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**"Chapter 2 – Layout and Fabrication of
Structural Steel and Pipe"**

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Chapter 2

Layout and Fabrication of Structural Steel and Pipe

Topics

- 1.0.0 Fabricating Plate and Structural Members
- 2.0.0 Pipe Fitting
- 3.0.0 Pipe Cutting
- 4.0.0 Pipe Bending

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Overview

As a Steelworker, you need to know how to lay out and fabricate steel plate and structural steel members. While plate layout procedures are similar to those for sheet metal, there are some procedures of plate fabrication that are fundamentally different, and they are described in this chapter. Steelworkers are also tasked with constructing and installing piping systems designed to carry large quantities of liquids over long distances, so pipe layout and fabrication are other project tasks you can expect.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the procedures associated with fabricating plate and structural members.
2. Describe the procedures associated with pipe fitting.
3. Describe the procedures associated with pipe cutting.
4. Describe the procedures associated with pipe bending.

Prerequisites

None

1.0.0 FABRICATING PLATE and STRUCTURAL MEMBERS

In Steelworker Basic, you dealt with already fabricated assemblies such as the PEBs and the towers. However, in order to get to the assembly stage of a structural project, someone needs to lay out and fabricate the steel plate into structural members (*Figure 2-1*), and that someone may be you.



Figure 2-1 — Structural members.

Steel plate is much thicker than sheet steel, and it is more difficult to work with and form into the desired shapes (*Figure 2-2*).

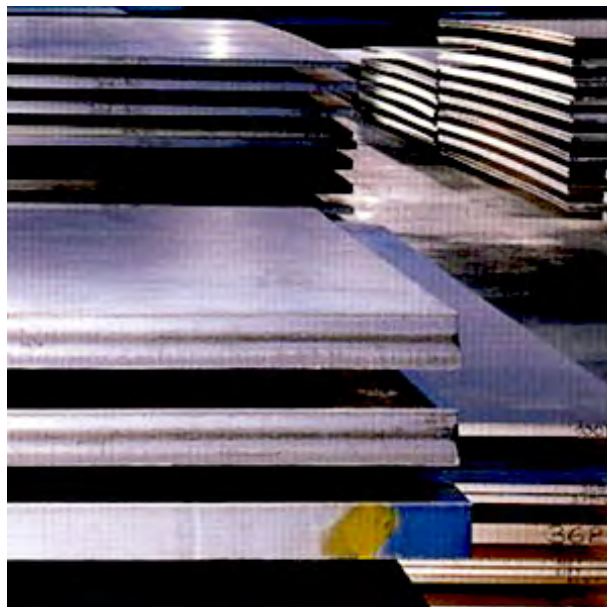
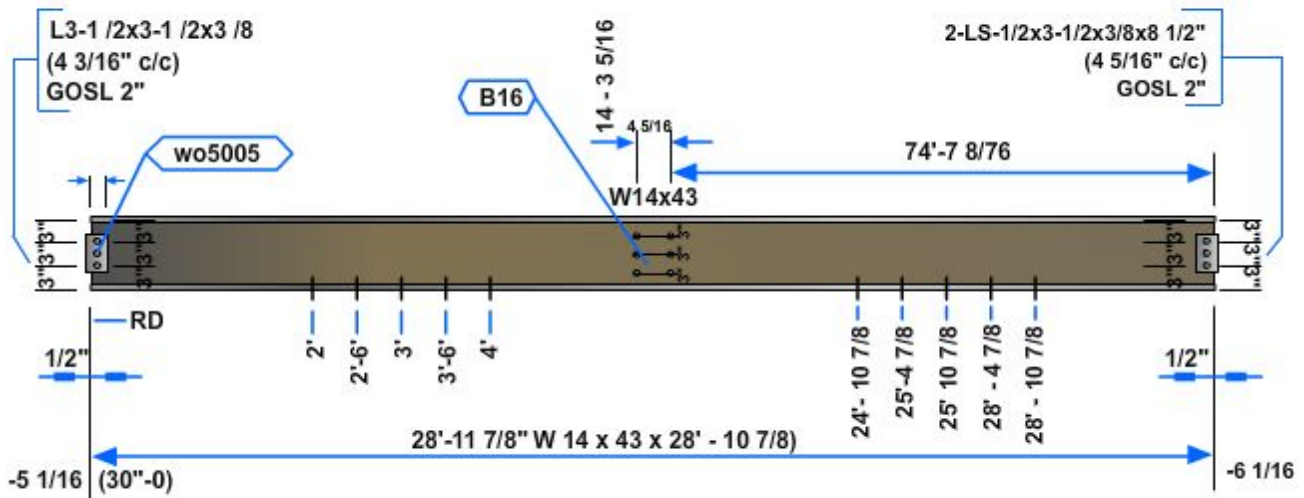


Figure 2-2 — Steel plate.

In order to fabricate steel plate properly, you will need the following:

- Adequate lighting to see the small marks you will scratch on the steel.
- Tools available and accessible in the work area.
- Accurate field sketches or shop drawings of the item to be fabricated, such as the one shown in *Figure 2-3*.



No.	Qty	POS. Number	Part Name	Length	Weight	Total Num
1	1	B16	W 14 x 43	28'-11 7/8"	1267.1700	1
2	1	16	W 14 x 43	28'-10 7/8"	1243.0583	1
3	4	wo5005	L3-1/2x3-1/2x3/8	B 1/2"	8.0279	20

Figure 2-3 — Shop drawing.

1.1.0 Layout of Steel Plate

When laying out steel plate you need the following tools:

- Adequate straightedge scale, such as a combination square with a square head
- Accurate protractor
- Set of dividers
- Prick punch
- Center punch
- Ball peen hammer

Before you make any layout marks on steel, first wire brush the intended mark area and then remove all residues with a brush or rag. Next, paint the surface with a colored

marking compound. Aerosol spray works very well; it allows the paint to fall only in the areas to be laid out and it produces a thin coat of paint that will not chip or peel off when you begin scribing the lines.

When appropriate, you can use a soapstone marker or a similar device to lay out the lines, but remember that many of the markings from these drawing devices can be either burned off or blown away by the flame or the force of oxygen from the cutting torch.

This is unacceptable and it can ruin an entire fabrication job. If you have no other options besides soapstone or a similar marker, be sure you use a punch and ball peen hammer to make marks along the cut lines. By “connecting the dots” in your cutting operation, you can ensure accuracy.

Plan ahead for minimal material usage before you start scratching the layout on a plate. However, be sure to include enough room between parts to allow for the *kerf* of the cutting torch, depending on the tip size. An example of proper plate layout and material usage is shown in *Figure 2-4*. Observe the material used for the cooling box; it will take up slightly more than half of the plate, and the rest of the material can then be used for another job. This is only one example, but the idea is to conserve materials. An example of poor layout is shown in *Figure 2-5*. The entire plate is used up for this one project; it wastes material and increases layout time.

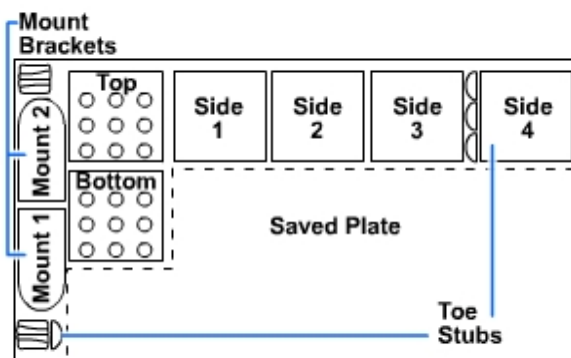


Figure 2-4 — Proper plate steel cooling box layout.

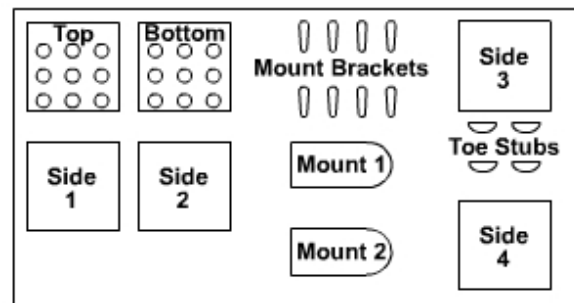


Figure 2-5 — Improper plate steel cooling box layout.

As the layout person, you must have a straight line or straightedge as the reference to which you can refer all measurements. This straightedge or line can be one edge of the work that has been finished straight, or it can be an outside straight line fastened to the work, such as a straightedge clamped to the work. Once you have established the reference line, you can proceed with the layout as you learned in *Steelworker Basic*, Chapter 13, *Layout and Fabrication of Sheet-Metal and Fiber and Glass Duct*.

When your layout is complete, check it for accuracy, ensuring all the parts are in the layout and the measurements are correct. After determining the layout is accurate, center punch all cutting lines; this ensures accurate cutting with either torch or shears. If the shears are used, you can easily check the work after cutting because each piece will have one-half of the center punch marks on the edge of the material. If a torch is used, always remember to cut with the kerf of the torch on the outside edge of the cutting lines.

1.2.0 Layout of Structural Shapes

Structural shapes are slightly more difficult to lay out than plate because the layout lines may not be in your view at all times, and in fact, the reference line may not always be in view either. Note the angle, bolt hole, and coping difficulties in laying out the beam in *Figure 2-6*.

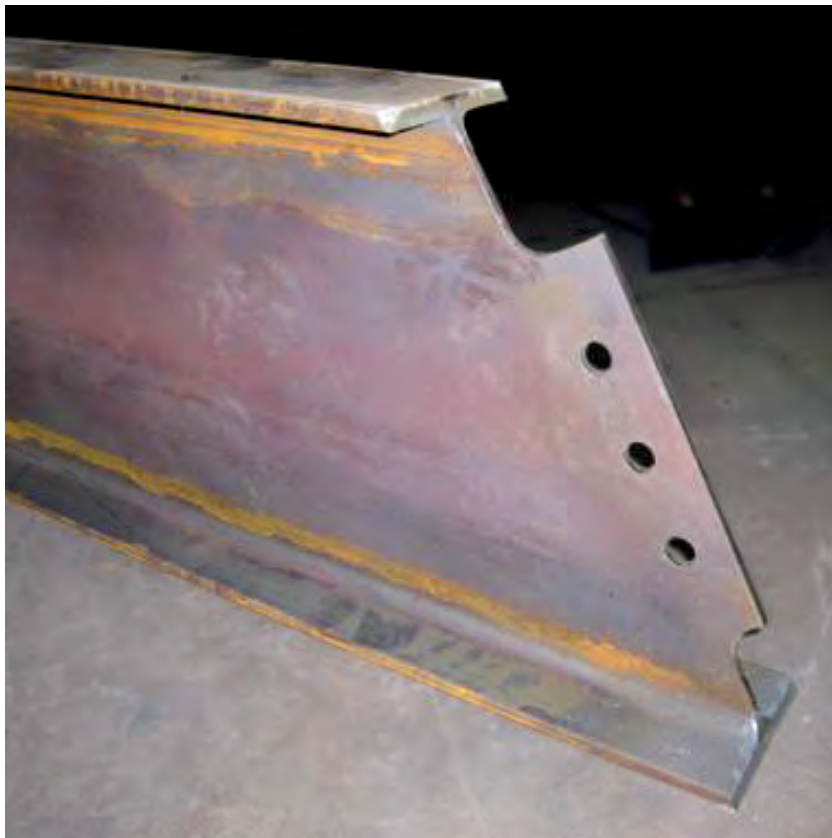


Figure 2-6 — Steel beam layout.

Steel beams are usually fabricated to fit up to another beam, which requires coping and slotting to accomplish. *Figure 2-7* shows two W 10 x 39 beams being fitted up, with beam A intersecting beam B at a flush elevation. Coping is required so beam A will butt up to the web of beam B; then the connecting angles can be welded to the web and the flanges can be welded together (welding symbols omitted).

Note the fillet allowance cut of 1 1/8 inches (2.8 cm) long at 45 degrees at the end of the flange cope. This will allow for the fillets at the intersection of beam B's web and flanges. The size of the cope for beam A is determined by dividing the flange width (8") of the receiving beam (B) in half (4") and then subtracting one-half of the thickness of the 5/16 web (5/32") plus 1/16 (2/32) inch. This determines how far back on beam A the cope should be cut.

Solution:

$$4'' - \left(\frac{5}{32} + \frac{2}{32} \right) = 3 \frac{25}{32} \text{ or rounded up to 16ths} = 3 \frac{13}{16}''$$

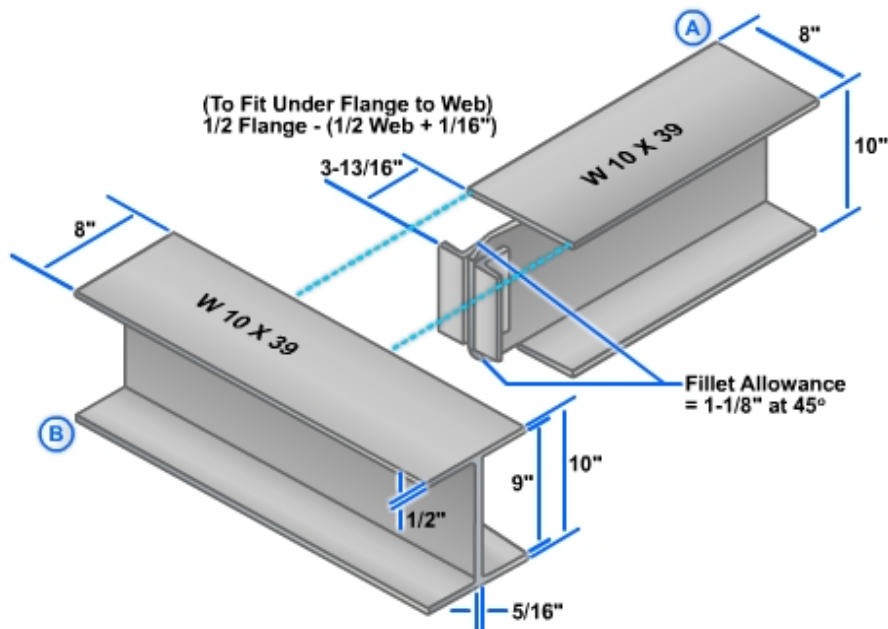


Figure 2-7 — Fabrication and fit-up for joining two beams of the same size.

When beams of different sizes are connected, the layout is determined by whether the intersecting beam is larger or smaller than the intersected beam, and whether a flange of each is to be on a common plane. In the case shown in *Figure 2-8*, the intersecting beam is smaller (S 8 vs S 10); therefore, only one flange is coped to fit the other since in this case the top flanges will be flush. Note that in this case the necessary coping is much less than the previous example because the beams are not W or wide-flange beams; also note that the angles on this connection are to be bolted, rather than welded.

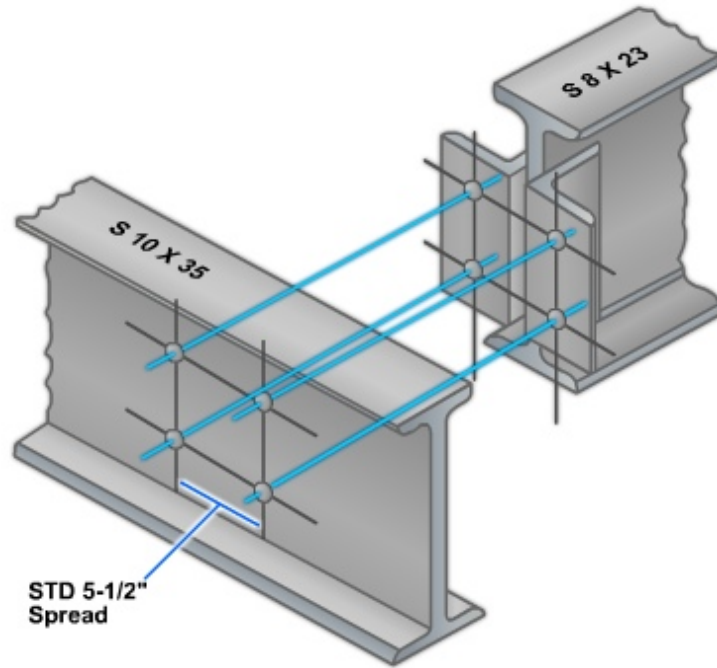


Figure 2-8 — Typical framed construction, top flange flush.

1.3.0 Connection Angle Layout

The connection angle is a very common connection with framed construction (*Figure 2-9*).

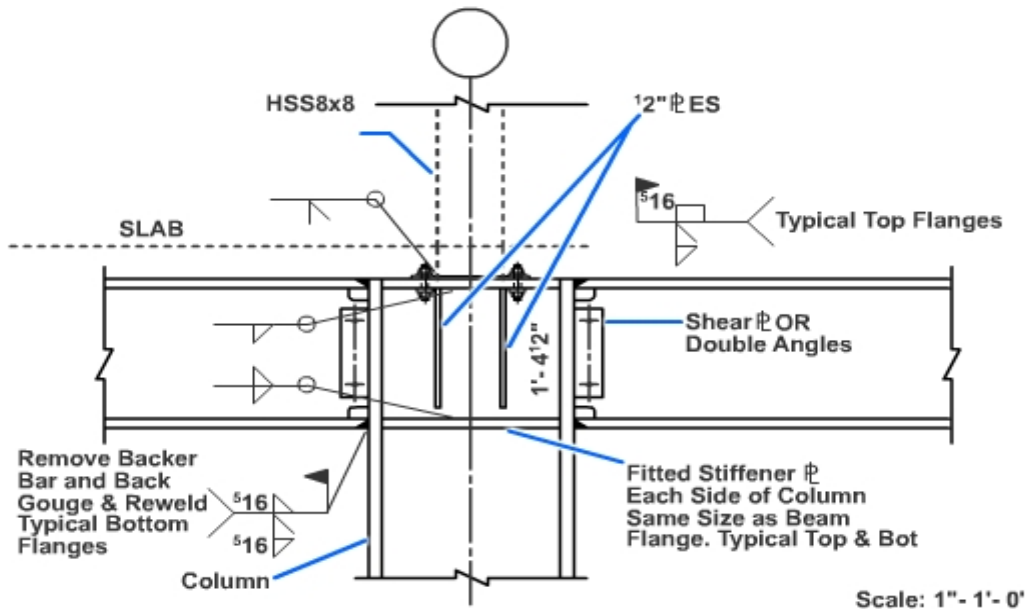


Figure 2-9 — Connection angle layout.

The legs of the angles used as connections are specified according to the surface to which they are to be connected, and use distinct terminology:

- Web legs — the legs of the angle that attach to the intersecting steel beam.
- Outstanding legs — the legs of the angles that attach to the supporting or intersected steel beam.
- Gauge lines — the lines in which holes in the angle legs are placed.
- Gauges — the distances between gauge lines and known edges.

Figure 2-10 shows an example of a completed connection with the various terms for connection angles, and the constant dimensions for a standard 4" X 4" X 8 1/2" connection angle are shown in Figure 2-11.

The distance from the heel of the angle to the first gauge line on the *web leg* is termed the *web leg gauge*. This dimension has been standardized at 2 1/4 inches (5.6 cm).

NOTE: This dimension is constant and does not vary.

The distance from the heel of the angle to the first gauge line on the *outstanding leg* is called the *outstanding leg gauge*. NOTE: This dimension varies as the thickness of the member, or beam, varies. This variation is necessary to maintain a constant 5 1/2-inch-spread dimension on the angle connection. You can determine the outstanding leg gauge dimension in either one of two ways:

1. Subtract the web thickness from 5 1/2 inches (13.8 cm) and divide by 2.
2. Subtract 1/2 of the web thickness from 2 3/4 inches.

The distance between holes on any gauge line is called *pitch*. This dimension has been standardized at 3 inches (7.5 cm).

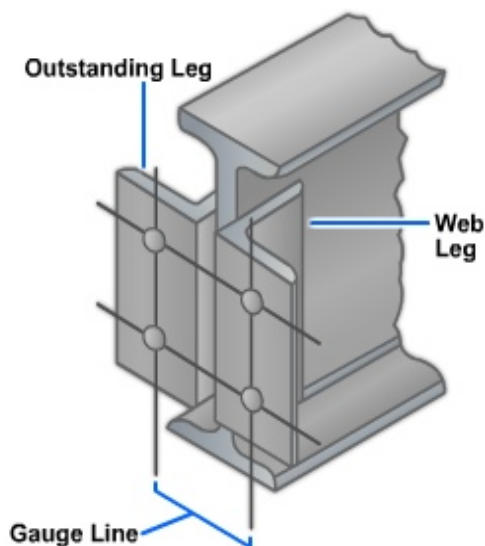


Figure 2-10 — Gauge lines.

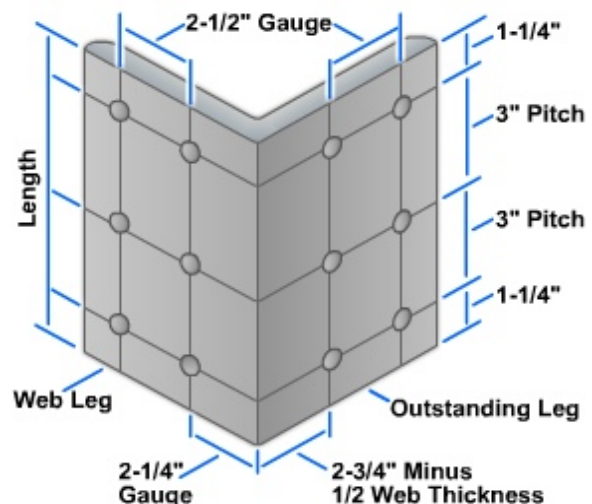


Figure 2-11 — Standard layout for connecting angle using 4x4 inch angle.

The end distance is equal to one-half of the remainder left after subtracting the total of all pitch spaces from the length of the angle. By common practice, the angle length that is selected should give a 1 1/4-inch (3-cm) end distance.

This section cannot cover all layout and fabrication procedures, but some examples are shown in *Figure 2-12*. Notice that the layout and fabrication yard has a table designed to allow for layout, cutting, and welding with minimum movement of the structural members, and the stock materials are stored with like kinds of materials.

In addition, the fab table is holding two columns being fabricated out of beams with added baseplates and cap plates, as well as two angles that have already been coped, and there are angle clips for seated connections being installed before erection. *Figure 2-13* shows a seated beam to column connection where the beam and column flanges are the same size.

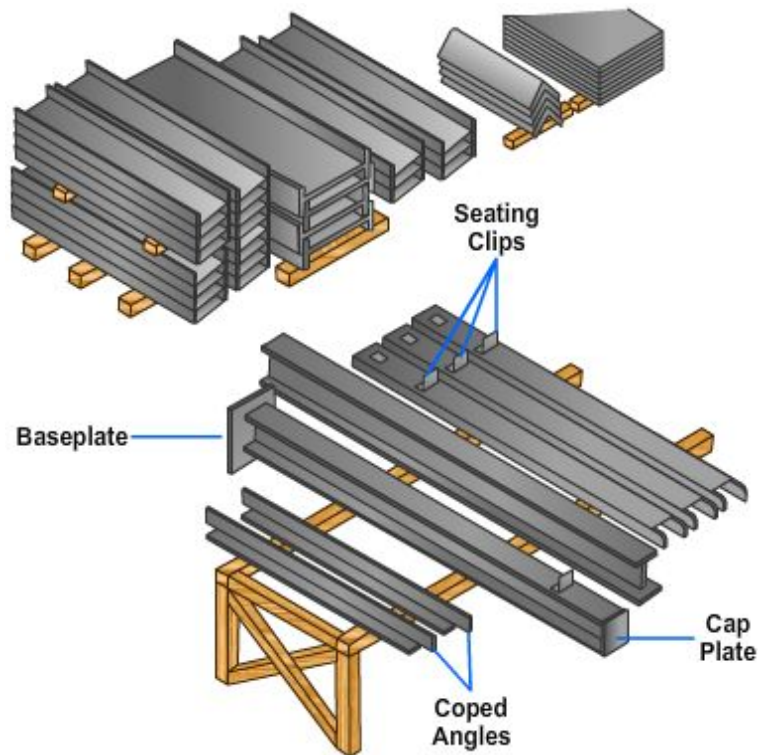


Figure 2-12 — Prefab table and steel storage.

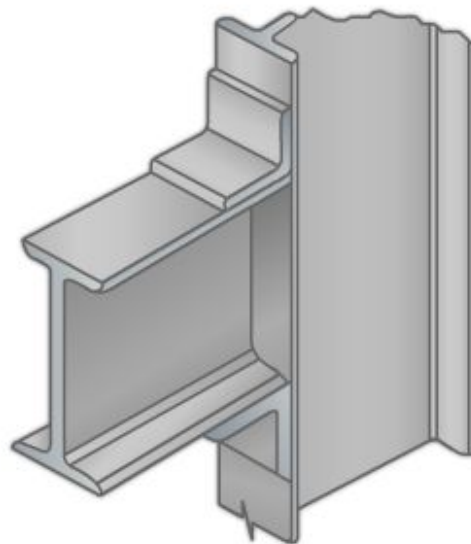


Figure 2-13 — Seated connection.

1.4.0 Cutting and Splicing Beams

As the fabricator, at times you will need to split a beam lengthwise to make a tee shape from an I shape, and you do this by splitting through the web. However, unless you carefully control the splitting process, the split parts will bend or warp from the release of internal stresses locked up in the beams during the manufacturer's rolling process. Use the following procedure to cut and split a beam.

1. Cut the beam to the desired length.
2. Make splitting cuts about 2 feet (60 cm) long, leaving 2 inches (5 cm) of undisturbed metal between all cuts and at the end of the beam (*Figure 2-14*).
3. Cool the steel behind the torch with a water spray or wet burlap.
4. Allow the beam to cool.
5. Starting at the center of the beam and working toward the ends, cut through the metal between the cuts following the order shown in *Figure 2-14*.

This procedure also works very well when splitting plate and you should use it when making bars from plate. You can make multiple cuts from plate by staggering the splitting procedure before cutting the space between slits. If you use this procedure, be sure to cool the entire plate so the bars will not warp or bend.

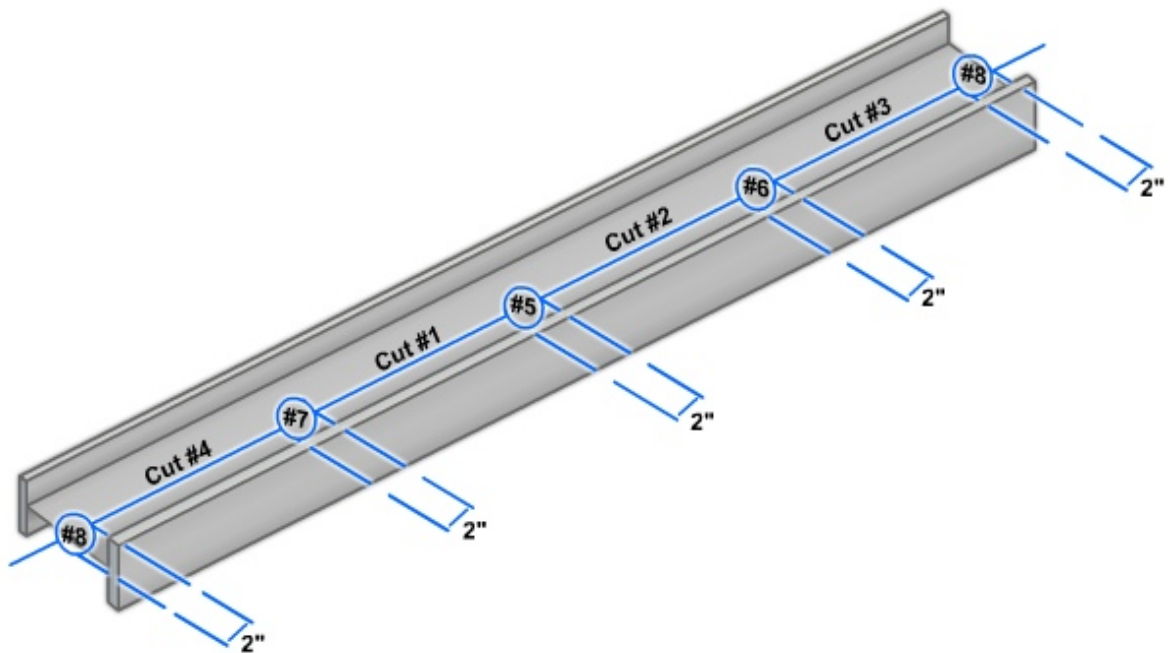


Figure 2-14 — Cutting order for splitting a beam.

1.5.0 Templates

When you need to produce a part in quantity, make a template first and lay out the job from the template. A template is any pattern made that is used as a guide for the work to be done; you can make it from sheet metal, regular template paper, wood, or any other suitable material. A template can be the exact size and shape of the corresponding piece (*Figure 2-15, Views 1 and 2*), or it may cover only the portions of the piece that contains holes or cuts (*Figure 2-15, Views 3 and 4*).

When you are going to make holes, cuts, and bends in a finished piece, the pilot holes, punch marks, and notches in the template must correspond exactly to the desired location in the finished piece. To make templates for short members and plates, use template paper of the same size as the piece to be fabricated. To make templates for angles, fold them longitudinally along the line of the heel of the angle (*Figure 2-15, View 3*).

Templates need specific attention and double-checking for accuracy, and often need to be held to closer tolerances than production models. Obviously, when you are going to produce a number of parts from a template, using inaccurate measurements to make the template will mean all parts produced from it will also be wrong, thus wasting time and resources.

Template paper is a heavy cardboard material with a waxed surface well adapted to scribe and divider marks. When size, dimensions, and planned reuse are appropriate, you can make a template from a combination of wood and template paper.

For long members, such as beams, columns, and truss members, your templates may cover only the connections joined by a wooden strip to ensure accurate spacing (*Figure 2-15, Views 1 and 2*). Alternatively, you can handle them separately, with the template for each connection being clamped to the member after spacing, aligning, and measuring along the production piece for the proper location.

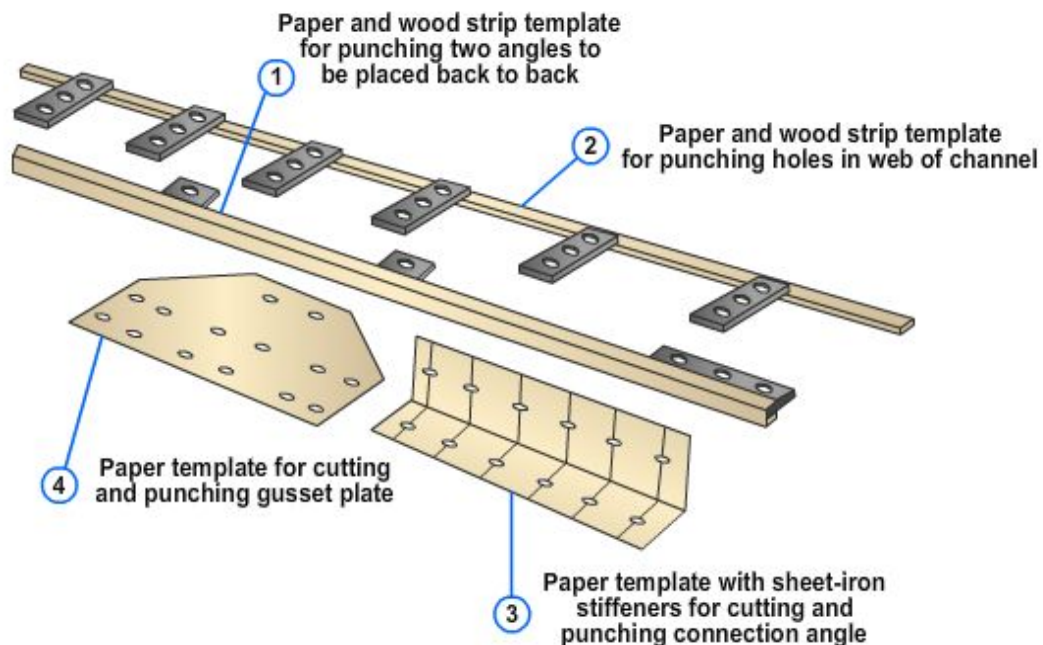


Figure 2-15 — Paper and combination templates.

To make the templates, use the same layout tools discussed in *Steelworker Basic*, Chapter 13, *Layout and Fabrication of Sheet-Metal and Fiber and Glass Duct*, except that for marking lines, you can use a pencil or Patternmaker's knife on the template paper. Also, remember when you align punch holes in a template, the purpose of the holes is to specify the center location, not the size of the hole; therefore, you can use a single diameter punch for all holes. If necessary, make holes and cuts more prominent by marking them with paint.

Mark each template with the following information:

1. Item number of the stock material to be used in making the piece.
2. Description of the material.
3. Assembly mark of the piece it is to be used with.

When you lay out a production piece from a template, do the following:

1. Clamp the template to the material in the exact position.
2. Center punch the holes directly through the holes in the template (*Figure 2-16*).
3. Mark all cuts.
4. Remove the template.
5. Center punch the cut marks to make permanent rows.

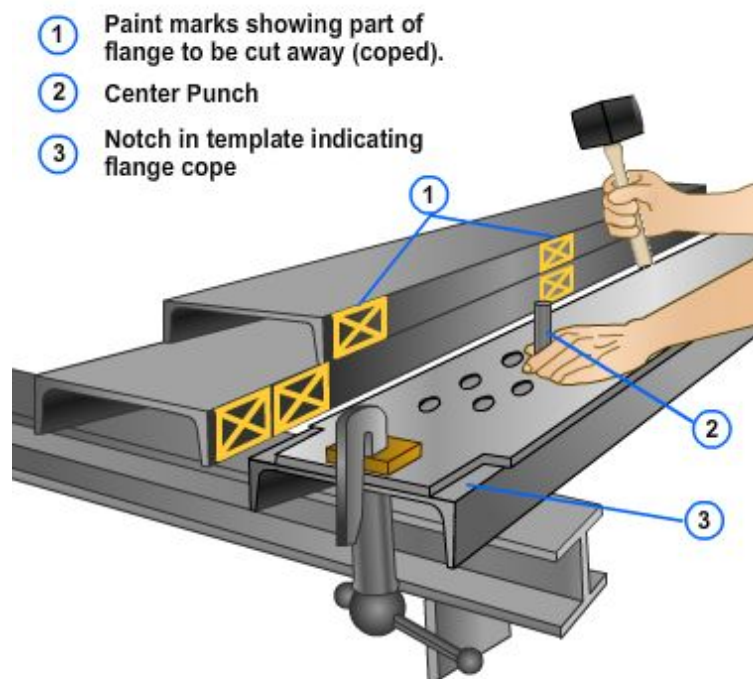


Figure 2-16 — Use of template in laying out a steel channel.

In the fabrication area, many pieces can start to look similar; after all, they are usually made of the same stock materials. Therefore, each member or individual piece of material for a given project must be given identifying marks to correspond with marks shown on the detail drawing (*Figure 2-17*).

Assembly mark — a mark painted on each piece on completion of its layout so that the piece can be identified during fabrication and fit-up with other pieces to form a finished member such as a truss assembly.

Erection mark — a mark used to identify and locate it for erection at the job site. It is painted on the completed member at the left end, as shown on the detail drawing, and in a position so that it will be right side up when the member is right side up in the finished structure.

Various systems of erection markings can be used as long as all members of the project understand the system. The following are a few examples of erection marks:

C12 (2-4) **C** is the designation identifying a column
 12 is the column number
 (2-4) specifies the 2nd through the 4th floors

B3(4) **B** is the designation identifying a beam
 3 is the beam number
 (4) specifies the 4th floor

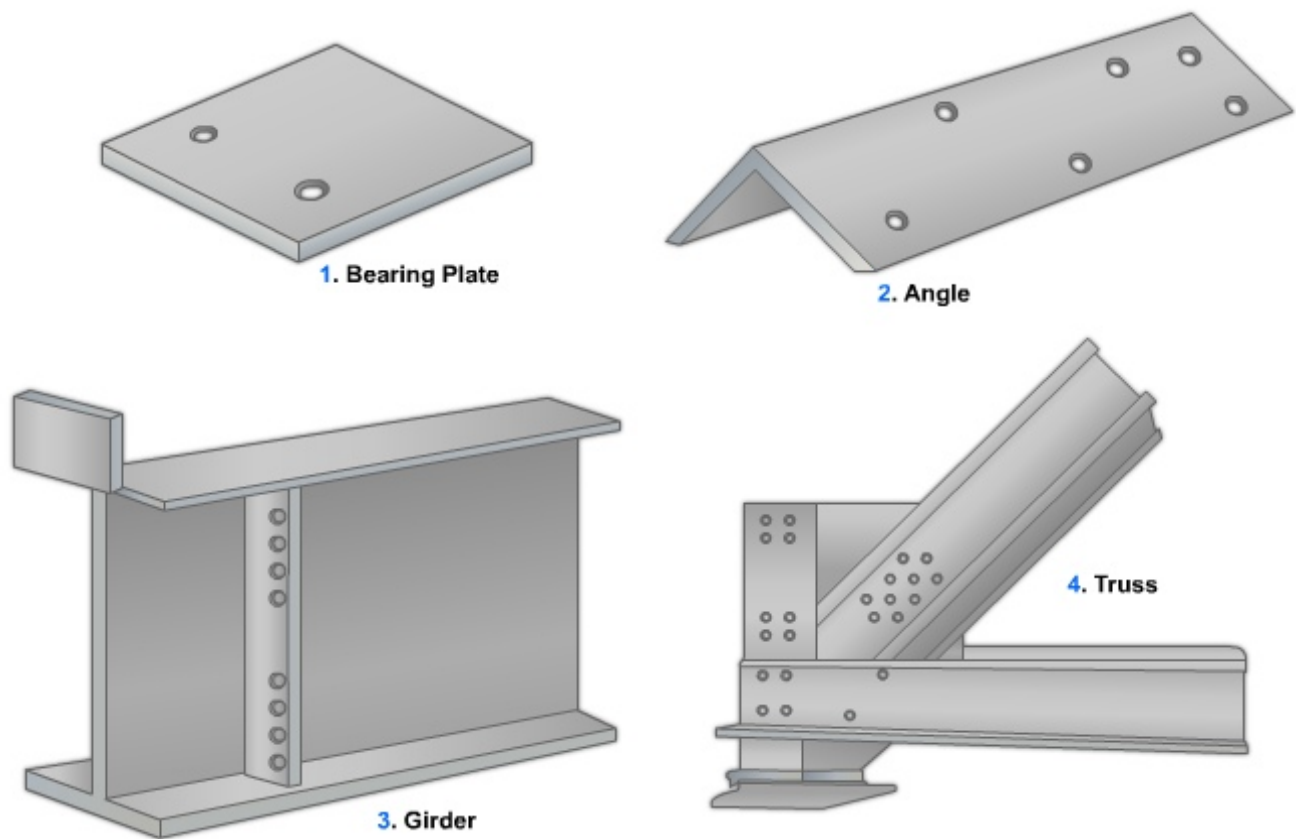


Figure 2-17 — Erection and assembly marks.

2.0.0 PIPE FITTING

Do not let the lack of templates, charts, or mathematical formulas hinder your layout of pipe connections. In emergencies, you can quickly and easily lay out for welded pipe of equal diameter in the field by using the methods described here. With a few simple tools, you can lay out branches and Y connections as well as turns of any angle, radius, and number of segments.

Through almost daily use, a Steelworker is familiar with these readily available tools:

- Framing square
 - For this discussion, the long part of the framing square is referred to as the blade; the short part is referred to as the tongue.
- Bevel protractor with a 12-inch (20-cm) blade
- Spirit level
- Spring steel wraparound (or tape)
 - A stiff strip of cardboard or a tin sheet about 3 inches [7.5 cm] wide also makes a good wraparound.
- Center punch
- Hammer

- Soapstone

2.1.0 Layout Operations

You can use one of two commonly used methods: the one-shot method and the shop method. Use the one-shot method (so named because you only use it once) in the field. With this method, you use hand tools and make your layout on the pipe to be cut.

Use the shop method to make templates for pieces that are going to be duplicated in quantity. For example, a job order comes into the shop for 25 pieces of 6-inch (15-cm) pipe, all cut at the same angle. Obviously, it would be time consuming to use the one-shot method to produce 25 pieces, so use the shop method for laying out. Like structural member templates, use patterns to make templates of paper or thin-gauge sheet metal. The major advantage of thin-gauge sheet metal templates is that when you are finished with them for one project, you can store them for later use.

Keep in mind that you measure pipe turns by the number of degrees they turn from the course set by the adjacent straight section, and you measure the angle at the centerlines of the intersecting sections. You measure branch connections in angle of turn, away from the main line, that is, the number of degrees by which they deviate from a straight line. For example, a 60-degree branch is so named because the angle between the centerline of the main pipe and the center line of the branch connection measures 60 degrees. For more information and illustrations see *Figure 2-18*, and refer to ASTM F681 - 82(2008) Standard Practice for Use of Branch Connections.

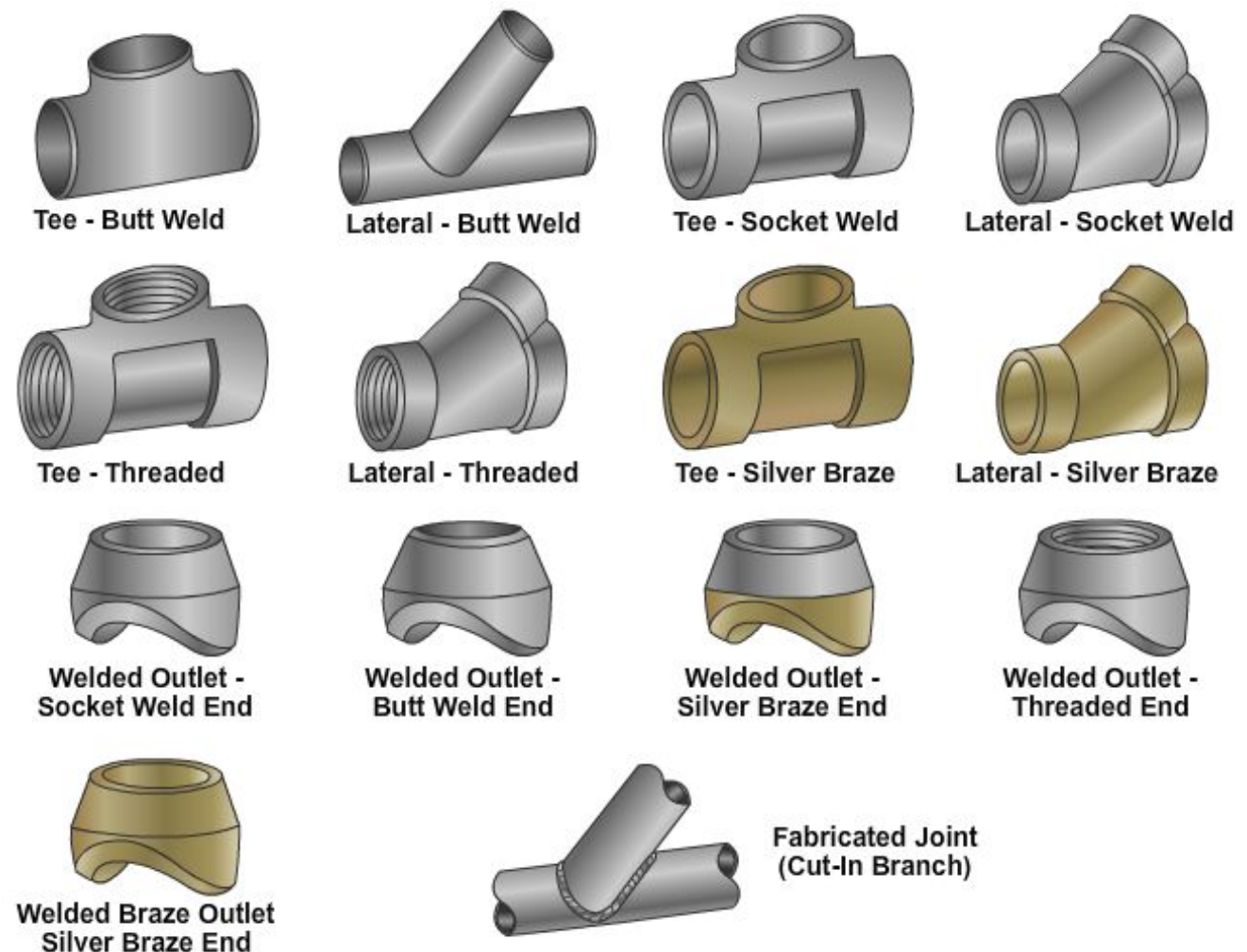


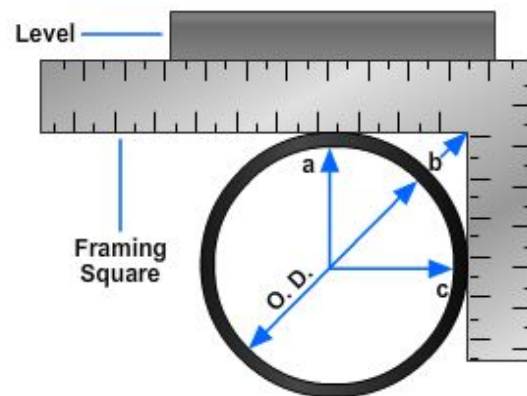
Figure 2-18 — Pipe connections.

2.2.0 Quartering the Pipe

In laying out any joint, the first step is to establish reference points or lines from which you can make additional measurements or markings. Do this by locating a center line, then dividing the outside circumference of the pipe into 90-degree segments, or quarters.

Use the framing square, spirit level, and soapstone in the following manner:

- Block the pipe so it cannot move or roll.
- Place the inside angle of the square against the pipe and level one leg.
 - One point on the centerline is then under the scale at a distance of one-half the outside diameter from the inside angle of the square (*Figure 2-19*).
- Repeating at another part of the pipe will locate two points and hence the centerline.
 - By this same method, you can locate the quarter points. This operation is a must before you begin any layout with the field method.



$$ab = bc = 1/2 \text{ O.D.}$$

Figure 2-19 — Locating the top and side quarter points.

If you are using a long piece of pipe and are going to cut both ends, to locate the top and the bottom centerlines, in addition to the square you will need a piece of carpenter's chalk line with a plumb bob on each end and two 24- or 36-inch (60- or 90-cm) flat steel rules (depending on the diameter of the pipe). *Figure 2-20* shows plumb bobs and rules being used to locate the top and the bottom centerlines.

Another quicker one-shot method of quartering pipe is to take a strip of paper and wrap it around the pipe, then mark, tear, or cut the overlap. The marks or ends should touch. Remove the paper from the pipe and fold it in half (*Figure 2-21, View A*), then fold the doubled strip in half once again (*Figure 2-21, View B*). This will divide your strip into four equal parts. Now place the strip of paper around the pipe again, lap the original marks (or butt the ends), and your pipe will be quartered at the crease marks and where the ends meet for marking with soapstone.

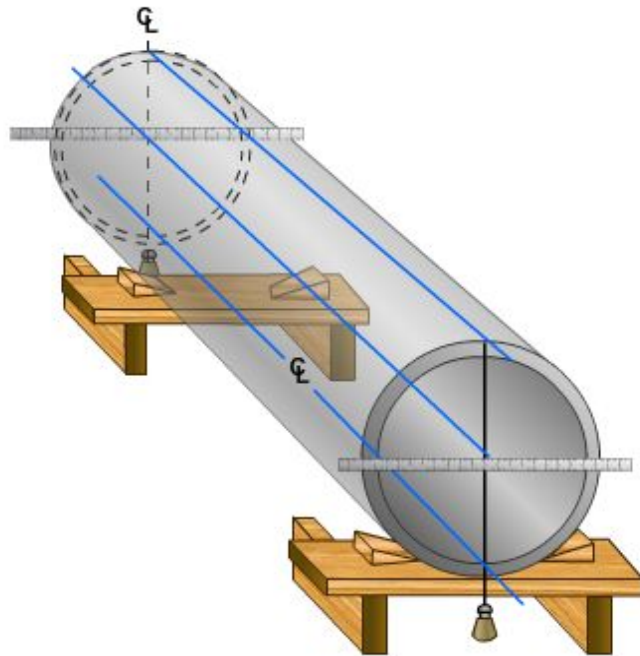
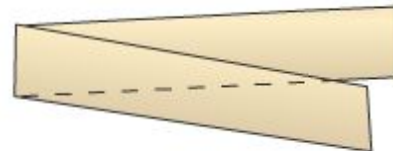
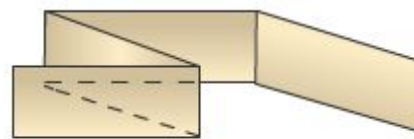


Figure 2-20 — Locating the top and bottom center lines.



A



B

Figure 2-21 — Folding a tip of paper for use in quartering pipe.

2.3.0 Template for Two-Piece Turn

Pipe with square ends can be fabricated by wrapping a rectangular section of plate into a cylindrical form. This fact makes available a method (known as parallel forms) of developing pipe surfaces, and hence developing the lines of intersection between pipe walls. Based on this principle, you can make wraparound templates for marking all manner of pipefittings for cutting preparatory to welding.

In practice, you develop a template by dividing the circumference (in the end view) of the pipe into a specific number of equal sections, then project these sections in parallel onto the side view of the desired pipe section. Following that, you lay out the lengths of the various segments that make up the pipe wall, evenly spaced, on a base line. This line is, in effect, the unwrapped circumference (Figure 2-22).

If you wrap the template developed in Figure 2-22, View C around a pipe with the base line square with the pipe, the curved line, a-b-c-d-e-f-, and so forth, will locate the position for cutting to make a 90-degree, two-piece turn. Use the following procedure to develop the template:

1. Figure 2-22, View A — Draw a circle equal to the outside diameter of the pipe.
2. Divide half of it into equal sections (the more sections, the more accurate the result).
3. Figure 2-22, View B — Perpendicular to the centerline and bisected by it, draw line a-i equal to the O.D.
4. To this line, construct the template angle (TA) equal to one-half of the angle of turn, or in this case, 45 degrees.
5. Draw lines parallel to the centerline from points a, b, c, and so forth, on the circle and mark the points where these lines intersect line a-i with corresponding letters.

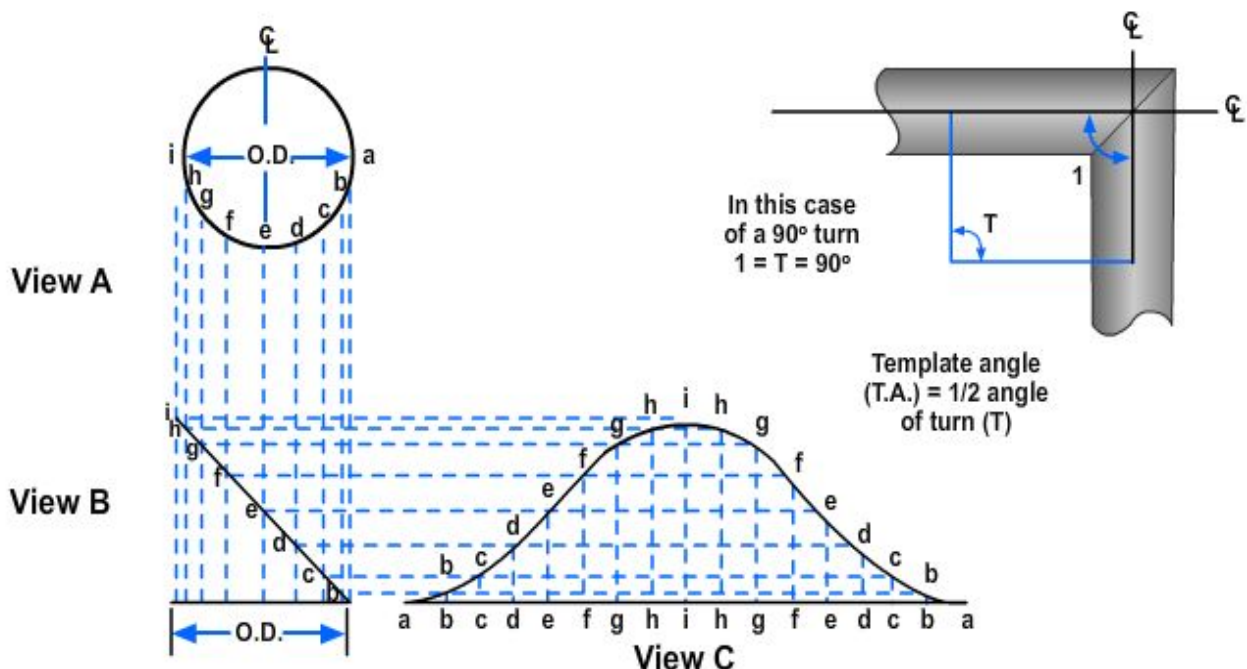
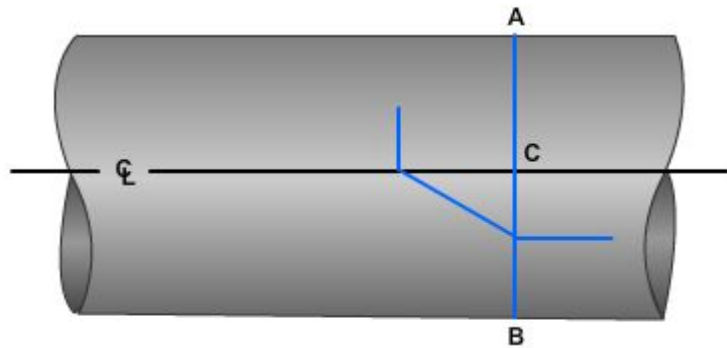


Figure 2-22 — Principles of template layout.

6. *Figure 2-22, View C* — As an extension of a-i but a little distance from it, draw a straight line equal to the pipe circumference (the circle in View A).
7. Divide this line into twice as many equal spaces as the semicircle, a-b-c-, and so forth, and letter as shown.
8. Project perpendiculars from these points.
9. Project horizontals from View B parallel to the base line in View C.
10. Their intersections determine the curve of the template. .

2.4.0 Simple Miter Turn

You can make a simple miter turn after quartering the pipe (*Figure 2-23*). First, locate the center of the cut (point c) in the general location where the cut is to be made, and then use a wraparound to make line a-b completely around the pipe at right angles to the center and quarter lines. This establishes a base line for further layout work.

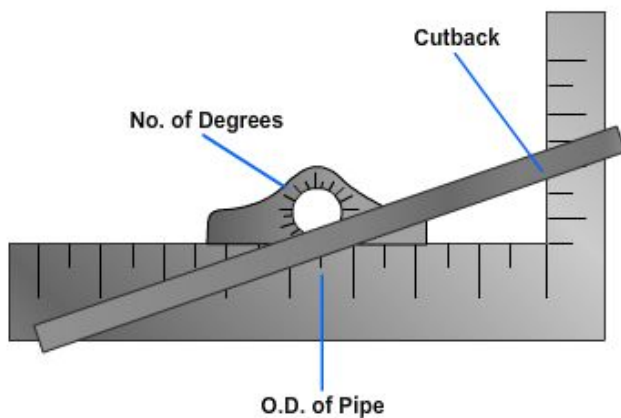


Note: When you are measuring, treat the surface of the pipe as if it were a flat surface. Use a flat-steel rule or tape, which will lie against the surface without kinks, even though it is forced to follow the contour of the pipe. You can check these angles for

Figure 2-23 — Simple miter turn.

accuracy by sighting with the square.

Use the protractor and square to determine the proper cutback for the desired angle of the miter turn by using the following procedure:



1. Start with the protractor scale set at zero so the flat surface of the protractor and the blade are parallel.
2. Set the protractor for the number of degrees desired and lock the blade.

Figure 2-24 — Finding the cutback.

3. Place the protractor on the square with the bottom blade on the outside diameter of the pipe (*Figure 2-24*).
4. Read up to the cutback on the vertical blade of the square.
5. Be sure the flat surface of the protractor is flush against the blade of the square. (The outside radius of the pipe should have been determined during the quartering operation).
6. After you have obtained the cutback measurement, mark one-half of this measurement off along the center line on top of the pipe.
7. From the opposite side of the base line, measure off the same distance along the bottom quarter line.
8. Make punch marks with the center punch on each side of the line along the side quarter lines. These marks will make it easy to align the pipe for welding after the joint is cut.
9. Use the spring steel wraparound and pull the loop to the cutback point.
10. Draw a chalk line over the top half of the pipe through the first cutback point. (**NOTE:** Do not allow the wraparound to twist or kink, and hold the chalk at a right angle to the wraparound while marking the pipe.)
11. Roll the pipe one-half turn and mark a chalk line in the same way around the bottom half of the pipe.

2.5.0 Two-Piece Turn

For the cut necessary for a two-piece welded turn of any angle between 1 and 90 degrees, if a template is not available you can determine the dimensions and markings by making a full-sized drawing, as shown in *Figure 2-25*.

Draw the centerlines intersecting at *b* by using the angle of turn *T* and then draw the outlines of the pipes by using the centerlines and their respective diameters *D*. These will intersect at *a* and *c*. By laying the pipe over the drawing so point *b* coincides with the angle determined by construction details, you can draw the lines *a-b* and *c-b* in preparation for miter cutting and beveling.

After being prepared for welding, one section of pipe should be rotated through 180 degrees to form the desired angle, and then it should be tack-welded. Spacing should be slightly greater at the inside of the turn.

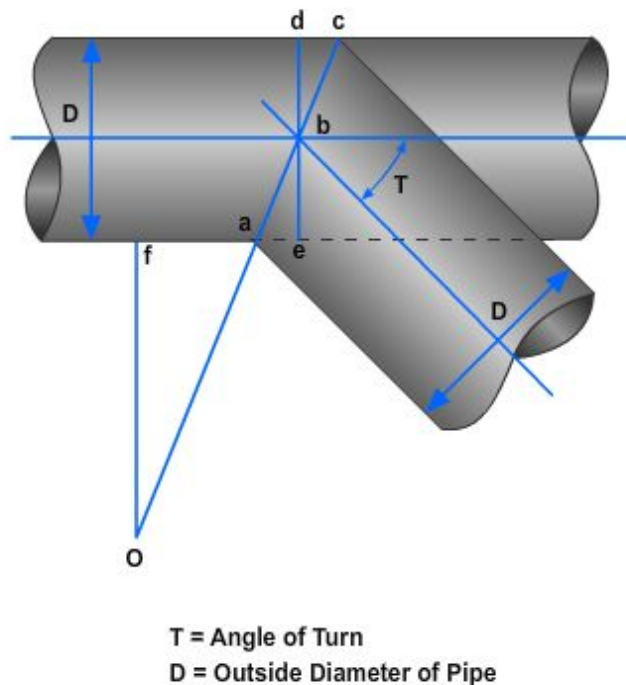


Figure 2-25 — Locating a cut on a pipe for any angle of a two-piece turn.

2.6.0 Welded Tee

To lay out the template for cutting the branch and header of equal diameter for a 90-degree tee, draw the side and end view, as shown in *Figure 2-26, Views A and B*.

In making the template for the branch in *Figure 2-26*, use the following procedures:

1. View A — Draw lines 1-5 at 45 degrees to the centerline.
2. Lay off distance 1-P equal to twice the thickness of the pipe wall and draw the smooth curve s-P-s.
3. View B — Project point P from View A to View B and draw the lines P-t radially.
4. At a distance above point t equal to the thickness of the header wall, draw a-t horizontally, and vertical lines a-a, and t-t.
5. With lower points a as center, swing arcs r-s.
6. Using the intersections of these arcs as centers and with the same radius, draw the curved lines a-b-c-d-e and e-d-c-b-a.
7. Divide the outside circumference of the branch top into equal parts and draw the vertical lines b-b, c-c, and so forth.
8. View D — Draw the horizontal base line a-a.
9. Lay off the unwrapped circumference and divide each half into the same number of equal parts as the branch semi-circumference.
10. Plot the distances a-a, b-b, and so forth, from View B. This gives the distances from the base line to the branch curve of the intersection and determines the location of the branch template.

To make the template for the hole in the header in *Figure 2-26*, use the following procedures:

1. View B — Divide the circumference of the header into equal parts, as at points 1, 2, 3, and so forth.
2. View A — Project these points across to View A as shown.
3. View C — Lay off the line 1-5-1 equal to one-half the circumference of the header, and divide it into the same number of equal parts as was done on the header.
4. Locate point P, a distance from 1 equal to 1-P in View B.
5. With this point P and the distances 5-5, 4-4, and so forth, in View A, plotted as shown in View C, you have identified the curve of the template for the hole in the header.

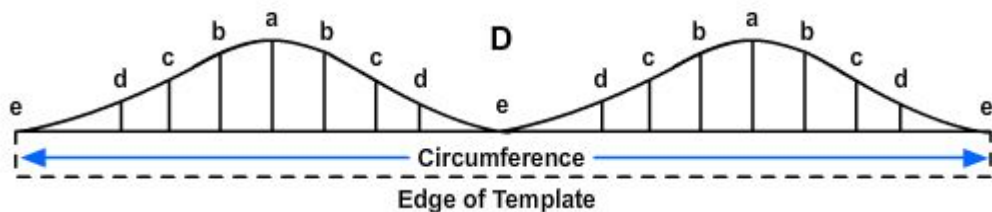
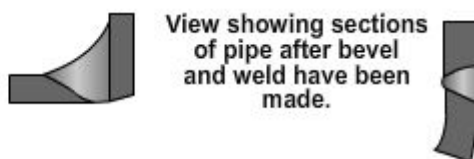
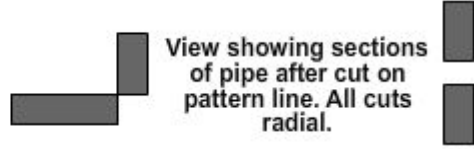
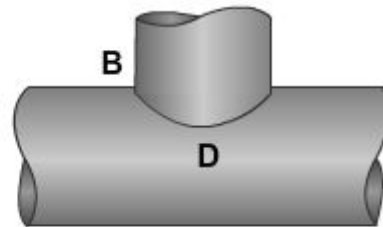
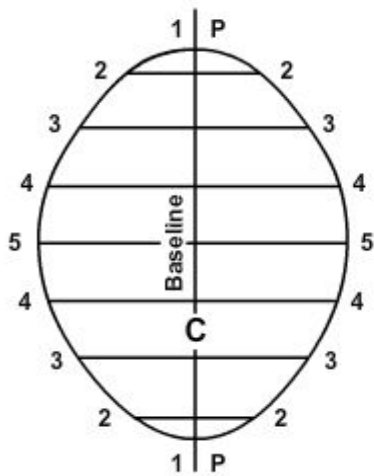
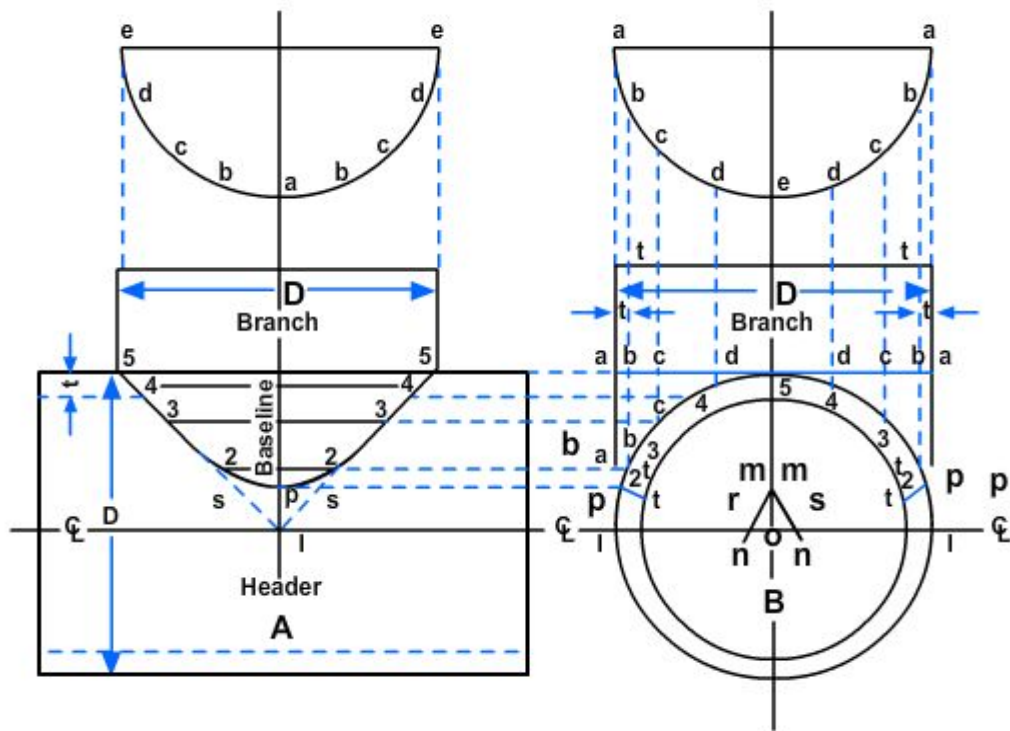


Figure 2-26 — 90° tee.

2.7.0 Branch Connections

You can lay out templates for cutting branch-to-header connections of equal diameter at any angle of 45 to 90 degrees (*Figure 2-27*). Note: You can make templates with angles less than 45 degrees, but the difficulty of welding the crotch section imposes a practical limitation.

Use the following procedures to lay out the cut for the header:

1. Quarter both sections of pipe.
2. Locate the centerline of the intersection (point B) on the header.
3. Draw line GF around the pipe at this point.
4. Set the diameter FG on the blade of the square.
5. Set and lock the protractor at one-fourth of the number of degrees of turnaway from the header (in the example, $1/4$ of $60^\circ = 15^\circ$).
6. With the blade along FG, the first cutback measurement, FA, will be indicated on the tongue of the square.
7. Measure off this distance along the centerline of the header from line FG, and mark point A.
8. Join point A with the points of intersection of line FG and the two side quarter lines to outline the first cut.
9. With the same protractor setting, flip the square and mark point H. Distance FH is equal to FA. FH is the first portion of the second cutback measurement.
10. With the same settings and with the square upside down (as compared to before), locate point I the same way you located point H.
11. Set the protractor to one-half of the number of degrees of turnaway from the header (in the example, $1/2$ of $60^\circ = 30^\circ$).
12. With the blade set to the diameter, the second portion, HD, of the second cutback measurement will be indicated on the tongue of the square. The second cutback measurement is the total distance FC.
13. Connect points C and B and connect C with the point, which corresponds to B, on the quarter line on the opposite side of the header. This outlines the second cut and completes the marking of the header.

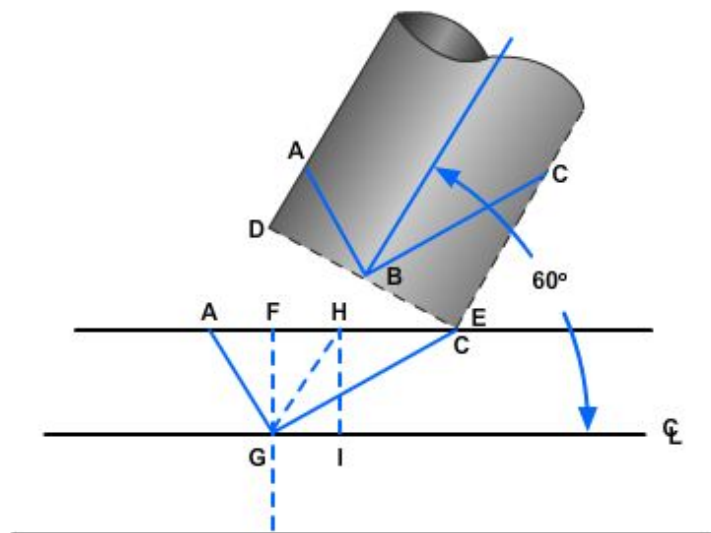


Figure 2-27 — Branch connections.

Use the same two cutback measurements to

lay out the end of the branch.

- Branch cutback distance DA is equal to header cutback distance FA.
- Branch cutback distance EC is equal to header cutback distance FC.
- If the branch end is square, make cutback measurements from the end, rather than marking in a circumferential line.
- Make all cuts as before; level and join the branch and header by welding.

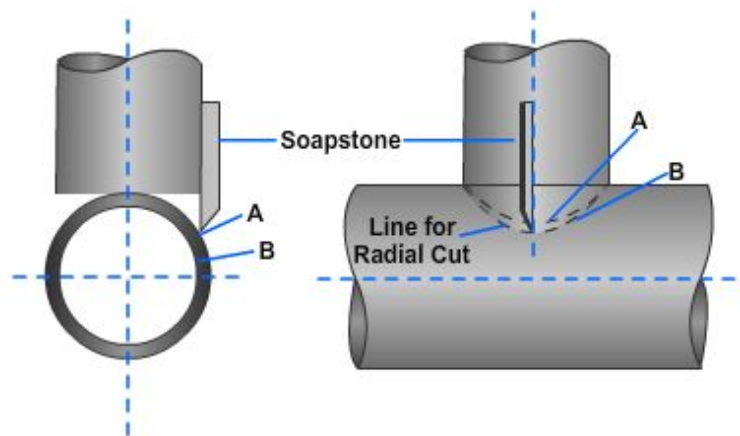
2.8.0 Welded Tee (Branch Smaller Than the Header)

Where the branch is smaller than the header, you can obtain one of the best types of joints for a 90-degree branch connection by inserting the smaller branch pipe through the wall down to the inner surface of the header. This allows the outside surface of the branch to intersect the inside surface of the header at all points, and when the header is properly beveled, this type of intersection presents a very desirable vee for welding. Templates are always recommended, but in case templates or template dimensions are not available, you can locate the line of cut on both header and branch by other methods.

In the first method, you place the square end of the branch in the correct position against the header and mark the line of intersection with a flat soapstone pencil (*Figure 2-28*).

Since you will use radial cutting in this case, and since the outer branch wall should intersect the inner header wall, locate point B on both sides of the branch a distance from A equal to slightly more than the header wall thickness. Now mark a new line of cut as a smooth curve through the points, tapering to the first line at the top of the header and follow the radial cutting with a beveling cut.

Then slip the branch into the hole until even with point B to locate the line of cut on the branch for radial cutting; no beveling is necessary.



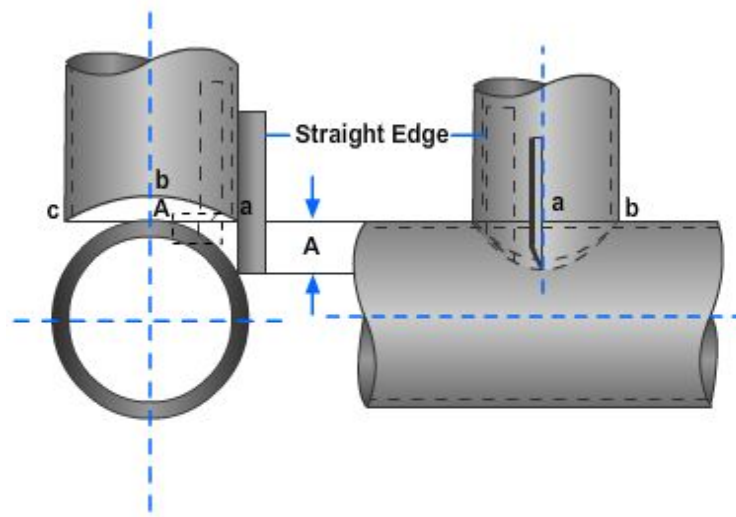
Branch 4" Diameter and Less

Figure 2-28 — Method where the line of cut is first marked on main.

Figure 2-29 shows a second method for larger diameter pipe. After you have drawn the centerlines, place the branch against the header, as shown. With a straightedge, determine the distance A between the branch and the header wall, and transfer this measurement to the branch wall, as represented by the curved line a-b-c.

After you have cut this line, use the branch to locate the line of cut on the header, allowing for the intersection of the outer branch wall and inner header wall as before. Then, radial cut this line on the header, and follow by beveling.

If you need to make an eccentric branch connection in the extreme case where the side of the branch is even with the side of the header, use a similar procedure by projecting the cut location with a straightedge, as shown in *Figure 2-30*.



Branch 6" Diameter and Less

Figure 2-29 — Line of cut is first marked on branch with this method.

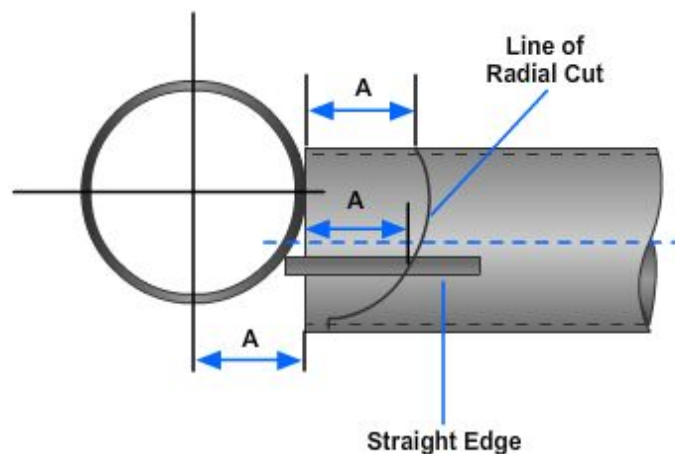


Figure 2-30 — Marking cut on branch for eccentric branch connection.

2.9.0 Three-Piece Y Connection

The entire procedure for fabrication of an equal diameter, three-piece Y connection is based on the individual operations just described. As usual, the first step is to quarter the end of all three pieces of pipe and apply circumferential lines. When the three pieces are welded together to form the Y, there will be three centerlines radiating from a common point.

You must decide the open angle between each pair of adjacent centerlines, for each of these angles will be the angle of one of the branches of the Y. As shown in *Figure 2-31*, these open angles determine the angle of adjoining sides of adjacent branches. Thus, half of the number of degrees between centerlines A and B (90°) is included in each of the adjoining cutbacks between these two branches. The same is true with respect to the other angles and cutbacks between centerlines (B and G= 160° as well as A and G= 110°). Moreover, each piece of pipe must have a combination of two angles cut on the end.

To determine the amount of cutback to form an angle of the Y:

1. Set the protractor at one-half of the open angle between adjacent branch center lines.
2. Place the protractor on the square, crossing the outside radius measurement of the pipe on the tongue of the square, and read the cutback distance off the blade of the square.
3. Mark off this distance on one side quarter line on each of the two pieces that are to be joined.
4. Mark the cutback lines.
5. Repeat this procedure for the other two angles of the Y, taking care to combine the cutbacks on each pipe end. Three settings of the protractor determine all cutbacks.

An alternate method for determining each cutback is to treat two adjacent branches as a simple miter turn.

1. Subtract the number of degrees of open angle between centerlines from 180 degrees and set the protractor at one-half of the remaining degrees.
2. Cross the outside radius measurement on the tongue.
3. Mark one side of each adjoining pipe section.
4. Repeat for the other two branches. Take care to combine the proper cutbacks on each pipe end.

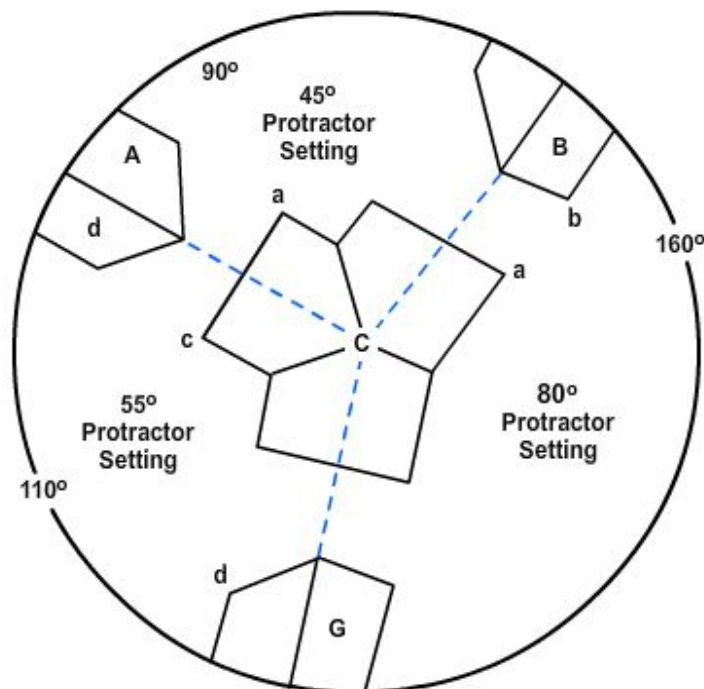


Figure 2-31 — Three-piece Y connection.

5. Set the protractor for each open angle of the Y connection.

The computations and measurements for the layout (*Figure 2-31*) are shown in *Table 2-1*. The pipe is 12 inches in diameter and has a radius of 6 inches (15 cm).

Table 2-1 — Computations and Measurements for a Y Connection.

	ACB	ACG	BCG
Open angle between center lines	90°	110°	160°
Protractor setting (half of each angle)	45°	55°	80°
Cutbacks	6"	4 1/8"	1 1/16"
Centerlines	A	B	C
Paired cutback measurements (inches)	fe = 6" cd = 4 1/8"	ab = 1 1/16" fe = 6"	ab = 1 1/16" cd = 4 1/8"

2.10.0 Layout of a True Y

In laying out pipe for the fabrication of a true Y without the use of templates or tables, you should make a full-sized drawing of the intersection (*Figure 2-32*). The intersection of the centerlines of the three pipes will locate point B, and lines from B to the intersections of the pipe walls will locate points A, C, and D. From these points, you can mark the pipe for miter cutting and suitable beveling to prepare it for welding.

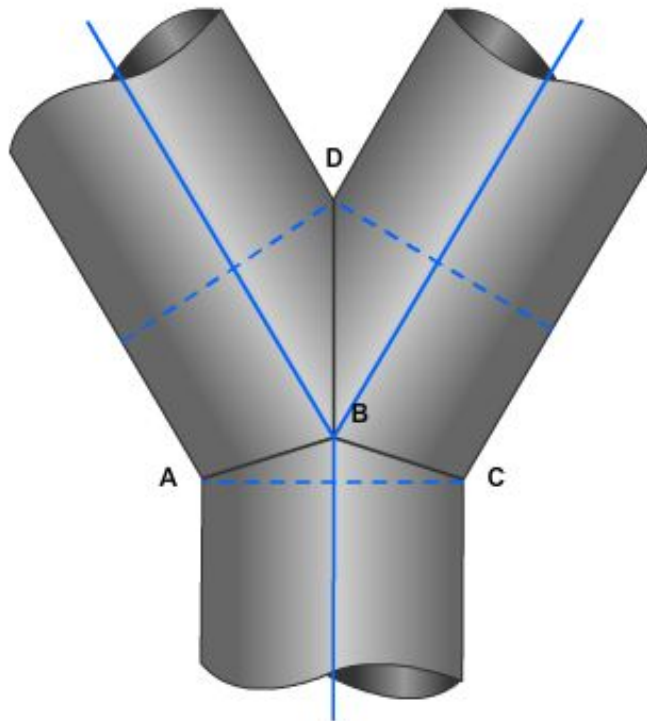


Figure 2-32 — True Y.

2.11.0 Template Layout for True Branches and Main Lines

In laying out a template for a true Y, make a drawing of the intersection, as shown in *Figure 2-33, View A*. After drawing the lines of intersection, follow the same essential methods used for other templates. Note: here it suggests that the equally divided semi-circumferences are more conveniently placed directly on the base line, and when you plot the distances from the base line to the line of intersection (View A, a-d-g) onto the unwrapped base lines [(View B a-d-g-d-a) and (View C g-d-a-d-g)x 2], it determines the template.

2.12.0 Orange Peel Head

Welded pipe construction uses a number of different types of heads. Here we are interested in one general type, the orange peel, since it will often concern you in your work. A main advantage of the orange peel is that it has high strength in resisting internal pressure.

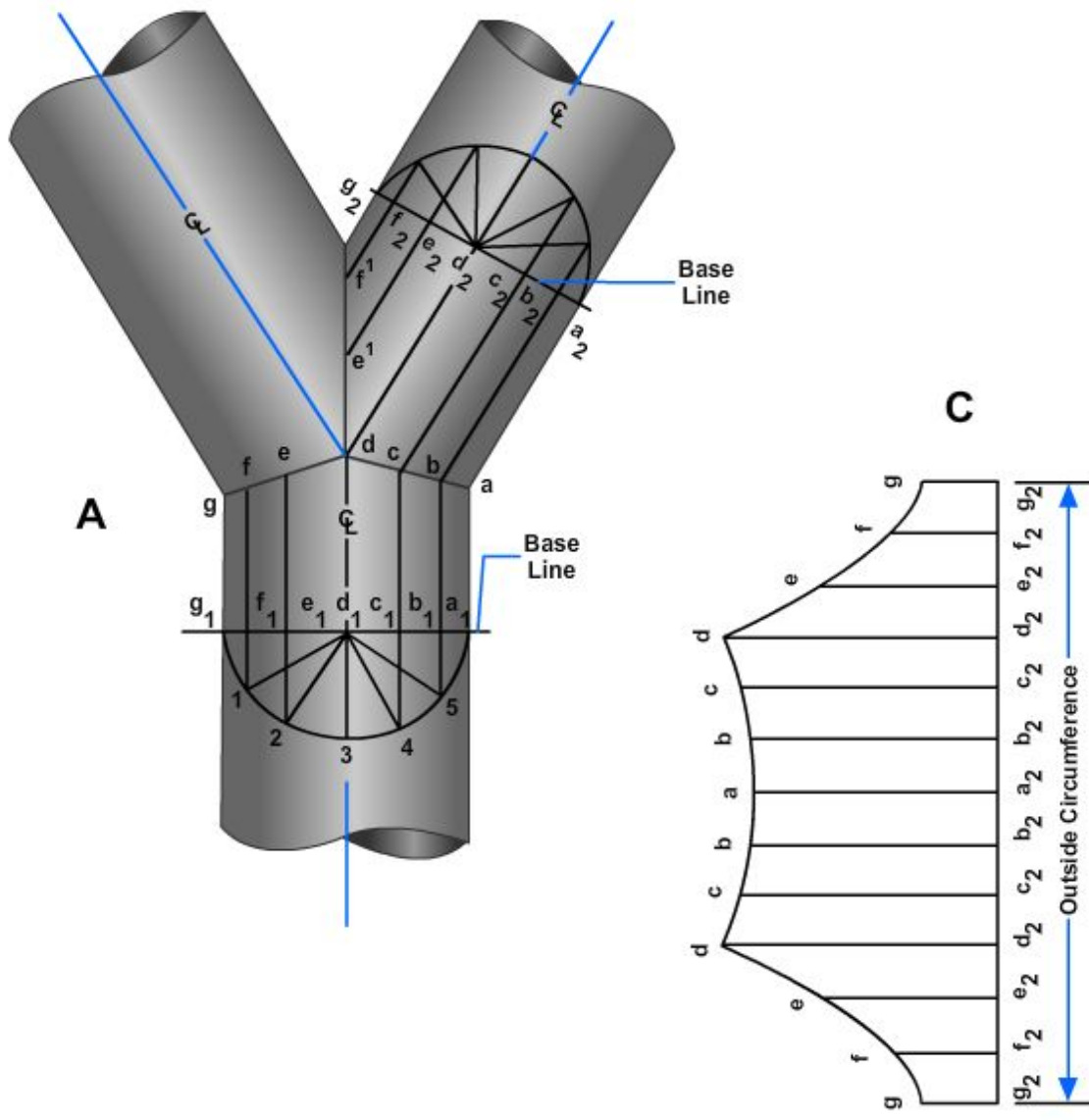
If templates or tables are not available for making an orange peel head, you can still lay out a reasonably accurate template.

The number of arms to make an orange peel head should be the minimum number that you can easily bend over to form the head. Five arms and welds are the recommended minimum for any pipe, but you should increase this number for larger diameter pipes. Dividing the circumference by 5 is a good method for deciding the number of arms, provided there are at least 5.

To lay out the template, use the following procedures:

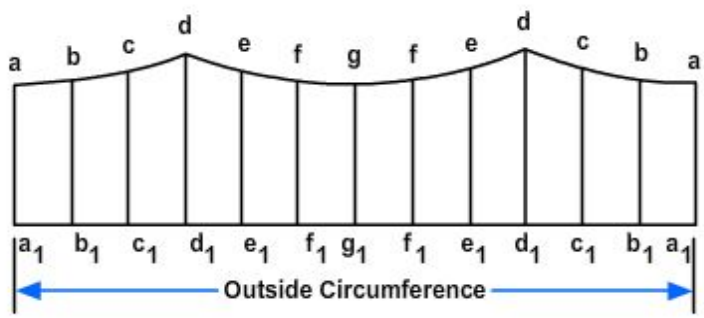
1. Draw the side and end views as shown in *Figure 2-34, Views A and B*.
2. Divide the pipe circumference in View B into the number of equal parts you plan to weld.
3. Draw the radial lines o-a, o-b, and so on.
4. Project the points a, b, and so on, in View B onto View A.
5. Divide x-o-x into equal parts, in this case, 6.
6. Draw the lines x1-x1 and x2-x2 in View A. These represent the concentric circles in View B. In laying out the template, the distances a-b, b-c, a1-b1, a2-b2, and so on, are taken from View B. The distances x-x1, x-x2, b-b1, and so on, are taken from View A.
7. All cutting should be radial followed by a beveling cut.

Actually, it is not necessary to draw Views A and B since you can determine all the values by a simple computation. *Figure 2-35 shows* a one-shot field method of making an orange peel when you are going to make only one, and it will help to line up your template better.



B

Template For Two Branch Lines



Template For Main Line Pipe

Figure 2-33 — Template for true Y branches and main of equal diameter.
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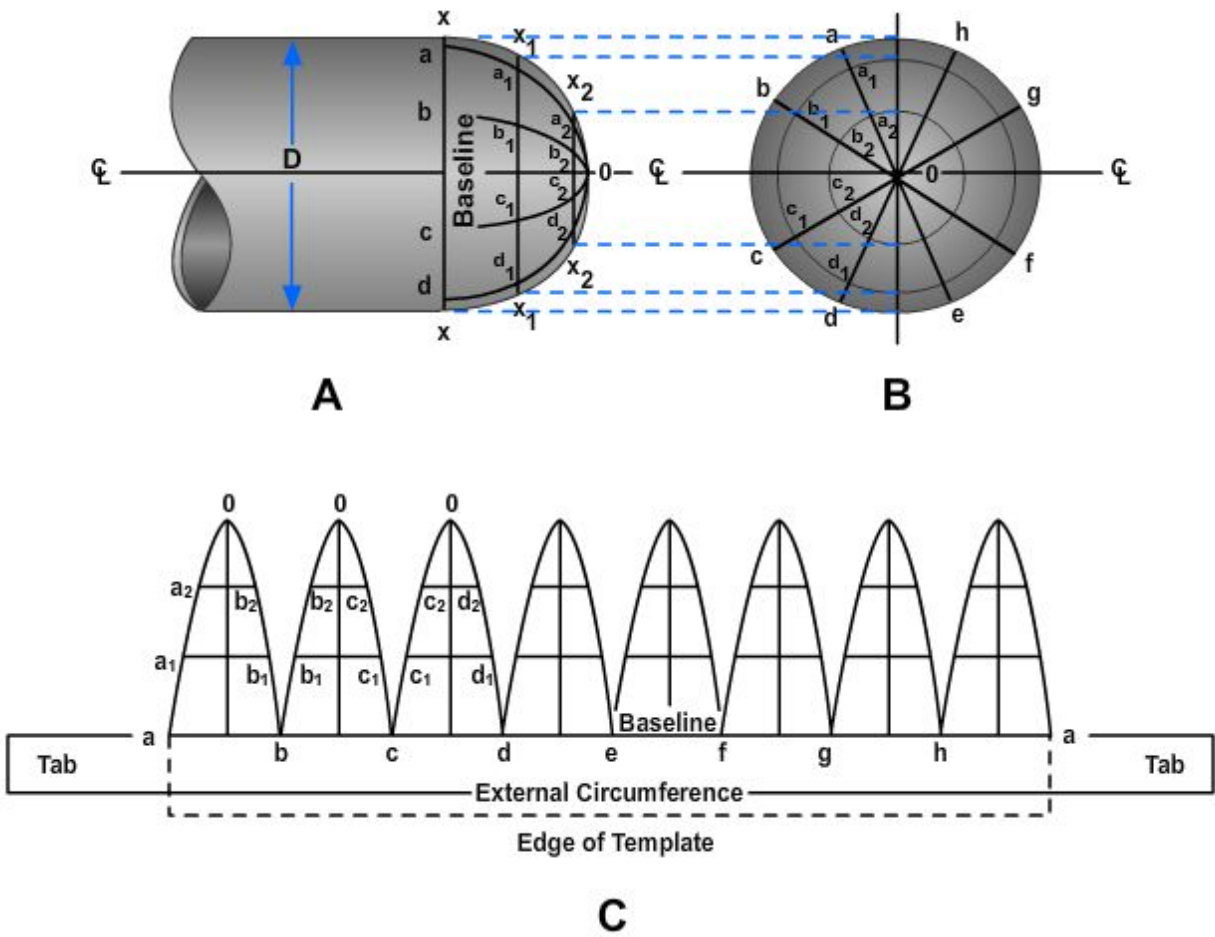


Figure 2-34 — Orange peel head.

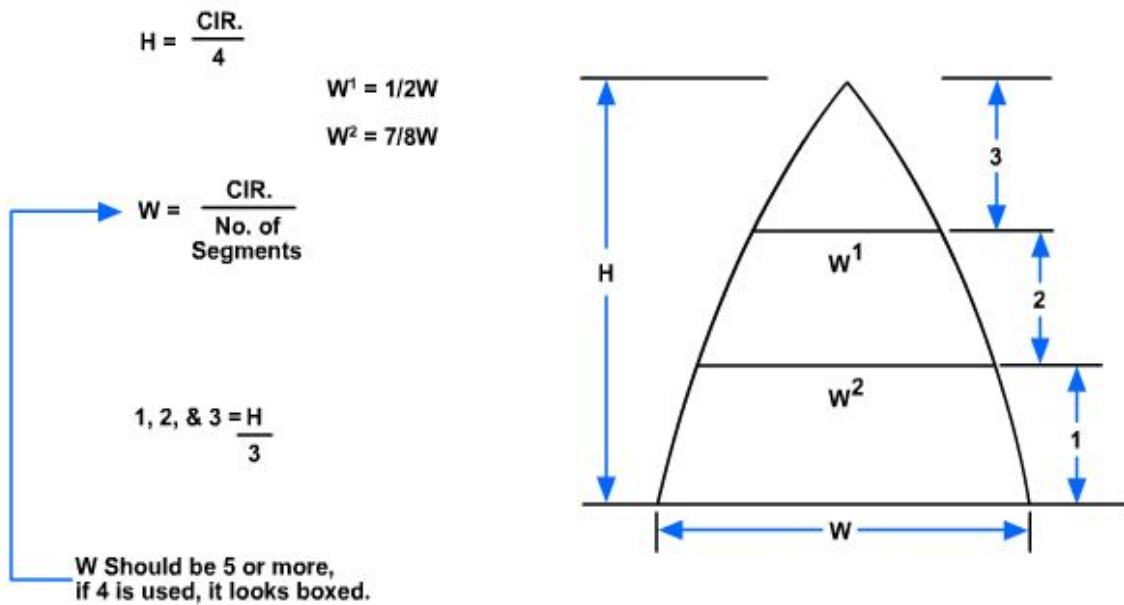


Figure 2-35 — A field method of making an orange peel.

3.0.0 PIPE CUTTING

Cutting pipe is not much different from cutting structural shapes, except you must always keep in mind that the cut will be either radial or miter. Use a gas-cutting torch to cut pipe for welding. To review procedures for using a cutting torch, refer to *Steelworker Basic*, Chapter 4, Gas Cutting. The torch may be hand operated, or it may be mounted on a mechanical device for more accurate control.

Cutting machines are able to prepare many fittings without the use of templates. These machines cut and bevel the pipe in one operation, with the bevel extending for the full pipe wall thickness. When pipe is cut by hand, beveling is done as a second operation.

Many types of welded fittings require a radial cut before beveling. Radial cutting simply means the cutting torch is held perpendicular to the interior centerline at all times, in other words, the cutting orifice always forms a continuation of a radius of the pipe, making the cut edge square with the pipe wall at every point. *Figure 2-36* shows radial cutting. Except in the case of the blunt bull plug, for which the radial cut provides the proper vee, you should always follow the radial cut with a beveling cut for pipe with 3/16-inch (4.8 mm) or more wall thickness.

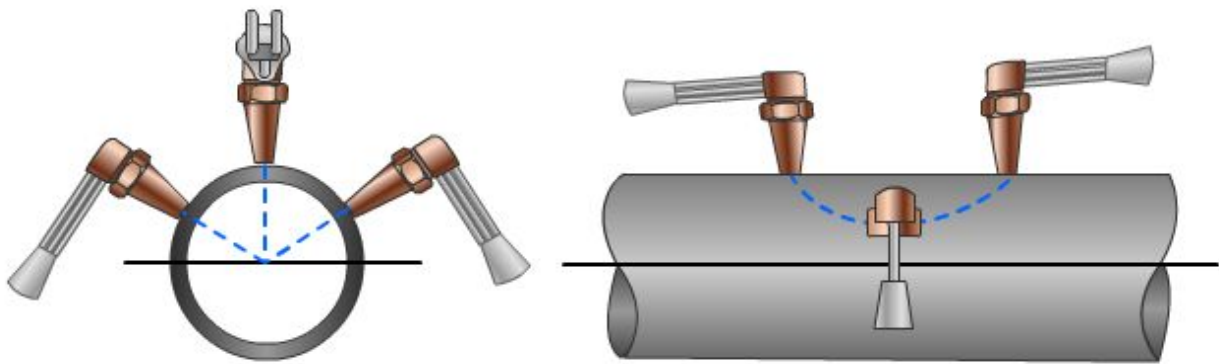


Figure 2-36 — Radial cutting.

In miter cutting, you hold the torch tip so the entire cut surface is in the same plane. The miter cut is followed by a beveling cut, leaving a 1/32- to 1/16-inch (.8 to 1.6-mm) nose at the inner wall. *Figure 2-37* shows miter cutting.

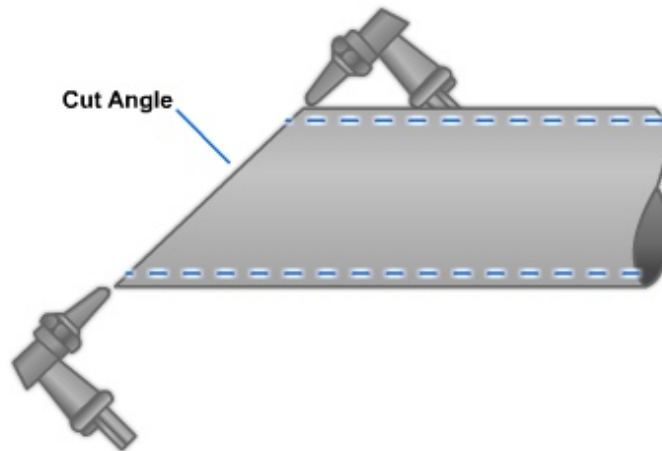


Figure 2-37 — Miter cutting.

4.0.0 PIPE BENDING

Any piping system of consequence will have bends in it. When fabricating pipe for such a system, you can make bends by a variety of methods, either hot or cold, and either manually or on a power-bending machine. Cold bends in pipe are usually made on a bending machine, and various types of equipment are available, ranging from portable handsets to large hydraulically driven machines that can cold bend pipe up to 16 inches (40.64 cm) in diameter (*Figure 2-38*). You will be concerned primarily with hot bending techniques, using a bending slab, or using a method known as wrinkle bending.



Figure 2-38 — Types of pipe benders.

4.1.0 Templates

Whatever method you use to bend pipe, you should normally have some pattern that represents the desired shape of the bend. Templates made from wire or small, flexible tubing can be invaluable in preparing new installations as well as in repair work. When properly made, they will provide an exact guide to the bend desired.

The centerline template is one simple type of bend template. It is made to conform to the bend or bends of the pipe being made, and is used to lay off the bend area on the pipe as well as a guide during the pipe or tube bending operation. *Figure 2-39* shows the use of a centerline template. You make these templates out of wire or rod, and shape them to establish the centerline of the pipe to be installed. You secure the ends of the wire to special clamps called flange spiders, and add clearance discs the same diameter as the pipe if there is any doubt about the clearance around the pipe.

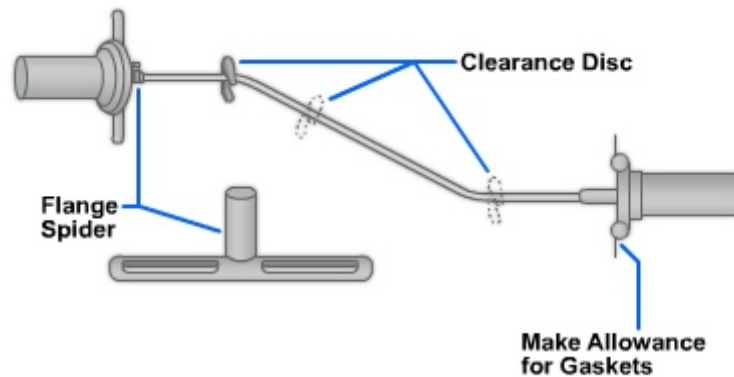


Figure 2-39 — Center line template.

4.2.0 Hot Bends

You can make hot bends on a bending slab, which requires little maintenance beyond a light coating of machine oil to keep rust in check (*Figure 2-40*). Use the following procedures:

1. Pack the pipe with dry sand to prevent the heel or outside of the bend from flattening. If flattening occurs, it will reduce the cross-sectional area of the pipe and restrict the flow of fluid through the system.
2. Drive a tapered, wooden plug into one end of the pipe.
3. Place the pipe in a vertical position with the plugged end down.
4. Fill it with dry sand.
 - Leave just enough space at the upper end to take a second plug.
 - To ensure that the sand is tightly packed, tap the pipe continually with a wooden or rawhide mallet during the filling operation.
 - The second plug is identical to the first, except for a small vent hole drilled through its length to vent any gases (mostly steam) that may form in the packed pipe when you apply heat.
 - No matter how dry the sand may appear, there is always a possibility that some moisture is present. This moisture will form steam that will expand and build up pressure in the heated pipe unless you provide

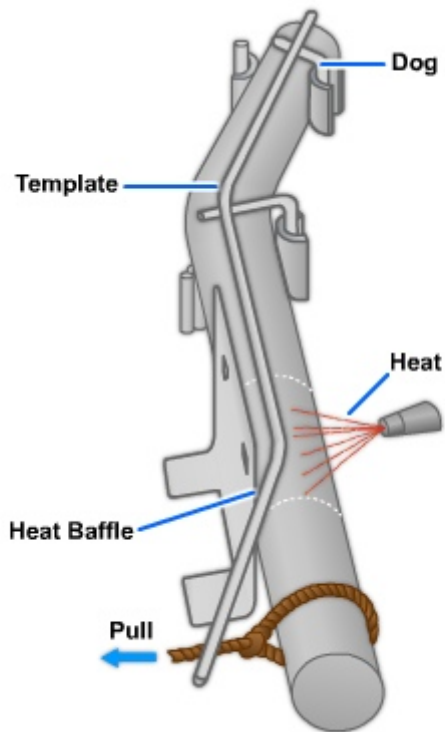


Figure 2-40 — Bending on a slab.

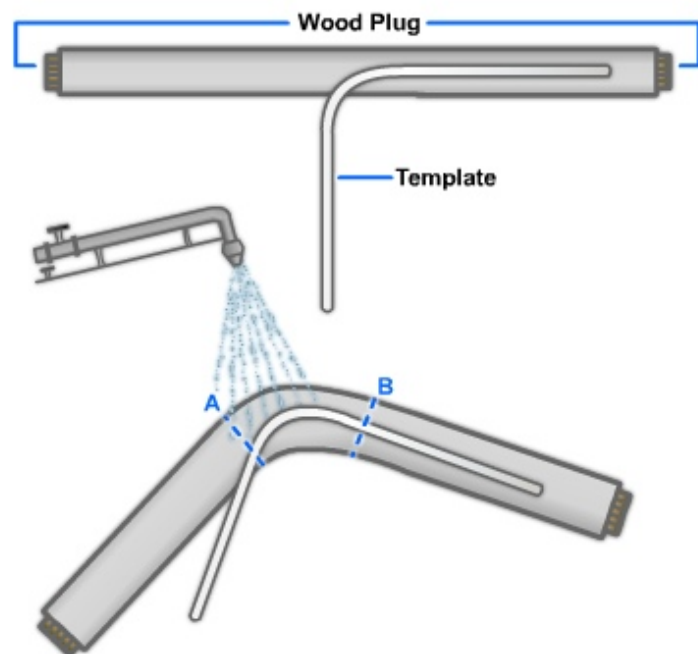


Figure 2-41 — Heating and bending pipe to conform to a wire template.

some means of escape. If you do not provide a vent, you will almost certainly blow out one of the plugs before you get the pipe bent.

5. Heat the pipe and make the bend.
6. Mark the bend area of the pipe with chalk or soapstone, and heat it to an even red heat along the distance indicated from A to B in *Figure 2-41*.
7. Apply heat to the bend area, first on the outside of the bend, then on the inside. When you have obtained an even heat, bend the pipe to conform to the wire template. Use the template also to mark the bend area on the pipe.

Exert the pull to make the bend in a direction parallel to the surface of the bending slab. You can gain the necessary leverage for forming the bend by using chain falls, block and tackle, or another length of pipe large enough to slip over the end of the packed pipe. Use bending pins and hold-down clamps (dogs) to position the bend at the desired location.

Be sure to wear the proper gloves when working on hot bending jobs. Often, you must remove pins, clamps, and baffles during the bending operation, and these items absorb heat radiated from the pipe as well as from the torch flame. You cannot safely handle these bending accessories without proper gloves.

The main problem you will have in bending copper tubing and pipe is preventing wrinkles and flat spots. Wrinkles are caused by compression of the pipe wall at the throat (inside) of the bend. Flat spots are caused by lack of support for the pipe wall, by stretch in the heel (outside) of the bend, or by improper heating.

If you properly pack and heat the pipe, you can prevent wrinkles and flat spots by bending the pipe in segments so the stretch is spread evenly over the whole bend area. When you bend a pipe, the stretch tends to occur at the middle of the bend. If you divide the bend area into segments, and bend in segments, the stretch will occur at the center of each segment and thus spread more evenly over the bend area. Another advantage of bending in segments is that this is almost the only way you can follow a wire template accurately.

When you bend steel and some other piping materials, you can control wrinkles and flat spots by slightly overbending the pipe and then pulling the end back (*Figure 2-42*).

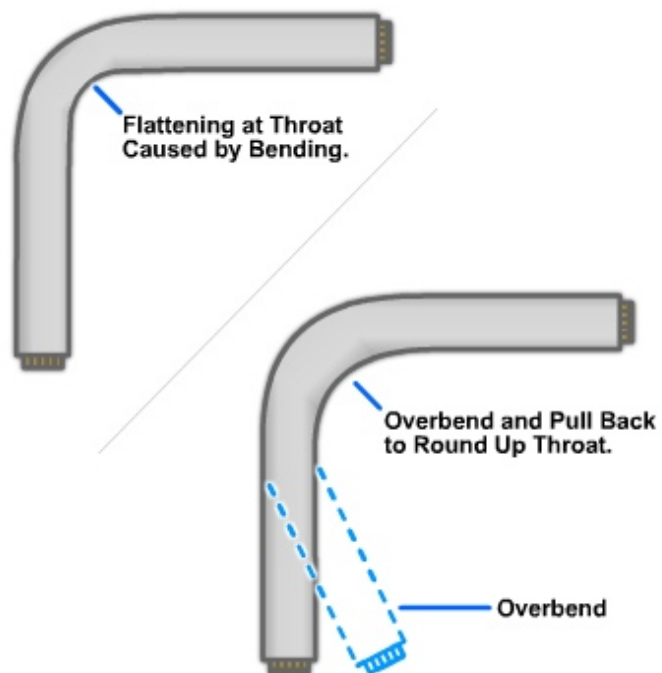


Figure 2-42 — Overbending to correct flattening of pipe.

Each material has its peculiar traits, and you need to know about these traits to get satisfactory results. The following hints for bending different materials should prove helpful:

- Wrought iron — Wrought iron becomes brittle when hot, so always use a large bend radius. Apply the torch to the throat of the bend instead of to the heel.
- Brass — Do not overbend; brass is likely to break when the bend direction is reversed.
- Copper — You can make hot bends on copper, but the copper alloys are more adaptable to cold bending. This material is one that is not likely to give any trouble.
- Aluminum — Overbending and reverse bending do not harm aluminum, but because there is only a small range between the bending and melting temperature, you will have to work with care. Keep the heat in the throat at all times. You will not be able to see any heat color, so you must depend on “feel” to tell you when the heat is right for bending. You can do this by keeping a strain on the pipe while the bend area is being heated. As soon as the bend starts, flick the flame away from the area. Play it back and forth to both maintain the bending temperature and avoid overheating.

Carbon-molybdenum and chromium-molybdenum — If necessary, you can heat these for bending, but exercise caution to not overheat the bend area. These types of metal easily crystallize when you apply extreme heat. You should cold bend pipes made from these materials in manual or power-bending machines.

4.3.0 Wrinkle Bends

After just describing precautions necessary to keep a bend free of wrinkles, it may seem odd to next describe a method that deliberately produces wrinkles as a means of bending the pipe. Nevertheless, you will find the wrinkle-bending technique a simple and direct method of bending pipe, and perhaps in many pipe-bending situations, the only convenient method. This would particularly be the case if no bending slab were available or if time considerations did not permit the rather lengthy sand-packing process.

Wrinkle bending consists of a simple heating operation in which you heat a section of the pipe on the inside of the bend with a gas-welding torch. When the metal becomes plastic (bright red color), you slightly bend the pipe, either by hand or by tackle rigged for that purpose. The unheated portion forms the heel (outside) of the bend, while the wrinkle forms at the throat (inside) of the bend due to compression.

To avoid buckling the pipe, do not bend it through very large angles (12 degrees is the maximum for one wrinkle). To make a large bend, make several small wrinkles one at a time instead. If, for example, you want to produce a bend of 90 degrees, make a minimum of eight separate wrinkles of about 12 degrees (8 X 12° = 96°). *Figure 2-43* shows a 90-degree bend made with ten separate wrinkles. To determine the number of wrinkles, divide the degrees per wrinkle required into the degrees of the bend required.

Wrinkle bending has been successful on pipe of more than 20 inches in diameter. Experience has shown that, for 7-inch diameter pipe and over, you can accomplish more complete and even heating by using two welding torches rather than one. In any event, the heating procedure is the same; use the torch or torches to heat a strip approximately two thirds of the circumference of the pipe (*Figure 2-44*). The heated strip need not be very wide (2 to 3 inches, or 5.08 to 7.62 cm, is usually sufficient) since the bend will only be through 12 degrees at most. As already noted, the heated portion is the part that will compress to become the inside of the bend; the portion not heated directly will form the outside of the bend.

The technique most often used to bend the pipe once it has been heated is simple and straightforward. The pipe is merely lifted up by gloved hand (or by tackle), while the other end is held firmly in position.

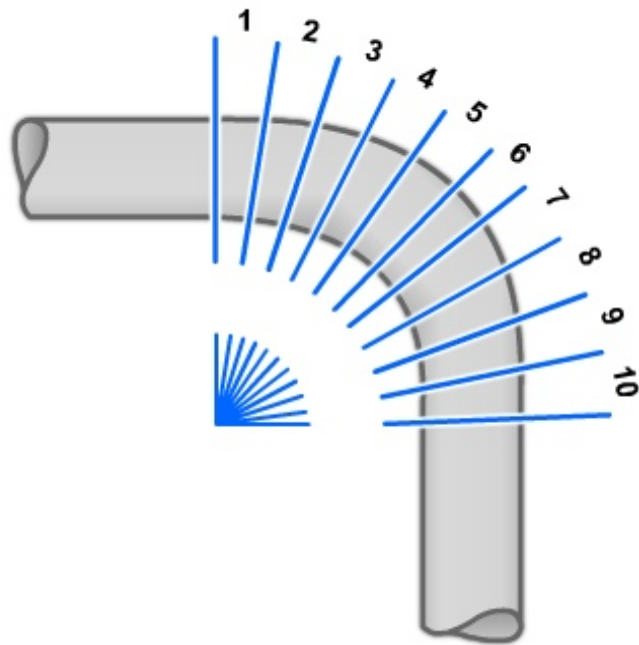


Figure 2-43 — 90° bend made with ten separate wrinkles.

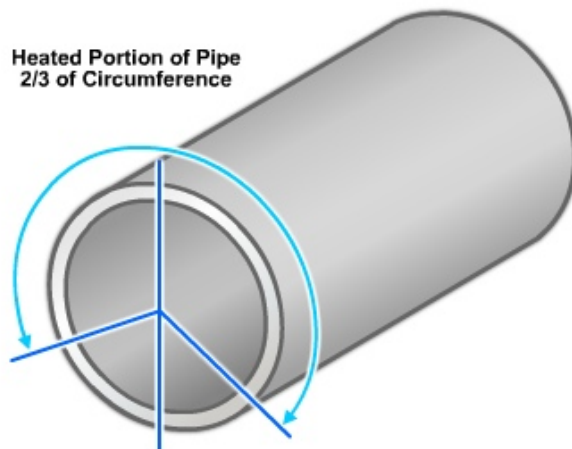


Figure 2-44 — Part of pipe heated before wrinkle bending.

Summary

This chapter discussed how to lay out and fabricate steel plate and structural steel members. Information was also provided on pipe layout and fabrication, along with specific instructions on pipe cutting, fitting, and bending. As always, use the manufacturer's operator manuals for the specific setup and safety procedures of the equipment you will be using, and wear the proper personal protective equipment.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Frankland, Thomas, W., *The Pipefitter's and Pipe Welder's Handbook*, Glencoe/McGraw-Hill Publishing Company, Woodland Hills, CA, 1984.

Frankland, Thomas, W., *Pipe Trades Pocket Manual*, Glencoe/McGraw-Hill Publishing Company, Peoria, IL, 1969.

Nelson, Carl, A., *Millwright's and Mechanic's Guide*, 2d ed., Theodore Audel and Company, Indianapolis, IN, 1972.

The *Oxy-Acetylene Handbook*, 2nd ed., Linde Company, New York NY, 1960.

Walker, John, R., *Modern Metalworking*, Goodheart-Wilcox Company Inc., South Holland, IL, 1973.