CAAP Quarterly Report

12/31/2024

Project Name: *Easy Deployed Distributed Acoustic Sensing System for Remotely Assessing Potential and Existing Risks to Pipeline Integrity*

Contract Number: *693JK3215002CAAP*

Prime University: *Colorado School of Mines*

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Reporting Period: *[10/01/2024 – 12/31/2024]*

Project Activities for Reporting Period:

During this reporting period, we published a peer-reviewed journal paper in 11/2024, which has been uploaded to MIS:

Garcia-Ceballos, A., Benabid, M-K., Jin, G., and Fan, Y. 2024. Monitoring Slug Flow Using Distributed Acoustic Sensing Technology with Different Sensing Cable Configurations. SPE J. 29 (12): 6980–6992. SPE-223932-PA. https://doi.org/10.2118/223932-PA.

We also completed the experiments outlined in the project proposal for the unburied pipe installation configuration, specifically focusing on Task #3: Detection of Corroded Spots on Pipeline Interior Surface. These experiments were conducted on three test sections with different internal corrosion depths: a 3 mm corroded pipe, a 5 mm corroded pipe, and a severely corroded pipe with a small leak. The findings, along with detailed data analysis and results, are presented in the first following sub-section.

Additionally, we finalized the preparation of the buried pipe at the Edgar Mine. As shown in Figure 1, the buried pipe is contained within wooden boxes, placed on a sand bed, and covered by pouring additional sand along its entire length.

During this reporting period, we also completed the experiments in the buried configuration for Task #6: leakage detection. The results, findings, and associated discussions are outlined in the subsequent sub-section.

Task#3. Detection of Corroded Spots on Pipeline Interior Surface (Unburied Pipeline)

During this reporting period, experiments were conducted using the three internally corroded pipe sections (3 mm corroded depth, a 5 mm corroded depth, and a severely corroded pipe with a small leak) in the unburied pipeline setup where the pipeline is laid on the ground. For data processing, standard deviation calculations were initially performed to check the quality of the data. This was followed by Fourier transform analysis to extract the frequency amplitudes along the fiber for each cable. The amplitudes were then averaged across frequencies for each cable to generate frequency intensity profiles. For further details on the data processing steps, please refer to our previously submitted reports. This approach enabled a comparative analysis between the corroded pipe data and the control experiment, which utilized a 1-meter defect-free section.

The results showed that the cable was able to detect the severely corroded pipe, but not effective for the 3 mm and 5 mm corroded pipe.

<u>Task#6. Detection of Leakage (Buried Pipeline)</u>

During this reporting period, we successfully completed the recording, processing, and analysis of data for the leakage detection task in the buried pipe configuration. The same data processing workflow used in previous leakage detection experiments in the supported pipeline was followed. Initially, the standard deviation (STD) of the data was calculated, followed by a Fourier transform analysis to examine the frequency content and identify frequency bands associated with the leakage signal and anomaly detection. Additionally, the average vibration intensity along the cables was computed. For further details on the data processing steps, please refer to our previously submitted reports. The buried pipe leakage experiment utilized spliced fiber cables in the following sequence:

- Straight cable (externally taped to the top of the pipeline): Fiber distance from 35-58 meters, flow direction from 58 to 35.
- Black cable (internally deployed within the pipeline): Fiber distance from 118-140 meters, flow direction from 118 to 140.
- Flat cable (internally deployed within the pipeline): Fiber distance from 154-175 meters, flow direction from 175 to 154.

Figure 2 presents the STD data attributes for the leakage experiment conducted on the same day. The experiment began with a control test (no leakage), followed by sequential leakage tests at the top, bottom, and side of the pipe. Leakage tests were performed at various hole sizes (1", ¾", ½", and ¼") and flow rates (around 2, 6, 10, 14, and 18 m/s). Blue lines in the figure mark the beginning and end points of the three cables. The figure illustrates variations in vibration intensity along the sensing fibers. Higher values (depicted in red) correspond to higher standard deviation values, indicating increased vibration intensity at specific times and locations along the cables. Similar to the results from leakage detection in the supported pipeline, higher flow rates consistently induce stronger vibrations across all cable types. More intense vibrations are observed near the pipe's center, where the leakage is introduced, with the black cable showing the highest sensitivity. However, compared to the results from the supported pipeline, the overall detection capability across all cables is reduced. Vibration anomalies diminish with decreasing hole size and are absent in control tests.

<u>Discussion on Leakage Detection based on Leak Size and Orientation</u>

Figure 3 illustrates the average vibration intensity profiles along the fiber cables of interest during the control, top, side, and bottom leakage experiments. These experiments were conducted with four leak sizes (1", ¾", ½", and ¼") at a flow velocity of 10 m/s. The overall detectability of leakage across all cables, when compared to the previously reported results from leakage detection experiments in the supported pipeline, is reduced. Among the cables, the black cable is the most sensitive one that detects the leakage anomaly across all orientations (top, side, and bottom). The leakage at the top seems to give the strongest signals, followed by the bottom and side. Its ability to detect the bottom leakage is limited to where the leakage size exceeds ¾ of an inch. The flat cable demonstrates detection sensitivity mainly for the bottom leakage and exclusively when the leak size is 1 inch. In contrast, the straight cable shows no sensitivity for leakage detection across all tested leakage sizes and orientations. We will investigate further the other flow rates in the near future to verify these findings.

Discussion on Leakage Detection based on Flow Rate

The sensitivity of leakage detection is also influenced by the gas flow rate within the pipe. Figure 4 illustrates the vibration intensity distribution along the three fiber cables at different flow rates for a 1" leakage hole. The figure initially presents the results of the control experiment, as detected by the flat cable. In this control test, vibration intensity increases with rising flow rates, and no vibration anomaly is observed at the pipe's center since no leakage holes were introduced. In contrast, the experiment with a 1" leakage hole at the bottom reveals a vibration anomaly at the leakage location. This anomaly becomes detectable at flow velocities exceeding 3 m/s for the black cable and 10 m/s for the flat cable. The straight cable does not show any obvious leakage anomaly across all tested flow rates. The black cable, being the most sensitive to detecting the vibration anomalies, demonstrates increased detectability with higher flow velocities. This trend aligns with our previously reported results from the leakage detection experiments conducted on the supported pipeline.

Spectrum Analysis

Figure 5 to Figure 7 present the 2D spectra obtained from experiments conducted with various leakage sizes positioned at the top (Figure 5), side (Figure 6), and bottom (Figure 7) of the pipe, respectively, at a flow velocity of 10 m/s. Similar to the findings from the average vibration intensity profiles, leakage anomalies are not easily observed for any leakage size or orientation when using the straight external or flat internal cables. The leakage anomaly is more obvious from the black cable. Compared to the results from the leakage detection experiments in the supported pipeline, the overall sensitivity of the cables is reduced in this configuration. Further analysis will be conducted for the other flow rates in the near future.

Moving forward, we will complete the remaining experiments in the buried pipe configuration, focusing on Task #4: Detection of Dent/Deformation and Task #3: Detection of Corroded Spots on Pipeline Interior Surface.

Project Financial Activities Incurred during the Reporting Period:

The following table summarizes the financial activities and the corresponding expenses during the reporting period. Also shown are the updated total budget for the last two quarters in Year 3 and Year 4 (i.e., Q11-Q16), and the total expenses in this reporting period (Q13), as well as in the last two quarters in Year 3 and Year 4 (Q11-Q13). Please note that the actual amount for the expenses might be slightly different from the numbers in the final financial report, since some of the expenses occurring in late of the quarter may not be included in the university's financial system that we use for managing the funds and expenses by the time the report is submitted. Normally, it takes several days for an expense to be shown in the system after its occurrence.

Items\Budget and Expenses		Total Budget for Q11-Q16	Total Expenses in Q13	Total Expenses in Q11-Q13
1	Faculty Salaries and Wages including Fringe Benefits	$33,502.00	$0	$29,031.37
2	Student Salaries	$34,701.00	$9,110.04	$19,685.13
3	Graduate Student Tuition	$24,564.00	$0	$12,367.50
4	Experimental Expenses (experimental work supplies, services, maintenance, cables, etc.)	$15,537.00	$3,627.05	$6,843.14
5	Travel	$8,000.00	$3,555.01	$4,081.71
6	Indirect Costs (51.5%)	$47,246.80	$8,390.43	$30,715.30
Total		**$163,550.80**	**$24,682.53**	**$102,724.15**

Project Activities with Cost Share Partners:
The cost shares are the AY efforts of the PI and co-PIs. Activities are the same as above.
Project Activities with External Partners: No external partners.
Potential Project Risks: Same as previous reports.
Future Project Work:
In the next 30 days, we will continue processing the data recorded from the previous quarter.
In the next 60-90 days, we are planning to conduct experiments for the buried pipeline, and perform corresponding data processing and analysis.

Potential Impacts to Pipeline Safety:
Tasks#1 and #2 can potentially help identify and characterize the possible liquid accumulation in a gas gathering or transmission pipeline using DAS, while Tasks#3-6 will potentially help detect the internally corroded surface, deformation, infrastructure damage, and leakage in a gas pipeline.

Appendix

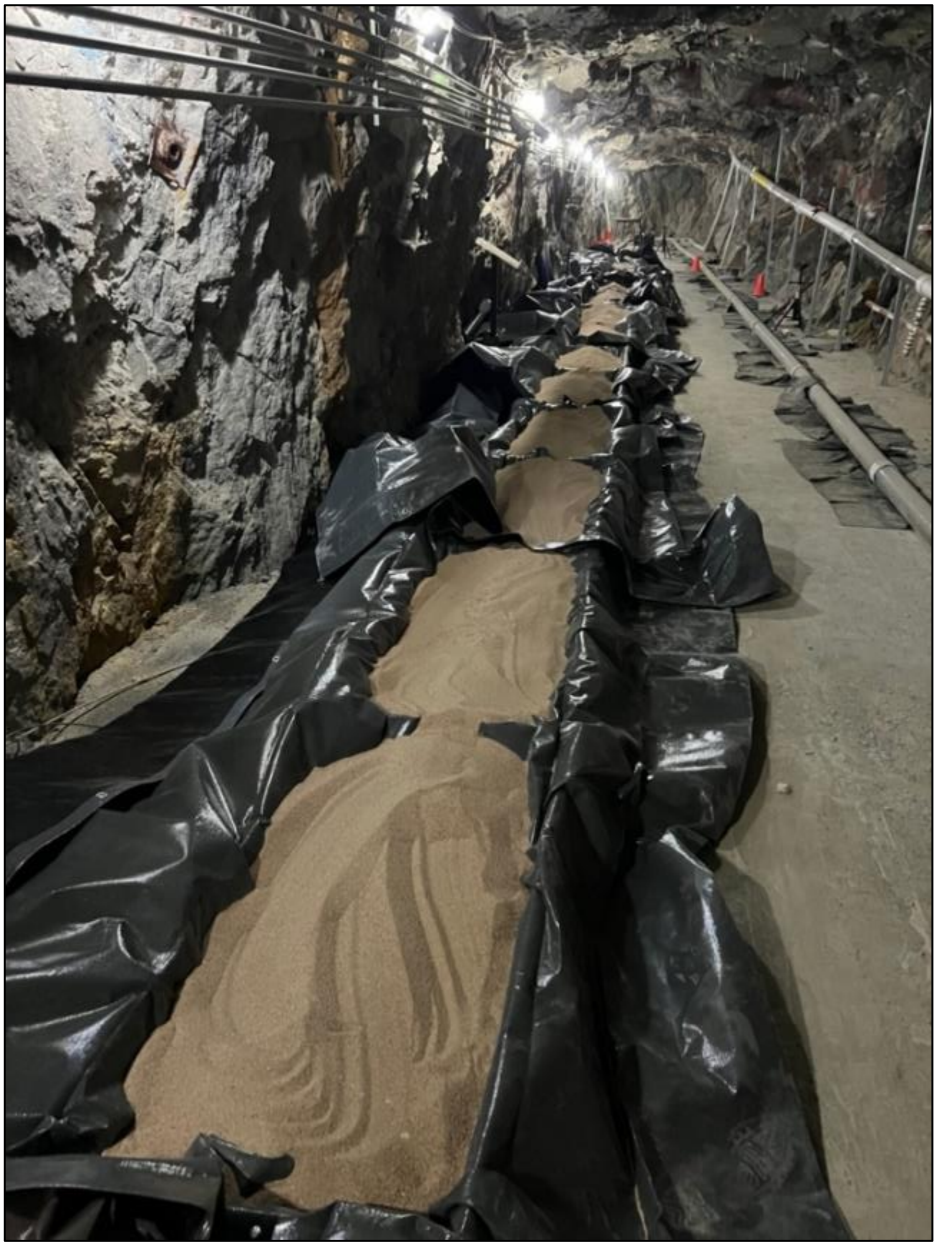


Figure 1. Photograph of the Buried Pipeline

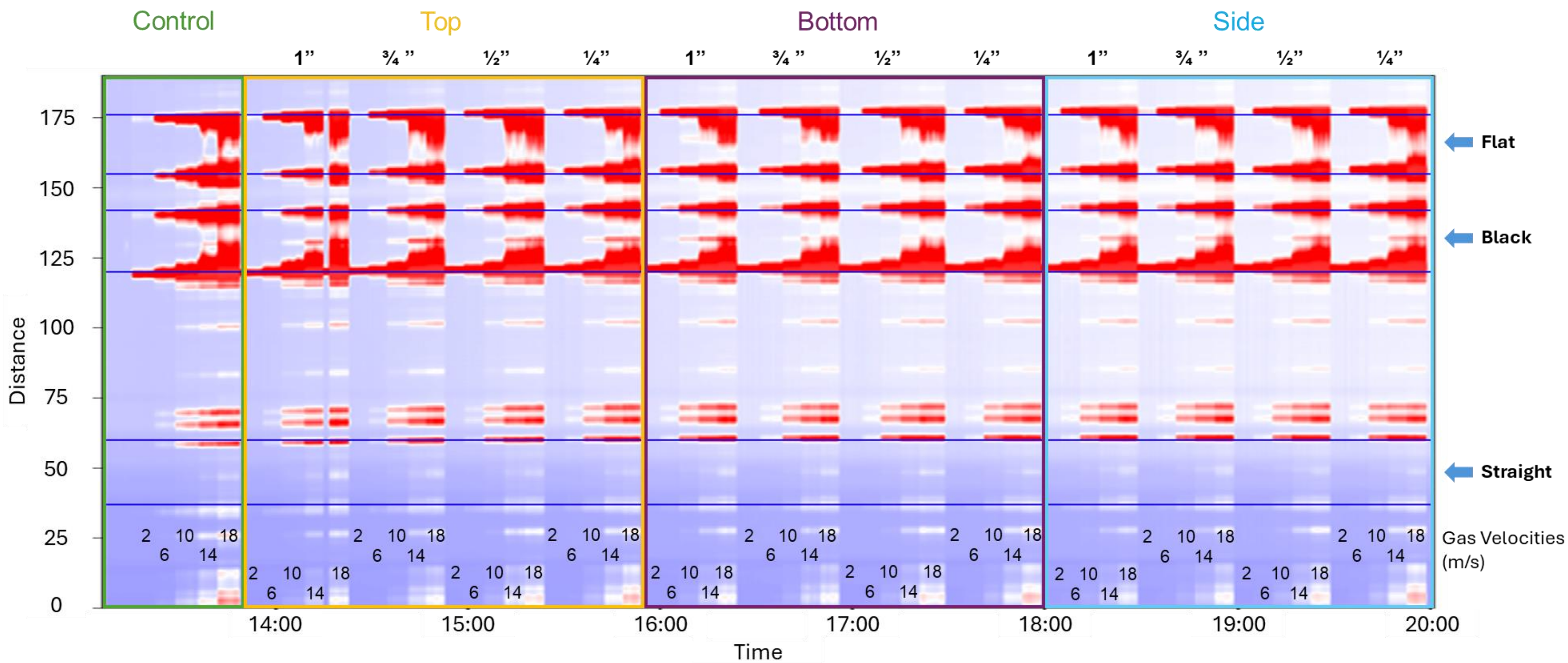


Figure 2. Magnitude of standard deviation values in straight external, black, and flat fiber sections during the control, top, bottom, and side leakage experiments with different hole sizes. The flow velocities inside the pipe change from 2, 6, 10, 14 and 18 m/s (indicated at the bottom left, which can be extended to other time period according to the vibration intensity or color). The arrows indicate the leakage location (at the center of all cable sections).

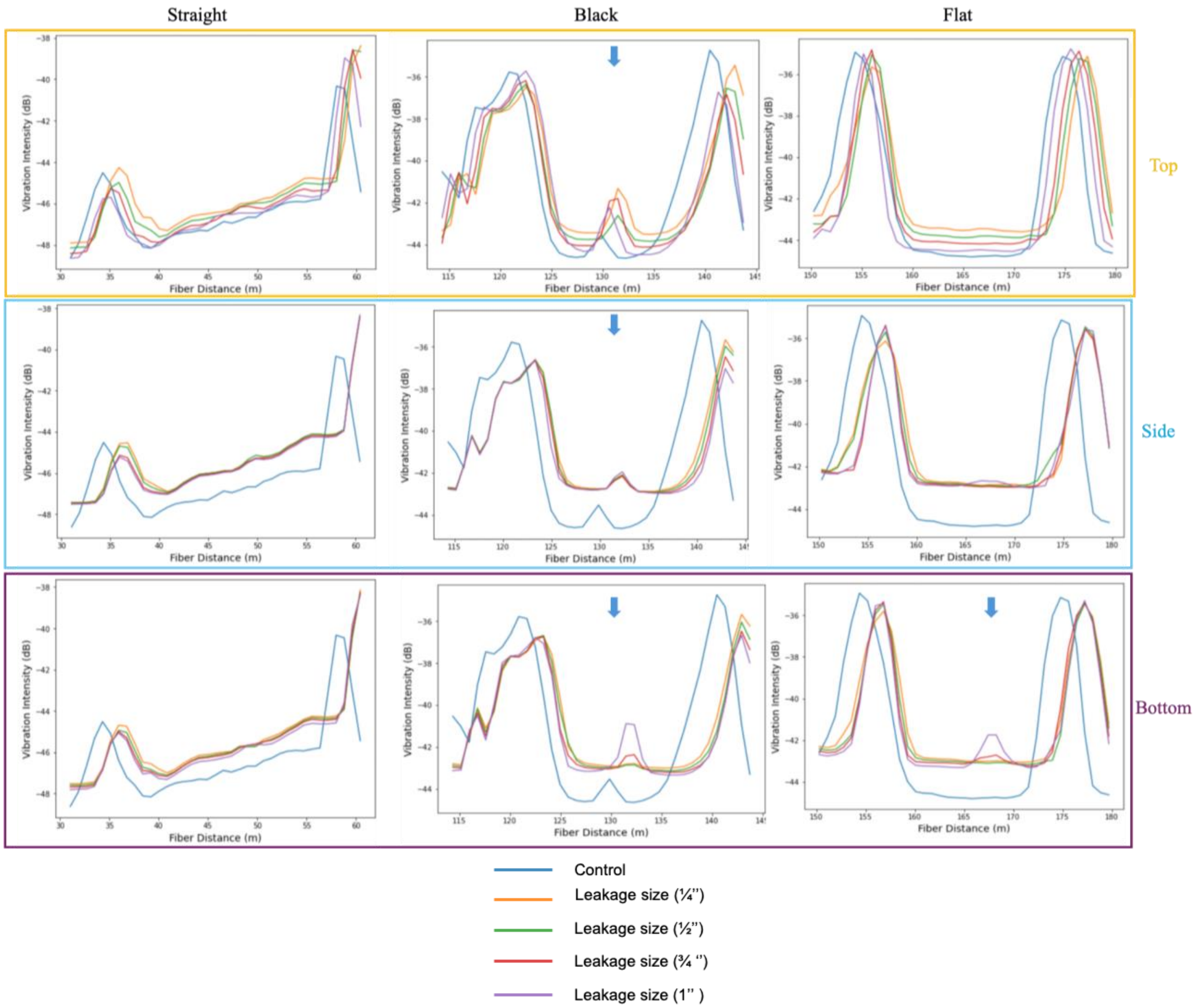
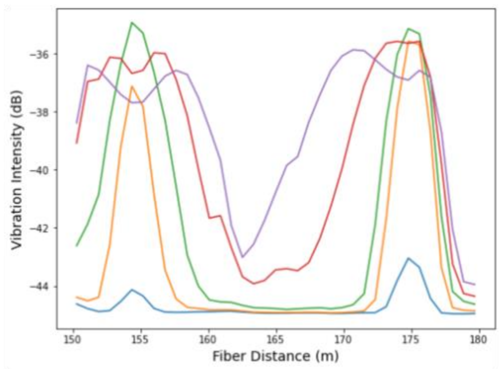
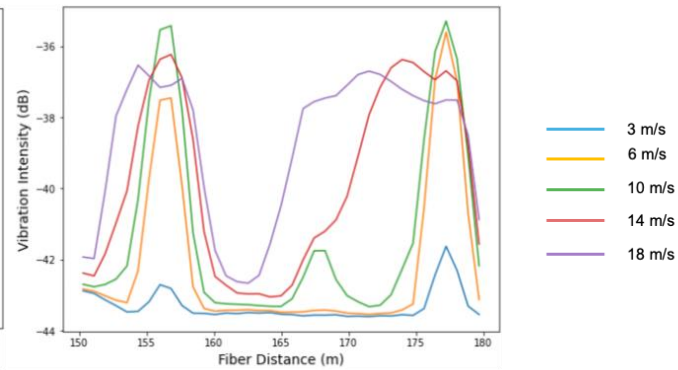


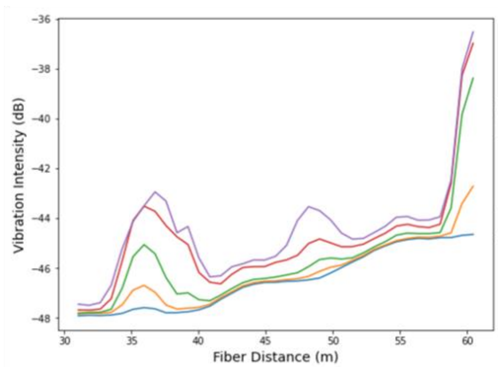
Figure 3. Vibration intensity profiles in straight external (left), black (middle), flat (right), fiber sections during the top, side, and bottom leakage experiments. The different curves represent vibration intensities associated with varying leakage hole sizes at a flow velocity of 10 m/s. Anomalies in vibration, induced by leakage holes and marked by blue arrows.



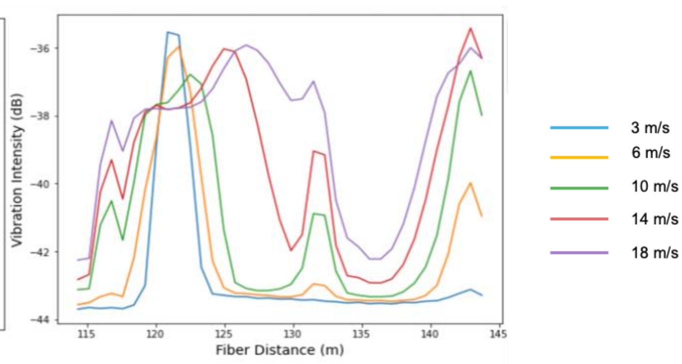
Flat (control)



Flat (1" Leak)



Straight (1" Leak)



Black (1" Leak)

Figure 4. Comparison of the leakage detection sensitivity during a bottom leakage experiment across different cable types at varying flow velocities. Top left shows a flat cable without leakage as a control experiment. Top right features a flat cable with a leakage hole size of 1 inch. The bottom left, and bottom right sections present the straight, and black cables with the same leakage size of 1 inch, respectively.

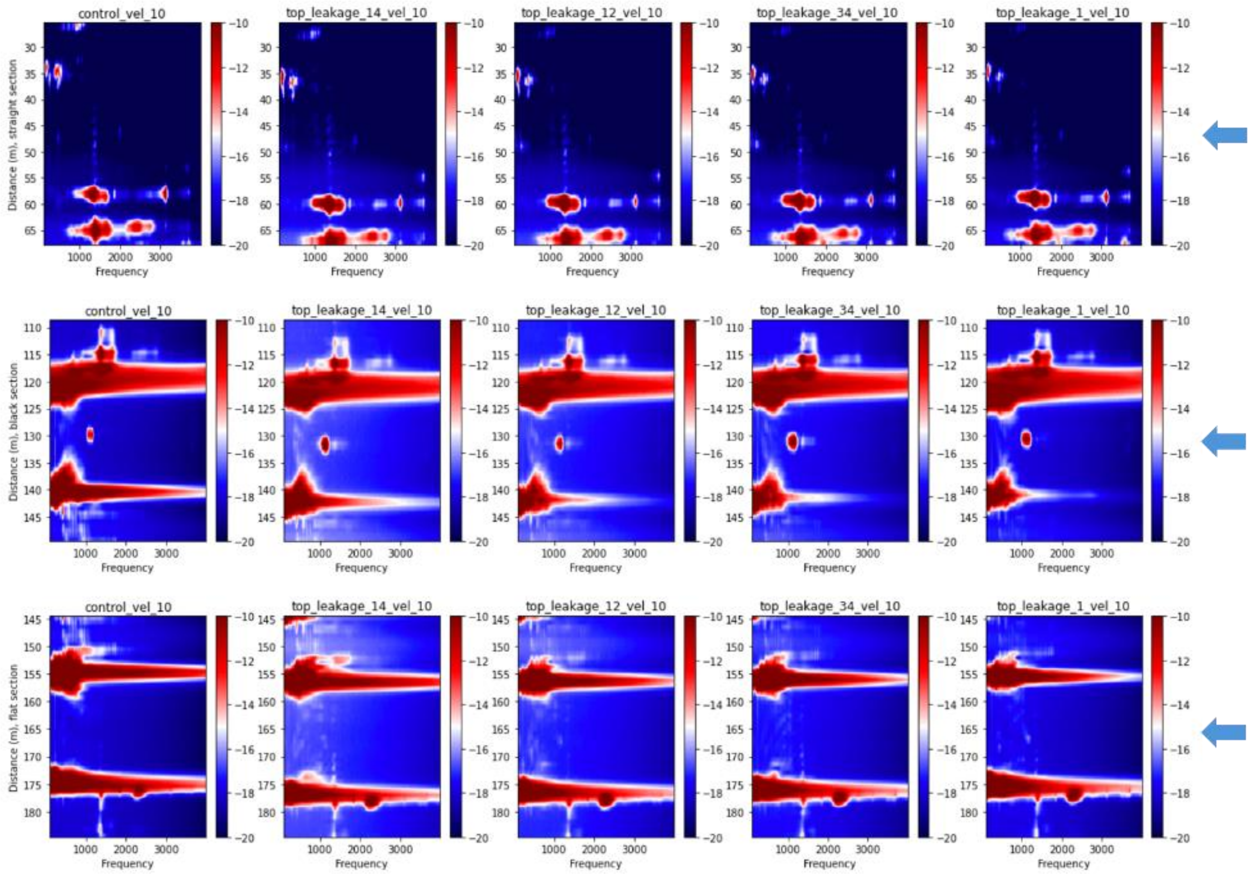


Figure 5. 2D spectra of fiber sections with varying leakage hole sizes at the top of the pipe, measured at a flow rate of 10 m/s. The top row displays the straight cable section, followed by the black, and the flat cable sections. Columns from left to right represent the control experiment (no leakage), followed by leakage sizes of ¼", ½", ¾", and 1", respectively. The color scale is measured in dB. Blue arrows indicate the leakage locations.

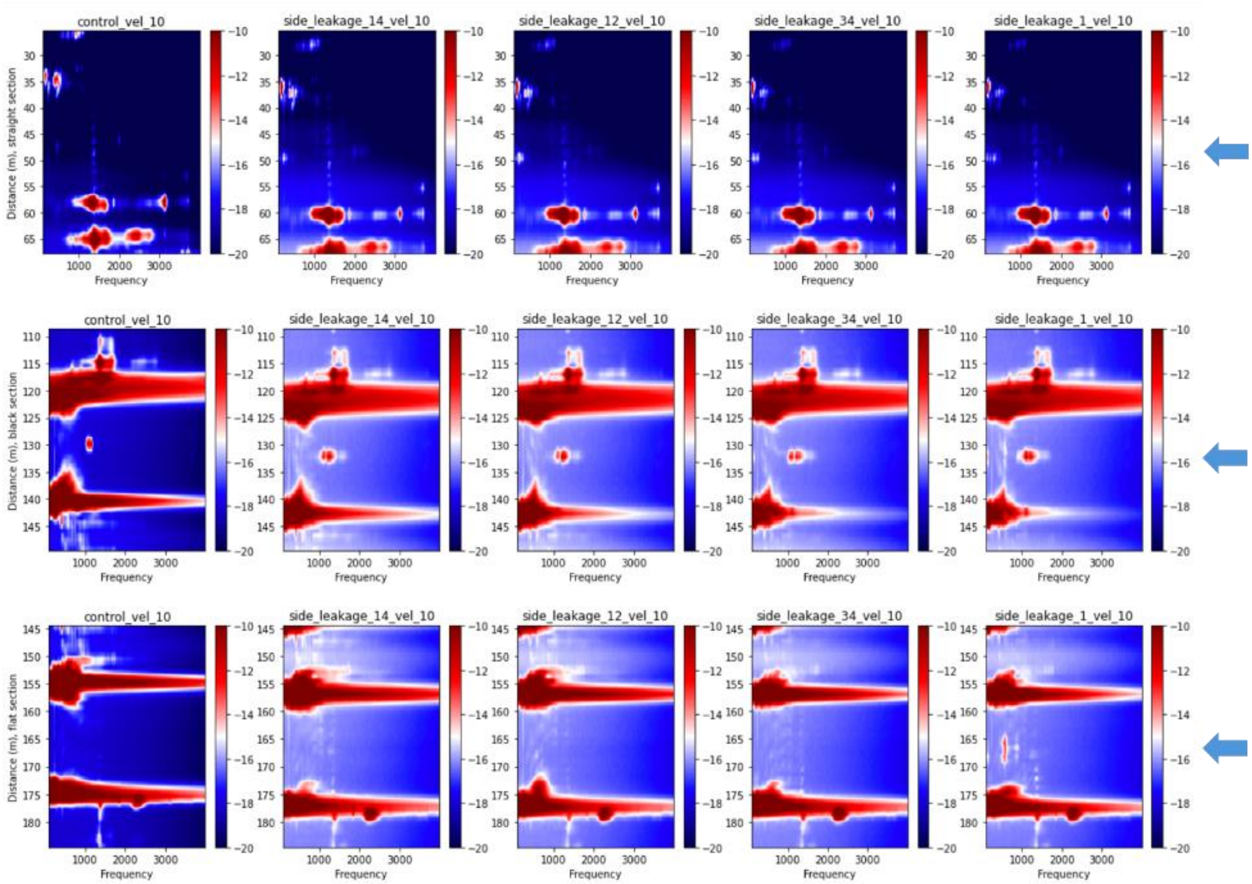


Figure 6. 2D spectra of fiber sections with varying leakage hole sizes at the side of the pipe, measured at a flow rate of 10 m/s. The top row displays the straight cable section, followed by the black, and the flat cable sections. Columns from left to right represent the control experiment (no leakage), followed by leakage sizes of ¼", ½", ¾", and 1", respectively. The color scale is measured in dB. Blue arrows indicate the leakage locations.

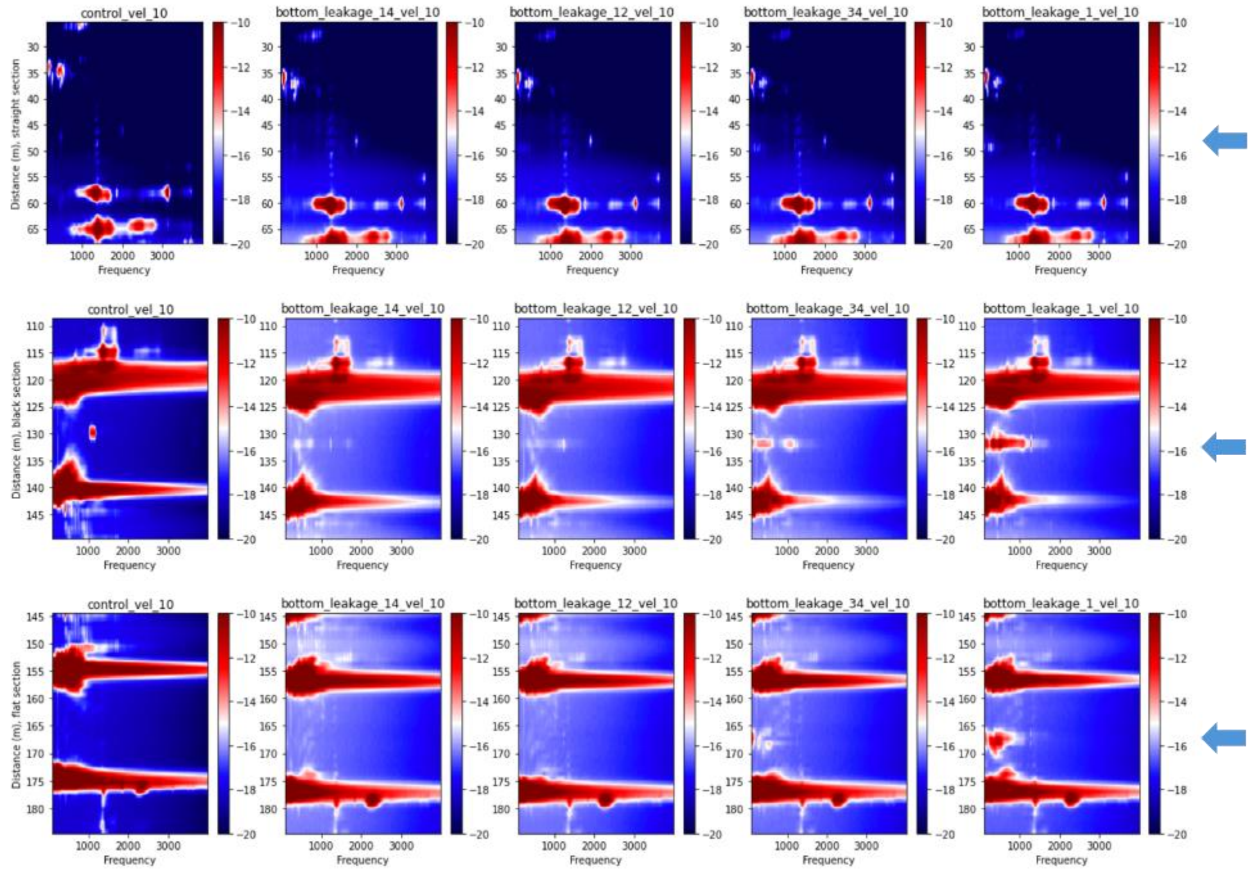


Figure 7. 2D spectra of fiber sections with varying leakage hole sizes at the bottom of the pipe, measured at a flow rate of 10 m/s. The top row displays the straight cable section, followed by the black, and the flat cable sections. Columns from left to right represent the control experiment (no leakage), followed by leakage sizes of ¼", ½", ¾", and 1", respectively. The color scale is measured in dB. Blue arrows indicate the leakage locations.