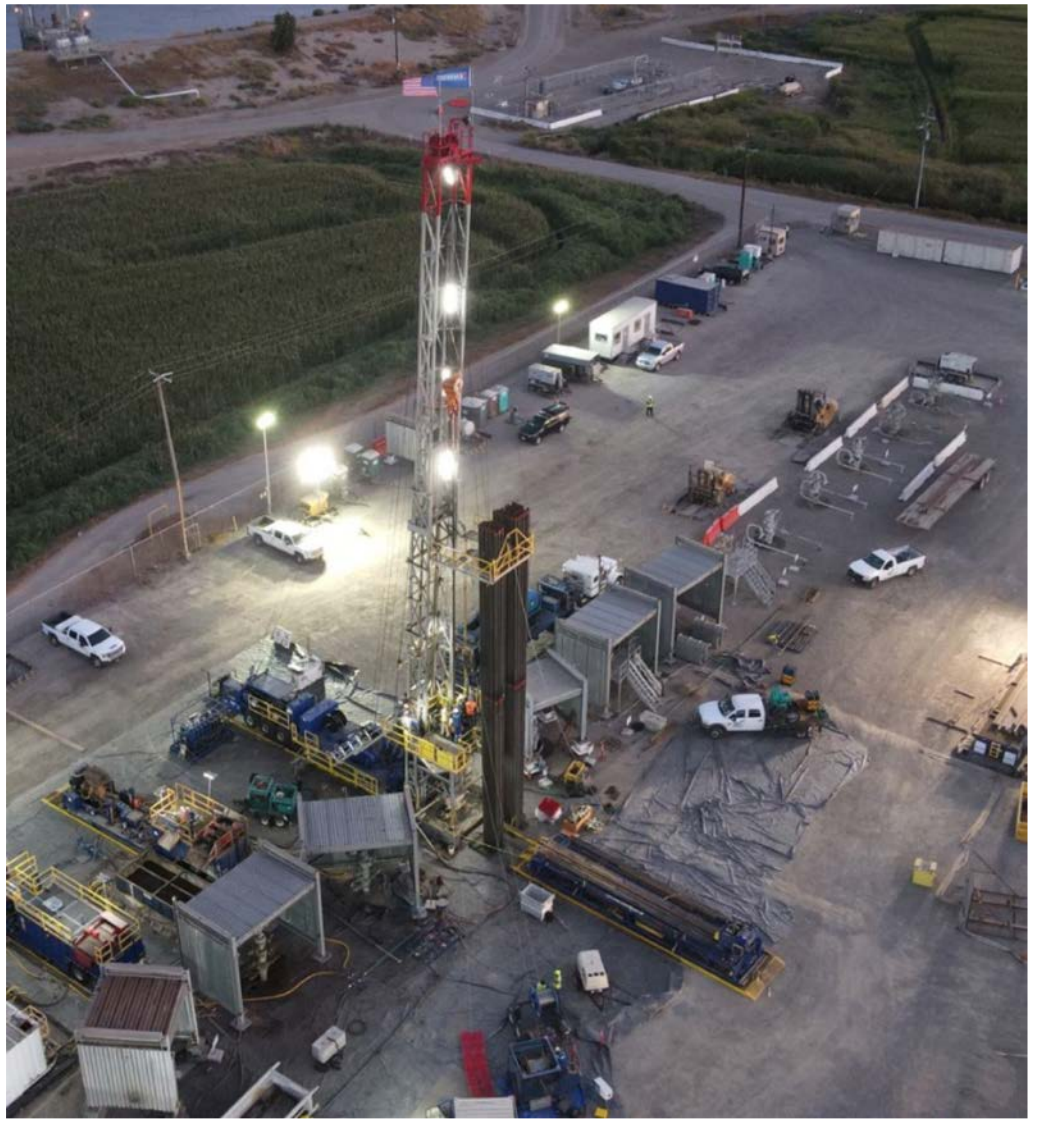




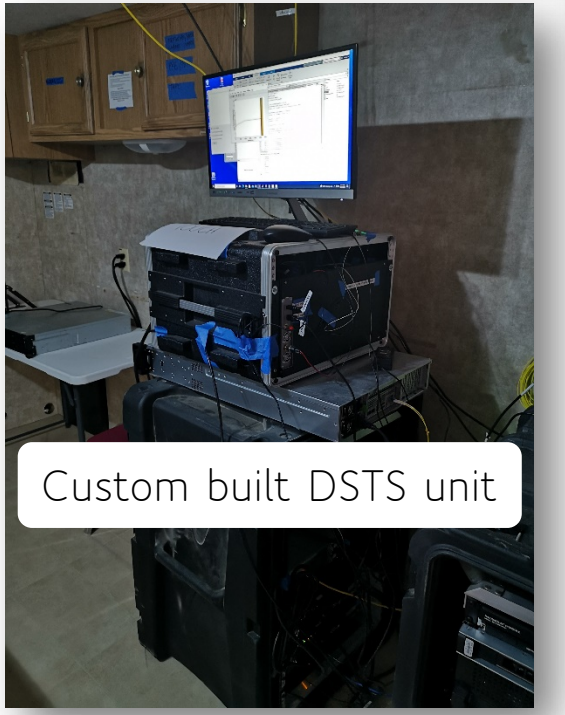
Strain Monitoring in Natural Gas Wells

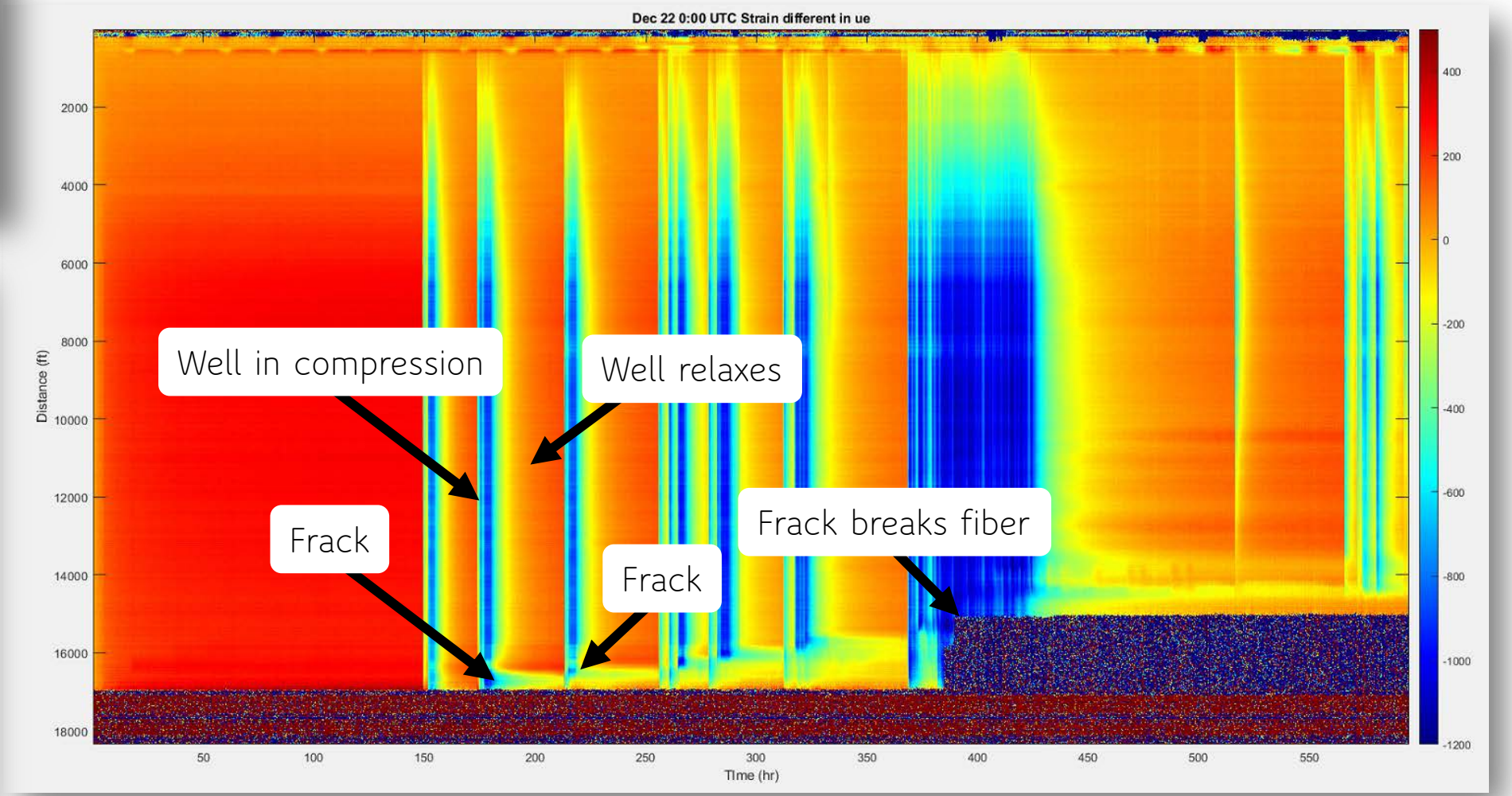
- DFOS deployment in natural gas wells





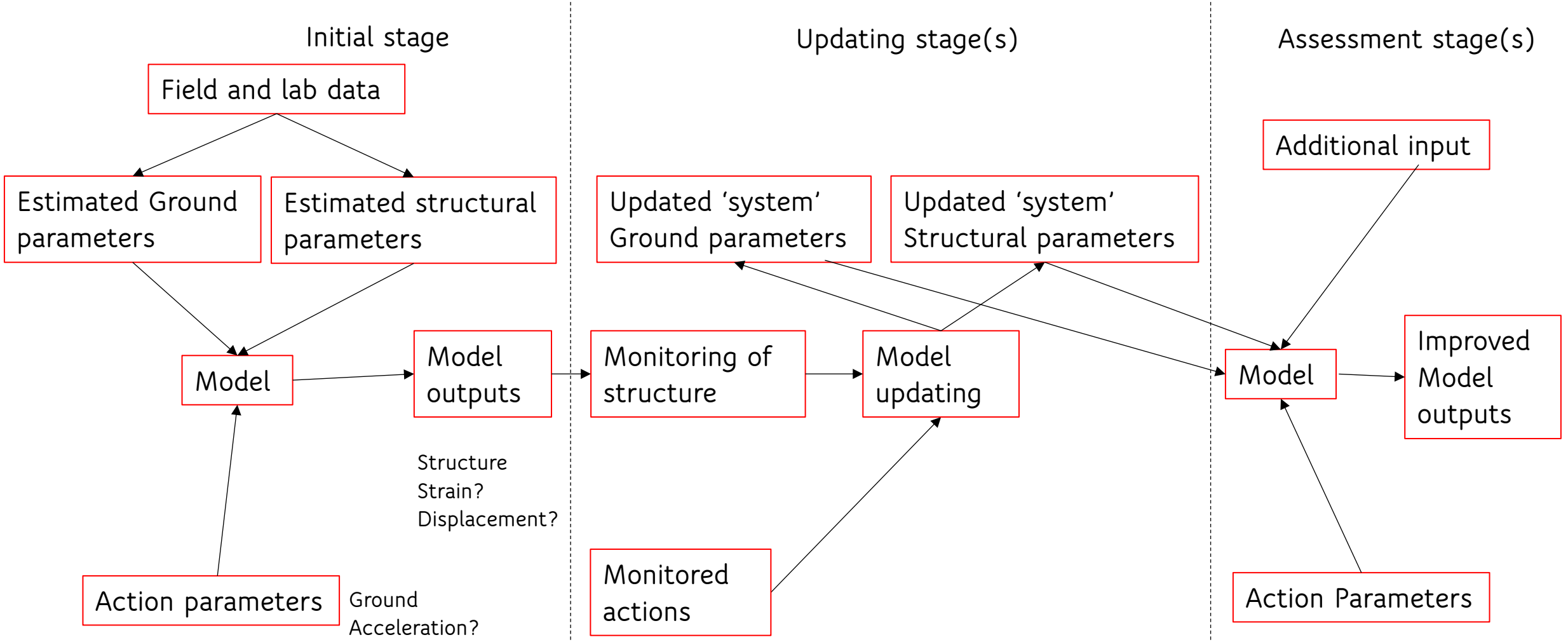
Strain Monitoring in Natural Gas Wells





Next Step: Risk Model Updating

Adopting Measurement to Simulation Tools



Model updating framework

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THANK YOU!

Any Questions?