THE ENGINEER'S RESPONSIBILITIES AND THE STRUCTURAL WELDING CODE

Duane K. Miller, Sc.D, P.E.

Duane K. Miller, Sc.D, P.E., is Manager of The Welding Technology Center The Lincoln Electric Company Cleveland, OH.

Introduction

"I specified the use of AWS D1.1 – what else do you expect me to do?"

"I don't know anything about welding – and I don't want to know anything about welding."

"Maybe I'm supposed to do something as it relates to welding, but I don't have the foggiest idea of what's right and wrong."

Perhaps in jest, maybe with a bit of intentional sarcasm, or perhaps with an honest expression of a heartfelt attitude, in one way or another, all of the preceding have been expressed by engineers working on projects involving the welding of structural steel. Regardless of a given engineer's level of experience with welding, the AWS D1.1 Structural Welding Code – Steel requires the engineer's interaction on a variety of fabrication and erection issues. This paper aims to identify examples of such instances, and to provide practical insights into the issues that need to be considered when addressing circumstances requiring the engineer's participation.

The need for the engineer's involvement in welding should not come as a surprise to anyone with even a casual knowledge of steel construction. Significant effort and resources are expended in determining structural systems and member sizes. However, in those few situations where failures occur, they inevitably involve connections, whether the connections be riveted, bolted, or welded. Rarely do failures occur within the main steel member itself, at a distance removed from the connection. Connections often involve significant changes in load paths. In other cases, connections are the points of highest load concentration. The method of making the connection may introduce stress concentrations. Welding introduces residual stresses, new materials (the deposited weld metal, as well as the heat-affected zones), and potential stress raisers. For all of these reasons, the engineer must become involved with certain aspects of welding in a structural steel system.

Codes and specifications, particularly in a mature industry such as steel construction, do a good job of addressing most routine applications. Codes, however, will never be able to address the issues arising from innovative designs that press the envelope of what was considered by the code writers. Moreover, the code writers identify a range of options that are applicable only when specified by the engineer, knowing that they are not justified in all applications. Only the engineer is in a position to understand the unique demands upon a new structure, and therefore, code writers, including those of AWS D1.1, rely upon these individuals to identify specific requirements for unique structures.

NORTH AMERICAN STEEL CONSTRUCTION CONFERENCE

Unfortunate Use of Terms

Most code users are familiar with provisions that "require the approval of the engineer" as well as those that are applicable "when specified by the engineer". Unfortunately, in D1.1, sometimes the wording describing the engineer's responsibilities is not as definitive as it should be.

The following are just a few examples in which the wording of D1.1 is weak or tentative when addressing the duties of the engineer:

- "[All provisions are applicable], except those that the engineer specifically modifies or exempts…" (1.1)
- "The engineer shall use" (2.39.2.1)
- "…performance shall otherwise be to the satisfaction of the engineer…" (6.27.2)
- "…provided the contractor demonstrates to the engineer … "(5.15.4.1)
- "…when requested by the engineer…" (5.3.1.1)
- "…shall be brought to the attention of the engineer…" (6.27.4)
- "…the engineer should evaluate …" (C 7.6.1)
- "The engineer may choose…" (C 5.15.4.3)

As the preceding examples illustrate, it is not sufficient to simply review the code for every mention of "specify" or "approve". A comprehensive understanding of the code is necessary in order to make certain that every interaction the code expects of the engineer is accomplished.

Fortunately, the D1 Structural Welding Committee has recognized the confusion that could result from the unfortunate choice of words and a systematic review of the entire code is underway. The goal is to create a more uniform pattern throughout the code, generally using the terms "when approved by the engineer"; or, "when specified by the engineer", depending on the nature of the provision.

THE ENGINEER'S INVOLVEMENT

The code invokes the engineer's involvement in the construction process in a variety of manners, but in general, the engineer's responsibilities can be placed into one of five categories as contained below:

1) The engineer establishes basic construction contract documents.
2) The engineer specifies that certain options in the code are to be applied to the project.
3) The engineer approves various aspects of the construction process.
4) The engineer evaluates and may approve alternatives submitted by the contractor .
5) The engineer addresses unexpected fabrication difficulties.

CONTRACT DOCUMENTS

The engineer is responsible for the creation of the general contract documents that will govern the fabrication and erection of a structure, and development of the documents that address welding-related issues is no different. The engineer has the latitude, and the responsibility, to add to the contract documents any provisions not addressed in the code, but necessary for the specific project.

Six major topics are required by D1.1 to be addressed in contract documents, as follows:

1) Complete and detailed drawings
2) Determination of whether the structure is statically or dynamically loaded
3) Inspection issues
4) Alternate acceptance criteria (if applicable)
5) Impact testing (if applicable)
6) Criteria for welding on existing structures (when applicable)

It should be noted that failure to specify some of the above issues results in a default condition that, depending on the application, may or may not be acceptable. When the engineer chooses not to address a specific area and the default condition results, the consequences must be understood.

Drawings

Drawings are one of the critical means by which important information relating to a specific project is communicated to the parties involved. This includes not only data that address the materials involved, sizes of members, length and locations of welds, etc., but also provides the opportunity to include notes that communicate detailed approaches to be used when fabricating the affected member(s).

Drawings, whether physically prepared by the engineer or by a detailer, or even when prepared by the contractor, are ultimately the engineer's responsibility and are a key ingredient in any successful project.

D1.1 has a specific subsection (2.2) entitled "Drawings" that details most of the requirements. Provision 2.2.1 requires that the drawings contain "full and complete information regarding location, type, size, and extent of all welds…" Field and shop welds are to be distinguished from each other. Provision 2.2.2 requires that weld joints requiring careful attention to welding sequence be so noted. Provisions 2.2.3 and 2.2.4 spell out specific requirements for different weld types; and 2.2.4.2 warns that just because a weld detail may be prequalified, this does not mean that such prequalified details are suitable for all applications. Specifically, it states that prequalified joints ". . .have repeatedly demonstrated their adequacy in providing the conditions and clearances necessary for depositing and fusing sound weld metal to base metal. However, the use of these details in prequalified WPSs shall not be interpreted as implying consideration to the effects of the welding process on material beyond the fusion boundary, or suitability for a given application." (Subsection 3.1 goes further and states that a prequalified joint detail should not be used without the application of engineering judgment).

Provision 2.2.4.3 requires that special joint details be shown on drawings, and special inspection applied to specific joints is required to be shown on the drawings per provision 2.2.5. Skewed T-joints are required to have special details outlined on the drawings according to provision 2.11.1. When cyclic loading is applied, subsection 2.21 states that the engineer ". . .shall provide either complete details, including weld sizes, or shall specify the planned cycle life and the maximum range of moments, shears, and reactions for the connections." While it is not specified that this must be incorporated into the design drawings, it is the normal convention to do so.

For tubular T-, Y-, or K- connections the "Z" loss dimensions (a function of the welding process, groove angle, and position of welding) are listed in Table 2.8. Provision 2.39.2.1 requires that "The engineer shall use [Figure 3.5] in conjunction with Table 2.8 to determine the minimum weld size in order to determine the maximum weld stress . . ."

For evaluating the suitability of specific joint details, whether prequalified or not, the commentary to provision 2.1.3 is especially helpful. Lamellar tearing in particular is discussed in great detail, providing valuable insight into preferred practices.

Static versus Cyclic Loading

D1.1 contains criteria for both statically and cyclically loaded members. Nowhere in the code is there a direct statement requiring the contract documents to specify whether the structure is statically or dynamically loaded, but there are provisions that imply this requirement. It is undebatable, however, that somehow this must be communicated to those involved in the construction process. Provision 2.1.1 requires that the "base-metal stresses shall not exceed those specified in the applicable design specifications." Provision 2.1.2 warns that any increase in allowable stress not be extended "to the stress ranges permitted for base metal or weld metal subject to cyclic loading." Since otherwise identical steel members can be applied to both statically and cyclically loaded applications, and yet the fabrication conditions are different, this detail must be communicated to the contractor; contract documents are the appropriate vehicle for this purpose.

Inspection

For those who think the engineer has no welding-related role in steel construction, consider this: when the engineer specifies nothing regarding inspection in the contract documents, all that he/she will get is visual inspection, performed by the contractor's inspector. There will be no nondestructive testing, no independent verification inspection – just the code-mandated visual inspection performed by (typically) an employee of the contractor.

Should the engineer subsequently elect to perform some nondestructive testing when it was not originally specified in the contract documents, then the owner "shall be responsible for all the associated costs including handling, surface preparation, nondestructive testing, and repair of the discontinuities at rates mutually agreeable between the owner and the contractor," according to provision 6.6.5. The only relief afforded the owner is that, "If such testing should disclose an attempt to defraud or gross nonconformance to this code, repair work shall be done at the contractor's expense." A much better situation exists if the engineer considers inspection issues where the contract documents are being created.

In provision 6.1.1, the code requires that nondestructive testing (NDT) requirements be stated in the bid documents, including the types of welds to be examined, the extent of examination, and the method or methods of testing. The code automatically requires fabrication/erection inspection, which are the responsibilities of the contractor unless the contract documents indicate otherwise. The engineer is obligated in 6.1.2.2 to determine whether verification inspection is required – the type of inspection that is independent of the contractor, and the results of which are reported to the engineer. Provision 6.1.2.2 permits the engineer to waive verification inspection, perform all inspection functions with the verification inspector, or use both fabrication/erection and verification inspection.

The code provides three bases for qualification of inspectors in provision 6.1.4.1, which also states that, "If the engineer elects to specify the basis of inspector qualification, then it shall be so stated in contract documents." Provision 6.1.4.5 authorizes the engineer to verify the qualification of inspectors.

As previously mentioned in the section on drawings, provision 2.2.5 requires "any special inspection requirements" to be noted on the drawings or in the specifications.

When the engineer specifies radiographic inspection (RT), he/she may need to approve alternate locations for image quality indicators (IQIs) [Figures 6.11 - 6.14 and C6.17.7] , as well as alternate radiographic sources (C6.17.6).

Ultrasonic inspection (UT), when specified by the engineer, raises a number of opportunities for the engineer's involvement. For example, annex "K" contains alternate techniques for UT of welds, but the use of the annex procedures is subject to approval by the engineer. Annex "K" allows for inspection of welds beyond the conditions stated in part "F" of Section 6, and includes variations such as other weld geometries, transducer sizes, frequencies, couplants, painted surfaces, and testing techniques, but such variations must be approved of in the contract documents, according to 6.20.2.

For T-, K-, and Y- tubular connections, and when such joints are to be ultrasonically inspected, provision 6.27.1 requires that, "Prior to use on production welds, the procedure and acceptance criteria shall be approved by the engineer . . . " The acceptance criteria for all tubular connections is to be identified in the contract documents, according to provision 6.13.3.

Part G of Section 6 deals with "other examination methods," permitting the use of less conventional nondestructive testing methodologies. Subsection 6.34 requires that all NDT methods in part G have "specific written approval of the engineer." The code recognizes radiation imaging systems, including real-time imaging, and such NDT may be used when so approved by the engineer, in conformance with provision 6.35.1. Provision 6.35.2 outlines twelve specific essential variables that are to be addressed in the written procedures. The specifics of many of the nondestructive testing techniques may be quite foreign to the typical Structural engineer, but the independent testing laboratories that commonly are charged with executing these assignments are usually highly cognizant of these details and can provide the necessary help for such situations. Reliance on these other experts, however, should not obscure the relative roles of the engineer and the inspector.

Alternate Acceptance Criteria

D1.1 is a workmanship standard, not a fitness-for-service document. This attitude is conveyed in the Commentary where C5.1 states "The criteria contained in Section 5, are intended to provide definition to the producer, supervisor, engineer and welder of what constitutes good workmanship during fabrication and erection." This is further amplified upon in C6.8, which says, "The criteria in section 5 should not be considered as a boundary of suitability for service. Suitability for service analysis would lead to widely varying workmanship criteria unsuitable for a standard code." The code does permit the engineer to specify alternate acceptance criteria (provision 6.8), providing they are "suitably documented by the proposer and approved by the engineer." The proposer could be the engineer, and this can be specified in the contract documents. As will be discussed later, the proposer could be the contractor, in which case the engineer would be called upon to evaluated and approve the suitability of the alternate criteria.

The alternate criteria can be either more or less demanding than the standard criteria in the code. More demanding criteria may be important for new and unproven designs, higher strength materials, extremely thick material, very rigid structures, extreme operating temperatures, high loading conditions, applications involving little redundancy, and other factors. Conversely, well understood applications with a long history of satisfactory performance may be instances where the engineer would use the option of 6.8 to permit less rigorous acceptance criteria, providing their use can be justified.

Impact Testing

Provision 4.1.1.3 states: "When required by contract documents or specifications, impact tests shall be included in the WPS qualification. The impact tests, requirements, and procedures shall be in conformance with the provisions of Annex III, or as specified in the contract documents." Annex III contains a variety of details regarding the location of the Charpy impact testing specimen, the number of required specimens, the procedures of retests and other details. What is not contained therein, however, is the testing temperature or the minimum average energy level. Annex III 1.3 makes this the responsibility of the engineer. Also, the engineer is to "consider the effects of welding position as it may relate to heat input on the heat-affected zone (HAZ) test results…."

The role of impact properties, fracture toughness, and the requirements for minimum specification of properties as they relate to these issues is beyond the scope of this paper. Excellent references are available that address the complex issues involved. (2.) However, the engineer must understand that, when no impact requirements are specified in contract documents, there is no minimum level of notch toughness that can be assumed for the weld metal, heat-affected zone, or the base metal.

Welding on Existing Structures

When one is strengthening and repairing an existing structure, the number of situations that conceivably could be encountered is practically endless. Thus, it is impossible for any code to provide specific requirements applicable to every situation that could arise. D1.1 Section 8 is devoted to the subject of welding on existing structures, and so issues requiring the engineer's involvement are concentrated in this section for this topic. The specific plans drawn up by the engineer constitute the means by which the code writers have addressed these situations.

D1.1 Section 8 obligates the engineer to prepare "a comprehensive plan for the work", with plans that include "but are not limited to, design, workmanship, inspection, and documentation" (8.1). The base metal type used in the original structure is to be determined before drawings and specifications are developed (8.2.1), and the suitability of welding of the base metal is to be established (8.2.2). For base metals other than those that are prequalified and listed in Table 3.1, "Special consideration by the engineer must be given to the selection of filler metal and WPSs" (8.2.3).

Provision 8.3.5 requires that, "The engineer shall determine the extent to which a member will be permitted to carry loads while heating, welding, or thermal cutting is performed."

If fatigue life enhancement is required, provision 8.4.1 identifies methods that can be used, when approved by the engineer. The engineer is obligated to determine appropriate increases in the allowable stress range, according to 8.4.2. When members are to be "heat straightened", the provisions of 8.5.5 apply; and, additionally, 8.5.2 requires the engineer to determine whether unacceptable discontinuities are to be repaired prior to heat straightening or welding.

Visual inspection is required for the work performed to strengthen or repair a structure, in accordance with provision 8.6.1. However, such visual inspection is also subject to conforming with the "engineer's comprehensive plan." Nondestructive testing criteria are required to be specified in contract documents as well (8.6.2).

Strengthening existing structures is a challenge. Repairing damaged structures is an even greater challenge. Performing such procedures on structures with materials that were not welded in the first place compounds the problem further. Under such circumstances, the engineer should seek out the experts with experience in this particular field. These unique situations are prime examples of circumstances that codes cannot be expected to address sufficiently. Job-specific specifications need to be developed by the engineer in order to address these unique circumstances.

OPTIONS TO BE ORDERED BY THE ENGINEER

The code tries to provide general requirements that are applicable to most situations. There are other conditions that are made available as "options" to the engineer, fully described, but not made universally applicable. Rather, the code relies upon the engineer to determine when these options should be specified for a specific application. Such specification is typically done in the contract documents.

1) Options that the engineer may specify fit into four categories:
2) Structural details
3) Certifications for welding materials
4) Qualification of weld details
5) Stud welding activities

Structural Details

There are a variety of structural details that the engineer may elect to require for a specific project. What is an acceptable detail for one type of structure may not be acceptable for another. The type of loading may be a major factor in determining such acceptability. The engineer must evaluate these details and the structural requirements and order the optional details appropriate for the specific application.

Provision 5.18.1 requires that temporary welds be made to the same quality criteria as final welds. Even though the quality should be the same as a final weld, when the engineer so requires, the temporary welds are to be removed. Conversely, when the engineer does not require their removal, they may remain in place except as follows: "for cyclically-loaded non-tubular connections, there shall be no temporary welds in tension zones or members made of quenched-and-tempered steels except at locations more than 1/6 of the depth of the web from tension flanges of beams or girders…" For architecturally exposed steel, or for other conditions of dynamic loading, such temporary welds may be unacceptable. In such circumstances, the engineer can specify their removal.

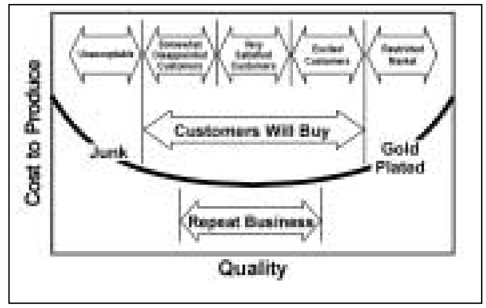

Figure 1

Tack welds are to be incorporated into the final welds. Provision 5.18.2.3 requires that tack welds not incorporated into the final welds be removed. This provision, however, does not apply to statically loaded structures, unless required by the engineer. Without the engineer's involvement, therefore, tack welds need not be incorporated, and they need not be removed from statically loaded structures. This may be undesirable for architecturally exposed steel, and may not be considered a conservative approach for higher-strength steels.

There are no secondary members in welded design, and therefore, attachments such as steel backing may affect the performance of the overall structure. Provision 5.10.4 requires the removal of backing from joints that are transverse to the direction of computed stress, but permits steel backing of welds that are parallel to the direction of stress to stay in place, unless their removal is specified by the engineer (5.10.4). Additionally, the longitudinal welds that attach backing are required to be welded full length for cyclically-loaded structures, but for statically-loaded structures, provision 5.10.5 permits intermittent welds, and allows all the backing to stay in place, regardless of the direction of loading, unless required to be removed by the engineer.

Weld tabs permit groove welds to be made in a manner that will ensure weld soundness to the end of the joint.

Provision 5.31.2 permits weld tabs to remain in place (and this is typical practice) unless the engineer requires them to be removed. Aesthetics may dictate their removal, and AISC requires the removal of weld tabs from jumbo section splices (AISC LRFD J15). When removal is required as in these examples, D1.1 stipulates that the engineer must specify it.

Certification of Materials

If the engineer desires certification of certain welding materials, these must be requested. This would include welding filler materials (5.3.1.1), welding shielding gas (5.3.1.3), and welding stud certification (7.3.3).

Qualification of Welding Joints

The weld throat in a flair groove weld is dependent upon the actual groove geometry and the welding procedures employed. As such, provision 4.10.5 permits the engineer to order tests that are used to verify that the required weld throat is consistently obtained. The engineer must specify the extent of testing, the sizes of members involved, etc.

Stud Welding Operations

The engineer has a variety of options with regard to stud welding. Provision 7.3.5 allows the engineer to select the studs that will be used for testing. The studs are supplied at the contractor's expense, although the testing is done at the owner's expense. Regarding stud bases, 7.2.4 permits the engineer to request descriptive information on the stud and arc shield, certification from the stud manufacturer regarding the stud base qualification, and qualification test data. In all of these situations, the engineer must evaluate the option's significance and relative applicability to a specific project. There is generally some degree of cost associated with these activities, and therefore, the Committee has not chosen to make them universally applicable. It is the engineer's obligation to determine when and where such options should be applied.

APPROVALS

The engineer is required to make a significant number of evaluations of alternatives that the code permits. These are generally in response to requests by the contractor. Issues that require the engineer's approval are concentrated in D1.1 Section 5, although such items are dispersed throughout the code. The relative suitability of these various alternatives must be considered by the engineer, always with an eye to whether the alternatives being sought will permit the structure to perform in its intended manner.

Approval or denial of these alternatives may significantly affect the contractor's cost. Not knowing whether an alternative will be approved or not places a contractor in a difficult position during the bidding process. To eliminate this risk, some contractors will submit bids contingent upon approval of certain code-permitted alternatives that are subject to the engineer's approval. In accepting the bid, the engineer agrees to also approve such alternatives. If the contract is modified later, the contractor is then in a position to renegotiate the financial aspects of the project.

Sometimes, after the contract is let, cost-saving alternatives are identified which still require the engineer's approval. In order to make the situation into a 'win-win' proposition, "value-engineering" can be applied, and the savings divided between the contractor and the owner. Regardless of any possible financial incentives, the integrity of the project cannot be sacrificed.

In most situations, the contractor makes the request to the engineer to approve an alternative. When the option is not granted, a default position exists and the project can progress accordingly, utilizing the standard practice identified in the code.

There is one known exception to the general pattern where the default position exists: provision 4.1.1 requires the engineer to approve WPSs that have been qualified by test, and if the WPSs are not approved, there is no default status presented in the code. Provision 4.1.1 clearly states that this is applicable to WPSs that are qualified by test, and a similar, clear-cut statement cannot be found in Section 3 regarding welding procedures that are prequalified. This topic has been previously discussed (see Funderburk & Miller, 1998) and further details are beyond the scope of this paper. In this situation, the engineer must approve the WPS qualified by test in order for welding to begin.

When the engineer is called upon to approve a request made by the contractor, it typically fits into one of the following general categories:

1) New materials and processes not covered by the code.
2) Routine items that are generally approved but should be critiqued for anomalies.
3) Practices that need careful review to make certain they are appropriate for the application.
4) Practices that may or may not be acceptable, depending on the specific application.

New Materials and Processes

The code provides for methods of allowing new welding and cutting processes, new base metals and new filler metals. New developments will always precede code changes that reflect such advances. If such provisions did not exist, progress would be impeded as innovations are put "on-hold," waiting for incorporation into the governing specifications.

The code lists welding processes that may be used for prequalified WPSs, as well as welding processes that may be used for construction under the code. The code further extends the opportunity for the use of other welding processes, when the engineer (3.2.3, 4.15.2) approves these other methods. Alternate processes could involve a variety of new or different controls that need to be monitored, and the evaluation of such variables is part of the alternate process approval activity.

The code approves specific thermal cutting processes including electric arc cutting and gouging, and oxyfuel cutting. Provision 5.15.4.1 permits other thermal processes to be used for cutting, provided the engineer approves the method.

The code lists various base metals that can be used for construction, but materials that are not listed in Table 3.1 or Annex M can be used if the WPSs are qualified by test, and are approved by the engineer (4.7.3).

Routine Items

While nothing should be viewed as truly routine, the code contains some provisions that are generally accepted by engineers for most projects, and these have been placed into this category.

All welders, welding operators, and tack welders who perform work governed by the code must be qualified by test as prescribed in the code. In most situations, contractors will have previously qualified their work force in other projects, and the code extends to the engineer the option of approving the use of previous personnel qualification tests, eliminating the need for retesting (4.1.2.1).

The engineer's involvement in approving the qualifications of personnel goes beyond welders, and includes inspectors (6.1.4.5).

Stud welding is covered in Section 7 of the code, and there are a number of situations where the engineer may become involved. Provision 7.2.1 permits alternate stud head configurations, when approved by the engineer. Provision 7.3.4 permits the use of studs that do not have quality control tests provided the manufacturer of the studs performs mechanical tests. The engineer is to determine the number of tests to be performed. To prove the suitability of stud welding procedures, "bend tests" are performed and often can be used in the bent condition. When straightening is required, provision 7.8.3 requires that it be done without heating, except as otherwise provided in the contract, and as approved by the engineer.

When performing reduced section tension tests, and when the steels involved are high strength, some tensile testing machines may be incapable of pulling the high strength specimen to destruction. Under these conditions, Figure 4.14, Note 8, permits changes to the specimen dimensions when "agreed upon by the engineer and the fabricator."

Practices Requiring Careful Review

The following options need careful review since the test data that is required to support these alternatives may not be applicable to the specific project involved. In other words, the tests may accurately demonstrate the capability of a concept to work under test conditions, and yet it may not perform under actual fabrication conditions. This warning should not cause the engineer to automatically reject such options. Rather, they need to be carefully reviewed, with the assistance of a consulting expert if necessary, to ensure the expected results will be achieved.

According to provision 4.1.1.2, the engineer can accept welding procedures that have been previously qualified, and can also approve the use of standard welding procedures as published in AWS B2.1.XXX-XX. In most cases, the acceptance of previously qualified welding procedures is a routine practice, providing that these WPSs have the proper documentation, and are applicable to the proposed work. The use of standard welding procedures, a new provision in D1.1-2000, can be reviewed with the same scrutiny, except that the supporting PQRs would not be available to the engineer for review. However, the AWS B2 Committee has performed this task already, simplifying the process, and perhaps adding another level of assurance to the sequence.

Preheat for welding is an essential variable of a WPS, and the code provides minimum levels of preheat for prequalified WPSs. The code extends the option of reduced preheats, based upon the use of Annex XI; or, for SAW welding,when hardness checks are made in the HAZ. Also, WPSs could be qualified by test with a reduced preheat. In all three of these cases, the engineer must approve the reduced preheat before it can be used in production (3.5.2, 3.5.3, 4.1.1).

The required level of preheat for a project is a function of many variables, including the actual composition of the steel being used, the degree of restraint, and the hydrogen content of the deposited weld metal. These conditions may not be replicated under testing conditions. Restraint is almost never replicated with small test specimens, and the engineer should carefully review supporting data for the reduced preheats in order to make certain that the tests adequately represent the conditions that will be encountered in production.

Alternate acceptance criteria, previously discussed above under "Contract Documents," may also fit into the approval category when someone other than the engineer proposes the alternate criteria. Such options are addressed in subsection 6.8, and provision 6.5.5. The code makes such alternate criteria acceptable, providing that certain stipulations are met, and that the engineer approves of the alternative.

Table 6.1
Visual Inspection Acceptance Criteria[1] (see 6.9)

Discontinuity Category and Inspection Criteria	Statically Loaded Nontubular Connections	Cyclically Loaded Nontubular Connections	Tubular Connections (All Loads)
(1) Crack Prohibition Any crack is unacceptable, regardless of size or location.	X	X	X
(2) Weld/Base-Metal Fusion Thorough fusion shall exist between adjacent layers of weld metal and between weld metal and base metal.	X	X	X
(3) Crater Cross Section All craters shall be filled to provide the specified weld size, except for the ends of intermittent fillet welds outside of their effective length.	X	X	X
(4) Weld Profiles Weld profiles shall be in conformance with 5.24.	X	X	X
(5) Time of Inspection Visual inspection of welds in all steels may begin immediately after the completed welds have cooled to ambient temperature. Acceptance criteria for ASTM A 514, A 517, and A 709 Grade 100 and 100 W steels shall be based on visual inspection performed not less than 48 hours after completion of the weld.	X	X	X
(6) Undersized Welds The size of a fillet weld in any continuous weld may be less than the specified nominal size (L) without correction by the following amounts (U): L, specified nominal weld size, in. (mm) — U, allowable decrease from L, in. (mm) ≤ 3/16 (5) — ≤ 1/16 (2) 1/4 (6) — ≤ 3/32 (2.5) ≥ 5/16 (8) — ≤ 1/8 (3) In all cases, the undersize portion of the weld shall not exceed 10% of the weld length. On web-to-flange welds on girders, no underrun is permitted at the ends for a length equal to twice the width of the flange.	X	X	X
(7) Undercut (A) For material less than 1 in. (25 mm) thick, undercut shall not exceed 1/32 in. (1 mm), except that a maximum 1/16 in. (2 mm) is permitted for an accumulated length of 2 in. (50 mm) in any 12 in. (300 mm). For material equal to or greater than 1 in. thick, undercut shall not exceed 1/16 in. (2 mm) for any length of weld.	X		
(B) In primary members, undercut shall be no more than 0.01 in. (0.25 mm) deep when the weld is transverse to tensile stress under any design loading condition. Undercut shall be no more than 1/32 in. (1 mm) deep for all other cases.		X	X
(8) Porosity (A) Complete joint penetration groove welds in butt joints transverse to the direction of computed tensile stress shall have no visible piping porosity. For all other groove welds and for fillet welds, the sum of the visible piping porosity 1/32 in. (1 mm) or greater in diameter shall not exceed 3/8 in. (10 mm) in any linear inch of weld and shall not exceed 3/4 in. (20 mm) in any 12 in. (300 mm) length of weld.	X		
(B) The frequency of piping porosity in fillet welds shall not exceed one in each 4 in. (100 mm) of weld length and the maximum diameter shall not exceed 3/32 in. (2.5 mm). Exception: for fillet welds connecting stiffeners to web, the sum of the diameters of piping porosity shall not exceed 3/8 in. (10 mm) in any linear inch of weld and shall not exceed 3/4 in. (20 mm) in any 12 in. (300 mm) length of weld.		X	X
(C) Complete joint penetration groove welds in butt joints transverse to the direction of computed tensile stress shall have no piping porosity. For all other groove welds, the frequency of piping porosity shall not exceed one in 4 in. (100 mm) of length and the maximum diameter shall not exceed 3/32 in. (2.5 mm).		X	X

1. An "X" indicates applicability for the connection type; a shaded area indicates non-applicability.

Table 6.1. Reprinted with permission of the American Welding Society, from AWS D1.1: 2000, Structural Welding Code-Steel.

Practices That May or May Not Be Acceptable

The acceptability of application-specific provisions may depend on the structure, loading, specific location within the structure, or other factors. It is not a matter of "good practice" or "bad practice," but rather, what is right for the particular conditions involved.

Specific roughness requirements for various thermal cuts are outlined in 5.15.4.3, and gouges that exceed those limits can be repaired under the provisions of 5.15.4.4, which ends by stating "In thermal-cut surfaces, occasional notches or gouges may, with approval of the engineer, be repaired by welding." The commentary applied to these provisions specifically addresses the topic of "occasional notches and gouges" by stating that the Committee "refrained from assigning any numerical values on the assumption that the engineer, being the one most familiar with the specific conditions of this structure – will be a better judge of what is acceptable. The engineer may choose to establish the acceptance criteria for occasional notches and gouges."

Caulking involves the mechanical, plastic deformation of weld metal and base metal and historically has been prohibited by the code since it can be used to fraudulently mask weld discontinuities. D1.1:2000 was changed to permit caulking under certain conditions because it may prevent failure of various coatings that are subsequently applied. Weld inspection must be completed prior to the caulking treatment, and "the technique and limitations on caulking are [to be] approved by the engineer" (5.28).

s various base metals that can be used for construction, but materials that are not listed in Table 3.1 or Annex M can be used if the WPSs are qualified by test, and are approved by the engineer (4.7.3).

Provision 6.5.6 requires the inspector to identify parts that have been inspected and accepted, but the method of identification is not defined. However, "die stamping" cannot be used on cyclically loaded members, unless approved by the engineer.

Provision 5.21.3 requires a distortion control plan where "excessive shrinkage or distortion can be expected." The plan is to be submitted to the engineer ". . . for information and comment" before welding is performed on the member in which the excessive shrinkage or distortion is expected. The code provides no "default" position for the condition when the engineer does not supply comments, nor is there a code-defined timeframe, or method for communication of such comments.

In addition to ascertaining that all required welds have been placed in the proper location and are of the required size and length, provision 6.5.1 requires that the inspector check to make certain "that no unspecified welds have been added without approval." While a citation to the engineer is not made, 1.2 states that "the need for approval shall be interpreted to mean approval by the building commissioner or the engineer."

Weld tabs are required by 6.17.3.1 to be removed prior to radiographic inspection unless otherwise specified by the engineer.

For cyclically loaded structures, thermal cutting is to be done in a mechanized or automatic manner unless the engineer approves of free-hand thermal cutting 5.15.4.2).

UNEXPECTED CIRCUMSTANCES

Irregularities that may occur during a project often present undesirable circumstances for both the contractor and the engineer, but they must be resolved in order for the project to move ahead. Time is of the essence, since while the engineer is evaluating such situations, projects are typically put on hold, resulting in delays. Unlike situations in which the code has provided a default alternative, these circumstances require the engineer to act. Efforts at mutual cooperation on the part of the contractor and the engineer will facilitate progress in difficult circumstances.

When unexpected construction difficulties arise, and when such difficulties are potentially significant to the project and the performance of the structure, it is important for the engineer to obtain the necessary technical guidance in order to perform the code-mandated obligations. This expertise frequently comes from consultants who have unique expertise in dealing with such problems.

Unexpected issues requiring the engineer's involvement fit into these categories:

1) Base metal discontinuities
2) Fit-up and alignment problems
3) Welding problems
4) Post-welding corrections

Base Metal Problems

During fabrication and erection, discontinuities in base metals may be detected. The shrinkage stresses induced by welding are significant, and cracking or lamellar tearing may result. Cutting of plates or shapes may expose internal discontinuities within the base metals. Such discontinuities may or may not affect the performance of the final structure, and as such, the code requires the engineer to evaluate any non-routine imperfections in the base metal.

Provision 5.15.1 permits removal and repair of mill-induced discontinuities on the surface of the material. The discontinuity is required to be removed and all welded repairs are required to be done in accordance to the code. The total length of repair welding may not exceed 20% of the length of the plate surface being repaired, except with the approval of the engineer. For edge discontinuities that are discovered on cut material, provision 5.15.1.1 provides specific levels of acceptability and repair practices. If these limits are exceeded, the part "shall be rejected and replaced, or repaired at the discretion of the engineer."

During weld inspection, discontinuities in the base material may be observed. Provision 6.20.4 deals with UT inspection and requires that base metal discontinuities such as cracking, lamellar tearing and delaminations that are discovered adjacent to the weld be reported to the engineer for disposition. For UT inspection of T-, Y-, and K- connections in tubular steel, base metal discontinuities detected are required to be "brought to the attention of the engineer or inspector."

Fit-up and Alignment Problems

When steel is assembled, fit-up between adjacent members may not be what was expected on the drawings. Such misalignment may be the result of poor workmanship. It can also result from the accumulation of acceptable tolerance variations, whether in the as received materials, or in the fabricated pieces, resulting in dimensions that exceed code limits. Such variations may have no effect on the final structures behavior, but in other situations, such differences may be critical. The engineer must make this evaluation.

Provision 5.22.3.1 provides specific girth weld alignment requirements for tubular members; additional tolerance relief is available for this alignment, when approved by the engineer. Specific acceptable tolerances for groove weld root openings are given in provision 5.22.4.3. If these tolerances are exceeded, they may be corrected by welding, but only when approved by the engineer (5.22.4.4).

Welding Problems

A crack in a weld, or in the adjacent base metal, is a very serious issue that needs to be addressed. The causes or implications of such cracking need to be understood, and the potential impact on the structure evaluated. When major cracking occurs, the engineer is to be notified so such an evaluation can take place.

When base metal is damaged because of faulty welding, or when the base material is damaged by removal of faulty welds for re-welding, and the base metal is no longer "in accordance with the intent of the contract documents, the contractor shall remove and replace the damaged base metal or shall compensate for the deficiency in a manner approved by the engineer" (6.6.3).

Provision 5.26.3 requires the engineer's approval for "repairs to base metal . . . repairs of major or delayed cracks, repairs to electroslag and electrogas welds with internal defects, or for a revised design to compensate for deficiencies." This provision is in place because such defects can have a major impact on the performance of the structure and the repair techniques to deal with such problems may be complex in and of themselves.

When electroslag welding is performed, and if the welding is inadvertently stopped, and then restarted, such restarts are required by Provision 5.4.4 to be reported to the engineer. Other criteria apply to these conditions as well, including radiographic inspection.

When unacceptable welds are made, and further work is performed which makes access to the original defective weld impossible, a plan must be established to address the problems. If the members are not cut apart in order to gain access to the original weld, the deficiency in the original weld "shall be compensated for by additional work performed according to an approved, revised design" (5.26.4). The engineer is responsible for this approval, consistent with subsection 1.2.

Post-Welding Corrections

Before steel is cut apart for any reason, 5.26.3 requires that the engineer be notified. This is particularly important for structures during the erection stage, since the member being cut may be performing critical load-bearing functions at that time.

When holes are mislocated, provision 5.26.5 provides a detailed sequence that must be followed. The engineer must approve such procedures when the base metal is subject to cyclic loading. In many cases, it is preferred to leave the mislocated hole in place since welding under these conditions frequently introduces weld defects that may be more harmful than the hole itself.

When camber is incorrect on a built-up member, heat straightening can be applied in order to correct for camber variations. Provision 5.19.1 permits such adjustments, but 5.19.2 requires that any corrections in the camber of quenched-and-tempered steel members be done only with the approval of the engineer.

Provision 5.26.2 prescribes the temperature limits for heat straightening, and quenched-and-tempered steels have a lower approved temperature limit (1100ºF) than other steels (1200°F). This requires more careful monitoring of the steel and thus requires the engineer's involvement.

Conclusion

As the preceding has demonstrated, there are a host of situations that may require the engineer to become involved with the construction process as it relates to welding. This involvement can range from nearly routine events to major unexpected occurrences with potentially monumental consequences. The Structural Welding Code relies upon the engineer to use engineering judgment in determining how specific issues are to be addressed for individual applications. Particularly challenging circumstances may dictate that the engineer consult with experts in the field in order to properly evaluate the situation and determine the correct course of action to follow.

DISCLAIMER

An attempt was made to comprehensively identify circumstances cited within AWS D1.1-2000 where the engineer is required to interact in the fabrication and erection processes that relate to welding. It is possible and even probable that provisions have been missed. The author welcomes feedback regarding items that may have been missed, and also strongly encourages the user of this information to perform his/her own independent review of the entire code to address all the issues that may be applicable to a specific project. While the author is a member of the AWS D1 Committee, opinions and views expressed in this article are his alone, and not those of the AWS D1 Structural Welding Committee.

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