Development and Testing of a Linear Polarization Resistance Corrosion Rate Probe for Ductile Iron Pipe [Project #4361]

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Linear Polarization Resistance (LPR) is an electrochemical method for measuring the corrosion rate of a material in a given environment. It is an indirect measurement of the corrosion rate of surrogate electrodes that are part of the testing apparatus. LPR has primarily been applied in aqueous environments, but it can also be used in soils. In soils, LPR measures the corrosivity of the soil to a specific metal. LPR has gained acceptance in Australia as a means of screening centrifugally-cast gray iron pipelines for areas of higher and lower potential corrosion. As practiced in Australia, soil samples are collected in the field from as near the pipeline as possible. The soils are then transferred to a laboratory where the LPR measurements are made in soil boxes under controlled moisture conditions.

An LPR data point provides a measurement of the corrosion rate at a certain time, for a specific soil/metal combination. The corrosion rate will vary over time at the same location, as field soil conditions change. Soil conditions often change in terms of moisture content, chemical content, and other physical and chemical variables. Corrosion products on the surface of the metal will also change over time. The corrosion rate will also vary both horizontally and vertically from any given point on a pipeline, as soil and surface conditions vary. Small chemical and physical changes in the environment can create a corrosion cell. These unpredictable changes in the natural environment make it desirable to collect more characterization data rather than less, at least until a generally accepted soil/pipeline corrosion model is developed that can accurately predict changes in corrosion rates.

This project focused on advancing and modifying the LPR technique for soils/pipelines by making it field-based, and eliminating or minimizing the need for laboratory analysis of the soils. These changes are expected to make the collection of useful data far easier and cheaper than the existing approach, thus significantly increasing the value of the LPR technique.

This project created a field LPR probe for the assessment of the corrosion rate of ductile iron pipe. No standard currently exists for LPR measurements in soil. A field probe needs to work in environmental conditions not controlled as they might be in a laboratory. The field probe could give LPR readings, but since this new probe was also applied in uncontrolled conditions and to a new metal (ductile iron), the data needed to be relatively consistent and repeatable, and verified in some way. The approach taken was to generate LPR data in association with other soil data in standard and non-standard conditions, allowing correlation of data from the field probe to standard soil analyses through multiple analyses. By demonstrating reproducibility of field data and correlating these data to soils data for which standards did exist, the relevance of field probe LPR data could be verified. Unfortunately, no actual field-testing of the field probes was conducted as originally envisioned, due to water utility coordination issues. Instead, all testing of the field probes was conducted in simulated field conditions in the laboratory with soil samples collected by the water utility partners from the field.

Primary accomplishments of this project were as follows:

1. The project team fabricated two identical prototypes of a field LPR probe for ductile iron pipe. The two field LPR probes included annealed ductile iron electrodes to customize these probes for the testing of external ductile iron pipe corrosion (Figure ES-1).

Figure ES-1 Prototype Field LPR Probe from this project with annealed ductile iron rings

2. Tested two identical, commercially available corrosion rate monitoring meters (AquaMate CORRATER meters) with the same probe to generate LPR data. These identical meters were found to generate comparable LPR data on field condition soils when used with the same probe. These results indicate data reproducibility regardless of which meter was used.
3. Tested two identical field LPR probes in simulated field conditions to generate LPR data on the same soil. These two probes were found to generate comparable LPR and conductivity data on field condition soils. These results indicate data reproducibility regardless of which of the two probes was used.
4. Determined that the field probe readings stabilized quickly once in contact with the test soils. Stable readings could be taken after two minutes of probe-soil contact time. Readings were taken over various timeframes, but shorter timeframes are desirable so that

data generation can be maximized, and two minutes was found to be sufficient for stabilized readings under these test conditions.

5. Laboratory-tested the field LPR probes in a variety of soils that were collected from the field for the generation of LPR and other data, in particular resistivity/conductivity of the soils. The data generated by the field probes were correlated to other data through a series of tests in non-standard and standard conditions allowing comparison of the different types of data. Results of the testing include:

    a. The field probe generated reproducible and consistent LPR measurements when tested on the same field collected soils.
    b. The field probe-generated LPR data were compared to LPR data generated by the soil box method. Good correlation between the two sets of data was found, but the soil box LPR data (corrosion rate) were typically higher than that measured by the probe.
    c. The field probe-generated LPR data were compared to LPR data generated by the soil box method under typical test conditions of saturated soil. No standard exists for generation of soil LPR data, but saturated soil conditions are a standard test condition set forth for generation of soil resistivity data (ASTM 2005) and would theoretically seem to correlate with LPR measurement methods in aqueous solutions. Good correlation between the two sets of data was found, but the soil box LPR data (corrosion rate) in saturated soil conditions were almost always higher than that measured by the probe.
    d. The field probes generated reproducible and consistent soil conductivity measurements on field condition soils. Soil resistivity is the reciprocal of soil conductivity, and thus can be calculated from soil conductivity.
    e. The field probe-generated soil conductivity data were compared to soil conductivity data generated by the soil box method. Good correlation between the two sets of data was found.
    f. The field probe-generated soil conductivity data were compared to soil resistivity data generated by the soil box method under standard saturated soil conditions using the Nilsson resistivity meter (ASTM 2005). Good correlation between the two sets of data was found both in terms of absolute measurements and in terms of data trends.

The soil samples collected and analyzed in this project were not correlated with detailed ductile iron pipe corrosion data, so which set of LPR corrosion rate data are most correlated with ductile iron pipe corrosion in the field cannot be determined. However, based on the data generated in this project, it seems that adequate proof-of-concept testing has been completed to verify that a field-based LPR probe could be developed and its data correlated with corrosion losses from ductile iron pipe. A field-based LPR probe would allow generation of more LPR (corrosion) data more quickly, and these data would be helpful in screening existing ductile iron pipelines for areas of higher corrosion rate.

BACKGROUND

The North American water and wastewater community has hundreds of millions of feet of ductile iron pipe in service. Only a portion of the inventory has any form of external corrosion control. Ductile iron pipe, in certain environments, is subject to external corrosion.

Considerable research has been done on soil characteristics likely to result in corrosion of metallic pipelines. However, despite much work, no single unifying model of soil corrosion has been developed that is generally accepted. What is generally acknowledged is that corrosion rates will vary over time and distance (Romanoff 1957, Ricker 2010, Cole and Marney 2011, Rajani et al. 2011). Clearly, a complex set of chemical and environmental variables impact pipeline corrosion.

LPR is an electrochemical method for measuring the corrosion rate of a material in a specific environment. A detailed description of LPR theory and application in soils can be found in a recent Department of Transportation study (Silverman 1996, Farrag 2010). LPR measures the electrochemical resistance of the surface in its environment. The lower the measured polarization resistance, the higher the general corrosion rate. In addition, the Current Imbalance between the electrodes can also be measured. When the Current Imbalance is higher, there is a greater tendency for localized, or pitting, corrosion (Farrag 2010).

As applied to pipelines, LPR provides an indirect method of assessing the instantaneous corrosion rate of a ferrous pipeline. The LPR technique does not require the pipe to be taken out of service. Nothing has to be inserted into the pipe, nor, theoretically, would the pipe need to be excavated for direct measurement of corrosion losses. The existing LPR technique, primarily used in Australia where it is available from a commercial vendor, involves the collection and removal of test soils to the laboratory, where the soils are carefully prepared and LPR measurements are made in a soil box. The resulting LPR data provides information on the corrosion rate of the pipelines, and these data are useful in prioritizing existing pipelines for further investigation. Some utilities, especially Sydney Water and Hunter Water in Australia, have found LPR to be a cost-effective screening method to assess their centrifugally-cast gray iron pipelines, and have used the technique year after year (Dafter 2014). This LPR technique, as applied in Australia, has not been developed for application to ductile iron pipe, nor has it been developed for field generation of LPR data. Development of a field-based LPR probe for ductile iron pipe may provide more data that could be useful in preliminary assessment of buried ductile iron pipelines.

APPROACH

A prototype LPR field probe had already been developed by the researchers in previous work, but modifications were envisioned to improve the probe's usefulness in the field. The probe also needed further adaptation for improved measurement of corrosion rates on ductile iron pipes. Thus, two identical prototype field LPR probes were created as part of this project. Improvements on the original prototype included a smaller diameter body, relocation of wiring, and use of heat-treated ductile iron rings in the probe with an annealing surface oxide, similar to that found on ductile iron pipe.

Utilities were asked to provide three soil samples from their service area to be characterized and tested with the new LPR probes in the laboratory. These soil samples were used to generate LPR data from the new probes, and the data were correlated to other soil characteristics associated with soil corrosivity. All work was done in the laboratory, with simulated LPR field data generated by testing soils in buckets, and correlating these data with soil box and other testing done on the same soils.

RESULTS/CONCLUSIONS

This project established confidence that measurements from the two identical prototype LPR probes were similar in the same soil, were reproducible, and are indicative of soil corrosivity. In soil, the probes reached equilibrium and stabilized within two minutes. Side-by-side testing of the probes in the same soils obtained comparable corrosion rate values. The LPR data also trended well with the data obtained using an established two-electrode soil box corrosivity measurement. Also, solution conductivity readings taken by the LPR probes and converted to soil resistivity data were in close agreement with standard laboratory-generated soil resistivity data. Further studies will be required to establish a direct correlation between field-based LPR measurements (corrosion rate), actual corrosion loss, and possible pit corrosion of in-service ductile iron water mains.

APPLICATIONS/RECOMMENDATIONS

A fully developed field-based LPR corrosion rate probe for ductile iron pipe could be an important tool for the water industry. Such a tool would allow many measurements to be made along the alignment of an existing pipeline. The sturdy construction of the probe developed in this project allows it to be pushed into the soil to obtain soil LPR and related data. By providing instantaneous direct readings of the corrosion rate at a specific site, the timeframe for complete corrosion penetration of a section of ductile iron water main could be projected based on those readings. Depending on the nature of the data, a more detailed examination of a pipeline could be better prioritized, or subsequent follow-up readings could be scheduled. A large quantity of LPR data along a pipeline would allow more accurate predictions of corrosion rate and better predictions of corrosion penetration of the pipeline. While this project has demonstrated a viable field probe, more research will be required to determine key probe reliability issues and fully develop the empirical model to relate these LPR field measurements to corrosion losses and also possibly corrosion pit depth of ductile iron pipelines. Future studies to support development and eventual commercialization of this probe would need to include detailed soils testing near existing pipelines and excavation of pipeline sections to allow direct readings of pit depths and overall corrosion loss. These data could then be related to the LPR field measurements.

RESEARCH PARTNERS

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