CAAP Quarterly Report

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Prepared for: *U.S. DOT Pipeline and Hazardous Materials Safety Administration*

Contract Number: 693JK32050007CAAP

Project Title: Distributed Strain Sensing for Pipeline Safety Against Fault Moving and Landslide

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Business and Activity Section

(a) Contract Activity

No modification.

(b) Status Update of Past Quarter Activities

The research team conducted (i) literature review, (ii) laboratory experiments, and (iii) preparation of the numerical modeling task.

(c) Cost share activity

The research team had several online meetings and email exchanges with Dr. David Xu of PG&E.

(d) Task 1 Design

1. Background and Objectives in the 2nd Quarter

The fiber optic distributed strain sensing (DSS) system was tested for its ability to measure strain associated with pressurized steel pipeline bending by a full-scale laboratory test at ADV Integrity in Waller, TX. The purpose of the test was to evaluate the fiber optic cable type and attachment method for adequate strain transfer during pipe deformation.

The pipe was a 20-foot long, 12.75-inch diameter pipe made of grade X52 steel, with a wall thickness 0.188 inches. The pipe had 6-inch-long steel caps welded on both ends to allow for pressurization. The pipe was instrumented with NZS-DSS-002 fiber optic cables manufactured by NanZee Sensing Technologies. This cable consists of a fiber optic core surrounded by a tight buffer and wrapped within six helically wound steel braids. The cable has been used extensively in the civil engineering industry and has been proven to be robust enough to survive embedment into reinforced concrete, compacted soil and even vibro-compacted hot-mix asphalt. The cable cross-section can be seen in Figure

1. The cables were oriented approximately 28° above and below the neutral axis, which in this case is the centerline of the pipe when viewed from the side.

The cables were attached to the pipeline using a three-stage process. First, the cables were epoxied to the pipe using 3M DP8010 structural plastic adhesive. The adhesive was applied using a pump applicator that laid a bead of adhesive adjacent to each sensing cable. Next, the adhesive was manually spread along the cable length to fill the meniscal space between the cable sheath and the pipe surface. The epoxy set for 10 minutes. Next, the pipe was wrapped helically with Trenton Wax-Tape. This product provides an anti-corrosion barrier to the pipe and is a layer of protection for the fiber optic cable. The tape was applied by wrapping around the pipe and overlapping each successive pass by 1 inch. Finally, Trenton MCO outer wrap was applied on top of the Wax-Tape. This outer wrap was applied as specified by the manufacturer, with a 50% overlap of each successive pass. The wrap reacts to moisture in the air and cures into a hard shell surrounding the pipe and fiber optic cables. The fully instrumented pipe is shown in Figure 2.

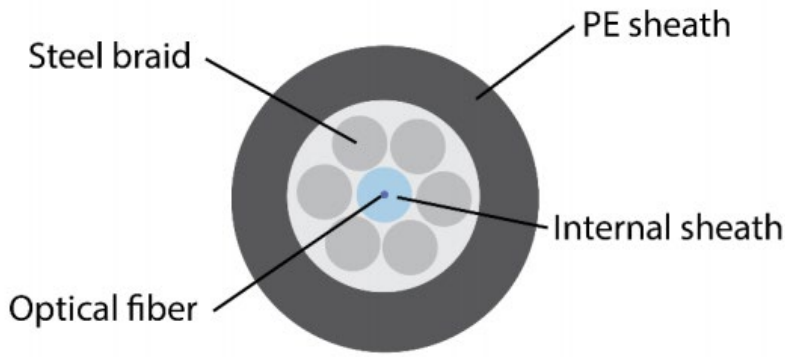

Figure 1. Cross-section of NZS-DSS-002 fiber optic cable

Figure 2. Instrumented pipe in four-point bending apparatus

2. Results and Discussions

After all attachment materials were applied and allowed to fully cure, the pipe was pressurized to 1106 psi and deformed by four-point bending. The apparatus is also shown in Figure 2. The test was strain-controlled, with foil strain gauges at the middle crown of the pipe being used for reference. The pipe was strained to a target level and then held there for 20 minutes so several DSS readings could be taken. The strain increments applied were 0.05%, 0.1%, 0.15%, 0.2%, 0.25%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.75%, 0.8%, 0.8%, 0.9%, and 1%. The pipe failed by local buckling at the north actuator. The final pipe condition is shown in Figure 3.

The DSS system, cable selection and attachment method all behaved exceptionally well, for both the pressurization process and the bending test. Figures 4 and 5 show the distributed strain data associated with the pressurization process and bending process, respectively. The pressurization process resulted in a consistent tensile strain increasing from zero to ~300 με as measured with DSS. This was in agreement with the strain gauges observed on site. The strain measurements taken during the bending process show the behavior very comprehensively, including the local buckling at the north support. The strain values shown in Figure 5 are not equivalent to the control strain (listed in the legend) because the cables were not oriented at the extreme axis of bending. DSS measured approximately 50% of the expected strain when the pipe was behaving elastically (up to 0.15% control strain) which is expected for 28° offset from the neutral axis. As the pipe plasticized, the strains localized at yield locations. Eventually a wrinkle appeared at the north support. The DSS data shows an increase in tensile strain above the north support, and a decrease in compressive strain below it, which is indicative of buckling behavior.

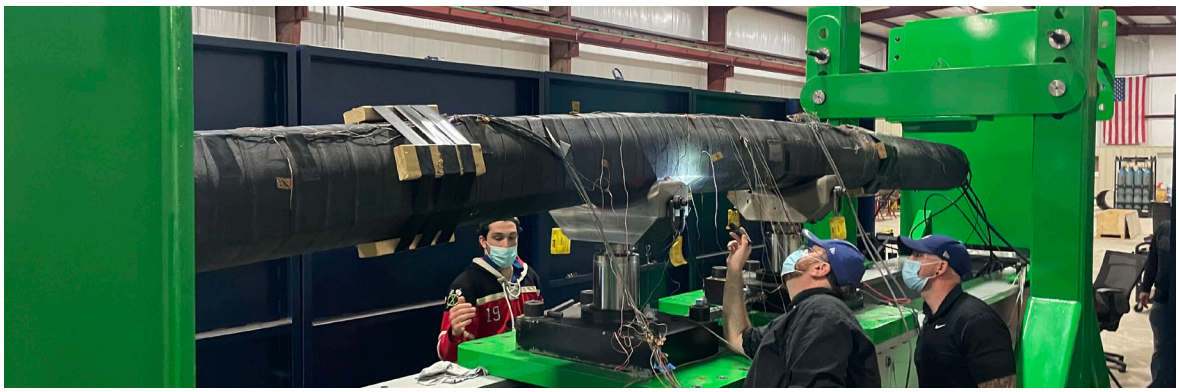

Figure 3. Deformed pipe after bending with North end showed in near field

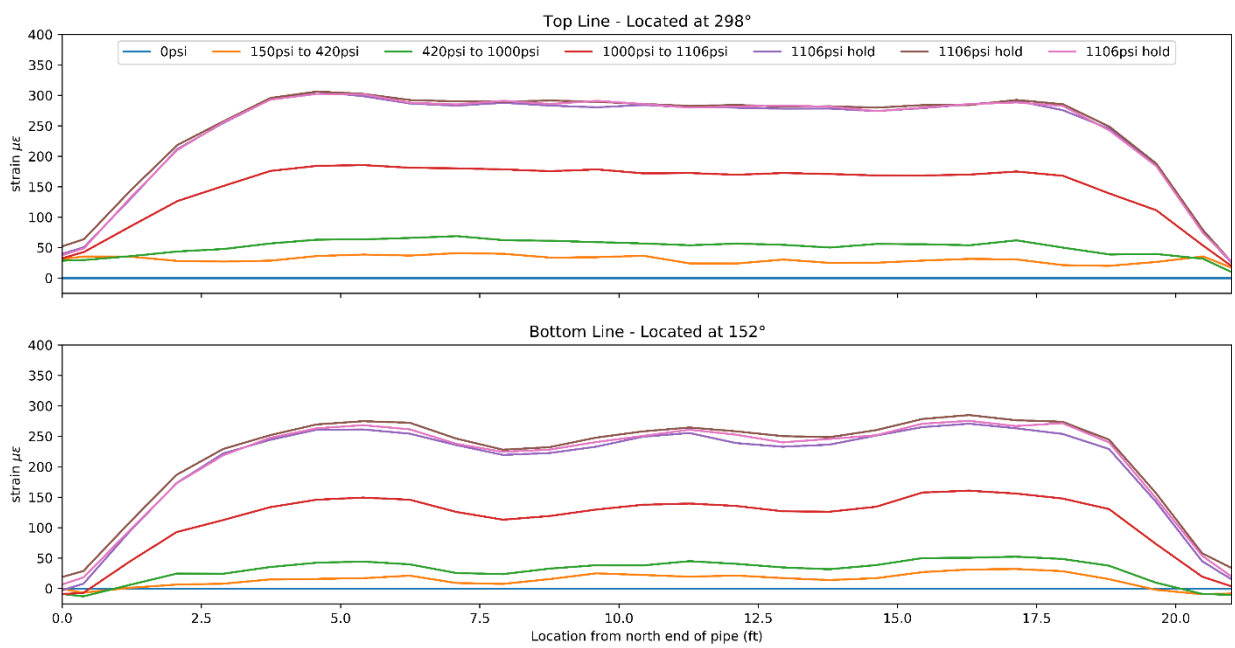

Figure 4. Strain profiles measured during pressurization to 1106 psi

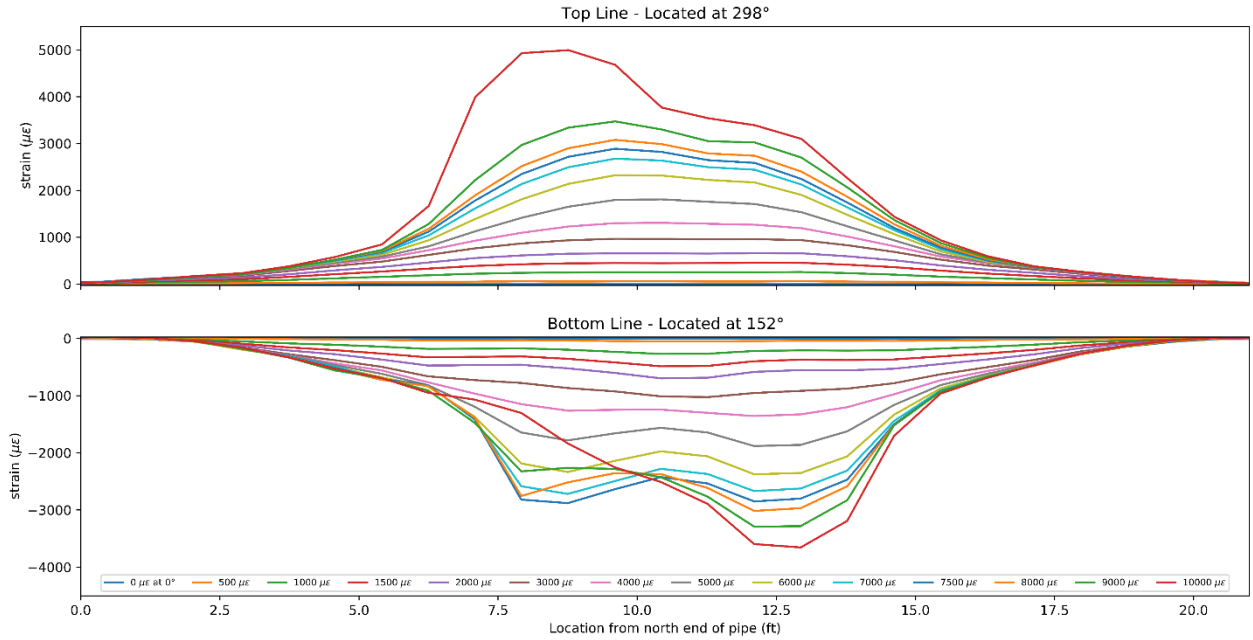

Figure 5. Strain profiles measured during bending

3. Future work

The test was a successful assessment of the attachment method and cable selection, leading to our recommendation of its use in further field applications. We will use this finding to investigate the cost of installation type for the most cost-effective and beneficial use of the technology. Our next step is to conduct experiments on steel pipelines as part of Task 2 Experiments at the UC Berkeley laboratory. We have started to develop soil-pipeline model for our numerical modeling task (Task 5) and we plan to report the preliminary findings in the next report.