Determining Weld Size

1. WHEN TO CALCULATE WELD SIZE

Overwelding is one of the major factors of welding cost. Specifying the correct size of weld is the first step in obtaining low-cost welding. This demands a simple method to figure the proper amount of weld to provide adequate strength for all types of connections.

In strength connections, complete-penetration groove welds must be made all the way through the plate. Since a groove weld, properly made, has equal better strength than the plate, there is no need for calculating the stress in the weld or attempting to determine its size. However, the size of a partial-penetration groove weld may sometimes be needed. When welding alloy steels, it is necessary to match the weld-metal strength to plate strength. This is primarily a matter of proper electrode selection and of welding procedures.

With fillet welds, it is possible to have too small a weld or too large a weld; therefore, it is necessary to determine the proper weld size.

Strength of Welds

Many engineers are not aware of the great reserve strength that welds have. Table 1 shows the recognized strength of various weld metals (by electrode designation) and of various structural steels.

Notice that the minimum yield strengths of the 'inary E60XX electrodes are over 50% higher than the corresponding minimum yield strengths of the A7, A373 and A36 structural steels for which they should be used.

Since many E60XX electrodes meet the specifications for E70XX classification, they have about 75% higher yield strength than the steel.

Submerged-Arc Welds

AWS and AISC require that the bare electrode and flux combination used for submerged-arc welding shall be selected to produce weld metal having the tensile properties listed in Table 2, when deposited in a multiple-pass weld.

2. FILLET WELD SIZE

The AWS has defined the effective throat area of a fillet weld to be equal to the effective length of the weld times the effective throat. The effective throat is defined as the shortest distance from the root of the diagrammatic weld to the face.

According to AWS the leg size of a fillet weld is measured by the largest right triangle which can be inscribed within the weld, Figure 1.

This definition would allow unequal-legged fillet welds, Figure 1(a). Another AWS definition stipulates the largest isosceles inscribed right triangle and would limit this to an equal-legged fillet weld, Figure 1(b).

Unequal-legged fillet welds are sometimes used to get additional throat area, hence strength, when the

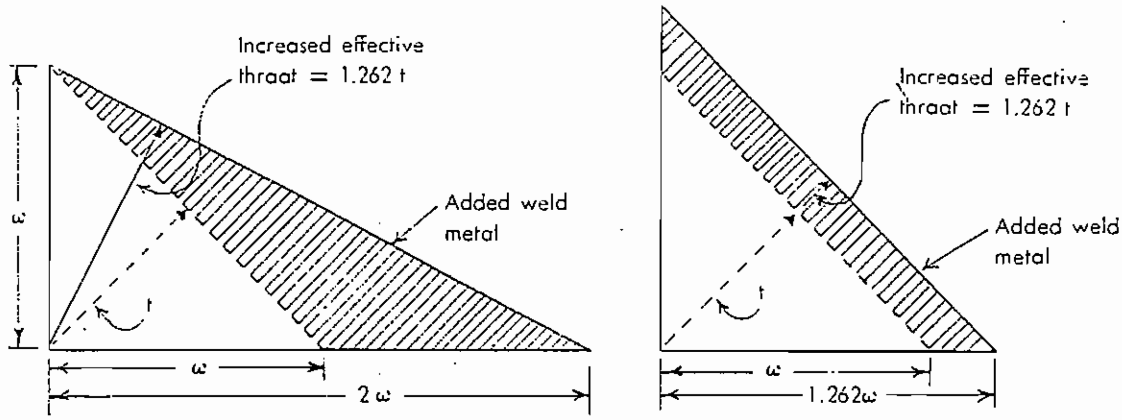
TABLE 1—Minimum Strengths Required of Weld Metals and Structural Steels (AWS A5.1 & ASTM A233) (as-welded condition)

	Material	Min. Yield Strength psi	Min. Tensile Strength psi
Weld Metals	E6010	50,000 psi	62,000 psi
	E6012	55,000	67,000
	E6024	58,000	62,000
	E6027	50,000	62,000
	E70XX	60,000	72,000
Steels	A7	33,000	60,000
	A373	32,000	58,000
	A36	36,000	58,000
	A441	42,000 46,000 50,000	63,000 67,000 70,000

TABLE 2—Minimum Properties Required of Automatic Submerged-Arc Welds (AWS & AISC) (as-welded; multiple-pass)

Grade SAW—1	
tensile strength	62,000 to 80,000 psi
yield point, min.	45,000 psi
elongation in 2 inches, min.	25%
reduction in area, min.	40%

Grade SAW—2	
tensile strength	70,000 to 90,000 psi
yield point, min.	50,000 psi
elongation in 2 inches, min.	22%
reduction in area, min.	40%



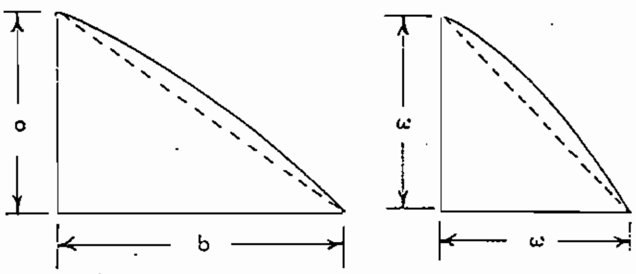
(a) Throat increased by 26%
Area increased by 100%

(b) Throat increased by 26%
Area increased by 59%

FIGURE 1

vertical leg of the weld cannot be increased. See Figure 2(a).

Where space permits, a more efficient means of obtaining the same increase in throat area or strength is to increase both legs to maintain an equal-legged fillet weld with a smaller increase in weld metal. See Figure 2(b).



(a) Unequalled-legged fillet weld

(b) Equal-legged fillet weld

FIGURE 2

One example of this would be the welding of channel shear attachments to beam flanges, Figure 3. Here the vertical leg of the fillet weld must be held to the thickness at the outer edge of the channel flange. Additional strength must be obtained by increasing the horizontal leg of the fillet.

The effective length of the weld is defined as the length of the weld having full throat. Further, the AWS requires that all craters shall be filled to the full cross-section of the weld.

In continuous fillet welds, this is no problem because the weldor will strike an arc for the next electrode on the forward edge of the crater of the previous weld, then swing back into the crater to fill it, and then proceed forward for the remainder of the weld. In this manner no crater will be left unfilled.

In practically all cases of intermittent fillet welds, the required length of the weld is marked out on the plate and the weldor starts welding at one mark and continues to weld until the rim of the weld crater passes the other mark. In other words, the crater is beyond the required length of the intermittent fillet weld and is not counted.

There may be some cases where the crater is filled and included in the weld length. This may be accomplished by filling the crater, or by using a method of welding part way in from one end, breaking the arc and welding in from the other end, and then overlapping in the central portion, thus eliminating any crater.

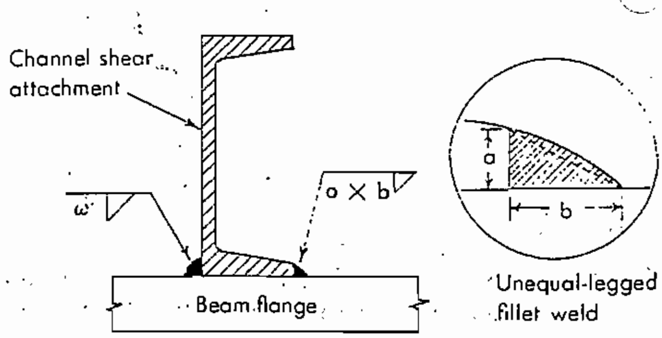


FIGURE 3

The effective throat is defined as the shortest distance between the root of the joint and the face of the diagrammatical weld. This would be a line from the root of the joint and normal to the flat face, Figure 4.

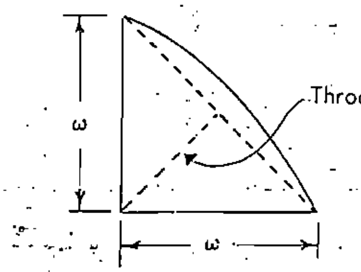


FIGURE 4

For an equal-legged fillet weld, the throat is equal to .707 times the leg size (ω):

$$t = .707\ \omega$$

The allowable force on the fillet weld, 1" long is—

$$\boxed{f = .707\ \omega\ \tau} \qquad (1)$$

where:

f = allowable force on fillet weld, lbs per linear inch

ω = leg size of fillet weld, inches

τ = allowable shear stress on throat of weld, psi

The AWS has set up several shear stress allowables for the throat of the fillet weld. These are shown in Tables 6 and 7 for the Building and Bridge fields.

Minimum Weld Size

(AWS Bldg Art 212(a)1, AWS Bridge Par 217(b), AISC 1.17.4)

In joints connected only by fillet welds, the minimum leg size shall correspond to Table 3. This is determined by the thickness of the thicker part joined, but does not have to exceed the thickness of the thinner part joined.

The American Welding Society recognizes that thick plates offer greater restraint, and produce a faster cooling rate for the welds.

Table 3 is predicated on the theory that the required minimum weld size will provide sufficient welding heat input into the plate to give the desired slow rate of cooling.

This is not a complete answer to this problem; for example, a plate thicker than 6" would require a minimum weld size of ⅝", yet in actual practice this would be made in several passes. Each pass would be equivalent to about a $\frac{5}{16}$" fillet, and have the heat input of approximately a $\frac{5}{16}$" weld which may not be sufficient unless the plates are preheated.

A partial solution to this problem would be the following: Since the first pass of the joint is the most critical, it should be made with low-hydrogen electrodes and a rather slow travel speed. Resulting superior weld physicals, weld contour, and maximum heat input provide a good strong root bead.

TABLE 3—Minimum Weld Sizes for Thick Plates (AWS)

THICKNESS OF THICKER PLATE JOINED t	MINIMUM LEG SIZE OF FILLET WELD ω
to ½" incl.	$\frac{3}{16}$"
over ½" thru ¾"	¼"
over ¾" thru 1½"	$\frac{5}{16}$"
over 1½" thru 2¼"	⅜"
over 2¼" thru 6"	½"
over 6"	⅝"

Minimum leg size need not exceed thickness of the thinner plate.

Maximum Effective Weld Size

(AWS Bldg Art 212(a)2, AWS Bridge Par 217(c), AISC 1.17.5)

Along the edge of material less than ¼" thick, the maximum effective leg size of fillet weld shall be equal to the plate thickness (t):

$$\boxed{\omega_{max} = t_{P\!L}}$$

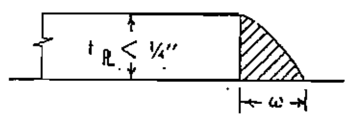
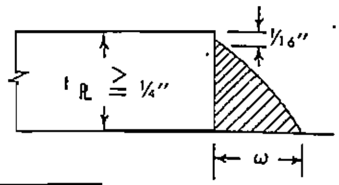
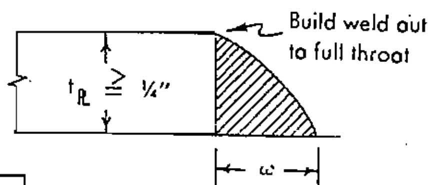


FIGURE 5

Along the edges of material ¼" or more in thickness, the maximum effective leg size of fillet weld shall be equal to the plate thickness (t) less $\frac{1}{16}$", unless noted on the drawing that the weld is to be built out to full throat:



$$\boxed{\omega_{max} = t_{P\!L} - \tfrac{1}{16}"}$$



$$\boxed{\omega_{max} = t_{P\!L}}$$

FIGURE 6

Minimum Effective Length
(AWS Bldg Art 212(a)4, AWS Bridge Par 217(d), AISC 1.17.6)

The minimum effective length (L_e) of a fillet weld designed to transfer a force shall be not less than 4 times its leg size or 1½″. Otherwise, the effective leg size (ω_e) of the fillet weld shall be considered not to exceed ¼ of the actual length (short of the crater unless filled).

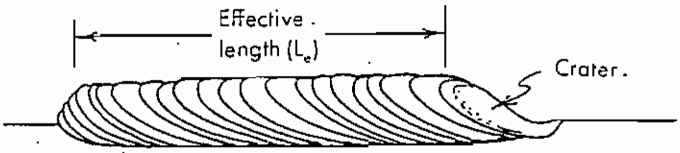


FIGURE 7

$L_e \geqq 4\ \omega \geqq 1½''$*

Otherwise,

$\omega_e \leqq ¼\ L$

If longitudinal fillet welds are used alone in end connections of flat bar tension members:

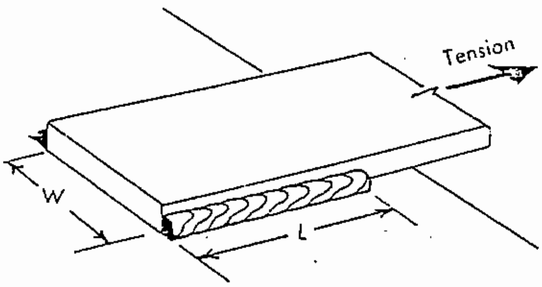


FIGURE 8

(AWS Bldg Art 212(a)3, AISC 1.17.6)

$L_e \geqq W$

$W \leqq 8''$

unless additional welding prevents transverse bending within the connection.

*In addition, the effective length (L_e) of an intermittent fillet weld shall not be less than 1½″ (AISC 1.17.7).

3. OTHER WELD REQUIREMENTS

Minimum Overlap of Lap Joints
(AWS Bldg Art 212(b)1, AISC 1.17.8)

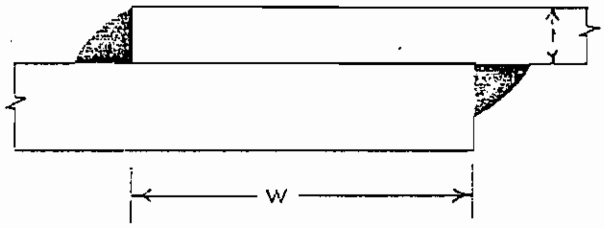


FIGURE 9

$W \geqq 5\ t \geqq 1''$

where t = thickness of thinner plate

Thickness of Plug or Slot Welds

(AWS Bldg Art 213, AWS Bridge Par 218, AISC 1.17.11)

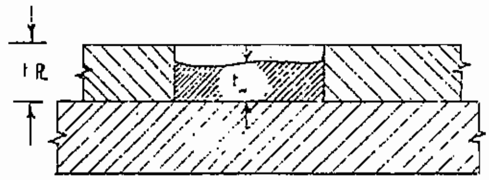


FIGURE 10

1. If $t_{℄} \leqq ⅝''$
   then $t_w = t_{℄}$
2. If $t_{℄} > ⅝''$
   then $t_w \geqq ½\ t_{℄} \geqq ⅝''$

Spacing and Size of Plug Welds
(AWS Bldg Art 213, AWS Bridge Par 218, AISC 1.17.11)

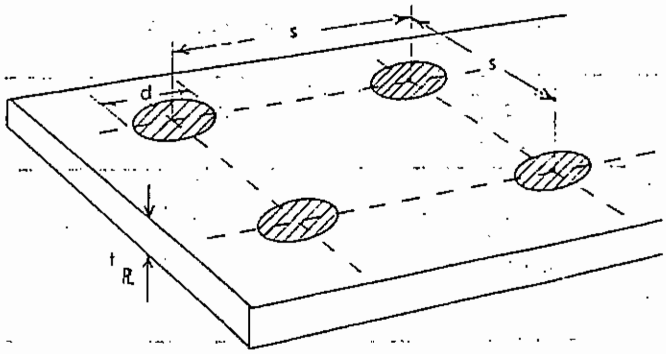
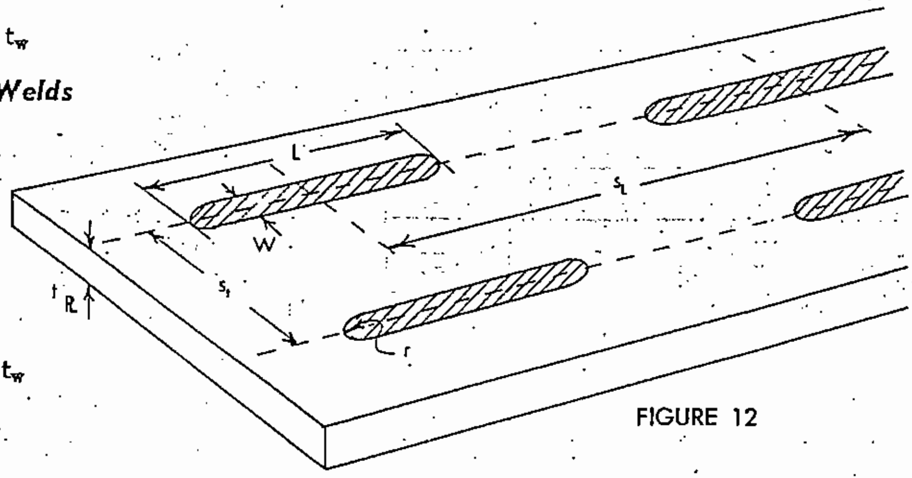


FIGURE 11

$s \geqq 4\ d$

$d \geqq t_{P\!\!L} + 5/16'' < 2\tfrac{1}{4}\ t_w$

Spacing and Size of Slot Welds



$L \leqq 10\ t_w$

$W \geqq t_{P\!\!L} + 5/16'' \leqq 2\tfrac{1}{4}\ t_w$

$s_T \geqq 4\ W$

$s_L \geqq 2\ L$

$r \geqq t_{P\!\!L}$

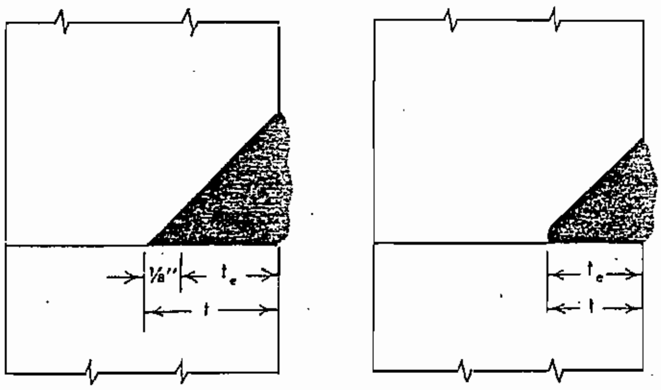
FIGURE 12

4. PARTIAL-PENETRATION GROOVE WELDS

Partial-penetration groove welds are allowed in the building field. They have many applications; for example, field splices of columns, built-up box sections for truss chords, etc.

For the V, J or U grooves made by manual welding, and all joints made by submerged-arc welding, it is assumed the bottom of the joint can be reached easily. So, the effective throat of the weld (t_e) is equal to the actual throat of the prepared groove (t). See Figure 13.

If a bevel groove is welded manually, it is assumed that the weldor may not quite reach the bottom of the groove. Therefore, AWS and AISC deduct ⅛" from the prepared groove. Here the effective throat (t_e) will equal the throat of the groove (t) minus ⅛". See Figure 13(a).



(a) Single bevel joint (b) Single J joint

FIGURE 13

Tension applied parallel to the weld's axis, or compression in any direction, has the same allowable stress as the plate.

Tension applied transverse to the weld's axis, or shear in any direction, has a reduced allowable stress, equal to that for the throat of a corresponding fillet weld.

Just as fillet welds have a minimum size for thick plates because of fast cooling and greater restraint, so partial-penetration groove welds have a minimum effective throat (t_e) which should be used —

$$t_e \geqq \sqrt{\frac{t_p}{6}}$$

where:

t_p = thickness of thinner plate

5. TYPES OF WELDS

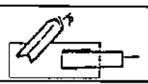
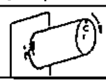
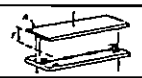
a. Primary welds transmit the entire load at the particular point where they are located. If the weld fails, the member fails. The weld must have the same property as the member at this point. In brief, the weld becomes the member at this point.

b. Secondary welds simply hold the parts together, thus forming the member. In most cases, the forces on these welds are low.

c. Parallel welds have forces applied parallel to their axis. In the case of fillet welds, the throat is stressed only in shear. For an equal-legged fillet, the maximum shear stress occurs on the 45° throat.

d. Transverse welds have forces applied transversely or at right angles to their axis. In the case of fillet welds, the throat is stressed both in shear and in tension or compression. For an equal-legged fillet weld, the maximum shear stress occurs on the 67½° throat, and the maximum normal stress occurs on the 22½° throat.

TABLE 4—Determining Force on Weld

Type of Loading		standard design formula stress lbs/in^2	treating the weld as a line force lbs/in
	PRIMARY WELDS transmit entire load at this point		
	tension or compression	$\sigma = \frac{P}{A}$	$f = \frac{P}{A_w}$
	vertical shear	$\sigma = \frac{V}{A}$	$f = \frac{V}{A_w}$
	bending	$\sigma = \frac{M}{S}$	$f = \frac{M}{S_w}$
	twisting	$\sigma = \frac{T\,C}{J}$	$f = \frac{T\,C}{J_w}$
	SECONDARY WELDS hold section together - low stress		
	horizontal shear	$\tau = \frac{V A y}{I t}$	$f = \frac{V A y}{I n}$
	torsional horizontal shear*	$\tau = \frac{T}{2 A t}$	$f = \frac{T}{2 A}$

A = area contained within median line.
(*) applies to closed tubular section only.

6. SIMPLE TENSILE, COMPRESSIVE OR SHEAR LOADS ON WELDS

For a simple tensile, compressive or shear load, the given load is divided by the length of the weld to arrive at the applied unit force, lbs per linear inch of weld. From this force, the proper leg size of fillet weld or throat of groove weld may be found.

7. BENDING OR TWISTING LOADS ON WELDS

The problem here is to determine the properties of the welded connection in order to check the stress in the weld without first knowing its leg size. Some design texts suggest assuming a certain weld-leg size and then calculating the stress in the weld to see if it is overstressed or understressed. If the result is too far off, then the weld-leg size is readjusted.

This has the following disadvantages:

1. Some decision must be made as to what throat section is going to be used to determine the property of the weld. Usually some objection can be raised to any throat section chosen.

2. The resulting stresses must be combined and, for several types of loading, this can be rather complicated.

In contrast, the following is a simple method to determine the correct amount of welding required for adequate strength. This is a method in which the weld is treated as a line, having no area, but a definite length and outline. This method has the following advantages:

1. It is not necessary to consider throat areas because only a line is considered.

2. Properties of the welded connection are easily found from a table without knowing weld-leg size.

3. Forces are considered on a unit length of weld instead of stresses, thus eliminating the knotty problem of combining stresses.

4. It is true that the stress distribution within a fillet weld is complex, due to eccentricity of the applied force, shape of the fillet, notch effect of the root, etc.; however, these same conditions exist in the actual fillet welds tested and have been recorded as a unit force per unit length of weld.

8. DETERMINING FORCE ON WELD

Visualize the welded connection as a single line, having the same outline as the connection, but no cross-sectional area. Notice, Figure 14, that the area (A_w) of the welded connection now becomes just the length of the weld.

Instead of trying to determine the stress on the weld (this cannot be done unless the weld size is known), the problem becomes a much simpler one of determining the force on the weld.

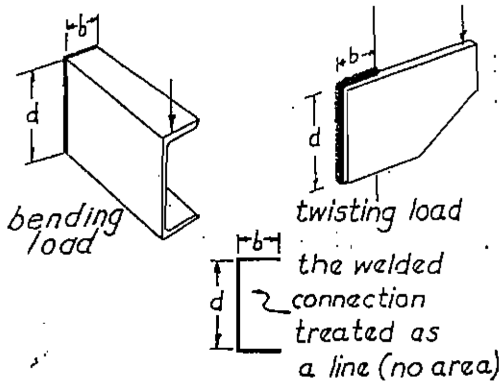


FIG. 14 Treating weld as a line.

By inserting the property of the welded connection treated as a line into the standard design formula used for that particular type of load (see Table 4), the force on the weld may be found in terms of lbs per linear inch of weld.

Example: Bending

Standard design formula (bending stress)	Same formula used for weld (treating weld as a line)
$\sigma = \frac{M}{S} = \frac{\text{lbs}}{\text{in.}^2}$ stress	$f = \frac{M}{S_w} = \frac{\text{lbs}}{\text{in.}}$ force

Normally the use of these standard design formulas results in a unit stress, psi; however, when the weld is treated as a line, these formulas result in a force on the weld, lbs per linear inch.

For secondary welds, the weld is not treated as a line, but standard design formulas are used to find the force on the weld, lbs per linear inch.

In problems involving bending or twisting loads Table 5 is used to determine properties of the weld treated as a line. It contains the section modulus (S_w), for bending, and polar moment of inertia (J_w), for twisting, of some 13 typical welded connections with the weld treated as a line.

For any given connection, two dimensions are needed, width (b) and depth (d).

Section modulus (S_w) is used for welds subject to bending loads, and polar moment of inertia (J_w) twisting loads.

Section moduli (S_w) from these formulas are for maximum force at the top as well as the bottom portions of the welded connections. For the unsymmetrical connections shown in this table, maximum bending force is at the bottom.

If there is more than one force applied to the weld, these are found and combined. All forces which are combined (vectorially added) must occur at the same position in the welded joint.

Determining Weld Size by Using Allowables

Weld size is obtained by dividing the resulting force on the weld found above, by the allowable strength of the particular type of weld used (fillet or groove), obtained from Tables 6 and 7 (steady loads) or Tables 8 and 9 (fatigue loads).

If there are two forces at right angles to each other, the resultant is equal to the square root of the sum of the squares of these two forces.

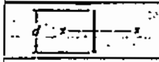
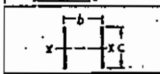
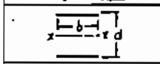
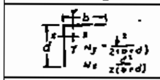
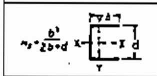
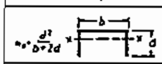
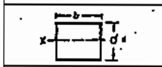
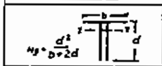
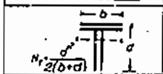
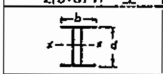
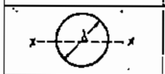
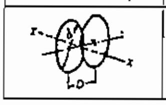
$$\boxed{f_r = \sqrt{f_1^2 + f_2^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

If there are three forces, each at right angles to each other, the resultant is equal to the square root of the sum of the squares of the three forces.

$$\boxed{f_r = \sqrt{f_1^2 + f_2^2 + f_3^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

One important advantage to this method, in addition to its simplicity, is that no new formulas must be used, nothing new must be learned. Assume an engineer has just designed a beam. For strength he has used the standard formula $\sigma = M/S$. Substituting the load on the beam (M) and the property of the beam (S) into this formula, he has found the bending stress (σ). Now, he substitutes the property of the weld, treating it as a line (S_w), obtained from Table 5, into the same formula. Using the same load (M), $f = M/S_w$, he thus finds the force on the weld (f) per linear inch. The weld size is then found by dividing the force on the weld by the allowable force.

TABLE 5—Properties of Weld Treated as Line

Outline of Welded Joint b=width d=depth	Bending (about horizontal axis x-x)	Twisting
	$S_w = \frac{d^2}{6}$ in.^{2}	$J_w = \frac{d^3}{12}$ in.^{3}
	$S_w = \frac{d^2}{3}$	$J_w = \frac{d(3b^2+d^2)}{6}$
	$S_w = bd$	$J_w = \frac{b^3+3bd^2}{6}$
	$S_w = \frac{4bd+d^2}{6} = \frac{d^2(4b+d)}{6(2b+d)}$ top bottom	$J_w = \frac{(b+d)^4-6b^2d^2}{12(b+d)}$
	$S_w = bd + \frac{d^2}{6}$	$J_w = \frac{(2b+d)^3}{12} - \frac{b^2(b+d)^2}{(2b+d)}$
	$S_w = \frac{2bd+d^2}{3} = \frac{d^2(2b+d)}{3(b+d)}$ top bottom	$J_w = \frac{(b+2d)^3}{12} - \frac{d^2(b+d)^2}{(b+2d)}$
	$S_w = bd + \frac{d^2}{3}$	$J_w = \frac{(b+d)^3}{6}$
	$S_w = \frac{2bd+d^2}{3} = \frac{d^2(2b+d)}{3(b+d)}$ top bottom	$J_w = \frac{(b+2d)^3}{12} - \frac{d^2(b+d)^2}{(b+2d)}$
	$S_w = \frac{4bd+d^2}{3} = \frac{4bd^2+d^3}{6b+3d}$ top bottom	$J_w = \frac{d^3(4b+d)}{6(b+d)} + \frac{b^3}{6}$
	$S_w = bd + \frac{d^2}{3}$	$J_w = \frac{b^3+3bd^2+d^3}{6}$
	$S_w = 2bd + \frac{d^2}{3}$	$J_w = \frac{2b^3+6bd^2+d^3}{6}$
	$S_w = \frac{\pi d^2}{4}$	$J_w = \frac{\pi d^3}{4}$
	$I_w = \frac{\pi d}{2}\left(D^2 + \frac{d^2}{2}\right)$ $S_w = \frac{I_w}{c}$ where $c = \frac{\sqrt{D^2+d^2}}{2}$	

Applying System to Any Welded Connection

1. Find the position on the welded connection where the combination of forces will be maximum. There may be more than one which should be considered.

2. Find the value of each of the forces on the welded connection at this point. (a) Use Table 4 for the standard design formula to find the force on the weld. (b) Use Table 5 to find the property of the weld treated as a line.

3. Combine (vectorially) all of the forces on the weld at this point.

4. Determine the required weld size by dividing this resultant value by the allowable force in Tables 6, 7, 8, or 9.

TABLE 6—Allowables for Welds—Buildings (AWS Bldg & AISC)

Type of Weld	Stress	Steel	Electrode	Allowable
Complete-Penetration Groove Welds	tension compression shear	A7, A36, A373	‡E60 or SAW-1	same as
		A441, A242*	E70 or SAW-2	
Partial-Penetration Groove Welds	tension transverse to axis of weld or shear on effective throat	A7, A36, A373	E60 or SAW-1	σ or τ = 13,600 psi
		A441, A242*	E60 low-hydrogen or SAW-1	
		A7, A373	E70 or SAW-2	
		A36	E70 or SAW-2	σ or τ = 15,800 psi
		A441, A242*	E70 low-hydrogen or SAW-2	
	tension parallel to axis of weld or compression on effective throat	A7, A36, A373	‡E60 or SAW-1	same as
		A441 or A242*	E70 or SAW-1	
Fillet Weld	shear on effective throat	A7, A36, A373	E60 or SAW-1	τ = 13,600 psi or f = 9600 ω lb/in
		A441, A242*	E60 low-hydrogen or SAW-2	
		A7, A373	E70 or SAW-2	
		A36	E70 or SAW-2	τ = 15,800 psi or f = 11,200 ω lb/in
		A441, A242*	E70 low-hydrogen or SAW-2	
Plug and Slot	shear on effective area	Same as for fillet weld		

* weldable A242
‡ E70 or SAW-2 could be used, but would not increase allowable.

TABLE 7—Allowables for Welds—Bridges (AWS Bridge)

Type of Weld	Stress	Steel	Electrode	Allowable
Complete-Penetration Groove Welds	tension compression shear	A7, A373	‡E60 or SAW-1	Same as
		A36 $\leq$ 1" thick		
		A36 $>$ 1" thick	‡E60 low-hydrogen or SAW-1	
		A441, A242*	E70 low-hydrogen or SAW-2	
Fillet Welds	shear on effective throat	A7, A373	‡E60 or SAW-1	τ = 12,400 psi or f = 8800 ω lb/in
		A36 $\leq$ 1" thick		
		A36 $>$ 1" thick	‡E60 low-hydrogen or SAW-1	
		A441, A242*	E70 low-hydrogen or SAW-2	τ = 14,700 psi or f = 10,400 ω lb/in
Plug and Slot	shear on effective area	A7, A373, A36 $\leq$ 1" thick	‡E60 or SAW-1	12,400 psi
		A36 $>$ 1" thick A441, A242*	‡E60 low-hydrogen or SAW-1	

* weldable A242
‡ E70 or SAW-2 could be used, but would not increase allowable

Problem 1

Determine the size of required fillet weld for the bracket shown in Figure 15, to carry a load of 18,000 lbs.

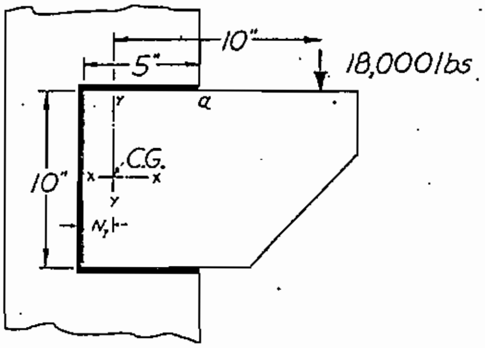


FIGURE 15

Step 1: FIND PROPERTIES OF WELD, TREATING IT AS A LINE (use Table 5).

$$N_y = \frac{b^2}{2\,b + d} = \frac{(5)^2}{2\,(5 + 10)} = 1.25''$$

$$J_w = \frac{(2\,b + d)^3}{12} - \frac{b^2\,(b + d)^2}{(2\,b + d)} = \frac{(2 \times 5 + 10)^3}{12} - \frac{(5)^2\,(5 + 10)^2}{(2 \times 5 + 10)} = 385.9 \text{ in.}^3$$

$$A_w = 20''$$

(Continued on page 10)

TABLE 8—Allowable Fatigue Stress for A7, A373 and A36 Steels and Their Welds

	2,000,000 cycles	600,000 cycles	100,000 cycles	But Not to Exceed
Base Metal In Tension Connected By Fillet Welds But not to exceed →	(1) $\sigma = \frac{7500}{1 - 2/3\,K}$ psi P_t	(3) $\sigma = \frac{10{,}500}{1 - 2/3\,K}$ psi P_t	(5) $\sigma = \frac{15{,}000}{1 - 2/3\,K}$ psi P_t	$\frac{2\,P_t}{3\,K}$ psi
Base Metal Compression Connected By Fillet Welds	(2) $\sigma = \frac{7500}{1 - 2/3\,K}$ psi	(4) $\sigma = \frac{10{,}500}{1 - 2/3\,K}$ psi	(6) $\sigma = \frac{15{,}000}{1 - 2/3\,K}$ psi	P_c psi $\frac{P_c}{1 - \frac{K}{2}}$ psi
Butt Weld In Tension	(7) $\sigma = \frac{16{,}000}{1 - \frac{8}{10}K}$ psi	(11) $\sigma = \frac{17{,}000}{1 - \frac{7}{10}K}$ psi	(15) $\sigma = \frac{18{,}000}{1 - \frac{K}{2}}$ psi	P_t psi
Butt Weld Compression	(8) $\sigma = \frac{18{,}000}{1 - K}$ psi	(12) $\sigma = \frac{18{,}000}{1 - .8K}$ psi	(16) $\sigma = \frac{18{,}000}{1 - \frac{K}{2}}$ psi	P_c psi
Butt Weld In Shear	(9) $\tau = \frac{9{,}000}{1 - \frac{K}{2}}$ psi	(13) $\tau = \frac{10{,}000}{1 - \frac{K}{2}}$ psi	(17) $\tau = \frac{13{,}000}{1 - \frac{K}{2}}$ psi	13,000 psi
Fillet Welds ω = Leg Size	(10) $f = \frac{5100\,\omega}{1 - \frac{K}{2}}$ lb/in.	(14) $f = \frac{7100\,\omega}{1 - \frac{K}{2}}$ lb/in.	(18) $f = \frac{8800\,\omega}{1 - \frac{K}{2}}$ lb/in.	8800 ω lb/in.

Adopted from AWS Bridge Specifications. K = min/max
P_c = Allowable unit compressive stress for member.
P_t = Allowable unit tensile stress for member.

Step 2: FIND THE VARIOUS FORCES ON WELD, INSERTING PROPERTIES OF WELD FOUND ABOVE (see Table 4).

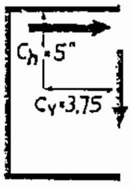
Point a is where combined forces are maximum. Twisting force is broken into horizontal and vertical components by proper value of c (see sketch).

twisting (horizontal component)

$$f_{t_h} = \frac{T\ c_h}{J_w}$$

$$= \frac{(180{,}000)(5)}{(385.9)}$$

$$= 2340 \text{ lbs/in.}$$



twisting (vertical component)

$$f_{t_v} = \frac{T\ c_v}{J_w}$$

$$= \frac{(180{,}000)(3.75)}{(385.9)}$$

$$= 1750 \text{ lbs/in.}$$

vertical shear

$$f_{s_v} = \frac{P}{A_w}$$

$$= \frac{(18{,}000)}{(20)}$$

$$= 900 \text{ lbs/in.}$$

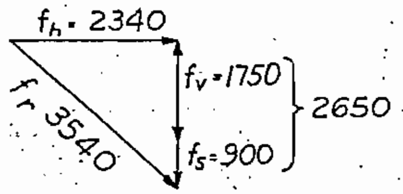
(Continued on page 11)

TABLE 9—Allowable Fatigue Stress for A441 Steel and Its Welds

	2,000,000 cycles	600,000 cycles	100,000 cycles	But Not to Exceed
Base Metal In Tension Connected By Fillet Welds	(1) $\sigma = \frac{7500}{1 - 2/3\,R}$ psi	(3) $\sigma = \frac{10{,}500}{1 - 2/3\,R}$ psi	(5) $\sigma = \frac{15{,}000}{1 - 2/3\,R}$ psi	$\frac{2\,P_c}{3\,R}$ psi P_t psi
Base Metal Compression Connected By Fillet Welds	(2) $\sigma = \frac{7500}{1 - 2/3\,R}$ psi	(4) $\sigma = \frac{10{,}500}{1 - 2/3\,R}$ psi	(6) $\sigma = \frac{15{,}000}{1 - 2/3\,R}$ psi	$\frac{P_c}{1 - \frac{1}{2}R}$ psi P_c psi
Butt Weld In Tension	(7) $\sigma = \frac{16{,}000}{1 - .8\,R}$ psi	(11) $\sigma = \frac{19{,}000}{1 - .7\,R}$ psi	(15) $\sigma = \frac{24{,}000}{1 - \frac{1}{2}R}$ psi	P_t psi
Butt Weld Compression	(8) $\sigma = \frac{24{,}000}{1 - 1.7\,R}$ psi	(12) $\sigma = \frac{24{,}000}{1 - R}$ psi	(16) $\sigma = \frac{24{,}000}{1 - \frac{1}{2}R}$ psi	P_c psi
Butt Weld In Shear	(9) $\sigma = \frac{9000}{1 - \frac{1}{2}R}$ psi	(13) $\sigma = \frac{10{,}000}{1 - \frac{1}{2}R}$ psi	(17) $\sigma = \frac{13{,}000}{1 - \frac{1}{2}R}$ psi	13,000 psi
Fillet Welds ω = leg size	(10) $f = \frac{5100\,\omega}{1 - \frac{1}{2}R}$ lb/in.	(14) $f = \frac{7100\,\omega}{1 - \frac{1}{2}R}$ lb/in.	(18) $f = \frac{8800\,\omega}{1 - \frac{1}{2}R}$ lb/in.	* $f = 10{,}400\,\omega$ lb/in.

Adopted from AWS Bridge Specifications.
* if SAW-1, use 8800
R = min/max load
P_t = Allowable unit compressive stress for member.
P_c = Allowable unit tensile stress for member.

Step 3: DETERMINE ACTUAL RESULTANT FORCE ON WELD.



$$
\begin{aligned}
f_r &= \sqrt{f_{t_h}{}^2 + (f_{t_v} + f_{s_v})^2} \\
&= \sqrt{(2340)^2 + (2650)^2} \\
&= 3540 \text{ lbs/in.}
\end{aligned}
$$

Step 4: NOW FIND REQUIRED LEG SIZE OF FILLET WELD CONNECTING THE BRACKET.

$$
\begin{aligned}
\omega &= \frac{\text{actual force}}{\text{allowable force}} \\
&= \frac{3540}{11{,}200} \\
&= .316 \text{ or } \underline{\text{use } 5/16'' \Delta}
\end{aligned}
$$

9. HORIZONTAL SHEAR FORCES

Any weld joining the flange of a beam to its web is stressed in horizontal shear (Fig. 16). Normally a designer is accustomed to specifying a certain size fillet weld for a given plate thickness (leg size about ¾ of the plate thickness) in order for the weld to have full plate strength. However, this particular joint between the flange and web is one exception to this rule. In order to prevent web buckling, a lower allowable shear stress is usually used; this results in a thicker web. The welds are in an area next to the flange where there is no buckling problem and, therefore, no reduction in allowable load is used. From a design standpoint, these welds may be very small, their actual size sometimes determined by the minimum allowed because of the thickness of the flange plate, in order to assure the proper slow cooling rate of the weld on the heavier plate.

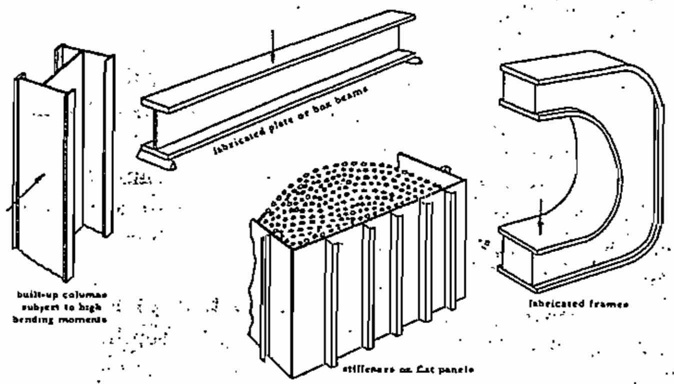


FIG. 16 These flange-to-web welds are stressed in horizontal shear and the forces on them can be determined.

General Rules

Outside of simply holding the flanges and web of a beam together, or to transmit any unusually high force between the flange and web at right angles to the member (for example, bearing supports, lifting

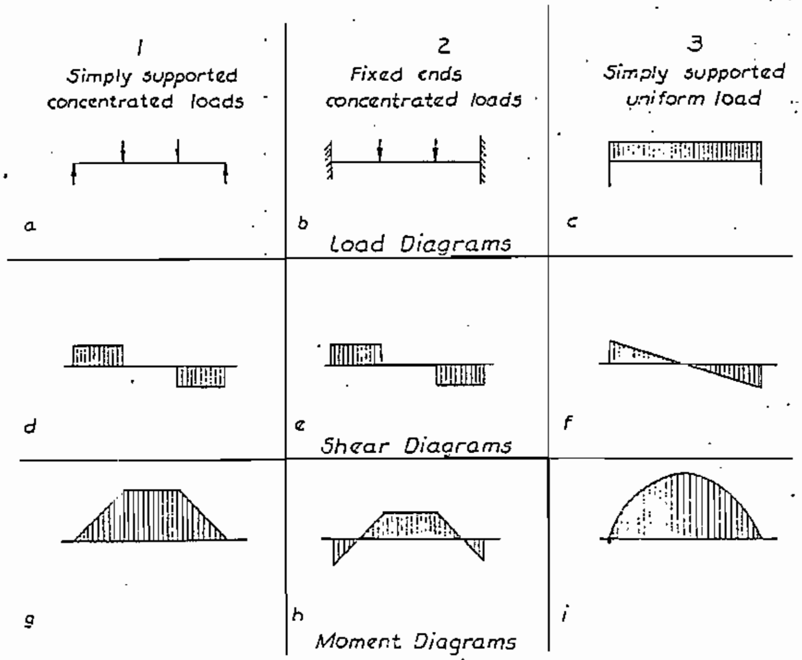


FIG. 17 Shear diagram pictures the amount and location of welding required to transmit horizontal shear forces between flange and web.

lugs, etc.), the real purpose of the weld between the flange and web is to transmit the horizontal shear forces, and the size of the weld is determined by the value of these shear forces.

It will help in the analysis of a beam if it is recognized that the shear diagram is also a picture of the amount and location of the welding required between the flange and web.

A study of Figure 17 will show that 1) loads applied transversely to members cause bending moments; 2) bending moments varying along the length of the beam cause horizontal shear forces; and 3) horizontal shear forces require welds to transmit these forces between the flange and web of the beam.

Notice: 1) Shear forces occur only when the bending moment varies along the length. 2) It is quite possible for portions of a beam to have little or no shear—notice the middle portions of beams 1 and 2—this is because the bending moment is constant within this area. 3) If there should be a difference in shear along the length of the beam, the shear forces are usually greatest at the ends of the beam (see beam 3). This is why stiffeners are sometimes welded continuously at their ends for a distance even though they are welded intermittently the rest of their length. 4) Fixed ends will shift the moment diagram so that the maximum moment is less. What is taken off at the middle of the beam is added to the ends. Even though this does happen, the shear diagram remains unchanged, so that the amount of welding between flange and web will be the same regardless of end conditions of the beam.

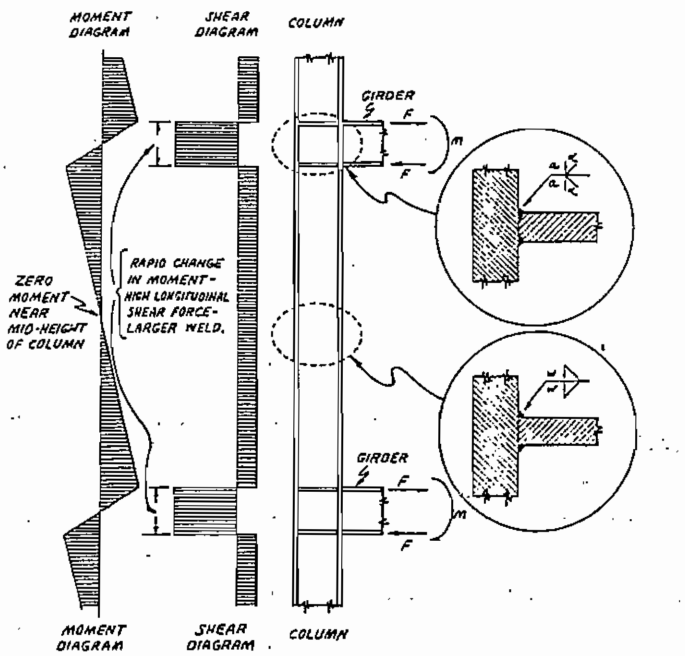


FIG. 18 Shear diagram of frame indicates where the amount of welding is critical.

To apply these rules, consider the welded frame in Figure 18. The moment diagram for this loaded frame is shown on the left-hand side. The bending moment is gradually changing throughout the vertical portion of the frame. The shear diagram shows that this results in a small amount of shear in the frame. Using the horizontal shear formula ($f = Vay/In$), this would require a small amount of welding between the flange and web. Intermittent welding would probably be sufficient. However, at the point where the crane bending moment is applied, the moment diagram shows a very fast rate of change. Since the shear value is equal to the rate of change in the bending moment, it is very high and more welding is required at this region.

Use continuous welding where loads or moments are applied to a member, even though intermittent welding may be used throughout the rest of the fabricated frame.

Finding Weld Size

The horizontal shear forces acting on the weld joining a flange to web, Figures 19 and 20, may be found from the following formula:

$$\boxed{f = \frac{V\,a\,y}{I\,n}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where:

f = force on weld, lbs/lin in.

V = total shear on section at a given position along beam, lbs

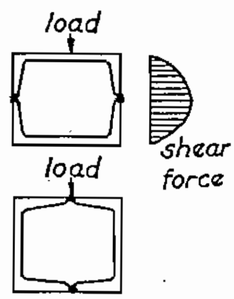
a = area of flange held by weld, sq in.

y = distance between the center of gravity of flange area and the neutral axis of whole section, in.

I = moment of inertia of whole section, $in.^4$

n = number of welds joining flange to web

FIG. 19 Locate weld at point of minimum stress. Horizontal shear force is maximum along neutral axis. Welds in top example must carry maximum shear force; there is no shear on welds in bottom example.



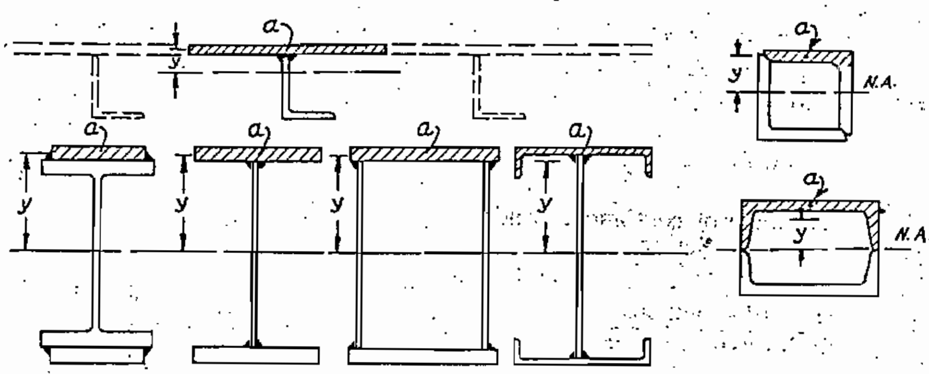


FIG. 20 Examples of welds in horizontal shear.

The leg size of the required fillet weld (continuous) is found by dividing this actual unit force (f) by the allowable for the type of weld metal used.

If intermittent fillet welds are to be used divide this weld size (continuous) by the actual size used (intermittent). When expressed as a percentage, this will give the length of weld to be used per unit length. For convenience, Table 10 has various intermittent weld lengths and distances between centers for given percentages of continuous welds.

$$\% = \frac{\text{calculated leg size (continuous)}}{\text{actual leg size used (intermittent)}}$$

Problem 2

For the fabricated plate girder in Figure 21, determine the proper amount of fillet welds to join flanges to the web. Use E70 welds.

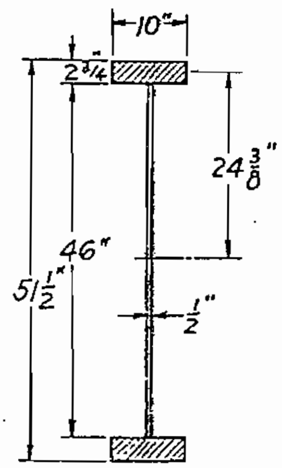


FIGURE 21

where:

$V = 189{,}000$ lbs

$I = 36{,}768$ in.^{4}

$a = 27.5$ in.^{2}

$y = 24.375''$

$n = 2$ welds

horizontal shear force on weld

$$f_h = \frac{V\,a\,y}{I\,n}$$

$$= \frac{(189{,}000)(27.5)(24.375)}{(36{,}768)(2)}$$

$$= 1720 \text{ lbs/in.}$$

required leg size of weld

$$\omega = \frac{\text{actual force}}{\text{allowable force}}$$

$$= \frac{1720}{11{,}200}$$

$$= \underline{.153''}$$

This would be the minimum leg size of a *continuous* fillet weld; however, ½" fillet welds are recommended because of the thick 2¾" flange plate (see table). In this particular case, the leg size of the fillet weld need not exceed the web thickness (thinner plate). Because of the greater strength of the ½" fillet, intermittent welds may be used but must not stress the web above 14,500 psi. Therefore, the length of weld must be increased to spread the load over a greater length of web.

Weld vs Plate

$$2\,(11{,}200\,\omega)\,L \leqq 14{,}500 \text{ psi } t \times L$$

$$\omega \leqq \frac{14{,}500 \text{ psi } t}{2(11{,}200)} \leqq .643\ t$$

or $\boxed{\omega \leqq ⅔\ t}$

TABLE 10—Intermittent Welds
Length and Spacing

Continuous weld, %	Length of intermittent welds and distance between centers, in.		
75	..	3-4	..
66	..	..	4-6
60	..	3-5	..
57	..	..	4-7
50	2-4	3-6	4-8
44	..	..	4-9
43	..	3-7	..
40	2-5	..	4-10
37	..	3-8	..
33	2-6	3-9	4-12
30	..	3-10	..
25	2-8	3-12	..
20	2-10	..	..
16	2-12	..	..

For this reason the size of intermittent fillet weld *used in design calculations or for determination of length* must not exceed ⅔ of the web thickness, or here:

⅔ of ½″ (web) = .333″

The percentage of continuous weld length needed for this intermittent weld will be—

$$\% = \frac{\text{continuous leg size}}{\text{intermittent leg size}}$$

$$= \frac{(.153'')}{(.333'')}$$

$$= 46\%$$

Hence, use—

½″ ◺ 4″ — 8″ (see Table 10)

Problem 3

A fillet weld is required, using

⅜″ ◺ 4″ — 12″

that is, intermittent welds having leg size of ⅜″ and length of 4″, set on 12″ centers. A ⅜″ fillet weld usually requires 2 passes, unless the work is positioned. A 2-pass weld requires more inspection to maintain size and weld quality. The shop would like to change this to a ⁵⁄₁₆″ weld. This single-pass weld is easier to make and there is little chance of it being undersize.

This change could be made as follows:

The present ⅜″ ◺ is welded in lengths of 4″ on 12″ centers, or 33% of the length of the joint, reducing the leg size down to ⁵⁄₁₆″ ◺ or ⅚ of the previous weld. This would require the percentage of length of joint to be increased by the ratio 6 / 5 or 33% (⁶⁄₅) = 40%.

Hence, use—

⁵⁄₁₆″ ◺ 4″ — 10″

In other words, ⅜″ intermittent fillet welds, 4″ long on 12″ centers, may be replaced with ⁵⁄₁₆″ welds, 4″ long on 10″ centers, providing same strength. This change would permit welding in one pass instead of two passes, with a saving of approx. 16⅔% in welding time and cost.

Problem 4

Determine the leg size of fillet weld for the base of a signal tower, Figure 22, assuming wind pressure of 30 lbs/sq ft or pressure of p = .208 psi. Use A36 Steel & E70 welds.

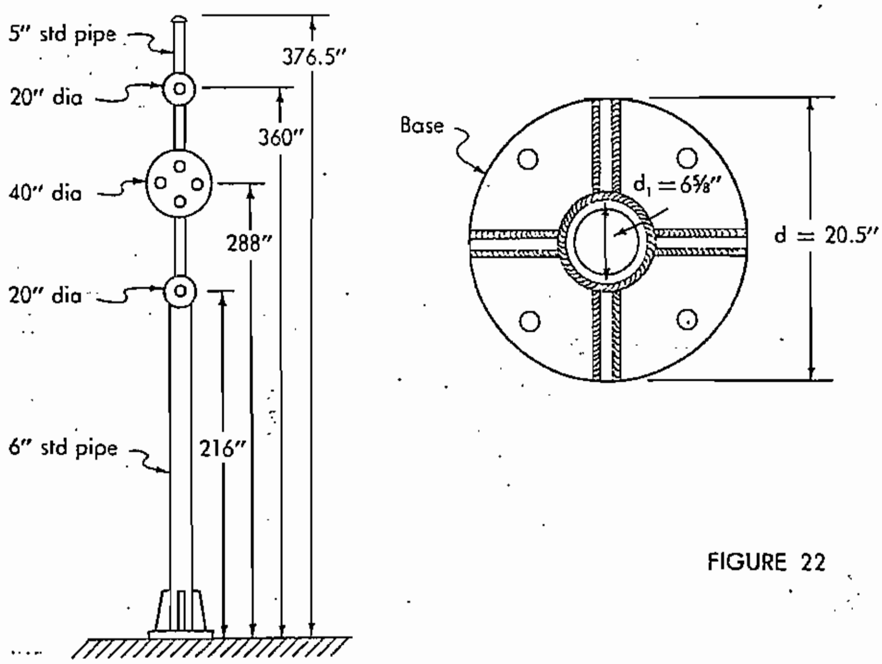
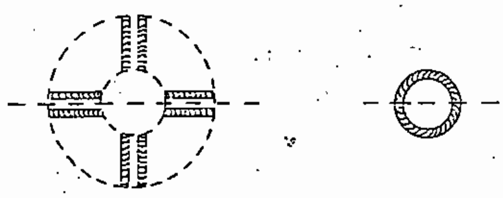


FIGURE 22

Step 1: FIND PROPERTIES OF WELD, TREATING IT AS A LINE.



$$I_w = \frac{d^3 - d_1^{\,3}}{6}$$

$$= \frac{(20.5)^3 - (6\tfrac{5}{8})^3}{6} = 1386 \text{ in.}^3$$

$$I_w = \frac{\pi\ d_1^{\,3}}{8}$$

$$= \frac{\pi\ (6\tfrac{5}{8})^3}{8} = \frac{114 \text{ in.}^3}{\text{Total } I_w = 1500 \text{ in.}^3}$$

$$S_w = \frac{I_w}{d/2}$$

$$= \frac{1500}{10.25}$$

$$= 146 \text{ in.}^2$$

Step 2: FIND THE FORCE INVOLVED.

Moment acting on tower due to wind pressure:

$$M = (.208)\left(\frac{\pi\ 20^2}{4}\right)(360)$$

$$+ (.208)\left(\frac{\pi\ 40^2}{4}\right)(288)$$

$$+ (.208)\left(\frac{\pi\ 20^2}{4}\right)(216)$$

$$+ (.208)(556)(160.5)(296.3)$$

$$+ (.208)(6\tfrac{5}{8})(216)(108)$$

$$= 200{,}000 \text{ in.-lbs}$$

bending stress in pipe (column)

$$\sigma = \frac{M\ c}{I}$$

$$= \frac{(200{,}000)(3.3125'')}{(28.14 \text{ in.}^4)}$$

$$= \underline{23{,}600 \text{ psi}}$$

Step 3: FIND FORCE ON FILLET WELD AT COLUMN BASE.

$$f = \frac{M}{S_w}$$

$$= \frac{(200{,}000 \text{ in.-lbs})}{(146 \text{ in.}^2)}$$

$$= 1370 \text{ lbs/linear in.}$$

Step 4: NOW FIND REQUIRED LEG SIZE OF FILLET WELD AT BASE.

$$\omega = \frac{\text{actual force}}{\text{allowable force}}$$

$$= \frac{1370}{11{,}200}$$

$= .123''$ but use $\frac{5}{16}''$ ◺ all around, the minimum fillet weld size for 1″ base plate

Problem 5

To determine amount of fillet weld to attach masonry plate to beam, using E70 welds. The following conditions exist:

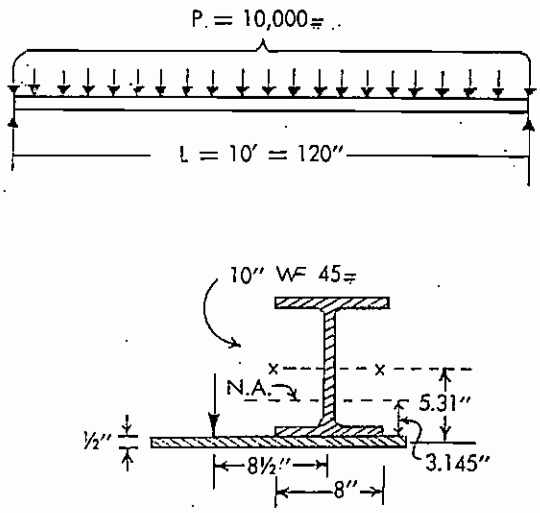


FIGURE 23

Built-up member	A	d	M	I_x	I_g
10″ WF 45#	13.24	0	0	0	248.6
18″ x ½″	9.00	— 5.31	—47.79	+253.8	—
Total ➻	22.24		—47.79	502.4	

properties of section

$$NA = \frac{M}{A} = \frac{(-47.79)}{(22.24)}$$

$$= -2.145'' \text{ below axis x-x}$$

$$\therefore \frac{M_z}{A} = (-2.145)(-47.79)$$

$$= +102.7$$

$$I_{NA} = I_y - \frac{M^2}{A}$$

$$= (502.4) - (102.7)$$

$$= 399.7 \text{ in.}^4$$

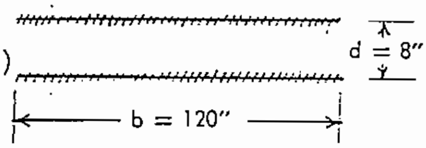
horizontal shear force on weld

$$f_h = \frac{V\,a\,y}{I\,n}$$

$$= \frac{(5000)(9.0)(3.415)}{(399.7)(2 \text{ welds})}$$

$$= 192.0 \text{ lbs/in., max. at ends}$$

properties of weld, treating it as a line



$$S_w = b\,d$$

$$= (120)(8)$$

$$= 960 \text{ in.}^2$$

$$A_w = 2\,b$$

$$= 2(120)$$

$$= 240''$$

bending force on weld

$$f_b = \frac{M}{S_w}$$

$$= \frac{(10{,}000)(8.5)}{(960)}$$

$$= 88.5 \text{ lbs/in.}$$

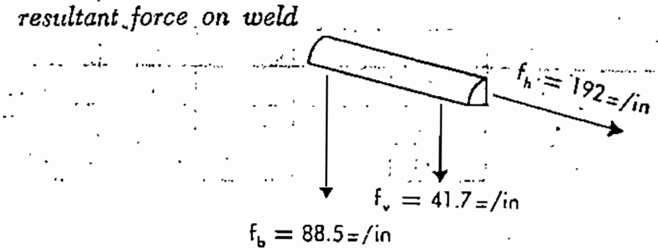
vertical shear force on weld

$$f_v = \frac{V}{A_w}$$

$$= \frac{(5000)}{(120)}$$

$$= 41.7 \text{ lbs/in.}$$

resultant force on weld



$$f_r = \sqrt{(f_b + f_v)^2 + f_h^2}$$

$$= \sqrt{(88.5 + 41.7)^2 + (192)^2}$$

$$= 232 \text{ lbs/in.}$$

leg size of weld

$$\omega = \frac{232}{11{,}200}$$

$$= .0207'' \text{ if continuous}$$

If using $\frac{3}{16}''$ intermittent weld, then

$$\% = \frac{\text{calculated continuous leg size}}{\text{actual intermittent leg size used}}$$

$$= \frac{.0207''}{\frac{3}{16}''}$$

$$= 11\%$$

Hence, use

$\frac{3}{16}''$ ◸ 2 — 8 on each side (25%)

Problem 6

DRIVE ROLL FOR CONVEYOR BELT

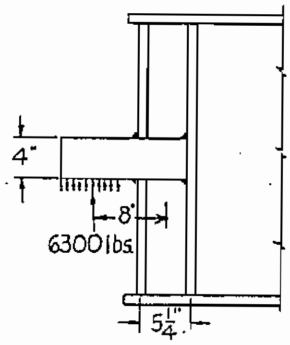


FIGURE 24

Determine size of required fillet weld for hub shown in Figure 24. The bearing load is 6300 lbs. Torque transmitted is 150 HP at 100 RPM, or:

$$T = \frac{63{,}030 \times HP}{RPM}$$

$$= \frac{63{,}030 \times (150)}{(100)}$$

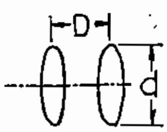
$$= 94{,}500 \text{ in.-lbs.}$$

Step 1: FIND PROPERTIES OF WELD, TREATING IT AS A LINE (use Table 5).

$$J_w = 2\,\frac{\pi\,d^3}{2}$$

$$= 2\,\frac{\pi\,(4)^3}{2}$$

$$= 100.5 \text{ in.}^3$$



$$I_w = \frac{\pi\, d}{2}\left(D^2 + \frac{d^2}{2}\right) = \frac{\pi\, 4}{2}\left[(5\tfrac{1}{4})^2 + \frac{(4)^2}{2}\right]$$
$$= 223.3 \text{ in.}^3$$
$$c = \tfrac{1}{2}\sqrt{D^2 + d^2} = \tfrac{1}{2}\sqrt{(5\tfrac{1}{4})^2 + (4)^2}$$
$$= 3.3''$$
$$S_w = \frac{I_w}{c} = \frac{(223.3)}{(3.3)}$$
$$= 67.6 \text{ in.}^2$$
$$A_w = 2\,\pi\, d$$
$$= 2\,\pi\,(4)$$
$$= 25.2''$$

Step 2: FIND THE VARIOUS FORCES ON WELD, INSERTING PROPERTIES OF WELD FOUND ABOVE (use Table 4).

bending

$$f_b = \frac{M}{S_w} = \frac{(6300)(8)}{(67.6)} = 746 \text{ lbs/in.}$$

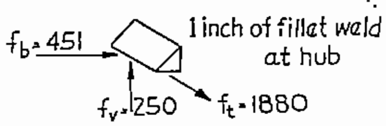
twisting

$$f_t = \frac{T\ c}{J_w}$$
$$= \frac{(94{,}500)(2)}{(100.5)}$$
$$= 1880 \text{ lbs/in.}$$

vertical shear

$$f_v = \frac{V}{A_w}$$
$$= \frac{(6300)}{(25.2)}$$
$$= 250 \text{ lbs/in.}$$

Step 3: DETERMINE ACTUAL RESULTANT FORCE AND ALLOWABLE FORCE ON THE WELD.



$$f_r = \sqrt{f_b^2 + f_t^2 + f_v^2}$$
$$= \sqrt{(746)^2 + (1880)^2 + (250)^2}$$
$$= 2040 \text{ lbs/in.} \quad \text{(actual resultant force)}$$

Since this is fatigue loading, assume service life of N = 2,000,000 cycles and use Table 8 formula. In this case, assume a complete reversal of load; hence K = min/max = −1 and:

$$f = \frac{5100}{1 - \frac{K}{2}}$$
$$= \frac{5100}{1 + \frac{1}{2}}$$
$$= 3400 \text{ lbs/in.} \quad \text{(allowable force)}$$

Step 4: NOW REQUIRED LEG SIZE OF FILLET WELD AROUND HUB CAN BE FOUND.

$$\omega = \frac{\text{actual force}}{\text{allowable force}}$$
$$= \frac{(2040)}{(3400)}$$
$$= .600'' \text{ or use } \tfrac{5}{8}''$$

Problem 7

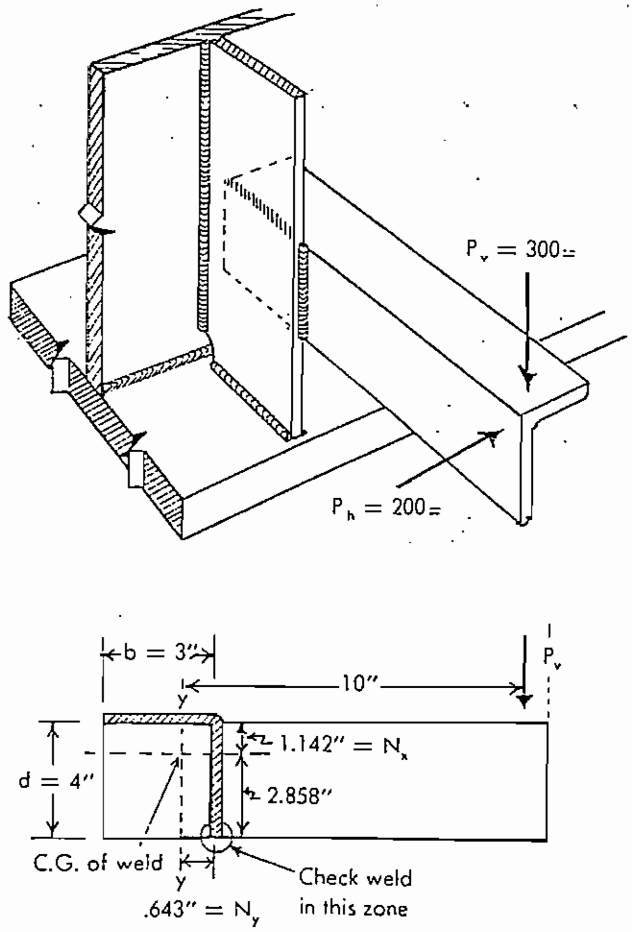


FIGURE 25

A 3" ... " angle for support of a pipe extends out from the transverse intermediate stiffeners on a plate girder, Figure 25. This must be field welded. It will be difficult to weld in the overhead position along the bottom edge of the angle as well as to make the vertical weld along the end of the angle next to the girder web because of poor accessibility. Check whether just two fillet welds would be sufficient, assuming the pipe's weight on the hanger is 300 lbs and a possible horizontal force of approximately 200 lbs is applied to the hanger during erection of the pipe.

$$N_y = \frac{b^2}{2(b+d)} = \frac{(3)^2}{2(3+4)} = .643''$$

$$N_x = \frac{d^2}{2(b+d)} = \frac{(4)^2}{2(3+4)} = 1.142''$$

properties of weld treated as a line

1. For twist about connection's center of gravity, due to P_v

$$J_w = \frac{(b+d)^4 - 6\,b^2\,d^2}{12\,(b+d)} = \frac{(3+4)^4 - 6(3)^2(4)^2}{12\,(3+4)} = 18.3 \text{ in.}^3$$

2. For bending about (y-y) axis, due to P_h

$$S_w = \frac{4\,bd + b^2}{6} = \frac{4(3)(4) + 3^2}{6} = 9.5 \text{ in.}^2$$

twisting force on weld

1. Horizontal

$$f_{h_1} = \frac{T\,c_h}{J_w} = \frac{(300 \times 10)(2.858)}{(18.3)} = 470 \text{ lbs/in.}$$

2. Vertical

$$f_{v_1} = \frac{T\,c_v}{J_w} = \frac{(300 \times 10)(.643)}{(18.3)} = 105 \text{ lbs/in.}$$

vertical shear

$$f_{v_2} = \frac{P}{L} = \frac{(300)}{(3+4)} = 43 \text{ lbs/in.}$$

bending force on weld (about y-y), due to P_h

$$f_{h_2} = \frac{M}{S_w} = \frac{(200 \times 10)}{(9.5)} = 211 \text{ lbs/in.}$$

resultant force on weld at bottom of connection

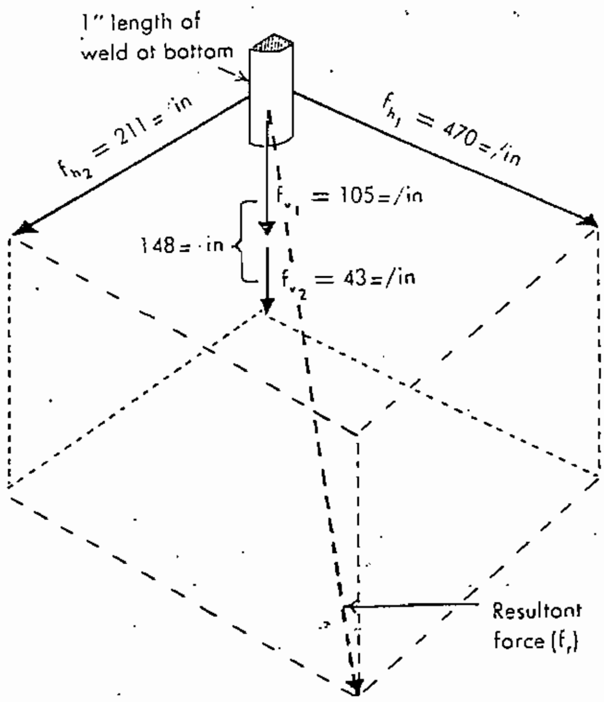


FIGURE 26

$$f_r = \sqrt{f_{h_1}{}^2 + f_{h_2}{}^2 + f_v{}^2} = \sqrt{(470)^2 + (211)^2 + (148)^2} = 536 \text{ lbs/in.}$$

leg size of fillet weld

$$\omega = \frac{536}{11{,}200}$$

$= .048''$ or $\frac{3}{16}''$ would be sufficient

10. HOW TO MEASURE SIZE OF FILLET WELDS

The size of a fillet weld is difficult to measure without proper gages. Fillet shapes are concave, convex, or flat. They may have equal or unequal legs. However, the true fillet size is measured by finding the leg-length of the largest isosceles right triangle (a triangle with a 90° corner and legs of equal length) which can be inscribed within the weld cross-section, with the legs in line with the original surface of the metal.

The gages shown in Figure 27 give quick, easy measurement of fillet size. Two gage types are available: one for a convex fillet, another for a concave fillet. See Section 7.10 for series of illustrations which dramatically show how poor gaging can seriously offset the accuracy of engineered welds.

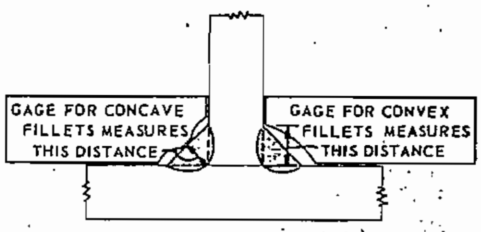


FIG. 27 Convex fillets may be measured with gage of type shown on right; in this case it measures the leg size. Concave fillets are measured with gage like the one on left; in this case it measures the weld throat.

TABLE 11—Maximum Allowable Shear Stress and Shear Force For Given Applied Normal Stress on Fillet Weld or Partial-Penetration Groove Weld

Applied normal stress (σ) parallel to weld (psi)	Max. allowable shear stress (τ) which may be applied to throat of fillet weld or partial penetration groove weld (psi): E60 welds	E70 welds	Max. allowable shear force (f) which may be applied to fillet weld (lbs/lineal inch): E60 welds	E70 welds
zero	13,600	15,800	9,600	11,170
1,000	13,590	15,790	9,600	11,160
2,000	13,560	15,770	9,590	11,150
3,000	13,520	15,720	9,560	11,110
4,000	13,450	15,660	9,510	11,070
5,000	13,380	15,600	9,460	11,030
6,000	13,270	15,510	9,380	10,970
7,000	13,130	15,410	9,280	10,890
8,000	13,000	15,290	9,190	10,810
9,000	12,840	15,140	9,080	10,710
10,000	12,650	14,990	8,940	10,600
11,000	12,430	14,810	8,790	10,470
12,000	12,200	14,610	8,630	10,330
13,000	11,940	14,400	8,440	10,180
14,000	11,660	14,160	8,240	10,010
15,000	11,340	13,910	8,020	9,840
16,000	11,000	13,620	7,780	9,630
17,000	10,620	13,320	7,510	9,420
18,000	10,200	12,980	7,210	9,180
19,000	9,730	12,630	6,880	8,930
20,000	9,220	12,230	6,520	8,650
21,000	8,640	11,810	6,110	8,350
22,000	8,000	11,340	5,660	8,020
23,000	7,260	10,840	5,130	7,660
24,000	6,400	10,280	4,530	7,270

11. WELDS SUBJECT TO COMBINED STRESS

Although the (1963) AISC Specifications are silent concerning combined stresses on welds, the previous specifications (Sec 12 b) required that welds subject to shearing and externally applied tensile or compressive forces shall be so proportioned that the combined unit stress shall not exceed the unit stress allowed for shear.

Very rarely does this have to be checked into. For simply supported girders, the maximum shear occurs near the ends and in a region of relatively low bending stress. For built-up tension or compression members, the axial tensile or compressive stresses may be relatively high, but theoretically there is no shear to be transferred.

In the case of continuous girders, it might be well to check into the effect of combined stress on the connecting welds in the region of negative moment, because this region of high shear transfer also has high bending stresses.

Even in this case, there is some question as to how much a superimposed axial stress actually reduces the shear-carrying capacity of the weld. Unfortunately there has been no testing of this. In general, it is felt that the use of the following combined stress analysis is conservative and any reduction in the shear-carrying capacity of the weld would not be as great as would be indicated by the following formulas. See Figure 28.

In Figure 28:

τ = shear stress to be transferred along throat of weld, psi

σ = normal stress applied parallel to axis of weld, psi

From the Mohr's circle of stress in Figure 28:

$$\boxed{\sigma_{max} = \frac{\sigma_1}{2} + \sqrt{\left(\frac{\sigma_1}{2}\right)^2 + \tau_3{}^2}} \quad \text{..........(6)}$$

$$\boxed{\tau_{max} = \sqrt{\left(\frac{\sigma_1}{2}\right)^2 + \tau_3{}^2}} \quad \text{..........(7)}$$

From these formulas for the resulting maximum shear stress and maximum normal stress, the following is true:

For a given applied normal stress (σ), the greatest applied shear stress on the throat of a partial-penetration groove weld or fillet weld (and holding the maximum shear stress resulting from these combined stresses within the allowable of τ = 13,600 psi for E60 welds, or τ = 15,800 psi for E70 welds) is—

for E60 welds or SAW-1

$$\boxed{\tau \leqq \sqrt{13{,}600^2 - \frac{\sigma^2}{4}}} \quad \text{..........(7a)}$$

for E70 welds or SAW-2

$$\boxed{\tau \leqq \sqrt{15{,}800^2 - \frac{\sigma^2}{4}}} \quad \text{..........(7b)}$$

This same formula may be expressed in terms of allowable unit force (lbs/linear inch) for a fillet weld:

for E60 welds or SAW-1

$$\boxed{f \leqq \omega \sqrt{9600^2 - \frac{\sigma^2}{8}}} \quad \text{..........(8a)}$$

for E70 welds or SAW-2

$$\boxed{f \leqq \omega \sqrt{11{,}200^2 - \frac{\sigma^2}{8}}} \quad \text{..........(8b)}$$

For the same given applied normal stress (σ), the greatest applied shear stress (τ) on the throat of a groove weld or fillet weld (and holding the maximum normal stress resulting from these combined stresses within the allowable of $\sigma = .60\ \sigma_y$) is—

$$\boxed{\tau \leqq \sqrt{(.60\ \sigma_y)^2 - (.60\ \sigma_y)\ \sigma}} \quad \text{..........(9)}$$

Formulas #7 and #8 are expressed in table form, as in Table 11. The general relationship of these formulas is illustrated by the graph, Figure 29.

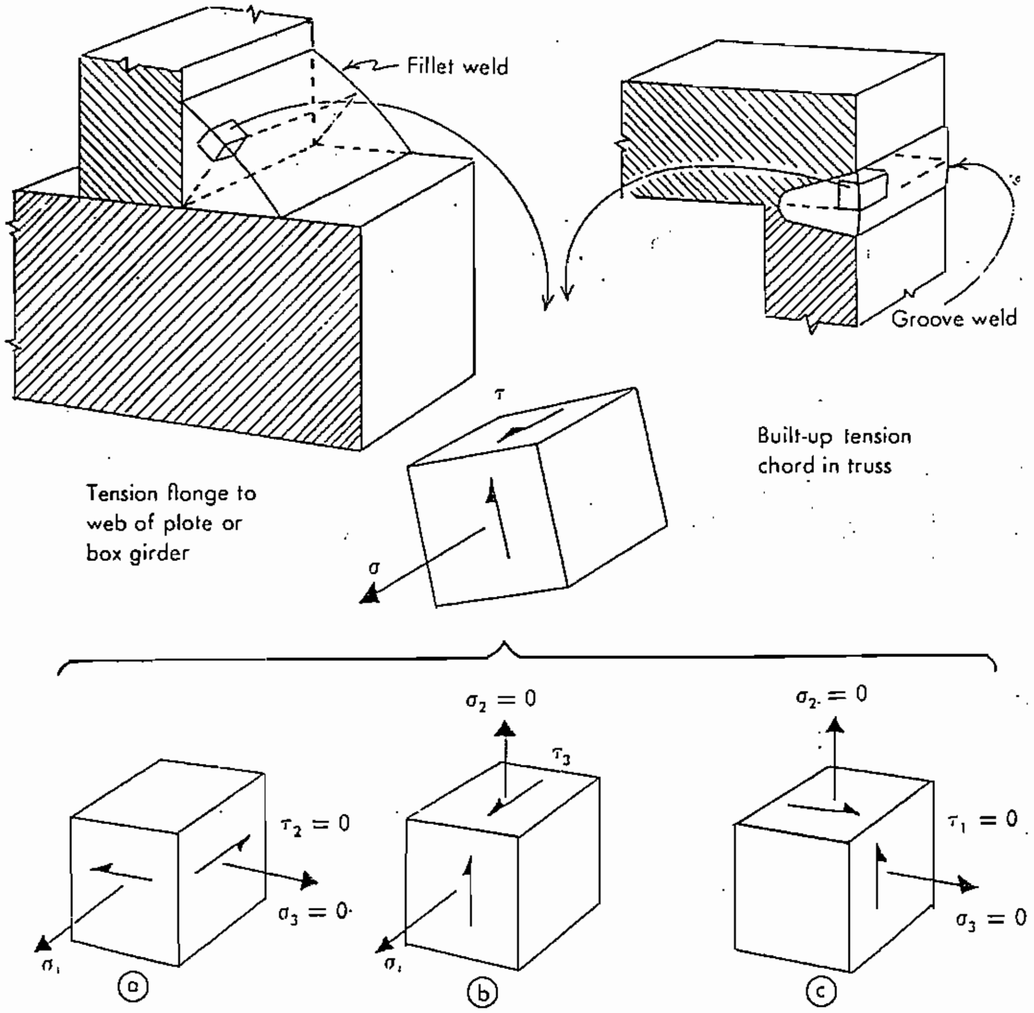


FIG. 28 Analysis of weld, using Mohr's Circle of Stress.

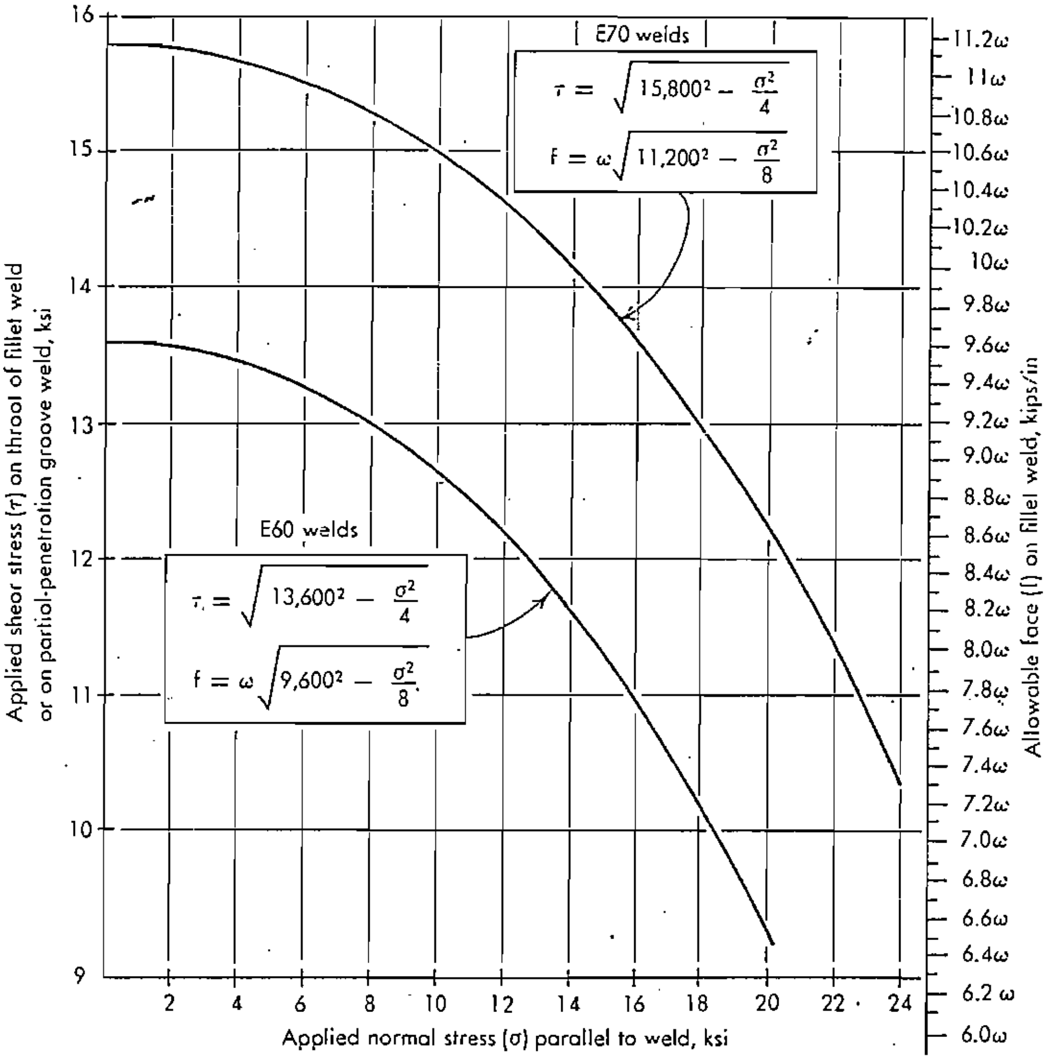


FIG. 29 Relationship of Formulas #8 and #9; see Table 11, page 19.