Baseplate and Flange Weld Inspection of Tubular Steel Transmission Structures

The purpose of this paper is to inform our industry on the importance of the proper inspection of tubular steel transmission structures and the potential pitfalls that could occur in the process.

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Abstract: Baseplate and Flange Weld Inspection of Transmission Tubular Steel Structures

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The purpose of this paper is to discuss the shortcomings of the AWS D1.1 weld inspection standards when applied to tubular steel transmission structures, and to inform our industry of the importance of the proper inspection of tubular steel transmission structures and the potential pitfalls that could occur in the process.

The AWS D1.1 standard has been the most widely accepted standard for tubular steel transmission structures and has provided the industry with guidance for many years. However, AWS D1.1, which was originally adopted for building and bridge construction, does not recognize or adequately address the unique characteristics of tubular steel transmission structures. Using AWS D1.1 as a starting point, we can, however, remedy the existing weaknesses and gaps, and develop a more robust inspection process which will validate the structural integrity of the weld.

Our experience indicates that a single structure can be tested by multiple UT (Ultrasonic Testing) Level II personnel, certified in accordance with ASNT (American Society for Nondestructive Testing), with each inspector arriving at conflicting results. Interpretations of the results can also vary. The key to sound inspection practices lies in knowledge of the joints and fabrication methods, consistent equipment and techniques, and an objective basis for the interpretation of results. Properly trained individuals can understand the geometry of a steel pole and interpret any indication found by applying a consistent, repeatable and, most importantly, accurate UT testing methods.

This paper will:

1. Explain the framework and shortcomings of AWS D1.1 when utilized for UT inspection of tubular steel transmission structures, in particular, T-joints.

2. Communicate how critical it is to establish a repeatable UT inspection practice to ensure that results are consistent and accurate.

3. Discuss forensic metallurgical examinations and validations of NDE (Non-Destructive Examinations).

4. Recommend a "standard" for the inspection and identification of structurally significant defects in tubular steel transmission structures.
Introduction /Background

History of the American Welding Society and AWS D1.1.

The roots of the American Welding Society go back to World War I. Sudden demands for producing military equipment brought about the need for standardization of the manufacturing industry.

President Wilson created a *Welding Committee of the Emergency Fleet Corporation*, which worked with the already existing *National Welding Council*. By 1919, industry leaders agreed that dependable and objective information on welding was crucial for further U.S. industrial development. The two organizations merged to create the *American Welding Society*. Comfort A. Adams was the first president of the *American Welding Society*. Today’s Society president is Nancy C. Cole.

In 1928, the American Welding Society published the first edition of the *Code for Fusion Welding and Gas Cutting in Building Construction, Code 1 Part A*. It was revisited and revised in 1930, 1937, and 1941. After its 1941 revision, it was given the *AWS-D1.0* designation.

The first bridge welding specification was published separately in 1936. It was eventually designated *AWS-D2.0, The Specification for Welding Highway and Railway Bridges*. AWS Codes were developed by three basic types of users; designers and builders of buildings; designers and builders of bridges; and starting in 1972, designers and builders of tubular-steel structures used in the off-shore oil and gas industry.

In 1972 *D1.0* and *D2.0* combined to form *AWS D1.1 - Structural Steel Code* and eventually *Section 10, Tubular* was added. This created a Buildings Group (Section 8) a Bridges Group (Section 9) and a Tubular Group (Section 10).

In 1988 the Bridges Group separated when the joint *AASHTO/AWS D1.5 Bridge Welding Code* was published. It addresses the specific requirements of State and Federal Transportation Departments. After that separation the AWS-D1.1 code changed references of buildings and bridges to statically loaded and dynamically loaded structures, respectively, in order to make the document applicable to a broader range of structural configurations.

In the 1990’s *Section 10, Tubular* was removed and the committee decided to merge all inspection criteria into Section 6, Inspection (now Clause 6). This change was significant to the tubular steel transmission structure industry. It was the Tubular Group that developed the alternative UT techniques that were eventually incorporated into Annex K (now Annex S). Annex S is included in the *Informative* (Non-Mandatory) Annexes, meaning it is included in AWS D1.1 for informational purposes only, yet it contains some critical information necessary for the proper evaluation of tubular steel transmission structures.

*AWS D1.1/D1.1M:2010, Structural Welding Code - Steel* is maintained and revised by volunteer members of the American Welding Society. It is developed in accordance with the rules of the American National Standards Institute (ANSI). This is a voluntary consensus standard that is currently on a 5 year review cycle.
Framework of AWS D1.1

There are advantages to having a standard that is recognized throughout the industry. The words, “All Welding per the latest revision of AWS D1.1” have become a standard requirement found in virtually all structure specifications and fabrication prints. Such references should let all involved in the fabrication know what is expected in the design, qualification, fabrication and inspection of welds up-front. It has, however, become the default standard that most specification writers reference over and over without consideration of what is actually in AWS D1.1. In the case of Ultrasonic Testing (UT), it could even involve two different acceptance standards.

The steps to qualifying both the process and persons are clear and well laid out in Clauses 3 & 4 of D1.1. Many of the required steps for qualification found in D1.1 are used in other codes and standards published by the American Welding Society. They are time proven and understood by Welders, Inspectors and Engineers.

AWS D1.1 also lays out an alternative means of inspection. Understanding the wide range of weldments that can be fabricated under this code, the AWS-D1 committee included alternative methods for the UT. [See Annex S]

The American Welding Society has a very solid and well-recognized inspector certification program (QC1) for visual inspection (VT), but for the qualification of inspectors in all other forms of Nondestructive Testing (NDT) it turns to another widely recognized organization, the American Society for Nondestructive Testing (ASNT). ASNT’s Recommended Practice Number SNT-TC-1A is a recommended practice that becomes a requirement of AWS-D1.1 in paragraph 6.14.6 – Personnel Qualification. SNT-TC-1A lays out the requirements for a NDT inspector qualification program and includes certification requirements to:

1. Level I – Receives instruction and supervision from a Level II or Level III. This person is qualified for very specific calibrations and evaluations.
2. Level II – Gives guidance to Trainee and Level I personnel. A Level II also sets up and calibrates equipment, evaluates results, and is thoroughly familiar with the scope and limitations of the method(s) qualified.
3. Level III – Capable of developing, qualifying, and approving NDT procedures. Establishes and approves techniques, interprets codes, standards, and specification, and is capable of qualifying Level I & II personnel.

AWS D1.1 Clause 6 Part F details a very comprehensive process for the calibration of Ultrasonic Test equipment. Using the recognized IIW Type Block and other reference standards, Part F covers the equipment requirements, how that equipment is calibrated, and the specifics of the inspection. In addition, Annex S also includes a very comprehensive process for alternative techniques for UT examination.
The Shortcomings of AWS D1.1

The primary disadvantage for the Tubular Steel Transmission Structures industry is that AWS D1.1 covers such a wide range of designs and conditions that it’s not specific enough for our industry. Some sections of Clause 6 are not practical for some of the industry's proprietary joint designs.

Although AWS-D1.1 gives clear guidance for the UT inspection acceptance criteria for statically and cyclically loaded non-tubular connections of 5/16” weld sizes and greater (Tables 6.2 & 6.3), there are no criteria for materials less than 5/16” or for tubular connections. In our industry, we use 1/4” and 3/16” thick steel. This opens up a point of contention for both the fabricator and end user. As a result, a standard must be developed by the fabricator to establish alternate inspection and acceptance criteria for production welds, which can vary greatly from fabricator to fabricator.

Another short-coming is that AWS D1.1 does not consider UT inspection on galvanized structures.

On a groove weld in a T-Joint with material thicknesses typical of steel structure tower walls, the AWS D1.1 scan requirement would be from a single side (Face-A). So, unless there is a signal from the base metal/weld metal interface, no scanning from Face-C is required. A more appropriate approach is to scan both the A and C Faces. [See Figure 4]

Although based on 40-50 yrs. historical information for UT inspection, AWS D1.1 does not account for modern technology. The current code is written based on cathode ray technology, not digital equipment that we use today. In addition, new UT technologies such as Phased Array have yet to be fully represented in AWS D1.1 with a clear calibration and comprehensive acceptance criteria.

Charpy V-Notch (CVN) testing has been an industry requirement since the 60’s and has proven to be a beneficial test to ensure weld toughness. CVN testing is noted in the Clauses of AWS-D1.1, but perhaps visual acceptance criteria for weldments meeting a specific CVN requirement would be beneficial to our industry.

AWS D1.1 acknowledges that some defects are more critical than others. Near surface, linear, crack-like defects are more critical than slag inclusions near the center of the weld. Also, AWS D 1.1 says that the orientation of the defect is more critical if it is perpendicular to the load.

In other steel fabrication industries, the frequency of UT inspection on Complete Joint Penetration (CJP) welds is generally based on a sampling of maybe 10% or 25% as determined by the project specifications. Using the AWS D1.1 criteria for UT and scanning at a high sensitivity level takes a lot more time and makes sense when you’re only inspecting a small percentage of the CJP welds. Some might be called the “Inch wide, Mile deep” approach where you have an intense inspection of a small sample. If that small sample passes the intense inspection, then the process is considered sound and will provide reliable welds throughout the project with no further UT inspection required.
AWS acknowledges that some defects are more critical than others. Near surface, linear, crack-like defects are more critical than slag inclusions near the center of the weld. Also, AWS says that the orientation of the defect is more critical if it is perpendicular to the load. However, our industry design standard requires 100% inspection of CJP welds and the goal for UT inspection should be to identify the critical defects and not spend time identifying and evaluating non-critical defects that you will find with scanning at a higher sensitivity level. Therefore, a lower scanning level is more appropriate in order to identify and evaluate the critical defects that could affect the weld reliability.

In summary, when it comes to weld inspection, AWS D1.1 is more of a general structural welding code and not specific to any industry. It’s a big square peg, and we’re trying to fit it into a 12-sided hole. It is not a perfect fit for our industry, and some adjustments are necessary to ensure reliable welds are produced.

**A Proper Inspection Program**

AWS D 1.1 says that each industry should determine the suitable acceptance criteria for the intended service. Clause 6.8 lays the ground work for determining a more suitable acceptance criteria, however, the tubular steel transmission structure industry, as a whole, has not yet undertaken this task.

The goal of an inspection program should be to identify the critical defects that may affect the performance of the structure for its intended purpose, not to identify every imperfection that will have no consequence to the structure’s performance. Any NDT program should start with good visual (VT) inspection. Visual inspection of welds begins long before an arc is struck. Before welding begins the inspector needs to ensure they are familiar with the codes, standards, specifications, and drawings for the project.

Ensuring that base, filler metals, and fluxes are correct for the project, are tested in advance, and are specified in the fabricator’s Weld Procedure Specifications (WPS) is critical. It is the inspector who will ensure that the electrodes, fluxes, and filler metals are stored to the manufacturer specifications and governing code requirements. The inspector will also ensure proper joint fit-up and cleanliness are maintained, that all welders are qualified to the processes and positions, and that the proper pre-heat is applied.

Once welding begins, good visual inspectors monitor welding parameters, technique and bead placement along with interpass temperature and cleaning. When inspection is carried out before and during welding inspection, the after welding is far more successful. After welding is complete, the inspector is simply looking to verify that the finished weld meets the visual acceptance criteria (such as that in AWS D1.1-Table 6.1), and the weldment meets its dimensional requirements.

Although most codes allow for the qualification of welding inspectors to be an internal program, the preferred method of qualification for visual inspectors is through third party certification such as those developed by such organizations as AWS, Canadian Welding Bureau (CWB), and ASNT. Inspector certification through third parties ensures that inspectors are objectively qualified and that their qualifications are documented.

In the case where more than visual inspection is required, other NDE methods can be utilized. All NDE methods require skilled and qualified inspectors. A good inspection program will seek to consistently minimize variation between inspectors. Conducting studies and identifying key differences will aid in establishing sound inspection practices and procedures. This enhances a fabricator’s ability to get repeatable results to ensure reliable welds. Certain
criteria critical to performance are transducers (defined by procedure), certifications (by ASNT course), qualifications (by a Level III in method tested), experience (specific to industry), and calibrated equipment (traceable to a national standard). Mockups should also be developed and used as training for inspectors applying VT and UT methods.

It sounds easy enough, but eliminating the human variables that influence inspection is the most difficult factor to control. The key elements to eliminating the human variables are industry experience and proper training. To be effective, an inspector must know and understand the complexities involved in welding tubular members to perpendicular plates. A program developed to train an inspector in the geometry and design of tubular steel transmission structure is critical to enable the inspector to make proper decisions utilizing established acceptance criteria.

**T&B Destructive Testing Results and Validation of NDE**

Based on several destructive forensic metallurgical examinations, Thomas & Betts has found that the vast majority of UT and radiographic NDE indications are dispersed slag inclusions at the root of weld repairs that were made during the original fabrication of the structure. Finite element analysis (FEA), metallurgical analyses, and full-scale testing have confirmed that structural integrity was not compromised by the sub-surface indications in any of the structures we have examined.

**Lessons Learned**

The below figures represent the analysis of a single indication that was found in an inspection of a base plate to tower weld. Multiple cuts were made to analyze the indication found.

![Figure 1](image)

A single indication was reported by UT. It was characterized as 2.0"L x 0.75" W x 0.12" D. The section containing that defect was sent for metallurgical analysis.
Examination of the cut slices revealed a defect. Under 20X magnification, an indication is shown. Exhibited a small slag defect in the center of the weld at the base of the weldment. Actual flaw was less than 0.1” on a side and only 0.5” long.

Thomas & Betts inspection protocol was used, and this indication found was rejectable in accordance with AWS D1.1. It should be noted that:

- The indication was rejectable as measured by UT.
- The metallurgical examination confirmed the indication being rejectable. However, there was a major reduction in the size and geometry reported than was measured using UT.
- This indication was of a size and in a location which would have had no effect on the structural integrity of the pole.

Other industry inspection protocols, such as building, bridge, or pipeline fabrications, are usually focused on identifying visual cracks as a means to ensure structural integrity has not been compromised, and rely less on comprehensive UT inspections where no surface indications are present.

**T&B Enhancements to AWS D1.1 for Full Penetration Welds in T-Joints**

After 50+ years of industry experience, performing multiple Gage R&R Studies to hone inspector’s skills to achieve consistent repeatable results, and years of researching testing requirements and UT evaluation, Thomas & Betts recommends specifying ultrasonic testing of tubular steel transmission structures full penetration welds in accordance with AWS D1.1, except modified per Clause 6.8 as follows:

1. **Scanning and evaluation**

Scan and evaluate at +7db’s (after calibrating to 80% full screen height on the 0.060 side drilled hole), and add 2db per inch after 2 Inch of Sound Path. AWS D1.1 scans at +14db and calibrates on side drilled hole between 50-75%. AWS D1.1 uses an evaluation of 1 db. difference for all its class of defects A, B, C, D.
Rationale: One db. during the calibration of a machine can be easily misconstrued. The code also uses a + or – 2 degrees for angle of sound, this means that the difference between two transducers maybe a total of four degrees. A second scan is necessary from Face C as shown in Figure 4 below.

Figure 4.

2. **Acceptance criteria**

Evaluate from Scan Level:

80% FSH for 0.060 hole plus 7db

Alter the Acceptance Criteria to:

<table>
<thead>
<tr>
<th>Percentage</th>
<th>FSH</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>80%</td>
<td>FSH</td>
<td>Reject Regardless of Length</td>
</tr>
<tr>
<td>40% - &lt;80%</td>
<td>FSH</td>
<td>Reject after 1 inch of Length</td>
</tr>
<tr>
<td>20% - &lt;40%</td>
<td>FSH</td>
<td>Reject after 2 inches of Length</td>
</tr>
</tbody>
</table>

Comparatively the AWS D 1.1 acceptance criteria are:

Indication level (a) – Reference Level (b) – Attenuation Factor (c) = Indication Rating

Compare Rating to Table 6.2 and determine acceptance.

Rationale: This method will simplify and speed up the evaluation of indications without compromising the detection of structurally significant defects. AWS D1.1 requires more calculation once an indication is identified.

3. **Length evaluation from Maximum Indication**:

Scan Left and Right until indication drops below 10% FSH

Comparatively, AWS D1.1 Method is to scan Left and Right until indication drops by 50% (6db). This could still be 37.5% FSH. This would not be less than 25% FSH

Rational: This Thomas & Betts Recommended Method provides the advantages of exceeding AWS requirements, being more critical on longer lengths and allowing evaluations after 2nd, 3rd, and 4th leg (that is crucial on thinner materials).

4. **Post Galvanizing Inspection**:

The word “galvanized” cannot be found anywhere in the 540 pages of AWS D1.1. Galvanizing is prevalent in our business, and the galvanizing process can have a profound effect on weldments made with multiple brake lines and greatly varying material thicknesses. Post galvanizing toe crack inspection should be a requirement. Although this is considered above and beyond typical industry requirements, T&B firmly believes that post-galvanizing inspections including visual inspection and ultrasonic testing should be required.

Rationale: Toe cracks are associated with galvanized structures. Toe cracks historically were considered to be mostly a tower wall problem after galvanizing. There is a theory that the toe crack was also associated with a base plate to tower plate thickness ratio and that if
the ratio was small enough, there would be no toe cracking. Nevertheless, toe cracks occur regularly in galvanized structures and should be evaluated like other surface or near surface defects.

**Considerations for a New Standard**

API 2X and D1.8 Seismic Supplement, having similar requirements, should be considered for the basis of a modified standard. Also, fitness for use should be examined.

**API 2X Recommended Practice**

AWS-D1.1-Annex S is the AWS version of the API 2X Recommended Practice. It contains some of the same ideas but it has much more detail. It was written with the needs for Tubular Steel Off-Shore Structures in mind while AWS D1.1 was written with steel building in mind. Both would be an adaptation to use either with the tubular steel transmission structure industry. API uses a distance amplitude curve (DAC) and a transfer loss comparison. The transfer correction method would also account for any loss due to coatings. The API code does recognize fitness for purpose, FEAs, or fracture mechanics. API also recognizes certain flaws may be better left in the weld than to try to repair them.

**D1.8 Seismic Code**

Intended to ensure that welded joints that are designed to undergo significant repetitive, inelastic strains as a result of earthquakes and connect members designed to resist such inelastic strains, have adequate strength, notch toughness, and integrity to perform as intended. Certain defects are more critical than others (i.e. bigger lengths if deeper in). AWS D1.8 Commentary recognizes that “when the repair may result in more harm to the joint than benefit”, alternative acceptance criteria may be called for.

**Fitness for Use**

The ultimate goal of the new standard should be to determine whether or not the structure should be expected to perform as intended. Inspectors should look at the type of defect and the location and orientation of the defect, and thoroughly evaluate whether or not the defect could affect the structural integrity of the structure. Include a safety factor for the inaccuracies of the examination. Only defects that would affect the structural integrity would be rejected.

**Conclusion**

Simply specifying that tubular steel transmission structures be subject to ultrasonic testing in accordance with AWS D1.1 is inadequate due to the fact that AWS D1.1 is based on incomplete and outdated requirements with respect to our industry.

The shortcomings can be resolved in a production environment by adding requirements encompassing all thicknesses, inspection from two faces of a baseplate weld, and specifying post galvanizing inspections. The long-term approach for the industry is to work within our industry committees to collectively develop, as AWS D1.1 recommends, a standard suitable specifically for tubular steel transmission structures.