Reese TOWER SERVICES

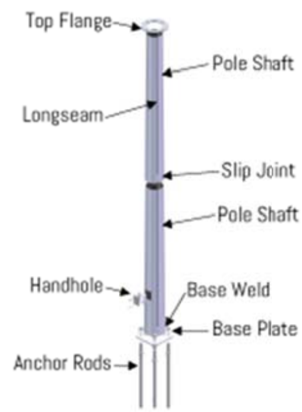
Pole Base Weld Toe Cracking

Brian Reese, PE, CWI
Reese Tower Services

Tubular steel poles are a popular support structure in many industries and have been utilized as support structures in the communications, sports lighting, utility, and transportation industries for many decades. Additional recent applications have also included small wind generation. Combining a long history of reliable performance, competitive pricing, and ease of use and installation, steel poles remain a viable solution for numerous aerial support requirements. However, in the last decade, there have been numerous failures of steel poles across the country. The property damage in some cases has been significant. As with America's other aging infrastructure, the cost of ignoring this issue can be significant to public safety, welfare, and your assets.

STEEL POLES

An anchor-based pole base plate connects the structure via the anchor bolts to the foundation. The connection is facilitated by welding of the members during fabrication at the original manufacturer's facility. As the only connection and one that is non-redundant, the structural adequacy and integrity of this connection is crucial to the performance of the structure. A failure, if one was to occur at this joint, will in almost all cases be catastrophic resulting in the collapse of the pole. The connection detail of the pole shaft structure to the base plate can vary depending on the type of pole or the original manufacturer.



Typical pole base connection weld details include complete joint penetration groove weld (CJP) and socket style (double fillet weld) connections as shown below. The CJP connection base plate is butted against the pole shaft and consists of a circumferential single-groove weld with 100% complete weld penetration (CJP) and a reinforcing fillet weld. In other words, the connection zone is all weld material. This connection style is very popular, a cost economical method of fabrication, and traditionally the base connection of choice for most major tubular steel pole manufacturers. The socket connection base plate sleeves over the pole shaft and is welded with double fillet welds below and above the sleeved base plate. This connection is also popular due to the fact that the welds are simple fillet welds and a non-destructive examination (NDE) ultrasonic test is not performed on this joint post-fabrication reducing quality assurance costs. While other joints may be possible (including base plate stiffeners), the majority of anchor-based poles manufactured fall into one of these two base joint categories.

Complete Penetration Joint (CJP)

Socket Joint

FAILURES

Pole collapses, while traditionally a very infrequent occurrence, have made news in recent years due to failures in both the communication and sports lighting industries. With their proximity to areas where people live, work and gather, there is a significant potential for loss of property damage, injury and possibly even loss of life.

Almost all recent pole failures have possessed one similar characteristic: toe cracks in the pole shaft wall immediately above the base plate weld that propagate over time causing this connection to fail and the pole to collapse. In recent years, many owners have implemented inspection programs to identify base defects that can be detrimental to the long-term performance of their structures. Toe cracks have been routinely identified during these preventative inspections.

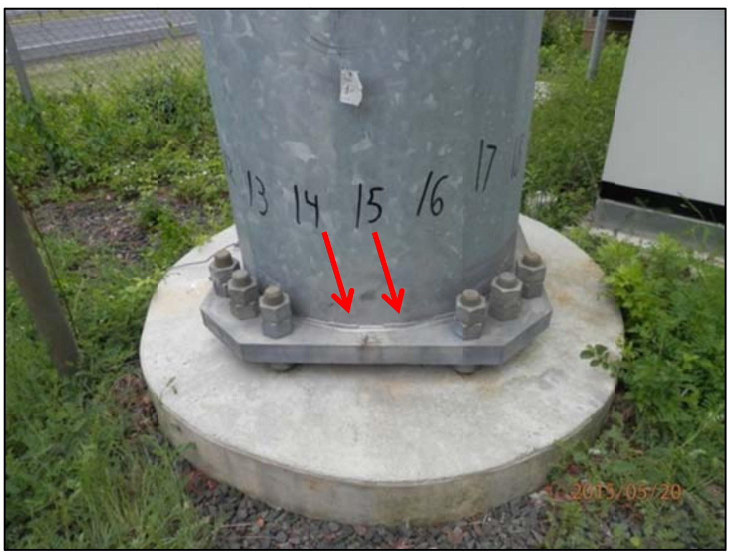
TOE CRACKS

According to the American Welding Society (AWS), a defect is a discontinuity which exceeds the permissible limit of a code (AWS A3.0). A crack is a fracture type discontinuity characterized by a sharp tip and high ratio of length and width to opening displacement (AWS A3.0). Cracking occurs in a weld and base metal when the localized stresses at the connection exceed the ultimate strength of the steel material. Cracking is often associated with stress amplifications near discontinuities in welds and base metal, or near mechanical notches associated with the weldment design. Left in place without repair, cracks may propagate over time and continued loading and can be very detrimental to structural integrity. In addition, cracks greatly reduce the fatigue strength of a member. AWS Structural Welding Code D1.1 does not allow a crack to be left in the weldment after inspection per Table 6.1, Part 1, regardless of size or location (AWS D1.1).

Cracks can be classified as either hot or cold types. Hot cracks develop at elevated temperatures and commonly form during solidification of the weld metal. Cold cracks develop after solidification of a fusion weld as a result of stresses, are sometimes called delayed cracks, and are often associated with hydrogen embrittlement. Hot cracks propagate between the grains while cold cracks propagate both between grains and through grains. Cracks may be longitudinal or transverse with respect to the weld axis. Longitudinal weld metal cracks and the heat-affected zone cracks are parallel to the axis of the weld; transverse cracks are perpendicular to the weld axis (excerpted from: "*Welding Technology - Welding Handbook*," 8th Edition, American Welding Society, 1987).

A toe crack is defined as a crack in the base metal at the toe of a weld. Toe cracks are generally cold cracks that initiate approximately normal to the base material surface and then propagate from the toe of the weld where residual stresses are higher. These cracks are generally the result of thermal shrinkage strains acting on a weld heat-affected zone that has been embrittled. Toe cracks sometimes occur when the base metal cannot accommodate the shrinkage strains that are imposed by welding. The crack can occur immediately after galvanizing or a period of time after galvanizing. Toe cracks have not typically been observed in weathering steel or painted poles (not hot-dip galvanized). Typically toe cracks are identified at the upper toe of the base plate weld in the pole base section shaft material.

The phenomenon of toe cracking has been known to the pole industry since the 1970's. ANSI/NEMA TT 1 "*Tapered Tubular Steel Structures*" from 1983 in Section 10.5 states that *"Shaft to base plate welds shall be inspected by the ultrasonic method for evidence of cracking in the shaft or base plate heat affected zone."* The American Society of Civil Engineers (ASCE) Manual 72, "*Design of Steel Transmission Pole Structures,*" 2nd edition from 1990 states in Section 3.5.3.3 "Special Design Considerations" on pg. 45: *"Toe cracking of weldments: Toe cracks, around T-joint welds, undetectable prior to galvanizing have been detected after galvanizing. The formation of these cracks appears to be influenced by several factors in the fabrication process. Requirements for post-galvanizing inspection should be considered."* Most pole manufacturers inspect for toe cracks after the galvanizing process as a normal part of their quality assurance program. In instances where preventative field inspections have been performed on the base plate weld connection while in service, cracks have been found in the pole shaft wall in the toe above the base plate weld. This has occurred on multi-sided and round poles in both complete joint penetration (CJP) groove weld and socket base plate connections.



OEM Toe Crack Repairs Visible in the Field

ROOT CAUSES

As a recognized issue in the pole industry for many years, there have been numerous investigations and discussions on this subject. One of the largest investigations was performed by Valmont in 2006 and published in a paper entitled, "*Toe Cracks in Base Plate Welds – 30 Years Later*" by Richard Aichinger and Warren Higgins. While all the contributing issues and their interactions are still not fully understood, discussions regarding toe crack root causes continue and involve the following:

1. Design – incorrect base plate design resulting in an under-sized base plate and increased joint flexibility; relationship between base plate weight and base tube section weight. Contrary to engineering judgement, bigger (thicker) base plates are not always

better. The larger the difference between the base section pole shaft thickness and the base plate thickness the more probable the occurrence of toe cracking due to the thermal stresses induced during galvanizing of the section. During the galvanizing process, the larger base plate requires more time to heat and cool, whereas the pole base section heats up and cools rather quickly. The heat-effected zone at the upper toe of the weld in the relatively thin pole shaft is where the cracking occurs.

2. Materials – includes quality of material being joined, high yield/tensile material strengths, high carbon equivalents (CE). The Valmont paper identified the importance of carbon equivalent, Columbium (C_b), and Vanadium (V) contents with respect to base weld cracking.
3. Fabrication – the manufacturing (bending) of a polygonal tube section - a polygonal tubular pole section is fabricated by press-forming high-strength steel plate. Embrittling of the steel can occur at the bend points due to the cold working of the material resulting in high residual stresses.
4. Welding - poor welding quality, lack of pre-heat during welding fabrication, weld profile, heat input during welding process.
5. Quality – poor manufacturing quality control; quality checks at the original manufacturer after fabrication and galvanizing overlooked or incorrectly performed.
6. Galvanizing – thermal expansion during the galvanizing process, hydrogen embrittlement from the galvanizing process, and the thermal stresses due to the large differences in thicknesses between the base section pole wall and the base plate. The quenching process after hot-dip galvanizing.
7. Installation – loose leveling nuts or improper grouting of the base plate may cause unanticipated stress increase in the weld joint.

While any single item on the list above can be detrimental, a combination of any of the above items can facilitate more rapid failure of the base weld connection.

FIELD OBSERVATIONS

Pole base weld toe cracks have been observed in the field with regularity. Findings are as follows:

1. In the most severe cases, visible with the naked eye 'wandering' along the upper toe of the weld on the press bend line between two flats on a multi-sided pole (see photos below)
2. Identified with magnetic particle (MT) testing at surface or near-surface, but not visible with naked eye (see photo below)
3. Identified with ultrasonic testing (UT) but not identified with magnetic particle (MT) testing or visible with naked eye
4. Ranging from one location only to each bend line of the pole base section
5. Varying from fractions of an inch to multiple inches in length
6. Depths ranging from thousands of an inch to clear through the base wall thickness (see photo below)

Toe Cracks at Upper Toe of Weld in Pole Shaft at Bend Line (Visible Rust)

Minor Toe Crack Visible via MT Powder after Light Grinding

Toe Crack Visible via MT Powder after Grinding

Socket Style Base Connection Toe Cracking
Viewed From the Inside of the Pole (Visible Rust)

MT Powder at Upper Toe Crack

CONCLUSION

Toe cracking of the base connection of tubular steel poles has been an industry challenge for many years. There are many contributing factors to this issue. Field inspections have shown the importance of understanding and reacting appropriately regarding this subject. Visual and NDE inspection techniques are critical and should be regularly scheduled. It is imperative that inspections are carried out by qualified personnel with specific pole experience, CWI credentials, and non-destructive ASNT credentials. Left unresolved, propagating toe cracks will cause eventual failure of the base connection and collapse of the structure. If identified via inspection, these defects can be resolved via weld repair restoring the original integrity of the structure.

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