CAAP Quarterly Report

June 30th, 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: April 1st – June 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 generation and development of Deterministic Modeling continues via the Transmission Line approach. The current 2D modeling includes different parameters influencing the CP, such as the type of coating, size of the holiday, and level of cathodic protection. The model has been able to simulate different parameters existing in the buried pipeline, via theoretical estimations. 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 impedance distribution, and the profiles are associated with the influence of coating anomalies during the CP system. This latter will be validated in the laboratory as described in task 2. This approach will allow us to indicate if there is a potential mobile technology that cannot only detect the state of the coating but also quantify the state of the substrate.

The laboratory setup and the simulation of the buried pipelines with different parameters have started. Different setup conditions have been characterized via different techniques and methods, mainly electrochemical. Electrochemical Impedance Spectroscopy, DC-decay, and AC reflectometry are the methods and technologies that will be used in the laboratory to characterize and quantify each parameter influencing the cathodic protection. The results will be able to correlate with field measurements.

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 including 68 miles of an X52 API pipeline. We also selected a second Right of Way that considers 37.5 miles of X65 API grade pipeline. Also, we are in the process of getting more RoW within the USA, an operator company will be able to help with the new database required for task 2 and subsequent. We discussed the current available RoW 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.

We are also organizing a technical Workshop for the current status of the project and the technical feedback between the team about the concept of the proposal.

Project Financial Activities Incurred during the Reporting Period:

- The personnel from TAMU includes one full-time PhD student, one full PhD student, one part-time PhD student, and one Master's degree student starting in June 2024. Two PhDs will perform task 1 and part of task 2. The Master's student will help to perform the testing methods.
- The UDayton team includes Sreelakshmi Sreeharan as a PostDoc researcher in this project and continues her efforts in Task 2 and initiating Task 3.
- No financial activities related to conferences or related activities.
- The laboratory has continued to increase the number of setups and measurements. The simulation of buried conditions will require more budget for Laboratory work and accessories. During the Laboratory work, we will perform different high-resolution characterization tools.

Project Activities with Cost Share Partners:

During the third quarter of this project, we met three times 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 are working with our team to set the proper NDA and channels to get access to the database. The team was able to discuss this with the pipeline operators to select the required RoW database.
- We will organize a technical Workshop with the team partners to get feedback about our proposal concept.

Project Activities with External Partners:

- We will organize a technical Workshop with the team partners to get feedback about our proposal concept. We will include operators and external partners for feedback.
- The obtention of the RoW is underway with the external partners.

Potential Project Risks:

For this third quarter, we identified some delays with the NDAs for 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 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 continue with Task 2's activities for the next 30, 60 and 90 days.

Theoretical work, laboratory work, and database selection, collecting, and 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 Evaluation/Validation												
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:

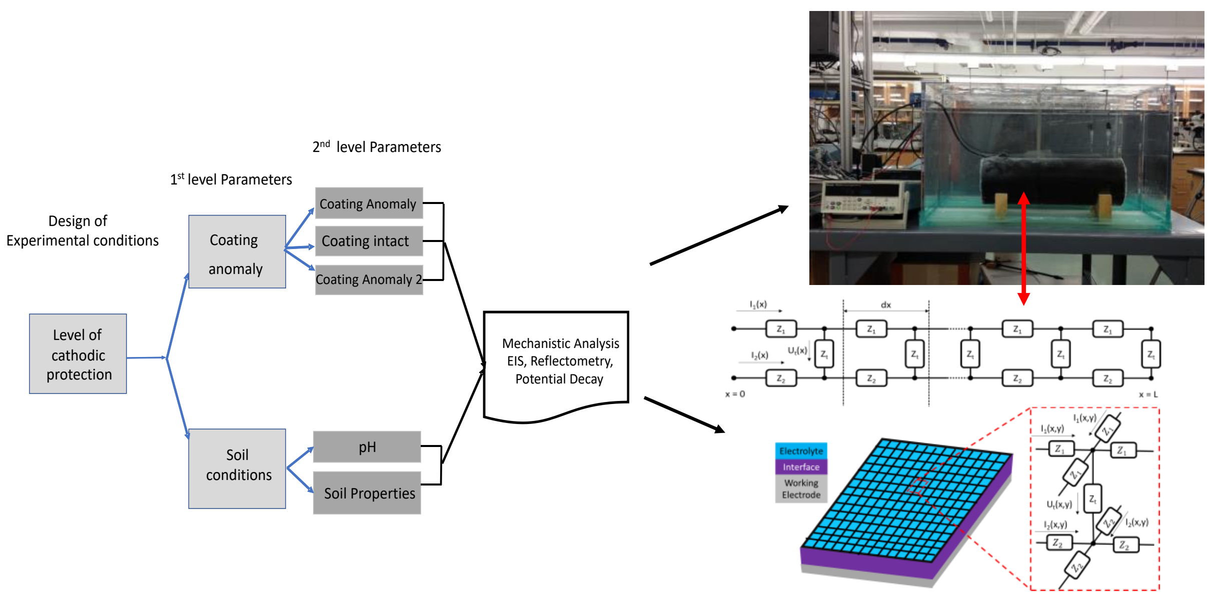
Laboratory simulations in tasks 1 and 2 will involve small-scale pipelines whose RoW reflects different soil conditions to cover a diverse range of typical U.S. soil properties. The laboratory simulations will also incorporate different environmental and operation conditions of steel pipe and coating conditions to soil exposure as consistency for coating anomalies characterization under different CP conditions. Task 1 will illustrate the current technologies' advantages and potential expansion use for new methodologies. The results can lead to a new methodology/technology able to detect/monitor different active-passive conditions under the CP conditions.

Appendix

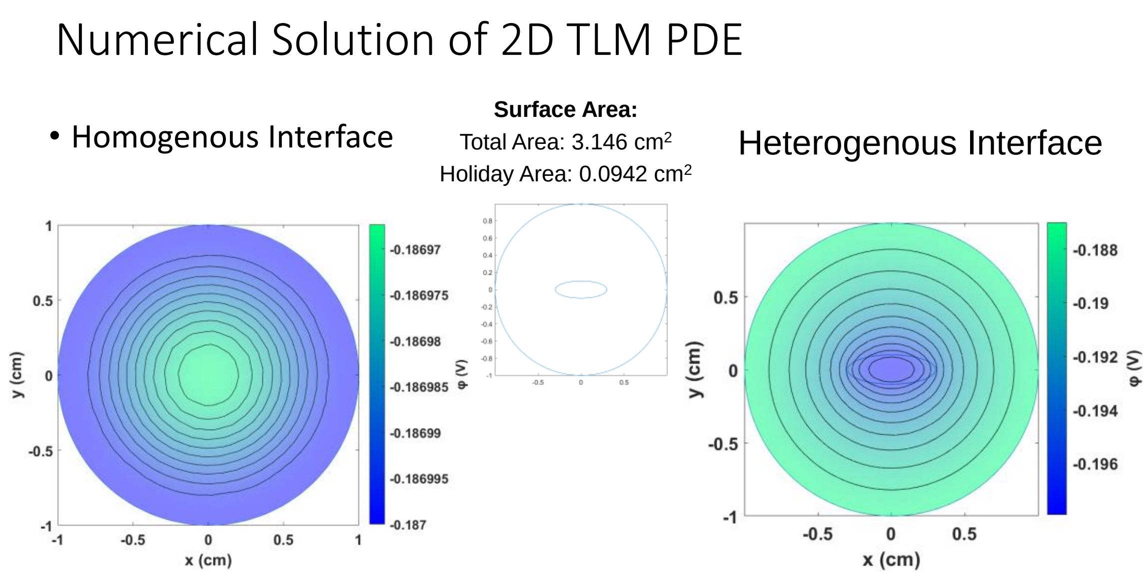
TLM Overview

The continuous development of the TLM includes not only the theoretical simulation but also the validation with the laboratory setup and testing with electrochemical, DC and AC methods. The following are some results obtained during the third quarter.

Task 1. Designing and building the physical prototypes in laboratory conditions and deterministic modeling (Task leaders: TAMU).



Extension of 1D generalized TLM model to 2D

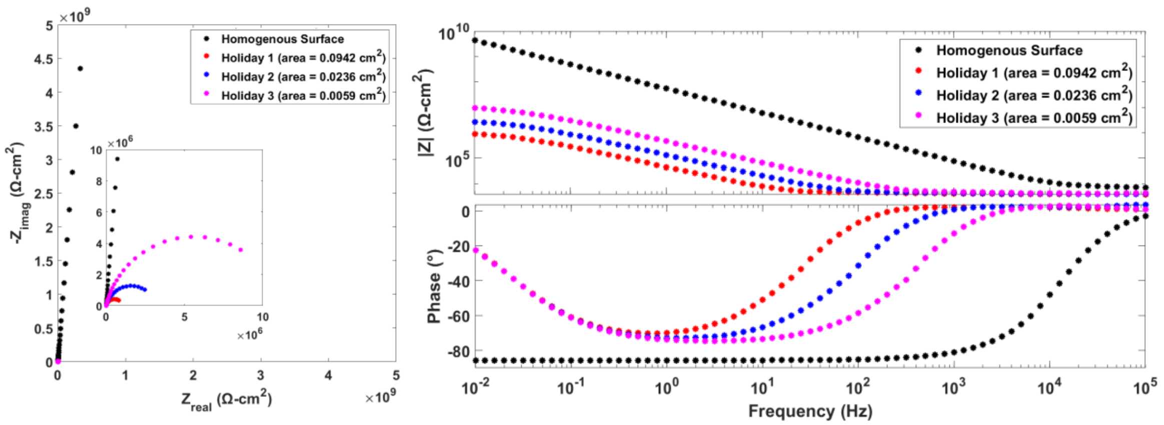


Comparison of Global Impedance

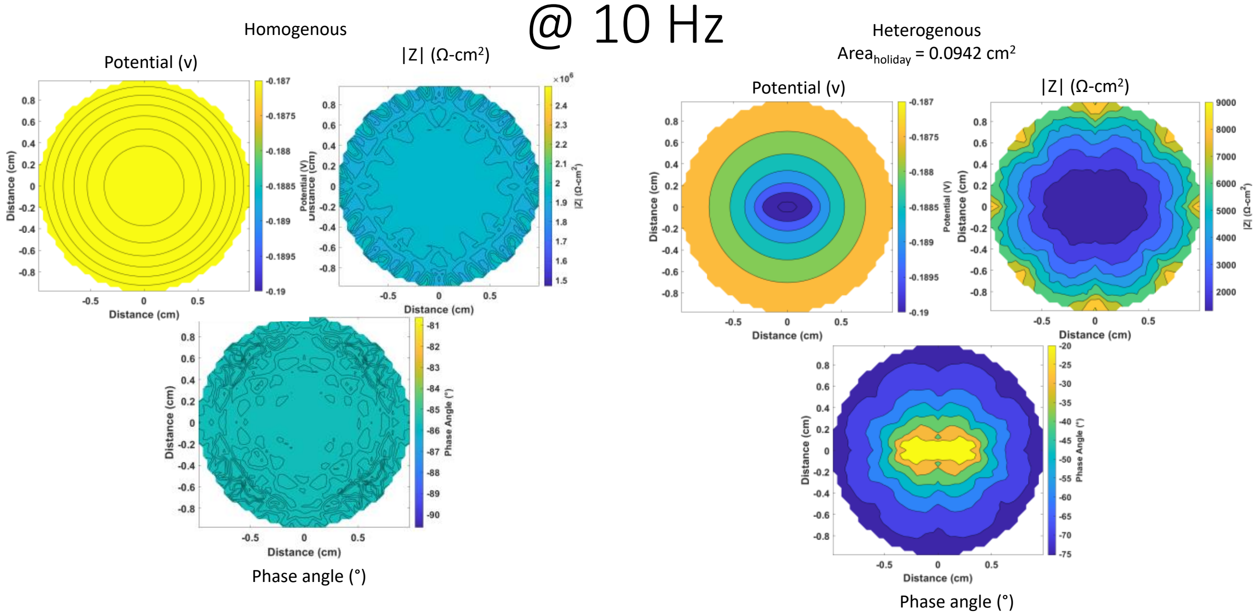
- Sharp decrease in overall impedance with adding holiday into the model.

```
Qc = 1e-8; %Coating Capactiance Value (F*s^n)
n = 0.952;%CPE exponeent
```

```
Rct = 50e3; %Charge T ransfer resistance (Ω)
Qdl = 100e-6; %Double layer capacitance (F*s^n)
n = .85;%CPE exponent term of corroded segment
```

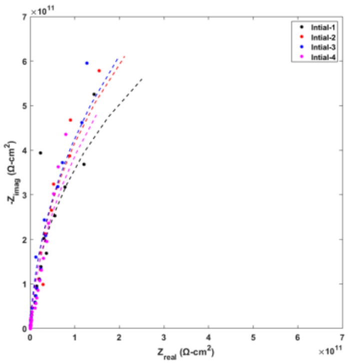


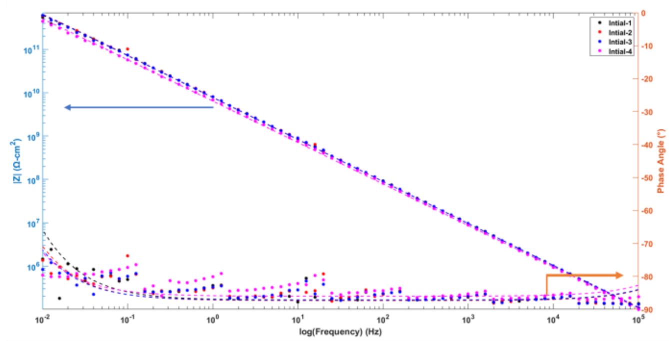
Comparison of Local Impedance Distribution @ 10 Hz

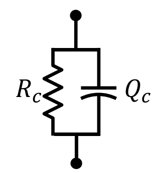


Validation – Intact Coating

Sample	Rs (Ω-cm²)	R_c (Ω-cm²)	Q_c (F-cm^{-2}-s^{n})	n_c	RMS
Intact 1	2708	$1.69 * 10^{12} \pm 1.37 * 10^{11}$	$2.17 * 10^{-11} \pm 2.74 * 10^{-13}$	0.968 ± 0.0015	0.0716
Intact 2	2708	$2.29 * 10^{12} \pm 2.92 * 10^{11}$	$2.14 * 10^{-11} \pm 2.55 * 10^{-13}$	0.970 ± 0.0014	0.0682
Intact 3	2708	$2.44 * 10^{12} \pm 2.95 * 10^{11}$	$2.17 * 10^{-11} \pm 2.17 * 10^{-13}$	0.969 ± 0.0012	0.0575
Intact 4	2708	$2.19 * 10^{12} \pm 3.84 * 10^{11}$	$2.68 * 10^{-11} \pm 3.41 * 10^{-13}$	0.956 ± 0.0015	0.0735

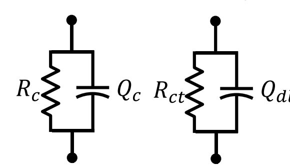


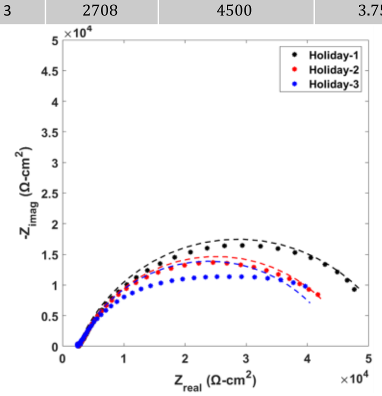


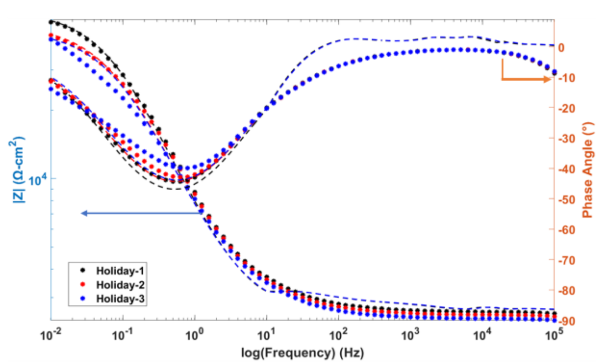


Validation Testing – Holiday

Sample	Rs (Ω-cm²)	R_c (Ω-cm²)	Q_c (F-cm^{-2}-s^{n})	n_c	RMS
Coating	2708	$6.86 * 10^{11}$	$7.19 * 10^{-11}$	0.966	-----
Sample	**Rs (Ω-cm²)**	**R_{ct} (Ω-cm²)**	**Q_{dl} (F-cm^{-2}-s^{n})**	**n_c**	**RMS**
Holiday 1	2708	5500	$3.5 * 10^{-4}$	0.750	0.1012
Holiday 2	2708	4750	$3.75 * 10^{-4}$	0.733	0.1104
Holiday 3	2708	4500	$3.75 * 10^{-4}$	0.733	0.1367



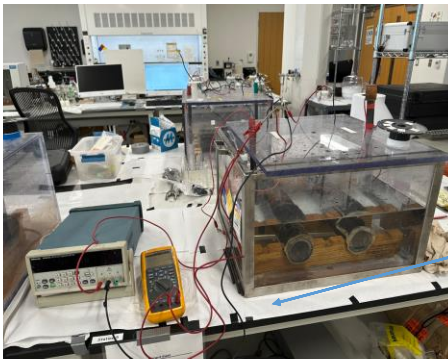




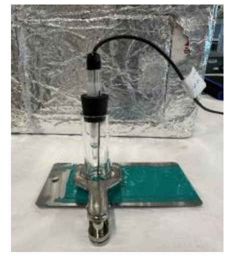
Laboratory Characterization

Table 3: Near-neutral simulated soil (NS4) solution composition (in mg/L).

KCl	$CaCl_2.H_2O$	$NaHCO_3$	$MgSO_4.7H_2O$
122	181	483	131



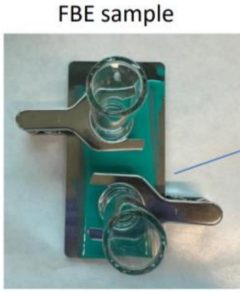
Flat Panels



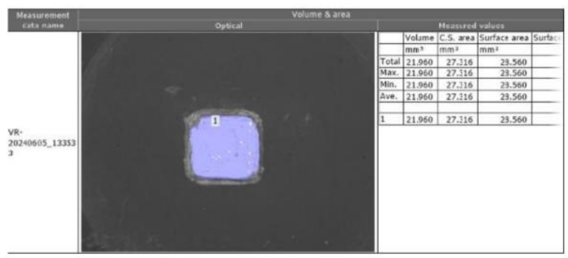
Pipeline simulation

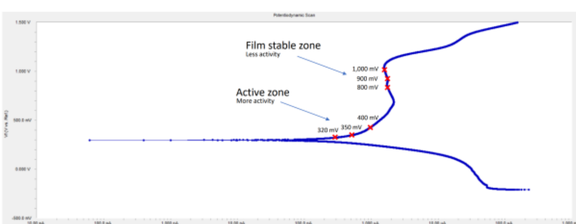
FBE- Holiday

FBE sample

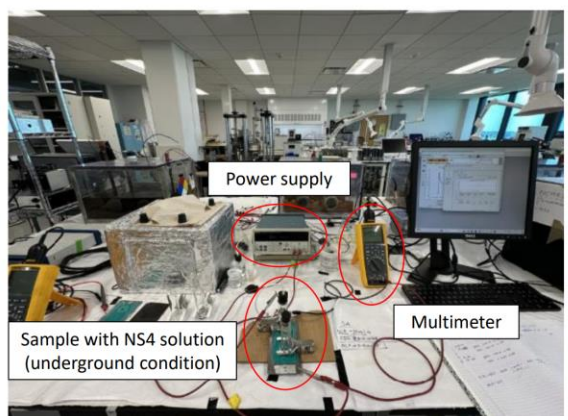


Detach coating

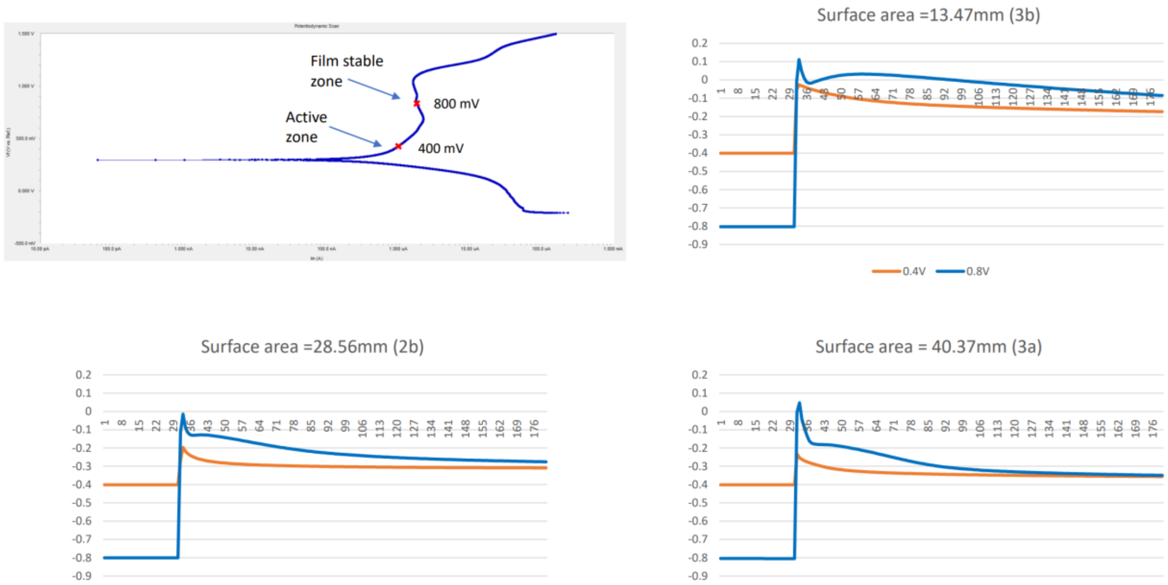




Reference electrode : Ag/AgCl



Potential decay for active characterization under CP-Different Surface



TLM and Laboratory Next Steps

Continuous work

- Add the effect of CP (Cathodic Protection) to the current iteration of the model
- Finalize the design of the CE/RE holder for lab verification
- Use data from lab and field systems to validate the 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