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External Corrosion Growth on an Ageing Pipeline: a Case Study

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Abstract

Regarding the threat posed by corrosion in ageing pipelines, metal-loss in-line inspection – ILI – (Smart Pig) provides the most valuable insight into pipeline integrity assessment. However, ILI data offers only the static damage accumulation at inspection time. In order to estimate future pipeline integrity, time dependent effects must be considered before applying any of the currently available criteria for defect assessment. Growth modeling of metal-loss defects plays a major role in the safe and cost-effective operation of pipelines. The construction of accurate integrity scenarios would allow operators not only to optimize inspection intervals and minimize overall rehabilitation cost, but also guarantee proper operation safety margins. The accuracy of such scenarios relies on proper corrosion rate modeling. The diversity of mechanisms acting concomitantly along a single pipeline and the inherent stochastic nature of corrosion process makes its mathematical modeling along an entire pipeline quite a complex task. This paper presents a case study where an empirical approach is used to determine external pipeline corrosion rates. The investigation procedures were based on statistical analysis of ILI results and coating and cathodic protection surveys data.

Palavras-chaves: corrosion rate, pipeline, modelling

Introduction

The worldwide economy's constant growth a represents continuing boost in energy demands. Hydrocarbons play an important role in the global energetic matrix and pipelines are one of the most cost effective ways to transport large quantities throughout process facilities and consumer zones. Notwithstanding their comparative reliability, pipelines usually face many threats during their service lives. In order to guarantee their safe serviceability, damage acting mechanisms must be model towards assess immediate and future pipeline structural integrity, which takes into account, the damage evolution.

However, despite pipeline integrity management being supported nowadays by so many measurement and monitoring techniques, a considerable amount of uncertainty is usually associated with damage progression forecasting, which consequently affects the reliability of future structural performance estimations.

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The ability to realistically forecast corrosion growth is a key component of a cost effective integrity management system. Despite corrosion being a well-known phenomenon that can be quantitatively described by means of electrochemical laws, so many mechanisms could be acting simultaneously along a pipeline and the attack severity of each one of those mechanisms could vary so significantly, that the prediction of realistic corrosion rates along pipeline profiles represented a considerable challenge in pipeline integrity forecasting studies.

This paper presents a case study where a simplified approach, based on statistical analysis of a single smart pig inspection-running data collection has been adopted to characterize corrosion evolution rates along external pipeline surfaces. The applied methodology has divided the entire metal-loss anomaly population into subgroups, by means of straightforward assumptions regarding the coating and the CP system effectiveness. The overall goal was to provide reliable corrosion rate estimations to perform a cost effective assessment of the pipeline's future integrity.

2. Case Study – Background Information

This case is an on land buried pipeline 24" diameter, 360 kilometers (223,7 mi) length, and has been used to transport crude oil from coastal facilities into the inner country region. It has been operational since the 1980's. The rights-of-way for this pipeline cross a mountainous farming region, although both ends are in suburban areas. Accordingly to field measurements and historical data, those areas are subjected to DC stray current. The data collected includes ILI results from an MFL pig run performed late 2005, together with recently conducted coating and CP survey.

3. Corrosion Growth Modeling

The tendency of an unprotected outside steel pipewall surface exposed to soil attack is to be corroded by electron loss in anodic areas. To prevent the occurrence of such event, buried pipelines are usually protected by a combination of polymeric or organic coating and a cathodic protection system. The former function is electric isolation, i.e. to prevent electron exchange among anodic and cathodic areas by the electrolyte (represented by the wet soil). When coating damage occurs, it is expected that the exposed area should be protected from corrosion by the latter. So, the existence of active corrosion sites on external pipeline surfaces will be restricted to regions where these two defensive lines had been broken.

In order to keep a simplistic approach, each ILI external defect has had its corrosion rate computed individually by using Equation (1), taking into consideration the premise of constant damage accumulation along the pipeline service life. A coating damage nucleation period of five years had also been assumed, aiming at taking into account the coating material property degradation over time.

$$Rm_i = \frac{d_i}{\Delta t_s - \Delta t_n} \tag{1}$$

Where,

- R_{mi}: corrosion rate;
- d_i: defect reported depth [mm];

- Δt_s: current pipeline service life;
- Δt_n: coating damage nucleation time.

It is well known that, depending upon local protective system conditions allied to the local acting mechanisms, corrosion attack severity could vary radically along a pipeline length, and the above suggested procedure may result in too conservative or even non-conservative predictions for future corrosion growth. Nevertheless, the study of large data population could lead to very valuable insights, concerning to pipeline general corrosion activity distribution. Indeed, coating degradation can be investigated by considering material and manufacturing process; eg: field joint areas, river crossing areas etc. On the other hand, cathodic protection effectiveness can be studied by correlation of metal-loss areas with ground survey data, or by investigating any atypical variations regarding the proximity of rectifiers, different characteristics of soil, site, under casing areas, stray current areas etc.

Accordingly, the population segmentation had been performed, aiming to provide a better understanding of coating and CP effectiveness. Thus, the probability distribution features of each population were determined. The results have been evaluated by a team of experts, paying special attention to the identification of secondary and/or unpredicted interdependencies of the all parameters in order to assure consistence on the final results.

3.1. External Corrosion Rates – General Distribution

A total number of 1680 external anomalies due to pipewall metal loss deeper than 10%, had been reported by a recent ILI inspection. Individual corrosion rates had been determined admitting a coal-tar damage nucleation period of 5 years. Figure 1 presents the anomalies number (ILI indication) per kilometer over the pipeline length, considering segments of 5 kilometers. More detailed investigation work has been carried out at the sections with abnormal concentrations.

The corrosion rate histogram is show in Figure 2, where it can be noted that it is a right skewed distribution, Kolmogorov Smirnov methodology had been applied to model the lognormal best fitting distribution.

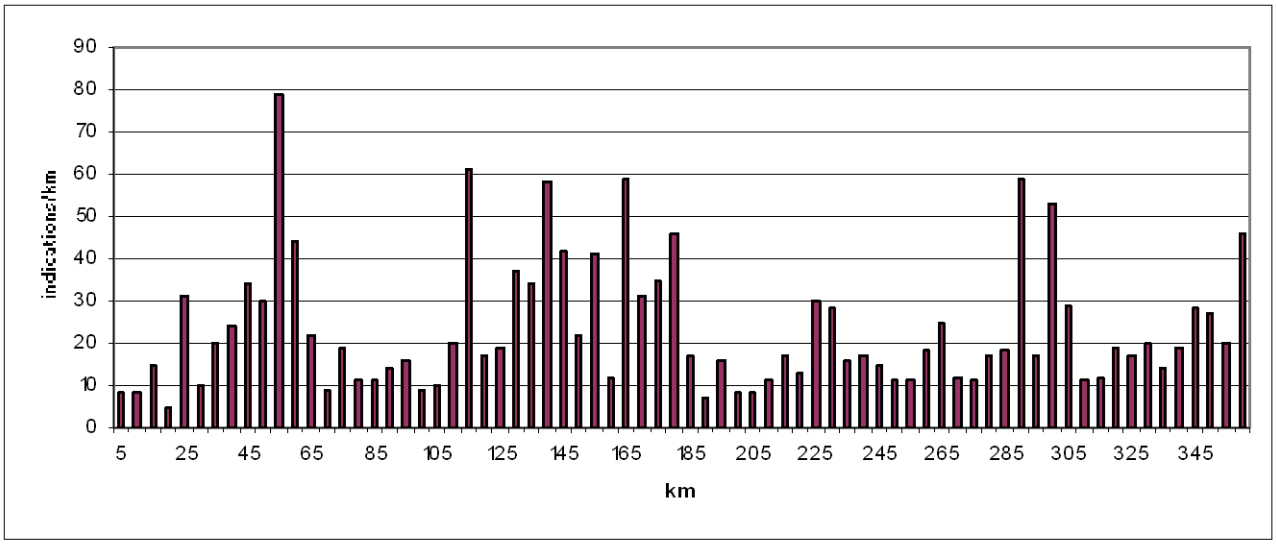

Figure 1: *External metal-loss indication frequency distributions over the pipeline length.*

Note 1: left skewed frequencies are limited due to a minimum metal loss of 10% assumed on this evaluation. Values lower than 10% was considered negligible and not considered in the ILI analyses data.

3.2 Coating effectiveness Investigation

The coating material is coal-tar, which had been applied at the pipes manufacturer facilities. The girth weld region had been covered by the same material, but using a field application process. During the construction procedures, many pipes had been field bent, mainly in the region crossing mountains. The investigation carried out considered the following hypothesis:

- Coating at the field joint areas does have a different performance than overall coating and;
- Coating could be damaged during the field bending process.

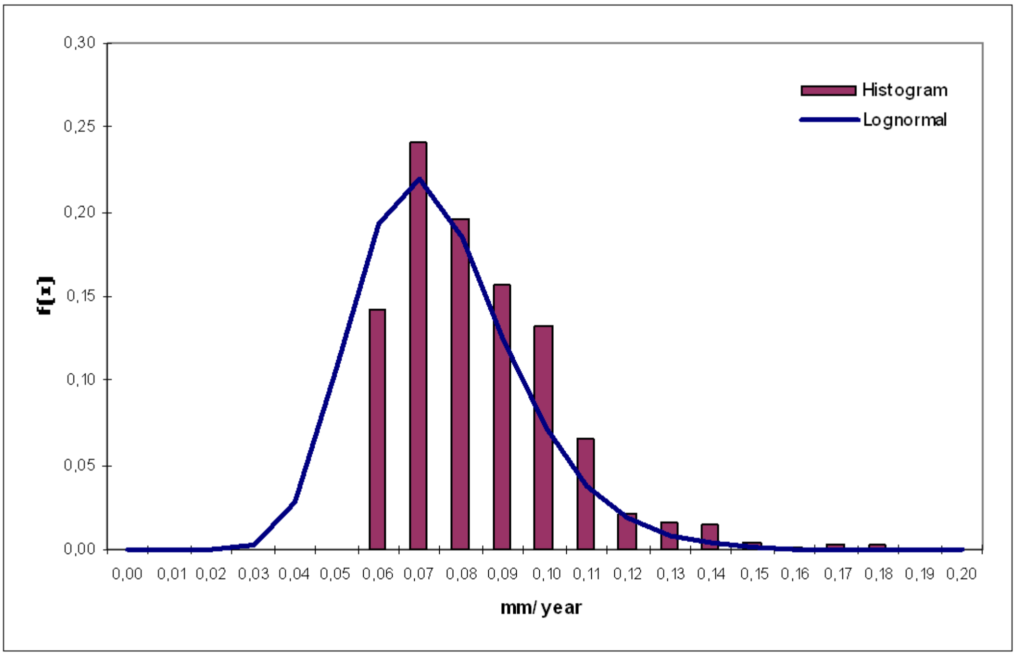

***Figure 2:** Pipeline corrosion rate frequency distribution.*

The metal-loss anomalies were segregated accordingly, with former premises and a descriptive statistic study performed on each separate population. Obtained results are presented in Table 1 and shown that the field joint area presents almost 90% more indications of metal loss. Figure 3 compares the relative frequency distributions of corrosion rates in the manufacturer and the field coating, showing their similar overall behavior.

***Table 1:** Corrosion rate distribution features, regarding coating effectiveness.*

POPULATION		CORROSION RATE [mm/year]			INDICATIONS/KM
		MEAN	STD. DEVIATION	95% CONFIDENCE LEVEL	
Overall		0.080	0.021	0.115	4.7
Coating	Field Joint	0.080	0.021	0.125	8.3
	Manufacturer	0.080	0.022	0.115	4.4
Pipe	Bent	0.079	0.018	0.114	6.5
	Straight	0.076	0.020	0.121	3.9

Evidences of a similar deleterious effect of the pipe bending on the coating effectiveness had been also provided by the analysis.

The coating over the line survey, such as Coating Attenuation/ACVG, had been performed in order to detect coating failure regions and the associated effectiveness of the cathodic protection in those areas. Figure 4 depicts coating anomaly numbers per pipeline segment of 5 kilometers, according to their severity.

The concentration of the metal loss reported by pig inspection has also been analyzed. Results showed a very significant and unexpected concentration of pipe external defects at the neighborhood of two rectifiers. The resulting data's are presented in Table 2.

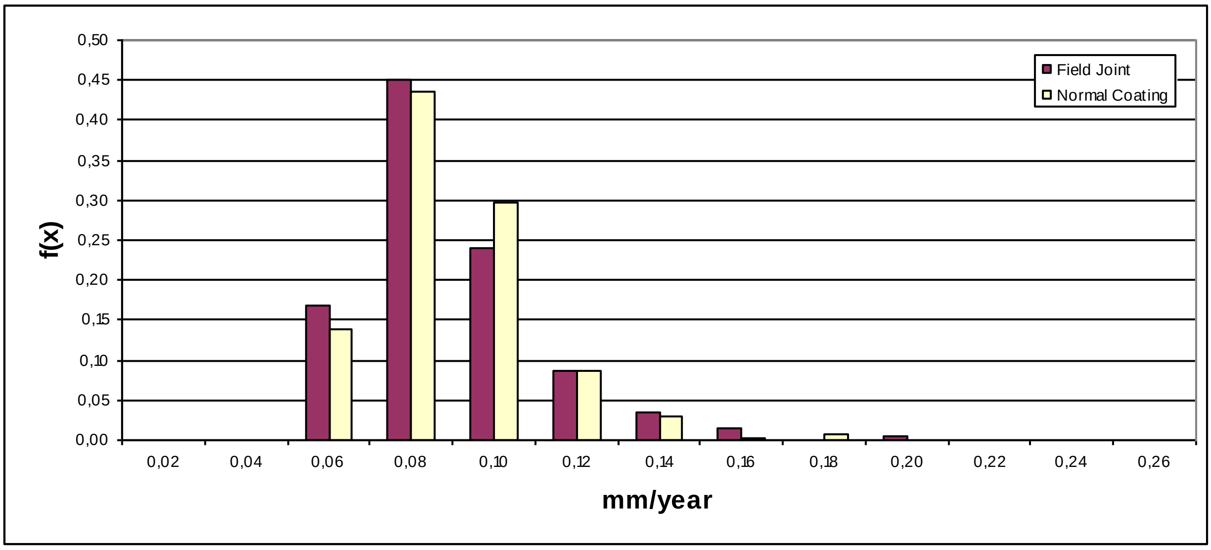

Figure 3: *Normal coating and field joint coating corrosion rate frequency distributions.*

Table 2: *Concentration of metal loss indications.*

	NUMBER OF INDICATIONS PER KM			
	DISTANCE FROM RECTIFIER			PIPELINE AVERAGE
	500 m	**1 km**	**2 km**	
Ret A	47,0	28,5	17,8	4,7
Ret B	21,0	13,5	9,5	
others	2,4	2,4	3,2	

<u>3.3 Stray Current Influence Investigation</u>

It is known that pipelines located in urban areas can present a specific corrosion mechanism, called Stray Current Corrosion, as a consequence of the presence of DC powered railway systems. In the presence of such Stray Current, the pipeline works as a metallic electric conductor, and as the current leakages at coating damage areas, those leakages of current from the steel to the earth could leads to a severe localized corrosion. The occurrence of this mechanism has already been observed in this pipeline metropolitan suburban area. Figure 5 illustrates some past occurrences at the studied pipeline area due to the influence of this mechanism.

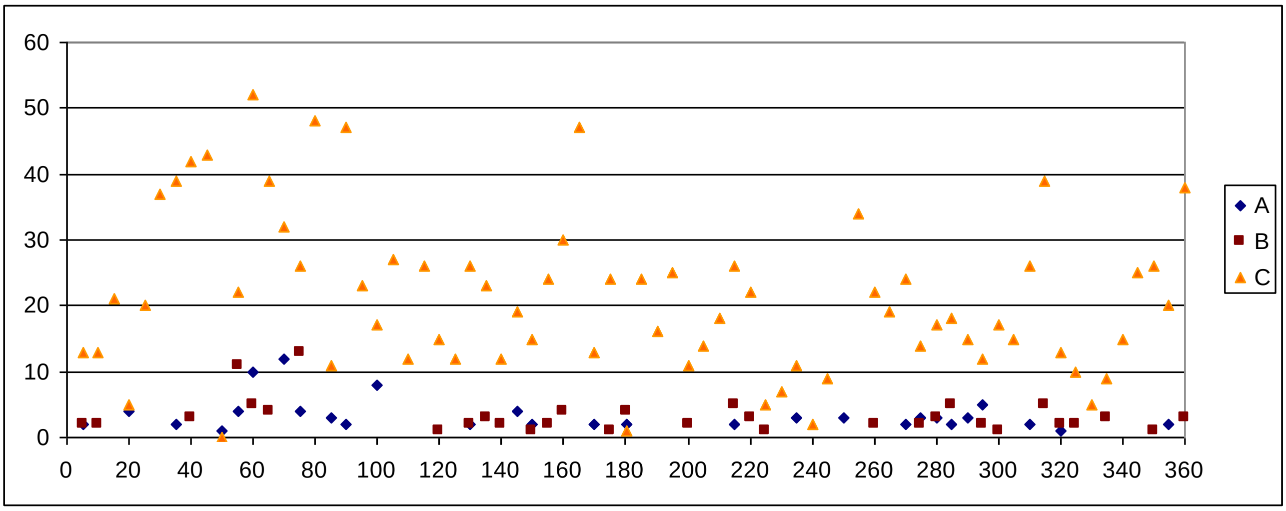

Figure 4: *Current attenuation anomalies per pipeline segment of 5 km.*

A) severe attenuation
B) moderate attenuation
C) light attenuation

In order to investigate the influence of this mechanism on the corrosion rates of this pipeline, the first 58 kilometers had been analyzed separately, because of the known influence of stray currents in this area. Moreover, the section under the influence of the suspected rectifiers had also been isolated. The results (presented in Table 3 below) show that despite the first 50 pipeline kilometers having a lower number of metal-loss indications per kilometer, the corrosion severity is 10% higher in this region. Additionally, the section between kilometers 50 and 58, which is also under the influence of the rectifiers A and B had shown corrosion rates even greater with occurrence probability 3 times higher.

(A) (B)

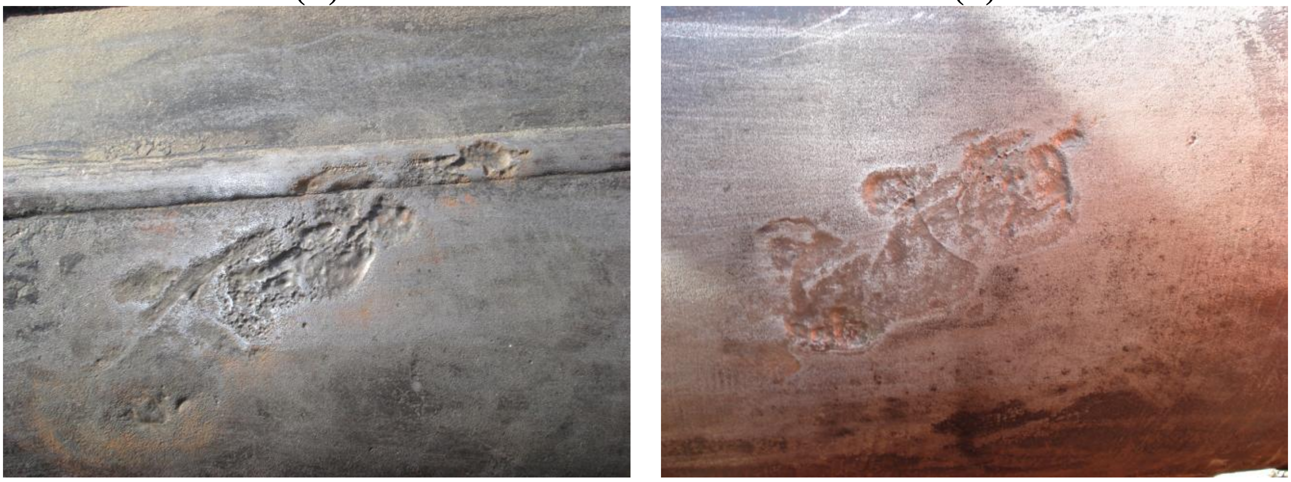

Figure 5: *pipeline corrosion.*

Table 3: *Corrosion rate distribution features, regarding CP effectiveness.*

POPULATION	CORROSION RATE [mm/year]			INDICATIONS/KM	BEST FITTING DISTRIBUTION
	MEAN	STD. DEVIATION	95% CONFIDENCE LEVEL		
0-50 km	0.087	0.027	0.140	3.7	Gama
50-58 km [Ret A&B]	0.090	0.040	0.170	13.6	Lognormal
58-358	0.079	0.018	0.109	4.6	Lognormal

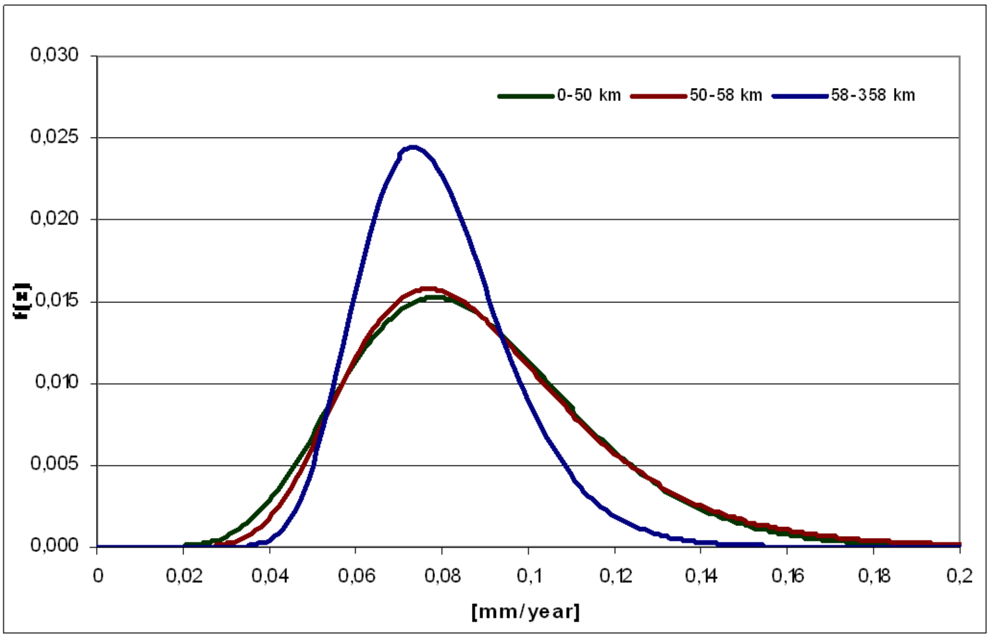

Figure 6: *Best fitting probability density distributions.*

Figure 6 compares the corrosion frequency distributions of the three segments considered, in order to gives a better display of their different features. It can be noted that from origin to kilometer 58, the corrosion rate distribution maintains a very close correlation, with a slightly higher corrosion activity and data dispersion in the pipeline segment located between kilometers 50 to 58. The other 300 kilometers of pipeline length had been submitted to lower levels of corrosion activity as the average corrosion rate of the defects located in this segment show. Additionally, a lower dispersion and more normalized behavior indicate a lower probability to elevated growth rate values being found in this area.

4. Conclusions

A case study of corrosion growth in external pipeline surface has been presented. An exploratory data analysis, based on the study of metal-loss anomaly population reported by ILI, has been performed. To each metal-loss anomaly, an individual corrosion rate has been determined based on the premise of constant damage accumulation. Potential corrosion mechanisms have been investigated by segregation of the original population into sub-groups. The study concluded that:

- on the probabilistic Distribution of External Pitting Corrosion Rate the best fitting probability is a lognormal density distribution (out of stray current areas).
- different external corrosion rates should be considered in a corrosion growth modeling depending on stray current areas.
- stray current corrosion has been found to have a significant influence on the corrosion rate distributions range; where anomalous corrosion activity has been identified in the vicinities of two specific rectifiers;
- field performed coating for the girth weld presented a performance inferior to the coating performed at the manufacturer’s facilities;
- pipe bends also have a slight deleterious effect on the coating properties or performance.

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