



Planning Advisory Notice

Welding Discontinuities and Defects

This Planning Advisory Notice (PAN) is a follow up to the PAN from the March/April issue. In that PAN we discussed some of the codes, standards, and specifications that apply to proper welding design, performance, and inspection. In this article we would like to discuss some common welding defects encountered in our industry. We all have experienced failing certified weld inspection (CWI) report(s) after a tower or mono-pole modification project, and have struggled with interpreting and understanding the results. This article will give you some of the basics of welding discontinuities and defects, and it is our hope that it will assist you with interpreting your next CWI report!



Weld inspection is performed per the American Welding Society *Structural Welding Code – Steel*, AWS D1.1:2015. Per Section 6.9, the weld inspector is to visually inspect all of the welds and the welds shall be acceptable if the criteria of Table 6.1 are satisfied (Table 9.16 for Tubular). Table 6.1, Visual Inspection Acceptance Criteria, details discontinuity categories and inspection criteria for both statically loaded non-tubular connections and cyclically loaded (fatigue sensitive) non-tubular connections. The table addresses the following discontinuity categories: cracks, weld/base metal fusion, craters, weld profiles, time of inspection,

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undersized welds, undercut, and porosity. As discussed in the last PAN article, almost all welding defects can be attributed to a welding process, technique, or welder that was out of control or not qualified. If welding is performed in accordance with codes, standards and specifications, the chances of a quality weld without defects are greatly increased.

The terms discontinuity and defect are frequently used by CWI's. Per the American Welding Society (AWS) A3.0, *Standard Welding Terms and Definitions*, a discontinuity is defined as "an interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics". (A discontinuity is not necessarily a defect! So, what is a defect you ask?) AWS A3.0 defines a defect as "a discontinuity that by nature or accumulated effect render a part unable to meet minimum applicable acceptance standards or specifications." *The term defect designates a weld as rejectable.* Discontinuities are rejectable only if they exceed that allowed by the project specification. There are numerous weld defects that can occur. An important part of the CWI's job to inspect the welding and identify any defects that may be present. Common weld discontinuities related to tower welding in the field are listed below.

Typical Weld Discontinuities

- Crack
- Undercut
- Underfill
- Porosity
- Inclusion
- Incomplete Fusion
- Incomplete Joint Penetration
- Spatter
- Arc Strike
- Crater
- Weld Profiles
- Undersized Welds

A **crack** is defined as a fracture-type discontinuity characterized by a sharp tip and high ratio of length and width to opening displacement. Cracks can occur in the weld metal zone, heat-affected zone, or base

metal when localized stresses exceed the ultimate strength of the material. Cracking often initiates at stress concentrations caused by other discontinuities or near mechanical notches associated with the weldment design.

There are numerous types of cracks: longitudinal, transverse, crater, throat, toe, root, under bead, heat-affected zone. Per AWS D1.1 Structural Welding Code, no crack is allowed to remain in service after identification – "any crack shall be unacceptable, regardless of size or location." Cracks are very detrimental to the performance of a structure, can accelerate the negative effects of fatigue, and can cause the failure of the structure under load. A crack at the base of a monopole can cause catastrophic failure of the structure.



Monopole Base Plate Weld Upper Toe Crack



Base Plate Stiffener Weld Lower Toe Crack



Anchor Rod Bracket Longitudinal Crack (Shown in Red)



Stiffener Longitudinal & Transverse Cracks (in Black)



Monopole Modification Weld Undercut



Tower Leg Split Pipe Stitch Weld Undercut

Undercut is defined as "a groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal." Undercut can greatly reduce the fatigue-resistance of a welded connection. Undercut is generally associated with either improper welding techniques or excessive welding currents, or both. AWS D1.1 Table 6.1 allows some undercut as acceptable depending on whether the connection is a statically loaded non-tubular connection or a cyclically loaded (fatigue sensitive) non-tubular connection.

Underfill is a groove weld condition in which the weld face or root surface is below the adjacent surface of the base metal. Basically, the joint has not been completely filled with weld metal.

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Monopole Base Plate Stiffener Underfill

Porosity is a cavity type discontinuity formed by gas entrapment during solidification. The discontinuity formed is generally spherical and may be elongated. Porosity is caused by contamination during welding. There are various types of porosity including: scattered porosity, elongated porosity, aligned or linear porosity, and piping or wormhole porosity. Similar to undercut, AWS D1.1 allows some porosity in Table 6.1 as acceptable depending on whether the connection is a statically loaded non-tubular connection or a cyclically loaded (fatigue sensitive) non-tubular connection.



Examples of Porosity in Monopole Modification Welding

Inclusion is defined as entrapped foreign solid material, such as slag, flux, tungsten, or oxide. When it comes to tower and monopole upgrades, typically inclusion is slag left within a complete joint penetration (CJP) weld and is located by a post-modification ultrasonic testing (UT) non-destructive examination. Slag inclusions result from improper welding technique, lack of access, or improper cleaning between weld passes.



Monopole Base Plate Stiffener Weld CJP Connection Slag Inclusion

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Incomplete fusion is a weld discontinuity in which fusion did not occur between the weld metal and the fusion faces or the adjoining weld beads. Per AWS, non-standard terms for incomplete fusion are overlap and cold lap.

Incomplete joint penetration is a joint root condition in which the weld metal does not extend through the joint thickness. In other words, the weld does not penetrate into the root area of the weld. Typically, this condition is identified via UT non-destructive weld examination.

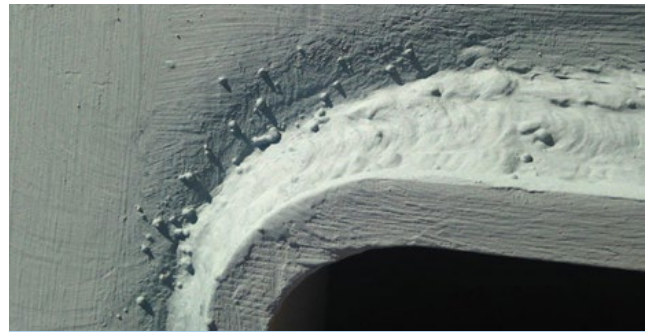


Tower Leg Split Pipe Modification Incomplete Joint Penetration to Leg Flange

Spatter is the metal particles expelled during welding that do not form part of the weld. Spatter is easily repaired with a grinder.



Weld Spatter at a Modification Stiffener and Field-Welded Port Installation



Weld Spatter at a Modification Stiffener and Field-Welded Port Installation

An **arc strike** is a discontinuity resulting from an arc, consisting of any localized re-melted metal, heat-affected metal, or change in the surface profile of any metal object. Arc strikes result when the welder initiates an arc on the base-metal surface away from the weld joint, either intentionally or accidentally. When arc strikes occur there is a localized area of the base metal surface that is melted and then rapidly cooled due to the massive heat sink created by the surrounding base metal. Arc strikes are not desirable as they can cause cracking.



Arc Strikes on Ice Bridge Post

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A **crater** is a depression in the weld face at the termination of a weld bead. AWS D1.1, Table 6.1 requires all craters to be filled to provide the specified weld size, except for the ends of intermittent fillet welds outside of their effective length.



Crater Defects

An **undersized** weld does not meet the size requirements of the project specifications. This defect is commonly seen in the field and is easily avoided. A welder should be checking the sizes of their welds after completion. Fillet welds are measured by CWI's with fillet weld gauges.



Required Stiffener/Plate Modification 1/4" Fillet Welds Undersized by Fillet Weld Gauge Measurement

Summary and Conclusion

Weld inspection is performed per AWS D1.1:2015 *Structural Welding Code – Steel*. Per Section 6.9 of the Code, the inspector is to visually inspect all of the welds and the welds shall be acceptable if the criteria of Table 6.1 are satisfied. Table 6.1 details discontinuity categories and inspection criteria and addresses the following discontinuity categories: cracks, weld/base metal fusion, craters, weld profiles, time of inspection, undersized welds, undercut, and porosity. The AWS



further defines a defect as a discontinuity that by nature or accumulated effect render a part unable to meet minimum applicable acceptance standards or specifications. Discontinuities are rejectable only if they exceed that allowed by the project specification.

As previously discussed, almost all welding defects can be attributed to a welding process, technique, or welder that was out of control or not qualified. If welding is performed in accordance with codes, standards and specifications, the chances of a quality weld without discontinuities and defects are greatly increased. Hopefully this PAN will help you with the information necessary to interpret your next CWI report. ■