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CORROSION RISK ASSESSMENT AT ANCHOR SHAFTS OF TELECOMMUNICATION TOWERS

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ABSTRACT

Corrosion of steel foundations in soil is a serious financial and technical problem for telecommunication companies. Underground corrosion is the primary cause of material degradation and structural failure at anchor shafts of guyed towers. Accordingly, accurate and practical methods to predict corrosion modes and corrosion rate are extremely beneficial for corrosion risk assessment and service life prediction. In this paper, field-proved guidelines for knowledge-based inspection, risk assessment, and risk mitigation of underground corrosion are highlighted which are specific to telecom structures. Effects of soil chemistry on corrosion of galvanized and carbon-steel anchor shafts are evaluated. A predictive model to estimate the corrosion rate and remaining service life of buried components are introduced. Four cases representative of different corrosion levels are presented and relevant mitigation process are given for each case.

Keywords: *Soil Corrosivity*, *underground corrosion*, *Corrosion Risk Assessment*, *Concrete Condition Assessment*, *Communication Tower*

INTRODUCTION

Guyed towers with anchor foundations is a common design for tall telecom towers that support antennas for broadcasting and telecommunication services such as radio, television, cellular networks, and satellite communications. Structural integrity of telecom towers is the key to ensure reliability of telecommunication and broadcasting services; nonetheless, many tower facilities are coming of age and corrosion related issues are turning into serious engineering and financial problems. These towers are suffering both from atmospheric corrosion at above-grade and underground corrosion at below-grade environments; however, the risk of structural failure is mostly associated with below-grade corrosion.

An anchor foundation is schematically shown in Figure 1. The anchor shaft, usually made from carbon- or galvanized-steel, plays a critical role in structural integrity of guyed towers. This component is constantly under tensile force due to opposing forces at its ends, i.e., tension in guy wires and weight of the soil and anchor block. Accordingly, any form of material loss on anchor shafts would lead to decrease of cross-sectional area and formation of 'stress risers', which in turn would increase the risk of structural failure.

This paper is a sequel to our previous NACE publication[1], which was mostly focused on corrosion modes and cathodic protection system design.

In the current paper, direct and indirect methods for corrosion risk assessment of anchor shafts are discussed, and sample case studies are presented. The direct approach includes visual examination and dimensional measurements, while the indirect method is based on soil characterization for corrosion rate determination and predictive modeling. The risk mitigation process is based on the identified risk factor.

As shown in Figure 1, common scenarios for underground corrosion in anchor shafts include: stray current corrosion, microbiologically induced corrosion (MIC), galvanic corrosion with copper grounding, and corrosion pitting due to soil corrosivity and non-homogeneity. More details are provided in referenced article in Ref. [1]. Moreover, information on corrosion of steel structures in soil and mitigation methods are reported in Refs. [2, 3, 4].

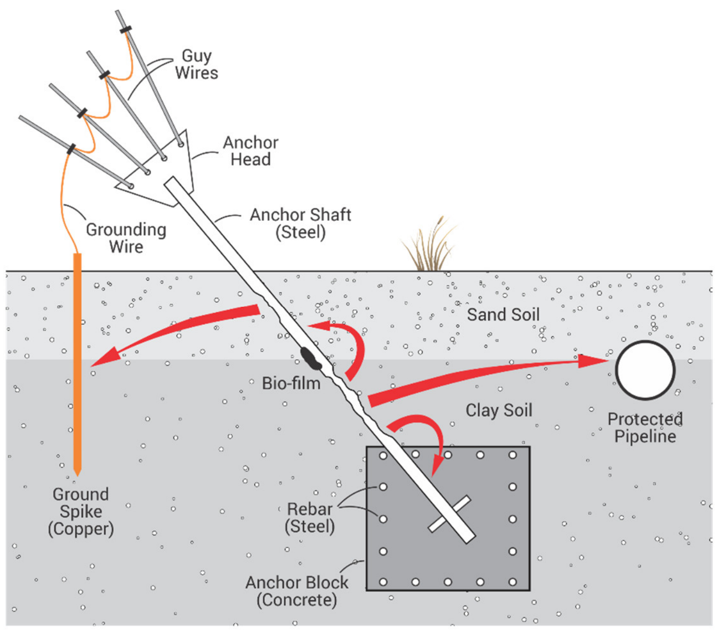

Figure 1. Different modes of corrosion in anchor shafts[1]

CORROSION RISK ASSESSMENT PROCEDURE

Assessment procedure includes a combination of field and laboratory assessments.

Field Assessment

On-site investigations include the following tasks:

Anchor-to-soil potential survey. A reference electrode is used to map the potential around the anchor shaft. As presented in Figure 2, at each anchor, several potential values are collected at three different directions. It is recommended to perform the potential measurements in 2 ft. intervals. Close-interval potential survey allows identifying abnormalities in potential distribution which are mostly associated with stray current corrosion[1].

Grounding resistance measurements. This test is performed at anchors' grounding system. At footings with low resistance value there is higher risk of galvanic corrosion, when copper is used as the grounding material.

In-situ soil resistivity measurements with Wenner four-pin method (ASTM G57)[5]. This test along with Barnes layer analysis is used to identify the water table, and conductivity of soil horizons.

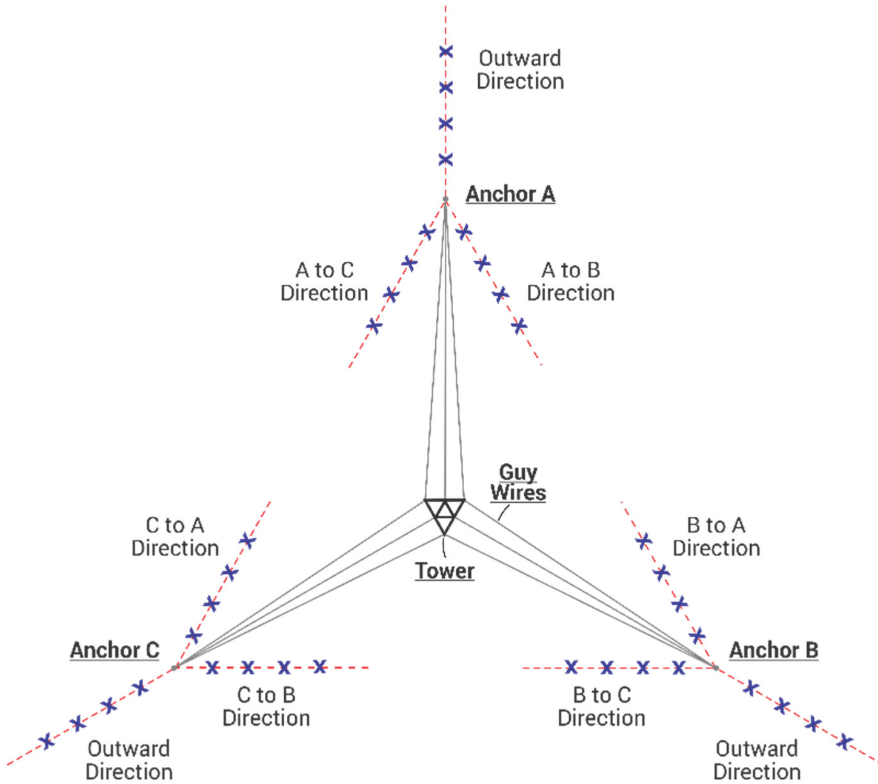

Figure 2. Schematic of the location and direction where potentials are measured relative to guyed anchor shafts and main tower

Concrete compressive strength measurement. A calibrated Schmidt hammer is used to measure compressive strength of concrete at anchors which are encased in concrete. This test determines the general uniformity of concrete and allows to identify questionable areas that may require further investigation and/or repairs.

Direct assessment. Selected anchor shafts are partially excavated (a minimum of 3 ft. along the shaft) to expose the shaft for visual inspection and dimensional measurements. Changes in material/coating thickness and corrosion pattern are measured/documented along the exposed section of the shaft.

Additional activities include: photographic documentation and soil sample collection for laboratory analysis. Soil samples must be collected from around the anchor shaft and quickly sent to lab for soil chemistry tests, as listed below.

Laboratory Assessment

Laboratory investigations on collected soil samples are performed to measure the following soil properties based on relevant ASTM and other applicable standards:

- ASTM G57 (soil box method) to measure soil resistivity in ohm-cm. This includes as-received measurement and minimum resistivity[5] measurement at saturated condition.

- ASTM D2216[6] to determine the soil moisture content in as-received condition.
- ASTM G51[7] to determine the soil pH level.
- ASTM G59[8] and ASTM G102[9] to measure the instantaneous corrosion rate. This test can be performed for carbon-steel or galvanized-steel.
- AASHTO T291[10] to measure water-soluble chlorides (Cl^-) content of soil.
- ASTM C1580 or AASHTO T290[11] to measure water-soluble sulfate (SO_4^{-2}) content of soil.
- Colorimetric method to measure sulfides (S^{-2}) content of soil.
- ASTM G200 and ASTM D1498[12] to measure the redox potential.

Predictive Model

Several predictive models for pit growth and material loss have been developed for steel pipelines based on statistical analysis of collected data obtained from:

- Surveys of the condition of buried structures
- Scientific exposure of buried materials
- Sensor-based studies or monitoring of buried materials and coupons

The predictive model adopted in this study is used to predict the corrosion rate of anchor shafts based on the collected data from field and laboratory investigations. The model formula is not presented here due to a nondisclosure agreement with our clients.

Corrosion Risk Assessment

In order to provide a reliable assessment of corrosion risk at anchor shafts, all collected data on soil properties, visual examinations, and site condition need to contribute in a risk factor analysis proportional to their influence in the risk. In our analysis, the corrosion risk factor is evaluated based on four parameters, as described below:

- *Model Factor (MF)*: An averaged corrosion rate (in mils per year) is calculated over 50 years from the predictive model; please see Figure 3 for sample results from the predictive model. The model factor (MF) is then determined based on the value of averaged corrosion rate; see Table 1. Parameters that contribute to model factor are anchor-to-soil-potential, redox potential, pH, and soil resistivity.

- *LPR Factor (LPRF)*: This factor comes from in-lab measurement of instantaneous corrosion rate (ASTM G59 and ASTM G102) on soil samples. Similar to the model factor (MF), the value for LPRF is determined from Table 1.

- *Visual Factor (VF)*: This factor is determined by visual inspection of the corrosion pattern and its severity. The more corroded the member is the higher the visual factor would be. Examples of different visual factors ranging from mild to severe are presented in the following sections.

- *Other Factors (OF)*: This factor, which is case sensitive, takes account for specific cases such as high concentration of corrosive chemicals in soil (i.e., chloride, sulfide, sulfate), terrain topology, water table, and stray current effects.

The overall risk factor (RF) is calculated using the equation below:

$$RF = MF \times A + LPRF \times B + VF \times C + OF \quad (1)$$

The coefficients A, B, and C are weight factors for MF, LPRF, and VF, respectively, where A + B + C = 1. The values for these coefficients are selected proportional to their importance. For example, in our analysis, coefficient C is the largest coefficient due to the importance/certainty of visual observations. Recommendations for corrosion risk mitigation are determined based on the overall corrosion risk factor; see Table 2.

Table 1. Reference table to determine model or LPR factor value

Corrosion Rate (mpy)	< 1	1 – 2	2 – 3	3 – 4	4 – 5	5 – 7	7 – 8	8 – 9	9 – 10	> 10
MF and LPRF	1.00	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00

Table 2. Corrosion risk factor, corrosivity level, and risk mitigation recommendations

Corrosion Risk Factor (FR)	Corrosivity Level	Recommendation
< 1.75	Low	Inspection in 5-10 years
1.75 − 2.5	Moderate	Inspection in 3-5 years
2.5 − 3.25	High	CP installation in 2 years
> 3.25	Severe	Immediate CP installation

CASE STUDIES

The approach rates corrosion risk in four levels as 'low, 'moderate', 'high', and 'severe'. In this section, four case studies with different corrosion risks are presented for guyed anchor shafts. For the selected case studies, the corrosion risk was also evaluated using DIN standard (DIN 50929; Part 3). The corrosivity levels suggested by the DIN standard were in qualitative agreement with the assigned corrosivities.

Table 3 is a summary of data collected from four different anchor shafts exposed to environments identified as low, moderate, high, and severe corrosivity level. These data were used to draw the predictive model and calculate risk factor.

Table 3. Examples of data collected in the field and lab in four different cases

Corrosivity Level	Mild	Moderate	High	Severe
Instantaneous Corrosion Rate	1.92	1.72	4.14	7.02
Anchor-to-Soil Potential (mV-CSE)	-384	-382	-519	-675
Redox Potential (mV-SHE)	538.7	541.9	675.6	618.5
Soil resistivity measured in the field (Ω-cm)	65,914	53,535	674	1,340
As received resistivity (Ω-cm)	251,000	18,330	1,363	3,946
Saturated Resistivity (Ω-cm)	13,790	10,550	1,712	3,267
pH	7.07	6.03	5.24	3.74
As received Moisture (%)	12	14	20	19
Chloride (ppm)	1.6	3.07	3.42	102
Sulfate (ppm)	12	20	43	< 5
Sulfide (ppm)	< 0.04	< 0.04	0.05	< 0.04

<u>Predictive Model for Difference Corrosivity Level Cases</u>

The plots in Figure 3 are obtained from the predictive model using the collected data from anchor shafts at different sites; as presented in Table 3. Each plot represents a different corrosivity level.

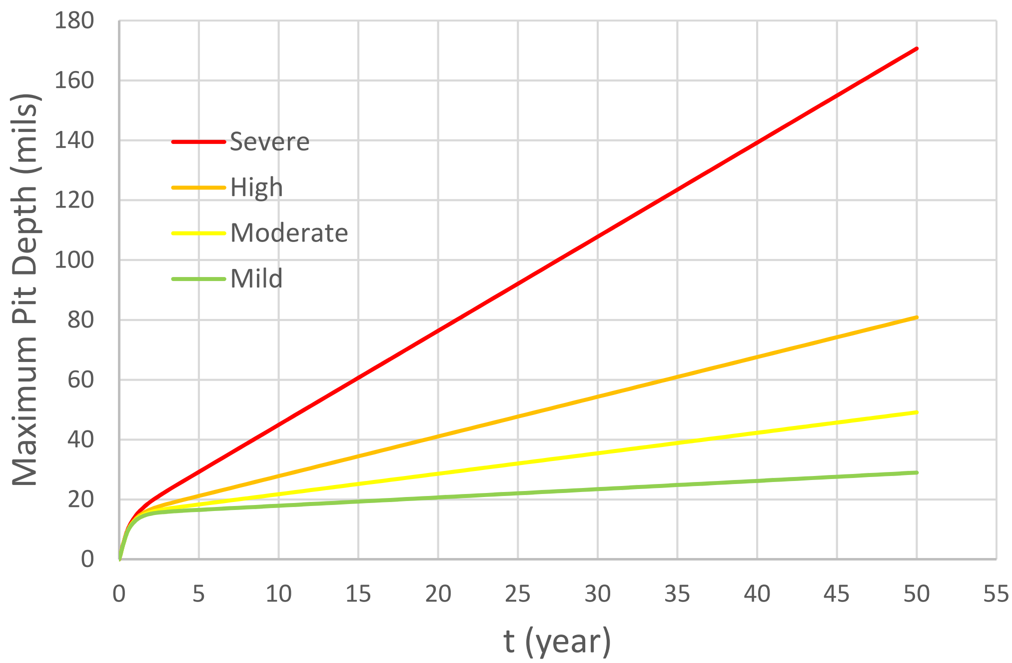

Figure 3. Material loss predictions for different case studies identified as Mild, Moderate, High, and Severe

Model Factor and LPR Factor

The average corrosion rates calculated from the predictive model, i.e., Figure 3, and Instantaneous Corrosion Rate or LPR measured in lab are presented in Table 4. These values were converted to model factor (MF) and LPR factor (LPRF) based on Table 1. These factors along with visual factor and other case-sensitive factors (OF) were used to calculate the risk factor from Eq. (1). The results are reported in Table 5.

Table 4. Average corrosion rate calculated from predictive model and measured LPR in lab

Corrosivity Level	Mild	Moderate	High	Severe
Average Corrosion Rate from Predictive Model (mpy)	0.58	0.98	1.62	3.41
Instantaneous Corrosion Rate or LPR (mpy)	1.92	1.72	4.14	7.02

Table 5. Data analysis, risk factor, and recommended mitigation process

Corrosion Severity	Model Factor (1 – 4)	LPR Factor (1 – 4)	Visual Factor (1 – 4)	Other Factors	Risk Factor (1 – 4)	Corrosion Risk	Recommendation
Mild	1.00	2.00	1.00	0.00	1.25	Low	Inspection in 5-10 years
Moderate	1.00	2.00	2.00	0.00	2.00	Moderate	Inspection in 3-5 years
High	2.00	2.75	3.00	0.00	2.69	High	CP installation in 2 years
Severe	2.50	3.25	4.00	0.50	3.94	Severe	Immediate CP installation

Visual Factor

Photos taken from anchor shafts with low, moderate, high, and severe corrosivity levels are shown in Figure 4, Figure 5, Figure 6, and Figure 7, respectively.

Figure 4. Example of visual factor = 1 or anchor shafts under a mild corrosivity level

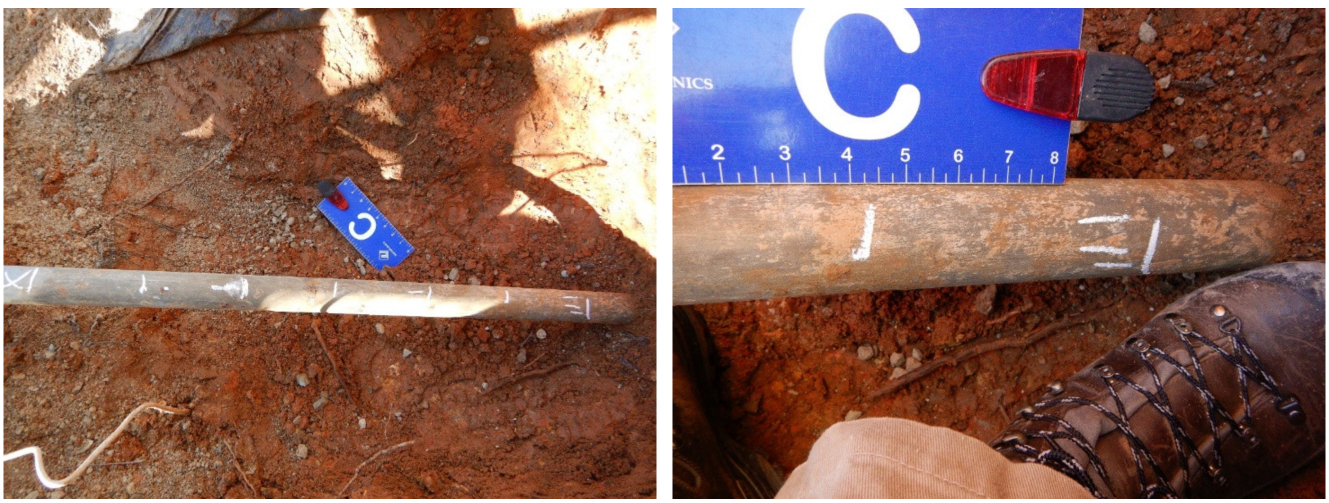

Figure 5. Example of visual factor = 2 or anchor shafts under a moderate corrosivity level

Figure 6. Example of visual factor = 3 or anchor shafts under a high corrosivity level

Figure 7. Example of visual factor = 4 or anchor shafts under a severe corrosivity level

Data presented in **Error! Reference source not found.** demonstrate data analysis and calculation of risk factor followed by a recommendation provided as a mitigating process.

<u>Dimensional Change</u>

Another factor used by Matergenics during inspections is measurement of dimensional change and calculation of cross-sectional material loss. Loss in cross-sectional area in anchor shafts is used as the reference to provide a mitigation/repair recommendation as shown in Table 6.

Table 6. Mitigation/repair recommendations based on cross-sectional material loss

Loss in Cross-Section (%)	< 1	1 – 5	5 – 20	> 20
Mitigation Process	Acceptable	CP installation	Reinforcement	Replacement

<u>Geometry</u>

Shape and size of anchor shafts are important factors in determining their service life. The cross-sectional and circumferential surface areas of a shaft are key parameters when it comes to life assessment. The risk of corrosion pitting on a shaft surface increases as its surface area increases—because when a large surface is exposed to inhomogeneous soil environment the possibility for formation of anodic and cathodic zones is high. On the other hand, the risk of mechanical failure due to corrosion pitting is higher at shafts with smaller cross-sectional area. Accordingly, it can be concluded that shafts with higher ratio of cross-sectional area to circumferential area are less prone to corrosion failure. For example, the ratio of cross-sectional surface area to circumferential surface area (for a unit length) of a circular shaft is R/2, where R is the shaft radius. The higher the shaft radius, the lower the corrosion failure risk.

Age

Age is also a factor that should to be considered in corrosion analysis. There is always a higher risk for older structures. The age factor is brought into analysis though “Other Factors” in Table 5.

Concrete Condition Assessment

The condition of the concrete encasing the anchor is assessed through visual inspection and also using a calibrated Schmidt hammer to measure compressive strength of concrete. Compressive strength is an indicative of integrity of concrete and would estimate the volume of entrapped air or crack within microstructure. Figure 8 in the left photo shows an example of a concrete in good condition. On the other hand, the concrete in the photo on the right has a coarse surface and large amount of coarse grains, contains entrapped air, and does not fully cover the anchor shaft.

Figure 8. Examples of concrete condition around anchor shafts

Compressive strength below 3000 psi is an indication that concrete is not in good condition and needs immediate attention to perform either repair or replacement.

CONCLUSIONS

A methodology for corrosion inspection of anchor shafts of telecommunication towers was introduced. Anchor shafts are the load-bearing members of guyed structures; thus, are critical to structural integrity. In the presented method, soil properties including soil resistivity, redox potential, pH, anchor-to-soil potential, and instantaneous corrosion rate along with visual factor are used in the assessment to calculate a risk factor. Other factors such as stray current, soil contamination, and age are considered in the analysis as well. This method has been applied to more than 500 towers and it is proved to provide an accurate and reliable results. However, efforts to improve it for example by including more factors will continue. These new factors are soil types (in terms of clays, silt, and sand percentage), water content, soil homogeneity, etc[13]. It is important to emphasize that our inspection method is able to provide an estimate of the corrosion severity at deep burial as well.

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