2001 T. R. Higgins Lecture: Creating Quality with Visual Inspection

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Dr. Miller earned a B.S. degree in Welding Engineering from LeTourneau University in Longview, Texas, an M.S. in Materials Engineering from the University of Wisconsin - Milwaukee, and was awarded a Doctor of Science degree from LeTourneau University in 1997. An AWS member since he was 19, he currently serves as Second Vice Chair of the AWS D1 Structural Welding Code Committee and Chair of the Seismic Welding Subcommittee. He is a former co-chair of the AASHTO-AWS D1.5 Bridge Welding Code Committee, a member of the AISC Specification Committee, a Professional Engineer, Certified Welding Inspector and Certified Welder. He is a member of Tau Beta Pi, Sigma Xi, LeTourneau University's Gold Key Club, and NSPE.

Summary

Welding is a process and the result of that process is a weld. To ensure weld quality, it is essential that the welding process be controlled. Visual inspection too often considered only after a weld is complete when, in contrast, the AWS D1.1 Structural Welding Code-Steel requires a variety of in-process visual inspections that must be performed before, during and after welding. Pre-welding inspections include a review of the Welding Procedure Specifications (WPSs), review of the materials to be used, the welder's certifications, the equipment to be used, and other issues. Immediately before welding, joint fit-up should be examined, joint cleanliness assured, and the preheat measured. During welding, the techniques of the welders can be observed, welding parameters measured, and interpass temperature measured. Once the weld is completed, and the part is cool, post weld inspection can occur, assuming there is no minimum delay period required due to concerns of delayed cracking. D1.1 provisions are explained, the consequences of nonconformance identified, and practical methods of ensuring compliance are presented. The additional requirements for specialized applications such as tension splices in jumbo sections and the new FEMA/SAC requirements for seismic applications are reviewed as related to the topic of visual inspection.

CREATING QUALITY WITH VISUAL INSPECTION

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THE QUALITY CURVE

Fifty years ago, conventional industrial wisdom claimed that "Cost increases with quality."(1.) Production was king. Make it fast, make it cheap and, if there's a bad one or two, find them by inspection. Rework the bad, or, better yet, pitch 'em. After all, our production is so efficient that it's hardly worth the effort to rework the product. That was the accepted view in American industry during the 1950s.

The "production is King" view of the 50's fell into disfavor, because this approach of achieving a quality product carried the price of more meticulous inspection, resulting in more rejects, and ultimately leading to the use of costlier materials and processes. And the entire bad product couldn't be found, resulting in dissatisfied customers.

In the 1990s, the rise of total quality management led to the axiom that "cost decreases with quality,"(2.) based on the theory that doing something right the first time will lead to the lowest overall cost while achieving the quality objectives.

It seems evident now that both statements are correct. *Cost both increases and decreases with quality.* If that is the case, how do we provide our customers with the quality they demand, at a price they are willing to pay?

On the quality continuum, we have everything from junk that nobody wants, to what I call "gold-plated" products that very few people are willing to pay for. The quality products or services reside in middle, where the customers range from somewhat satisfied to very excited (see Figure 1). These folks represent that all-important phenomenon: Repeat Business.

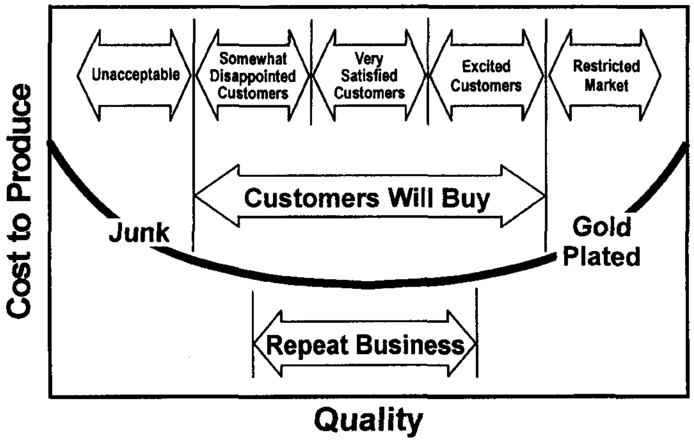

Figure 1

Management expert W. Edwards Deming calls this the "Chain Reaction" (3.). Improved quality leads to decreased costs due to less rework, fewer mistakes, fewer delays, better use of machine time and material. This in turn leads to improved productivity and a greater ability to capture the market with better quality and lower prices. Businesses then stay in business, and can provide jobs.

James F. Lincoln put it this way: "It is the job of the Lincoln Electric Company to give its customers more and more of a better product at a lower and lower price." (4.)

Repeat business results from customers who find value in the product they purchase, and are satisfied, or better yet, even excited about the quality of the goods and services they receive. In any business, there will be product variation. The fortunate customers who receive "better than average" products will be excited. The unfortunate ones who receive products and services that are below average will be disappointed. Minimizing variation in processes is the key to delivering products and services that will consistently meet customer expectations.

It is evident that creating Repeat Business entails reducing variations in quality, and this may or may not bear any relation to "meeting specifications." Deming and many others have pointed out the futility of sticking to the specs, which implies that anything that falls within the specifications is therefore sacrosanct, while anything that falls outside them is automatically wrong. Hopp and Spearman speak to this issue in *Factory Physics,* when they note: ".. .as the manufacturing boom of the 1950s and 1960s turned into the manufacturing bust of the 1970s and 1980s, it became plain that something was wrong....Because American goods were the envy of the world, firms could largely dictate the quality specifications of their products, and managers learned to take quality for granted." (5.) Specifications must reflect customer desires and wants. To better satisfy customers, the "bar must be raised," setting higher specifications, in order to meet and exceed customer's expectations.

The relevant approach is to examine and correct the six major factors that can cause variation in a business practice, as cited by the Six Sigma system and sometimes referred to as the 5M's and a P:

- *Material*—the consumables or raw inputs that are used in the process
- *Method*—procedures, processes, work instructions
- *Machine*—equipment, including computers and non-consumable tools
- *Measures*—techniques used for assessing the quality/quantity of the work, including inspection
- *Mother Nature*—the environment in which the work is done, or which affects any of the other variables; may include 'facilities,' not just the natural environment
- *People*—bipedal primates native to most continents on earth; reportedly show signs of intelligence (6.)

In order to improve our business processes, each of these six major factors need to be considered, and variability within each factor reduced. As processes are improved, the products and services produced by these processes will be more robust and less variable, more centered around customer needs. This starts the Deming chain reaction. "The old way: Inspect bad quality out. The new way: Build good quality in," declares Deming.(7.) Sure. But how?

I'd like to suggest a simple technique that will take us a long way: "Look at what you're doing." If designers, line workers, assemblers and packagers visually inspect their product, before, during, and after their work on it, quality will be vastly improved at very minimal cost. In-process inspection is also the quickest and most accurate route to process improvement.

A POWERFUL TOOL

In my field of welding, visual inspection is one of the most powerful tools that can be employed to ensure weld quality. The more technologically sophisticated nondestructive processes, such as ultrasonic or radiographic inspection, can only verify that the desired quality is present once welding is complete. That means rejects or rework, and both precipitously raise costs. Effective visual inspection examines each step of the welding process, well before the weld is completed. According to A. M. Gresnigt of Delft University, the Netherlands, "Most serious failures in performance are due to gross error; e.g., wrong consumables or omission of preheat, and not minor non-compliances."(8.) Such "gross errors" are the types of problems that can be detected by effective, in-process inspection.

Everyone involved in a welding project can—and should—participate in in-process visual inspection, including the welders, inspectors, foremen, etc. Minor discontinuities can be detected and corrected during the fabrication process, precluding the need for more expensive and complicated repair after the fabrication is complete. In order to be effective, visual inspection must take place *prior to, during,* and *after* welding.

"Steak Dinner" Analogy

To understand how visual inspection can be utilized to improve quality, consider the approach used in the restaurant industry. A sizzling steak is delivered on a plate, accented by appropriate side dishes and garnish. The customer applies a visual inspection to satisfy his/her desire for a high-quality meal. Dirty dishes, burned edges on the meat, and inappropriate sizing of portions would detract from an image of quality. It is also important to note that the steak is complete; that is, a test portion of the steak has not been removed for examination in the kitchen. It is strange to even consider the notion that a wedge of meat might be removed for inspection or testing. The steak has not received either nondestructive or destructive testing. Rather, the process of creating the dinner has been carefully controlled by regular visual inspections at each step in the preparation.

Examining the process in total, the dinner starts with meat that has been graded by a suitable government agency. The kitchen facility has been approved by the Board of Health. The chef has appropriate training and credentials. The recipe has been taste-tested and time-proven. All the ingredients involved with the meal are suitably controlled, with the proper amount of each added at the proper time. The temperature of the broiler, and the amount of time the beef will be cooked, are both carefully controlled and regularly verified. The finished product is visually inspected by the chef, the waiter, and finally by the consumer. Without visual inspection, most people would be unable to detect a poorly prepared piece of meat before tasting it. However, thanks to the application of visual inspection throughout the process, the desired results are achieved.

Inspecting the Welding Process

The same approach can be used in welding because, like cooking, welding is a process. The fabrication shop or erector is routinely inspected and approved by some outside agency such as the AISC Shop Certification Program or the AISC Erector Certification Program. The steels employed are governed by agencies such as ASTM, and the Mill Test Reports ensure product integrity. Welders are required to pass operator qualification tests to verify their ability. Just like restaurant chefs, they are trained to carry out specific operations. The welding procedure specification (WPS) is analogous to a recipe. The WPS sets forth specific welding parameters, including preheat and interpass temperatures, wire feed speeds, voltage used, travel speeds, etc. Finally, the completed welds are required to be visually inspected. With the major exception of gas metal arc/short arc transfer, visually acceptable welds routinely exhibit the required quality for their application.

Over the years, welding has been described as both an art and a science. While it is both, there has been a disproportionate emphasis on the art of welding. Welding is a complex science involving the interaction of many disciplines. Nevertheless, the welding process is subject to certain physical and chemical laws that allow it to be controlled and the results predicted.

The quality of a completed weld is predictable *providing the input variables are known.* Unfortunately, input variables (even critical input variables) are often misunderstood, ignored, or uncontrolled, resulting in welds of inconsistent quality. Variables may be overlooked for several reasons. During procedure qualification testing, for example, it is essential that critical welding parameters be evaluated and identified. During the qualification and testing of welders, the unique requirements of the specific application must be communicated to them. When all input variables are properly identified and controlled, welds of the required quality will be consistently achieved. Effective visual inspection can ensure that significant variables are controlled.

Discontinuities in welds do not occur by mere chance. They result from the failure to identify and control one or more critical variables. (Author's note: In our formal training, many of us have been taught the "scientific method," a system by which one variable is examined at a time. Experience demonstrates that variables rarely exist in isolation. First, in most applications, problems will be attributed to more than one variable. Secondly, the interaction of multiple variables is often overlooked. The more complex, but much more accurate methods associated with the "design of experiments" address these situations.) Even when critical variables are identified, they are frequently ignored or not properly communicated to the individuals involved.

While visual inspection is a powerful tool, some question its potency because of past experience. For example, if a visual inspection is so powerful, why are weld discontinuities and defects routinely found by nondestructive testing methods?

One explanation is that visual inspection is often improperly performed. Welding is a process, and the process must be observed throughout its application. If an Inspector arrives on the job site after the welds are complete, it is impossible to properly apply visual inspection. Because the nondestructive testing methods evaluate completed welds, Inspectors are trained to focus on finished products. Attention must be refocused on visually inspecting the process, not merely the finished result.

Inspecting the Completed Weld

Most of the emphasis up to this point has been upon process inspection. The quality of a completed weld can also be visually determined in many situations. A major exception to this, as previously noted, is gas metal arc/short arc transfer. With this process, a weld may have an excellent appearance and lack the essential fusion necessary for all forms of welding. In this case, extra emphasis on process inspection and nondestructive testing will be warranted. A good-looking weld is generally a good weld. An unattractive weld may or may not be a poor weld. However, the presence of visually discernible criteria that deviate from good appearance is generally an indication that one or more variables are not being properly addressed. For example, excessive spatter may not detract from the quality of the weld, but it is a sign that the process is not being controlled sufficiently.

In a meeting several years ago, a series of fatigue and brittle fractures that occurred on highway bridges was being examined. The organizer of the meeting was attempting to establish the need for more rigorous welding and fabrication requirements. Hydrogen cracking, brittle fracture, fracture mechanics, and fatigue details were all discussed. Most revealing in the meeting, however, was a comment made by a very skilled technician, a welder, who had no formal engineering training. He remarked: "I don't understand fracture mechanics, fatigue, or hydrogen embrittlement. However, from what I see in these photographs, none of these welds that failed would have met the visual acceptance criteria of the code." The silence in the room was deafening. The welder was correct. All of the technical issues that were being discussed had entered into these failures, but none of the welds should have ever been accepted based on a simple visual inspection.

AWS B1.11 - GUIDE FOR VISUAL INSPECTION OF WELDS

To provide practical information about the requirements for conducting visual inspections, the American Welding Society has published a concise, 28-page document, AWS B1.11, entitled "Guide for Visual Inspection of Welds." (9.) Consistent with the philosophy espoused in this paper, AWS B1.11 emphasizes the importance of inspection prior to welding, during welding, and after welding. Practical suggestions, presented in a checklist format, are offered for each phase.

In Section 3.2 of B1.11, the following items are highlighted as part of inspection prior to welding:

1. Review drawings and specifications.
2. Check qualifications of procedures and personnel to be utilized.
3. Establish checkpoints.
4. Set up a plan for recording results.
5. Review materials to be utilized.
6. Check for base metal discontinuities.
7. Check fit-up and alignment of welded joints.
8. Check preheat, if required.

When appropriate attention is paid to these issues, the quality of the yet-to-be-made weld can be expected to improve as a result of the pre-welding inspection. For example, when fit-up and alignment of the joint are carefully inspected, consistent uniform fusion to the root of the weld and avoidance of excessive distortion and/or residual stresses can be achieved.

Item No.3 discusses checkpoints. These are particularly critical on large Weldments or complex projects when subsequent fabrication activities may preclude further inspection of the fabrication process. Concurrent with this idea is the establishment of "hold points" where approval is required before further fabrication can be continued. The creation of hold points must be coordinated with the various contractors involved so that quality is maintained and the overall project can proceed on schedule.

In Section 3.3 of B1.11, items that should be inspected during welding are outlined. These include:

1. Quality of weld root bead.
2. Joint root preparation prior to welding the second side.
3. Preheat and interpass temperatures.
4. Sequence of welding passes.
5. Subsequent layer for apparent weld quality.
6. Cleaning between passes.
7. Conformance with the applicable procedure.

The root pass, often the most critical part of the weld, is frequently made under the most difficult conditions. Maintenance of the proper preheat and interpass temperatures is critical for the metallurgical integrity of both the weld metal and the heat affected zone. Inspection of intermediate weld layers, including removal of slag between layers, is absolutely essential for applications where only visual inspection will be applied. Conformance with the maximum layer thicknesses and bead widths as governed by the applicable welding code or WPS requirements can be visually verified at this point.

The requirements for post-weld inspection are covered in Section 3.4 of B1.11. Before the checklist is provided, the following statement is made: "Many people feel that visual inspection commences once the welding has been completed. However, if all of the previously discussed steps have been taken before and during welding, this final phase of visual inspection will be accomplished easily. It will simply provide a check to be sure that the steps taken have resulted in a satisfactory weld." This summary endorses the power of an effective visual inspection. The checklist of items to inspect after welding includes the following:

1. Final weld appearance.
2. Final weld size.
3. Weld length.
4. Dimensional accuracy.
5. Amount of distortion.
6. Post-weld heat treatment.

The importance of these issues is self-evident. The appearance of the weld is a strong indicator of the suitability of the actual welding procedure used, and the ability of the individual welder. More than merely a cosmetic issue, weld appearance provides insight into how the weld was made.

Visual inspection of the final weld requires good eyesight and good lighting. Good lighting often is scarce in a fabrication shop or even in certain parts of a construction site, so a simple flashlight can be a valuable aid to visual inspection. Prescription lens safety glasses, as well as a program of regular eye examinations, is additionally helpful in ensuring good visual inspection.

NON-DESTRUCTIVE TESTING

There is a far-reaching perception that post-welding, non-destructive testing is a reliable and effective means of ensuring the weld quality. It is not. Each NDT method has its own set of limitations. Dye penetrant inspection

(PT) will only detect surface breaking discontinuities. Magnetic particle inspection (MT) will only detect surface, or near surface discontinuities. Radiographic inspection (RT) and Ultrasonic inspection (UT) will examine the full cross-section of a weld, but limitations exist here too. RT is best at detecting volumetric discontinuities (slag, porosity) but may miss cracks, particularly when they are oriented perpendicular to the source of radiation. UT is most sensitive to planar discontinuities, but may miss volumetric discontinuities. Even when two or more methods of NDT are used, the result may not be definitive.

A recent study (10.) involved round-robin testing of 15 UT technicians, all examining the same mockups of typical welded joints. The technicians were deemed to be "generally more highly qualified than the average technician." The group missed an average of 25% of the known discontinuities, and furthermore, had an average of 16% rejectable indications for locations where no known discontinuities were implanted. These are known as "false calls". NDT will not detect all discontinuities.

NDT tells us nothing about the process that was used. It will not identify whether preheat was properly applied or whether the welding procedure was used as intended. It tells us nothing about the bead sequences, layer thicknesses, or levels of heat input. NDT will not tell us whether the proper electrode was used, or even if the proper steel was used in the welded assembly. NDT will not determine the mechanical properties of a deposited weld.

In contrast, careful documentation of the welding process with visual inspection can supply all of this information that NDT cannot.

VISUAL INSPECTION AND THE AWS D1.1 CODE

Inspecting work in process is not a new concept, but rather is part of the standard codes already. Take, for example, the AWS *D1.1 Structural Welding Code - Steel.* (11.) In D1.1, visual inspection is mandated by 6.9, which states: "All welds shall be visually inspected and shall be acceptable if the criteria of Table 6.1 are satisfied." Table 6.1, reproduced as Figure 2 to this paper, addresses "traditional" visual inspection issues, such as making certain the weld is crack free, has acceptable fusion, meets geometric requirements, etc. The Inspector's obligations, however, go beyond these "traditional" responsibilities, but also include in-process inspection requirements as well.

In Section 6 on Inspection, the following directions are given to the Inspector:

- The Inspector shall make certain that only materials conforming to the requirements of this code are used. (6.2)

- The Inspector shall review all WPSs to be used for the work and shall make certain that the procedures conform to the requirements of this code. (6.3.1)

- The Inspector shall inspect all welding equipment to be used in the work to make certain that it conforms to the requirements of 5.11. (6.3.2)

- The Inspector shall permit welding to be performed only by welders, welding operators, and tack welders who are qualified in accordance with the requirements of Section 4. (6.4.1)

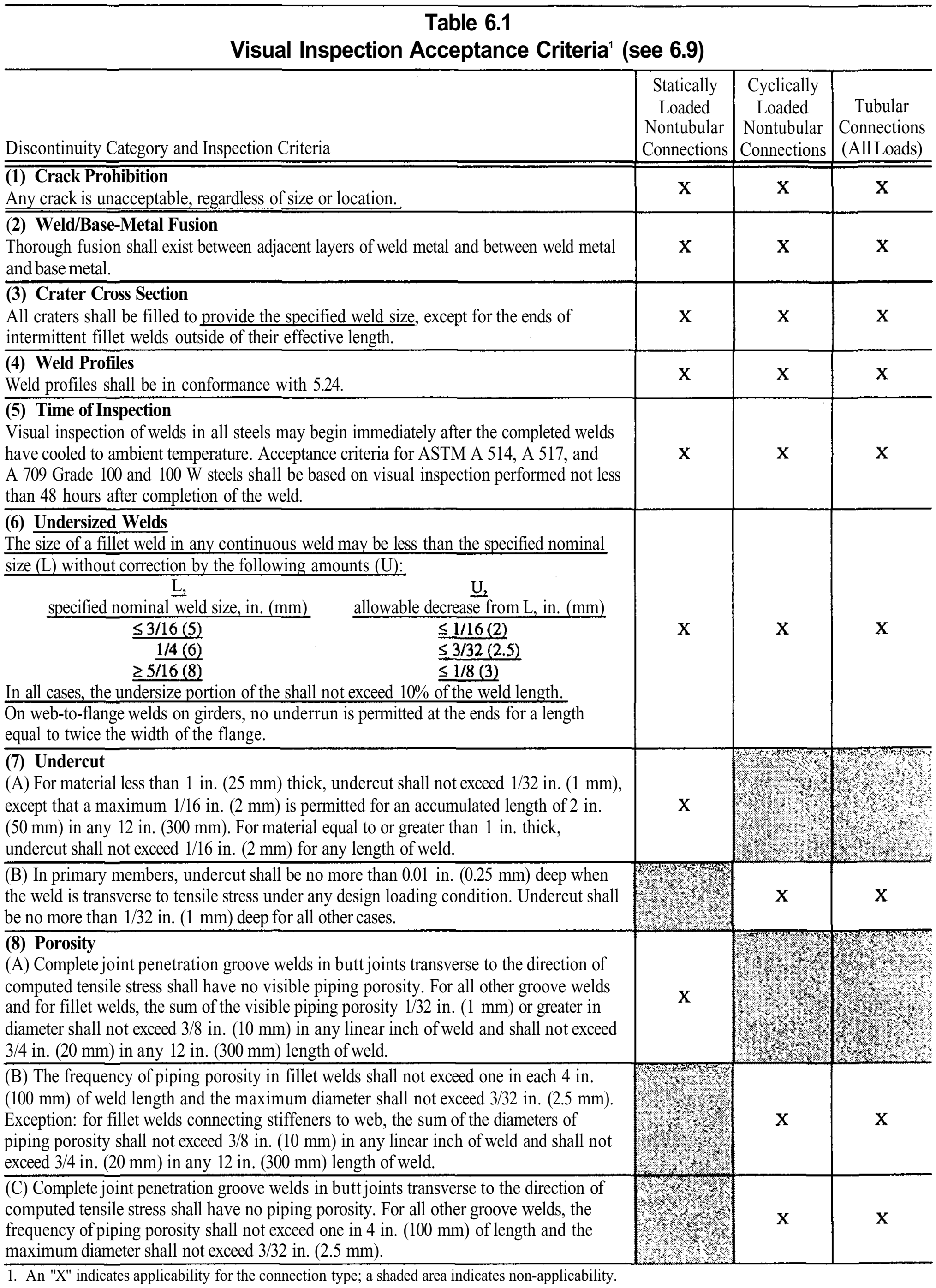

Table 6.1
Visual Inspection Acceptance Criteria[1] (see 6.9)

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 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.

Figure 2

- The Inspector shall make certain that only WPSs are employed which meet the provisions of Section 3 or Section 4. (6.5.2)

- The Inspector shall make certain that electrodes are used only in the positions and with the type of welding current and polarity for which they are classified. (6.5.3)

- The Inspector shall, at suitable intervals, observe joint preparation, assembly practice, the welding techniques, and performance of each welder, welding operator, and tack welder to make certain that the applicable requirements of this code are met. (6.5.4)

These code requirements make it obvious that aspects of visual inspection must take place well before the work is completed. This may deviate from the practice of many Inspectors, but it is the only approach that can actually prevent the formation of welding defects. For example, when the base materials being used are examined, the Inspector can prevent the use of the wrong type of material in a specific application. Careful examination of welding procedures will reveal the suitability of a specific procedure for a particular application. The welder's credentials will help to determine the suitability of that individual for the specific application.

While D1.1 requires visual inspection for all welds (6.9), it does not mandate NDT for any welds, with the single exception of when such inspection is required for the attainment of certain fatigue resistance (see 2.26.1). When NDT is specified in contract documents, the welds are required by 6.11 to have been found acceptable to the criteria of 6.9 and Table 6.1 before NDT is performed.

The D 1.1 code requirements as outlined above are comparable to the "5M's and a P" discussed earlier. Such a comparison, presented below, demonstrates that D1.1 addresses the major elements of the Six Sigma systerm.

Material:	AWS D1.1	6.2, 6.5.3
Method	AWS D1.1	6.3.1, 6.5.2, 6.5.3'
Machine	AWS D1.1	6.4.1
Measures	AWS D1.1	6.9
Mother Nature*		
People	AWS D1.1	6.4.1, 6.5.4

*(Only Mother Nature is not specifically cited in D1.1 as an issue the Inspector is to address, although contained within the code are various conditions in which welding is not to be performed, such as under windy conditions for gas shielded welding processes (5.12.1), when the ambient temperature is lower than 0° F., when surfaces are wet or exposed to rain, snow or high wind velocities, or when welding personnel are exposed to inclement conditions (5.12.2). While part of the code, the inspector is not specifically charged with the responsibility to monitor this condition.)

APPLYING VISUAL INSPECTION METHODOLOGY TO JUMBO SECTIONS

AISC and AWS both have specific, additional provisions that are applied to heavy sections (ASTM A6 Group 4 and 5 Rolled Shapes, or shapes built up by welding plates more than 2 in. thick together to form the cross-section), where the cross-section is to be spliced and subject to primary tensile stresses. In addition to the standard code and specification requirements, these heavy members (henceforth called jumbo sections) have specific requirements related to materials, thermal cutting, welding, and detailing, all of which can be effectively monitored with visual inspection. While the specification does call for some non-destructive testing as discussed below, this NDT is not to be applied to the welds per se, but to the weld access holes, an area that experience has shown to be problem-prone.

Before Welding

In *AISC-LRFD: 1994* (12.) Provision A3.1c requires that jumbo sections demonstrate Charpy impact test results of 20 ft. pounds @ +70°F at a specific location in the web-to-flange area for rolled shapes. For plate products, the same Charpy results are required, but testing is done in accordance with ASTM A6, Supplemental Requirement S5. Thus, the first visual inspection step to take when welding these materials is to verify that such tests have been performed.

M2.2 requires that for beam copes and weld access holes in jumbo sections, a 150°F minimum preheat be applied prior to thermal cutting. This applies only to copes and access holes, not for routine cutting of steel, and is not applicable to the surfaces on which weld metal will be deposited. Before such cutting processes are initiated, visual inspection can ensure that this preheat level has been achieved.

J 1.6 defines specific weld access hole dimensions, and while these dimensions are not restricted in their applicability to jumbo sections, the large sizes that result due to the application of the provisions of J1.6 to heavy members are such that these sizes should be verified. Visual inspection can help ensure that the final dimensions are achieved. This can start with review of the shop drawings and continue with inspection of the actual sizes as cut in the shop.

J1.6 imposes an additional requirement applicable only to jumbo sections, requiring that the thermally cut surface for beams and copes be ground to bright metal and inspected with either Magnetic particle inspection (MT) or Dye penetrant inspection (PT) prior to depositing the weld. Many fabricators have found that drilling the radius portion of the access hole is more cost-effective on these thicker materials, and J 1.6 states that for drilled or sawed holes, "that portion of the access hole or cope need not be ground." Although it is not expressly stated that such drilled holes need not be inspected with PT or MT, J1.6 is explicit that the MT or PT may be applied only to thermally-cut surfaces. Visual inspection can be used to verify that the grinding operations have been performed. Although MT and PT are non-destructive testing methods, it should be noted that their results are visually affirmed.

J2.8 requires a minimum preheat of 350°F when splicing jumbo sections. This is higher than would be required by AWS D1.1 for prequalified procedures using A572 Grade 50 materials. This preheat can be verified visually.

While not part of AISC LRFD 1994, the next edition of the specification is expected to require notch tough weld metal for such connections. The WPSs can be reviewed as part of the visual inspection process to ensure the proper materials are being used for the application. Furthermore, the actual electrode used on the project can be verified as conforming to the WPS requirements.

During Welding

Interestingly, the spec does not impose any additional during-welding inspection requirements when joining jumbo sections.

After Welding

J1.5 requires that jumbo sections have the weld tabs and backing removed, and the surfaces ground smooth. This should be noted on shop drawings, and can be visually verified after the operations have been completed. It is again noteworthy that the spec does not require any additional non-destructive testing of the weld in the requirements imposed on jumbo sections. This is not to say that RT or UT inspection of important joints should not be performed, but the specification requirements illustrate the value of controlling the *process* in order to ensure connection quality.

IN-PROCESS VISUAL INSPECTION AS APPLIED BY FEMA 353

As an output of the SAC project, the FEMA-sponsored effort to investigate improved behavior for steel moment frames in earthquakes, four major documents were issued (FEMA 350, 351, 352, and 353). FEMA 353, *Recommended Specifications and Quality Assurance Guidelines for Steel Moment-Frame Construction for Seismic Applications* (13.), contains a comprehensive list of the various in-process activities that are recommended for seismic applications. Contained within FEMA 353 are the normal and routine requirements of the UBC, AISC specifications, and AWS D1.1 Code. In additional, new provisions that have emerged from the SAC investigations have been incorporated. For the benefit of the user, new provisions are underlined. The document makes use of process-control methodology with a strong emphasis on in-process, visual inspection. If one deleted those provisions that are underlined, the remainder would constitute a comprehensive checklist of requirements that are generally applied to most structural steel projects in the U.S. As such, FEMA 353 serves as a comprehensive document that addresses items that need to be controlled in steel fabrication and erection in order to have control of this Process.

FEMA 353 contains two major sections: Part 1, Recommended Specifications; and, Part II, Recommended Quality Assurance Guidelines. Both address welding-related issues, as well as a variety of matters that are not welding-related. This presentation will offer some examples of the welding issues, and will illustrate the approach used within FEMA 353, but does not represent a comprehensive coverage of all of these issues.

Part 1, Section 6.6, contains a 19-Point List of Activities that should be performed. Interestingly, none of the nineteen items are outlined, indicating that these are not new requirements. Also, of the nineteen items, fifteen deal with in-process control checks, one calls for visual inspection of the final weld, one stipulates scheduling of NDT (when required), and the final two address documentation issues. Significant emphasis is placed on in-process activities.

Part 1, Table 6-2, contains a list of 47 specific activities under the title "Process and Visual Welding Tasks". Assigned are tasks to be performed by the welder, as well as those to be performed by the Inspector. This specific assignment helps to extend quality concerns beyond the realm of simply the Inspector.

Table 6-2 incorporates the concept of "hold points" as were discussed in the section above on B1.11. Hold points are identified with "H"; and observation points are identified with "O." Hold points are operations that require the welder to wait until the Inspector has evaluated the work before proceeding. Observation points are those where the welder can proceed after performing his/her own inspection. The Inspector periodically (but at least daily) is expected to randomly inspect work at the observation points.

The most critical operations are those that are identified as hold points for both QC and QA inspection. Two double-hold points include "Proper WPS Selected for Joint Detail" and "Proper Welding Materials Selected". These are obvious basic functions that should be verified before production commences. Failure to address these details will inevitably result in the need to remove the weld. Such emphasis on the WPS and welding details is consistent with Gresnigt's conclusion quoted earlier regarding "gross errors".

FEMA 353 affirms the concept of in-process, visual inspection, when applied to critical seismic welding applications. By emphasizing principles already elucidated in AWS D1.1, FEMA 353 also affirms the code approach. There are few new welding or inspection provisions in the FEMA document, indicating that, in general, existing code provisions are adequate. The greater degree of detail, however, provides a helpful template that can be used to ensure all code provisions are applied in the construction process.

CONCLUSION

Deming has emphasized the need to cease reliance on finished product inspection, and rely rather on improvement of the process. Six Sigma methods promise to reduce process variability, improve product consistency and increase customer satisfaction *by improving the process,* not by reliance on final product inspection. The steak dinner analogy illustrates that other industries rely on in-process visual inspection. Most operations associated with steel fabrication in erection can benefit from this in-process approach..

Like so many other manufacturing and construction activities, welding is a process. Only by properly controlling every element of the process can product quality be controlled. It is essential, however, that all the input variables be properly identified and controlled. During procedure qualification testing, critical variables can be identified. During welder qualification and training, important parameters must be appropriately stressed. Effective visual inspection can ensure that the variables are properly controlled and identified.

These principles are outlined in B1.11-88, and have been codified in AWS D1.1 Structural Welding Code Steel. These same principles are incorporated into AISC Specifications and can be applied to welding of jumbo sections. Finally, this approach has been incorporated into FEMA 353 as well. By carefully applying these principles into welding operations, as well as other steel fabrication activities, it is possible to simultaneously lower costs, increase quality, and better meet customer needs..

There are applications where additional types of testing methods are needed, but their use does not obviate the need to "look at what you're doing!" It is incumbent upon us as engineers and managers to insist on consistent visual attention to those issues that will contribute to the creation of higher quality products. When this is done, quality will improve, costs will be reduced, and the customer's best interests will be served.

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