Tubular TYK Fabrication and Inspection

It is important to plan ahead for these complex welds

BY CLIFFORD A. MANKENBERG

Some of the most challenging structural steel welding and inspection problems are encountered during the construction of round tubular members, especially at the T-, Y-, and K- end connections. Tubular construction is often used as an architectural detail in office buildings and airports for the pleasing lines of the resulting structures. Often, these are not primary load-carrying structures or they have limited structural function. In the offshore industry, tubular TYK construction is commonly used as the primary load path for structures such as fixed offshore platforms — Fig. 1. In addition to the weight of the structure and equipment, offshore structures are subjected to operational and extreme load conditions resulting from normal wind and wave action, earthquakes, hurricanes, vibrating equipment, extreme cold, etc. Loads are therefore either static or cyclic, and the quality of the structural weld for tubular connections must endure for the design life of the structure (typically between 15 and 30 years).

In the United States and many other parts of the world, AWS D1.1, *Structural Welding Code — Steel*, is the code used for the welding and inspection of tubular TYK joints. Even a cursory review of the code requirements for tubular welding and inspection reveals that it is more complex than flat plate structural fabrication. Thorough planning and training for all phases of a structural tubular fabrication project will help to avoid unnecessary problems and, therefore, maximize production and minimize rework and repair.

This article focuses on the fitup inspection (Fig. 2) of TYK joints with the objective of emphasizing the need for planning. Space considerations do not permit an in-depth examination of the other phases of tubular fabrication (weld procedure specification qualification, etc.), though it is critical that they also be considered in the planning stages. Here we are referring to one of the most commonly used tubular TYK end connection types, a simple round tubular Y connection, complete joint penetration (CJP) welded with the shielded metal arc process from one side without backing. It should be noted that differing connection types (e.g., square tubulars, overlapping connections, partial joint penetration welding, etc.) might introduce additional variables that should be considered.

Reference to paragraphs, figures, and tables of the AWS D1.1 Code is to the 2004 edition. Definitions of the terms used can be found in various locations in the code, including Figs. 2.14, 3.7, 3.8, 3.9, and 3.10, Tables 3.5 and 3.6, and Annex B.

Fig. 1 — An offshore tubular jacket structure near completion of fabrication. Note the extensive use of TYK connections of various types.

Fig. 2 — Typical TYK inspection/measurement tools, including clockwise from top left: root opening gauge, dihedral angle/groove angle gauges, W dimension rule, improved surface profile radius gauges. Note that the ends of the rule have a tapered cut at a dimension equal to the required W dimension that will allow the rule to be inserted into the root of the joint.

What Should Be Inspected?

When considering joint fitup, it is of course useful to look at finished weld requirements. Figures 3.8 to 3.10 (this article refers only to Fig. 3.8 because the others are essentially identical except for the weld cap surface profile requirements) and Table 3.6 give the requirements for finished weld dimensions of tubular TYK joints. Two curved surfaces welded and accessible from only one side means that to be able to verify after welding

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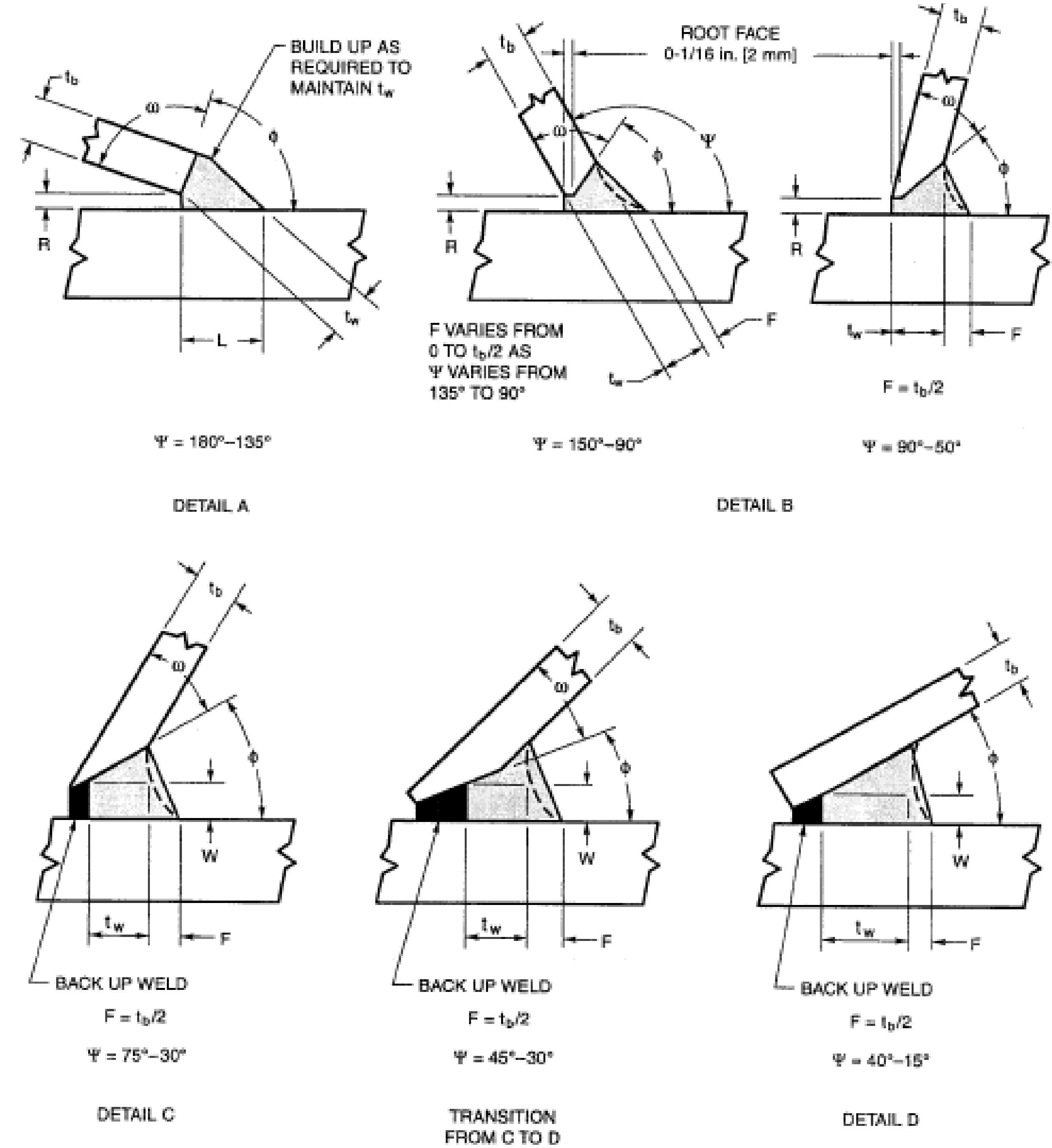

Fig. 3.8 of AWS D1.1 — Prequalified joint details for CJP groove welds in tubular T-, Y-, and K-connections — Standard flat profiles for limited thickness.

that the finished weld meets the requirements, some sort of reference marking system needs to be employed. This must be performed and verified after fitup and prior to commencement of the root pass.

At a minimum, reference marks will be needed to allow the welder, the welding inspector, and the ultrasonic testing (UT) technician to ascertain that the effective throat (t_w) and leg (L) dimensions have been achieved. The other fitup characteristics (local dihedral angle, included groove angle, root opening, etc.) need not necessarily be marked on the workpiece, but they must be verified during fitup inspection to ensure they meet the Code, WPS, and procedural requirements — Figs. 3, 4.

However, consideration should be given to recording these data on the workpiece at various points around the joint. It can be useful should any question arise during welding or inspection, but is most useful for the UT technician who will have to examine the completed weld. In fact, if UT is to be performed in accordance with D1.1 requirements, a method for establishing geometry as a function of dihedral angle is required [paragraph 6.27.1(9)], and this is the easiest way to accomplish that requirement. Just as tubular TYK joints are among the most difficult structural steel joints to weld, they are also among the most dif-

Table 3.6 of AWS D1.1
Prequalified Joint Dimensions and Groove Angles for CJP Groove Welds in Tubular T-, Y-, and K-Connections Made by SMAW, GMAW-S, and FCAW (see 3.13.4)

	Detail A ψ = 180–135°	Detail B ψ = 150–50°	Detail C ψ = 75–30°[2]	Detail D ψ = 40 – 15°[2]
End preparation (ϖ) max min		90°[1] 10° or 45° for ψ > 105°	(Note 1) 10°	
Fit-up or root opening (R) max min	FCAW-S SMAW[4]: max — min 1/16 in. [2 mm] No min for ϕ >90° GMAW-S FCAW-G[5]: max 3/16 in. [5 mm] min 1/16 in. [2 mm] No min for ϕ >120°	FCAW-S SMAW[4]: max 1/4 in. [6 mm] min 1/16 in. [2 mm] GMAW-S FCAW-G[5]: max 1/4 in. [6 mm] for ϕ > 45° 5/16 in. [8 mm] for ϕ ≤ 45° min 1/16 in. [2 mm]	(note 3) W max. — ϕ FCAW-S SMAW (1): 1/8 in. [3 mm] — 25–40° 3/16 in. [5 mm] — 15–25° GMAW-S FCAW-G (2): 1/8 in. [3 mm] — 30–40° 1/4 in. [6 mm] — 25–30° 3/8 in. [10 mm] — 20–25° 1/2 in. [12 mm] — 15–20°	
Joint included angle ϕ max min	90° 45°	60° for ψ ≤ 105° 37½°; if less use Detail C	40°; if more use Detail B 1/2 ψ	
Completed weld t_w	$\geq t_b$	$\geq t_b$ for ψ > 90° $\geq t_b/\sin\psi$ for ψ < 90°	$\geq t_b/\sin\psi$ but need not exceed 1.75 t_b	
L	$\geq t_b/\sin\psi$ but need not exceed 1.75 t_b		Weld may be built up to meet this	$\geq 2t_b$

General Notes:
- For GMAW-S see 4.12.4.3. These details are not intended for GMAW (spray transfer).
- See Figure 3.8 for minimum standard profile (liimited thickness).
- See Figure 3.9 for alternate toe-filled profile.
- See Figure 3.10 for improved profile (see 2.20.6.6 and 2.20.6.7).

Notes:
1. Otherwise as needed to obtain required ϕ.
2. Not prequalified for groove angle (ϕ) under 30°.
3. Initial passes of backup weld discounted until width of groove (W) is sufficient to assure sound welding; the necessary width of weld groove (W) provided by backup weld.
4. These root details apply to SMAW and FCAW-S.
5. These root details apply to GMAW-S and FCAW-G.

ficult to examine by UT. The recording of these data on the workpiece can facilitate timely performance of UT and help to avoid otherwise unnecessary weld rejects (especially at the root) caused by the UT technician having to guess at the bevel configuration and fitup conditions. Keep in mind that none of the joint geometry characteristics of local dihedral angle, included groove angle, root opening, and W dimension can be measured after welding or can be found on a drawing.

Check the General Condition of the Joint

A systematic approach to fitup inspection and marking should be used.

First, the brace intersection angle should be verified (the required angle will be found on the shop drawing) by placing the dihedral angle gauge that most closely matches the required angle at the heel of the joint — Fig. 5. Of course, this can be measured at the toe by using the converse of the angle. This is a very quick dimensional check — if the angle is way off there is a problem that needs to be addressed before the fitup itself is checked.

Next, a check of the general condition of the joint should be performed. Do the groove angles seem too small? Are there any very large or insufficient root openings? (Note that in Details C and D, a metal-bound condition is acceptable, refer to the backup weld/W dimension of Fig. 3.8.) If an effort was made to verify that the bevel preparation is correct,conditions such as these could indicate that the fitup has not been properly performed (some unintended offset, for instance) and there may be a larger dimensional problem.

Fig. 3 — Fitup of a TYK field joint.

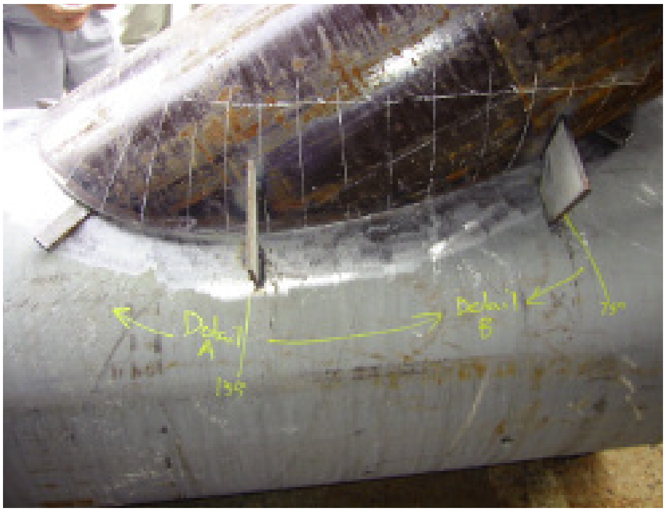

Fig. 4 — Measurement of the as-fit-up joint has begun. Note that the boundaries of the various Details have been marked on the chord member.

Fig. 5 — The author demonstrating the measurement of the brace intersection angle at the heel of the joint. The fitters were being trained to do this as part of verifying the proper location of the brace member prior to tacking.

Measure the Dihedral Angle

Now it is time for measurement and marking. Here the WPS and, if the WPS is not sufficiently detailed, a written procedure clearly delineating the TYK fitup and inspection requirements or the code will be needed. Why? Because all of the characteristics that need to be measured or for which reference point marking is necessary (groove angle, root opening, or W dimension, minimum throat, etc.) are a function of the local dihedral angle, as shown in Table 3.6.

Measurement should begin at either the toe or heel with the dihedral angle. Actually, this may have already been measured, because, at the heel, the dihedral angle is equal to the brace intersection angle, and at the toe it is equal to the converse of the brace intersection angle. It is important to remember that local dihedral angle and all other dimensions must be measured perpendicularly to the local weld axis (refer to the definition of local dihedral angle in Annex B and the sketches at Fig. 3.7 and Annex G).

It is generally convenient to continue measuring the dihedral angle with the appropriate gauges around the circumference of the joint and to mark on the chord the boundaries between the various Details (A, B, C, C to D, and D). This will aid the later measurements. Note that in the Code at Tables 3.5 and 3.6 there is overlap in dihedral angles between the various Details. This makes sense in that the joint geometry does not change abruptly from one Detail to the next, but instead changes continually. Nonetheless, it is convenient to precisely define the boundaries in the WPS or written procedure as it makes some of the measurement and marking easier and ensures that everyone involved is working on the same page.

Check the Other Dimensions and Make Reference Marks

Next, the localized areas need to be looked at. As an example, let's look at Detail B first. A point is chosen, the dihedral angle is measured, and the actual value recorded on the brace or chord with a paint marker, using a line to indicate the point at which the measurement was taken. The root opening and the included groove angle are then measured at this same point to verify that they fall within the code, WPS, and/or written procedure requirements, then the actual values are marked on the brace.

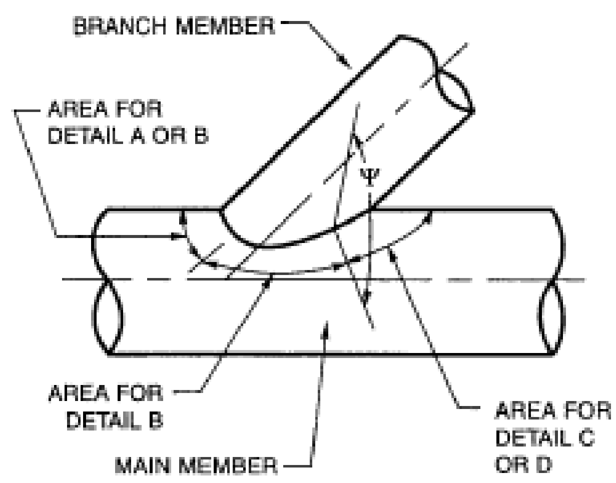

Fig. 3.7 of D1.1 — Definitions and detailed selections for prequalified CJP T-, Y-, and K-tubular connections.

From the root of the joint out onto the chord, a distance equal to the minimum required throat is measured. If the dihedral angle is 70 deg and the brace thickness 25 mm (1 in.), for example, the required minimum throat is 26.6 mm ($1\frac{1}{16}$ in.). This is derived from the Table 3.6 formula of $t_w \geq t_b/\sin\psi$. (While it is a bit cumbersome to make these calculations in the field, it is easy enough to include in the WPS or written procedure a table listing minimum throat multiplication factors as a function of dihedral angle.) A mark can be made at this point, but as it eventually needs to be covered with weld metal, it is more important to mark a reference point at some convenient, standardized distance from the point, say 100 mm (4 in.). So, for our example of 70-deg dihedral angle and 25-mm brace thickness, a reference point is made at 126.6 mm ($5\frac{1}{16}$ in.) from the root of the joint (i.e., 26.6-mm minimum throat plus 100 mm).

Any convenient means may be used for reference marking, such as punching, scribing, or paint marking, but with all the welding activity that will take place, the marks need to be reasonably permanent. Note that punch marking may not be possible at the heel area due to the acute angle and resultant lack of access between the two members.

This process is then continued at various locations in Details A and B until these areas are completed. For smaller braces, only a few reference marks may be necessary. On large braces many points will be required to give the welder enough reference marks to smoothly transition the weld around the circumference. Note that in Detail A if the included groove angle is greater than 45 deg, additional reference marks may be needed on the brace to ensure that the finished weld throat exceeds the minimum required (refer to Fig. 3.8).

Details C and D in More Detail

Details C and D are measured and marked similarly to Details A and B, but there are some slight differences. Instead of a root opening requirement, there is the "W" dimension. The W dimension is essentially that width of groove at which clean weld metal must begin. Beyond the W dimension, i.e., deeper into the groove, the weld metal ("backup weld" in Fig. 3.8) need not be defect free, and indeed it can be a void with no weld metal present. Note that if there is a fitup gap between the two members in Details C and D that is equal to or greater than the W dimension, then the weld penetration must extend to the root face of the brace (i.e., like Details A and B). The easiest way to measure the required throat in these areas, taking into account the W dimension, is to take a length of tape measure and make a tapered cut at the squared ends such that the remaining width of the tape measure is equal to the W dimension. This tool is then inserted into the groove until contact is made with the bevel, and the required throat dimension can be read directly from the scale.

Note the dihedral angle ranges for these two details in Table 3.6. Detail C can extend down to 30 deg, while Detail D can extend up to 40 deg. What this means in practice is that if the brace intersection angle (equal to the local dihedral angle at the heel) is 30 deg or greater, Detail C must be used for the range of dihedral angles for 30 deg to the Detail B boundary (i.e., there will be no Detail D). If the brace intersection angle is less than 30 deg, then there must be a Detail D, with the 40-deg limit shown in Table 3.6 being the point at which the C to D transition would begin. By looking at the Details C and D cross sections shown in Fig. 3.8, the distinct differences between these two zones of the joint can be seen readily. Clearly, an abrupt transition between the two would be undesirable. In the case where a Detail D is required, then we have Detail C down to a 40-deg dihedral angle, the C to D transition from 40 to 30 deg, and Detail D below 30 deg. Keep in mind that dihedral angle is not the same as groove angle, except in Detail D, and that prequalified welding procedures are prohibited for included groove angles of less than 30 deg, which there will definitely be in these zones of the weld.

Now Finish the Inspection

It is difficult to be extremely precise when measuring and marking tubular TYKs because the workpiece is composed of two elliptically curved surfaces while the tools that are used are straight and do not match the curvature in all cases. This should not be of great concern because the Table 3.6 minimum throat requirements ensure a smooth transition between the Details and in practice there is a tendency to slightly overweld.

When all of the reference point marking and recording of data on the workpiece are complete (Fig. 6), one last look should be given to ensure that sufficient reference marks and data are indeed present so as to allow the welder, the inspector, and the UT technician to properly perform their tasks. This is also an excellent time, if possible, to have all of the personnel who will be involved in the TYK fabrication take a look at an as-fit, as-marked joint, unless this has already been done with a mockup built for training purposes. Some training should be conducted, as necessary, so that all understand the required joint geometry and how it must be fit up, welded, inspected, and examined. It is actually a code requirement (paragraph 6.15.4) to furnish this type of information (joint configuration, etc.) to NDE personnel, and for TYKs one of the best ways is to have them look at an as-fit, as-marked joint.

It should be clear by now that tubular TYKs just cannot be tacked together and welded. There is just no way to verify that the required joint dimensions have been achieved if the fitup has not been inspected and reference marks provided. The most critical part of tubular TYK welding and inspection is the fitup. Plan ahead to avoid problems.

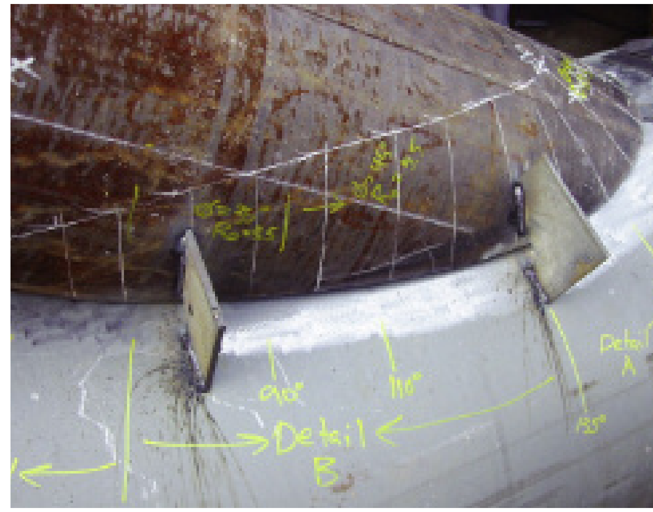

Fig. 6 — Measurement and marking of the as-fit-up joint is almost complete. The boundaries between the various Details have been marked on the chord, the actual root opening (Ro) and included groove angle (fl) have been marked in a number of locations on the brace, and the local dihedral angle in additional locations has been marked on the chord. The only thing missing is the reference marks for the required minimum throat (t_w) or leg (L).

Conclusions

The tubular TYK construction commonly found in many offshore structures presents some of the most difficult welding and inspection issues to be found in structural steel fabrication. This article has highlighted fitup inspection as a way of demonstrating that there are many specific items that should be taken into consideration when planning for structural tubular fabrication. Even more so than for other types of structural fabrication, it is useful to look at all phases (WPS qualification, dimensional control, NDE, etc.) as interrelated steps of one single process rather than as distinctly separate activities. They should all be evaluated during project planning to help in avoiding fabrication problems and to ensure project success. It is recommended that prior to the start of fabrication, a thorough review of all contract documents and code requirements be performed, a detailed written procedure describing the fitup and inspection requirements be prepared, and a training mockup be constructed and used. ❖