Connections for Tubular Construction

1. INTRODUCTION

Tubular construction is beginning to be used to a greater extent in this country, although for many years it has been an accepted method in Europe where it is used extensively. Although the advantages of the tube have been known for a long time, it was the introduction of welding to the connections which made its extensive use possible.

The tube represents an efficient section, having good properties in all directions. There is no problem in maintaining the inside of the tube against corrosion and in most cases this is left unpainted. The welded connections seal the tube against any moisture entering and prevents the circulation of air, hence any rusting very soon stops and equilibrium is reached.

The joints represent the intersections of curved surfaces, and therefore extra care and time is involved in cutting the pipe to prepare the joints. Usually these are flame-cut, although there are abrasive cut-off saws which make a series of straight cuts and provide good fit-up and there are shears with special tools which allow the end of the tube to be sheared. Fully automatic flame-cutting machines have been built which may be preset for the inner diameter of the tube to be cut, the outside diameter of the tube which it intersects, and the angle of intersection. This will very quickly provide the proper cut, at the proper bevel, and results in close fit-up of the joint.

Recently steel mills have introduced square and rectangular tubing; these of course, are much easier to connect because of their flat surfaces.

2. GUSSET PLATES

Gusset plates have been used in pipe connections for at least 3 reasons:

(1) Provides additional length of fillet welding to the pipe. Most pipe is not very thick. For example, 4" standard pipe has a ¼" thick wall. Unless extra care is used in cutting, beveling, and fitting, it is easier to use fillet welds rather than try to make 100% penetration groove welds on thin-wall pipe.

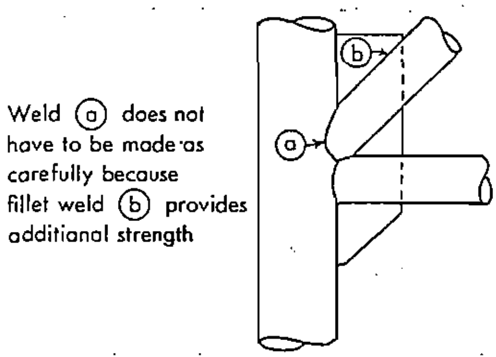


FIGURE 1

(2) Allows the intersecting pipe members to be cut short and the gusset plate carries the entire load back to the main member.

In some cases, the web members are shop fabricated and welded into assemblies. This facilitates field erection and welding because only vertical welds between the main pipe member and gusset plate are still required.

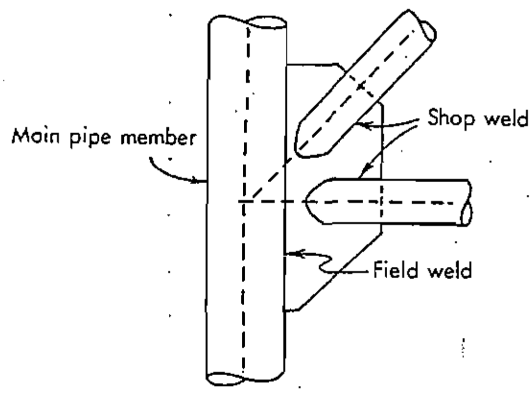


FIGURE 2

(3) Provides a direct transfer of force through a main pipe member when other members connect on opposite sides of the member. This may be done if it is felt that the main member has too low a thickness (t) to diameter (d) ratio and would need additional stiffness.

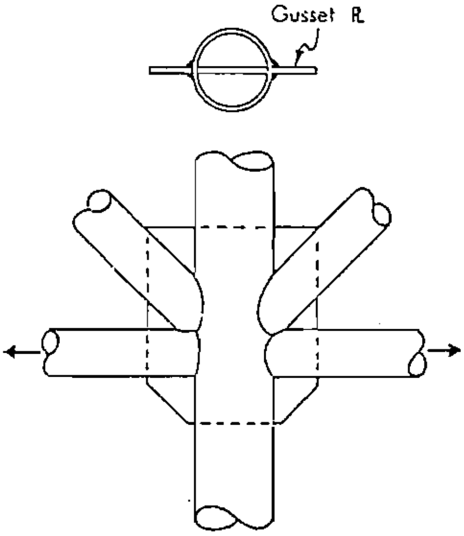


FIGURE 3

Another solution to this problem would be to add a "sleeve" or "collar" around the main member within this connection zone so that it would have the required thickness. It would be possible to insert by welding, a short length of thicker tubing within this zone. Usually the main pipe members must be butt welded together somewhere to provide the required length, and this weld could be located at this position. See Figure 4.

If the wall thickness, bevel, and fit-up of the pipe are sufficient for 100% penetration groove welds to be made, there should be no reason for gusset plates. In most cases, with proper care, groove welds could be made easily.

Although gusset plates are used in pipe connections, they tend to stiffen the pipe and, as a result, concentrate the stress in the pipe at the end of the plate. See Figure 5.

It has been suggested that, if gusset plates are to be used, they be tapered at their ends so as to have less stiffening effect on the pipe and thus provide a more even distribution of stress within the pipe at this connection.

Under static loads, any reasonable stress concentration in the pipe near the termination of the gusset plate would probably be reduced by some localized plastic yielding; so, this would not be a problem. However, gusset plates should be avoided for connections subject to fatigue loading.

3. ORDER OF ASSEMBLY

When web members intersect at a connection, normally the tensile member is first welded completely all the way around to the main member. Then the compression member is cut back to overlap the tensile member, and

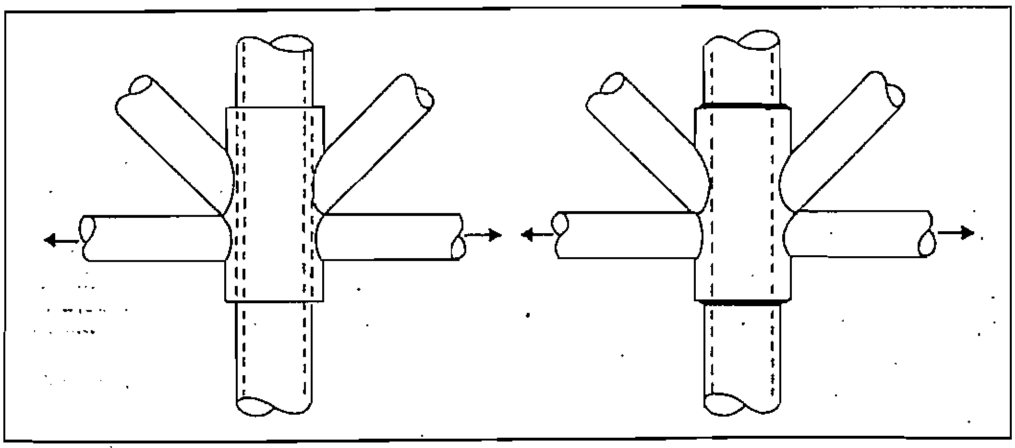


FIGURE 4

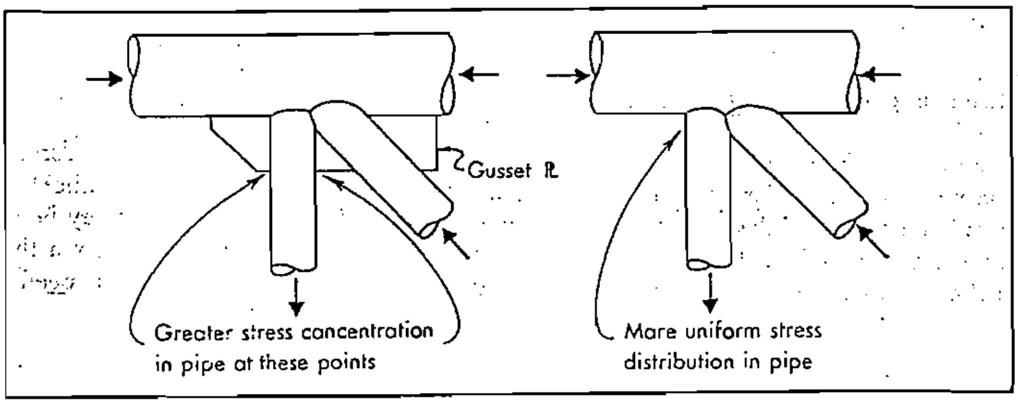


FIGURE 5

FIGURE 6

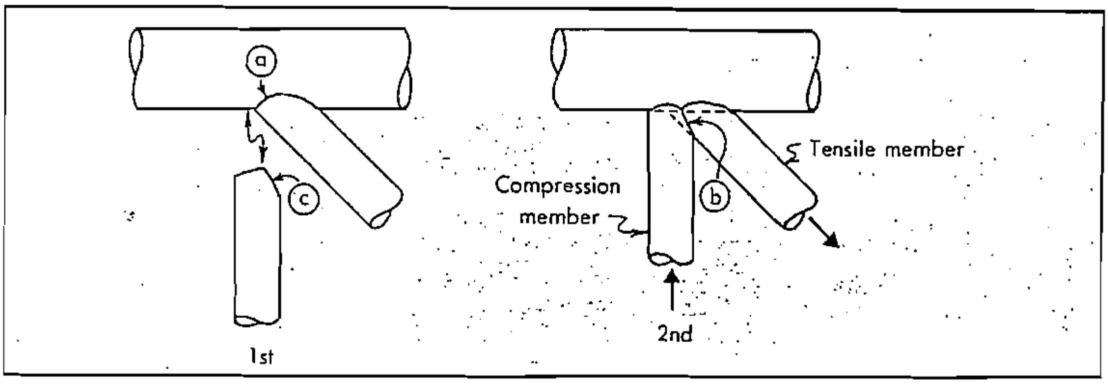
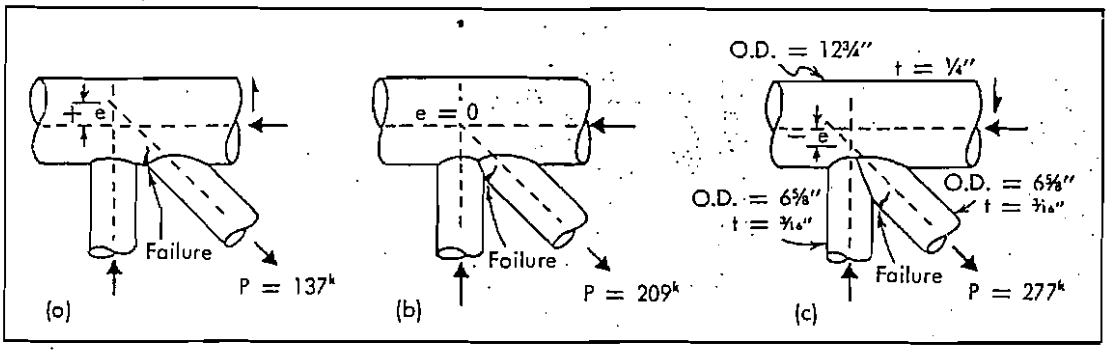


FIGURE 7



this is welded to both of these members. Every effort is made to obtain the best tensile connection; Figure 6.

This is not quite as important as it first sounds since most of the vertical component in the tension member is transferred directly into the compression member through the welds of this overlapping portion (b) without ever passing through the weld connecting the tension member to the main horizontal member (a).

The portion of the weld (a) in the overlapped area connecting the tension member to the main member is subjected to two forces: tension from the tensile member, and compression from the compression member since it pushes against this overlapped portion of the tensile member. One force offsets the other, so that very little of any vertical force must be carried by this portion of the weld at (a), just the horizontal force into the top member.

Figures 7 and 8 describe a test conducted at the University of California, "Research on Tubular Connections in Structural Work" J. G. Bouwkamp, WRC #71, Aug. 1961. This test shows the effect that overlapping the intersecting web members has on the strength of the joint.

It is seen that a more negative eccentricity of the connection (c) results in more overlapping of the web members and greater stiffness of the main member. With this great overlapping of the web members, the transfer of the vertical component of the diagonal web member into the vertical web member will occur before it enters the main horizontal chord member. The above test shows this connection to have the highest strength, actually slightly higher than the tube itself, which in a separate test pulled at an average of 260 kips. Notice all three of the above tests failed in the tube wall adjacent to the connecting weld.

4. APPLICABLE BRITISH SPECIFICATIONS

The following is taken from Addition No. 1 (Nov 1953) to B.S. 449 (1948), British Standards Institution:

Sealed tubes or sealed box sections, for exposed structures shall not be thinner than .160"; for non-exposed structures this limit is .128", and not less than—

$$t = .10 \sqrt[3]{D}$$

D = outside diameter of pipe

t = thickness of pipe

The angle between intersecting pipe shall not be less than 30°; otherwise the strength of the connection shall be demonstrated.

A complete penetration groove weld may be used regardless of the ratio of the diameters of the intersecting pipes.

If the ratio of the diameter of the pipes is less than ⅓, fillet welds may be used.

If this ratio is ⅓ or greater, a combination of fillet welds for a portion of the joint and groove welds for the remainder may be used.

Pipes connected end to end shall be groove welded.

In a fillet weld or a combination of fillet and groove

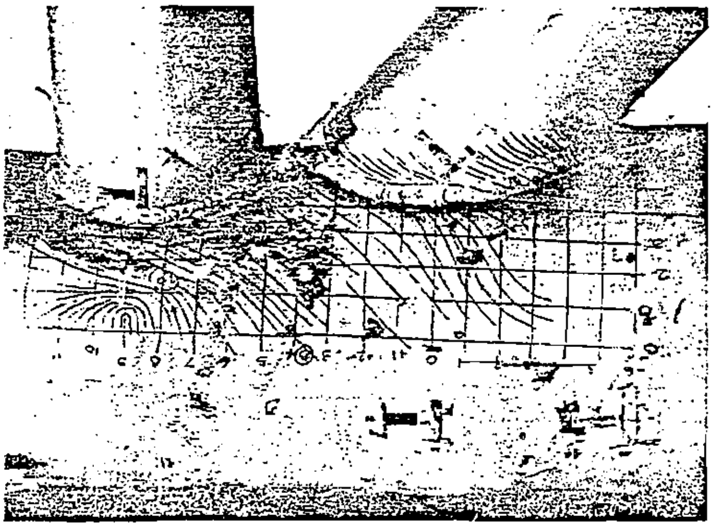


FIG. 8a This pipe connection (Fig. 7a) had a positive eccentricity of 1/4 the diameter of the larger pipe. Its ultimate load was 137 kips.

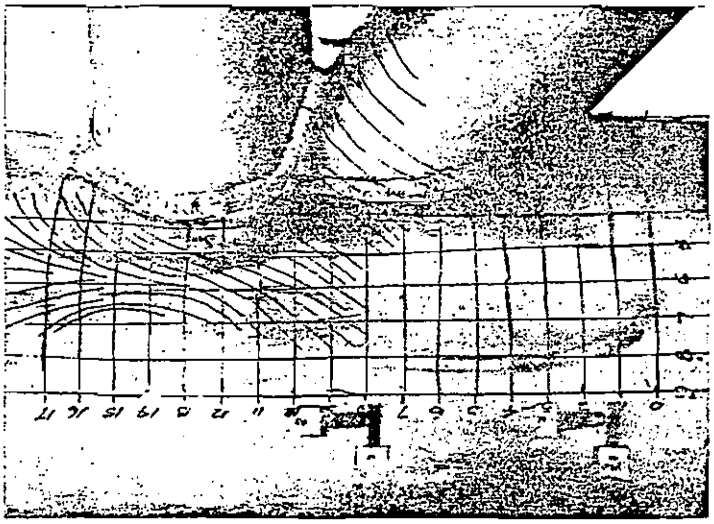


FIG. 8b This pipe connection (Fig. 7b) had no eccentricity. There's a slight overlapping of the connection. Its ultimate load was 209 kips.

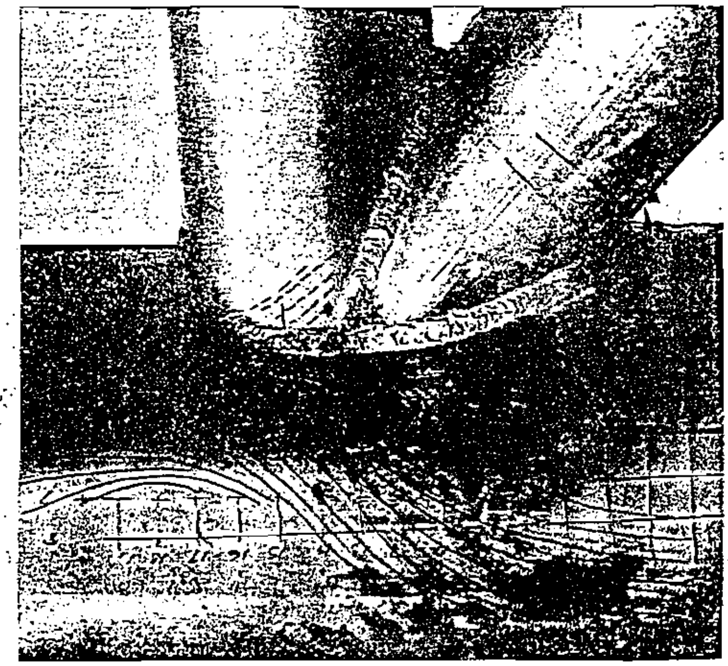


FIG. 8c This pipe connection (Fig. 7c) had a negative eccentricity of 1/4 the diameter of the larger pipe. Because of larger amount of overlapping, its ultimate load was 277 kips.

weld, the allowable stress on the throat shall not exceed the allowable shear stress of the pipe.

In a groove weld, the allowable tensile, compressive, or shear stress on the throat shall not exceed that of the pipe.

5. DESIGN OF TUBULAR TRUSS CONNECTIONS

The application of tubular construction to a truss arrangement is typified by the following problem. Here the loading is similar to that on the connection which was the subject of Problem 3, in the preceding Section 5.9.

Problem 1

To design an efficient connection on this tubular truss, Figure 9.

(a) First check the allowable loads on the various selected pipe sections against the actual loading.

Member Ⓐ

$$\frac{L}{r} = \frac{(432)}{(4.38)}$$
$$= 98.7$$

and the allowable is $\sigma = 12{,}520$ psi

$$P = \sigma A$$
$$= (12{,}520)(14.58)$$
$$= 182 \text{ kips} > 168 \text{ kips} \quad \underline{\text{OK}}$$

Member Ⓑ

$$\frac{L}{r} = \frac{(238)}{(4.38)}$$
$$= 54.3$$

and the allowable is $\sigma = 16{,}660$ psi

$$P = \sigma A$$
$$= (16{,}660)(14.58)$$
$$= 243 \text{ kips} > 200 \text{ kips} \quad \underline{\text{OK}}$$

Member Ⓓ

$$P = \sigma A$$
$$= (20{,}000)(7.265)$$
$$= 145.3 \text{ kips} > 126 \text{ kips} \quad \underline{\text{OK}}$$

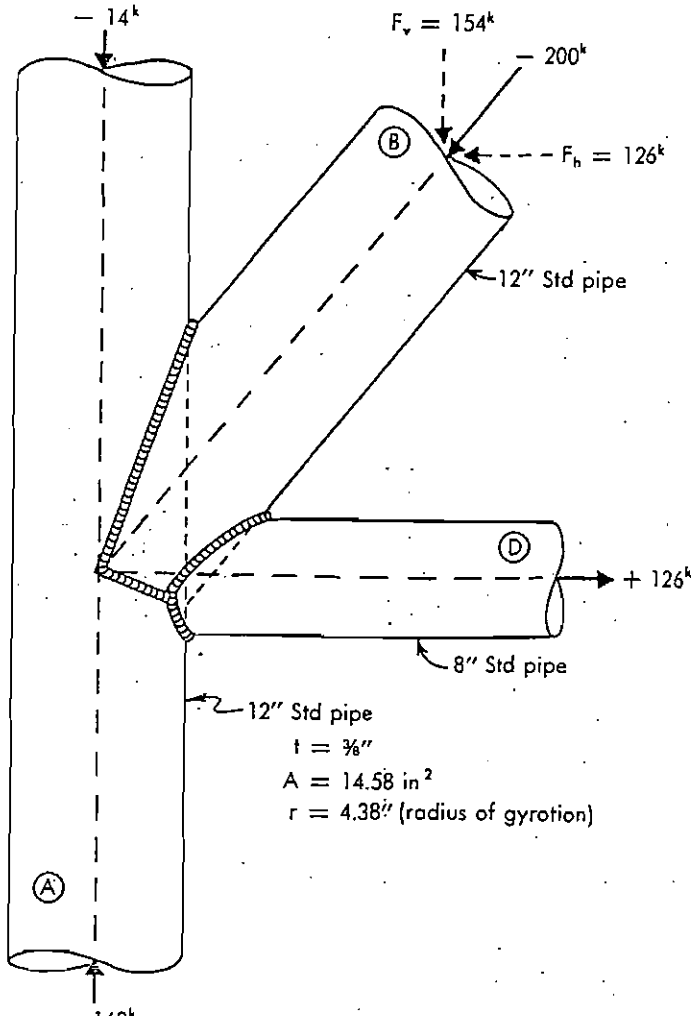


FIGURE 9

(b) Use a ⅝" gusset plate on this connection, resulting in Figure 10.

moment applied to pipe

$$M_h = (126^k)(7.86'')$$
$$= 990 \text{ in.-kips}$$

also

$$M_b = (154^k)(6\tfrac{3}{8}'')$$
$$= 982 \text{ in.-kips}$$

assumed value of e

$$e = 12\ t$$
$$= 12\ (\tfrac{3}{8})$$
$$= 4\tfrac{1}{2}''$$

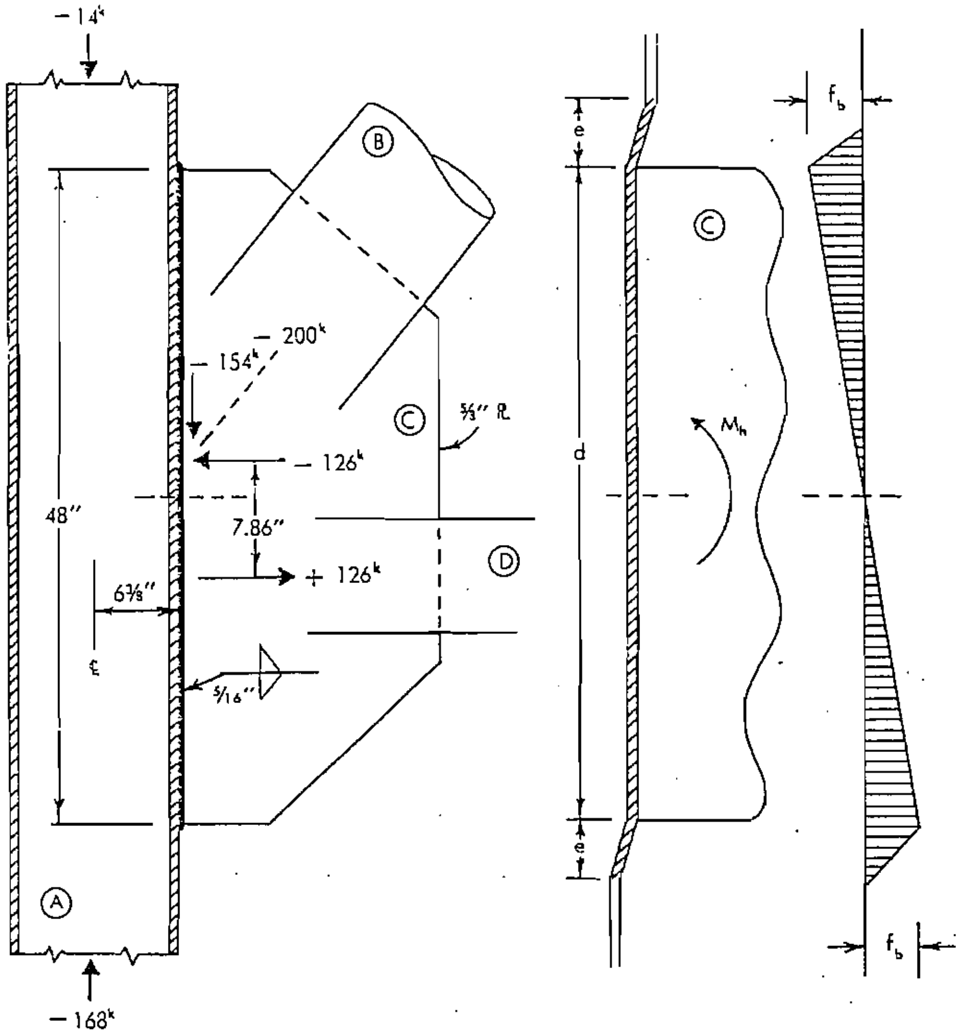


FIGURE 10

maximum unit force (radial) applied to 1″ ring section of pipe (A)

$$f_b = \frac{6\ M_h}{(d + e)(d + 2e)}$$

$$= \frac{6(990)}{(48 + 4\frac{1}{2})(48 + 9)}$$

$$= 1.98 \text{ kips}$$

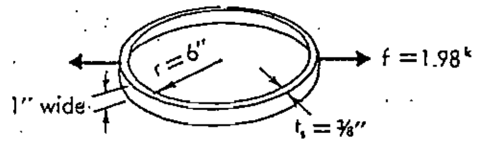


FIGURE 11

Although there is just a single radial force (f) acting on the pipe shell, assume there is an equal force on the opposite side of the shell, resisting this force. This represents a worse condition than actually exists.

$$S = \frac{t^2}{6}$$

$$= \frac{(\frac{3}{8})^2}{6}$$

$$= .023 \text{ in.}^3$$

$$M_{max} \text{ (at force f)} = k\ f\ r$$

$$= (.318)(1.98)(6)$$

$$= 3.78 \text{ in.-kips}$$

$$\sigma = \frac{M}{S}$$

$$= \frac{(3.78)}{(.023)}$$

$$= 164{,}000 \text{ psi} \quad \underline{\text{Excessive}}$$

Because of these excessive bending stresses within the pipe shell resulting from the moment applied by the connecting plate, some means of stiffening the pipe within this area must be used. There are several possibilities.

(1) One possible solution is to put a casing around the pipe so as to increase its wall thickness. This will provide sufficient section modulus so that the resulting bending stress is reduced to an allowable value. (Assume $\sigma = 18{,}000$ psi.)

$$S = \frac{M}{\sigma}$$

$$= \frac{(3.78)}{(18{,}000)}$$

$$= .210 \text{ in.}^3$$

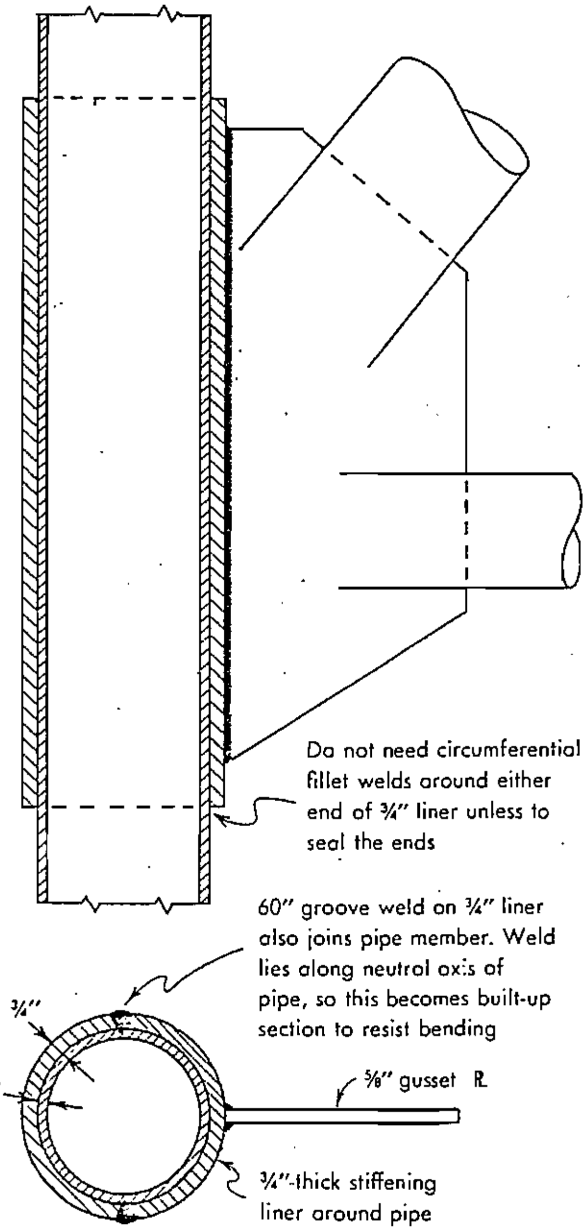


FIGURE 12

$$S = \frac{t^2}{6} \quad \text{or}$$

$$t = \sqrt{6\ S}$$

$$= \sqrt{6\ (.210)}$$

$$= 1.12'' \text{ required wall thickness}$$

Since 1.12" — ⅜" (present thickness of (A)) = .745" required additional thickness, or add a ¾"-thick wrap-around sheet around this pipe (A) in the area of the connection. See Figure 12.

(2) Another possible solution would be to add to the wall thickness at top and bottom of the connection.

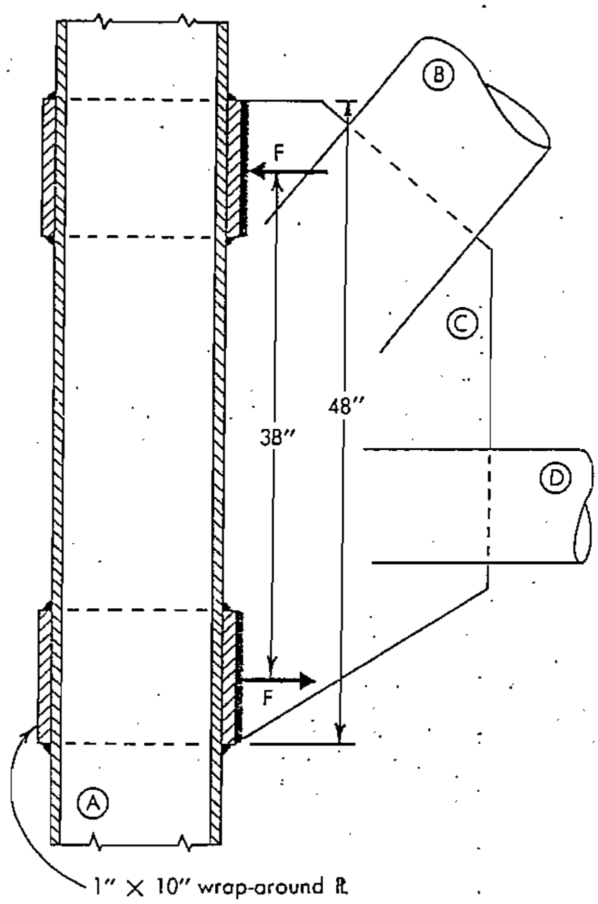


FIGURE 13

$$F = \frac{M_h}{d}$$

$$= \frac{(990 \text{ in.-kips})}{(38'')}$$

$$= 26.1 \text{ kips}$$

$$M = k\ F\ r_c$$

$$= (.318)(26.1^k)(6'')$$

$$= 49.8 \text{ in.-kips}$$

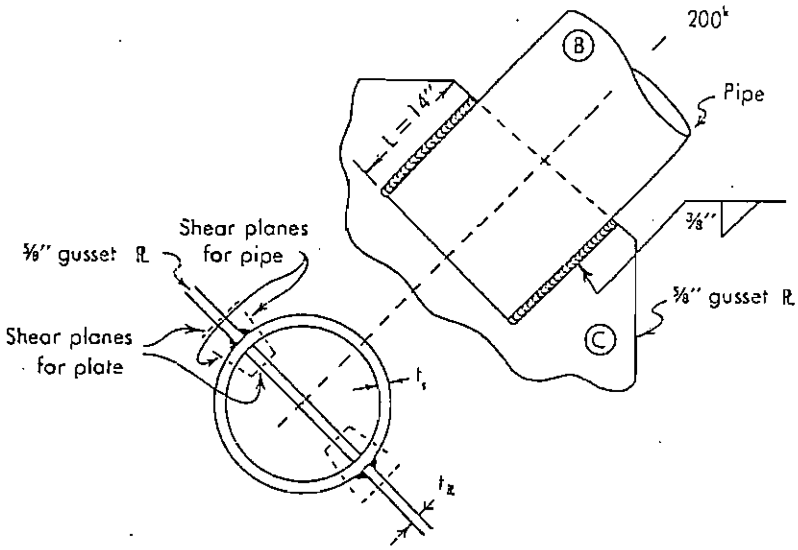


FIGURE 14

$$S = \frac{M}{\sigma}$$

$$= \frac{(49.8 \text{ in.-kips})}{(18{,}000 \text{ psi})}$$

$$= 2.77 \text{ in.}^3$$

$$S = \frac{w\ t^2}{6}$$ where: w = width of stiffening ring

$$\text{or} \quad t = \sqrt{\frac{6\ S}{w}}$$

$$= \sqrt{\frac{(6)(2.77)}{10}}$$

= 1.29″ required, and since 1.29″ — 3/8″ = .915″, add a 1″ x 10″ plate wrapped around the pipe (A) at the top and bottom of the connection.

(c) Determine the amount of required connecting weld between pipe (B) and gusset plate (C):

For determining the minimum length of connection (L) to hold shear stress (τ) within the allowable, use the following maximum leg size of weld:

plate

$$4\ L\ 9600\ \omega = 4\ t_{℞}\ L\ \tau$$

$$\omega = \frac{13{,}000\ t_{℞}}{9600} = 1.355\ t_{℞}$$

pipe

$$4\ L\ 9600\ \omega = 4\ t_s\ L\ \tau$$

$$\omega = \frac{13{,}000\ t_s}{9600} = 1.355\ t_s$$

$$\therefore\ \omega \leqq 1.355\ t_s$$

$$\leqq 1.355\ (3/8)$$

$\leqq$ .509″; so we'll use 3/8″ fillet weld

Since:

$$F = 4\ L\ 9600\ \omega$$

$$L = \frac{F}{4 \times 9600\ \omega}$$

$$= \frac{200^k}{4 \times 9600\ (3/8)}$$

$$= 13.9'' \text{ or } 14''$$

An alternate method would be to use 3/8″ fillet weld all the way around the end of the pipe (B):

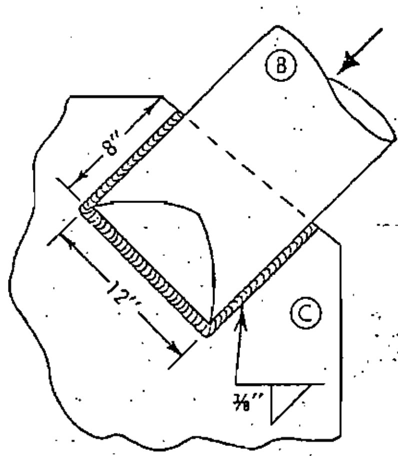


FIGURE 15

The total length of weld would be—

$$L = \frac{200^k}{3.6^k/\text{in.}}$$

$= 55.6''$, or $27.8''$ on each side of the ⅝″ gusset plate.

If the transverse weld is 12″ long, this leaves $27.8 - 12 = 15.8''$, or 8″ on each side.

6. TEMPLATES FOR PIPE CONNECTIONS

Although pipe fabricating shops have shop men who are experienced in laying out and preparing these joints by making their own templates, this is something new for most structural shops. It may be necessary to supply templates for the more critical pipe joints where a gusset plate is not specified.

There are tables of ordinates available for most standard pipe sizes and given angles of intersection (15°, 30°, 45°, 60°, and 90°). However, these may be of little value because other round tubular sections may be used which are not standard pipe sizes, and in structural work the angle of intersection will not necessarily be one of the above.

For good fit-up, it is necessary that the inner radius (r_1) of the smaller pipe (A) and the outer radius (r_2) of the larger pipe (B) intersect along a curve which forms the root of the joint.

Following is a suggested method for making templates which will cover all possible connections at any angle of intersection, any amount of offset, and any possible combination of pipe sizes. This template will allow the end of the smaller pipe to be cut for proper fit-up against the surface of the larger pipe. In structural work, it is not necessary to cut a hole into the side of the larger pipe at the connection, as is done in pressure piping so a second template is not needed for this cut.

The inner radius (r_1) of the smaller pipe (A) and the outer radius (r_2) of the larger pipe (B) are used to make the template. This is done graphically or analytically, as explained a few paragraphs further.

The template is made of some type of heavy paper. It is wrapped around the pipe to be cut, at the proper location. The center of this template edge is transferred onto the pipe with chalk. The chalked curve on the pipe is then marked with a series of centerpunch marks. The pipe is then flame-cut along this curve, keeping the torch tip normal or at right angles to the surface of the pipe. This will produce the proper curve for the joint as far as the inside of the pipe is concerned.

It is then necessary to bevel the edge of this pipe back from the outside, just touching this inside cut to provide the required included angle for the groove weld. A good experienced flame-cutting operator will do this without any difficulty.

If fillet welds are to be used instead of groove welds, this second cut or bevel is only needed at reentrant corners of the joint or where the angle between the surfaces of the intersecting pipes is less than 90°.

TABLE 1—Properties of Polar Angles

position	α	12 POSITIONS $\sin\alpha$	$\sin^2\alpha$	or (B) $1-\cos\alpha$
1	0	0	0.0000	0
2	30°	+ .50000	+ .2500	+ .1340
3	60°	+ .8660	+ .7500	+ .5000
4	90°	+1.0000	+1.0000	+1.0000
5	120°	+ .8660	+ .7500	+1.5000
6	150°	+ .5000	+ .2500	+1.8660
7	180°	0	0	+2.0000
8	210°	— .50000	+ .2500	+1.8660
9	240°	— .8660	+ .7500	+1.5000
10	270°	—1.0000	+1.0000	+1.0000
11	300°	— .8660	+ .7500	+ .5000
12	330°	— .5000	+ .2500	+ .1340
1	360°	0	0	0

TABLE 2—Properties of Polar Angles

position	α	16 POSITIONS $\sin\alpha$	$\sin^2\alpha$	or (B) $1-\cos\alpha$
1	0	0	0	0
2	22.5°	+ .3827	+ .1465	+ .0761
3	45.0°	+ .7071	+ .5000	+ .2929
4	67.5°	+ .9239	+ .8536	+ .6173
5	90.8°	+1.0000	+1.0000	+1.0000
6	112.5°	+ .9239	+ .8536	+1.3827
7	135.0°	+ .7071	+ .5000	+1.7071
8	157.5°	+ .3827	+ .1465	+1.9239
9	180.0°	0	0	+2.0000
10	202.5°	— .3827	+ .1465	+1.9239
11	225.0°	— .7071	+ .5000	+1.7071
12	247.5°	— .9239	+ .8536	+1.3827
13	270.0°	—1.0000	+1.0000	+1.0000
14	292.5°	— .9239	+ .8536	+ .6173
15	315.0°	— .7071	+ .5000	+ .2929
16	337.5°	— .3827	+ .1465	+ .7061
1	360.0°	0	0	0

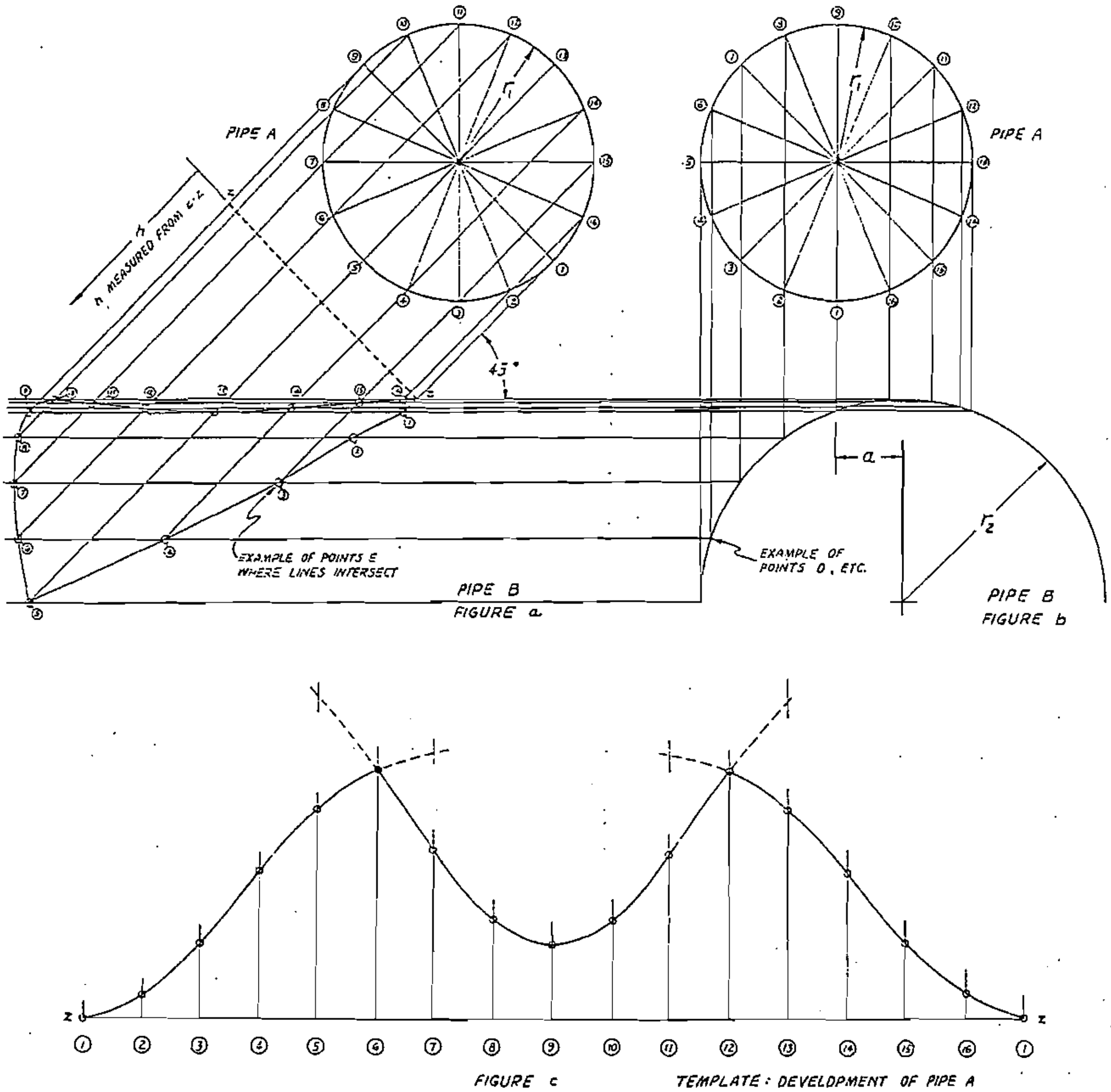


FIGURE 16

Graphical Method of Making Template

References are to views (a), (b), and (c) of Figure 16.

1. Draw a side view of the connection, figure (a). Draw an end view of the connection, figure (b).

2. Lay off pipe (A) into a given number of equal sections, for example 16, and number these 1, 2, 3, etc. through to 16. Draw lines through these points parallel to the axis of pipe (A) in both figures.

3. Where these parallel lines of pipe (A) intersect pipe (B), in figure (b), make points (D).

4. Through points (D), draw lines parallel to the axis of the large pipe (B), extending them into figure (a).

5. Where these parallel lines of pipe (B) intersect corresponding parallel lines of pipe (A), in figure (a), mark points (E). Number these points in accordance with the original division of the pipe (A).

6. In figure (c), lay off line z-z, equal to the outer circumference of pipe (A), and divide into 16 equal segments.

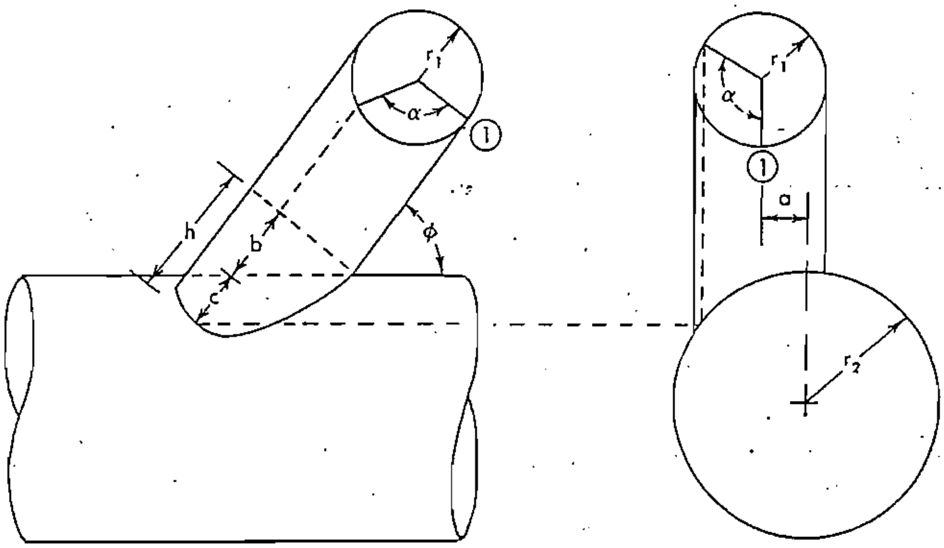


FIGURE 17

7. In figure (a), draw reference line Z-Z at right angles to the axis of pipe (A) and through the vertex of the connection angle. From this line Z-Z measure the ordinate distance (h) to the various intersecting points (E). Lay these distances (h) off vertically from line Z-Z in figure (c). Do this for all the points and draw a curve through the upper extremities of these vertical lines. This becomes the template for cutting pipe (A), figure (c).

Analytical Method

The following formula will give the value of the ordinate (h) for any polar position (α) along the smaller pipe. This method of finding ordinates by formula eliminates the mapping of figures (a) and (b) in the graphical method of Figure 16.

$$\boxed{h = \frac{r_2 - \sqrt{r_2^2 - (a - r_1 \sin \alpha)^2}}{\sin \phi} + \frac{r_1}{\tan \phi}(1 - \cos \alpha)} \quad (1)$$

Practically all structural pipe connections will have no offset, a = 0, and this becomes—

$$\boxed{h = \frac{r_2 - \sqrt{r_2^2 - r_1^2 \sin^2 \alpha}}{\sin \phi} + \frac{r_1}{\tan \phi}(1 - \cos \alpha)} \quad (2)$$

or:

$$\boxed{h = \frac{r_2}{\sin \phi}[A] + \frac{r_1}{\tan \phi}[B]} \quad \ldots\ldots\ldots\ldots (3)$$

where:

$$[A] = 1 - \sqrt{1 - K^2 \sin^2 \alpha} \qquad K = \frac{r_1}{r_2}$$

$$[B] = 1 - \cos \alpha$$

r_1 = inner radius of smaller intersecting pipe

r_2 = outer radius of larger intersecting pipe

ϕ = angle of intersection between axes of pipes

h = ordinate of the template for the smaller pipe for any position (α)

α = position along the smaller pipe

Tables 1 and 2 will give the necessary values for $\sin \alpha$, $\sin^2 \alpha$, and $1 - \cos \alpha$ for the various polar angles (α) for either 12 positions or 16 positions of the pipe.

If Formula 3 is to be used, the following nomograph, Figure 18, will give values of [A]. Values of [B] may be found in Tables 1 and 2.

Problem 2

For the tubular connection represented in Figure 16, the smaller pipe (A), inside radius $r_1 = 2''$, intersects the larger pipe (B), outside radius $r_2 = 3''$, at an angle of 45°, and with an offset of $a = 2''$.

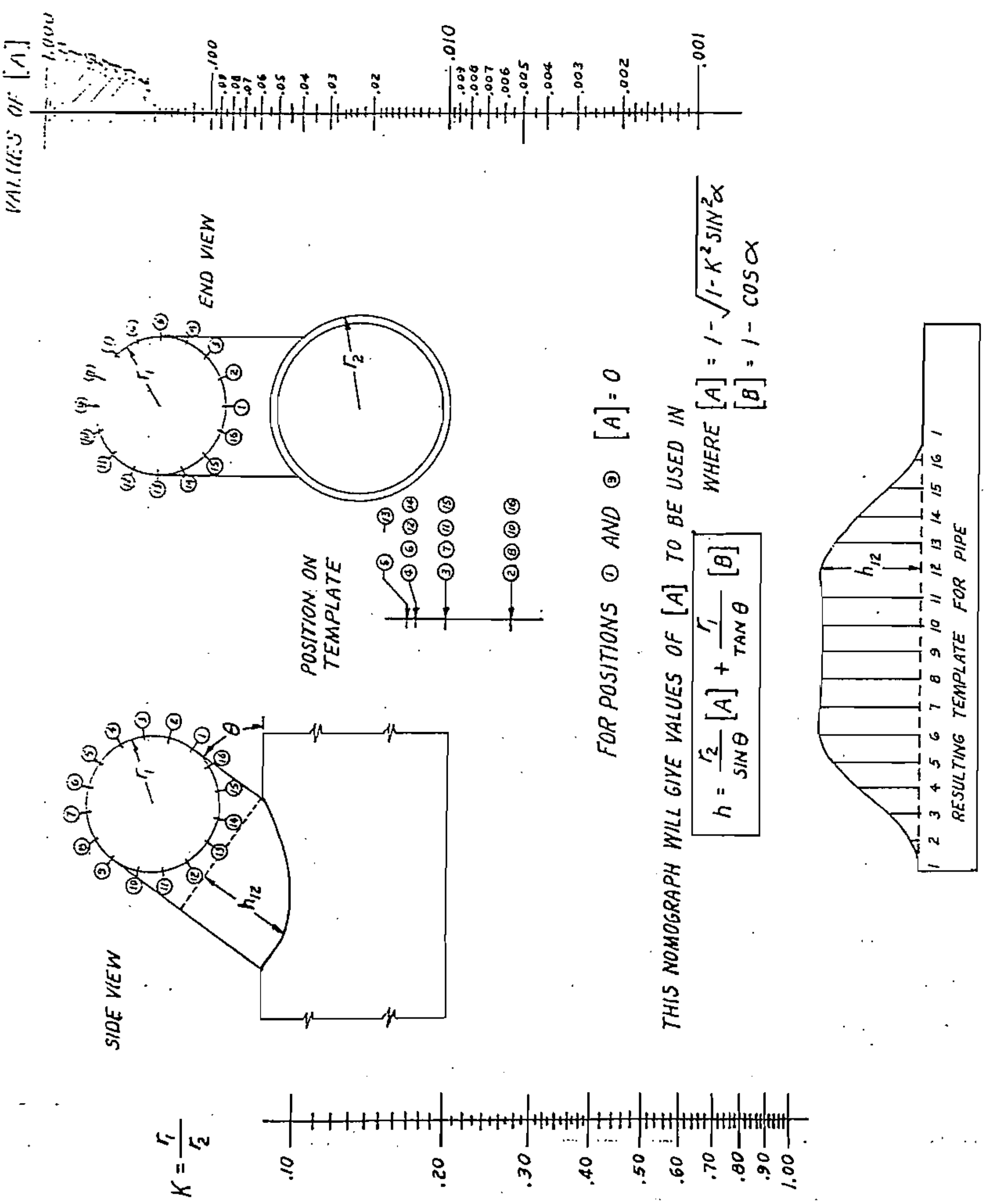

VALUES OF [A]
SIDE VIEW
END VIEW
POSITION ON TEMPLATE
FOR POSITIONS ① AND ⑨ [A] = 0
THIS NOMOGRAPH WILL GIVE VALUES OF [A] TO BE USED IN
$h = \frac{r_2}{\sin\theta}[A] + \frac{r_1}{\tan\theta}[B]$
WHERE $[A] = 1 - \sqrt{1 - K^2 \sin^2\alpha}$
$[B] = 1 - \cos\alpha$
RESULTING TEMPLATE FOR PIPE
$K = \frac{r_1}{r_2}$

FIGURE 18

Following are the ordinates (h) for the various positions figured both graphically (see Figure 16) and analytically (with Formula 1). This table shows close agreement between the two sets of values.

position	graphical	analytical
1	.26″	.242″
2	1.03″	.965″
3	2.31″	2.308″
4	4.14″	4.145″
5	6.25″	6.242″
6	5.70″	5.675″
7	5.17″	5.136″
8	4.65″	4.660″
9	4.29″	4.242″
10	3.87″	3.861″
11	3.52″	3.455″
12	3.00″	2.938″
13	2.30″	2.242″
14	1.40″	1.408″
15	.62″	.627″
16	.15″	.165″

A sheet of paper is laid out. A straight line X-X is drawn across the paper, parallel to the long edge and 2″ or 3″ from this edge. Starting from the left edge of the paper, measure off a distance on this line equal to the outer circumference of the smaller pipe A and mark this on the line. This can be done in two ways; the circumference of the pipe may be figured by knowing the outside diameter of the pipe, or this paper may be wrapped around the outside of the pipe and marked where this edge of the paper overlaps.

The easiest way to divide this line (which represents the circumference) into equal segments is to fold the left edge of the paper back toward the right until it lies directly on top of this mark, then fold this flat upon itself. This divides the circumference into two equal parts. Now fold this edge back toward the left until it lies directly over this fold, and fold down. Do the same for the similar portion on the bottom. This now divides the circumference into four equal parts. Open the paper and divide each of these quarter sections into three equal parts and number each of these vertical lines from 1 to 12. If 16 positions are to be used, divide each of these quarter sections into four equal parts and number from 1 to 16.

Lay off the corresponding ordinates (h) on these lines. Draw a curve through these points and cut along this curve; the lower portion of the paper is the template.

Problem 3

In the connection represented in Figure 19, the axes of these three intersecting pipes lie on a common plane; there is no offset ($a = 0$).

A template is required to cut pipe (A) which intersects both pipes (B) and (C). The inner radius of pipe (A) is 2″, the outer radius of pipe (B) is 3″, and the outer radius of pipe (C) is 2¼″. The graphical work is shown in Figure 19.

Notice that the finished template is made of two portions, that due to the intersection with pipe (B), and that due to intersecting pipe (C).

Problem 4

In this example, the nomograph (Fig. 18) will be used to find the ordinates (h) for a template to be used in cutting the smaller pipe of a two-pipe connection. The smaller pipe (A) has an inside radius of $r_1 = 2''$, the larger pipe (B) has an outside radius of $r_2 = 3''$, and the angle of their intersection is $\phi = 60°$.

$$K = \frac{r_1}{r_2} = \frac{2''}{3''} = .67$$

$\sin 60° = .8660$

$\tan 60° = 1.7321$

Formula (3)

$$\begin{aligned} h &= \frac{r_2}{\sin\phi}\ [A] + \frac{r_1}{\tan\phi}\ [B] \\ &= \frac{3}{.8660}\ [A] + \frac{2}{1.7321}\ [B] \\ &= 3.464\ [A] + 1.155\ [B] \end{aligned}$$

The results are shown below in table form. As a matter of interest, the values computed by Formula (2) are listed on the extreme right and indicate the reasonable accuracy of the nomograph.

position	Values of [A] from nomograph	Values of [B] from table 2	Value of h = 3.464[A] + 1.155[B]	Value of h from formula (2)
1	0	0	0	0
2, 16	.032	.0761	.20	.202
3, 15	.115	.2929	.74	.747
4, 14	.21	.6173	1.44	1.448
5, 13	.26	1.0000	2.06	2.037
6, 12	.21	1.3827	2.33	2.332
7, 11	.115	1.7071	2.37	2.380
8, 10	.032	1.9239	2.42	2.336
9	0	2.0000	2.31	2.309

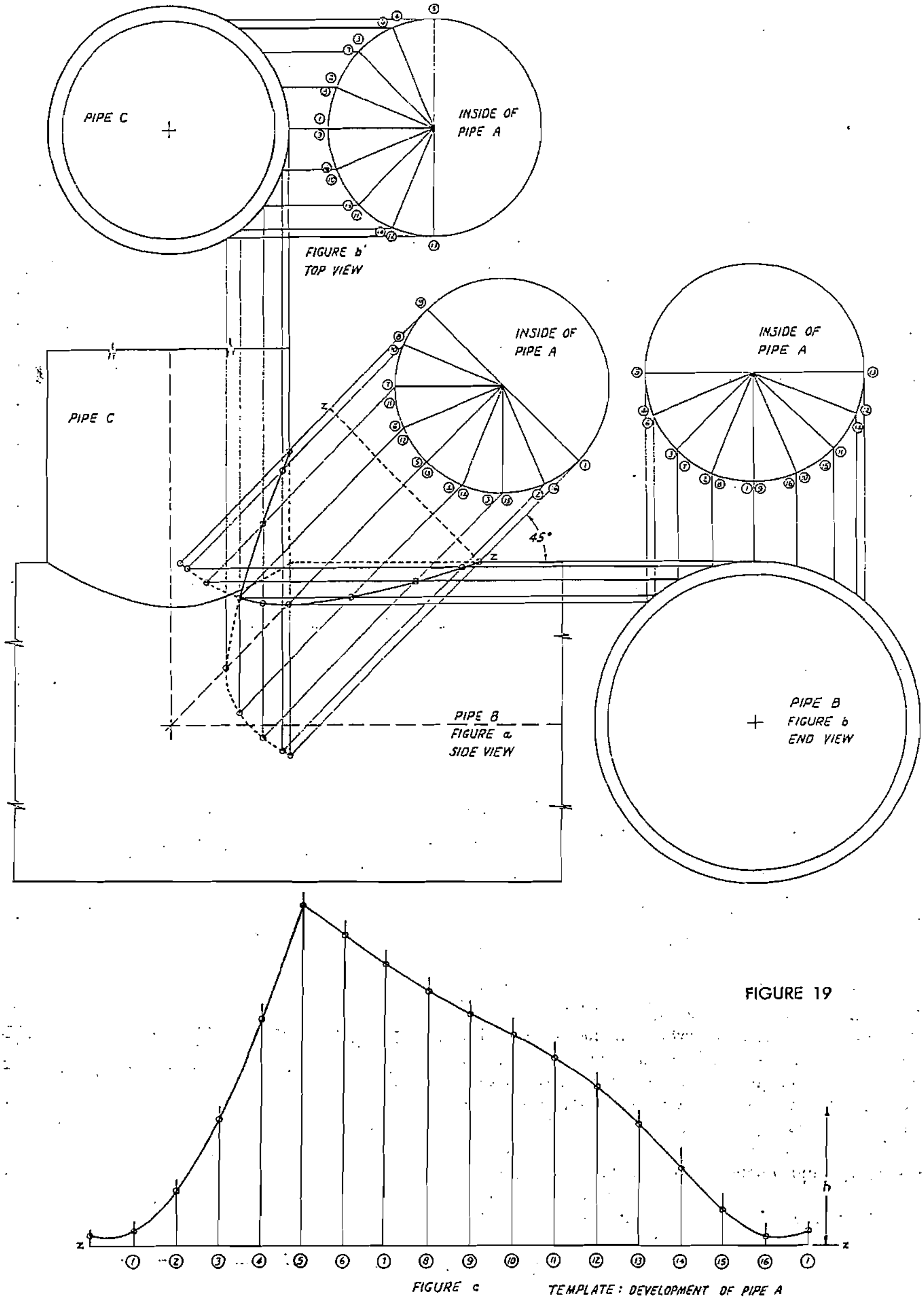
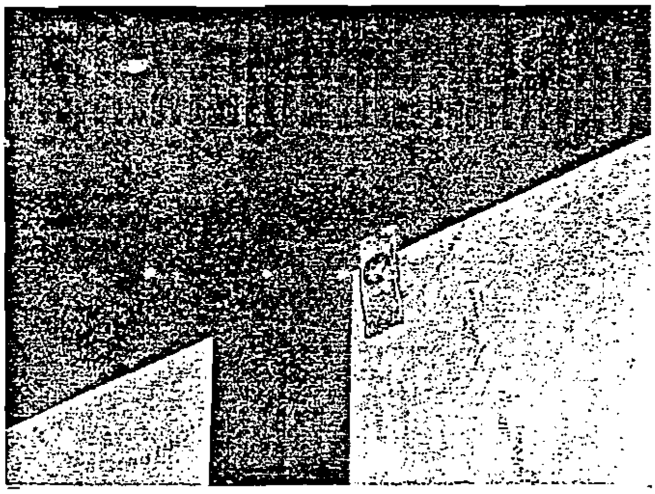

PIPE C
INSIDE OF PIPE A
FIGURE b' TOP VIEW
INSIDE OF PIPE A
INSIDE OF PIPE A
PIPE C
45°
PIPE B FIGURE a SIDE VIEW
PIPE B FIGURE b END VIEW
h
z
FIGURE c
TEMPLATE: DEVELOPMENT OF PIPE A

FIGURE 19

7. BOX SECTIONS

The square and rectangular box sections, in which tubing has more recently become available at competitive prices, eliminate the problem of fit-up that is associated with the round sections. With box sections, the end of the smaller tube can be simply sawed with a single cut at the required angle.

Field erection of box sections is easily simplified by the use of Saxe clips, Figure 20. The clip and its seat are shop welded to the two intersecting members. Usually the clip is welded to the inside of the box beam where it is less vulnerable to damage during shipment to the project site. The clip also functions as a seat to help in support of the beam. This allows the joint to be made without any attachments on the outside, and produces a pleasing appearance.



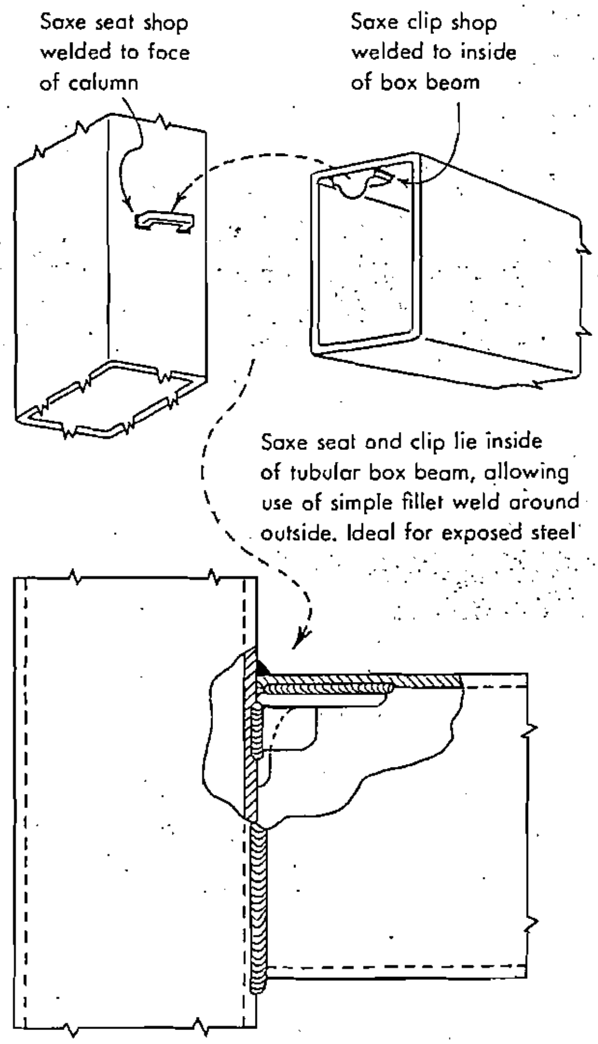
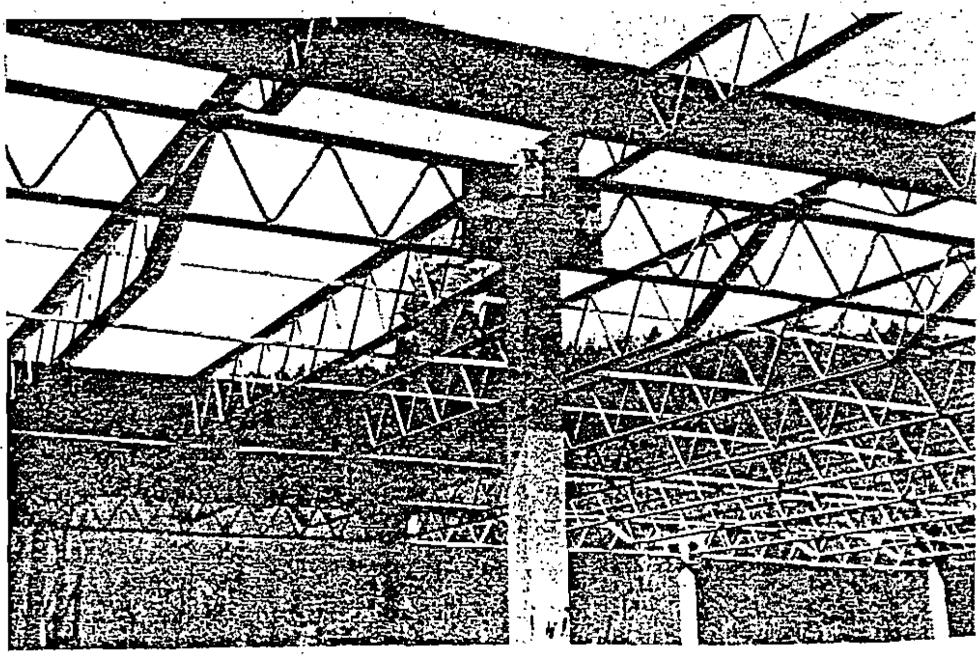
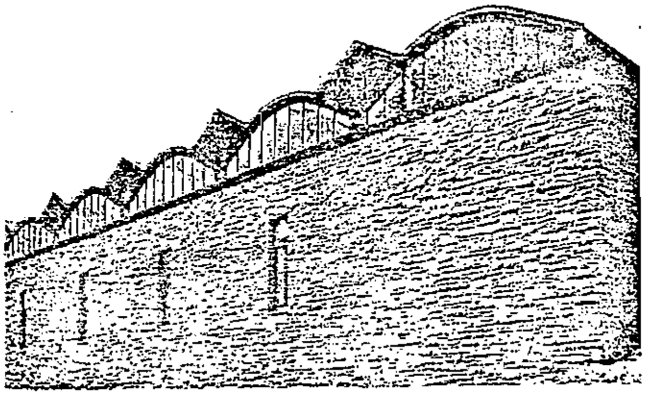


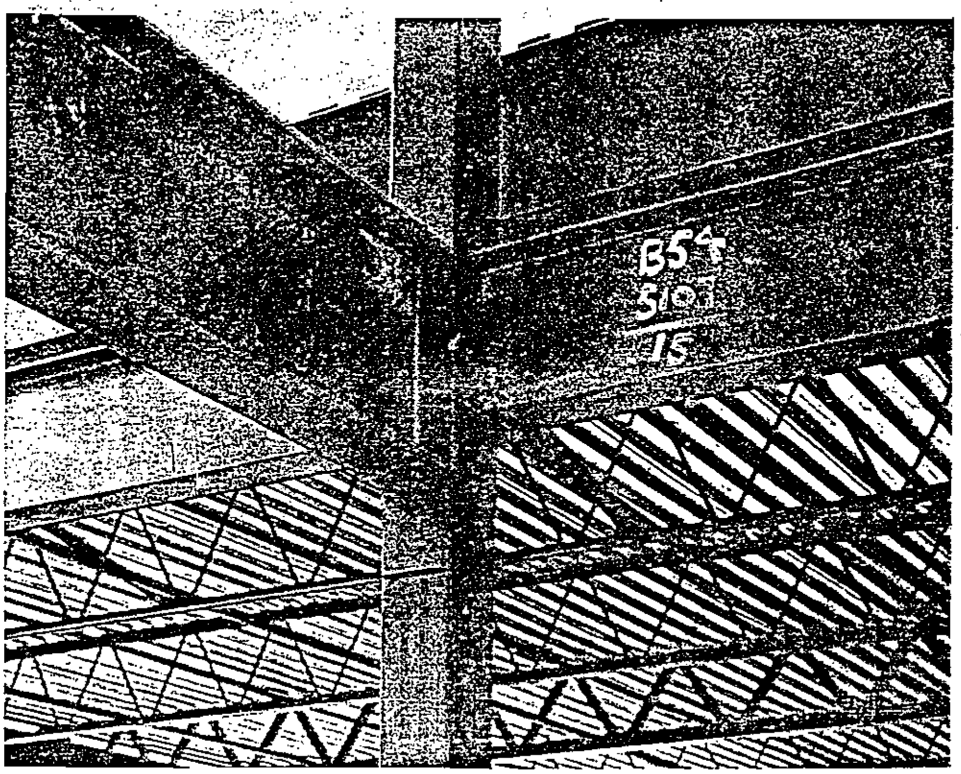
FIGURE 20

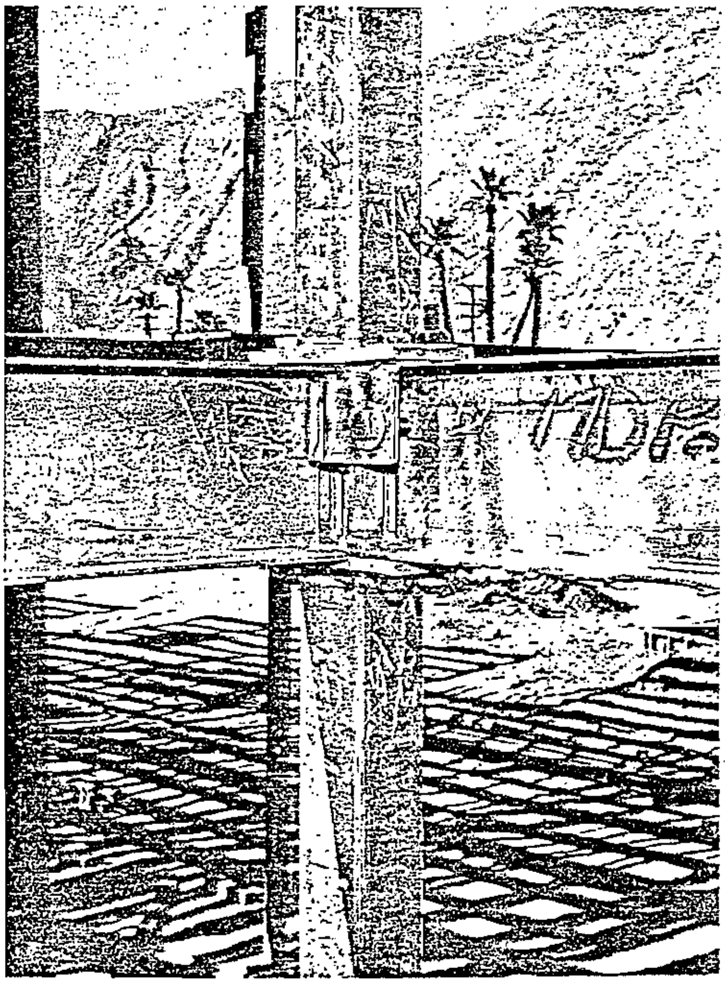


Square and rectangular structural tubing, now available in many standard sizes, tends to simplify design and facilitate erection. Both shop and field connections are generally more easily made than when using round tubing.

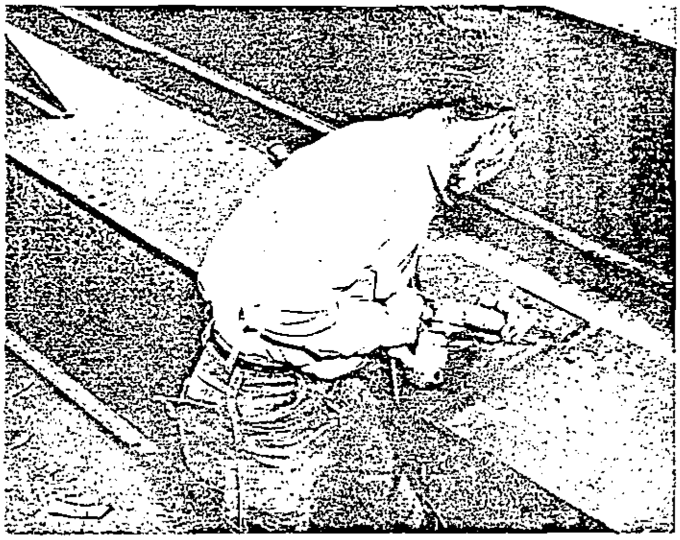


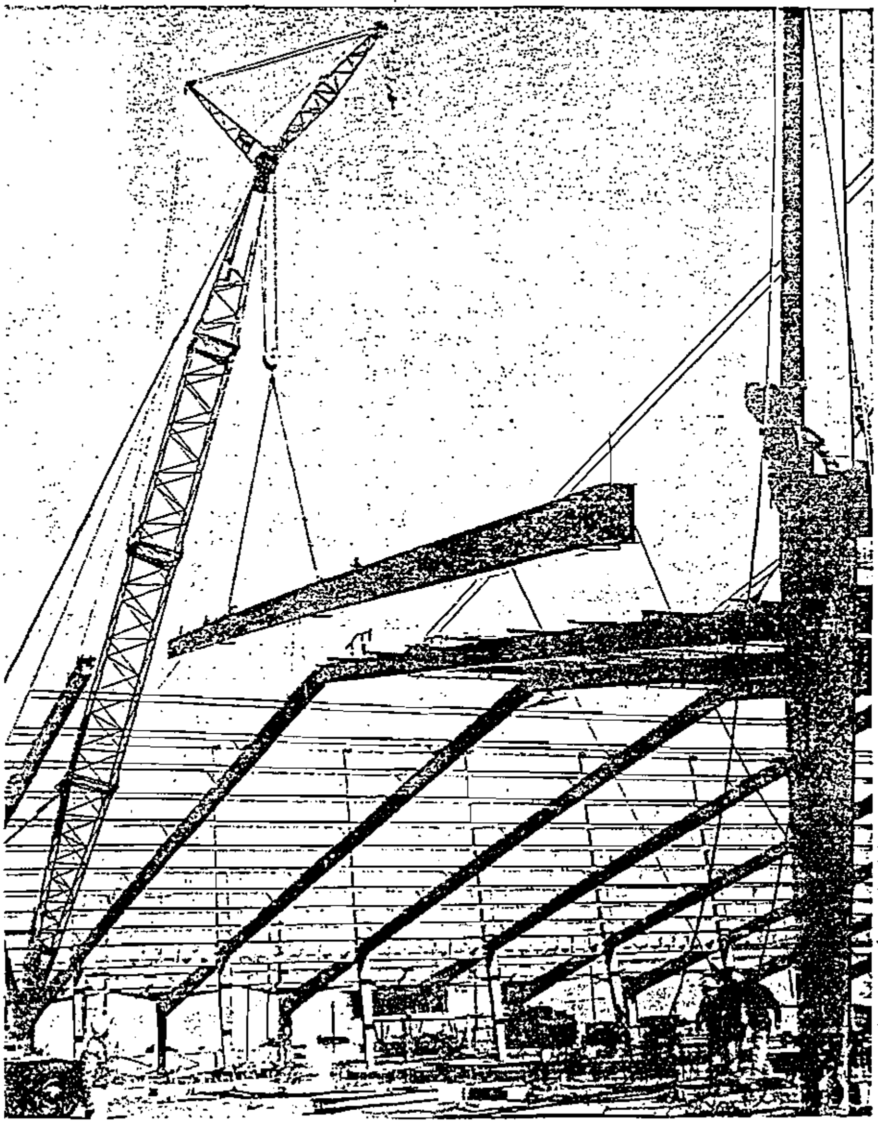
Space frame roof on the combined warehouse and machine shop in Bethlehem Steel Co.'s research complex offers an interesting silhouette (at top). Roof frame is formed by eleven 96′-span welded pipe trusses braced apart by inclined pipe struts and arched structural members. The result is a very rigid structure, although temporary stiffening with steel channels was required during erection.





Typical connections to facilitate erection of structure using square tubing for columns. Columns have equally high strength in both x and y directions, plus excellent torsional resistance. Connections combine welding and erection bolting.





Unique roof suspension system combines with "tubular" design of members and weld fabrication to provide vast unobstructed area and light airy atmosphere to the Tulsa (Oklahoma) Exposition Center. In photo above, slag is being chipped from root pass on splice of built up box-section roof girder, preparatory to making main fill passes.