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Welding Issues for Seismic Design Requirements

Metal Building Systems

by

W. Lee Shoemaker, P.E., Ph.D.

Director of Research & Engineering

Background

Welding requirements for buildings designed to resist seismically-induced energy have undergone a variety of changes in the past dozen years. With the publication of several specifications in 2005, some stability has now emerged. This bulletin is intended to outline and clarify the welding issues for seismic design that are specific to metal building systems.

Applicable Codes and Standards

Welding requirements are stipulated in a number of documents, including:

(1) AISC Specification for Steel Buildings (AISC 360-05)

(2) AISC Seismic Provisions for Structural Steel Buildings (AISC 341-05)

(3) AISC Prequalified Connections for Special and Intermediate Moment Frames for Seismic Applications (AISC 358-05)

(4) AWS Structural Welding Code – Steel (AWS D1.1-04) (as referenced by AISC 341-05)

(5) AWS Structural Welding Code – Seismic Supplement (AWS D1.8/D1.8M:2005)

Also, FEMA 353 – Recommended Specifications and Quality Assurance Guidelines for Steel Moment Frame Construction for Seismic Applications, June 2000, was often referenced as a resource before the above codes and standards incorporated the appropriate information. This is still sometimes referenced separately, but should not supersede these newer documents.

AISC 341 and AISC 358 are supplemental to the requirements of AISC 360, while AWS D1.8 is supplemental to AWS D1.1. The requirements of the supplemental documents add to and are not in lieu of, the requirements of the documents they supplement. AWS D1.8 contains provisions that correspond to similar provisions in FEMA 353 and AISC 341 Appendix W. AWS D1.8 may offer advantages over FEMA 353 and AISC 341 but it may be used only if referred to in a project specification or with approval of an engineer.

General Welding Requirements

Welding requirements for the seismic load resisting system (SLRS) depend on whether the weld is categorized as a demand critical weld, or is just part of the SLRS. The seismic load resisting system is defined as the assembly of structural elements in a building that resists seismic loads, including struts, collectors, chords, diaphragms and trusses. Demand critical welds are those that have been determined both to be subject to yield-level stresses and to have the potential to cause catastrophic results if they failed. Demand critical welds can include complete-joint-penetrations (CJP) groove welds for column splices in ductile frames[1], CJP groove welds for beam flange to column flange

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[1] For ductile moment frames (IMF and SMF) the "strong column" is necessary to force flexural yielding in the "weak beam", which is ensured by the AISC 341 beam and column proportioning requirements. For the OMF, which is intended for minimal inelastic deformations only, the "weak column – strong beam" concept is permitted. Hence, the demand critical weld does not guarantee better performance as long as the OMF column strength can be governed by limit states other than flexural yielding.

moment connections, and beam web to column flange CJP groove welds in moment connections (See AISC 341 Section 7.3b).

Whether a weld is demand critical or not depends in part on the type of seismic system involved, such as an ordinary moment frame (OMF), intermediate moment frame (IMF) or special moment frame (SMF).

In addition to the other applicable seismic design criteria listed in Section 5.1 of AISC 341, the classification of a weld is to be specified by the Engineer in the Contract Documents. This does not give the Engineer the authority to disregard the code requirements, but it is intended to makes it clear to the fabricator which welds are demand critical. Therefore, from this specified criteria, welds can be categorized as one of the following:

(1) Welds that are not part of the SLRS (AWS D1.1 applies)

(2) Welds that are part of the SLRS, that are not demand critical (AISC 341, Section 7.3a applies in addition to AWS D1.1)

(3) Welds that are part of the SLRS that are demand critical (AISC 341, Section 7.3b applies in addition to the requirements of AISC 341 Section 7.3a and AWS D1.1)

The typical metal building system should have only a few select welds that are demand critical. Guidance is provided below regarding the classification of common welds.

Demand Critical Welds in Metal Buildings

In typical metal building gable frames, the only welds that would be considered demand critical in an OMF are CJP groove welds of the end-plates at the haunch connection. For IMF's, a prequalified connection would have to be used for this connection, but the bolted end-plate connections in AISC 358 do not have any additional demand critical weld requirements other than what AISC 341 requires for OMF's. Other weld requirements of the web to flange in an IMF given in AISC 358 are discussed separately in this paper. Note that fillet welds used to weld the end-plate to the beam end would not be considered demand critical welds. Also, end-plate connections elsewhere in the frame, e.g. the ridge, are not defined as demand critical.

Weld Filler Metal Requirements

Weld filler metal requirements can be categorized as follows:

(1) Welds that are part of the seismic load resisting system that are not demand critical (AISC 341, Section 7.3a) shall have a minimum CVN toughness of 20 ft-lb at 0°F as determined by AWS A5 classification or manufacturer certification.

Most MBMA members use gas metal arc welding (GMAW) for semi-automatic welding, and automatic submerged arc welding (SAW) for web-to-flange built-up sections. Other welding processes are possible and acceptable, but these are the most common combinations. For GMAW, a typical filler metal is ER70S-3. For SAW, Lincoln 781/L50 or 781/L61 is commonly used. These filler metal combinations satisfy this requirement.

Self shielded flux cored arc welding (FCAW-S) is not commonly used for metal building fabrication today. However, in welded joints where FCAW-S is mixed with other processes including FCAW-G, the filler metal combination must be tested in accordance with D1.8 section 6.3.4.

(2) Welds that are part of the seismic load resisting system that are demand critical (AISC 341, Section 7.3b) shall have a minimum CVN toughness of 20 ft-lb at -20°F as determined by AWS A5 classification or manufacturer certification, and 40 ft-lb at 70°F as determined by AISC 341 Appendix X, AWS D1.1 Annex A, or other approved method.

As previously discussed, the only applicable welds that are demand critical in an OMF or IMF are the CJP groove welds of the end-plates at the haunch connection. In the metal building industry, this weld would typically be made with GMAW, and the typical filler metal used is classified as ER70S-3. The AWS A5.18 classification for ER70S-3 requires CVN toughness of 20 ft-lb at 0°F, not the -20°F required by AISC 341. However, AISC 341 also permits "manufacturer certification" as an acceptable alternative to demonstrate that the filler metal is capable of achieving 20 ft-lb at -20°F in a filler metal classification test. A manufacturer's typical certificate of conformance that lists 20 ft-lb at -20°F is suitable documentation for this purpose. Alternately, ER70S-6 may be used, which is classified at -20°F.

For the prequalified bolted end-plate moment connections included in AISC 358, the reinforcing fillet weld on the inside face of the flange shall also be demand critical (AISC 358, Section 6.9.7(3)).

Regarding testing in conformance with "Appendix X or other approved method", solid GMAW electrodes are exempted from this requirement when the aforementioned 20 ft-lb at -20°F is achieved. Thus, in the typical situation where GMAW is utilized, testing in accordance with Appendix X will not be required.

(3) For all welds, self shielded flux cored arc welding (FCAW-S) is not commonly used for metal building fabrication today. However, in welded joints where FCAW-S is mixed with other processes including FCAW-G, the filler metal combination must be tested in accordance with D1.8 Section 6.3.4.

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Protected Zones in Metal Buildings

The concept of "Protected Zone" is used in AISC 341, AISC 358 and AWS D1.8. A weld that is within the protected zone is not required to meet the demand critical requirements. The intent is to eliminate unintended stresses and fracture initiators in selected regions subject to significant inelastic deformations.

There are no protected zones specified for OMF's. However for IMF's, the extent of the protected zone is given in AISC 358 for pre-qualified connections and in AISC 341 Section 10.2d.

In typical IMF's that might be used in metal buildings when an OMF is not permitted, the protected zone is defined in AISC 358 Section 6.4(8) as follows:

(1) For an unstiffened extended end-plate, the protected zone extends from the face of the column to the lesser of (a) the depth of the beam, or (b) 3 times the width of the flange from the face of the column.

(2) For a stiffened extended end-plate, the protected zone extends from the face of the column to a location from the end of the stiffener plus the lesser of (a) the depth of the beam, or (b) 3 times the width of the flange from the face of the column.

The protected zone requirements are stated in AISC 341 Section 7.4 as follows:

(1) Discontinuities created by fabrication or erection operations shall be repaired. Examples include tack welds, erection aids and cuts.

(2) Shear studs and pins or screws are not permitted (arc spot welds for attaching deck are permitted)

(3) Welded, bolted, screwed or shot-in attachments for perimeter edge angles, exterior facades, partitions, duct work, piping or other construction are not permitted in the protected zone except that bolt holes in the beam web are permitted as noted in Section 2.6 of AISC 358.

Note that a butt splice of a web plate that falls within the protected zone must be free of discontinuities created by fabrication or erection operations, such as tack welds, erection aids, air-arc gouging and thermal cutting. However they are not specifically addressed in the codes, so they would only be classified as demand critical if specified by the Engineer in the Contract Documents. Discontinuities shall be repaired as required by the Engineer of Record. As part of the SLRS, these welds are required to be made with filler metals with a minimum CVN toughness of 20 ft-lb at 0°F as determined by AWS A5 classification or manufacturer certification.

In the protected zone, tack welds attaching backing and weld tabs shall be placed where they will be incorporated into a final weld, as noted in Section 3.5 of AISC 358.

Other Pertinent Welding Requirements

Welding Procedure Specifications (WPS's) – WPS's have to show the filler metal manufacturer and trade name for all welds. For demand critical welds only, the WPS must show a combination of variables that results in a heat input within the envelope to which the filler metal was tested and certified.

Filler Metal Atmospheric Exposure - While not a commonly used welding process, if FCAW is used, the filler metals must not be exposed to the atmosphere longer than 72 hours or the exposure limits for which they are tested.

The maximum diffusible hydrogen is limited in welding electrodes. They shall meet the requirements for H16 (16 mL maximum diffusible hydrogen per 100 grams of deposited weld metal) as noted in Section W5.2, AISC 341. Note that this does not apply to GMAW solid electrodes.

The maximum interpass temperature shall not exceed 550 °F unless additional qualification testing is carried out, as noted in Section W5.2, AISC 341.

Welder Qualification - AWS D1.8 requires that welders pass a supplemental qualification test if they will be making welds that meet all of the following requirements: a) demand critical, b) join the bottom beam flange to the column flange and c) are made through a weld access hole. Such conditions are rarely if ever encountered on metal building systems, and accordingly, the supplemental welder qualification tests will typically not be required for metal building applications, even if the requirements of AWS D1.8 are specifically invoked in the contract documents.

Other IMF Requirements

AISC 358, Section 6.4, has a requirement that at the haunch of welded built-up sections, within at least the depth of the beam or 3 times the width of the flange, whichever is less, the web to flange weld shall be either a CJP groove weld or a pair of fillet welds each having a size ¾ times the beam web thickness but not less than ¼ inch. This would typically require a change from the typical practice of single sided fillet welds.

Quality Assurance Plan

Quality assurance inspection performed by an independent inspection agency, is not a requirement of AWS D1.1. Inspection is required by AWS D1.1, but is addressed generically in a form that includes both the fabricator's or erector's inspection and the outside inspection that is provided by, but at the prerogative of, the owner. AWS D1.1 does include visual quality criteria, nondestructive testing (NDT) methodology and NDT quality criteria, but does not specify the location or types of welds that require NDT. This task is left to the engineer.

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AWS D1.1 does not contain specific quality criteria applicable for seismic loading, low cycle fatigue or plastic hinging regions, addressing only static (elastic) and high-cycle fatigue applications. Any special quality requirements for seismic applications are left to the engineer.

AISC 341 contains provisions for and requirements of a quality assurance plan in Section 18 and Appendix Q. The plan must meet any building code requirement such as those in the 2006 IBC, in addition to any requirements of the engineer. The emphasis is placed upon visual inspection. Nondestructive Testing (NDT), however, is required for CJP and PJP groove welds along with other items as detailed in Appendix Q. The form of NDT is specified within Appendix Q, based on the tested item.

The 2006 IBC requires special inspection for steel construction, with a few exceptions as noted in Section 1705.3. Special inspection is performed by independent, qualified individuals or agencies approved to perform such inspections by the building official. Special inspection includes an inspection of the fabricator's operations and quality control procedures, unless the fabricator is otherwise approved by the building official. Structural steel welding operations must receive continuous special inspection, except for single-pass fillet welds 5/16" or less, for which periodic special inspection is permitted (IBC Section 1707.2).

Section 1705 of IBC 2006 requires a quality assurance plan for seismic-force-resisting systems in Seismic Design Categories C, D, E or F. The quality assurance plan must be prepared by a registered design professional and specify the special inspection requirements and testing requirements, including the type of testing and frequency of testing. Structural observation by the engineer or his or her designated representative is also a requirement. The exact extent of additional special inspection, testing and structural observation for seismic applications is not defined within the IBC, but is rather left to the determination of the registered design professional. AISC 341, Appendix Q gives appropriate guidance in this area.

The fabricator and erector must complete a statement of responsibility acknowledging their awareness of the quality assurance plan, their plans and procedures for providing quality control to achieve the contract requirements, and identification of those individuals responsible for performing such functions. The 2006 IBC Section 1704.2.2 allows in-shop quality assurance activities to be waived if welding is performed on the premises of an approved fabricator.

Summary

For metal buildings, the following are the changes in practice that may be required in order to comply with AISC 341:

(1) The complete-joint-penetration welds of the end-plate at the haunch connection must meet the requirements for demand critical welds. Filler metals used for these welds must meet AWS classification requirements of 20 ft-lbs at -20°F, or be tested by the manufacturer as meeting the same requirement. Additionally, the filler metals are required to meet 40 ft-lbs at 70°F when testing in accordance with Appendix X, unless the particular electrode is exempt from this requirement (GMAW with solid electrodes are exempt from AISC 341 Appendix X testing).

(2) Welds that are part of the SLRS must be made with filler metals meeting 20 ft-lbs at 0°F. For most metal building manufacturers, commonly used welding products will meet these requirements.

(3) For IMF applications, fabrication restrictions apply to the portion of the member identified as the protected zone.

(4) For IMF applications, the welds at the end of built up sections between the web and flange will need to be CJP groove welds, or double sided fillet welds meeting certain size requirements. Additionally, the weld between the end of the beam and end-plate needs to be a CJP groove weld with a reinforcing fillet.

Disclaimer

The welding requirements that are discussed in this bulletin apply to typical metal building structures. The reader should confirm that their application is within the scope of these assumptions.

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For Further Information:

Metal Building Manufacturers Association, Inc.

1300 Sumner Avenue • Cleveland, Ohio 44115-2851

216-241-7333 • 216-241-0105 (fax)

Email: mbma@mbma.com • Website: www.mbma.com