Evaluating Strength Loss on Tubular Steel Poles Due to Corrosion

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ABSTRACT

Among the many serious challenges facing engineers responsible for the reliable operations of our electrical grid is the continuous evaluation of degraded structural capacity of poles and towers due to the deteriorating effects of aging and exposure. One of those deteriorating effects is corrosion. Corrosion of steel is a naturally occurring electrochemical conversion of a refined metal (steel) to its original, more chemically-stable form of various oxides, hydroxides, or sulfides. The chemical and/or electrochemical reaction the steel will have with the environment into which it is installed, is typically a gradual degradation. But, when steel begins to degrade due to corrosion, it loses strength. There are few guidelines available to help Utility Engineers evaluate this strength loss on installed tubular steel poles. This paper discusses and provides a methodology that can be used to evaluate strength loss when the effects of corrosion begin to degrade a tubular steel pole below its original design strength.

Background

There are an estimated 900,000 electric utility steel transmission and distribution structures in North America alone. The degradation effects of corrosion can have a significant effect on the structural reliability of this important segment of our utility lines infrastructure. While the predictability of strength for a newly installed tubular steel pole is relatively easy to calculate, deterioration of these poles over time due to corrosion presents a different challenge to those calculations. Informed, cost and risk-based decisions for the primary actionable asset management options available are needed. Those options include:

(a) Monitor - continue to monitor and observe the installed steel pole,
(b) Remediate - extend the asset life of the installed steel pole,
(c) Replace - replace the installed steel pole and reset the asset life expectancy.

A Methodology for Evaluating Strength Loss of a Steel Pole due to Corrosion

The methodology proposed to evaluate strength loss due to corrosion involves multiple steps including:

- Inspection and data collection to evaluate the presence of corrosion;
- If corrosion is observed, an evaluation of the specific actual strength capacity required based on actual wires and span data;
- If the strength remains adequate, despite the corrosion that has occurred, a plan would be developed to remediate the corrosion;

- If the strength loss due to the corrosion is not adequate, a strengthening and remediation plan would be implemented.

Field and Design Data Collection

A National Association of Corrosion Engineers (NACE) Standard jointly published with IEEE has been developed to provide a methodology to collect corrosion data. It is NACE SP0415-2015/IEEE Standard 1895™-2014. The collected field data is used to determine the extent of the corrosion deterioration on a steel pole structure and is necessary to begin the assessment of strength loss due to corrosion of the structure. The collected data should include:

- Conduct a thorough mapping, including pole wall thickness measurements, of the locations on the steel pole where corrosion is affecting the steel pole surfaces.
- Identify where the corrosion is occurring (at ground line, slip splices, hardware attachments, etc.). If a steel pole is an embedded pole with a ground sleeve, and the corrosion is limited to the sleeve but has not perforated it, no evaluation of strength loss is necessary;
- Identify the quadrants of the pole affected by the corrosion in relation to the line attachments and line directions on the steel pole;
- Identify the line directions and line angles and whether the poles are used in Tangent, Running Angle, or Dead-end type application.
- Thoroughly photographically document the pole surfaces, the location of the corrosion on those surfaces, and any manufacturer's markings, including data plates, etc.
- If possible, obtain the original design calculations for the structure, and/or recreate those calculations from the supplier drawings and/or actual dimensions of the pole and the span and wire conditions known to exist on the installation.

Evaluation of the Collected Data

The next step in the evaluation of the strength loss would be to calculate the required design capacity (strength) utilization of the steel pole with the actual installed span and wire tension conditions. Reasonable and justifiable adjustments to either the loads (i.e., a modified return period or other similar modification), or the strength (i.e., steel yield strength based on actual steel mill test report data if available and traceable to the precise pole section in question) can be considered. As an example, this may calculate to be a 90% design utilization when actual spans and original dimensions are considered including original strength and load factors.

The section properties for calculated strength should then be calculated using section properties taken from actual thicknesses measurements from the field data. Calculate (estimate) the reduced pole cross section properties of Area (A), Moment of Inertia (I), and/or Section Modulus (S) representing the revised strength of the cross section to resist the applied loads at the area(s) of corrosion. Formulas for these properties are provided in the ASCE/SEI 48 Standard *"Design of Steel Transmission Pole Structures"*. Allowance for the reduction in wall thickness (up to and including complete loss, if applicable should be accounted for in those areas of corrosion when calculating the reduced cross section properties of Area, Moment of Inertia, and Section Modulus.

Then calculate (estimate) the current capacity utilization of the cross section with corrosion. The formula for % capacity utilization at a given cross section with deterioration becomes Equation (1) below:

$$\frac{\frac{M}{S}+\frac{P}{A}}{\text{Fa}} * (100) = \text{\% Utilization of Pole Section with Corrosion Loss}$$ Equation (1)

where (at the reduced cross section due to corrosion, under analysis):
M = applied Moment, in-kips
P = applied Axial load, kips
S = reduced Section Modulus of the cross section due to corrosion*, in^3
A = reduced Area of the cross section due to corrosion*, in^2
Fa = Allowable Compressive Stress, ksi

* This reduced section modulus and reduced area are not trivial to calculate. A somewhat complex method can be used to calculate corroded area and corroded section modulus with shifted neutral axes. This is something that may not be apparent to engineers trying to quickly perform an analysis.

Consideration must be given to the increased pole section flat width to thickness ratio (for localized buckling limitations) when the wall thickness is reduced due to corrosion. If the corrosion loss is relatively uniform all the way around a section, the average thickness may be used in the equation for localized buckling limitation. For typical dodecagonal shaped poles (12-sided), the local buckling limitations that should be satisfied for the section depending on the "compactness" of the section is reflected in the equations (2) through (4) below from ASCE/SEI 48 Standard *"Design of Steel Transmission Pole Structures"*:

$$Fa = Fy$$ Equation (2)

$$\textit{when: } \frac{w}{t} \leq \frac{240}{\sqrt{Fy}}$$

$$Fa = 1.45Fy(1.0 - 0.00129\frac{w}{t}\sqrt{Fy}$$

$$\textit{when: } \frac{240}{\sqrt{Fy}} < \frac{w}{t} \leq \frac{374}{\sqrt{Fy}}$$ Equation (3)

$$Fa = \frac{104{,}980}{\left(\frac{w}{t}\right)^2}$$ Equation (4)

$$\textit{when: } \frac{w}{t} > \frac{374}{\sqrt{Fy}}$$

where:

w = pole section flat width, in.
t = pole section wall thickness, in.
Fa = Allowable design compressive strength of the steel, ksi
Fy = Yield strength of the steel, ksi

Other buckling formulas for different shape poles can be found in the ASCE 48 Standard: *Design of Steel Transmission Pole Structures*. When wall thickness loss is limited to a smaller percentage of the cross section (i.e., not uniform all around) good engineering judgment and consideration must be used for the problem. As an example, where the observed wall thickness loss is on flats of the pole which are predominantly in compression and where localized buckling may be a concern, or, on the tension flats of the pole, where localized buckling may not be as great a concern.

Evaluating Structural Adequacy

If the localized buckling formula of Equations (2), (3), or (4) is satisfied, and the calculated capacity utilization per Equation (1) is less than the capacity utilization as described above, then the pole has sufficient capacity to remain in service without structural remediation (except for remediation to stop the corrosion from continuing to deteriorate the pole). (NOTE: If the pole has adequate capacity but active corrosion is occurring, it may be appropriate to have ongoing monitoring of the progress of the corrosion).

If the localized buckling formula of Equations (2), (3), or (4) is satisfied, and the calculated capacity utilization per Equation (1) is greater than the capacity utilization as described in the paragraph above, then the pole does NOT have sufficient capacity to remain in service without structural remediation to strengthen the pole, or justification is made to lower the loading requirements.

Actionable Options Based on Strength Evaluation

Strength remediation should be evaluated by a qualified engineer. Such remediation options could include:

- Plate “collars” (plates fabricated to match the geometry of the pole and welded as a “collar” or sleeve around the pole).
- “Scab” plates (smaller plate[s] welded over localized corrosion damage area).
- Concrete “encasement” (an option to encase the damaged area with properly reinforced concrete).
- Other remediation schemes

Regardless of the structural remediation method(s) chosen, it is paramount that the design provides a sufficient load path and force transfer between the pole and the repair. It should be noted that the above structural remediation methods may restore capacity, but they do not necessarily eliminate ongoing active corrosion. Slowing, or eliminating ongoing active corrosion should be part of any remediation plan.

Furthermore, structural remediation can result in reduced corrosion resistance on the interior of non-sealed poles. For example, interior galvanizing is often damaged when welding on the exterior of a galvanized pole. As such, additional corrosion protection on the interior of the pole should be considered in addition to protection against corrosion on the exterior.

References

NACE SP0415-2015/IEEE Standard. 1895™-2014, "Below Grade Inspection and Assessment of Corrosion on Steel Transmission, Distribution, and Substation Structures" (Houston, TX: NACE, and New York, NY: IEEE).

ASCE/SEI 48-11 "Design of Steel Transmission Pole Structures" (Reston, VA: ASCE)

ABOUT THE AUTHOR

Mr. Wesley Oliphant is a 1974 Graduate from Texas A&M University and he began his professional career as a Civil Engineering Officer in the United States Air Force. He has since accumulated approximately 40 years of professional experience and expertise related to the structural design, manufacturing, installation, and inspection of all types of poles and towers supporting a variety of critical infrastructure. Mr. Oliphant has authored and presented numerous technical papers relating to the design, manufacturing, installation and on-going maintenance of various types of pole and tower structures. He has significant experience in the forensic failure analysis of steel and concrete pole failures as well as their components. He is a registered professional Engineer in Texas.