# Easy Deployed Distributed Acoustic Sensing System for Remotely Assessing Potential and Existing Risks to Pipeline Integrity

## CAAP Project Midterm Summary Meeting


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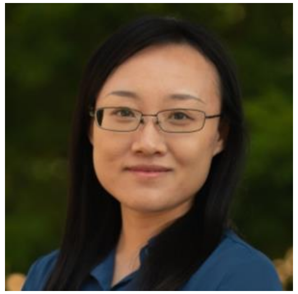
# Our Team



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Multiphase flow in pipes, multiphase flow related flow assurance, artificial lift, gas well deliquification, fiber optic sensing application in fluid flow measurement and transportation.

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Co-director of Reservoir Characterization Project (RCP). Distributed Fiber Optic Sensing (DFOS) applications, ML and data mining applications in Geophyics, advanced seismic imaging methods

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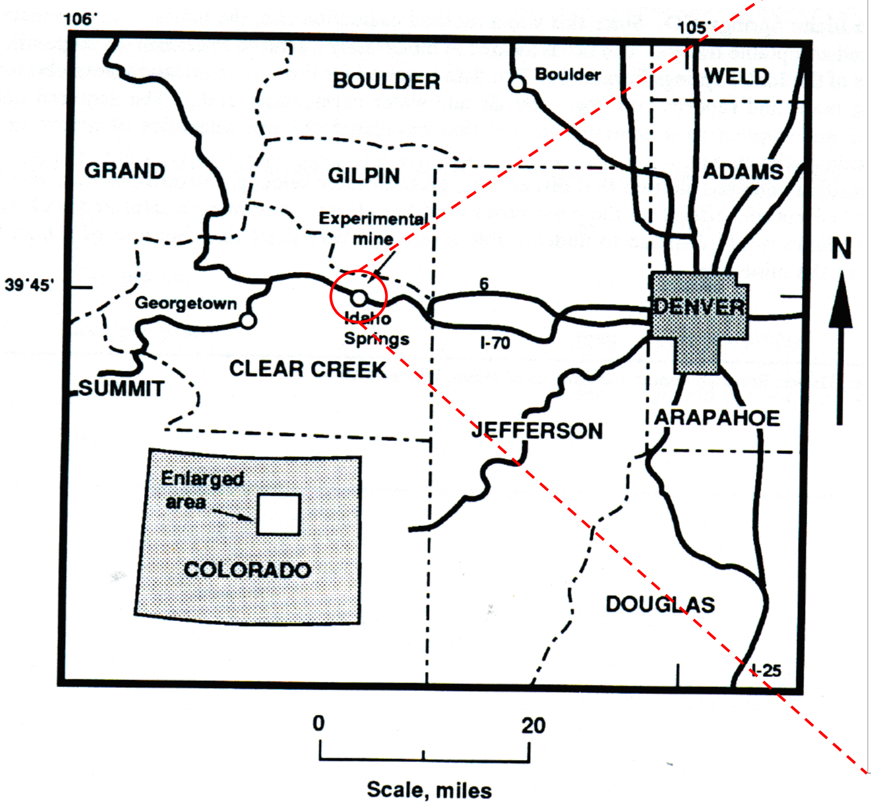
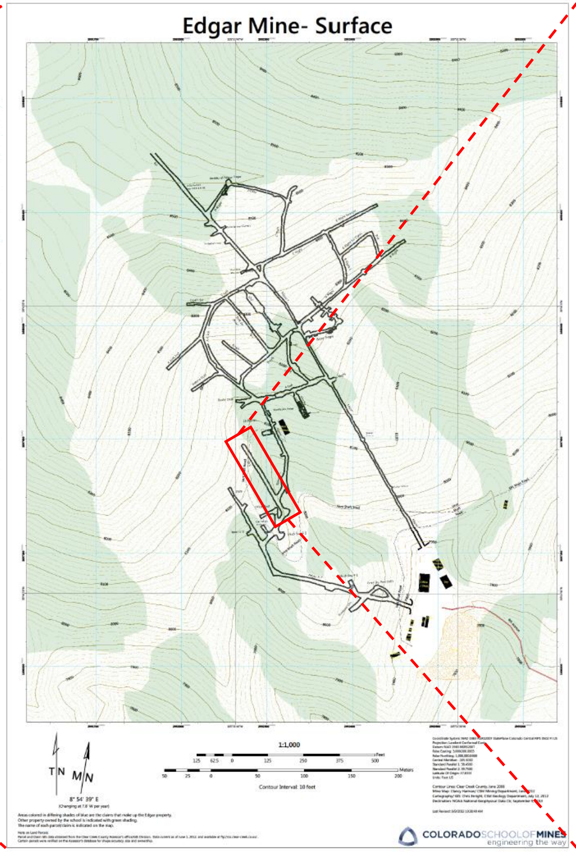
Ph.D. student in Geophysics. BS in Geology from University of Wyoming, BS in Geophysics from Colorado School of Mines. Intern with BP in 23 Summer.

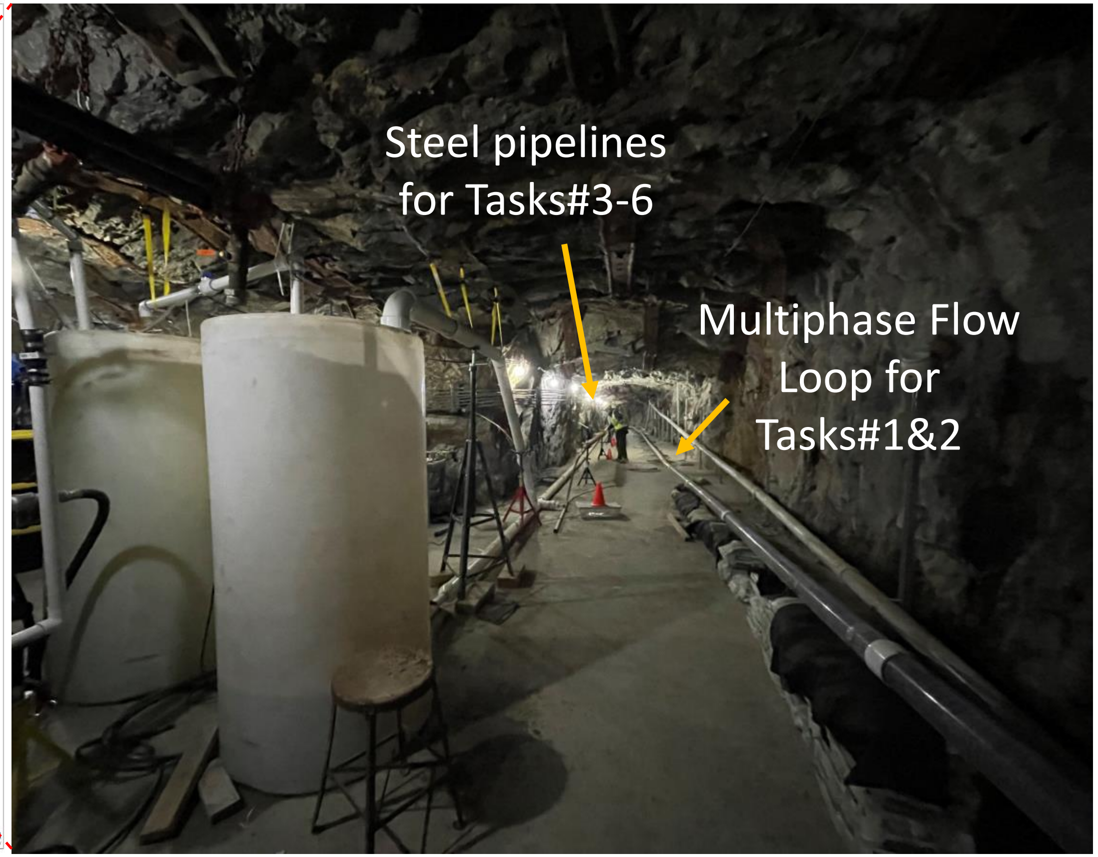
# Outline

- Project progress
  - Task#1. Detection of liquid accumulation at pipeline lower spots
  - Task#2. Detection of dynamic intermittent (slug) structure
  - Task#3. Detection of corroded spots on pipeline interior surface
  - Task#4. Detection of dent/deformation on pipeline
  - Task#5. Detection of infrastructure damage
  - Task#6. Detection of leakage
- Remaining tasks

# Edgar Mine Experimental Facility



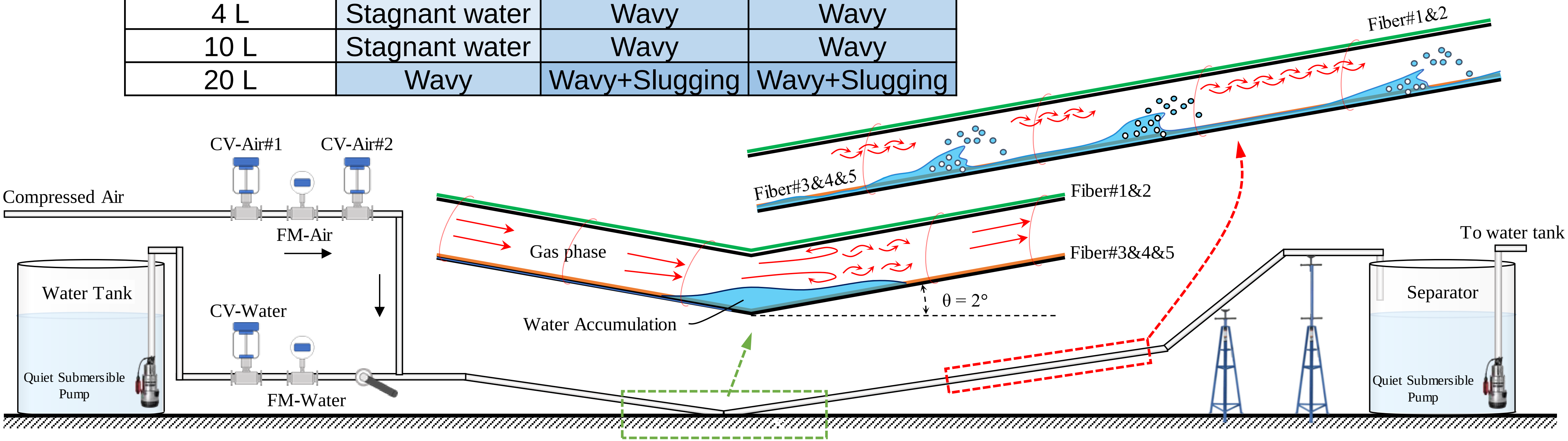



# Task#1. Detection of liquid accumulation at pipeline lower spots

- Objective: Investigate the capability of DAS to identify liquid accumulation spots in a pipeline, and its sensitivity for different deployment methods.
- A two-phase flow loop was built at Edgar Mine

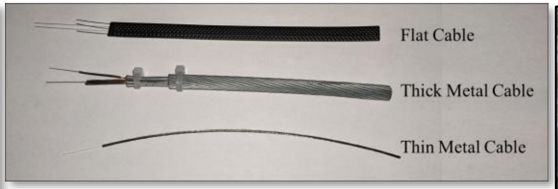
| $V_{water}$ \ Velocity | 2 m/s | 4 m/s | 6 m/s |
|---|---|---|---|
| 4 L | Stagnant water | Wavy | Wavy |
| 10 L | Stagnant water | Wavy | Wavy |
| 20 L | Wavy | Wavy+Slugging | Wavy+Slugging |



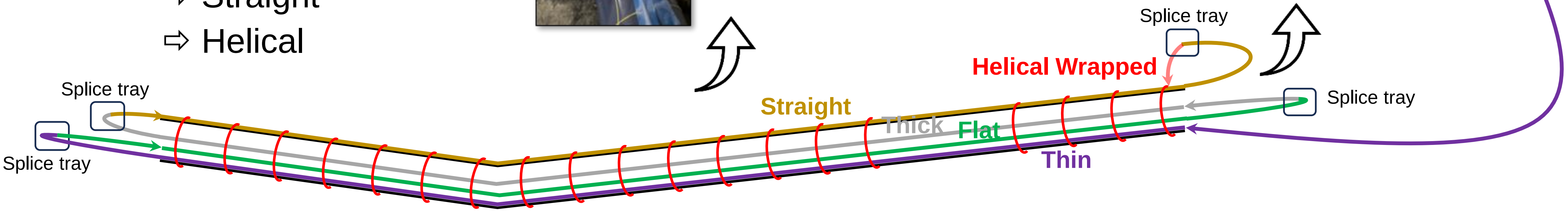
# Task#1. Detection of liquid accumulation at pipeline lower spots …

- Five cable were deployed
- Cable connection order:

  Interrogator
  ⇨ Thin
  ⇨ Flat
  ⇨ Thick
  ⇨ Straight
  ⇨ Helical





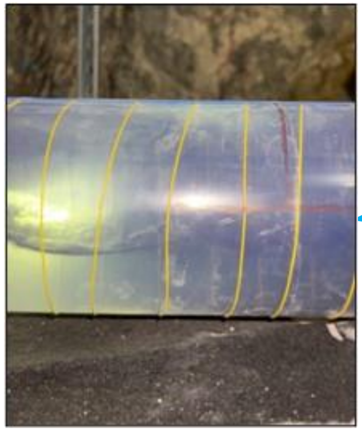


# Task#1. Detection of liquid accumulation at pipeline lower spots …

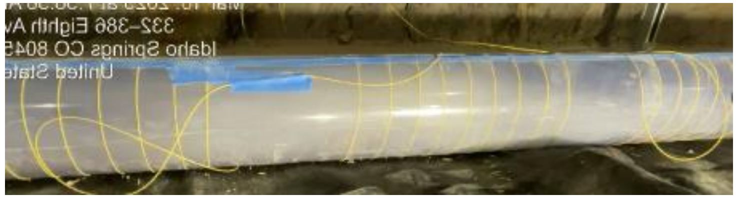
- 20L of water

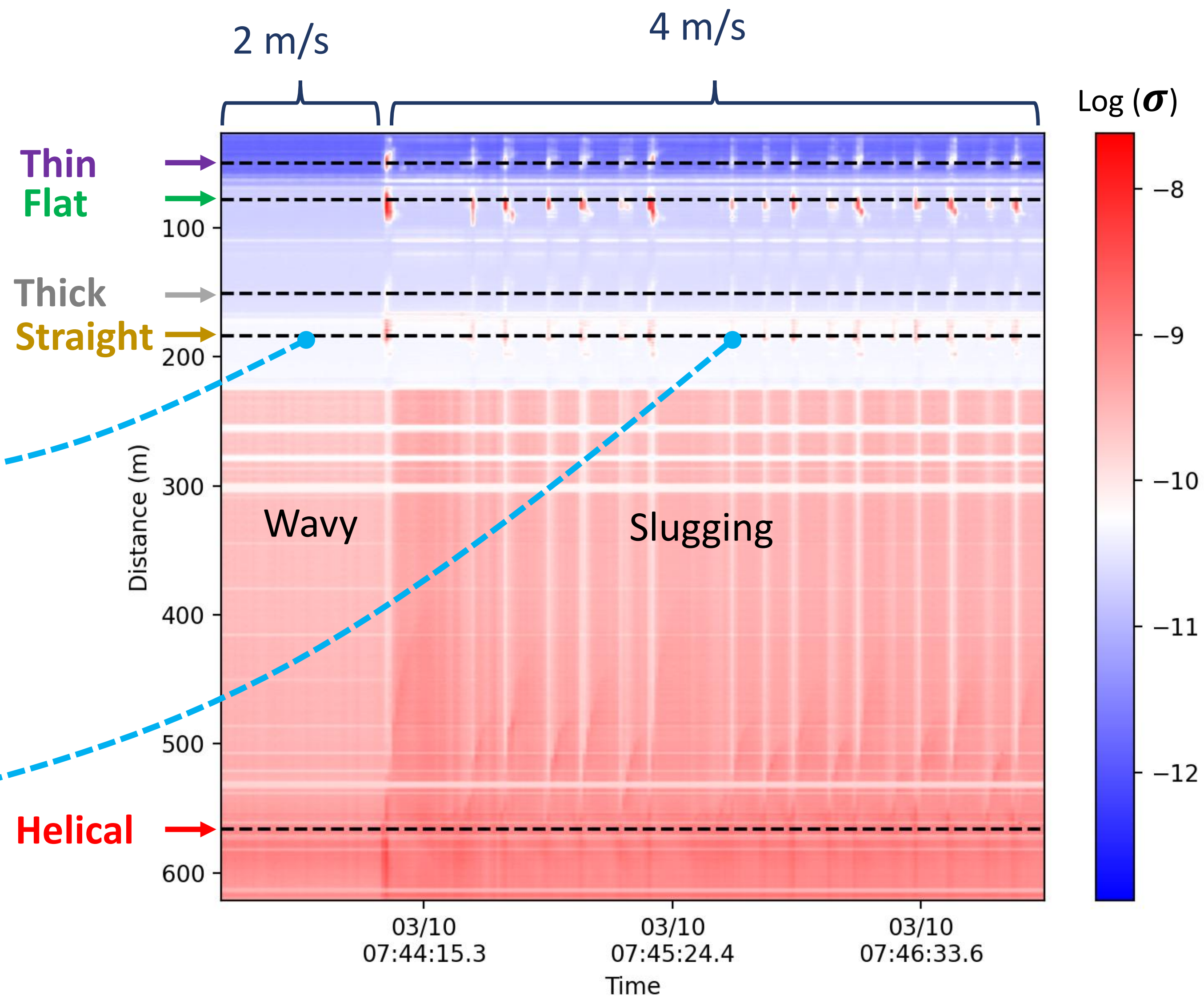
All cables can detect slugging phenomenon

**Wavy Interface**



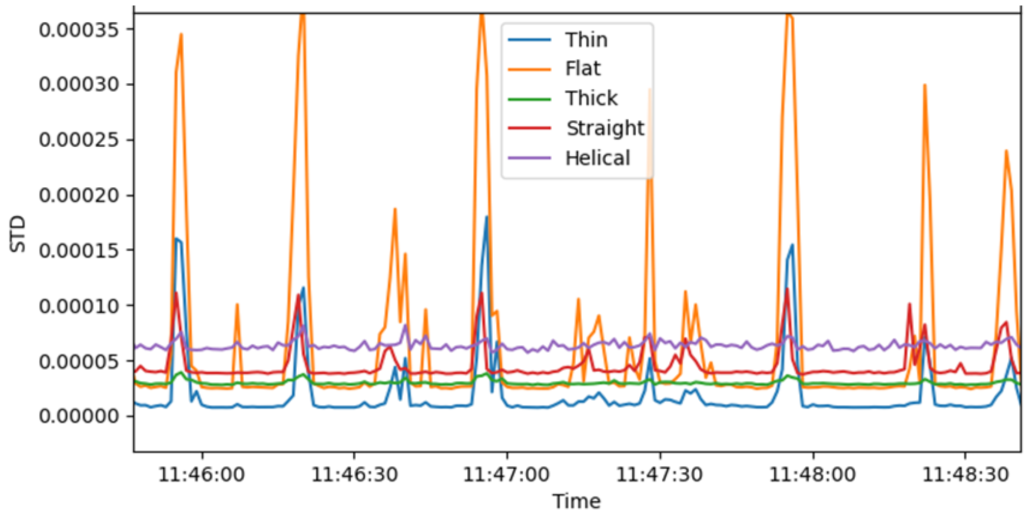
**Slugging**

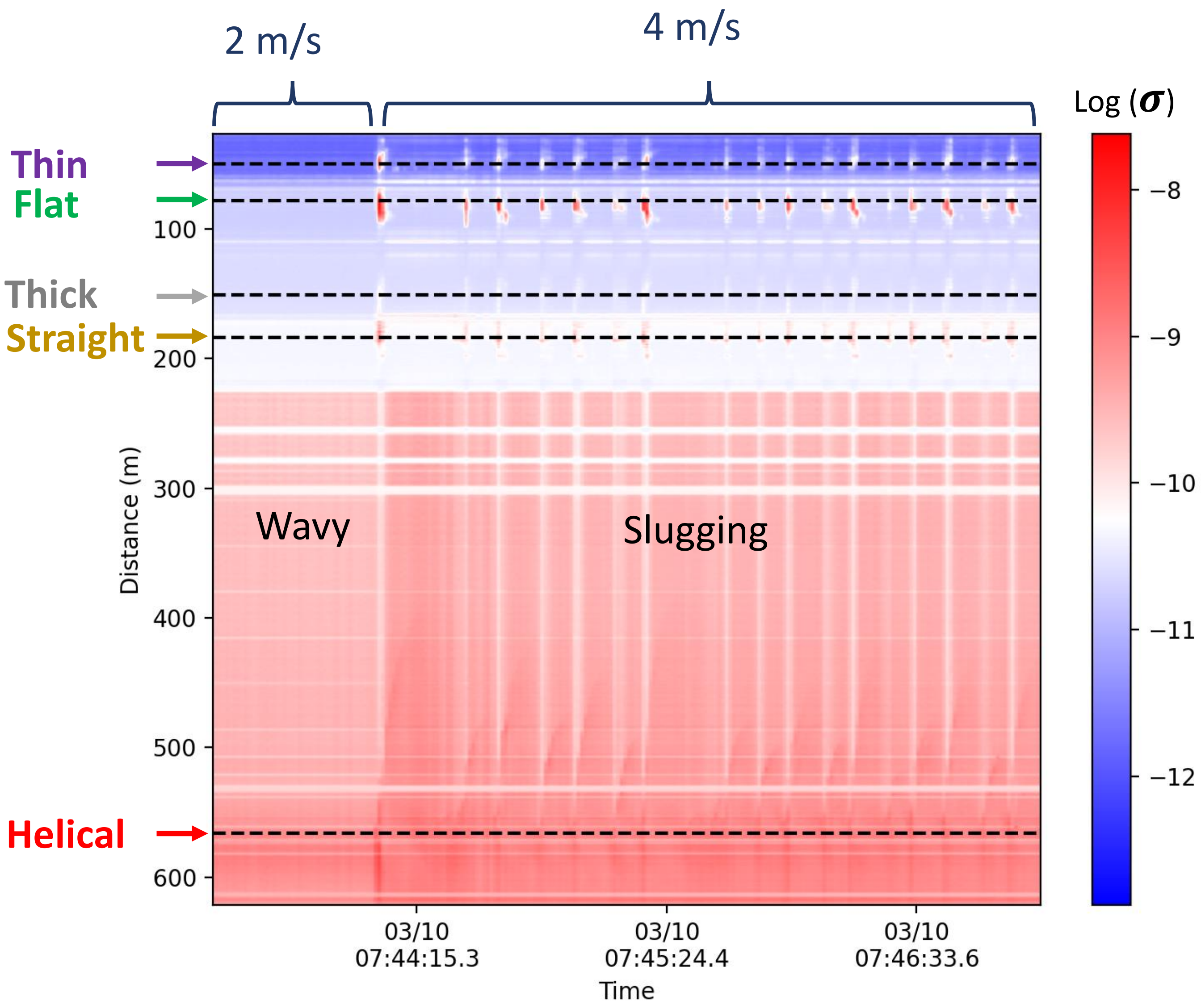




# Task#1. Detection of liquid accumulation at pipeline lower spots …

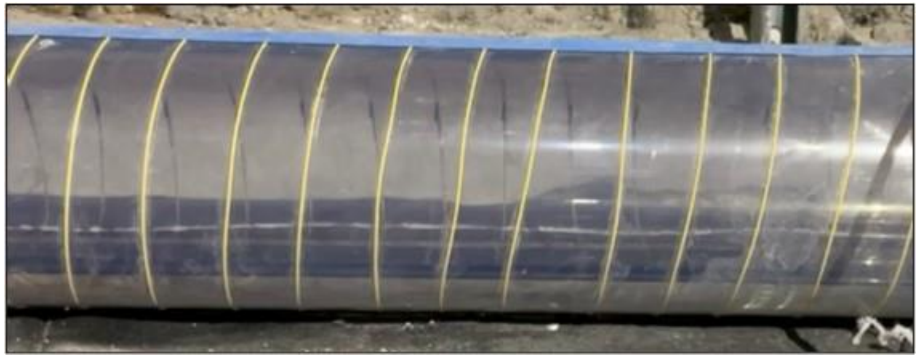
- Sensitivity
  - Flat most susceptible (light weight, flat shaped)
  - Thick least susceptible (heaviest)

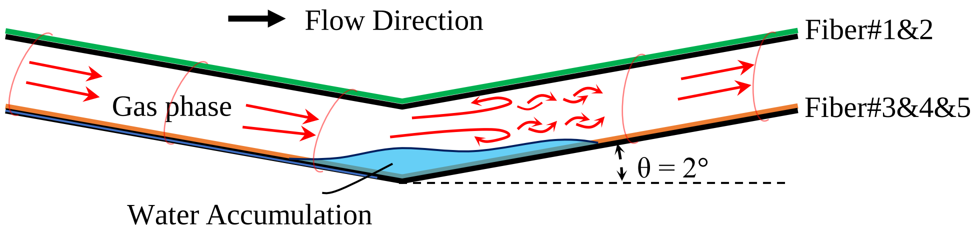


# Task#1. Detection of liquid accumulation at pipeline lower spots …

- 4L and 10L of water
  - Volume is small, no slugging
  - The higher water volume, the smaller the frequency peak, reflecting the dampening effect of water on vibration patterns.

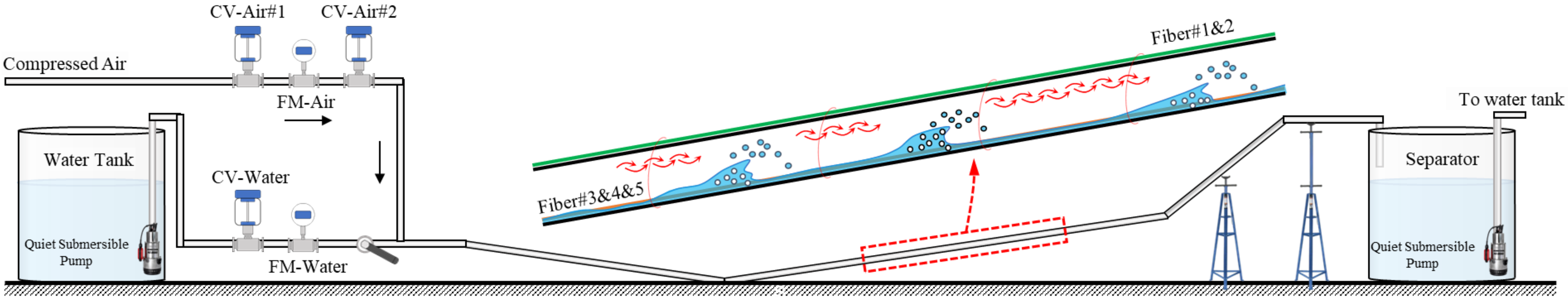




# Task#2. Detection of dynamic intermittent structure

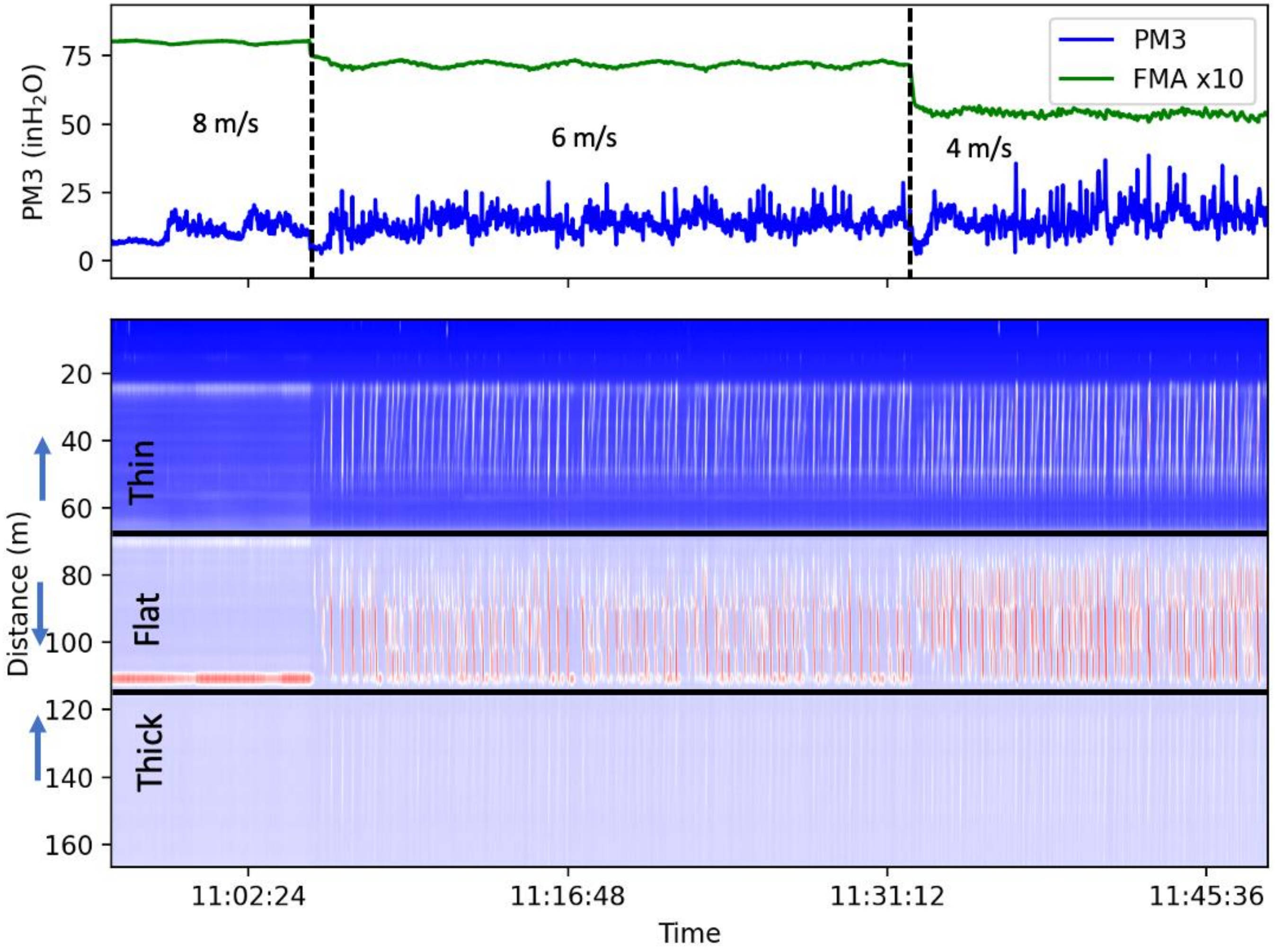
- Objective: Investigate the capability of DAS to identify and characterize the dynamic behavior of intermittent structures in a gas-dominant slightly inclined pipeline.

| $V_{water}$ \ $V_{air}$ (m/s) | 18 | 14 | 10 | 8 | 6 | 4 | 2 |
|---|---|---|---|---|---|---|---|
| 0.005 | Stratified | Stratified | Stratified | Stratified | Slug | Slug | Slug |
| 0.0025 | Stratified | Stratified | Stratified | Stratified | Slug | Slug | Slug |



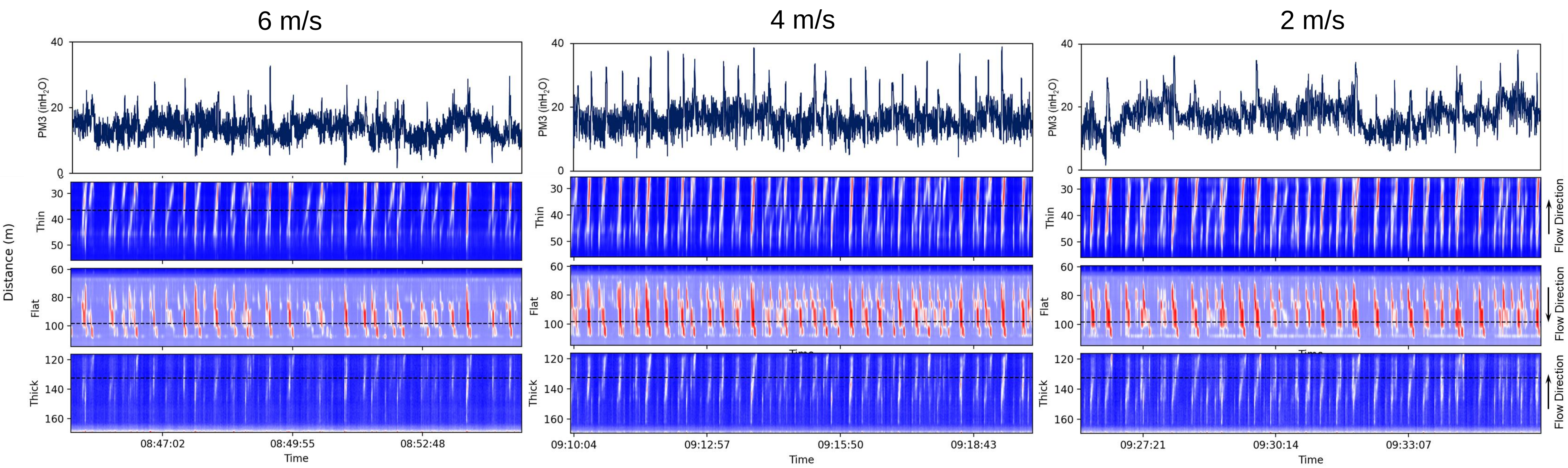
# Task#2. Detection of dynamic intermittent structure …

- Findings: DAS is able to differentiate stratified flow and slug flow



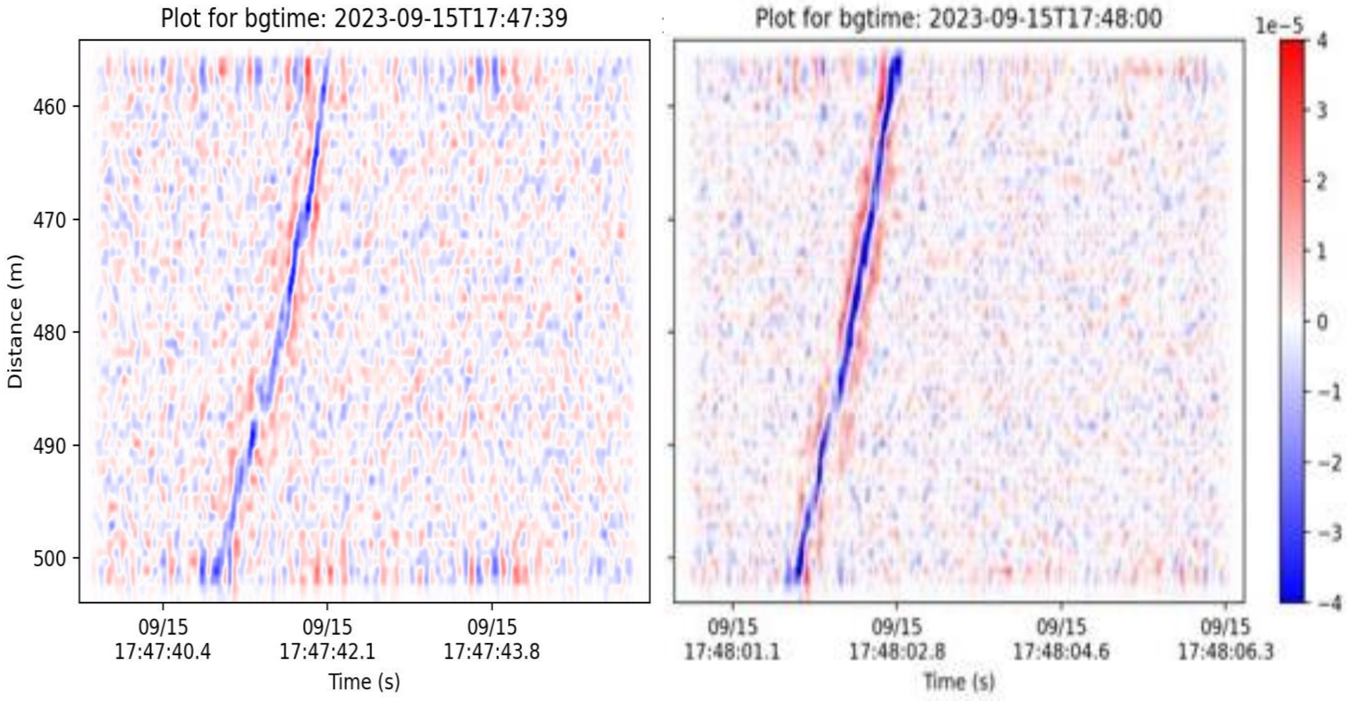
# Task#2. Detection of dynamic intermittent structure …

- Findings: Identified correlation between pressure sensor data and internal cable interference through analysis of DAS standard deviation processed data



# Task#2. Detection of dynamic intermittent structure …

- Findings: DAS data demonstrates that the magnitude, which is believed related to the structure size, is correlated with structure velocity

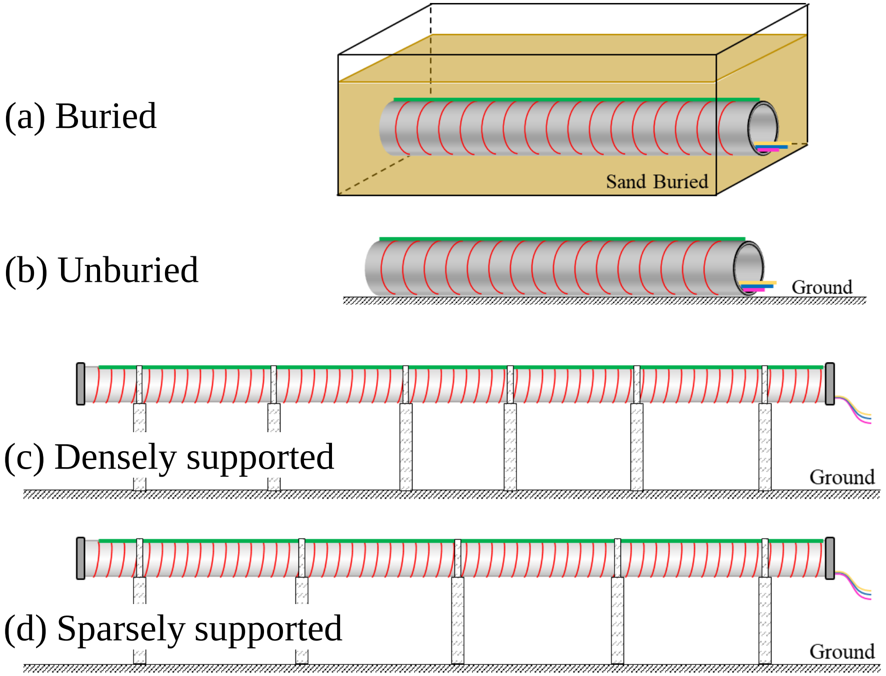


# Tasks#1&2. Milestone Summary

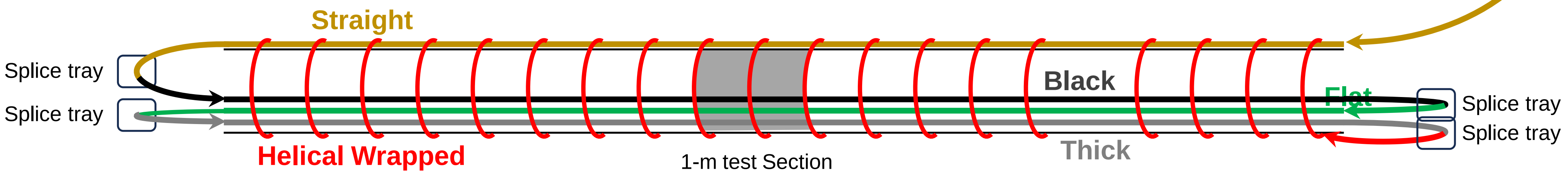
- Liquid accumulation spots were successfully identified through the detection of slugging phenomena occurring at the pipeline's low points. This identification utilized standard deviated process data and frequency spectrum curves, particularly at a frequency of 20 Hz, across all deployment methods.
- Sensitivity analysis revealed variations among deployment methods. The analysis, conducted using standard deviation DAS processed data, highlighted that the flat cable demonstrated the highest sensitivity, followed by thin, straight, helical, and thick cables.
- DAS captured well the slug-induced pressure fluctuations and correlated well with the pressure measurements.
- The study characterized slugging behavior using DAS, such as slug frequency and velocity, along the pipeline. Analysis revealed that the slug size could be related to the DAS signal magnitude. A positive relationship between the slug size and velocity at a certain flow rate condition was observed.

# Tasks#3-6. Detection of Pipeline Defects

- Experimental Design
  - Steel pipe used: API 5L, NPS 4-in, grade X65
  - 1-meter section of the pipe adapted based on the task investigated
  - Four installation methods (buried, unburied, densely supported, and sparsely supported)





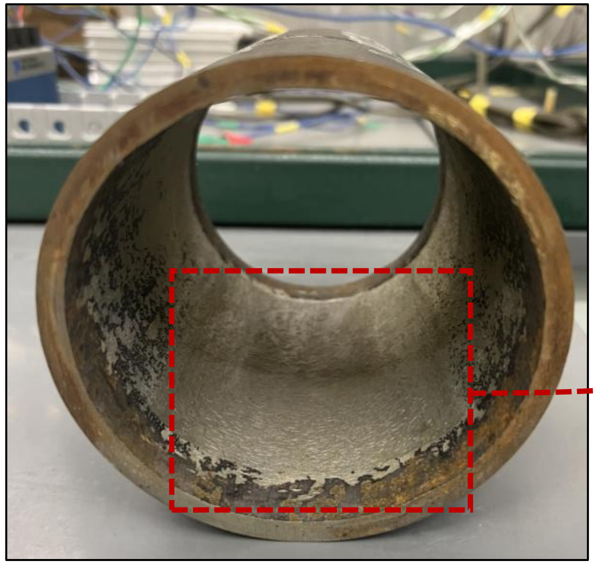


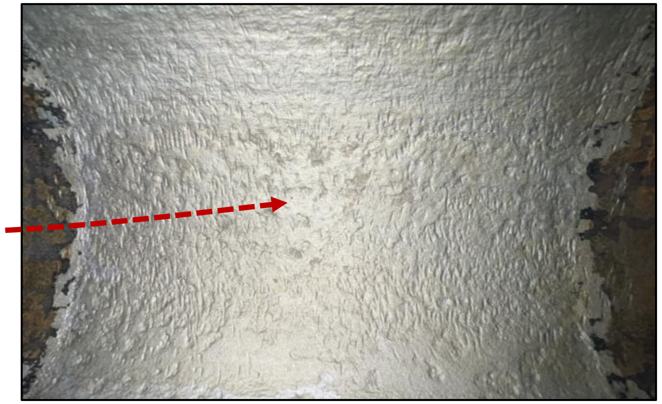
# Tasks#3. Detection of Internal Corroded Spots

- Objective: Investigate the detectability of DAS for internal corrosion with various cable deployment methods under four different pipeline installation conditions.
- Variables
  - 5 different deployment methods
  - 5 gas flow rates (2, 6, 10, 14, 18 m/s)
  - Corroded surface at different severity degrees (3)

# Tasks#3. Detection of Internal Corroded Spots …

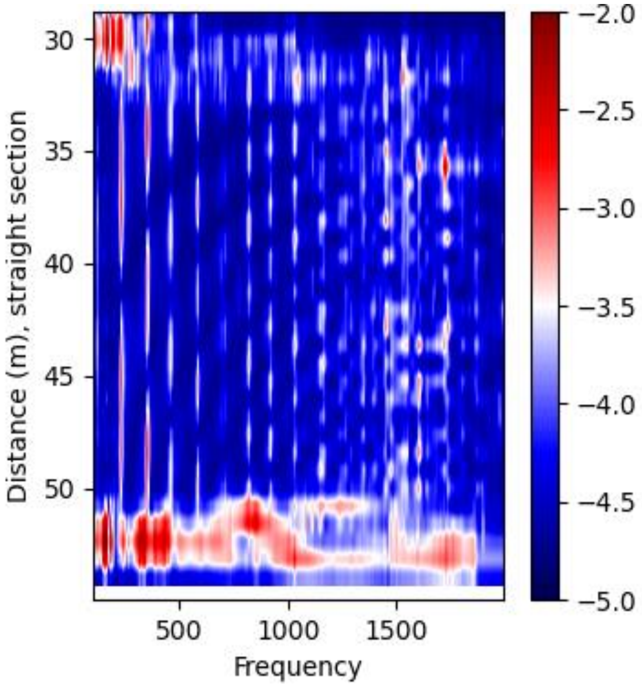
- Corrosion preparation
  - Acid: Hydrochloric acid (37%)
  - Heated system: 65 °C
  - Pipe wall thickness ~ 6.1 mm
  - Corrosion at the 6 O'clock position
  - Targeted corroded depth: 3 and 6 mm
  - The corrosion model indicates wall surface irregularities and pit presence in the corroded pipe surface
  - Final testing depths:
    - Medium corroded depth: 3 mm
    - Severe corroded depth: 5.5 mm
    - Severe corroded depth with a small pit (~ 2mm in diameter)

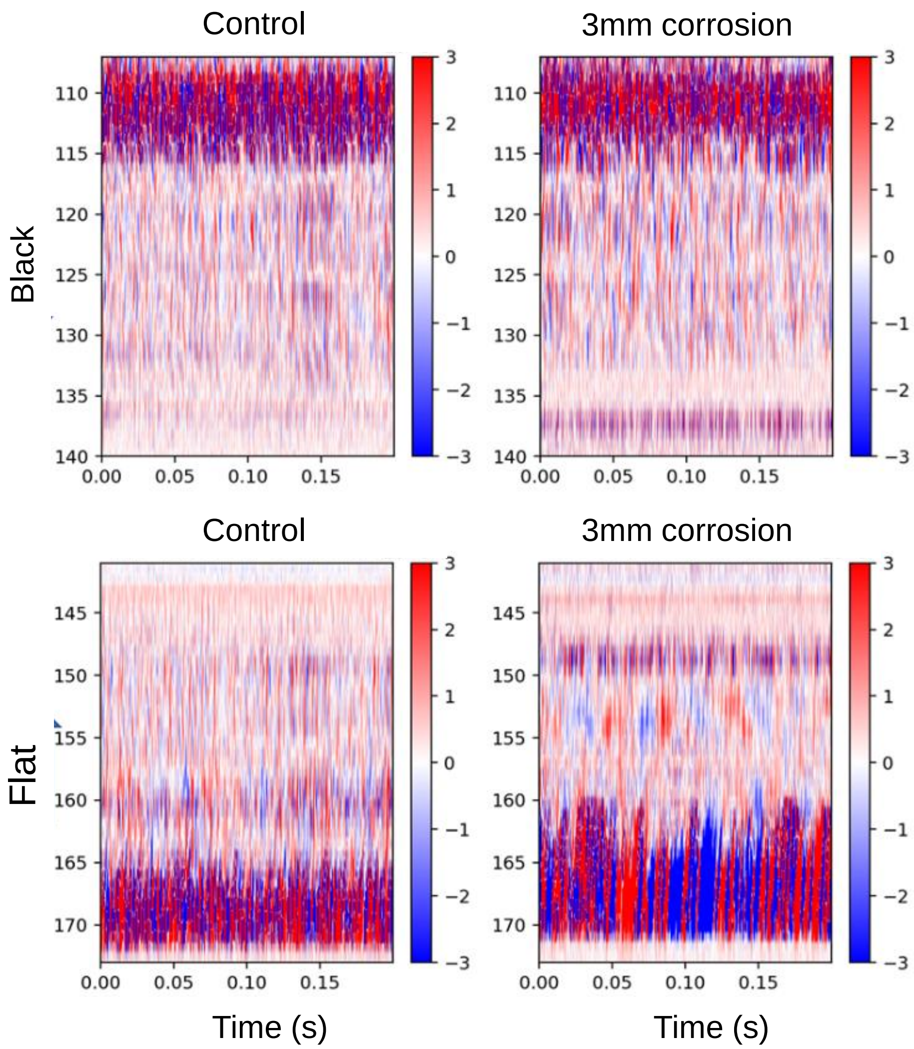




# Tasks#3. Detection of Internal Corroded Spots …

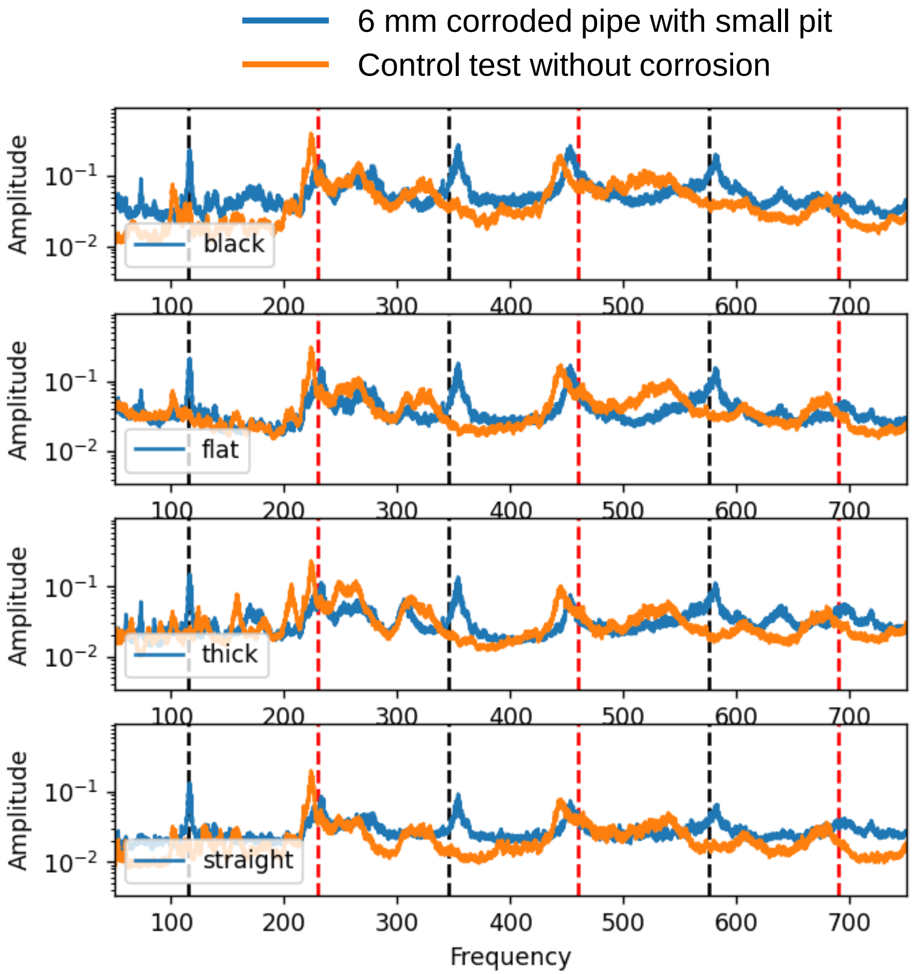
- Results
  - Minimal differences were observed between 3 mm corroded pipe and control experiment data
  - 3 mm is the minimal designed corrosion depth



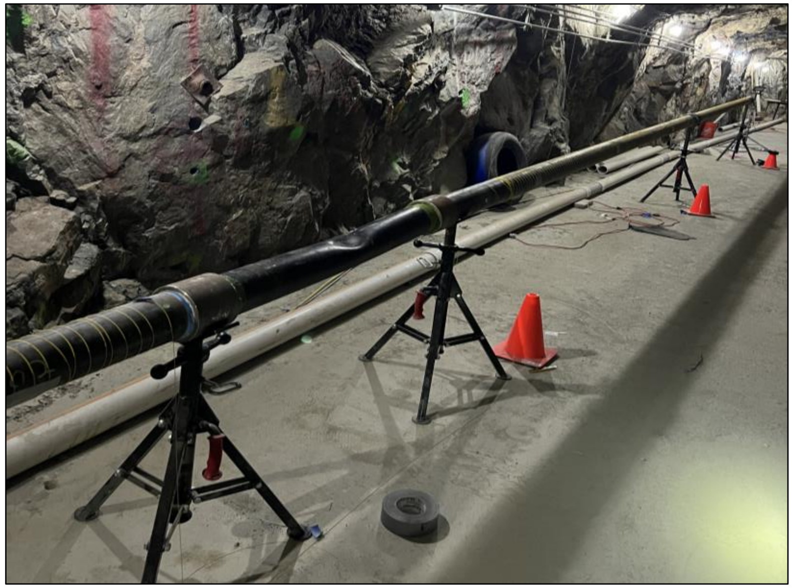
# Tasks#3. Detection of Internal Corroded Spots …

- Results…
  - The experimental design was altered for severe corroded test (6 mm corroded pipe with a small pit), complicating the distinction between the effects of corrosion and design changes
  - Future work:
    - Repeat the experiment with the severely corroded pipe at elevated pressure and the control test with the new joints
    - Test unburied/buried pipeline installation



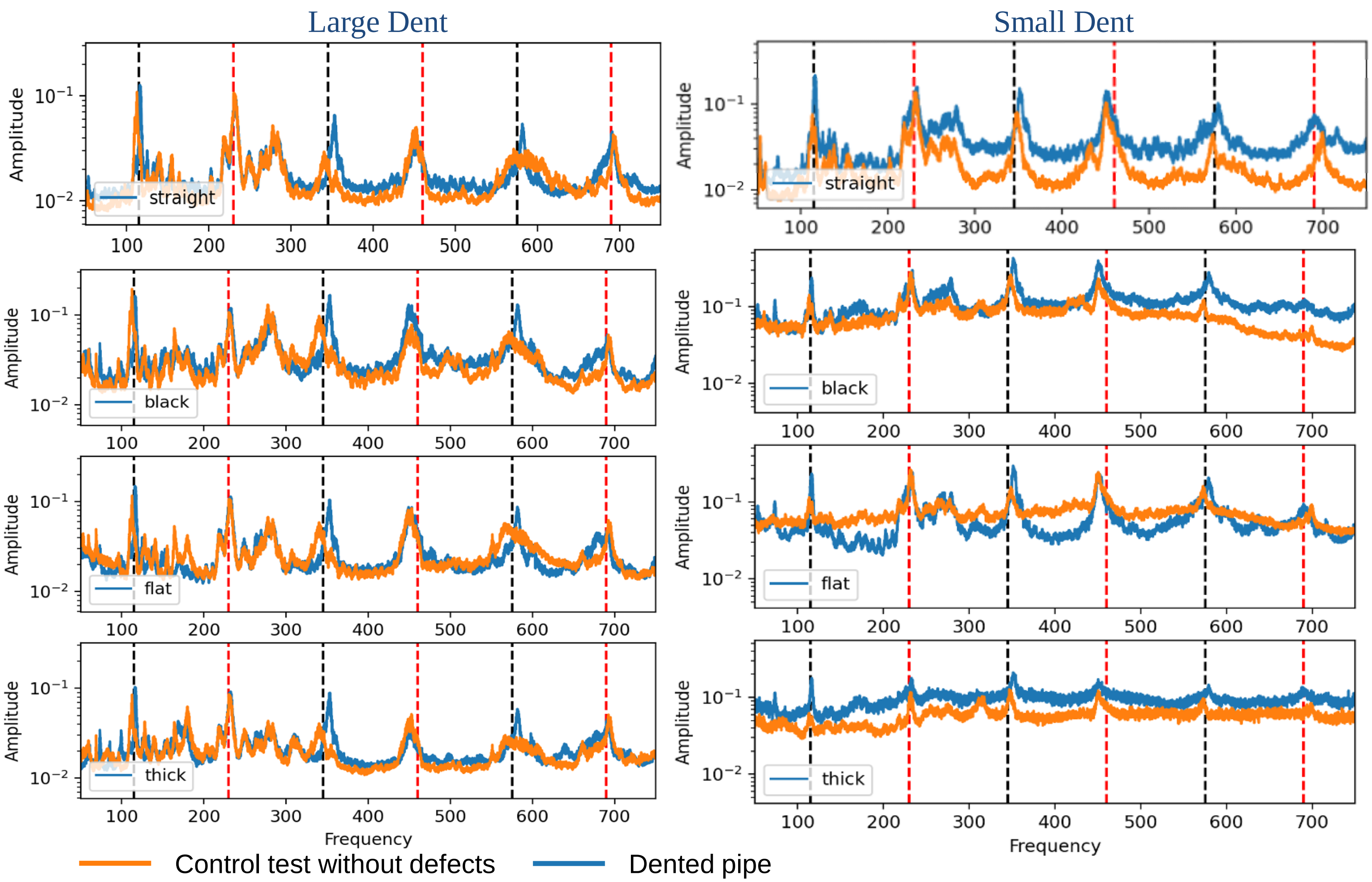
# Tasks#4. Detection of Dent/Deformation on Pipelines

- Objective: Investigate the capability of DAS to identify and locate dents
- Variables
  - 5 different deployment methods
  - 2 pipe installation methods (buried and sparsely supported)
  - 5 gas flow rates (2, 6, 10, 14, 18 m/s)
  - 2 dent sizes



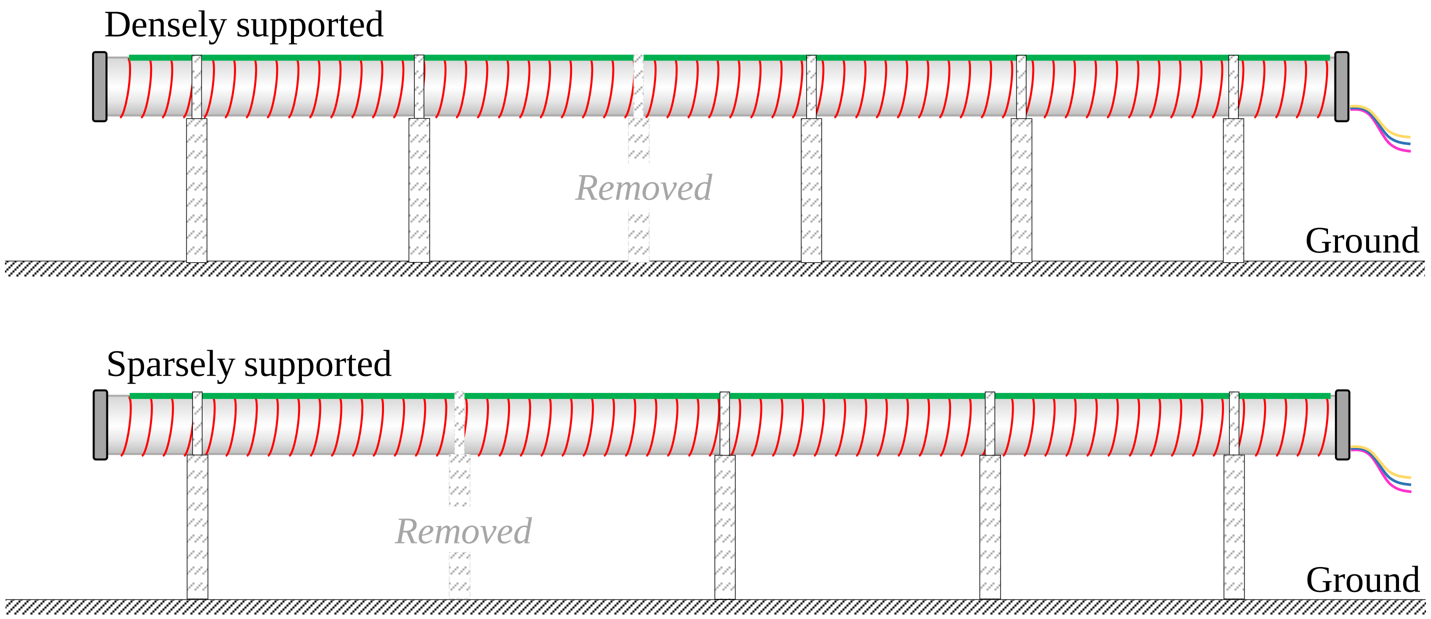

# Tasks#4. Detection of Dent/Deformation on Pipelines …

- Results
  - Sparsely supported pipeline
  - Frequency shift (even-indexed modes)
  - Future work:
    - Optimize data processing workflow
    - Test buried pipeline installation



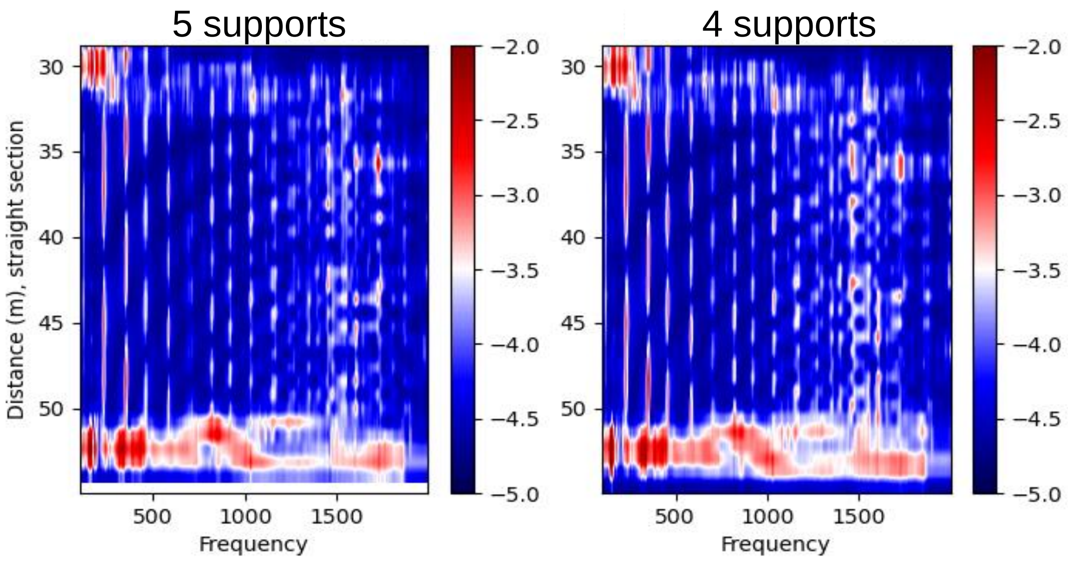
# Tasks#5. Detection of Infrastructure Damage

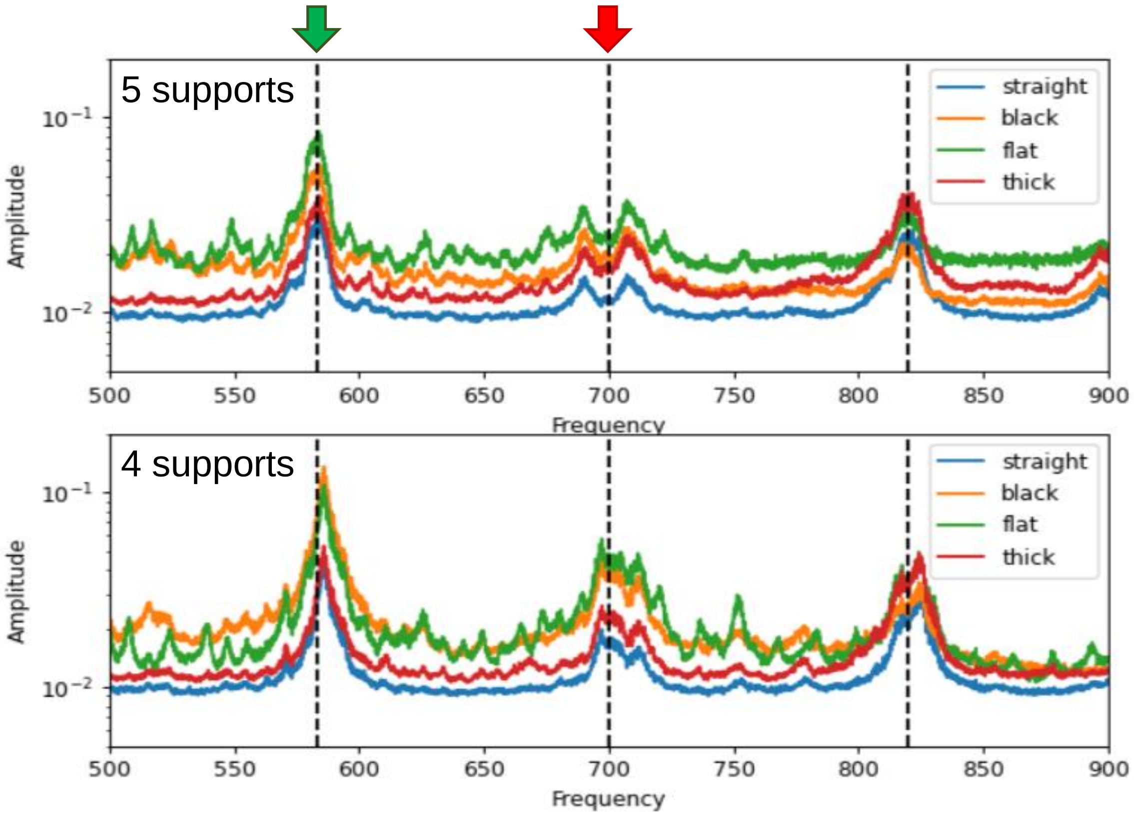
- Objective: Investigate the capability of DAS to monitor infrastructure damage, such as a loose pipeline support.
- Variables
  - 5 different deployment methods
  - 2 pipe installation methods (densely and sparsely supported)
  - 5 gas flow rates (2, 6, 10, 14, 18 m/s)



# Tasks#5. Detection of Infrastructure Damage …

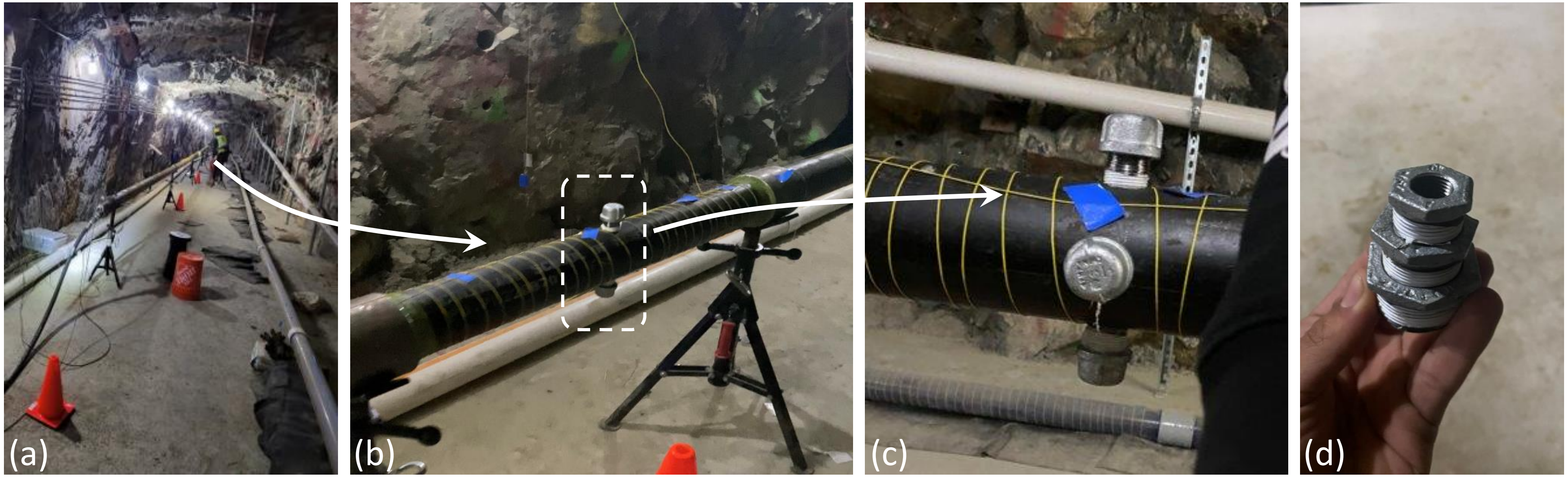
- Results for sparsely supported pipe
  - The frequency and amplitude of several resonant modes have changed after the support been removed.
  - All cables are able to detect these changes, while the flat cable demonstrates the highest vibration level



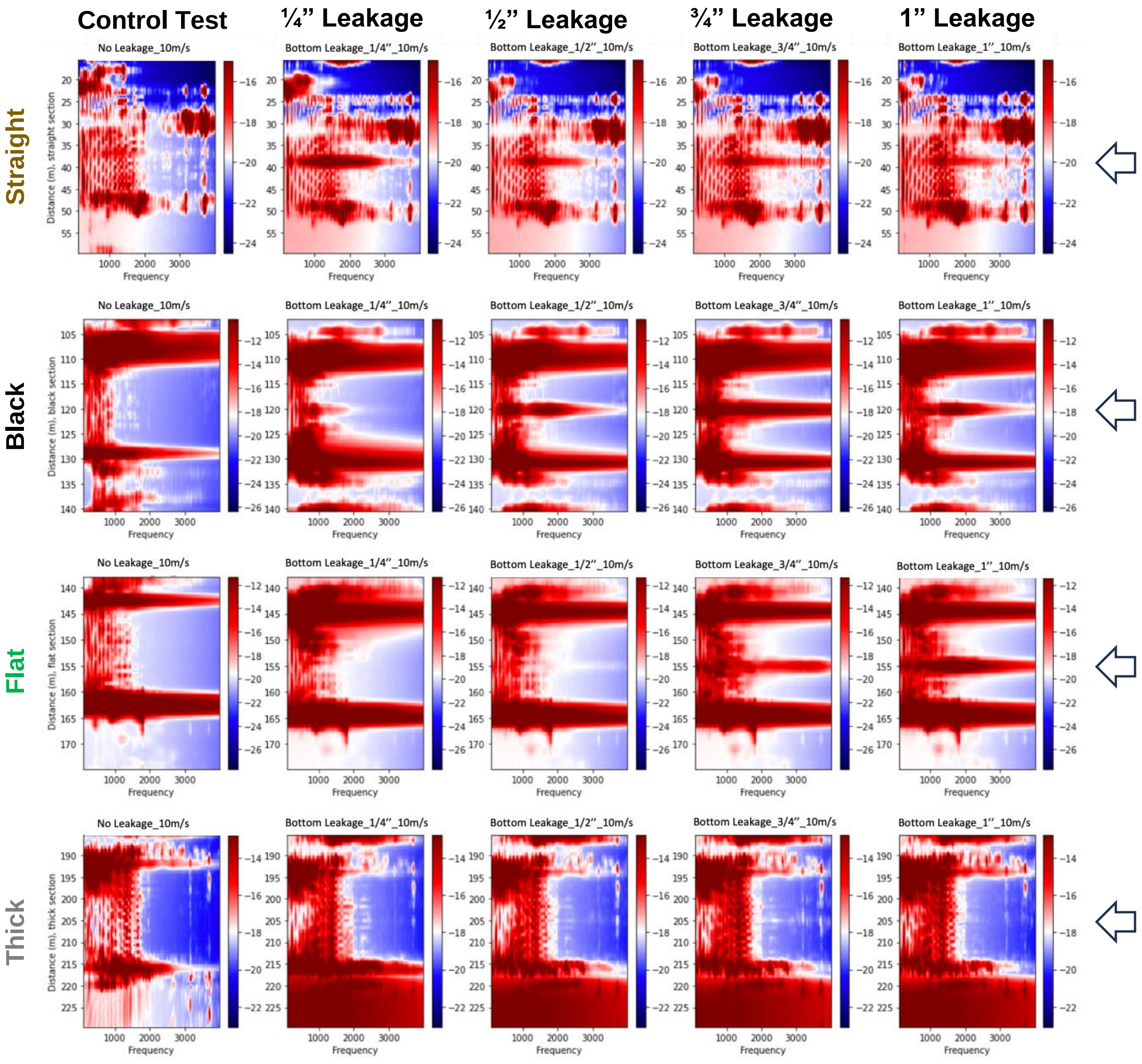
# Tasks#6. Detection of Leakage

- Objective: Experimentally investigate the feasibility of leak detection using DAS with cable internally deployed.
- Variables
  - 5 different deployment methods
  - Buried and sparsely supported pipe
  - 5 gas flow rates (2, 6, 10, 14, 18 m/s)
  - 4 leakage sizes (¼", ½", ¾", and 1")



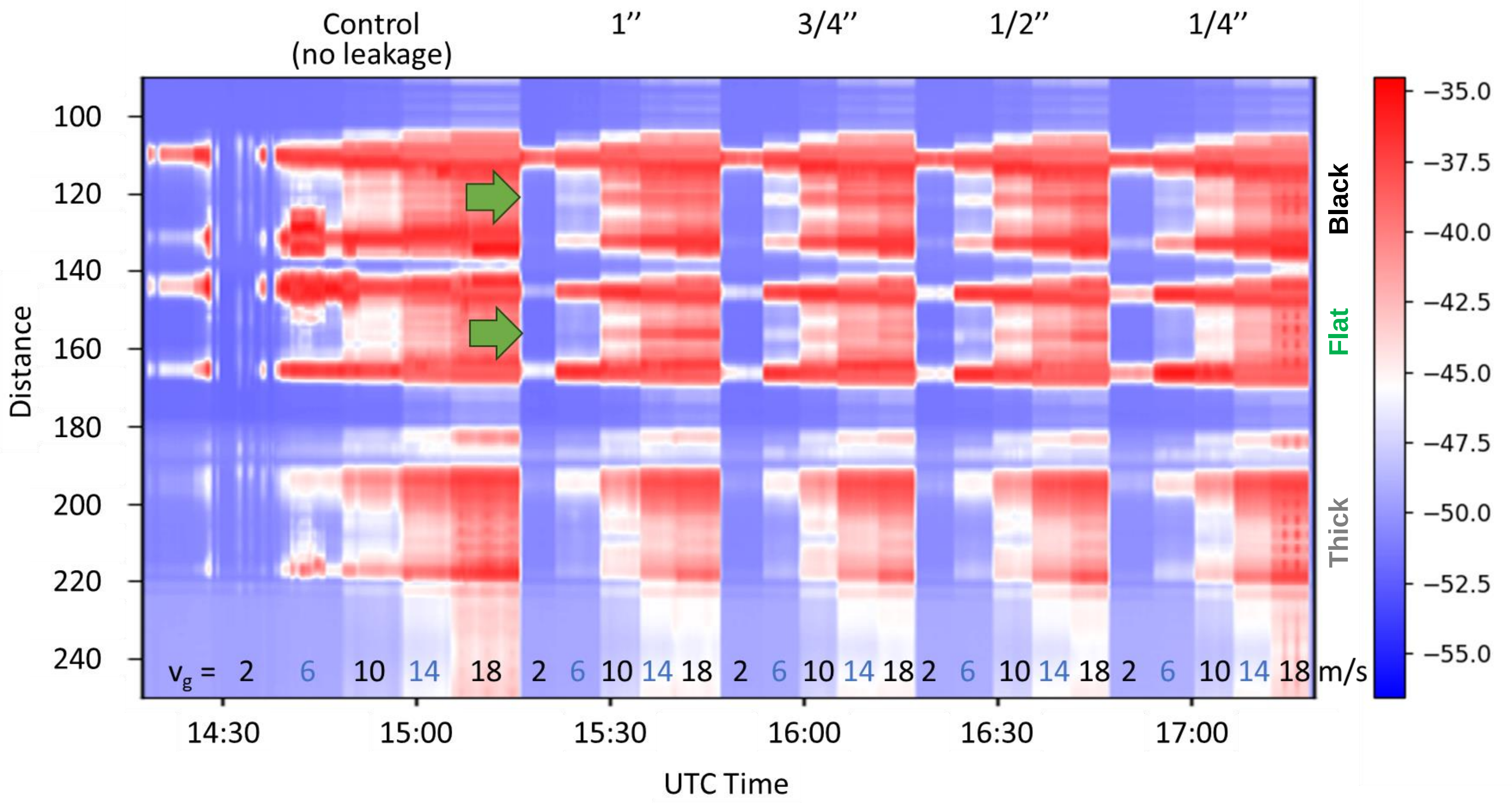
# Tasks#6. Detection of Leakage …

- Results
  - Vibration detected at leakage location (bottom)
  - Black and flat cables detect anomalies effectively
  - Detection with thick cable is reduced due to its heaviness
  - Enhanced mechanical coupling increases external fiber sensitivity



# Tasks#6. Detection of Leakage …

- Results
  - The leakage detection is getting easier as the hole size increases, or the gas velocity increases



# Tasks#3-6. Summary of Milestones

- The fibers currently deployed are not capable of effectively detecting corrosion on the interior surface of the pipe at the minimum designed depth of 3 mm. Further analysis and experiments are scheduled to enhance the detection capabilities.
- Infrastructure damage due to loosened pipeline supports was identified through frequency spectrum analysis, which revealed changes in frequency and amplitude specifically, merging peaks at 700 Hz and shifts at 580 Hz, indicating altered boundary conditions.
- Dents and deformations along the pipeline, indicated by changes in vibration modes, enable the detection of structural anomalies. Frequency shifts occur in even-indexed modes, with no corresponding shifts in odd-indexed modes. This phenomenon is due to even modes having their highest amplitude at the pipe's center, making them sensitive to changes there, while odd modes, with zero amplitude at the center, are not affected by dents at that location.
- Leakage spots at pipe bottom were accurately identified in the pipeline, with larger leak sizes being more detectable, using frequency spectrum curves and two-dimensional Fourier transform spectra. Internal cables, particularly black and flat ones, exhibited higher sensitivity in leak detection, whereas the detection ability of the thicker cable was limited by its heaviness. Enhancement in mechanical coupling facilitated external cables in efficiently detecting the anomalies.

Fiber Optics Research Program

# Thanks