CAAP Quarterly Report

12/30/2022

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: *[10/01/2022 – 12/30/2022]*

Project Activities for Reporting Period:

The activities completed during the reporting period were all on track. These activities are summarized below:

1. Activities completed during the reported period for Tasks#1&2: Detection of Liquid Accumulation and Dynamic Intermittent (Slug) Structures
   - Two new cable inlets to the PVC flow loop were added to reduce the loss of signal/light in the thin and flat cables as shown in Fig 1. The new inlet in Fig. 1a no longer utilizes a metal plate in order to prevent cable damage. Fig. 1b utilizes a leak paste for a smaller hole created whilst maintaining the flow loop system contained and pressurized.
   - The clear PVC flow loop is complete and equipped with all 5 different fiber optic cables on the testing section: external helically wrapped and straight cables, along with internal flat, thin, and thick cables have all been spliced together.
   - The splicing of all 5 cables was tested with visible light source successfully showing laser light at the end of the connection, as shown in Fig. 2a. However, testing with the Terra 15 interrogator indicated poor laser light transmission, at which point further re-splicing of flat and thin cables and a re-ordering of cable sequence was conducted. To further reduce light loss, tight yellow jack cable loops, shown in Fig. 2b, were unloosened as shown in Fig. 2c.
   - We have successfully conducted single gas phase tests without liquid accumulation as planned. The example waterfall plots for three different velocities are shown in Fig. 3.
   - We have also successfully conducted some preliminary experimental studies for Task#1 with different stagnant accumulated water volumes, namely 1L, 4L, 10L, and 20L, at different gas flow rates. Figs. 4 and 5 show some example waterfall plots for 10L and 20L water volumes in the lower spot for three different gas flow rates. The water was accumulated at the lower spot for the first two gas flow rates, but removed when the gas flow rates increased to the highest one.

- The color in the waterfall plots indicates the strain rate measurements along the fiber, which is believed related to the flow rates as can be seen clearly from the plots. The y-axis indicates the channels along the fiber. The corresponding channels for each cable section are as follows: internal thin fiber cable (26 - 48), internal flat fiber cable (49 - 105), internal thick fiber cable (106 - 160), external straight fiber cable (161- 218), and external helically fiber cable (218 - 700). The x-axis is the measurement time in seconds. The plots in Figs. 3-5 show the data for 1-second of measurement.
- The waterfall plots in Figs. 4&5 do not directly indicate the water accumulation in the Pipe. Our next step is to future process the DAS signals from each fiber cable, and try different data processing algorithms, to better identify the accumulated water in the V-section and the water removal dynamic process, and to understand how the signals are correlated with accumulated water in the pipe. Our preliminary data processing on acoustic intensity estimation shows promising results in capturing the accumulated water and its removal from the DAS signals. We will further verify the datasets before publishing it publicly. More findings will be reported in the future reports.
- During the past period, we also learned a lot of lessons on fiber cable deployment for different type of fiber cables from Tasks#1 and #2, which we believe will also benefit the industry in terms of the future real-world applications in pipeline systems. Therefore, we included a separate section discussing the lessons we learned and the modification we propose for Tasks#3-6, as given in the following section.

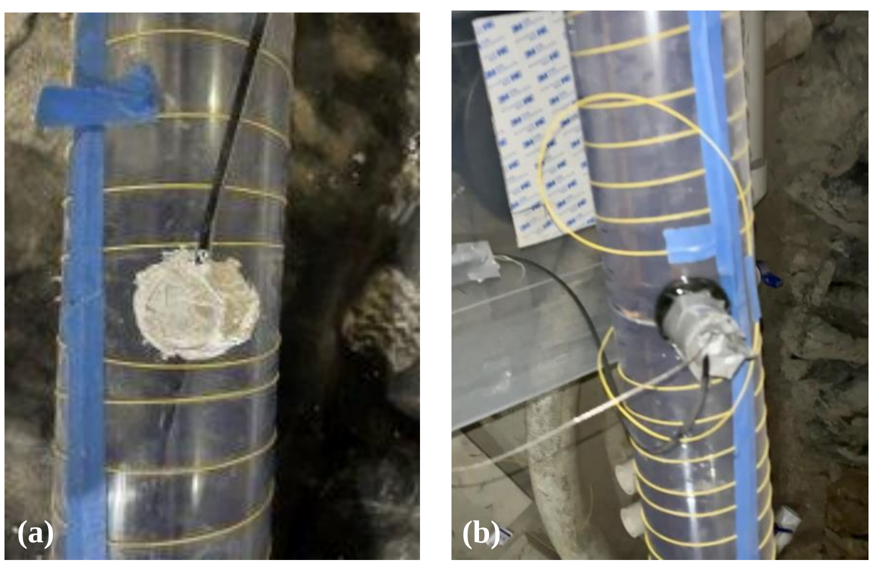

Figure 1. Photograph of the two newly added sealings for inlet and outlet of internal cables. (a) Leak paste used to seal small hole and (b) screw on seal with rubber cork to hold pressure inside.

Figure 2. (a) Photograph of red laser light transmitted to the last cable, helically wrapped cable from OTDR test. (b) Photograph of extra looped cable around a splice point. (c) Photograph of loosened loops to improve signal.

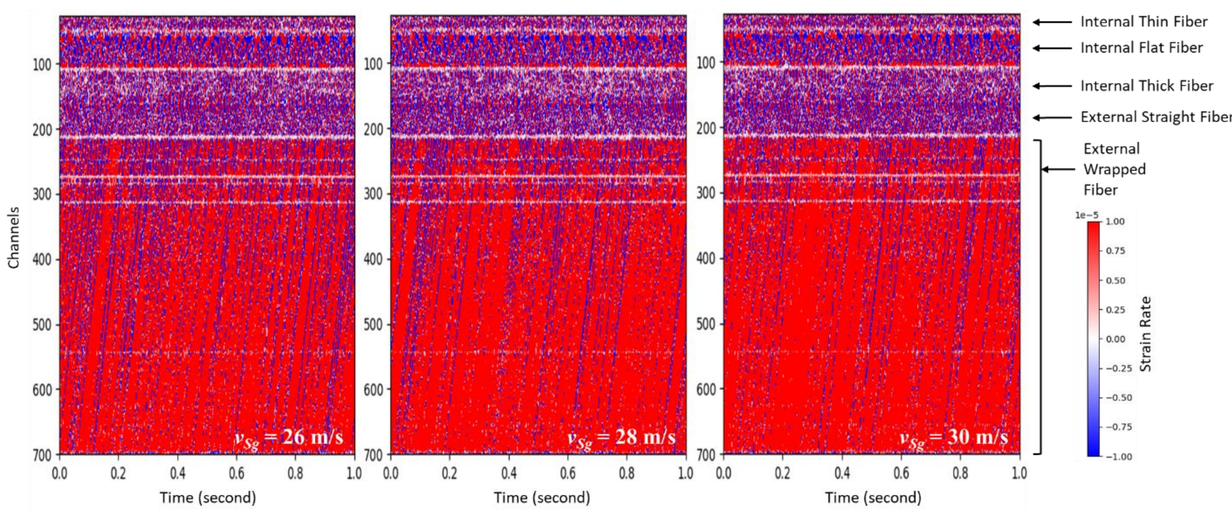

Figure 3. Waterfall plots of processed DAS data for all 5 cables with different gas flow rates (The gas velocities are 26, 28, and 30 m/s from left to right.)

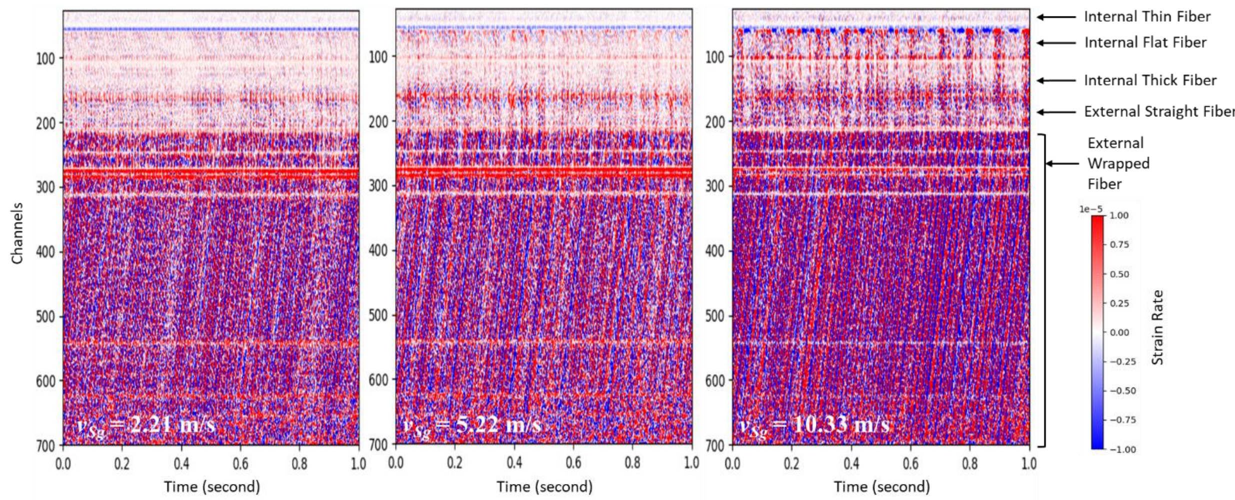

Figure 4. Waterfall plots of processed DAS data for all 5 cables with 10L water in the V-section at different gas flow rates (The superficial gas velocities, defined as the gas volumetric flow rate divided by the pipe cross-sectional area, are 2.21, 5.22, and 10.33 m/s from left to right. Note that all the water is removed when the superficial gas velocity is 10.33 m/s.)

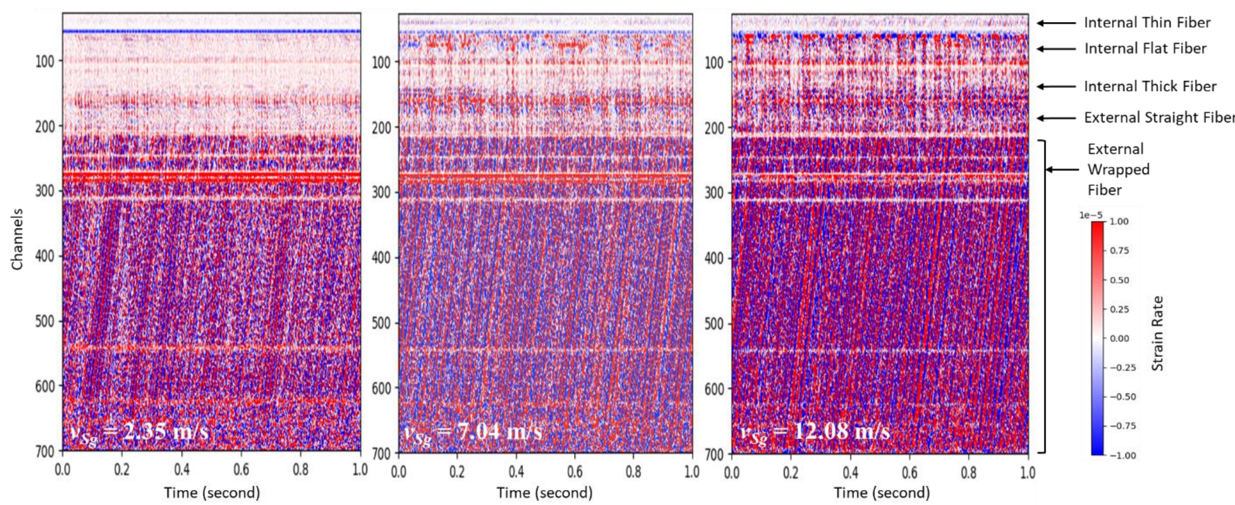

Figure 5. Waterfall plots of processed DAS data for all 5 cables with 20L water in the V-section at different gas flow rates (The superficial gas velocities are 2.35, 7.04, and 12.08 m/s from left to right. Note that all the water is removed when the superficial gas velocity is 12.08 m/s.)

2. Learning from our fiber cable deployment experiences from Tasks#1 and #2, and proposed modifications to Tasks#3-6 according to our experiences from Tasks#1 and 2
    - Four different types of cables have been tested up until the latest quarterly report. These include, yellow tight buffer cable from Fibertronics along with thin, thick, and flat cables from Neubrex Technologies. Initially, the cables were going to be connected consecutively with each other in the following order: straight external yellow buffer cable with the thin cable, followed by the straight cable and then succeeded by the thick cable and the external helically wrapped cable coming in last. However, after multiple

attempts to splice together the thin, flat and thick cables, all of which are internal cables, it was decided that a small section of the yellow buffer cable which is more versatile would be used to connect between the internal cables as shown in Fig. 6a. The internal cables, once stripped of the protection material, were very challenging to keep protected whilst still withstanding small movements in a field setting such as the one of Edgar Mine. Furthermore, the thin and flat cables were specifically prone to damages even with the protective material in place as observed at the two sealings. At the inlet and outlet sealings for the internal cables, the thin and flat cables were easily bent and permanently damaged, however, the thick cable withstood bending at both locations, proving to be more practical for field deployments. Junction boxes were used at the ends where the internal cables exited the flow loop section in order to provide protection for the exposed fiber.

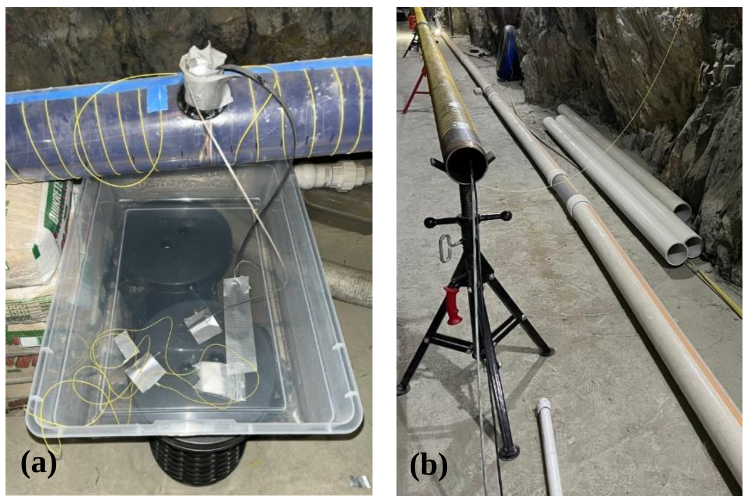

Figure 6. (a) Photograph of connection between thin and flat cable with yellow buffer cable in between. (b) Photograph of steel pipeline with three deployed fiber cables, including external helically wrapped yellow buffer cable, internal thick cable, and internal ground tactical cables.

- The lessons learned from Tasks #1 & 2's cable deployment have demonstrated that the thin and flat cables from Neubrex Technologies company are very delicate for a field setting, and can barely survive in harsh environment. Additionally, from preliminary data analysis, the thin cable is the least sensitive to flow as shown from Figs. 4&5. As a result, the cables implemented in Tasks #3-6 have been reevaluated. Instead of using three internal cables, two of which have been shown to be not practical for a harsh field setting, only two internal cables are used. The internal cables deployed in the steel pipeline for tasks #3-6 are the thick cable from Neubrex Technologies (same as the one in Tasks#1 and #2), and a ground-tactical cable from OCC that is more robust for harsh environments and better suited for deployment and retrieval for reuse, considering the 1-m section in the middle to be changed more frequently for Task #3-6. Fig 6b shows the three cable types deployed in the steel pipeline. This will reduce the time it takes to splice the cables whilst still maintaining the goal of comparing the sensitivity of various cable designs inside a flow loop.

3. Activities completed during the reported period for Tasks#3-6:

- We have completed the construction of the steel pipeline at Edgar Mine and connected the 1-m test section in the middle of the pipeline. We hired two specialists to help with the construction for safety consideration. The 1-m test section in place as of this report's date is non-corroded, non-deformed, and non-leaking to serve as a baseline for the experiments to be conducted in Tasks#3-6.
- The optical fibers deployment in the steel pipeline was re-designed, benefiting from the field deployment lessons learned during this project and applying the best practices. As aforementioned in the previous section, the internal cables deployed in the steel pipeline for tasks #3-6 are the thick cable from Neubrex Technologies and a ground-tactical cable from OCC that is considered relatively cheap, more robust for harsh environments and better suited for deployment and retrieval for reuse, considering the frequent change of the 1-m section in the middle for different testing. Fig. 7ab show the fibers deployed in the steel pipeline. Fig. 7c shows the fishing of the two internal cables at the very end of the pipeline.

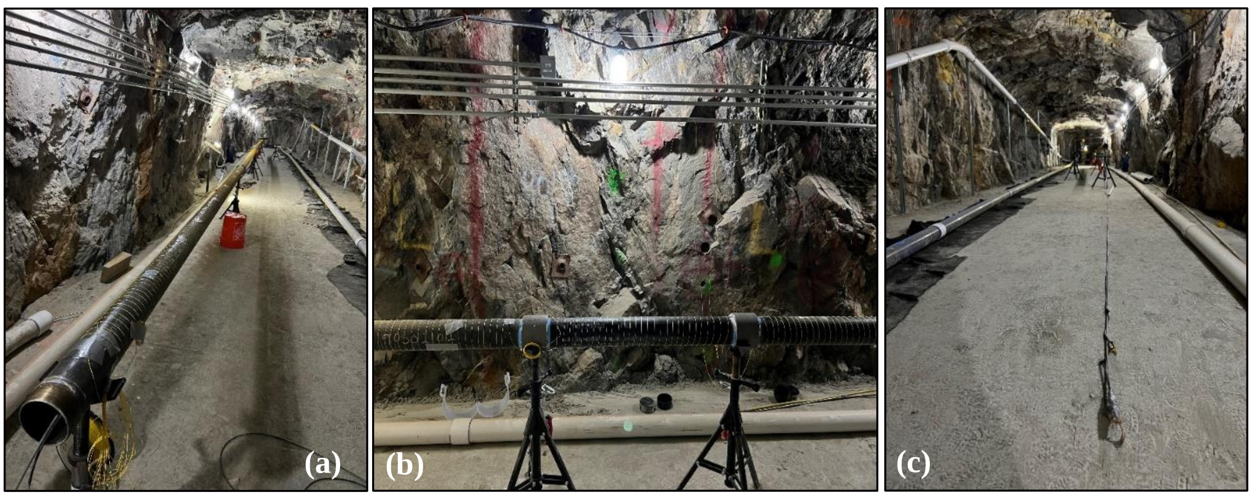

Figure 7. (a) Photograph of the optical fiber deployed along the steel pipeline; (b) Photograph of the 1-m section in the middle of the steel pipeline; (c) Photograph of the internal cables retrieved at the very end of the steel pipeline

- The yellow helically deployed fiber was wrapped first along the 10-m sections at the beginning and the end of the steel pipeline, respectively, the 1-m test section in the middle was first skipped and wrapped at the very end. This will make the change of the 1-m section easier.
- Currently, the steel pipeline is supported with tripods (as shown in Fig.7ab). The number of tripods in place will be changed accordingly in the future to test the different configurations explained and proposed for the project (densely and sparsely supported pipelines).
- For Task#3, the same methodology, materials, and experimental setup reported in the last quarterly report were used to generate corrosion inside the 1-m test section for the steel pipeline. Fig. 8 shows the 1-m test section during an ongoing experiment creating the corroded internal surface. For safety purposes, the acid experiments are being conducted inside the lab hood.

- 400 ml of hydrochloric acid was used and replaced every 48 hours to create corrosion inside the 1 m test section at the 6 O'clock position. During the reported period, a 2 ft long corroded internal surface and with a depth of 3 mm was targeted. Currently, a step is created inside the pipe, reflecting the pipe wall thinning. However, a caliper or a measurement method is to be figured out in order to precisely measure the depth of the corroded surface inside the 1-m pipe section.

Figure 8. Photograph of the 1-m steel pipe during an ongoing lab test

- Our next step is to splice the fibers for the steel pipelines and start the baseline tests as planned. The fiber cables deployed in the steel pipeline will be consecutively spliced with each other in the following order: straight external yellow cable with the thick cable, followed by the black cable, and then succeeded by the external helically wrapped cable coming in last to facilitate the change of the 1-m middle section as explained previously. Same as the PVC pipe flow loop, the integrity of the fibers will be checked with OTDR, and the interrogator laser lights, before collecting data.

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:
In addition to the potential risks mentioned in the annual and the last quarterly report, there are two additional factors that may potentially lead to some delays in the progress: first, the PhD student in petroleum engineering needs to take the Ph.D. qualifying exam in Jan. 2023. The qualifying exam lasts for 3 weeks approximately, including written and oral exams and an analytical writing. The student will need to concentrate on the qualifying exam during that month which may potentially lead to some delay in the experimental work. Second, the PI (Dr. Yilin Fan) will need to take parental leave from the end of March, that may also potentially impact the project progress. She will continuously monitor the project progress, but please expect some delays in replying to emails. The co-PI (Dr. Ge Jin) will take the lead of this project during this period and try to keep all the activities on track.

Future Project Work:
In the next 30 days, we will:

1. Try to complete Tasks#1.3 as planned. DAS data processing will be one of the major focuses for the next period. We will check the quality of the data and repeat some of the tests as needed.
2. Complete splicing of the fiber cables for the steel pipeline.

In the next 60-90 days, we will:

1. Conduct experiments in the steel pipeline with non-defects in the 1-m test section as the base case.
2. Continue Tasks#5.1 (Infrastructure damage for densely supported pipeline) as planned.
3. Continue Tasks#3.5 (Detection of corroded spots in pipeline interior surface for densely supported pipeline) as planned (please see the annual or last quarterly report for more details about the specific task).

Activities and Associated Cost for Nov 2022:
Per request, we included the activities and associated expenses for the month of November 2022. The breakdown of the expenses is given as follows:

1. Student monthly salary for the two Ph.D. students as planned: $4060.00
2. Experimental expenses: $1557.21 (including tools for building the flow loop, deploying the fiber optic cables, sealing, lab supplies, etc.)
3. Indirect cost (51.5%): $2892.86

That makes the total of $8510.07.

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.