CAAP Quarterly Report

March 27th, 2024

Project Name: Development of a Framework for Assessing Cathodic Protection (CP) Effectiveness in Pipelines Based on Artificial Intelligence (AI)

Contract Number: 693JK32350005CAAP

Prime University: ***Texas A&M Engineering Experiment Station***

Prepared By: PI Homero Castaneda-Lopez Professor, hcastaneda@tamu.edu, phone: 9794589844

Reporting Period: January 1st – March 30th, 2024

Project Activities for Reporting Period:

Task 1. Designing and building the physical prototypes in laboratory conditions and deterministic modeling.

In this task, the development of Deterministic Modeling started with the Transmission Line approach. The current 2D modeling includes different parameters influencing the CP, such as holiday location and presence. Technical description can be found in the Appendix. We designed different scales and configurations for the experimental setup to characterize and quantify the critical and meaningful parameters for deterministic and probabilistic modeling. The outcome of the TLM presents potential and current distribution, also the profiles are associated to the impedance signal. This latter will be validated in the laboratory as described in task 2.

Task 2. Integrating field inspection, theoretical with experimental data by applying pattern recognition techniques relating the pipeline-coating-soil system with CP

In this task, we have established a pipeline project database using some data accessible to the research team so far. Raw pipeline inspection data and soil environment information have been compiled and georeferenced. Some public data regarding soil, climate, and vegetation is being pulled out and integrated. We discussed different RoW (Pipeline sections) with the technical team members (UDayton and TAMU) regarding the required parameters for the soil/coating/soil system and data availability (data sources from both private and public databases). The conditions should include CP and direct and indirect technologies characterizing the RoW selected. This task will integrate the modeling, experimental setup, and field data.

Project Financial Activities Incurred during the Reporting Period:

- The personnel from TAMU includes one PhD student and one Master's degree student starting in January 2024. One undergraduate student will be integrated in summer 24.
- The UDayton team includes Sreelakshmi Sreeharan as a PostDoc researcher in this project and continues her efforts in Task 2.

- No financial activities related to conferences or related activities.
- The laboratory has started with preliminary setups and measurements.

Project Activities with Cost Share Partners:

During the second quarter of this project, we met twice with the co-sharing partners; the following outcomes from the meeting were:

- Meetings for updates on the project and future technical discussions. Meetings will be held twice a month.
- The partners are facilitating the collection of databases needed in this project. Some pipeline operators were introduced to the team.
- We included one more partner (Rosen) who will be integrated into the team and will add co-sharing in kind.

Project Activities with External Partners:

No activities are reported in this period.

Potential Project Risks:

For this second quarter, we identified some delays with the NDAs for open discussions with our industrial co-share partners and the acquisition of needed information. However, this latter is not critical for the project's performance. We believe there will be no impact during the second or third quarter, and no further risks have been identified yet.

Future Project Work:

We anticipate following the proposed timeline with no current changes during the next months. We will follow the Gantt chart to mark any progress and plans.

During the next 30, 60, and 90 days, we will perform task 1 activities. Also, we will start developing some of Task 2's activities the next 30 days.

Theoretical work, laboratory work, and database analysis will be considered for the next quarter.

The timeline and schedule for the project are in the Gantt chart.

Task/Subtask	Fiscal Year											
	2023	2024				2025			2025	2026	2026	2026
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Task 1: Designing and building the physical prototypes in laboratory conditions and deterministic modeling												

Task 2: Integrating field inspection, theoretical with experimental data by applying pattern recognition techniques relating the pipeline-coating-soil system with CP												
Task 3: Validation of the *a priori* framework with experimental and field conditions for characterization/modeling and Evaluate/Validate												
Task 4: Development and validation of the methodology for ECDA based on CP levels												

Deliverable Milestones are indicated in black*

Potential Impacts to Pipeline Safety:

Laboratory simulations in tasks 1 and 2 will involve small-scale pipelines whose RoW reflects different soil conditions to cover a diverse range of typical U.S. soil properties. The laboratory simulations will also incorporate different environmental and operation conditions of steel pipe and coating conditions to soil exposure as consistency for coating anomalies characterization under different CP conditions.

Appendix

TLM Overview

Two cases were studied for the first iteration of the TLM code. The geometries for the two cases are shown in Figure . Case 1 is for a fully intact coating with no damage, and for case 2, the coating has an oval-shaped holiday to simulate a holiday. A couple of assumptions were made about the system for some simplification. The first assumption is that due to the high conductivity of the working electrode compared to the interface and electrolyte/soil, it is assumed that the potential/current distribution through the electrolyte is homogenous and constant. The second assumption is that the impedance of the different phases is homogenous in their respective phases. For example, for Case 2, the impedance of the system has two discrete values for the coating and holiday, respectively.

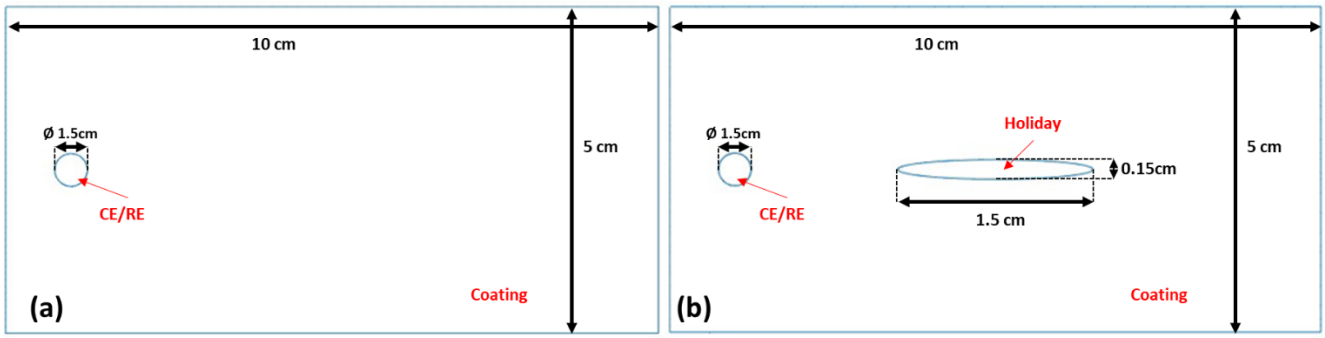

Figure 1a: Geometries for (a) Case 1 (fully intact coating) and (b) Case 2 (coating with holiday)

The potential and current distributions were calculated using a finite element method (FEM) to solve the governing equations numerically. Due to the interfacial impedance the potential and current distributions for both cases are frequency dependent and complex. Only the real part of the current distribution is shown in the following figures. Figure andFigure show the potential and current distribution at various frequencies for case 1 and 2 respectively.

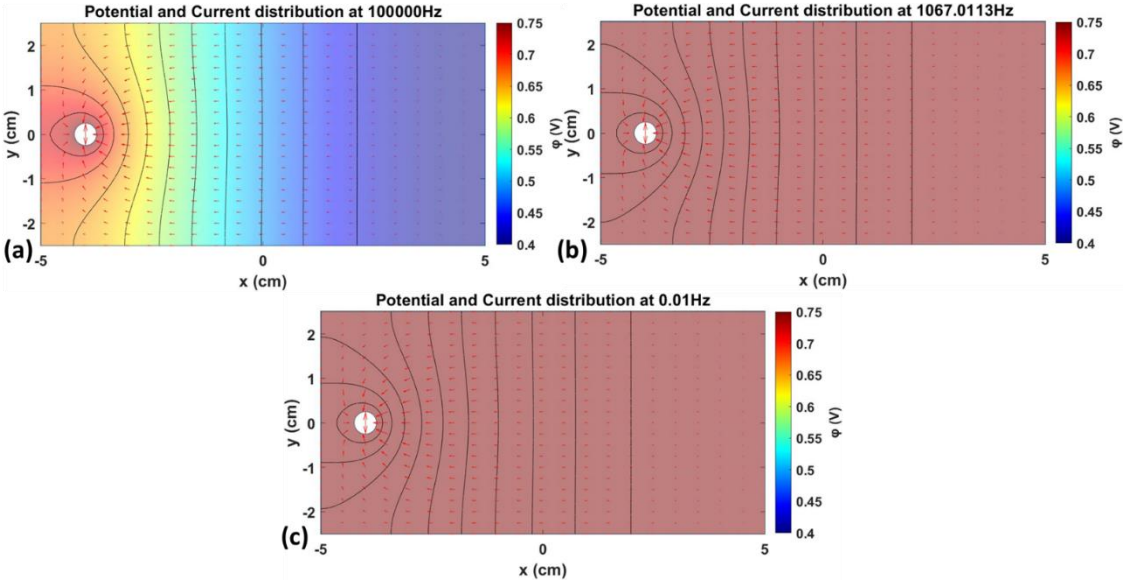

Figure 2: Case 1 potential and current distributions at (a) high (10^5 Hz) frequency, (b) medium (10^3 Hz) frequency, and (c) low (10^{-2} Hz) frequency

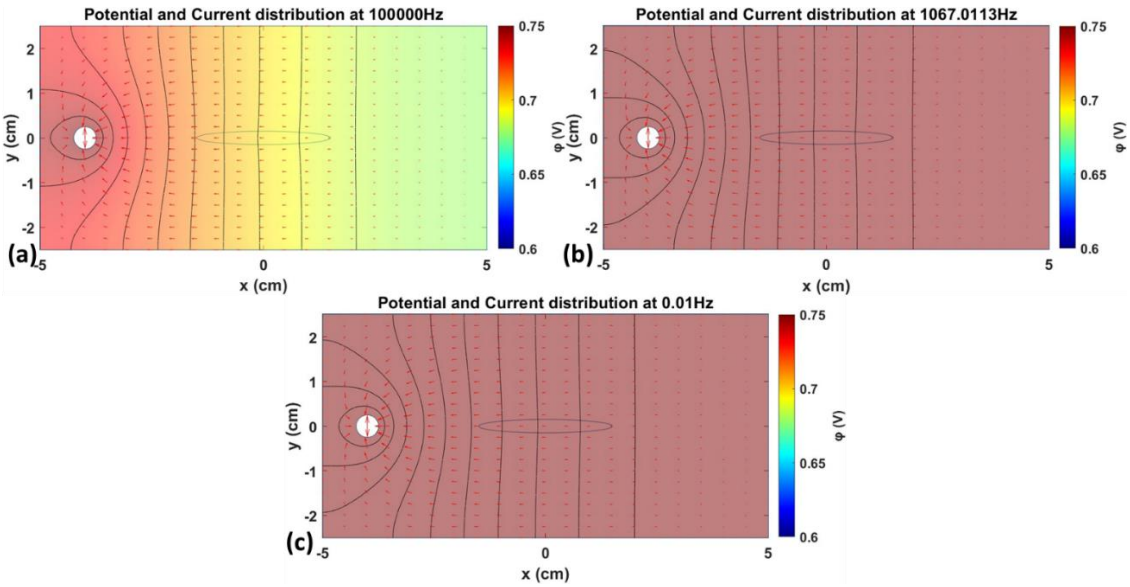

Figure 3: Case 2 potential and current distributions at (a) high (10^5) frequency, (b) medium (10^3) frequency, and (c) low (10^{-2}) frequency

It can be seen from the above figures that a heterogenous potential distribution arises in the high-frequency regime. For Case 1, in the medium to low-frequency regime, there is little difference in the potential/current distributions between the two frequencies. At higher frequencies (>10^4 Hz), there is a large drop in the potential across the surface. The intact coating from Case 1 showed the most significant potential difference distribution across the surface compared to the coating with the holiday. From Figure with the introduction of the holiday there is a bending of the equipotential lines in the vicinity of the holiday.

TLM Equivalent Impedance

Figure (a,b) show the comparison of the equivalent impedance for the intact (case 1) and damaged coating (case 2). The total impedance of the damaged coating was almost two orders of magnitude lower compared to the intact coating. This large drop in impedance was due to the introduction of the holiday where we assume that active corrosion is taking place. This overall lower impedance of Case 2 could explain why in Figure a there is a lower potential drop across the surface in the high frequency regime.

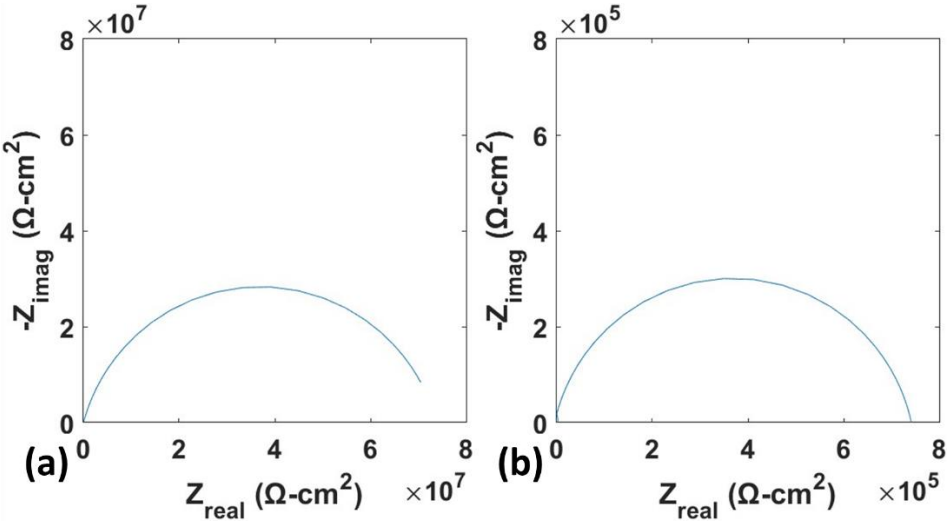

Figure 4: Comparison of the equivalent impedance Nyquist plots for (a) Case 1 and (b) Case 2

TLM Next Steps

Future steps

- Add in the effect of CP (Cathodic Protection) to the current iteration of the model
- Finalize the design of CE/RE holder for lab verification
- Use data from lab and field systems to validate 2D TLM model under multiple conditions
    - Intact coating with and without CP
    - Damaged coating with and without CP
    - Various coating systems with varying levels of damage with and without CP