Structural Integrity Associates

A White Paper On

Soil Analysis to Improve Management of Buried Steel Structure Integrity

February 2012

INTRODUCTION

SoilPro is an empirical model used to predict the corrosion rate of a buried steel structure based on the properties of the soil and cathodic protection system. Structural Integrity Associates (SI) has developed a methodology to improve the integrity management of buried steel structures such as pipelines or penstocks. This enables more effective allocation of inspection resources and aids the selection of re-inspection intervals.

This white paper discusses the research that SI conducted to determine both the soil characteristics that have the greatest effect on the predictability of corrosion, and how the integration of soil data and polarization measurements improves the predictability of corrosion rate. The analysis showed that the predictability (correlation) of corrosion rate using individual soil characteristics was poor. However, when individual characteristics were integrated the rate predictability increased substantially. As a result of this research, SI developed an analysis methodology that integrates soil characteristics with polarization data to estimate corrosion rates.

LITERATURE SEARCH RESULTS

A targeted literature search yielded surprisingly few articles providing specific corrosion data based on soil characteristics. No articles were found that quantitatively integrated the soil characteristics to predict corrosion rate. At best, the level of integration between soil characteristics was done qualitatively on a point scale. Frequently, corrosion characteristics are reported as very corrosive, corrosive, mild, etc. based on individual soil data elements such at soil resistivity, pH, and soluble salts. Though relative rankings are useful, they do not address the interrelational effects between individual soils components on the overall corrosion rate, nor the dramatic influence of pipe polarization on corrosion rate. Pipe buried in highly corrosive soils may not suffer any corrosion if sufficiently polarized. Conversely, pipe buried in mildly corrosive soil may exhibit significant corrosion damage if not adequately cathodically protected.

One paper, "*Techniques of Assessment of Soil Corrosivity*[1]" was particularly useful in describing how the various soil characteristics affect corrosion rate. These characteristics and the related SI findings are summarized below.

Position of Water Table

Steel buried below the water table has been reported as having a lower susceptibility to corrosion than steel that is intermittently wet and dry. The primary reason for this effect is the anaerobic condition of the pipe while underwater. Pipe segments that are consistently below the water table are usually less likely to have aggressive corrosion.

Soil Moisture Content

The literature supports the notion that pipes exposed to soil with higher moisture contents are at greater risk to corrosion than drier soils, and states that soils with greater than 20% moisture

[1] CL Durr, and JA Beavers, Techniques for Assessment of Soil Corrosivity, NACE International, Corrosion 98, Paper 667.

content are considered aggressive, while soils with less than 20% are non-aggressive. Also noted is field experience which shows (and it is generally understood) that coatings tend to degrade at a higher rate when exposed to high moisture levels.

However, the SI analysis did not show any improvement in the ability to predict corrosion rate when moisture content data was added to the baseline condition (the baseline condition consisted of assessment technique which considered “On” and “Off” polarization reads with soil resistivity measurements).

Soil Type

The soil type is generally believed to influence corrosion, with most of the classifications based on particle size distribution in accordance with the Unified Soil Classification System (USCS). Clays can better retain moisture and cause oxygen deficient environments due to their small particle size. This becomes an issue when a pipeline runs through stratified soil causing portions of the pipe buried in clay soils to become anodic to portions buried in more porous soils.

SI analysis found that soil type characterization only slightly improved the predictability of corrosions rate when integrated with the baseline condition of polarization and soil resistivity data. It should be noted that soil type may have greater influence on corrosion rate than the SI analysis showed since the samples studied were not exposed to stratified soils.

Increased soil stress on coatings by clay soils was not mentioned in the paper. Field experience has found that the coatings tend degrade more rapidly in clay soils due to increased soil stress and moisture content. This may play a role in explaining the observed tendency of clay soils contributing to greater corrosion rates. The deleterious effects of soil type on coatings were not considered in the SI analysis.

Soil pH

Soil pH is considered to be one of the primary controlling factors in underground corrosion. The paper also acknowledged considerable scatter in the observed corrosion rate data and pH. The literature noted that all factors should be considered when evaluating corrosion rate.

The SI analysis found that integrating pH alone into the analysis did not improve the predictability of corrosion rate over the baseline condition of polarization and soil resistivity. However integrating pH with other soil characteristics did improve the predictability of corrosion rate since corrosion rates tend to increase for lower pH solutions in the presence of Cl^-.

Soluble Salt Content

Very little data was reported on the effects of soluble salts, but there is recognition that salts are detrimental. The paper went on to indicate that one reason salts are detrimental is that they reduce resistivity of the soil. Also mentioned was that chloride promotes the breakdown of protective corrosion product films on metallic surfaces.

The current analysis showed that integrating soluble salt improved predictability of corrosion rate but to a lesser extent than Na, Cl, and SO_4 concentrations which substantially improved the predictability of corrosion rate. Incorporating the concentration of other salt ions did not improve the predictability of the corrosion.

Since soil resistivity was included into the baseline case, the analysis results showed that the Cl and SO_4 ions had other chemical effects beyond merely decreasing resistivity. As mentioned in the paper, it is expected that they attack the protective nature of corrosion product films on the metal surface. The lack of improvement from incorporating the concentration of cations could be attributed to the fact that they decrease the resistivity of the soil which is already accounted for in the soil resistivity measurements. This may confirm the observation made in the literature stating that salts reduce resistivity of the soil.

Microbes

Microbes are recognized for their potentially damaging effects on buried steel. However, there are a number studies that have shown high concentrations of microbes on buried steel surfaces with negligible results. Microbe analysis is not included in this study.

DEVELOPMENT OF A CORROSION PREDICTION METHODOLOGY

17 soil data elements were analyzed from 56 data sets to determine the optimal combination of elements to predict corrosion rate. The table below lists the data elements that were analyzed:

"On" Potentials	Sodium	Sulfate	Sand
"Off" Potentials	Potassium	Chloride	Silt
Free Corrosion Potential	Calcium	Total Soluble Salts	Clay
Resistivity	Magnesium	As Rec'd. Water Content	Gravel
pH	---	---	---

Over 130,000 regression analyses were used to determine correlation coefficients (R^2 values) for nearly all possible combinations of soil elements. Figure 1 below shows adjusted R^2 values versus soil data elements used. This figure shows that the greatest improvement in the adjusted R^2 is realized at five data elements. Improvement in the adjusted R^2 continues at a slower rate up to nine data elements. Beyond nine data elements, the adjusted R^2 drops - the apparent benefit of reducing the unknowns by adding more data is offset by the introduction of statistical uncertainty associated with simply having more data elements present.

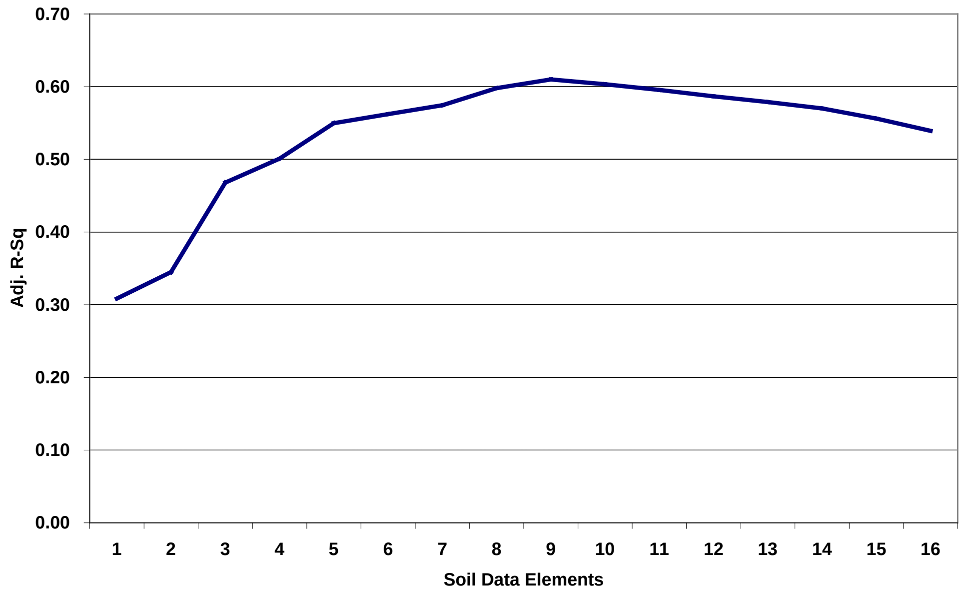

Figure 1: Adjusted R^2 versus number of soil data elements used in model[2]

Keeping in mind the objective of finding the most cost effective combination of variables, development of the methodology was focused on 5-element (incremental benefit inflection point) and 9-element (highest adjusted R^2) regression sets.

The methodology utilized maximum pit depth data since better correlation was observed with this data versus average pit depth or general corrosion rates. Maximum pit depth also exhibits the greatest influence on pipe failure and provides more conservative results.

DATA ELEMENTS

It is recognized that at times not all of the desired data elements may be available. To account for missing data elements, the methodology can be modified to accommodate different data element sets. Table 1 below shows an example of the different data sets that may be used with the methodology, and the corresponding errors. Methodologies for other combinations of data elements can be developed. However, the level of accuracy associated with modified data sets is anticipated to be lower than the models shown below.

Table 1: Required data elements and average errors for data sets

DATA ELEMENT	DATA SET NUMBER		
	1	2	3
CP On	X	X	X
CP Off	X	X	X
Resistivity	X	X	X
Free Corrosion Potential		X	X
pH	X		

[2] This chart represents preliminary results for a single algorithm. Since the development of this chart multiple algorithms have been developed for differing corrosion rate regimes.

Chloride	X	X	X
Sodium			X
Calcium	X	X	X
Potassium	X	X	X
Magnesium			
Sulfate	X	X	X
Dissolved Salts			
Gravel	X	X	X
Sand	X	X	X
Silt	X	X	X
Clay	X	X	X
Average Error (mpy)	2.9	2.3	2.0
Error in 0 – 12 mpy range	2.5	2.5	2.5
Error in 12 – 18 mpy range	5.6	4.8	5.1
Error greater than 18 mpy	2.5	1.4	1.4

Black filled cells are required data elements

ANALYSIS OF RESULTS

The methodology was tested against known data sets to assess the overall prediction capabilities. Figure 2 shows the scatter plot of predicted vs. actual corrosion rates for Data Set 3. The average error was about 2 mils per year. The larger errors exhibited in the 15 mpy range is a result of being near boundary conditions for different algorithms used in the methodology.

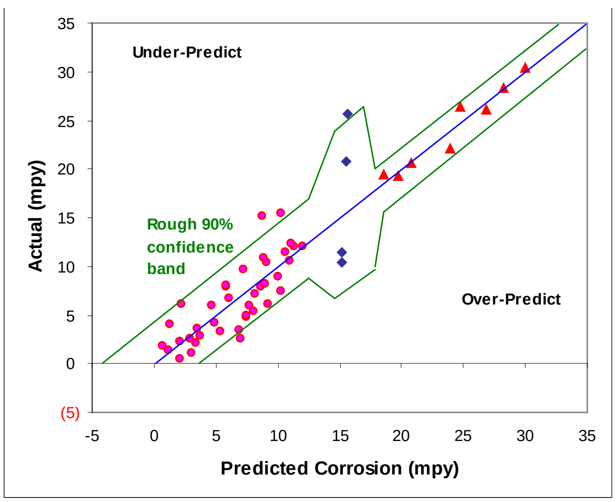

Figure 2: Actual vs. Predicted Corrosion Rate Prediction Using Data Set 3

RELATIVE RANKING

Relative ranking is a commonly used method for choosing direct inspection sites. The objective is to focus on the highest risk segments first. The soils analysis methodology will provide a relative ranking of sites based on predicted corrosion rates. A chart similar to the one shown in Figure 3 can be created to assist with the relative ranking of indications.

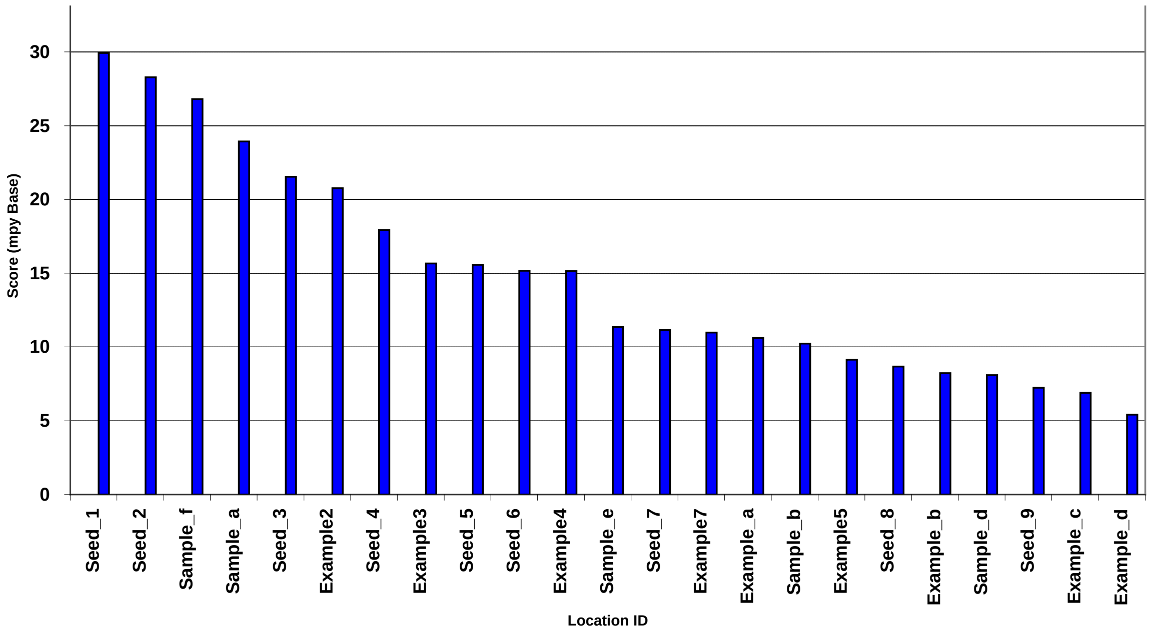

Figure 3: Relative ranking of proposed inspection sites based on predicted corrosion rate

CONFIDENCE RANKING TABLE

Understanding the level of certainty associated with corrosion rate predictions used in the ranking of one indication over another can be a valuable tool. Uncertainty levels in the predicted corrosion rates are presented in Table 1. Using this data, SoilPro can produce an estimate of the probability that a confidence ranking is correct. Table 2 shows an example of actual data that gives the level of confidence in ranking one indication over the other. For instance, the table shows that 54% of the time the predicted corrosion rate associated with Example 1 in the column heading will be greater than the predicted corrosion rate associated with Example 6. This table shows indications with a wide range of corrosion rates from 0.8 to 20 mpy.

Table 2: Confidence Ranking Table

		Example 6	Example 1	Example E	Example D	Example C	Example B	Example 5	Example A	Example 7	Example 4	Example 3	Example 2
Corrosion Rate (mpy)		0.80	1.20	2.20	5.40	6.90	8.20	9.10	10.60	11.00	15.10	15.70	20.80
Example 6	0.80	51%	54%	64%	88%	93%	97%	99%	99%	100%	99%	99%	100%
Example 1	1.20	46%	49%	62%	85%	92%	96%	98%	100%	100%	99%	99%	100%
Example E	2.20	36%	38%	50%	78%	86%	94%	95%	98%	98%	98%	99%	100%
Example D	5.40	12%	15%	22%	50%	62%	74%	82%	92%	91%	96%	97%	100%
Example C	6.90	7%	8%	14%	38%	50%	63%	71%	83%	83%	90%	91%	100%
Example B	8.20	3%	4%	6%	26%	37%	50%	59%	74%	76%	89%	89%	100%
Example 5	9.10	1%	2%	5%	18%	29%	41%	50%	65%	67%	83%	87%	100%
Example A	10.60	1%	0%	2%	8%	17%	26%	35%	50%	53%	77%	80%	100%
Example 7	11.00	0%	0%	2%	9%	17%	24%	33%	47%	50%	76%	77%	100%
Example 4	15.10	1%	1%	2%	4%	10%	11%	17%	23%	24%	50%	54%	80%
Example 3	15.70	1%	1%	1%	3%	9%	11%	13%	20%	23%	46%	50%	77%
Example 2	20.80	0%	0%	0%	0%	0%	0%	0%	0%	0%	20%	23%	50%

REMAINING LIFE CALCULATIONS

The predicted corrosion rate data can also be used to conduct remaining life calculations. In addition, the effect of adding or improving a cathodic protection system can be quantified. Figure 4 shows the predicted corrosion rate of an indication for various instant off pipe-to-soil potentials. In this example a four fold decrease in corrosion rate could be realized from changing the off reading from the initial -567 mV to -850 mV.

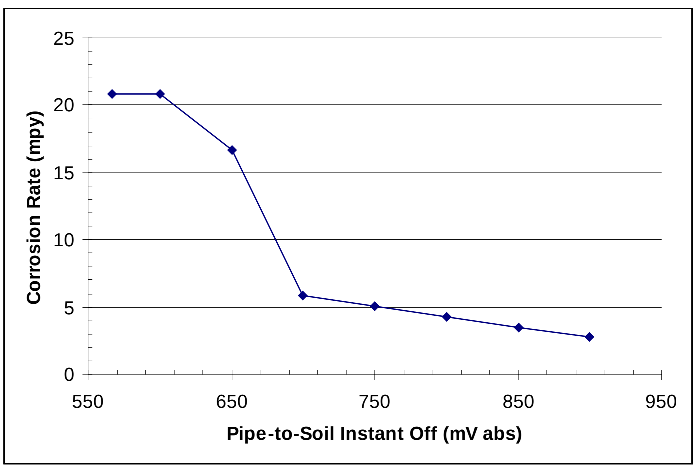

Figure 4: Predicted corrosion rate as a function of polarization (Example 2)

SOIL SAMPLING

Soil sampling will need to be conducted in proximity to the buried assets that are being evaluated. The soils sample should be representative of the environment at the pipe surface. About a gallon of soil is needed for the analyses.

The general objective of soil sampling is to collect samples representative of the desired equipment in the most cost effective manner. Typically, this is done by collecting soil samples in excavations that are already being conducted for another purpose. Sampling only in high risk areas reduces the cost of analysis, but limits the amount of information available for future decision making.

CORROSION RATE ANALYSIS & REPORTING

Upon completion of testing, soils data can be forwarded electronically directly to SI for corrosion rate prediction. The analysis can include the following determinations:

- Corrosion Rate Per Indication
- Relative Ranking Chart
- Confidence Ranking Table
- Corrosion Rate vs. Instant Off Potentials Curves per soil sample

Other analyses can be conducted as requested.

CONTACT INFORMATION

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