

The study of welding requirements during construction and installation of seismic-resistant steel structures

STROIANOVSKIY Dmytro *

**Faculty of Computer Science and Cybernetics, Taras Shevchenko National University of Kyiv, Kyiv, Ukraine*

ARTICLE INFO

Article history:

Received 18 Dec 2019

Received in revised form 28 Jan 2020

Accepted 09 Feb 2020

Keywords:

Steel Structure, Welding, Seismic-Resistant, Critical Welding Fittings, Standard Requirements.

ABSTRACT

In the last few decades, several horrible earthquakes have unfortunately caused irreparable damages in different parts of our country. The resulting pathology indicates that the damage to the steel structures is mainly due to insufficient resistance and failure in welding fittings. Therefore, extensive research has begun to study seismic behavior and ways to enhance welding fittings. Studies show that the Metallurgical properties of welding metals and the factors that influence the rate of energy absorption and crack growth in this area strongly influence the behavior of the critical fittings of structures. Factors such as solder geometry, weld metal and base metal specifications and welding technology can be mentioned. Given the lack of attention to these important details in the bylaws, the main purpose of this article is to review and compare the requirements of earthquake-resistant structural systems in modern international standards and research.

1. INTRODUCTION

The main reference for the implementation and control of welding processes in the construction and installation of steel structures are the Iranian Building Welding Code (Issue 228) and the 10th and 11th issues of the National Building Regulations. An examination of these regulations shows that there are few requirements for welding earthquake-resistant structures and a few brief notes. More importantly, the Regulations of 2800, which deals with the design and implementation of earthquake-resistant buildings, did not provide a detailed review of this issue and provided general justifications.

Therefore, details regarding the welding of earthquake-resistant structures fittings should be addressed in internal bylaws and technical documents should be provided to industry executives and supervisors. Whereas the internationally accredited standards such as AISC, AWS and FEMA, which is the main source of internal bylaws discuss the mechanics of the failure and destruction of steel structures during earthquakes from both theoretical and practical perspectives in detail.

The AWS D1.8 standard includes additional seismic requirements on the AWS D1.1 standard. It also provides AISC 358, AISC 341, 350 FEMA, 353 FEMA, 355 FEMA standards that present useful information on earthquake resistant welding fittings.

Therefore, in the following sections, the relevant subject matter of this article that have received little attention, will be discussed and compared in recent standards and research.

2. RESEARCH METHOD

Welding Fittings Classification:

In order to better identify welding fittings in earthquake resistant steel structures, their conventional classification is provided in the following sources:

1- Welding fittings that do not belong to Seismic force resistant systems and comply with AWS D1.1 standard requirements.

2- Welding fittings that are members of Seismic force resistant systems (SFRS), but are not critical welding fittings that comply with AWS D1.1 standard requirements. These connections are defined in Section 7.3a of AISC 341.

3. Welding fittings that are members of the Seismic force resistant systems (SFRS) are critical welding fittings and in addition to the AWS D1.1 standard requirements, they must also comply with the AWS D1.8 standard requirements. These fittings are defined in Section 7.3b of AISC 341.

The term critical welding fittings refers to a set of structural fittings that are highly susceptible to the yield stress during seismic loading and have inherently the possibility of early failure and catastrophic results. Therefore, their construction and monitoring process will require special care. These include full penetration welding joints for splice-column connection and beam-to-column connection.

3. RESULTS

3.1. Filler and Weld Metal Specifications in SFRS system

One of the most important requirements in the literature relates to the characteristics of the filler and weld metal in SFRS systems, which will play an important role in determining the final joint properties during seismic loading, and they are summarized as follows:

*Corresponding author: stroyanovskiy@gmail.com

DOI: <https://doi.org/10.24200/jrset.vol8iss02pp17-20>

1- According to AISC 341 Section 7.3a, the weld metal for non-critical fittings of the SFRS should provide at least 20 ft-lb slit sample toughness at zero degrees Fahrenheit. These specifications must either be explicitly approved by the electrode manufacturer or certified from the tests listed in AWS A.5.

2- In accordance with Section 7.3b of AISC 341, weld metal of critical-type fittings from SFRS should provide at least 20 ft-lb slit sample toughness at -20°F . In addition, at least 20 ft-lb slit sample toughness shall be provided at 70°F , in accordance with Appendix X of AISC 341 and Appendix A of AWS D1.8.

3- According to clause 6.2.2 of AWS D1.8 standards, a minimum slit sample equivalent of 54 joules at $+10^{\circ}\text{C}$ must be used for system members at the lowest expected temperature.

4- The internal heat test should be performed when using any filler metal according to the requirements of Attachment A of AWS D1.8. However, some mineral filler groups such as E7018 in the SMAW1 process, ER70 in the GMAW2 process, and E7X with a D extension in the FCAW3 process with low application temperatures above $+10^{\circ}\text{C}$ are exempt from this test.

In clauses 3 and 4, it is necessary to clarify that increasing the input temperature of base metal and weld metal and from Metallurgical aspect, lowering the operating temperature of the components increases the likelihood of brittle failure.

However, for 3 shipments manufactured from a single brand and the diameter of the electrode, tests can be carried out as Annexure A to the AWS D1.1 standard and approved for use.

5. According to section 6.3 of AWS D1.8, all consignments of filler metal purchased for welding of critical joints must be tested according to the requirements of AWS A.5. However, for 3 shipments manufactured from the same brand and electrode diameter, the tests in Appendix A of the AWS D1.1 Standard should be carried out to confirm usage.

3.2. Welding processes

Welding properties and conditions for their application in the construction and installation of seismic steel structures are discussed in AWS D1.8. Developed countries such as Japan and the United States have used the commonly accepted fittings used in the SFRS system in SMAW and FCAW processes, and the welding results have been satisfactory. The GMAW process has also been partially applied to the fittings of these structures. But the Submerged Arc Welding (SAW) process has not been specifically used for welding seismic joints. Due to the lack of sufficient information from the test results, the ESW and EGW processes cannot be used without the acceptance test or approval of the designer or structural supervisor. The impact of environmental conditions on the weld pool protection and potential defects in FEMA 355B similar to AWS D1.8 is discussed below.

Experiments have shown that the elasticity of weld metal and the slit sample toughness decrease with increasing wind speed and decreasing protection of the weld pool. In this way, the grooves of the slit sample will be reduced without noticing the porosity in the weld

metal. It is noteworthy that at a wind speed of about 8 to 10 mph (3.6 to 4.5 m / s), the internal porosity is greatly enhanced without any visible effect on the weld metal. The wind speed of about 3 miles per hour also results in a moderate deflection of the weld pool protective atmosphere. Therefore, processes with protective gas must be performed against minimum airflow.

The AWS D1.1 standard provides the maximum permissible wind speed of 8 mph, however, the toughness requirements of the weld metal slit sample in seismic conditions should not be considered as an appropriate criterion in the SFRS system. But in processes without gas protection, there is a great tolerance for wind speed. Minimum Inter-pass and Preheating temperature is provided by measures to prevent heat transfer and rapid freezing of weld metal and reduce the likelihood of cracking in the joint.

Therefore, in accordance with AWS D1.8, the maximum permissible Preheating and inter-pass temperature for both base and weld metals in the SFRS system is 300°C and its minimum complies with the requirements of the AWS D1.1 standard and internal regulations. The preheating and inter-pass temperature range is between 25 and 75 mm of the weld metal, and in the case of minimum temperatures, the distances exceed the radius of 75 mm.

3.3. The backing of Critical Weld Fittings

Research has shown that many of the fractures during the earthquake have been due to the presence of backing in full beam-to-column penetration fittings in the SFRS system. So even if there is a normal and uniform welding at the weld root, the non-fused weld interface between the backing and the local column flange is high. However, the presence of the backing makes it difficult to identify defects in the weld penetration root by non-destructive tests, including ultrasound tests. These defects are mainly incomplete fusion and slag inclusion, which will have more severe groove effects than the backing.

The FEMA 350 and FEMA 353 standards recommend removing the backing from the lower beam-to-column connection, but AISC 358 and AWS D1.8 require removal of backing from the lower beam flange.

Also, the weld root must be drained until it reaches the base metal after removing the backing, then the back weld should be performed along with the Fillet weld reinforcement. The size of the reinforcing fillet weld adjacent to the column flange is at least 8 mm, and this size adjacent to the beam flange should be such that the weld toe is placed on the beam flange. It should be noted that the destructive effects of backing on the lower beam flange are more severe and removal of backing at the upper beam flange is not necessary. Therefore, if the upper flange backing remains to reduce the impact of the backing groove, reinforcing Fillet weld with a caliper size of at least 8 mm is recommended. And if there are any defects in the size and appearance of the weld, the defective weld must be removed, and re-welding with a low hydrogen electrode followed by polishing the weld surface should be performed.

In the case of residual grooves on the surface resulting from the removal of the backing, grooves of less than 1.5

mm in depth must be repaired by grinding and sloping to a maximum ratio of 1 to 5 and by welding in accordance with approved welding Procedure Specification.

3.4. Weld access hole

In order to perform penetration welding of the beam-column flange, we usually have to run the access hole for ease of access to the welding stance. But the geometry and quality of its implementation strongly influence the joint behavior during seismic loading. According to FEMA 350, if the access hole is not large enough, the welder will have limited access to the joint and the welding quality will be reduced. Increasing the unauthorized access hole size will also increase the critical plastic strain on the weld metal and the beam flange near the access hole. Also, the mechanical tests of the joint in the presence of the access hole and the hard weld metal show the phenomenon of low cycle fatigue and ultimately failure of the joint. The geometry of the connection hole, dimensions and tolerances specified in AWS D1.1 and AISC 360 standards for critical welds in the SFRS system are mandatory. According to AWS D1.8, the conditions for checking and accepting the access hole are as follows:

1. The access hole should have a smooth surface and a roughness not exceeding 13 microns.
2. The grooves and cracks caused by thermal cut or irregular cutting should be removed by grinding and adjusted with a slope less than 1: 5 as well as a bending radius of less than 10 mm on the curved part of the cutting surface.
3. The depth of gaps that can be remedied by grinding is not limited, but deeper gaps that are not corrected by grinding should be repaired by welding. However, the surface must be smooth before welding and be pre-heated to a radius of at least 6 mm from the repair surface and a minimum temperature of 65 ° C and then be corrected. After welding, the entire repair surface should be smooth and soft with adjacent surfaces and also make sure that there are no cracks in the weld during the post-repair inspection.

Extra plate having a joint design according to the original piece are used on both sides of the weld groove, so-called welding end mesh. According to the AWS D1.8 standards, the end mesh in the penetration welding of the beam-to-column connection should be 25 mm or greater in thickness each but shall not exceed 50 mm. In cases such as near bulk space or intersecting with angles and corners where there is insufficient access to the welding end mesh point, Cascade sequence technique should be used.

Also for continuity plates should not be used at the weld end adjacent to the flange, except with the permission of the designer or supervisor. According to AWS D1.8 and AISC 358, the end mesh of the weld should be removed after welding and even 3 mm should be removed from the base metal surface and the remaining metal weld surface is polished. In the continuity plates, after removing the end mesh, 6 mm from the base metal edge should be removed and then the surface of the weld must be raised. The surface of the weld must be free of any slots, grooves and the sharp

corners should have a maximum surface roughness of 13 microns. Also, the final surface should be moved with a gentle inclination to the adjacent surfaces. In accordance with AISC 358, defects must be repaired by welding after removing the end mesh to a depth of more than 2 mm.

This size is set to 1.5 mm in the AWS D1.8 standards. After grinding these defects, the stance must be filled in accordance with the approved WPS. Other defects should only be removed by grinding at a ratio of 1 to 5.

3.5. Tack Weld

Creating tack weld on the base metal usually results in a small but hard heat-affected area. It is also possible to create cracks, sharp grooves and tension points around them. Since hard, crunchy stains and mechanical cracks are unable to tarnish plastic, their presence in the protected area is undesirable. Therefore, placing the tack welds in the main joint weld will reduce the risk of this area, and the heat of the main welding passes will result in heat treatment of the heat-affected area and reduce its undesirable mechanical properties.

Also, the presence of tack weld outside the welding joint in accordance with the principles of fracture mechanics causes unwanted force paths that can cause germination and crack growth at high strains. Therefore, the most reliable solution is the infusion of tack welds in the main weld pass.

In AWS D1.8 standards, tack welding can be performed on critical joints with the following conditions:

- It should be performed by certified and qualified welders according to WPS.
- In the protected area, the application of tack weld outside the main weld is prohibited.
- The required tack weld to join the weld groove backing to the base metal should be infused as much as possible in the main weld. This was also mentioned in AISC 358 regarding tack weld joints related to backing joint as well as end weld mesh.
- There are no barriers to using tack weld on the column to connect the beam joint backing to the column.
- The tack welds with incorrect location should be removed by grinding, and if there are any grooves and cracks left after grinding, they must be repaired in accordance with the welding repairing procedure.

4. CONCLUSION

According to studying and comparing the requirements of the International Reference Regulations concerning joint welding in seismic-resistant structural systems in the article, here are some suggestions:

1-The requirements contained in the internal building codes are a prerequisite for ensuring the quality of steel structures, but they are not sufficient. Therefore, the additional requirements of seismic readjustment, especially in the field of welding fittings, must be implemented according to the international standards mentioned above and repeated in the article.

2- Consumable filler metal is one of the most important factors affecting the seismic behavior of welded joints, which should be carefully selected when considering the fracture toughness of the cracked sample at low and medium temperatures.

3. The proper input heat rate is an essential parameter in the preparation of welding procedure for seismic-resistant structures. The type of welding process, welding parameters, and pre-heating and inter-pass temperature will determine the input heat.

4- The control of the implementation of the details of the full penetration welding backing, access holes, welding end mesh and tack welds according to the requirements of the article, is very effective in reducing the effect of stress concentration and crack growth during seismic loading.

REFERENCES

- [1] Vulcu, C., Stratan, A., Ciutina, A., & Dubina, D. (2017). Beam-to-CFT high-strength joints with external diaphragm. I: Design and experimental validation. *Journal of Structural Engineering*, 143(5), 04017001.
- [2] AWS D1.1/ D1.1M, structural welding code, 2016.
- [3] ANSI/AISC 358-16, prequalified connections for special and intermediate steel moment frames for seismic application, 2016.
- [4] Vulcu, C., Stratan, A., Ciutina, A., & Dubina, D. (2017). Beam-to-CFT high-strength joints with external diaphragm. II: Numerical simulation of joint behavior. *Journal of Structural Engineering*, 143(5), 04017002.
- [5] Silva, André Tenchini da. "Seismic Performance of High Strength Steel Building Frames." PhD diss., 2014.
- [6] de Construção, A. P. (2018). Design of Steel Structures for Buildings in Seismic Areas: Eurocode 8: Design of Structures for Earthquake Resistance. Part 1: General Rules, Seismic Action and Rules for Buildings. John Wiley & Sons.
- [7] FEMA- 353, recommended specifications and quality assurance guidelines for steel moment- frame construction for seismic application, 2016
- [8] Vulcu, C., Stratan, A., Ciutina, A., & Dubina, D. (2017). Beam-to-CFT high-strength joints with external diaphragm. I: Design and experimental validation. *Journal of Structural Engineering*, 143(5), 04017001.