# CAAP Quarterly Report

**04/04/2025**

*Project Name: A Novel Reliability-Based Approach for Assessing Pipeline Cathodic Protection (CP) Systems in External Corrosion Management*

*Contract Number: 693JK32350002CAAP*

*Prime University: Marquette University*

*Prepared By: Qindan Huang, Qindan.huang@marquette.edu, 414-288-6670; Qixi Zhou, qzhou@uakron.edu, 330-972-7159*

*Reporting Period: 01/01/2025-03/31/2025*

**Project Activities for Reporting Period:**

The research team has been working on Task 3 (DC interference lab testing) and Task 4 (probabilistic defect growth modeling).

***Task 3 Corrosion behavior under stray current interference***

The experimental setup was finalized, and initial testing was conducted this quarter.

Metal samples
Two types of metal, API 5L X60 and X70, were purchased from Metal Sample Company (US). Two types of testing coupons were produced for each of these metal types, mounted metal coupons and corrosion coupons. The mounted metal coupons are used for electrochemical measurements, including potentiostat, galvanostat, and potentiodynamic polarization. The corrosion coupons are used for weight loss measurements.

Testing solutions
The test solution used in this study is a simulated soil solution consisting of 8.933 g/L KCl (99%), 0.674 g/L $Na_2SO_4$ (98%), and 5.510 g/L $NaHCO_3$ (100%), with a pH of 8.35 and a conductivity of 18.60 mS/cm. The testing solution is designed considering the major elements in soils and followed previous studies on the simulated solutions.

Experimental setup
The schematic diagram of the experimental setup is shown in Figure 1, including the CP protection circuit and DC interference circuit.

In CP protection circuit, CP potential is applied potentiostatically (Potentiostat 1) by Gamry Reference 600 working station with a three-electrode system containing the steel specimen as working electrode (WE), a platinum sheet as counter electrode (CE), and a saturated calomel electrode (SCE) is used as reference electrode (RE). The CP potential under study is -0.775 V vs. SCE and -1.12 V vs. SCE.

In the DC interference circuit, Potentiostat 2 is used to apply DC interference between metal specimen and counter electrode. Various DC current, i.e., 0.1, 1, 10 $A/m^2$, are applied by Gamry Reference 600 Chronopotentiometry mode. It is necessary to investigate the pulse DC current interference rather than the stationary DC current interference. Traction current can be divided into two parts based on the speed of the metro: variable speed and constant speed. The variable speed scenario occurs when the metro approaches the entrance and exit of a metro station. The constant speed situation refers to when the metro maintains a stable state during uniform operation. Figure 2 shows the schematic representation of the rectangular wave signals considering pulse DC current density to simulate the traction current generated by the metro movement in the real world. The variable speed to the whole speed period is planned to be 1:10, 1:2 (5:10), 9:10, 1 (10:10). The variable speed was set as 12s. The total testing duration is set to be 1 and 3 days.

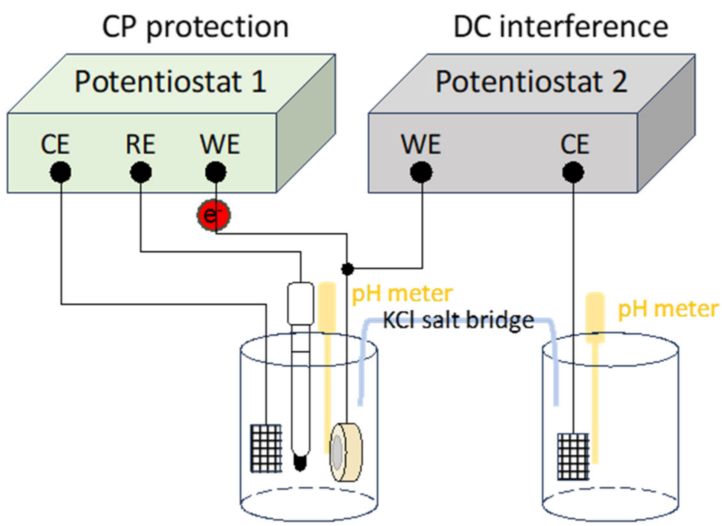



Figure 1 Experimental setup for pipeline corrosion under DC interference. Mounted coupon as working electrode (WE), saturated calomel electrode as reference electrode (RE), and platinum sheet as counter electrode (CE).

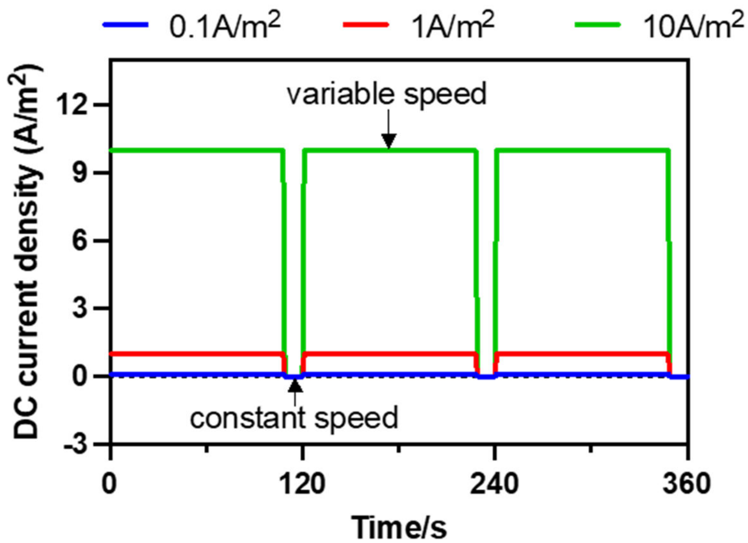



Figure 2 Schematic representation of the rectangular wave current signal.

Characterization method

Tafel testing and weight loss measurement are scheduled to determine the corrosion rate of X60 and X70 under various DC interference and CP potential conditions. First, the initial pH and the open circuit potential (OCP) of the metal will tested before the application of DC interference and CP potential. Then, the pulse DC interference will be applied using the Chronopotentiometry mode through Gamry Reference 600 working station. The CP potential will be applied potentiostatically using another Gamry Reference 600 working station. Following the predefined time period, EIS, Tafel, and morphology tests will be carried out to evaluate corrosion performance.

***Task 4 Probabilistic defect growth modeling***

Corrosion Density Estimation

A time-dependent probabilistic modeling framework has been developed to predict actual external corrosion density in buried steel transmission pipelines using MFL ILI data. The results are compared with a traditional approach of estimating density used by pipeline operators and also with a time-independent model proposed by Stephen and Nessim (2009). An abstract based on the results was submitted and accepted for oral presentation in AMPP 2025 Conference in Nashville, TN, in April 2025.

Corrosion Surface Area and Volume Growth

In addition to corrosion density, another way to describe the growth of external corrosion within pipe joints is to examine the total surface area and volume of all the detected defects within each pipe joint over time using the repeated ILIs.

Previously it was found that the total area and volume of all the detected defects within a pipe joint has negative growth for many joints. To exclude the possible effect of different coating types and also the reduced accuracy of ILI tools in the zones near girth welds, field-applied coating zones (FACZs) were excluded from analysis. To be conservative, a length of 12 in. from both downstream and upstream girth welds are considered as FACZs in this study. However, it was observed that despite this exclusion of FACZs, the sum of area and volume of all the detected defects within a pipe joint still have the negative growth over time for many of the joints.

Comparison of Test Station (TS) and Close-Interval Potential Survey (CIPS) Data

In the compiled dataset, for some joints pipe-to-soil ON and OFF potential values are available from both annual Test Station (TS) data and close-interval potential survey (CIPS) data. In order to evaluate the reliability of the data, a comparison was made between the pipe-to-soil OFF potential values available from both annual TS and CIPS. It was observed that the difference between these two values is less than 20% for 98% of the studied joints. In other words, only 2% of joints have difference between OFF potential values greater than 20%. This difference can be explained by 1) CIS was conducted not necessarily on the same month/day as TS was conducted, even though both were conducted in the same year. It is clear that different soil and CP conditions over a given year might have significantly contributed to this difference between TS and CIPS data; 2) TS and CIPS measurements themselves have inherent uncertainty and inaccuracy. Overall, it is concluded that there is a very good consistency between TS and CIPS data, and the OFF potential values are reliable to be used in the later analysis.

Cathodic Protection Level and Presence of Defects Within Pipe Body Joints

While cathodic Protection (CP) is utilized to protect pipelines against corrosion, there are multiple factors involved in the corrosion occurrence and its evolution, including soil characteristics, moisture, temperature, CP level, etc. Here, data analysis is carried out to evaluate the effectiveness of CP level on the existence of corrosion on pipe body. The pipeline joints studied in this project are divided into four groups depending on whether corrosion is detected in any of the latest two inspections, as shown in Table 1. Joints in Group 4 do not have any defects detected in the last two ILIs, while joints in Groups 1, 2, or 3 have defects detected in one or two of the two ILIs. In addition, CP is divided into five levels based on pipe-to-soil OFF potential ($P_{off}$) in volts relative to copper/copper sulfate (Cu/CuSO 4) reference electrode (CSE), as shown in Table 2.

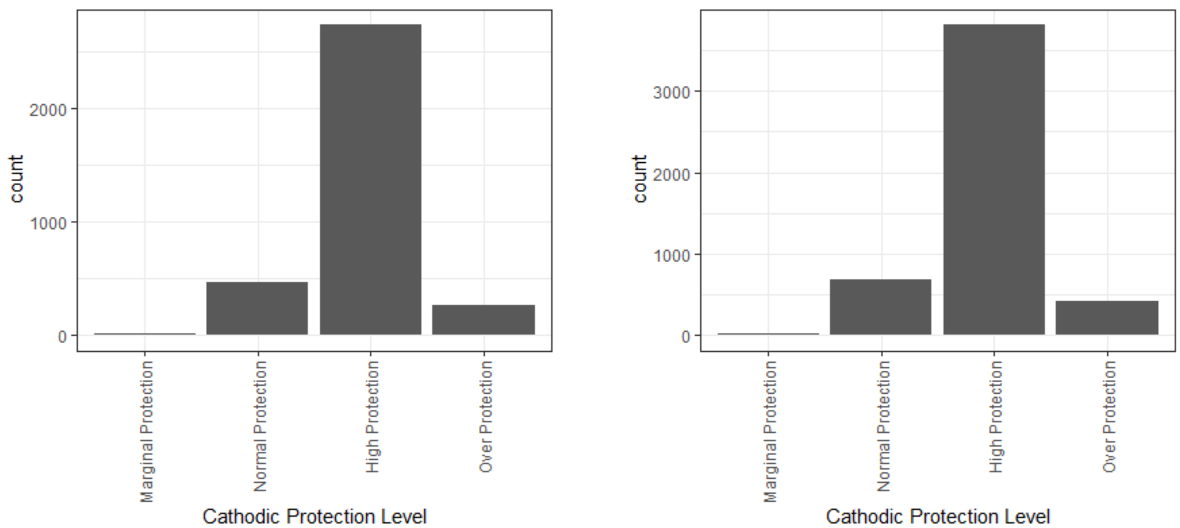
Table 1 Four groups of joints based on detection of defects in the last two ILIs

| Group | Defect in the 1st inspection | Defect in the 2nd inspection |
|---|---|---|
| 1 | Yes | Yes |
| 2 | No | Yes |
| 3 | Yes | No |
| 4 | No | No |

Table 2 Categorization of CP based on OFF potential in $V_{CSE}$

| Over Protection | High Protection | Normal Protection | Marginal Protection | No protection |
|---|---|---|---|---|
| $P_{off} < -1.2$ | $-1.2 \leq P_{off} < -1.0$ | $-1 \leq P_{off} < -0.85$ | $-0.85 \leq P_{off} < -0.7$ | $P_{off} \geq -0.7$ |

Figure 3(a) and Figure 3(b) show the distribution of CP level for joints belonging to Groups 1, 2, and 3 combined (Case 1) and Group 4 (Case 2), respectively. As shown, the distribution is very similar in the two cases: for example, 78.6% and 77% of the joints have High Protection CP level for Case 1 and Case 2, respectively. This suggests that the CP level alone cannot be used to judge whether corrosion exists within a pipe joint or not, and in fact, one should holistically consider CP level along with other influencing factors (e.g., pipeline features, soil type and characteristics), which is under further study.




(a) Case 1: Groups 1, 2, and 3 combined (b) Case 2: Group 4

Figure 3 Histogram of CP levels of pipe joints

**Project Financial Activities Incurred during the Reporting Period:**

The financial charges include the professional service from inferModel, graduate student stipend, tuition and corresponding fringe benefit, and indirect cost.

**Project Activities with Cost Share Partners:**

Cost share has been charged as planned.

**Project Activities with External Partners:**

Monthly meetings were held with our external industry partner to discuss the data collected and preliminary analysis results.

**Potential Project Risks:**

So far no risk has been identified.

**Future Project Work:**

In the next quarter, the following items will be taken for Task 3:

- All the experimental materials needed will be purchased in the next 30 days.
- The experimental setup will be ready in the next 30 days.
- The experimental testing will be conducted in the next 30 days. The initial testing results are expected to be obtained in the next 90 days.

For Task 4, The effect of all influencing factors and existence of corrosion on pipe joints will be further evaluated. Specifically, classification analyses, for example logistic regression analysis, will be carried out to develop a predictive model to predict the probability of corrosion occurrence within a pipe joint given the influencing factors. Such a model would help operators better understand and manage their assets and plan future in-line inspections more efficiently.

**Potential Impacts to Pipeline Safety:**

At the current phase, the project provides a better understanding of the usage limitation of CP survey data, and the needs in the existing defect analysis frameworks.