PLANNING ADVISORY NOTICE

Welding Inspection Refresher

This month's Planning Advisory Notice (PAN) is a follow-up to a previous three-part PAN series regarding codes, standards, and specifications that apply to welding design, performance, and inspection. It is recommended that this previous PAN series be reviewed (Part I - Introduction to Welding Basics; Part II - Welding Discontinuities and Defects; and Part III - Welding Inspection Tasks, The Role of the Inspector. The focus of this PAN is to expand upon Part II of the previous series which explored some of the common welding discontinuities and defects encountered on a daily basis in the telecommunications industry. Topics that will be addressed are detailing the updated welding code requirements and how inspection considerations impact a successful welding project.

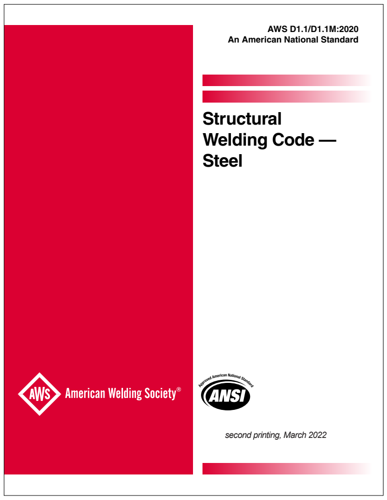
CHAPTER I
UPDATED CODE REQUIREMENTS

Updated D1.1 Welding Code

American Welding Society's D1.1, *Structural Welding Code – Steel* (the Code), has been relied on for years as the authority for structural steel welding. The American Welding Society ("AWS") originally published AWS D1.1-2020 on January 17, 2020, superseding the previous 2015 edition. The foreword of the Code outlines the extensive history of this valuable document.

History of the Code

Published in 1928, the first edition of the *Code for Fusion Welding and Gas Cutting in Building Construction* was called Code 1 Part A. The initial Code was revised in 1930 and 1937 and retained the same title. The document was revised again in 1941 and given the designation D1.0. The D1.0 document was revised again in the years 1946, 1963, 1966, and 1969. The 1963 edition published an amended version in 1965, and the 1966 edition published an amended version in 1967. In 1972, the Code was combined with D2.0, *Specifications for Welding Highway and Railway Bridges*, designated D1.1, and retitled *AWS Structural Welding Code*. D1.1 was revised again in the years 1975, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1988, 1990, 1992, 1994, 1996, 1998, 2000, 2002, 2004, 2006, 2008, 2010, and 2015. The 2010 edition of the Code is available in Spanish, Portuguese, Russian, and Chinese.



From 1972 to 1988, D1.1 covered welding applications for both buildings and bridges. In 1988, AWS, in partnership with the American Association of State Highway and Transportation Officials (AASHTO) published its first edition of *AASHTO/AWS D1.5, Bridge Welding Code*; coincident with this, the D1.1 Code changed references of buildings and bridges to statically loaded and dynamically loaded structures in order to make the document applicable to a broader range of structural applications. After the 2010 edition, AWS decided that the Code would be published on a five-year revision cycle instead of a two-year cycle. This decision was to align the publication cycle of the Code with the publication cycles of the

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Planning Advisory Notice *(CONTINUED FROM PAGE 1)*

American Institute of Steel Construction (AISC) Specification for Structural Steel Buildings (ANSI/AISC 360) and the International Building Code (IBC).

Overview of Changes in 2020 D1.1 Code from 2015 D1.1

The 24th edition of the Code was released in 2020. A summary of the changes in the Clauses from the 2015 version are as follows:

1. Clause 2 Normative References - This is a new clause listing normative references which are documents referenced within the Code that are mandatory to the extent specified within the Code. This Clause 2 replaces Subclause 1.9 and Annex S from the 2015 edition.

2. Clause 3 Terms and Definitions - This is a new clause that provides terms and definitions specific to the Code. This Clause 3 replaces Subclause 1.3 and Annex J.

3. Clause 4 Design of Welded Connections - Clause 4 was presented as Clause 2 previously. Annex A figures in the previous edition were incorporated into Clause 4.

4. Clause 5 Prequalification of Weld Procedure Specification (WPS) - Clause 5 was presented as Clause 3 in the 2015 edition. The Clause 5 has also been restructured to follow the normal progression of writing a prequalified WPS. Table 5.2 has been editorially renamed and reorganized to list WPS essential variables. Additional requirements have been added when using shielding gases and a new Table 5.7 was added on shielding gases. New materials have been added to Tables 5.3 and 5.8.

5. Clause 6 Qualifications - Clause 6 was presented as Clause 4 previously. Revisions include the requirements for the qualification of WPS using waveform technology. All Charpy V-Notch (CVN) testing requirements have been added to Table 6.7 in a single location. The WPS retest requirements have been clarified. The partial joint penetration (PJP) groove weld clause has been reorganized to clarify the qualification of PJP groove welds. Part D of Clause 6 has been reorganized to better align the testing procedures and qualification of CVNs with the order that they would be accomplished.

6. Clause 7 Fabrication - Clause 7 was previously presented as Clause 5. Revisions were made to the weld restoration of base metal with mislocated holes.

7. Clause 8 Inspection - Clause 8 was previously presented as Clause 6. Revisions were made to the qualification requirements for inspection personnel to ensure that all welding inspectors are qualified. The engineer's responsibilities as it relates to inspection were also clarified.

8. Clause 9 Stud Welding - Clause 9 was previously presented as Clause 7. The Code was updated to require the manufacturer's permanent identification on headed studs and deformed anchor bars. Revisions were made to provide weld procedure requirements for fillet welding of studs.

9. Clause 10 Tubular Structures - Clause 10 was previously presented as Clause 9. The calculations for static strength of welded tubular connections were removed in deference to the AISC design provisions.

10. Clause 11 Strengthening and Repair of Existing Structures - Clause 11 was previously presented as Clause 8.

A summary of the changes in the Annexes are in Table 1 as follows:

TABLE 1

2020 Code Annex	Previous 2015 Code Designation
Annex A	Annex B
Annex B	Annex H
Annex D	Annex F
Annex E	Annex D
Annex F	Annex E
Annex H	New addressing phased array UT
Annex J	Annex M
Annex K	Annex P
Annex L	Annex T

2020 Code Annex	Previous 2015 Code Designation
Annex M	Annex U
Annex N	Annex K
Annex O	Annex Q
Annex P	Annex L
Annex Q	Annex O
Annex R	Modified to contain preliminary design of circular tube connections previously contained in the Tubular Structures Clause
Annex T	Annex N
C-Annex H	Added Commentary

Visual Inspection Acceptance Criteria

Table 6.1 from the 2015 version of D1.1 is now identified as Table 8.1 in the 2020 version and remains the weld inspector's guidance for visual inspection. The basis for all visual weld inspections is found in this table. The table, *Visual Inspection Acceptance Criteria*, addresses the following discontinuities:

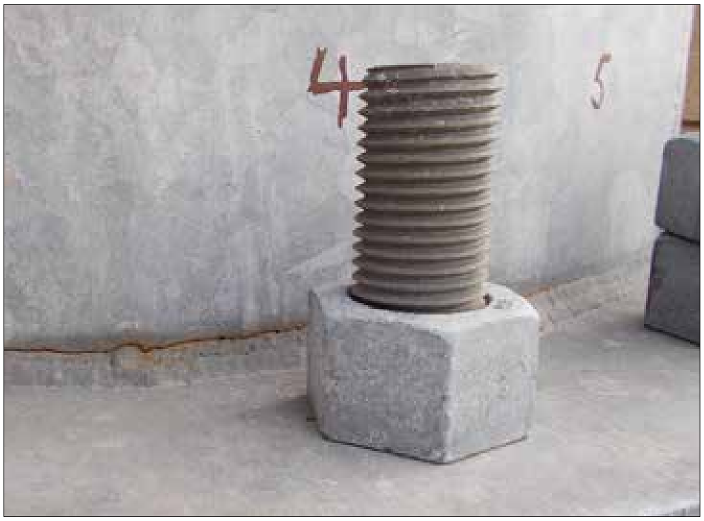
1. Crack Prohibition
2. Weld/Base Metal Fusion
3. Crate Cross Section
4. Weld Profiles
5. Time Of Inspection
6. Undersized Welds
7. Undercut
8. Porosity

The table specifies different acceptance criteria for statically loaded structures and cyclically loaded (fatigue sensitive) structures. The basic difference in acceptance criteria for each of these structures is based upon the difference between static and fatigue loading. When fatigue crack growth is anticipated, initial weld discontinuity size requirements are smaller per the Code. The goal of the Code is to prevent weld failure during the anticipated service life of the weldment. Note that tubular structures visual inspection criteria is addressed in Table 10.15 of the Code which is tailored specifically to this type of structure. There are numerous weld discontinuities as described by the Code as follows:

Typical Weld Discontinuities

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

Cracks are defined as fracture-type discontinuities 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, underbead, and heat-affected zone. Per Code, no crack is allowed to remain in service after identification. Cracks are very detrimental to the performance of a structure; cracks can accelerate the negative effects of fatigue and cause failure of the structure under load. A toe crack at the base of a monopole can cause catastrophic failure of the structure.



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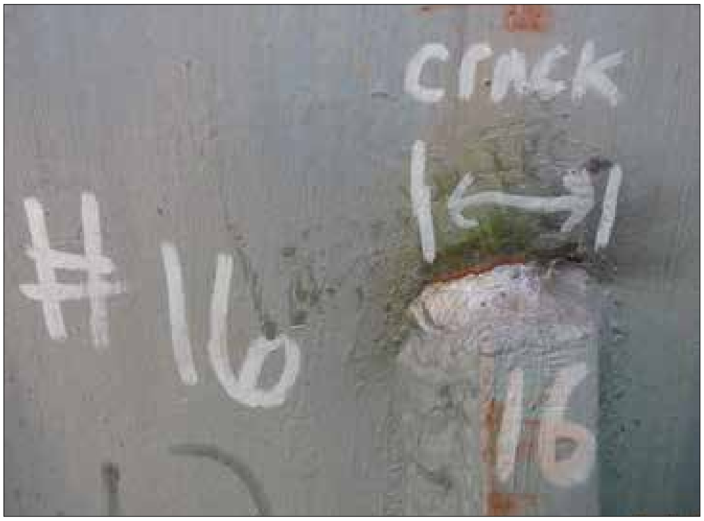
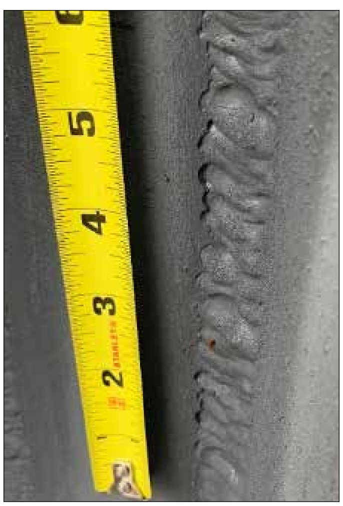
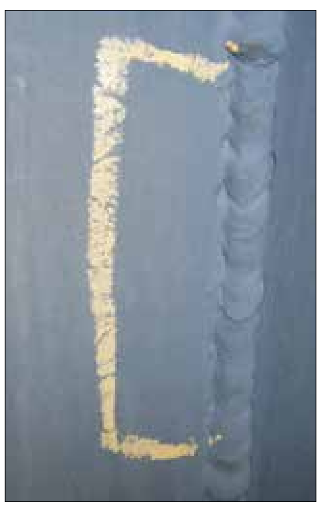
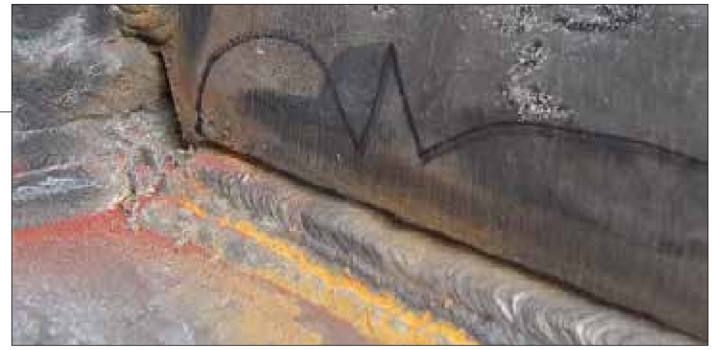


Undercut is defined as a groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal. Undercut can greatly reduce the fatigue-resistance of a welded connection. Undercut is generally associated with either improper welding techniques or excessive welding currents, or both. AWS D1.1 Table 8.1 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.

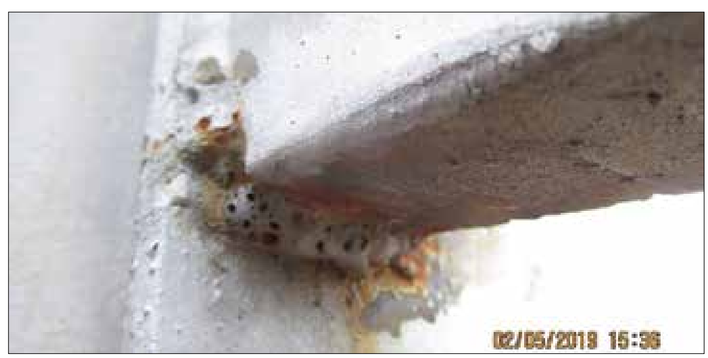


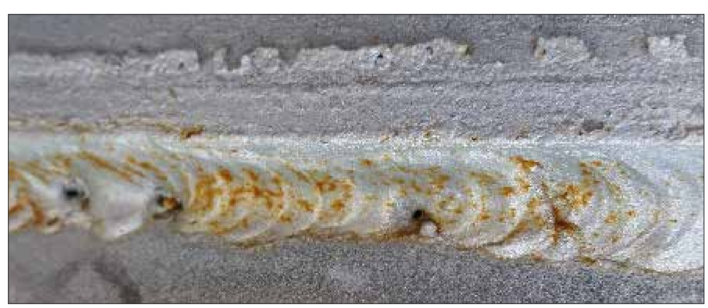


Underfill is a groove weld condition in which the weld face or root surface is below the adjacent surface of the base metal. In essence, the joint has not been completely filled with weld metal and is incomplete.



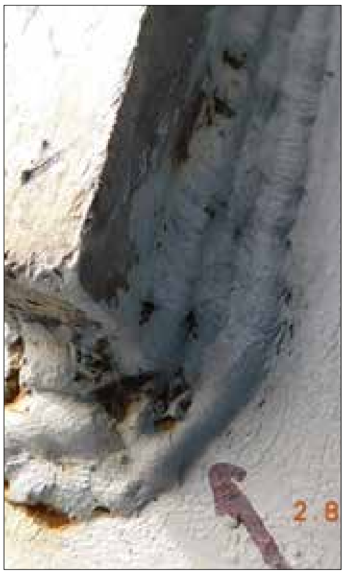
Porosity is a cavity type discontinuity formed by gas entrapment during solidification of the weld metal. The discontinuity formed is generally spherical and may be elongated. Porosity is caused by contamination during welding. There are various types of porosity including: scattered porosity, elongated porosity, aligned or linear porosity, and piping or wormhole porosity. Similar to undercut, the Code allows some porosity in Table 8.1 as acceptable depending on whether the connection is a statically loaded non-tubular connection or a cyclically loaded non-tubular connection.

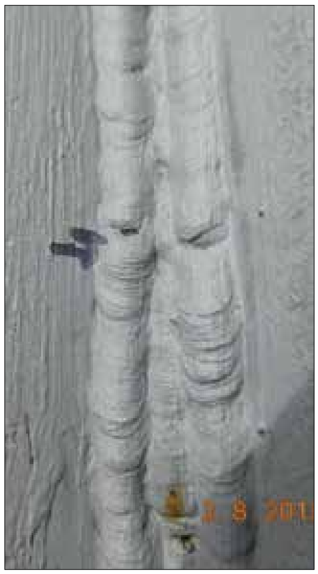




Inclusion is defined as entrapped foreign solid material, such as slag, flux, tungsten, or oxide. When it comes to tower and monopole upgrades, typically inclusion is slag left within a complete joint penetration (CJP) weld and is located by a post-modification ultrasonic testing (UT) non-destructive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

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.

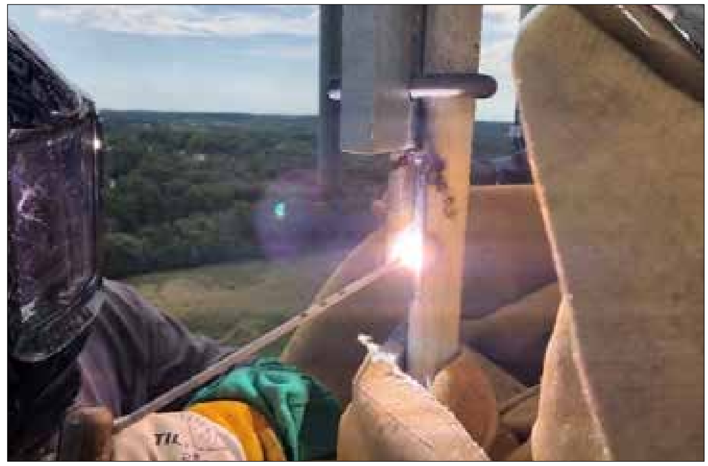


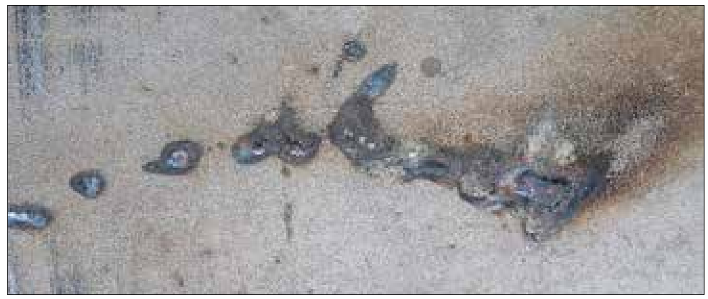


Incomplete joint penetration is a joint root condition in which the weld metal does not extend through the joint thickness. In other words, the weld does not penetrate into the root area of the weld. Typically, this condition is identified via UT non-destructive weld examination.

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

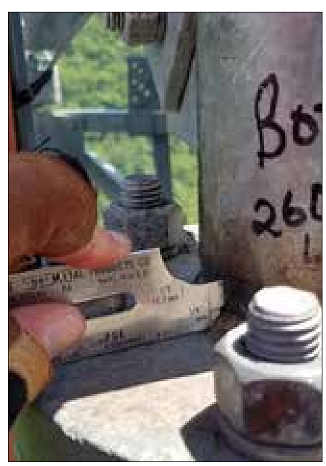
Arc strike is a discontinuity resulting from an arc, consisting of any localized remelted metal, heat-affected metal, or change in the surface profile of any metal object. Arc strikes result when the welder initiates an arc on the base-metal surface away from the weld joint, either intentionally or accidentally. 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.

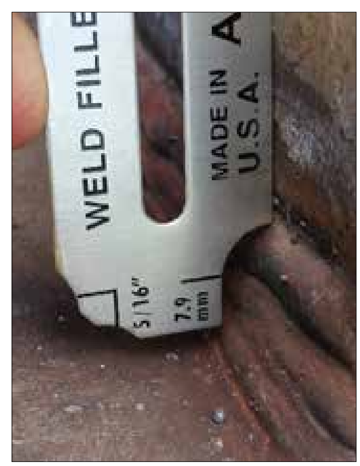




Crater is a depression in the weld face at the termination of a weld bead. The Code's Table 8.1 requires all craters to be filled to provide the specified weld size, except for the ends of intermittent fillet welds outside of their effective length.

Undersized welds do not meet the size requirements of the project specifications. This defect is commonly seen in the field and is easily avoided. It is best practice for a welder to check the sizes of their welds after completion. Fillet weld sizes are measured with fillet weld gauges.





Weld profiles should meet the visual acceptance criteria as specified in Tables 8.1. Welds should be free from cracks, overlaps, and unacceptable profile discontinuities

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exhibited in various Figures in the Code. Special profile allowances for fillet welds, intermittent fillet welds, and groove welds are as specified in the Code.

CHAPTER II
INSPECTION CONSIDERATIONS

Importance of Pre, During, and Post Weld Inspection Activities

It is important to recognize that the governing standard for telecommunications structures incorporates the requirements of the Code to ensure a level of quality, structural performance, reliability, and safety. TIA-222-H, *Structural Standard for Antenna Supporting Structures, Antennas and Small Wind Turbine Support Structures* (the Standard), requires all new tower fabrication to be in compliance with the Code in Section 5.5 of the Standard. In Annex O, the Standard requires all welded field modifications include pre/during/post welding inspection activities. Field modifications to towers have been prevalent in recent years as the telecommunications industry has installed less new towers in an effort to optimize existing structures. Welded modifications to towers can be challenging from a design, materials, logistics, environmental, and working at height standpoint.

Despite the recent changes to the Code, there is a consistent attribute of a successful welding project, inspection activities. Projects that are in compliance with the Code and that typically have little to no welding repairs are projects where weld inspectors are integrally involved with the project from the beginning. It is also important that inspections are performed prior to AND during the welding activities, not just a final inspection visit at the end of the project. Inspectors should be certified weld inspectors (CWI) per the AWS.

In fact, the Code requires the inspector to verify numerous aspects of the welding process from the welder's qualification paperwork including welding procedure specifications (WPS) to the type of electrode used, how the electrode is stored, and preheat temperatures. Proper joint configurations such as CJP vs PJP welds cannot be determined accurately after the welding is completed in the post condition. The weld inspector needs to inspect the joint prior to welding to confirm the geometry, member bevel(s), and weld root gap. Witnessing the welding process ensures that the welder is utilizing the correct electrode, performing preheat properly, and is operating within the ranges specified by their WPS documentation. Engineering changes with respect to the welds can occur with the inspector's feedback. Table 2 below provides Code references for each welding project milestone and corresponding Code inspection requirement. As can be seen, there are numerous critical milestones that require the weld inspector's involvement.

Conclusion

Welding activities and inspection should be performed in accordance with AWS D1.1:2020 Structural Welding Code – Steel. Per Section 8.9 of the Code, the inspector is to evaluate the welds to the criteria of Table 8.1. Table 8.1 details inspection criteria and addresses weld discontinuities. The importance of the weld inspector's involvement throughout a welding project cannot be understated. A successful project involves the weld inspector and includes pre, during, and post weld inspection activities as required by both the D1.1 Code and the TIA Standard. The Code provides very specific inspection criteria to ensure a quality welding project and adherence to Code requirements.

It is the intent that the information provided in this PAN on the background and history of the Code, along with the previous PAN series on welding, allows end users and the other stakeholders to appreciate the value in setting proper expectations for welding as a part of the procurement and field modification processes. When contractors are supported with a clear understanding of the requirements, appropriate planning then occurs, which, in turn, leads to an increase in quality, safety, and job site efficiency.

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TABLE 2

Pre Inspection Activities	AWS D1.1 Reference
Welding procedure specification (WPS) available	6.3.3, 8.3
Welder qualification	6.2.2 , Clause 6 Part C, 8.4
Fit-up of groove weld including joint geometry	-
Joint preparation	7.14.6, 8.5.2
Dimensions (alignment, root opening, root face, bevel)	7.21
Cleanliness (removal of galvanizing, condition of surfaces)	7.14
Tacking (tack weld quality & location)	7.17
Backing type & fit	7.2.2.2, 7.9, 7.21.1, 7.21.2
Fit-up of fillet welds	-
Dimensions (alignment, gaps at root)	7.21.1
Cleanliness (removal of galvanzing, condition of surfaces)	7.14
Tacking (tack weld quality & location)	7.17
Check welding equipment	7.10, 8.2
During Inspection Activities	**AWS D1.1 Reference**
Use of qualified welders	6.2.2 , Clause 6 Part C, 8.4
Welder period of effectiveness (continuity)	6.2.3
Control & handling of welding consumables	7.3, 8.2
Packaging	7.3.1.4, 7.3.1.5
Exposure control (SMAW)	7.3.2
Is the appropriate wire/electode strength utilized	5.6.1, Table 5.4
Environmental conditions	7.11
Wind speed within limits	7.11.1
Precipitation & temperature	7.11.2
Welding procedure specification (WPS) followed	7.5, 8.3.3, 8.5.2
WPS readily available & followed during welding	7.5
Settings on welding equipment	7.5, 8.3.3
Travel speed	7.5, 8.3.3
Selected welding materials	7.5, 8.3.3
Shielded gas type/flow rate if applicable	7.5, 8.3.3
Preheat applied	7.6, 7.20.6
Interpass temperature maintained	7.6
Proper welding position (F, V, H, OH)	7.5, 8.3.3
Welding techniques	7.23. 8.5.2, 8.5.3
Interpass & final cleaning	7.29
Eash pass within profile limitations	7.23
Each pass meets quality requirements	7.5, 8.9, Table 8.1
Post Inspection Activities	**AWS D1.1 Reference**
Time of inspection	Table 8.1 (5)
Welds cleaned	7.29
Size, length, and lcoation of welds	8.5.1
Welds meet visual acceptance criteria	8.9, Table 8.1, 8.5.3
Crack prohibition	Table 8.1 (1)
Weld/base-metal fusion	Table 8.1 (2)
Crater cross section	Table 8.1 (3)
Weld profiles	7.23, Table 8.1 (4)
Weld size	7.12, 7.13, 8.5.1, Table 8.1 (6)
Undercut	Table 8.1 (7)
Porosity	Table 8.1 (8)
Arc strikes	7.28
Repair activities	7.25
Documentation - acceptance or rejection	8.5.4, 8.5.5

Reference AISC 360-10; updated for D1.1-2020