

The Role of the Soil-Plant-Atmospheric System in Underground Corrosion Rates

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ABSTRACT

Modeling corrosion for underground assets is a heavily studied area for many reasons; it's exciting, high impact, and challenging work. Many confounding variables make the analysis complex, such as cathodic protection systems and interaction effects with the climate and soil. This paper addresses the role of the soil-plant-atmospheric system (SPAS) in corrosion growth by presenting datasets, a statistical analysis, and predictive models.

Using data from the International Soil Reference and Information Centre (ISRIC) and a North American pipeline operator, this research offers a correlation analysis, showing the impact of soil features and the critical role of cathodic protection systems. Incrementally, by adding variables and non-linear modeling, this paper shows a machine-learning powered framework for estimating corrosion growth rates with features from the soil-plant-atmospheric system, while controlling for confounding variables.

Key words: Pipelines, Corrosion Growth Rates, Soil, Atmospheric

INTRODUCTION

The role of soils in corrosion growth has been a primary research focus in the pipeline industry for decades. The magnitude of the problem is significant -- hundreds of thousands of kilometers of buried pipelines with various coatings, ages, depths, and cathodic protection systems, all exposed to the soil environment. Further, these pipeline parameters interact with soil features and exogenous variables in ways that are complex and non-linear. Consider a case with a pipeline through a right of way with an alternating current (AC) power corridor and highly acidic and porous wet soils. A relatively small increase in soil wetness may result in a non-linear increase in corrosion growth rates, influenced by the AC interference in possibly unpredictable ways.

A strong maintenance program for underground pipelines involve a thorough External Corrosion Direct Assessment (ECDA) process with a comprehensive pre-assessment and indirect assessment regime. An essential part of this pre-assessment is conducting remaining life calculations, for which a conservative corrosion growth rate (CGR) estimate is an input. An ideal model would allow operators to optimize the length of inspection intervals to suit regulatory parameters, risk minimization objectives, and cost factors. This theoretical model would generate an annualized CGR estimate as a function of multiple features, with soil parameters potentially playing a large predictive role. An active area of research is building this model through machine learning, statistics, and mechanistic modeling.

A useful CGR model incorporating soil (among other features) is an essential component of any risk-based inspection (RBI) schema. In particular, a program for inspection optimization requires cost of failure (COF) and probability of failure (POF) calculations. The POF calculations require an upper and lower bound of a given asset's corrosion growth rate. Soil parameters and the variability thereof may directly impact these bounds, especially when they are predictive of CGR.

This paper presents a comprehensive summary of soil data from a single provider, ISRIC. This research's grander plan seeks to model the relationship between soil parameters and ILI-based corrosion growth rates from a North American Operator. The ultimate objective is to incorporate this data into more comprehensive algorithms and models for CGR prediction.

DATASETS

Corrosion Growth Rates and Data Pre-Processing

This paper's key dependent variable is the maximum back-to-back depth-wise corrosion growth rate (CGR). This data, collected via inline-inspection (ILI) methods, is aggregated by the operator at the girth-weld level. For the entire network, this covers over 10 million unique feature observations. When more than one ILI run is available, the back-to-back corrosion growth rate can be computed by comparing the maximum feature depth in year 0 and that same feature again in year N. This calculation is done at each girth weld address. Regardless of the number of corrosion features at each location, a single value (the back-to-back corrosion growth rate) is available. This value represents the maximum change in depth of a single feature at a location.

The ILI measurements are collected via Magnetic Flux Leakage (MFL) and have a minimum detection threshold of 10% wall depth. This paper effectively sets that threshold to 20% wall depth, as a method to filter out additional measurement noise towards the 10% detection threshold. To factor out any issues with data collection on the higher end of the spectrum, this research also filters out any girth weld addresses with a greater than 2.0 mm/year CGR. This filtering process results in 128,447 girth weld addresses with available CGR measurements and soil parameters.

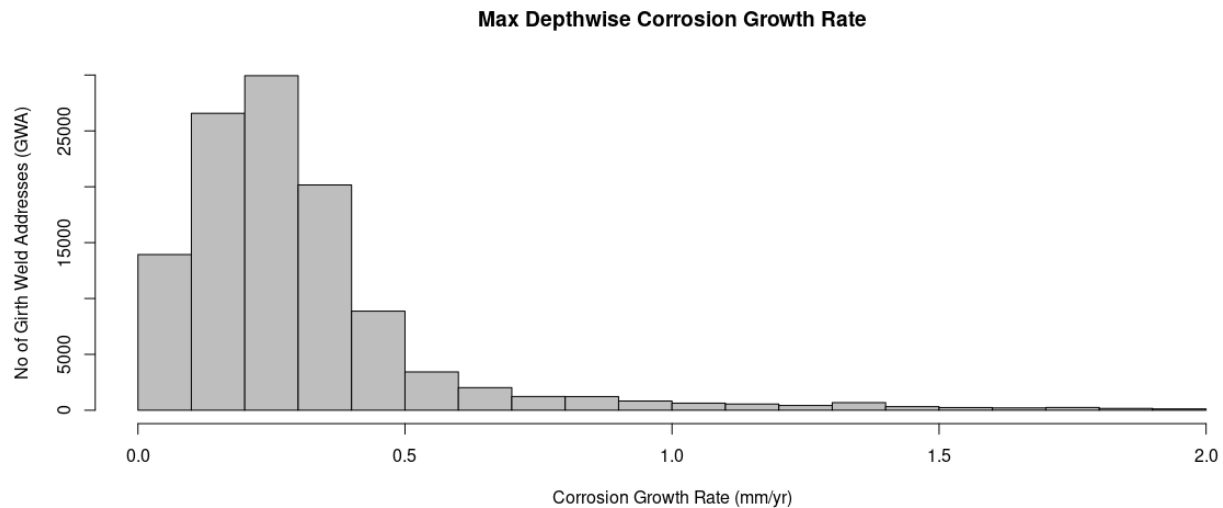


Figure 1: Distribution of Observed Corrosion Growth Rates

Descriptively, a Weibull distribution describes the corrosion growth rates with a dispersion parameter of 0.357104. [1] et al cite a dispersion rate of 0.5 to 10 as standard for modeling failure processes, such as corrosion growth rates. This value detected here is on the low end of that range for a few potential reasons. The observed corrosion process is generally not on bare metal and is subject to corrosion mitigation practices. Additionally, features with severe depth-wise corrosion are repaired and thus, removed from the data.

To avoid modeling the specific role of cathodic protection systems, this paper filters out any girth weld addresses with higher performance or newer coating systems, leaving shielded coating types on, such as PE Tape. This filtering process results in a total of 96,148 girth weld addresses suitable for analysis with a mean vintage of approximately 52 years.

Soil-Plant-Atmospheric System

The Soil-Plant-Atmospheric System (SPAS) is a model for explaining the dynamic relationship between the soil parameters, the influence of plants, and the role of the atmosphere. There is a large body of work on SPAS's agricultural impact, dating back to early work in the 1960s [2][3]. The introduction of higher resolution satellite imagery, the increased volume of in-situ measurement stations, and improved data processing technology have dramatically improved SPAS datasets' resolution and scale. Furthermore, SPAS's role in corrosion in underground pipelines is well studied and understood mechanistically, but there is limited prior work in corrosion. [4] and [5] show some results in the relationship between specific soil contaminants and the ECDA process and theoretical models. This work takes a more empirical approach, starting with the observed corrosion growth rates and working backward to correlations.

This work uses high-resolution soil data sourced from the International Soil Reference and Information Centre's (ISRIC) World Soil Information product [13]. The ISRIC project collates thousands of in-situ soil measurement stations worldwide, and uses machine learning to generate datasets of a wide range of soil parameters. While specifically tailored for agricultural use, the project datasets are easily transferrable to the corrosion industry. The product offers data at seven different depths, from surface level (SL0) to 1-2 meter depth (SL7). ISRIC does not provide any data products beyond the 2 meters of depth. Visible in table 1 is the full list of parameters offered by ISRIC and used in this work.