Fabricating, Welding, and Inspecting Turbular Structures

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INTRODUCTION

Tubular structures may range from relatively simple sign poles to complex towers for offshore drilling platforms. They may use pipe or box (square or rectangular) tubes. When a designer selects tubular members for a frame or truss, it is relatively easy to size the members for axial loads, in-plane or out-of-plane bending, and occasionally, torsional loads. Then, all concern focuses on the connections. Consider, for example, a tubular steel truss or space frame with welded connections for an architectural/ aesthetic application. The architect/engineer (AE) or designer must be conversant with the provisions of the Structural Welding Code - Steel, AWS D1.1-88[1] This includes an understanding of the following areas :

- Material properties (strength, ductility and toughness)
- Fabrication practices and techniques
- Welding (including qualification of procedures and welders)
- Workmanship
- Inspection

MATERIALS

Designers working to the Structural Welding Code can select from a list of pre-qualified materials ranging from 30 - 100 ksi minimum specified yield strength with corresponding tensile strengths ranging from 50 - 130 ksi.

One other material property that designers may or may not consider is toughness. At first, designers may dismiss the toughness issue as not relevant to their static structure. There are two dangers with that approach. First, some tubular applications may see service in cold winter environments (e.g., exposed roof trusses or unheated areas). Secondly, detailed investigations into the behavior of tubular connections indicate areas of "hot spot" strains. In order to achieve useful design efficiency, these localized regions around the perimeter of the connection undergo plastic yielding as the design loads are applied. Thus, tubular connections depend upon plastic flow and strain hardening to develop their ultimate capacity. For this to occur in the presence of welds with the potential for undiscovered discontinuities, some level of notch toughness performance should be specified for the material. For thicker materials and/or highly restrained connections, the first level of toughness may be the added requirement of fully killed fine-grain melting practice from the steel mill. The second level of toughness may be to add a requirement for normalization to the steel. The third level may be to require Charpy testing on a heat lot basis. The fourth level, for the most extreme cases, may be to require Charpy testing on a per plate basis.

Another material property that may become very important to the success of tubular connections with heavier wall-thicknesses is freedom from laminations. This occurs due to poor internal steel cleanliness which leads to lamellar tearing[1].

Proceed with caution when a tubular material not included in AWS D1.1 is proposed for use. Such materials require welding procedure qualification and careful consideration of its specified controls (or lack thereof) on chemistry and weldability.

FABRICATION PRACTICES AND TECHNIQUES

Cut and Cope

When a tubular branch member frames into another tubular member, a connection is created. TYK-connection is the term that refers to any one or combination of branch member intersections. The branch members usually require some type of a cope or miter cut. For round members, the copes are more complex than for box members. Also, compound copes, (members intersecting two or more members) add to the complexity. For box members, machine saw-cuts can be used to produce miter cuts to which torch cut and/or ground bevels can be added. For round members, the old conventional method for coping involves creating a wrap-around template to mark the pipe and handcutting with an oxy-fuel torch. An individual

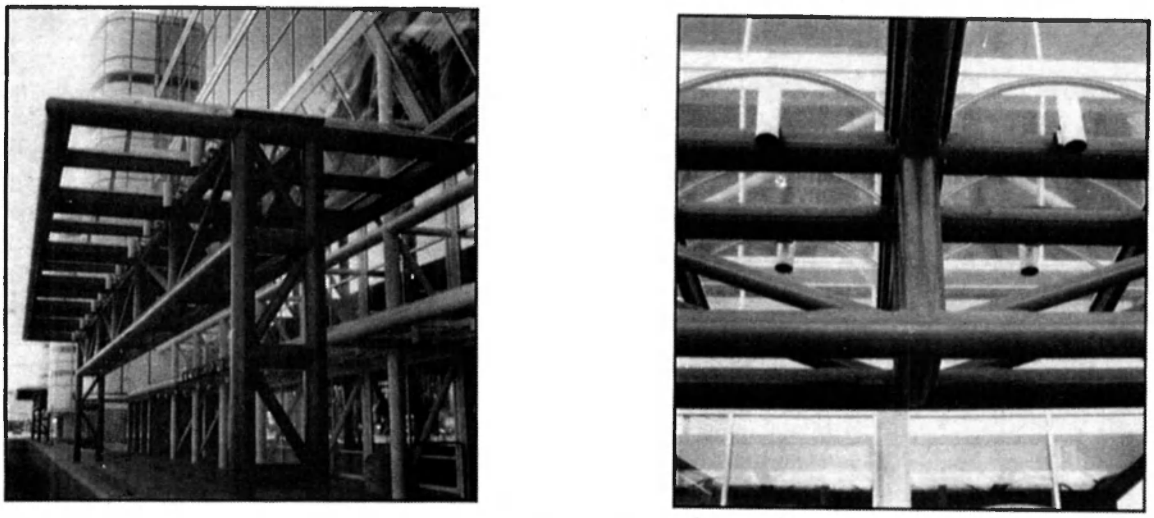


Fig. 1. *Building entrance showing (left) overlapped and (right) non-overlapped connections*

template is required for each combination of branch member thickness and I.D., versus main member O.D. and intersection angle. Once generated, however, these templates may be used again and again. Presently, computers can be used to generate the coordinates for these templates and, if large enough plotters are available, the template may be computer drawn.[3,4]

Handcut copes from wrap-around templates generally require two cuts. The template represents the I.D. intersection of the branch member with the main member, but it is drawn on the O.D. surface of the branch member. The first cut must be made square to the pipe's surface with the torch always pointing toward the axis of the pipe. In this way, the template outline is successfully transferred to the I.D. surface, which is the true intersection with the chord at the root of the weld. A second cut is then made with the torch tipped at varying angles to produce the required bevel for welding. This is the difficult step, in that the burner or fitter often must sense or feel the proper bevel or "feather edge" at the I.D. surface. Sometimes these angles leave a very thin "feather edge" that is easily melted or gouged. Significant grinding and touchup work is often required to produce a suitable coped member.

For manual coping, computer programs[1,3] have been enhanced so that the program can also give the coordinates for the entry point for the bevel cut, thus taking the guess work away from the burner. If he errs on the tight side, the welder cannot achieve the weld penetration required; and re-work (gouging, grinding, or remove the member and re-cutting) may be necessary. If he errs on the wide side, very large weld grooves are produced and welding man-hours rise rapidly, especially on thicker branch members.

Mechanized coping devices for pipe have been available for many years. Some machines are linkage and cam driven, while others may follow black lines on a white drum with a photoelectric cell. The more recent machines are computer driven. Almost all of the mechanized coping devices incorporate automatic torch tilting, so that the proper bevel angle is cut in one pass, not two, as with manual cutting.

Common limitations of the mechanized devices are their O.D. capacity and the limits of torch tilting, wherein the torch cannot lay over far enough for the most shallow angles found in the heel regions of braces with small intersection angles. The most serious limitation in dealing with the computer generated template or computer driven machine is the knowledge of the computer programmer. Too often the programmer does not have a good grasp of the 3-dimensional solid geometry involved in tubular connections. Regardless of how the cope is produced, it is wise to check it immediately. Make a trial fit against its mating chord or use a 3-dimensional template of model of the main member. In this manner, the accuracy of the cope, the groove angle, and the branch intersection angle can be checked quickly.

Fitting TYK-Connections

From a fabrication standpoint, the lowest cost connections are simple TYK's without overlapping members (see Figure 1). If possible, design the connection with a two-inch nominal gap between the toes of the adjacent branch members. This greatly simplifies fabrication and erection. Diagonal members can usually be adusted slightly about the theoretical workpoint to compensate for inaccuracies in length and position. The overlapped branch connections always have a compound cope and require

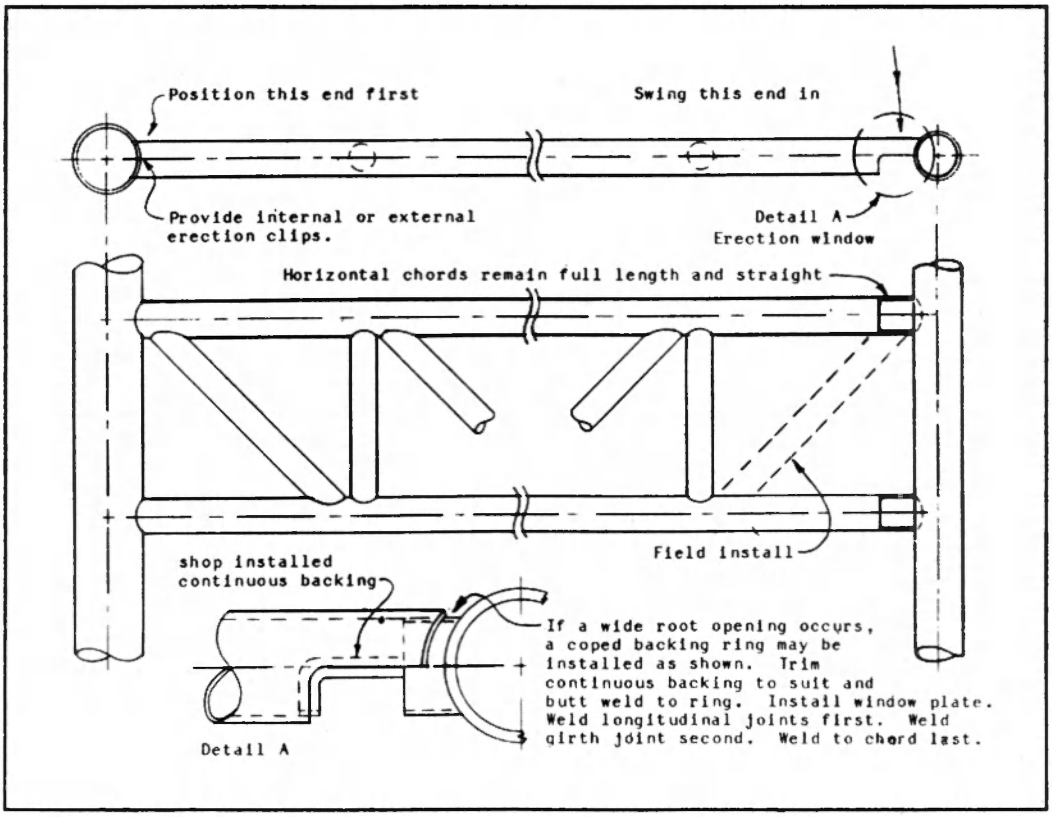


Fig. 2. *Field installation of an intermediate truss using erection "windows" in place of stubs.*

more careful layout and coping, especially for length. Also, the sequence of member installation must be planned and controlled. From the designers' standpoint on the other hand, overlapped connections usually require less strength or thickness from the chord member to prevent problems with punching shear.

With overlapping connections in a frame with round chords, one end of the last member installed may require an erection "window" in order to fit around the curvature of abutting members (see Figure 2). To cut a window is to remove a segment of the coped end of a member to allow it to be brought into position. In the larger offshore structures, the need for windows is sometimes unavoidable, but is always kept to a minimum due to the added fabrication cost.

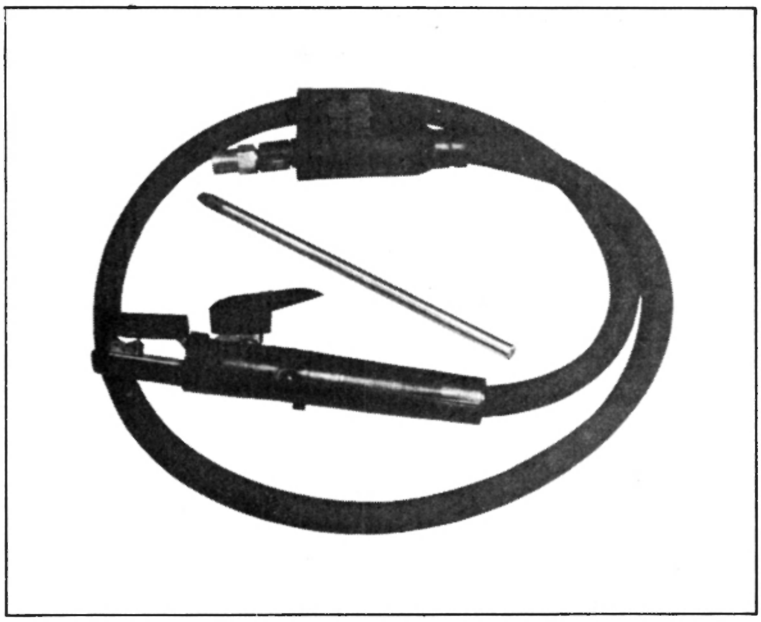
For intermediate trusses or individual members, the window approach shown in Figure 2 may be preferable to using stubs shop welded to the main member. A window has to be cut on only one end of the branch member. The window technique permits the branch member to retain its full length and overall straightness.

Box tubes do not suffer from this fitting problem. Compound coped (mitered) members can usually slide into position.

Complete versus Partial

Another major design consideration for tubular connections is the selection of complete or partial joint penetration groove welds. Too often the designer takes the easy way out and in one sweeping statement requires all complete joint penetration groove welds. This is usually a very expensive "cop-out". In most static applications using mild steels and 70 ksi filler metals (i.e., E7018 or F71T-1), the prequalified partial penetration TYK weld details will perform as well as the complete penetration welds; however, the designer must perform some additional strength checks. The advantages of the partial penetration weld details are found in less stringent requirements for fitups and welder's skill levels. For instance, the prequalified details for the complete joint penetration TYK-connection require a minimum root opening in order to develop the design penetration. Achieving this requires more fussy preparation of bevels and fitting. For partial penetration, on the other hand, the root opening can be zero and there are significant differences in welder skill requirements which will be discussed later.

metal arc GOUGING TORCH WITH 360° FREE REVOLING CABLE



Metal Arc Torches are used to Gouge, Chamfer, Groove, Cut, Bevel,Flush off all metals including Aluminium, Copper, Brass, Magnesium, Alloys, Steel, Stainless Steel, Cast Iron and is used by major foundries, shipyards, penstock/pipe and all structural fabricators, chemical & petroleum complexes.

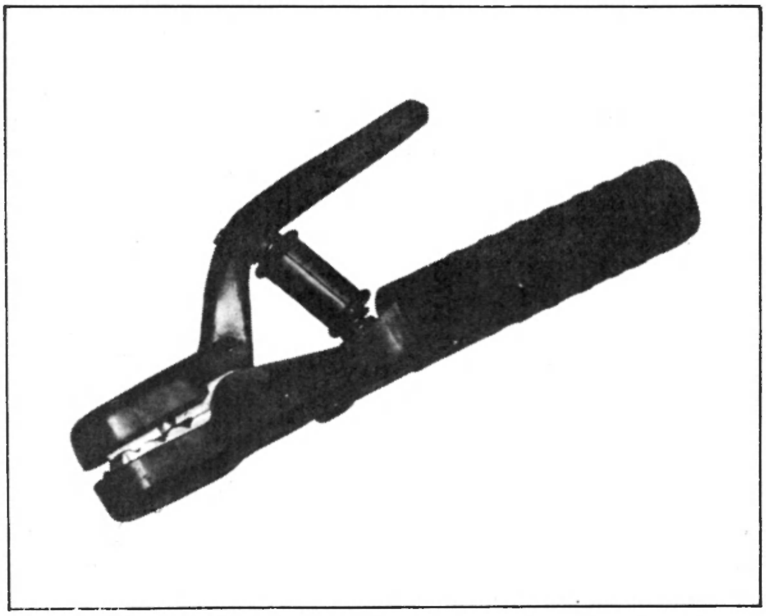
Gouging Torches are available in 3 models,M-1 for Standard Duty (for 3-8 mm Ø), M-2 for Heavy Duty (6-13 mm Ø) and Super Heavy Duty (8-19 mm Ø) Gouging Carbons.

PROCESS DESCRIPTION

The process involves (a) The striking of an ARC between the metal workpiece and the carbon electrode. (b) Melting by the ARC, and (c) Removal of the molten metal with compressed air jets, flowing parallel to the electrode from the torch.

SPECIAL FEATURES:

* For high conductivity of current, copper is used end to end.
* Heat resistant insulators (for longer life of the torch)
* Triple swivel head air nozzels (for better metal removal rate)
* High tension lever allowing firm grip of the electrode (prevents arcing)
* Insulated dual purpose monocable for compressed air and electrical current.
* 360° Free revolving movement between torch and monocable (resulting in less wrist stress for welder and better fatigue free working)

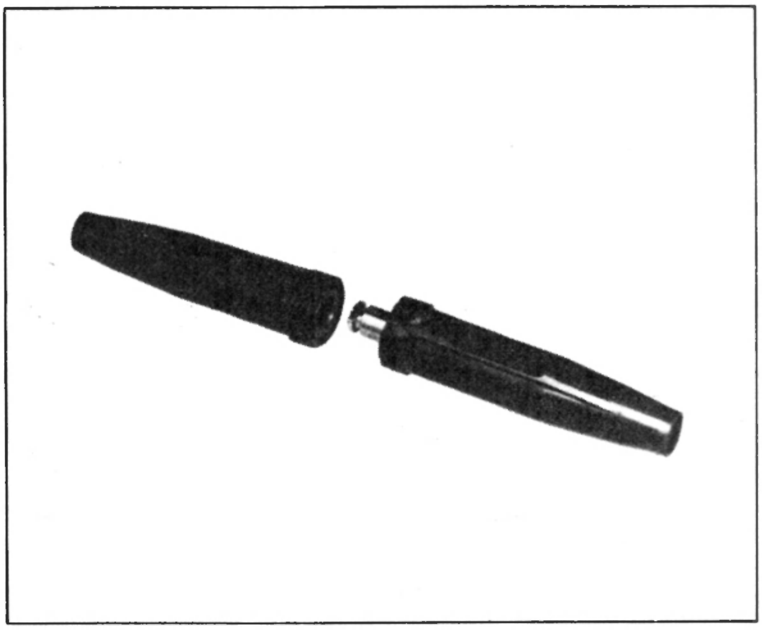


metal arc WELDING HOLDER WH-I

* For heavy duty manual arc welding.
* For current rating upto 600 Amps.
* Suitable for electrode dia up to 8mm.
* Open mouth jaw type.
* 100% fully insulated.
* Light weight and easy to handle.

SPECIAL FEATURES:

* Main body is made out of one piece brass alloy resulting in better current transmission, special design features ensure low heat and long life.
* Hood covers and handle are made out of special heat and arc resistant compounds to protect the welding holder from arc damage.
* For quick connection/disconnection of cable/holder, handle can be removed by one recessed allen screw.
* For better cable connection 3 allen screws provided with D shape grip plate



metal arc CABLE CONNECTORS 600 AMPS

SPECIAL FEATURES:

* Heavy duty cable connector suitable for high capacity usage and efficient operation to perform at nominal voltage drop and at high duty cycles.
* Interlocking parts made of high conductivity brass machined for close tolerance and perfect fit.
* The male and female ends of the connector have quick locking arrangement for positive engage/ disengage by 180° twist.
* Tension adjustments made easily on the split male plug with a screw driver.
* Better and quick cable connection at each end by alien screws and D shape grip plate.
* Fully insulated with special heat resistant rubber covers for safe operation under normal working conditions.

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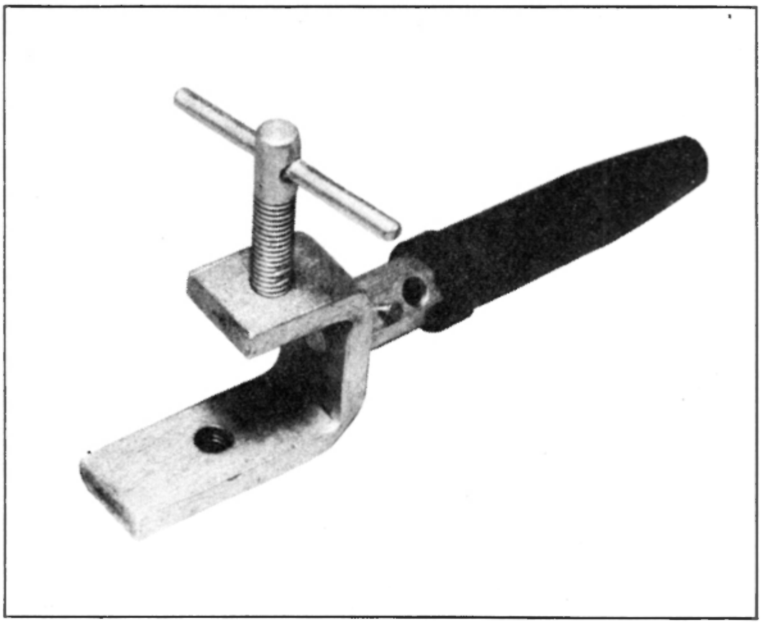
metal arc EARTH CLAMP 600 AMPS



SPECIAL FEATURES:

* For current rating upto 600 Amps.
* Robust construction from M.S. Section duly plated for longer life.
* Manual clamping effected through a screw ensuring full contact.
* Cable is fixed quickly and efficiently by two alien screws.
* Optional insulator cover available for cable connection.

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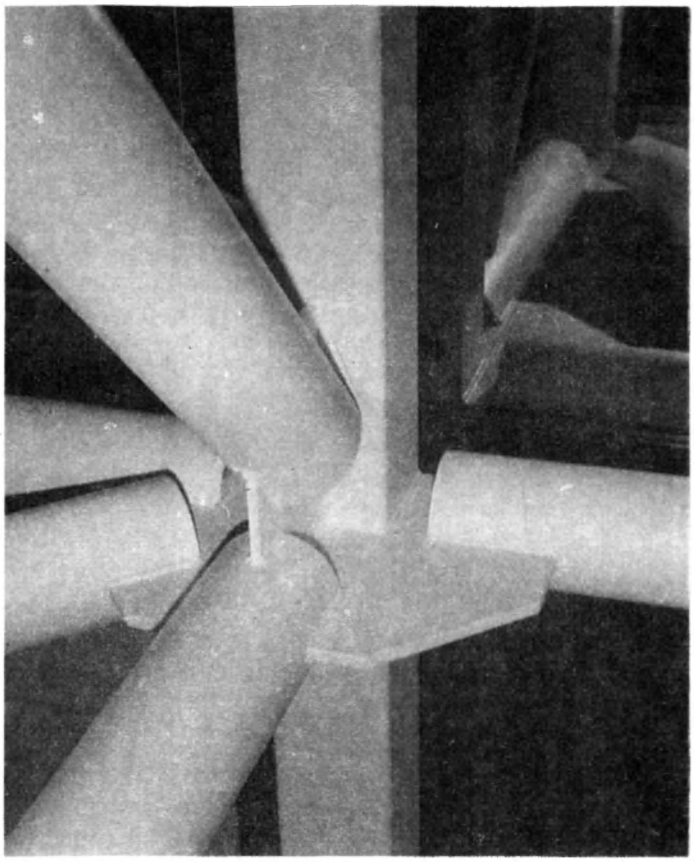

Fig. 3. *The knife-edge gusset shown here requires extra parts, more welding, and more blasting and painting.*

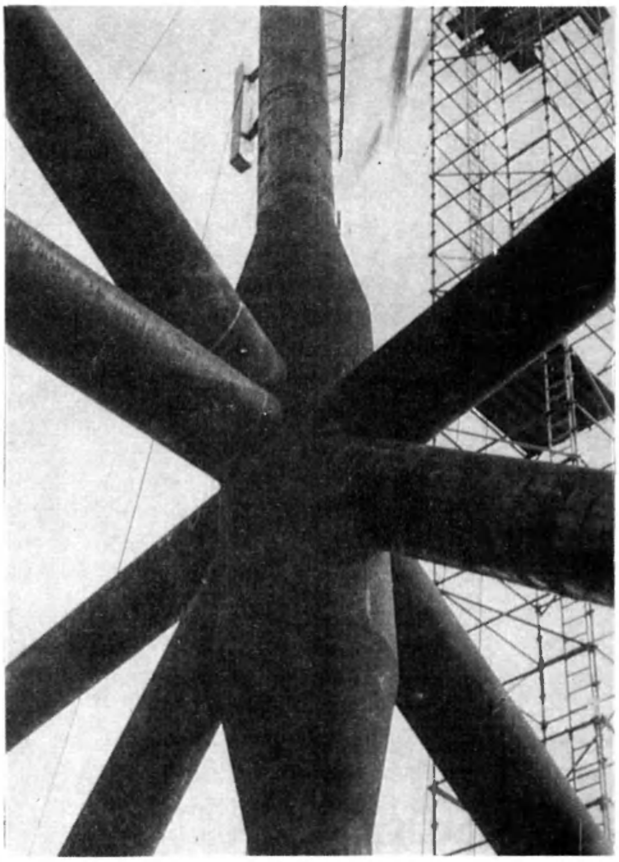

Fig. 4. *Example of a "balloon member".*

Knife-Edge Problem

Some designers or detailers feel that the use of shear plates or knife-edge gussets is the surest solution to a tubular connection problem. Indeed, the gusset-plate approach has been used successfully for many years. However, for aesthetic applications, the gusset plates make the connection appear awkward, busy, and cluttered. From a fabrication standpoint, the gusset plate concept added to coped branch member ends requires extra parts, added cutting costs, more welding, and more blasting and painting (see Figure 3).

Joint Cans

A joint can is a thicker section of pipe or tube spliced into a chord or main member. This provides a connection that is both structurally efficient and aesthetically pleasing. In most connections, the chord member must withstand the additional loads imposed by the branch members. These loads may be superimposed on its own axial loads in the form of punching shear, ovalyzing or shell bending. Design parameters[1,5] cover these cases for both round and box tube connections. A specialized type of joint can, called a "balloon member," is illustrated in Figure 4.

Butt Splices

Butt joints or splices in tubular members do not fall within the true definition of a tubular connection. However, in the cases of short segments or stubs welded to main members for field erection, economic use of material, or long-span truss chords, no discussion of fabrication practices for tubular connections would be complete without discussing butt joints. Also, the joint can concept previously discussed requires butt splices. For members larger than twenty-four inches and accessible from one or both ends, back welding is readily done. For smaller members or restricted access, other techniques are required. For tension members, complete joint penetration is required, while compression members in some applications may have partial penetration welds. In order to comply with the philosophy of AWS D1.1 for complete joit penetration groove welds, backing or back-gouging and back welding are required. For the special tubular butt joint case when access is prevented, backing or all of the special provisions of 10.12.3.1 of D1.1 are required.

Often fabricators or erectors devise field connections with short stubs shop welded to main members,

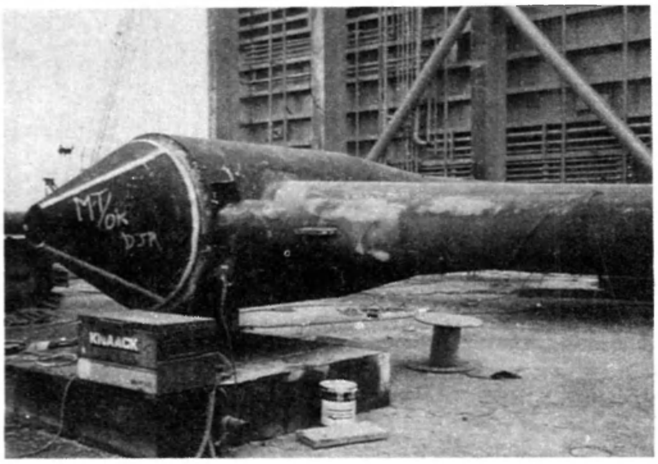

Fig. 5. *Examples of "stabbing points" for horizontal or vertical applications*

presumably to avoid field welded TYK-connections. In some cases there may be no acceptable alternative. However, in many cases the stubs cause more problems than they solve. Any stub automatically doubles the man-hours needed to cut, fit, weld, and inspect the additional joint added to the branch member.

Any use of stubs requires an inordinate amount of care in shop layout and fitup. Even where this is done, welding shrinkage may move or rotate the members. In the field, even the slightest misalignments show up as a ''dog leg''. The added shop care and the field alignment problems should far outweigh the fear of dealing with the connections in the field.

Commercial backing rings for pipe are available in a wide variety of styles and sizes. Some pipe sizes can be cut or machined to produce continuous rings. They can also be rolled from suitable flat bar stock. Rings can be clamped in place, cut to length, removed to make the complete penetration butt weld, and reinstalled as a continuous ring in the pipe ready for fitup. Larger rings are sometimes tacked in place, cut to length, and butt welded using the pipe I.D. as backing for half of the butt splice. The other half requires back gouging or grinding and back welding. Radiography easily shows the failure to produce proper butt splices in the backing ring. The tacking of backing rings should be done on the beveled face. Small tacks done on the inside may crack and go undetected at assembly, but may show up in subsequent radiography of the completed jint. At this stage, the repair or removal of cracked tacks would be very expensive.

A variation on simple backing rings that has proven very useful for offshore construction is the ''stabbing point'' (see Figure 5). These erection aids with integral backing are easy to engage during construction. Offshore, the points are made long and allow the member to become selfsupporting for piling add-on applications. Deck legs usually have stubby cones used as stabbing points. For horizontal applications, the point should be kept short to avoid alignment difficulties.

WELDING

Processes

The welding of tubular butt splices and connections utilize the group of welding processes familiar to structural shops. SAW is routinely used for long seams in pipe where a fabricator rolls his own. The process is also used for tubular butt joints and, with smaller diameter electrodes and flux dams, it has been used down to at least six inch diameter. SAW has prequalified status for diameters 24" and greater. SMAW, FCAW (both self-shielded and gas shielded), and GMAW have been used successfully for many years on tubular applications. The SMAW process is the old workhorse with a large selection of electrode types, alloys, sizes, and operating characteristics. It is very economical in terms of original cost and very portable, but the cost of the weld metal deposited is high compared to semi-automatic processes. GMAW in spray transfer mode is limited to flat and horizontal applications. GMAW-S (short-circuiting transfer) is good for thin materials less than three-eighths of an inch and for root passes where poor fitup may be present.

FCAW-G (gas-shielded) is a good allposition process and weld metal deposition rates are significantly higher than those of SMAW. The FCAW-G process and the GMAW require an auxillary gas shield and a gas cup on the head of the welding gun to deliver gas to the welding zone. This gas cup adds a visibility problem for the welder. It prevents access to the root of the joint with thicker beveled members or tight intersection angles. Also, the gas is easily disturbed by drafts and wind, all but precluding its use in field construction without suitable wind breaks.

FCAW-SS (self-shielded), on the other hand, has some outstanding features for tubular construction and does not require the auxillary gas. All of its shielding is produced in the arc by the burning of some of its core ingredients; therefore, it is immune to all but the strongest of winds. The welder has equal or better visibility, versus the SMAW welder, and the process doesn't have the accessibility problem in tight places. In fact, the welder can use longer electrode extensions and weld through tight heel areas without stopping to change electrodes. One disadvantage of FCAW-SS is that it may be too hot for thinner wall thickness pipe and tube.

Procedure Qualification

There is a family of prequalified joint details provided in Section 10 of AWS D1.1 suitable for use with SMAW, FCAW and GMAW-S. The SAW process usually can be done using the applicable prequalified butt joints found in Section 2 of the Code. For TYK-connections, prequalified welding procedures may be prepared by fabricators and erectors for SMAW or FCAW in accordance with the Code provisions. GMAW-S never has prequalified status and must always be qualified by testing. If there are other job-specific requirements such as toughness to be considered, and process will require procedure qualification testing. In addition, for any groove angle less than 30°, an Acute Angle Heel Test representing the tightest groove angle and greatest groove depth must be done even when the joint is otherwise prequalified. For the most common structural steel pipe or tube, with grooves 30° or greater, and where no other job-specific limitations on welding procedures exist, it is a relatively simple matter to prepare prequalified welding procedure specifications for tubular applications.

Performance Qualification

Performance qualification may pose an even greater challenge than procedure qualification. There are no prequalified welders. Each contractor is responsible to see that his welders are all properly qualified by testing. Welders must qualify for the welding process, in the position required for production, and in the direction (uphill or downhill) of weld progression. Welding on tubular connections differs from conventional plate and rolled shape construction in several important aspects. Position of welding changes continuously in going around the connection, and the local joint geometry also changes. For complete joint penetration groove welds, the Code requires welders to pass the more challenging 6GR test. The test uses a 37.5° groove angle and the welders are thus qualified down to 30° For grooves under 30°, the welders also must pass the Acute Angle Heel Test, which covers them down to 15°. Such cases frequently occur. For example, a 45° brace intersection requires a 22.5° groove angle in the heel area. Further, welders working on complete joint penetration groove welds in box tubes must also pass the special corner macroetch test. This test checks their ability to deposit sound weld metal around the relatively sharp corners, which are the areas of highest load transfer across the weld.

For partial penetration connections, the welder testing requirements are significantly reduced. The 6GR test is not required, but may be used. The 2G plus 5G tests with backing provide an acceptable alternative and are usually much easier for welders to pass. For box tubes, the macroetch corner test is not required. Also, since there are no groove angles less than 30° permitted with the prequalified details, the Acute Angle Heel Test does not apply.

The fact that a welder has passed the prescribed tests does not necessarily mean that he will be able to handle all conditions that may arise during production welding. Therefore, ongoing training and supervision are essential.

WORKMANSHIP

Workmanship standards and requirements are detailed in Section 3 and Part E of Section 10 of AWS D1.1. For aesthetic applications, weld profile appearance standards should be set higher and can be achieved with minimal increase in cost and usually without fully grinding the weld surface. Butt joints, however, usually should be ground flush and smooth. In this case, the welds should be made with minimal reinforcement and practically no undercutting prior to grinding. For the TYK-connections, a weave bead on the capping layer should only be used on the thinnest material. Usually, a uniformly spaced series of stringer beads looks better than wide weave beads. Downhill capping techniques produce flatter beads and smoother profiles than uphill capping beads. Concave surface profiles look better than convex profiles and are required for thicker sections[1].

For aesthetic applications, bid specifications should include a requirement for the contractors to submit a workmanship sample or mockup of an actual connection prior to the start of the job. When accepted by the owner and architect, this becomes the reference standard to judge workmanship of the production work.

For architectural consideration, the following aditional items should be addressed in the specifications:

1. Material purchasing restrictions to limit surface conditions (e.g., ASTM A53 can have 12.5 % deep pits and 0.25" deep dents).
2. Handling and storage of materials to minimize dents, scratches, gouges, and corrosion pitting.
3. Prohibit crescent moon dents on the members (hammer faces struck flat against pipe or onto a block of wood will minimize these dents).
4. High-build epoxy paints may be specified to hide small surface imperfections.

INSPECTION

Visual

Visual inspection by a competent inspector is the all-around best inspection method for tubular connections. The inspector may or may not be an AWS Certified Welding Inspector, but he really needs to have experience with tubular connections. The competent inspector can evaluate weld quality from surface workmanship. He can quickly determine its surface profile acceptability, meeting all the workmanship requirements and workmanship standards set by the mock-up. He should also inspect fit-ups prior to welding. For complete joint penetration groove welds of the highest quality, it is esential that all fit-ups be inspected. This is especially true for connections that will not or cannot be tested with ultrasonic methods.

Radiography

Radiography of tubular butt joints is practical and recommended. A variety of techniques are routinely used to cover the entire diameter range encountered. For diameters down to 10", panoramic shots are practicable. Contact shots are acceptable down to 3". Elliptical radiographic exposure may be used on pipe 3.5" or smaller. Box tubes may require additional shots to properly interpret the relatively sharp corner radii. Radiography is not practicable for the standard TYK-connections in round pipe. However, some special techniques may be used to investigate portions of matched box connections.

Ultrasonic

Ultrasonic testing methods have been developed and used successfully for many years in the offshore platform industry. The same techniques are usable onshore. Conventional tecnniques are applicable to diameters greater than 12", materials 0.5" and thicker. Special techniques are required beyond these limits and should be properly tested and evaluated. Here again, experience is the key operative word. The geometry of the connection can give many strange signals to the uninitiated. Also, ultrasonic testing is an excellent nondestructive testing method for evaluating chord members susceptible to lamellar tearing. This might occur on members that are highly restrained or are produced from material of questionable internal cleanliness (i.e., sulphur and other nonmetallic inclusions).

Magnetic Particle

Magnetic particle testing is useful with 50 ksi and higher yield strength steels that may be susceptible to delayed hydrogen cracking. Such testing should be done a minimum of forty-eight hours after welding is completed to allow hydrogen cracking to manifest itself. For all field and out-of-position shop testing, the wet method is preferred. In this case, a white background paint is applied to the weld joint. Black magnetic particles in a water suspension are then sprayed onto the weld area in the presence of a magnetic flux field produced by a portable AC yoke. The water suspended particles have greater mobility in the flux field than the dry particles, while the white paint provides exceptional contrast. The wet spray is preferable to dry particles for out-of-position work and in drafts.

SUMMARY

Tubular connections offer many practical and aesthetic design advantages. Consistent attention to the following principles will ensure successful results.

- Design for non-overlapping brace ends whenever practicable.
- Select prequalified materials. Beware of oil country tubular goods, e.g., well casing.
- Design for partial penetration welds wherever possible.
- Rely on visual inspection by experienced inspectors.
- Require visual inspection of fitups, especially for complete joint penetration TYK-connections.
- Consider toughness and through-thickness properties where warranted.
- Minimize the use of stubs and consider "windows" in place of stubs. Resist the temptation to use offset stubs for field connections.

In addition, for architectural and aesthetic application:

- Avoid knife-edge gussets in the connections.
- Require a workmanship sample or mock-up to set the standard for visual acceptance.
- Place limitations on surface finish of material.
- Require special care in fabrication and handling.
- Prohibit hammer marks.
- Require high-build epoxies.

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