Welded Joints

Introduction

The design of welded joints requires consideration of the manner of loading on the joint, the types of materials in the weld and in the members to be joined, and the geometry of the joint itself.

The load may be either uniformly distributed over the weld such that all parts of the weld are stressed to the same level or eccentrically applied.

Introduction

The materials of the weld and the parent members determine the allowable stresses. The table lists several examples for steel and aluminum.

The allowables listed are for shear on fillet welds.

For steel, welded by the electric arc method, the type of electrode is an indication of the tensile strength of the filler metal.

Allowable Shear Stresses on Fillet Welds for Steel and Aluminum

A. Steel

Electrode type	Typical metals joined (ASTM grade)	Allowable shear stress
E60	A36, A500	18 ksi (124 MPa)
E70	A242, A441	21 ksi (145 MPa)
E80	A572, Grade 65	24 ksi (165 MPa)
E90		27 ksi (186 MPa)
E100		30 ksi (207 MPa)
E110		33 ksi (228 MPa)

B. Aluminum

	Filler Alloy							
	1100		4043		5356		5556	
	Allowable shear stress							
Metal joined	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
1100	3.2	22	4.8	33				
3003	3.2	22	5.0	34				
6061			5.0	34	7.0	48	8.5	59
6063			5.0	34	6.5	45	6.5	45

Introduction

For example, the E70 electrode has a minimum tensile strength of 70 ksi (483 MPa).

Additional data are available in publications of the American Welding Society (AWS), the American Institute for Steel Construction (AISC), and the Aluminum Association (AA).

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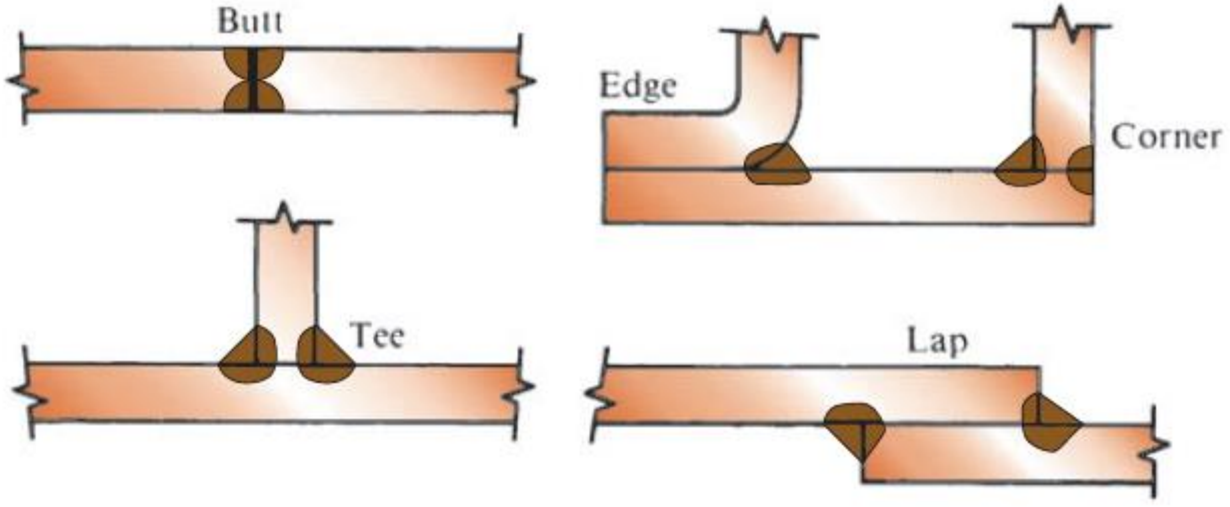
Types of Joints

Joint type refers to the relationship between mating parts, as illustrated.

The butt weld allows a joint to be the same nominal thickness as the mating parts and is usually loaded in tension.

If the joint is properly made with the appropriate weld metal, the joint will be stronger than the parent metal.

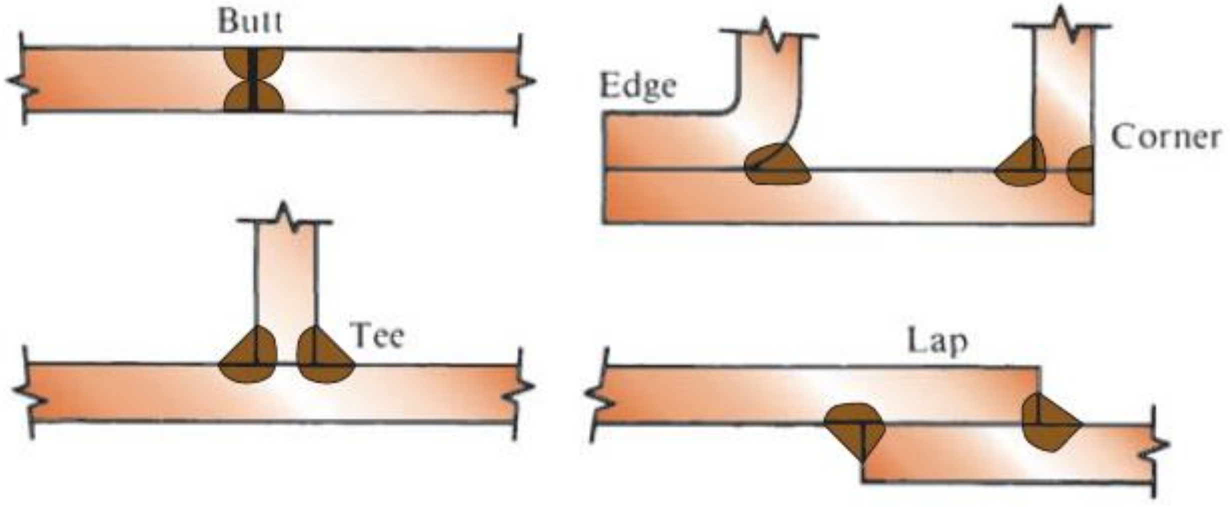
Thus, no special analysis of the joint is required if the joined members themselves are shown to be safe.



Types of Joints

Caution is advised, however, when the materials to be joined are adversely affected by the heat of the welding process.

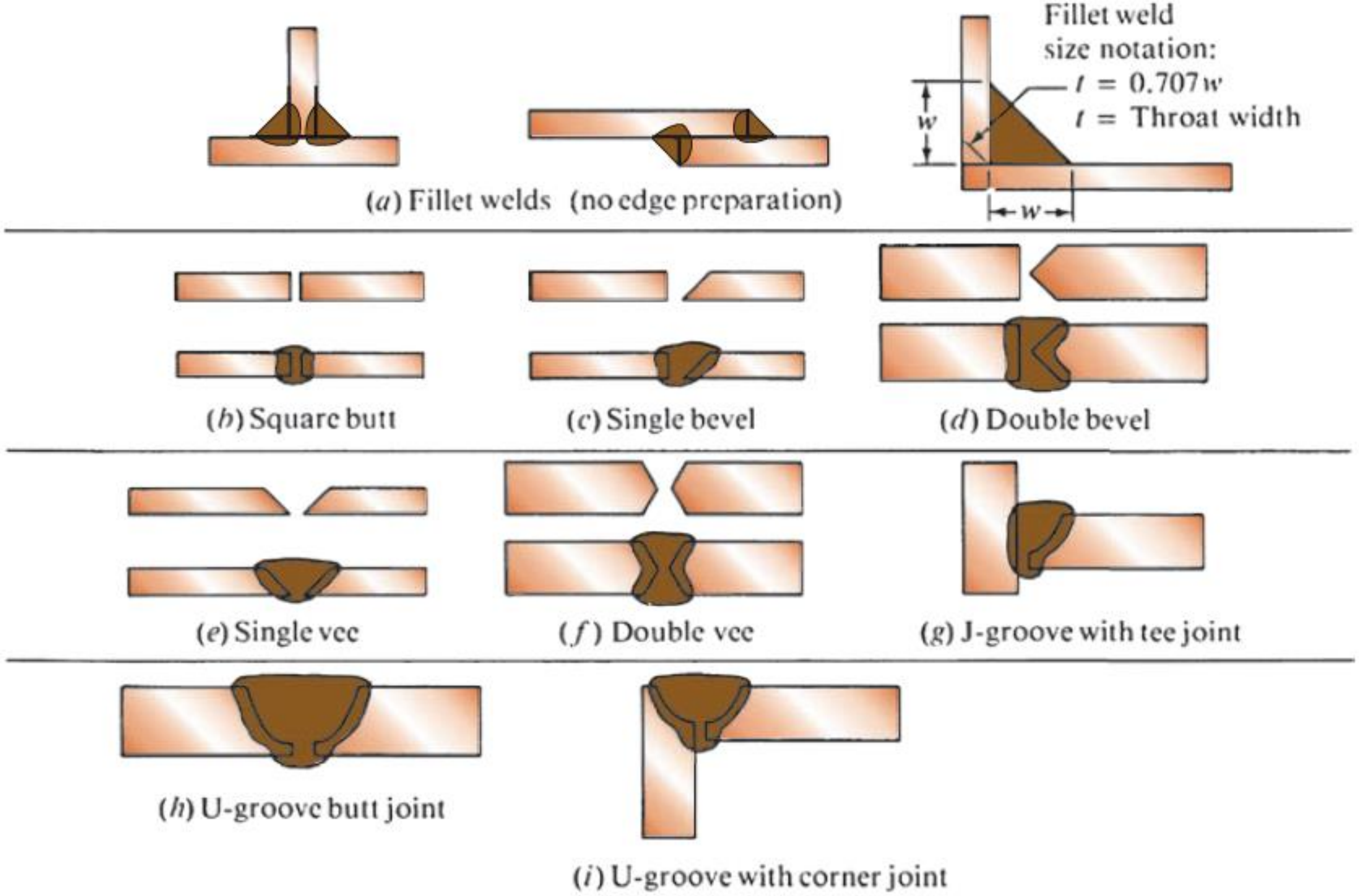
Heat-treated steels and many aluminum alloys are examples. The other types of joints in the figure are assumed to place the weld in shear.



Types of Welds

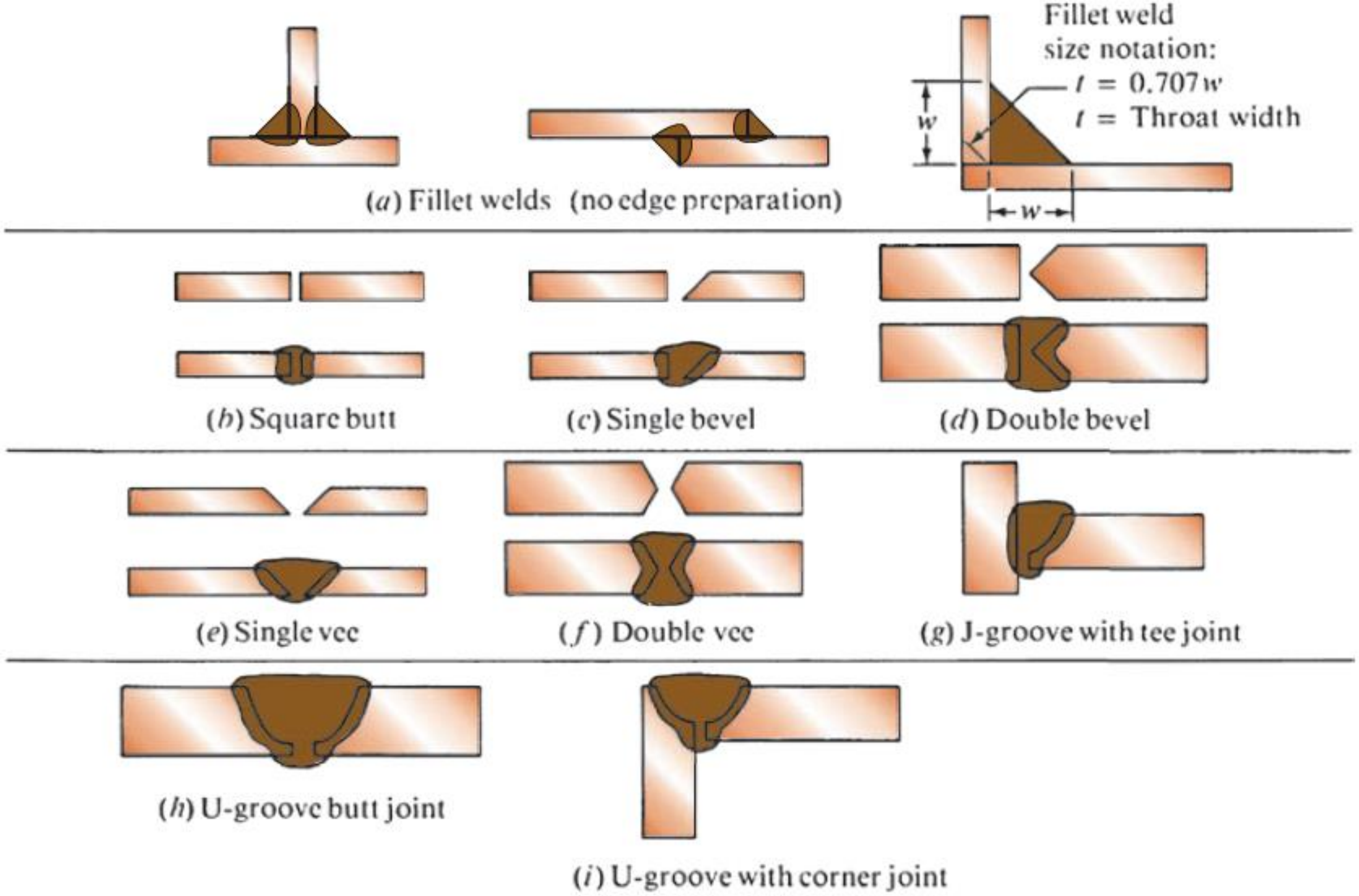
Several types of welds named for the geometry of the edges of the parts to be joined are shown.

Note the special edge preparation required, especially for thick plates, to permit the welding rod to enter the joint and build a continuous weld bead.



Types of Welds

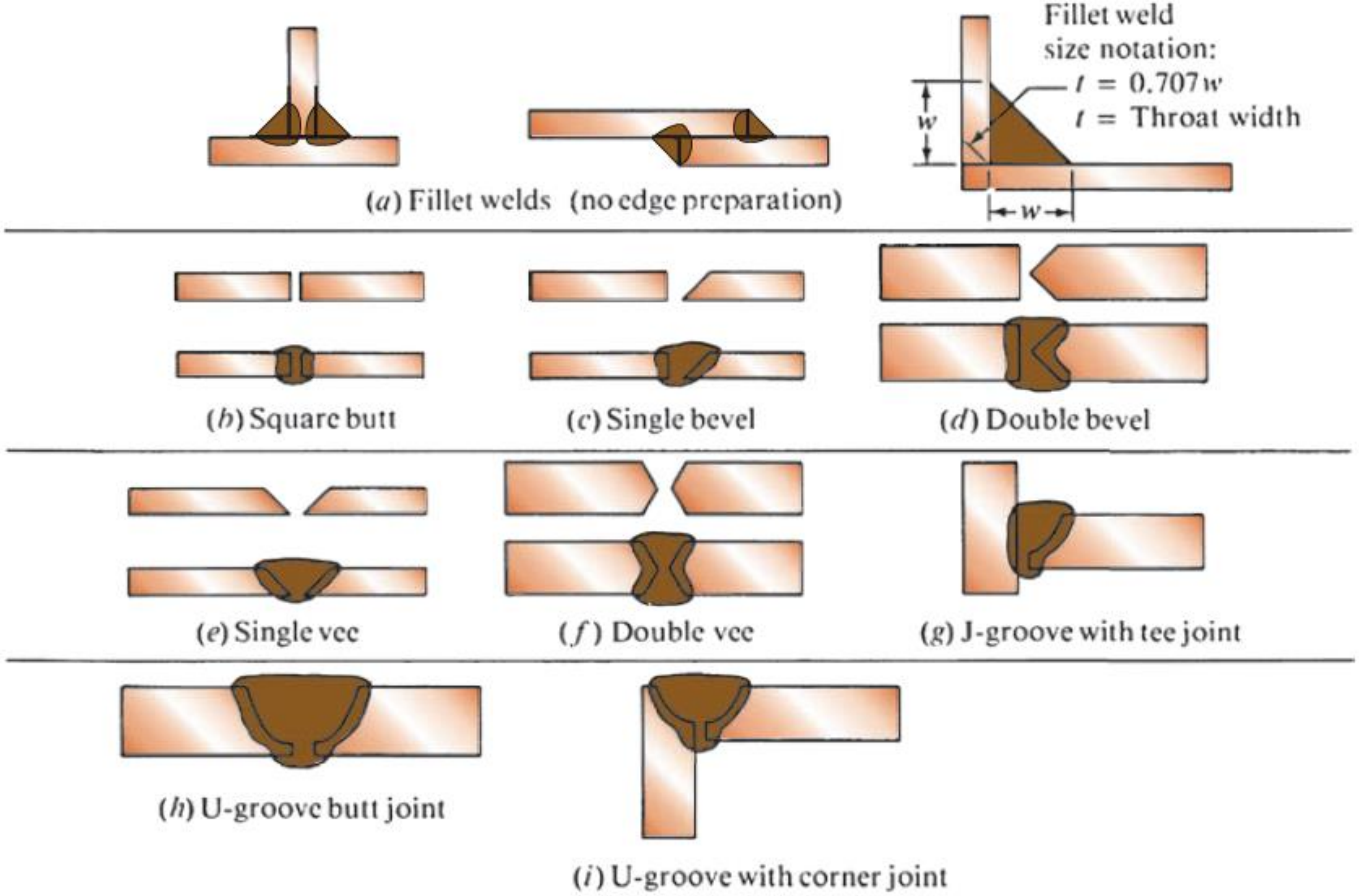
The five types of groove-type welds in the figure are made as complete penetration welds. Then, as indicated before for butt welds, the weld is stronger than the parent metals, and no further analysis is required.



Types of Welds

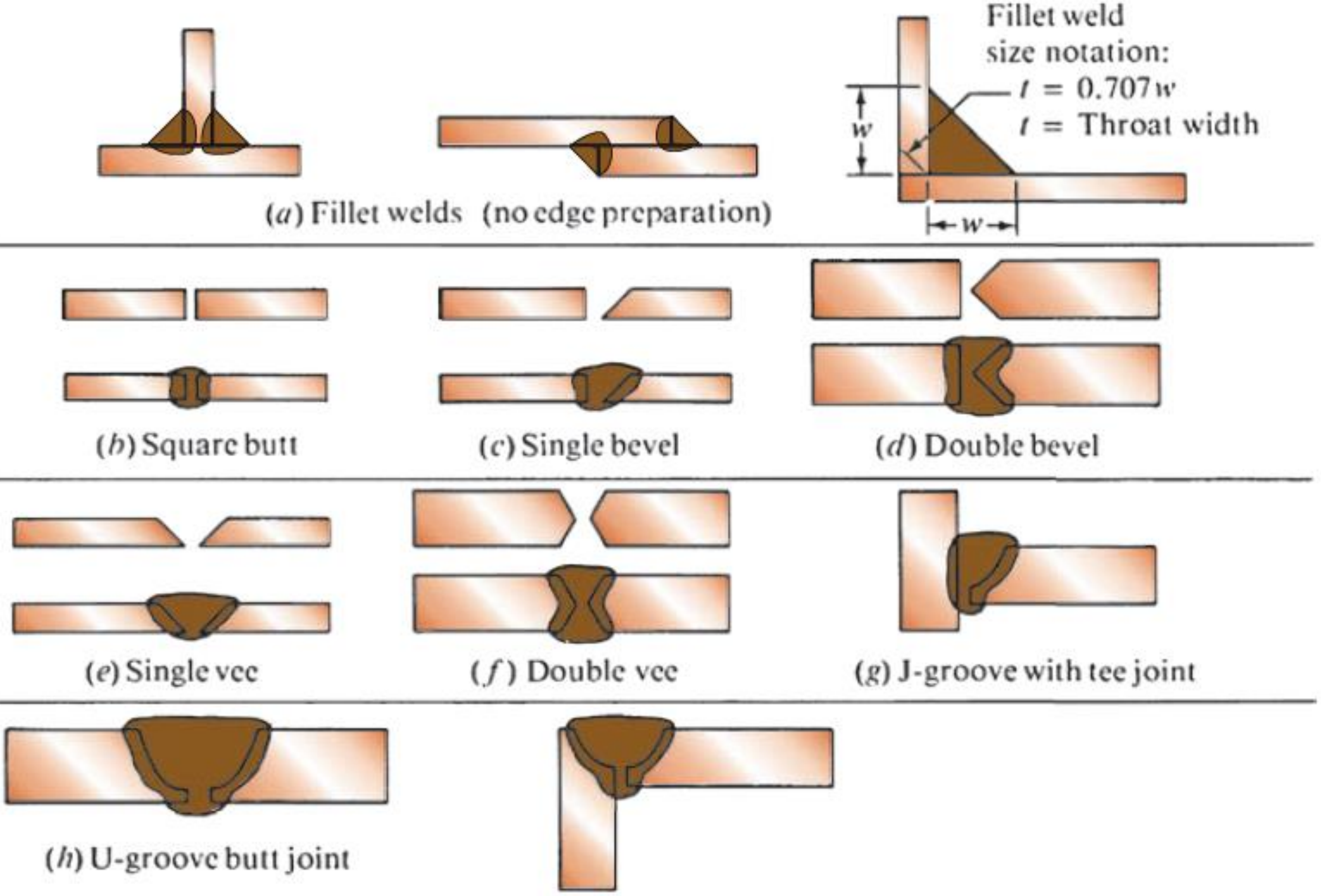
Fillet welds are typically made as equal-leg right triangles, with the size of the weld indicated by the length of the leg.

A fillet weld loaded in shear would tend to fail along the shortest dimension of the weld that is the line from the root of the weld to the theoretical face of the weld and normal to the face.



Types of Welds

The length of this line is found from simple trigonometry to be 0.707w, where w is the leg dimension.



(a) Fillet welds (no edge preparation)

(b) Square butt

(c) Single bevel

(d) Double bevel

(e) Single vee

(f) Double vee

(g) J-groove with tee joint

(h) U-groove butt joint

(i) U-groove with corner joint

Types of Welds

The objectives of the design of a fillet-welded joint are to specify the length of the legs of the fillet; the pattern of the weld; and the length of the weld.

Presented here is the method that treats the weld as a line having no thickness. The method involves determining the maximum force per inch of weld leg length. Comparing the actual force with an allowable force allows the calculation
of the required leg length.

Data for the allowable shear stress and the allowable force per inch for some combinations of base metal and welding electrode is provided.

In general, the allowables for building-type structures are for steady
loads. The values for bridge-type loading accounts for the cyclic effects.

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Allowable Shear Stresses and Forces on Welds

Base metal ASTM grade	Electrode	Allowable shear stress	Allowable force per inch of leg
Building-type structures:			
A36, A441	E60	13 600 psi	9600 lb/in
A36, A441	E70	15 800 psi	11 200 lb/in
Bridge-type structures:			
A36	E60	12 400 psi	8800 lb/in
A441, A242	E70	14 700 psi	10 400 lb/in

Method of Treating a Weld as a Line

Four different types of loading are considered here: (1) direct tension or compression, (2) direct vertical shear, (3) bending, and (4) twisting.

In general, the weld is analyzed separately for each type of loading to determine the force per inch of weld size due to each load.

The loads are then combined vectorially to determine the maximum force. This maximum force is compared with the allowables from the table to determine the size of the weld required.

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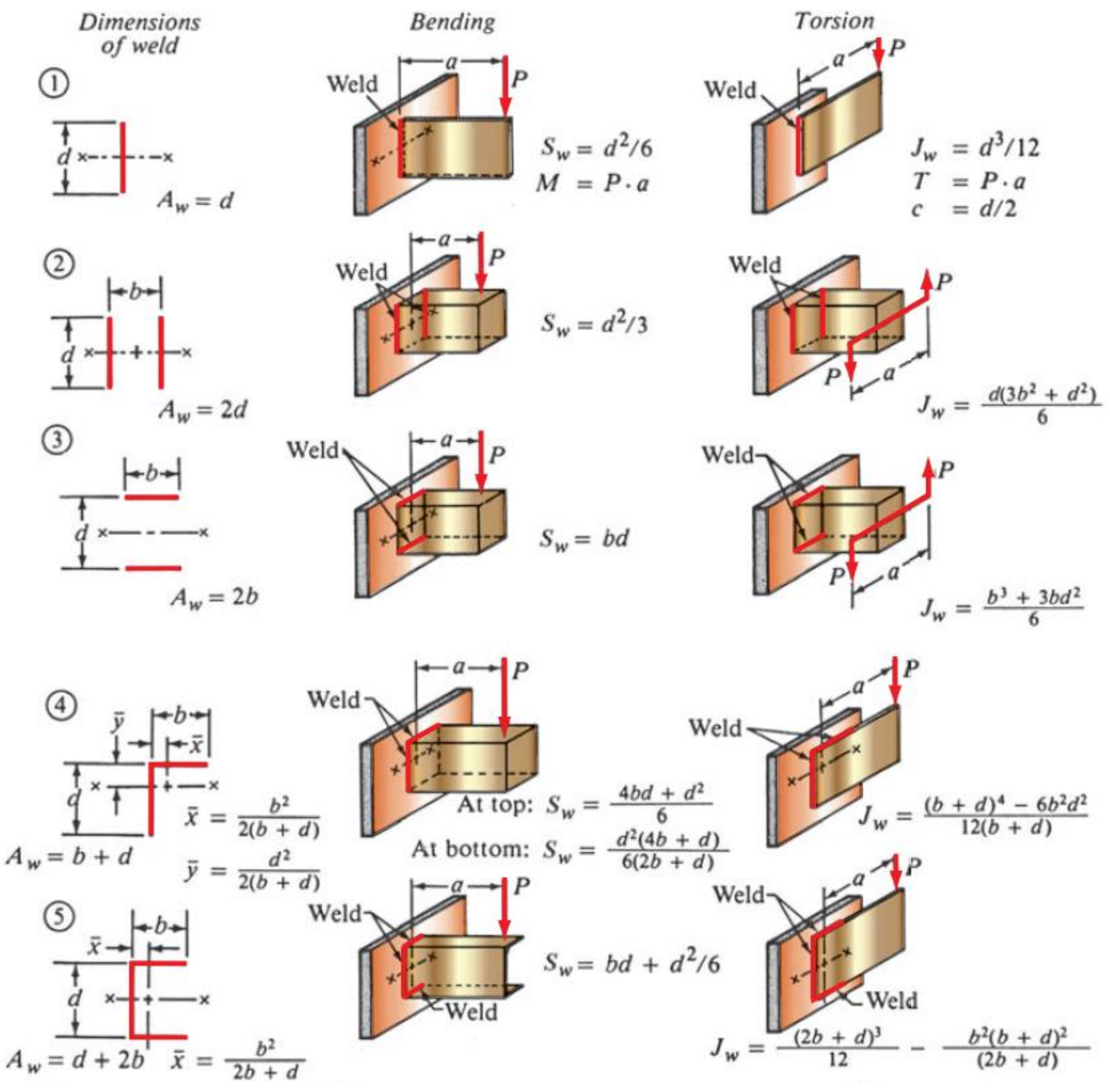
Method of Treating a Weld as a Line

The relationships used are summarized as follows:

Type of loading	Formula (and equation number) for force per inch of weld	
Direct tension or compression	$f = P/A_w$	(20–4)
Direct vertical shear	$f = V/A_w$	(20–5)
Bending	$f = M/S_w$	(20–6)
Twisting	$f = Tc/J_w$	(20–7)

In these formulas, the geometry of the weld is used to evaluate the terms Aw, Sw, and Jw, using the relationships shown.

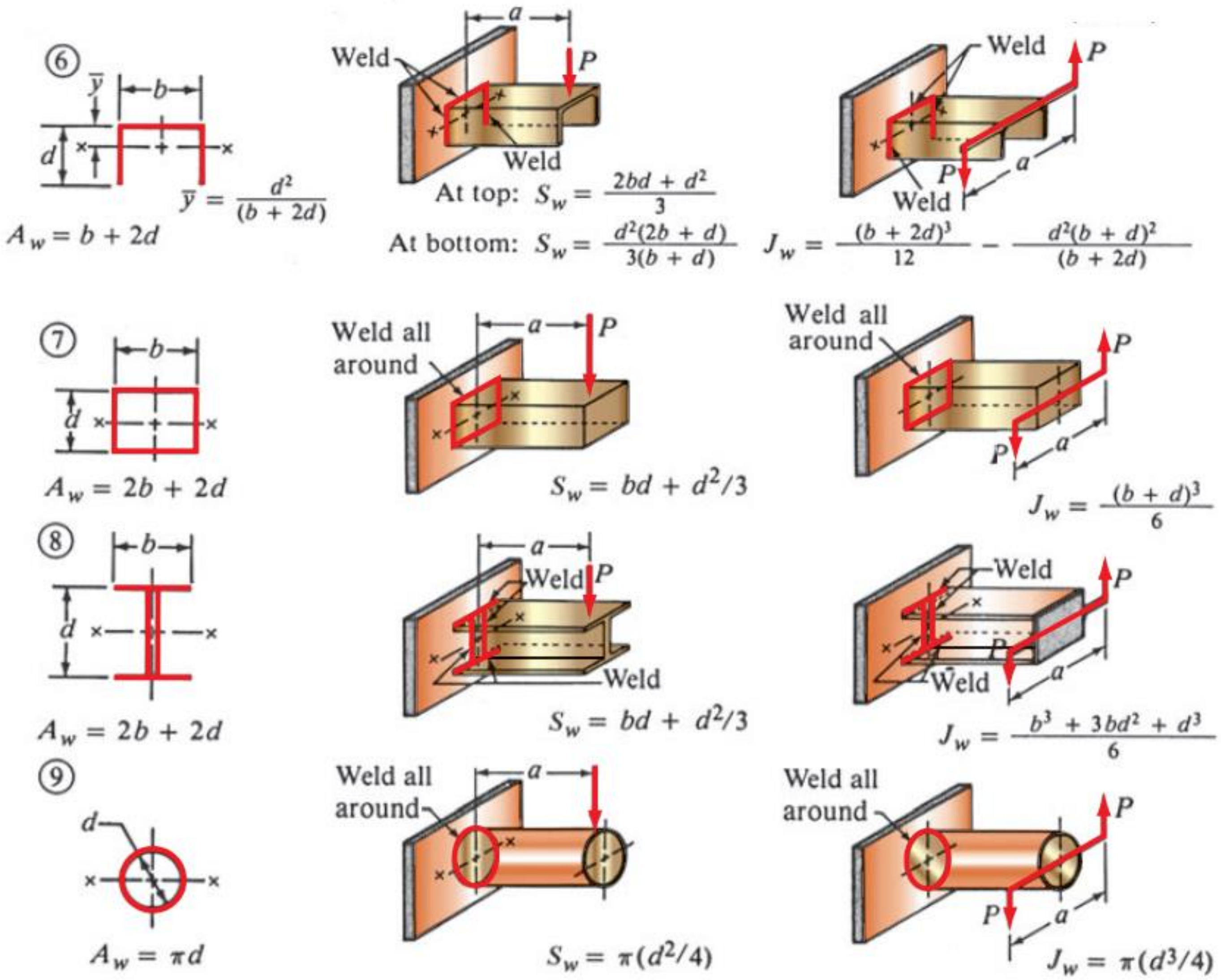
Note the similarity between these formulas and those used to perform the stress analysis.



Method of Treating a Weld as a Line

Note, also, the similarity between the geometry factors for welds and the properties of areas used for the stress analysis.

Because the weld is treated as a line having no thickness, the units for the geometry factors are different from those of the area properties.



GENERAL PROCEDURE FOR DESIGNING WELDED JOINTS

1. Propose the geometry of the joint and the design of the members to be joined.
2. Identify the types of stresses to which the joint is subjected (bending, twisting, vertical shear, direct tension, or compression).
3. Analyze the joint to determine the magnitude and the direction of the force on the weld due to each type of load.
4. Combine the forces vectorially at the point or points of the weld where the forces appear to be maximum.
5. Divide the maximum force on the weld by the allowable force from the table to determine the required leg size for the weld. Note that when thick plates are welded, there are minimum acceptable sizes for the welds as listed.

Allowable Shear Stresses and Forces on Welds

Base metal ASTM grade	Electrode	Allowable shear stress	Allowable force per inch of leg
Building-type structures:			
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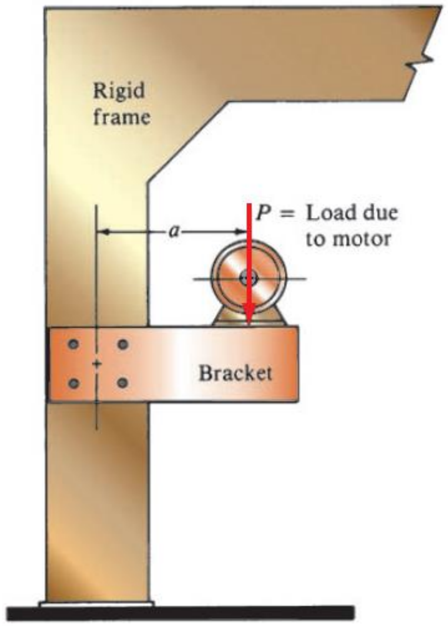
Minimum Weld Sizes for Thick Plates

Plate thickness (in)	Minimum leg size for fillet weld (in)
≤1/2	3/16
>1/2–3/4	1/4
>3/4–$1\frac{1}{2}$	5/16
>$1\frac{1}{2}$–$2\frac{1}{4}$	3/8
>$2\frac{1}{4}$–6	1/2
>6	5/8

Examples

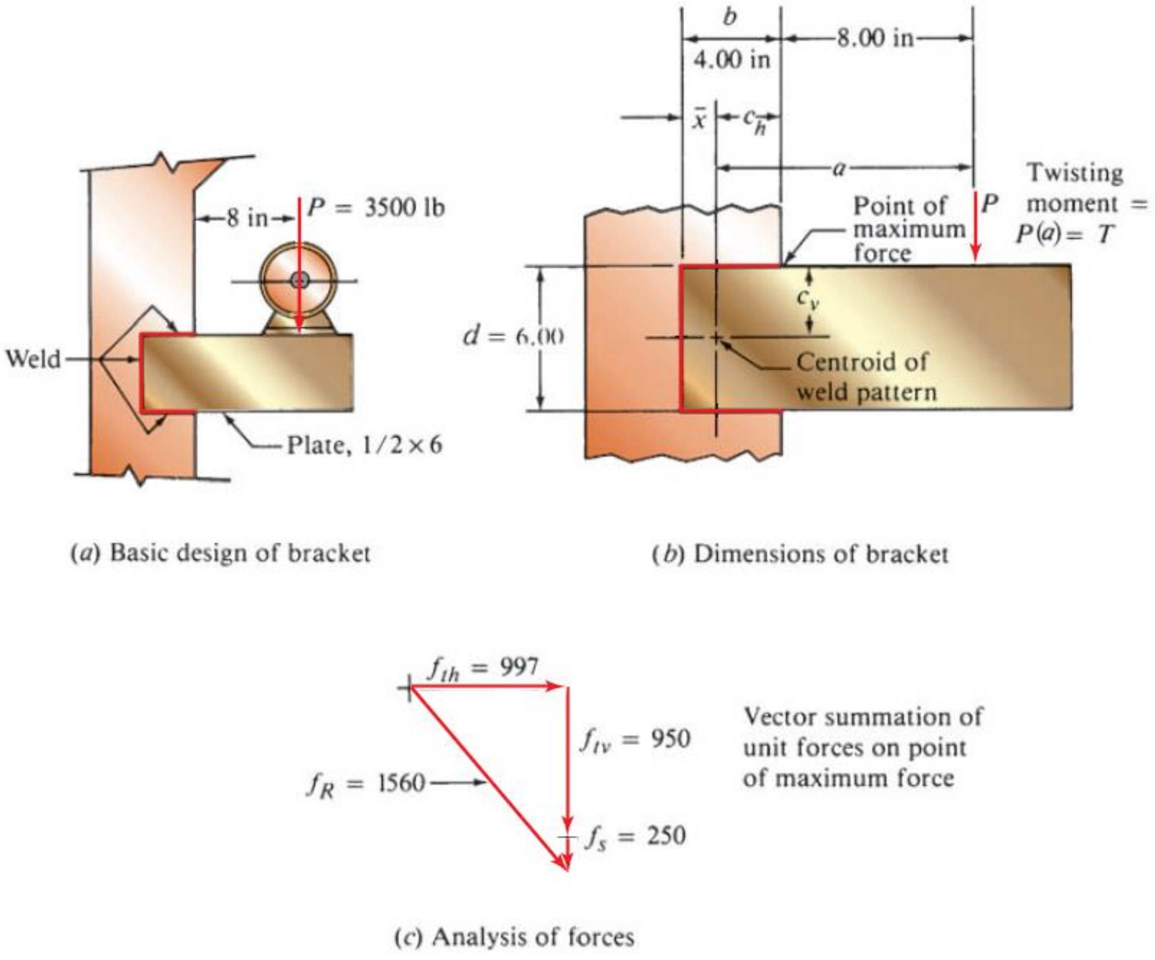
Design a bracket similar to that shown, but use welding to attach the bracket to the column (the total force *P* is 3500 lb and the distance *a* is 12 in.). The bracket is 6.00 in high and is made from ASTM A36 steel having a thickness of 1/2 in. The column is also made from A36 steel and is 8.00 in wide.



Eccentrically loaded bolted joint

Step 1. The proposed geometry is a design decision and may have to be subjected to some iteration to achieve an optimum design. For a first trial, use the C-shaped weld pattern.

Step 2. The weld will be subjected to direct vertical shear and torsion caused by the 3500-lb load on the bracket.



C-shaped weld bracket

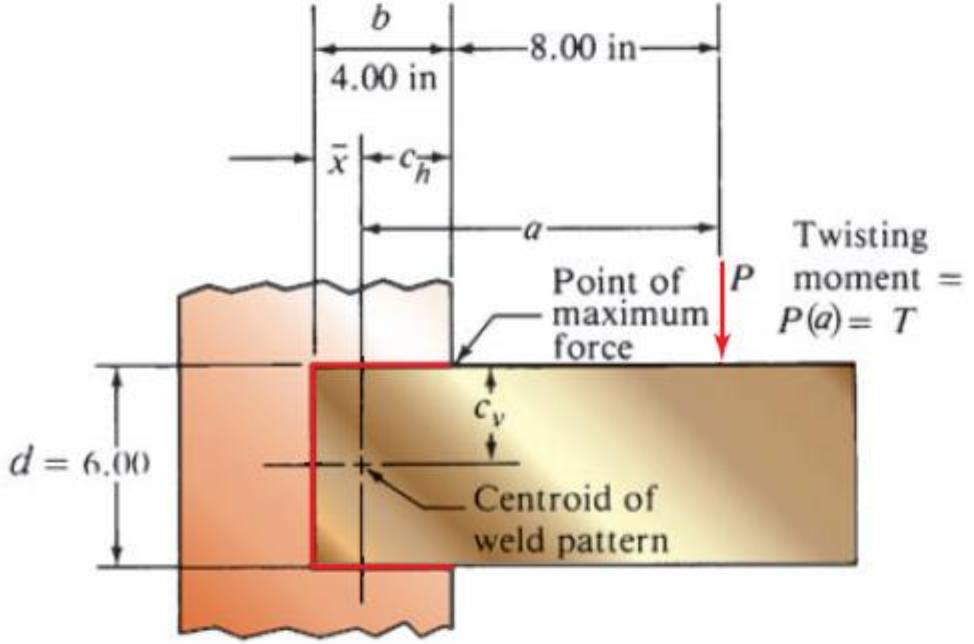
Examples

Step 3. To compute the forces on the weld, we must know the geometry factors *Aw* and *Jw*. Also, the location of the centroid of the weld pattern must be computed. Use Case 5.

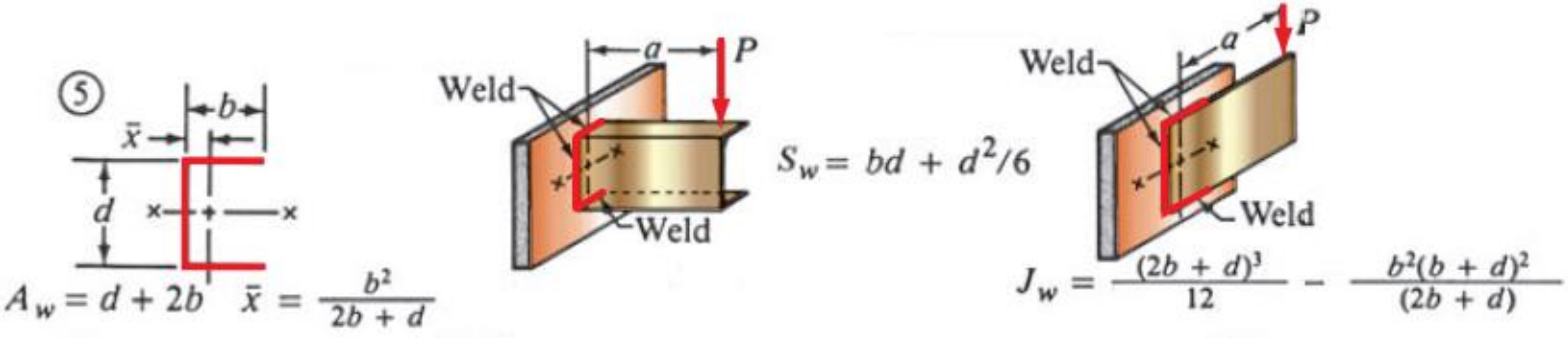
$$A_w = 2b + d = 2(4) + 6 = 14 \text{ in}$$

$$J_w = \frac{(2b + d)^3}{12} - \frac{b^2(b + d)^2}{(2b + d)} = \frac{(14)^3}{12} - \frac{16(10)^2}{14} = 114.4 \text{ in}^3$$

$$\bar{x} = \frac{b^2}{2b + d} = \frac{16}{14} = 1.14 \text{ in}$$



(b) Dimensions of bracket



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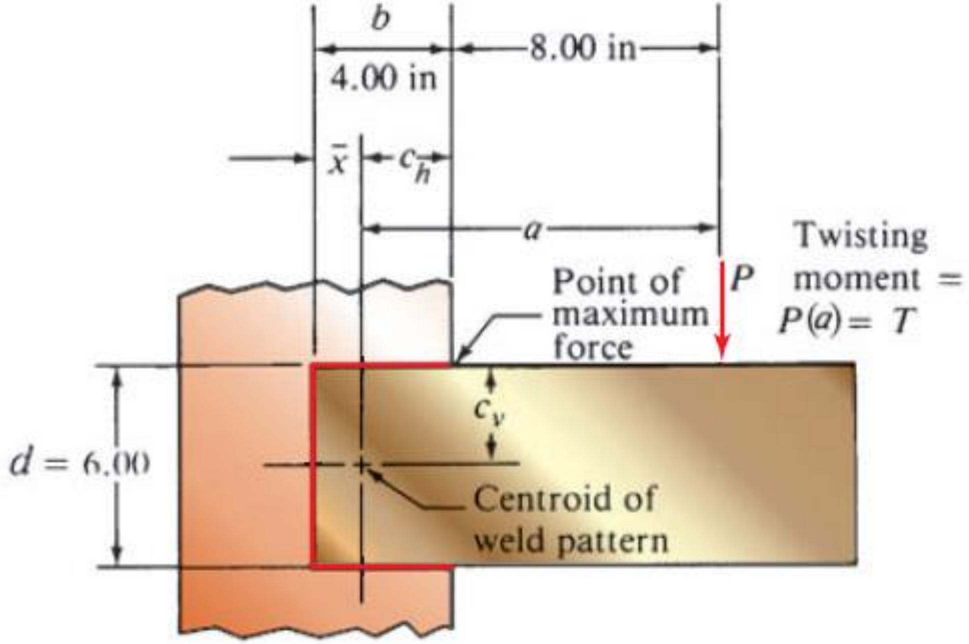


(*b*) Dimensions of bracket

Force due to Vertical Shear

$$V = P = 3500 \text{ lb}$$

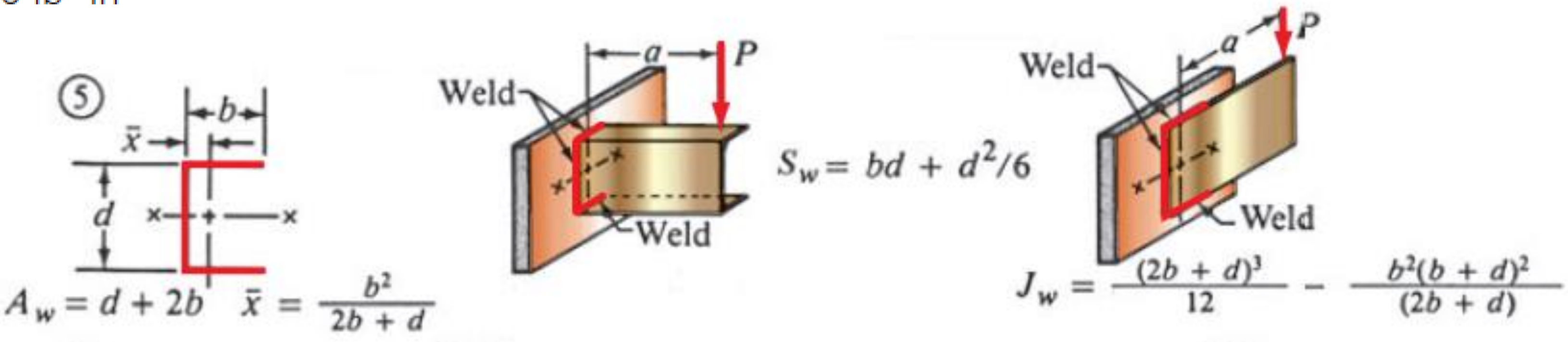
$$f_s = P/A_w = (3500 \text{ lb})/14 \text{ in} = 250 \text{ lb/in}$$

This force acts vertically downward on all parts of the weld.

Forces due to the Twisting Moment

$$T = P[8.00 + (b - \bar{x})] = 3500[8.00 + (4.00 - 1.14)]$$

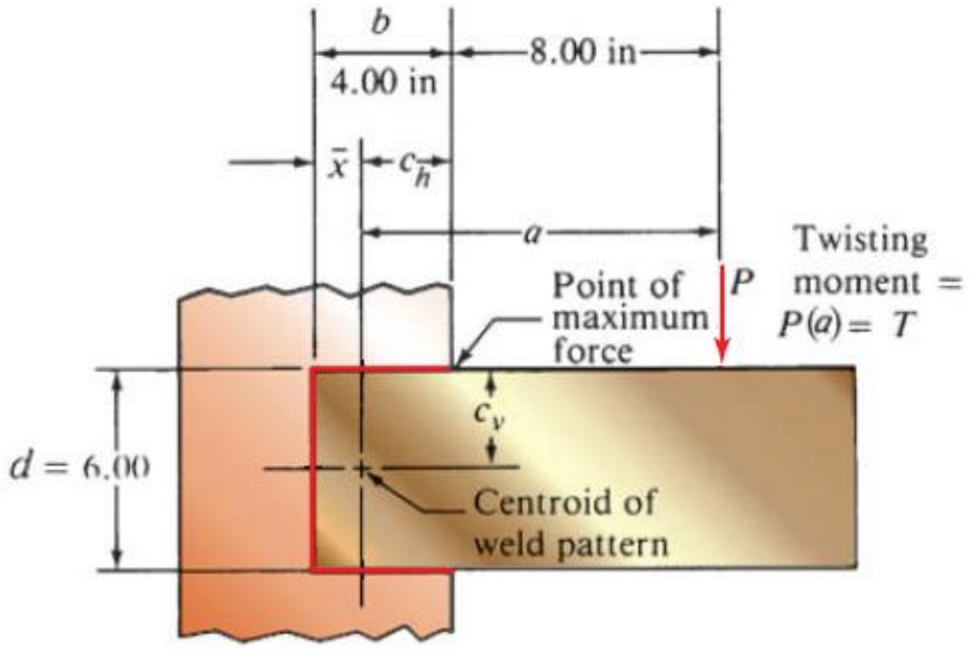
$$T = 3500(10.86) = 38\,010 \text{ lb} \cdot \text{in}$$



Examples

The twisting moment causes a force to be exerted on the weld that is perpendicular to a radial line from the centroid of the weld pattern to the point of interest. In this case, the end of the weld tc the upper right experiences the greatest force.

It is most convenient to break the force down into horizontal and vertical components and then subsequently recombine all such components to compute the resultant force:



(b) Dimensions of bracket

$$f_{th} = \frac{Tc_v}{J_w} = \frac{(38\,010)(3.00)}{114.4} = 997 \text{ lb/in}$$

$$f_{tv} = \frac{Tc_h}{J_w} = \frac{(38\,010)(2.86)}{114.4} = 950 \text{ lb/in}$$

Examples

Step 4. The vectorial combination of the forces on the weld is shown. Thus, the maximum force is 1560 lb/in.

Step 5. Selecting an E60 electrode for the welding, we find that the allowable force per inch of weld leg size is 9600 lb/in.

Then the required weld leg size is

$$w = \frac{1560 \text{ lb/in}}{9600 \text{ lb/in per in of leg}} = 0.163 \text{ in}$$

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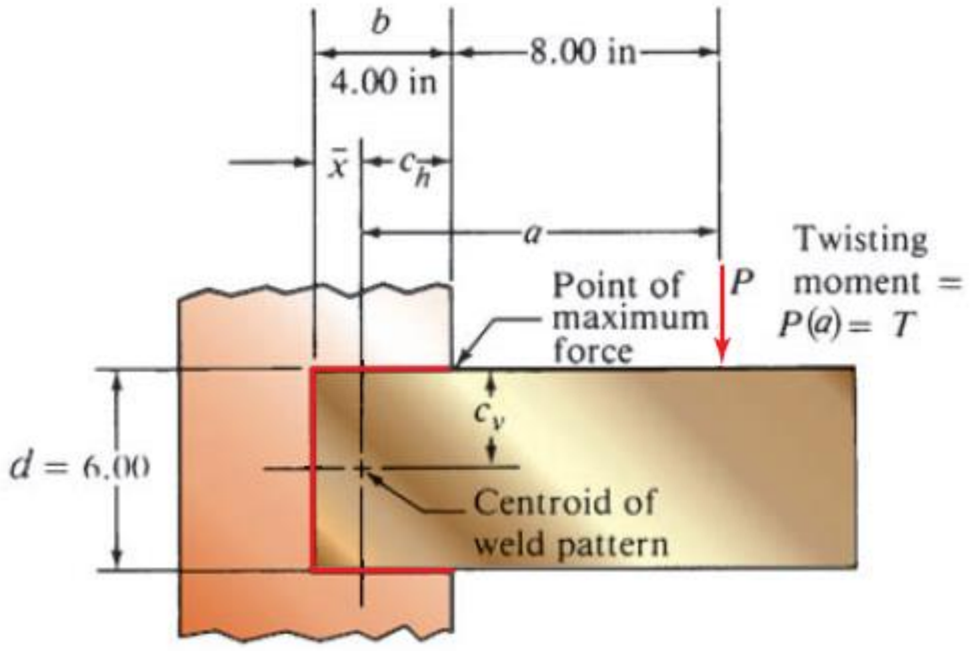
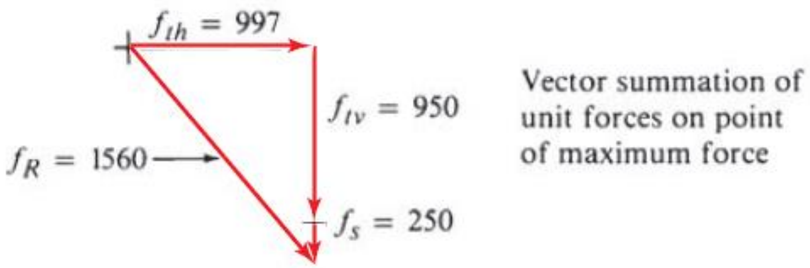


(*b*) Dimensions of bracket



(*c*) Analysis of forces

Examples

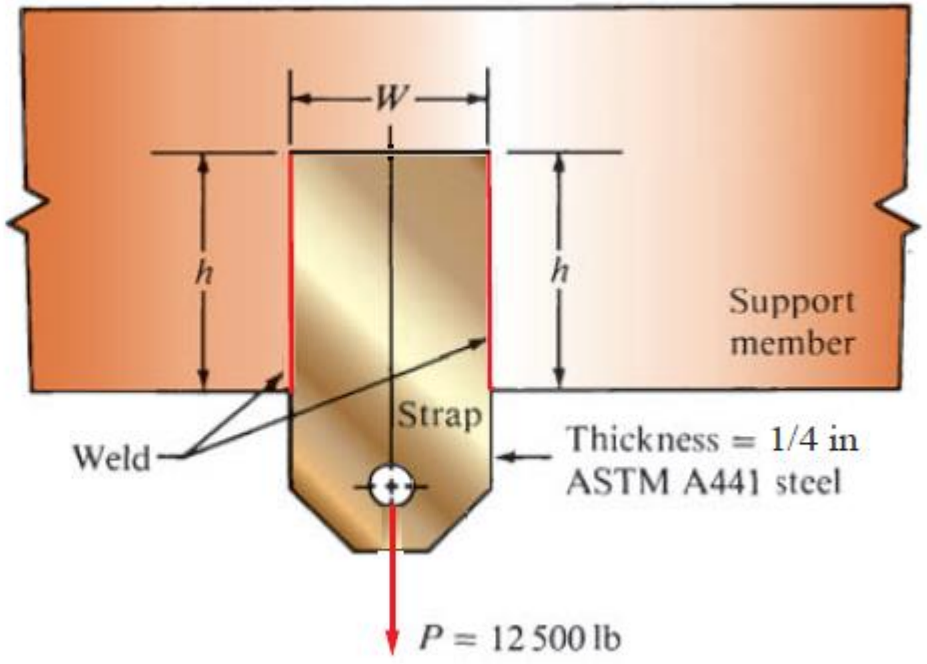
The table shows that the minimum size weld for a 1/2-in plate is 3/16 in (0.188 in).

Minimum Weld Sizes for Thick Plates

Plate thickness (in)	Minimum leg size for fillet weld (in)
$\leq 1/2$	3/16
$>1/2$–3/4	1/4
$>3/4$–$1\frac{1}{2}$	5/16
$>1\frac{1}{2}$–$2\frac{1}{4}$	3/8
$>2\frac{1}{4}$–6	1/2
>6	5/8

Examples

A steel strap, 1/4 in thick, is to be welded to a rigid frame to carry a dead load of 12 500 lb, as shown. Design the strap and its weld.



The basic objectives of the design are to specify a suitable material for the strap, the welding electrode, the size of the weld, and the dimensions *W* and *h,* as shown.

Note that the welds are only on the vertical sides of the strap.

Let's specify that the strap is to be made from ASTM A441 structural steel and that it is to be welded with an E70 electrode, using the minimum size weld, 3/16 in.

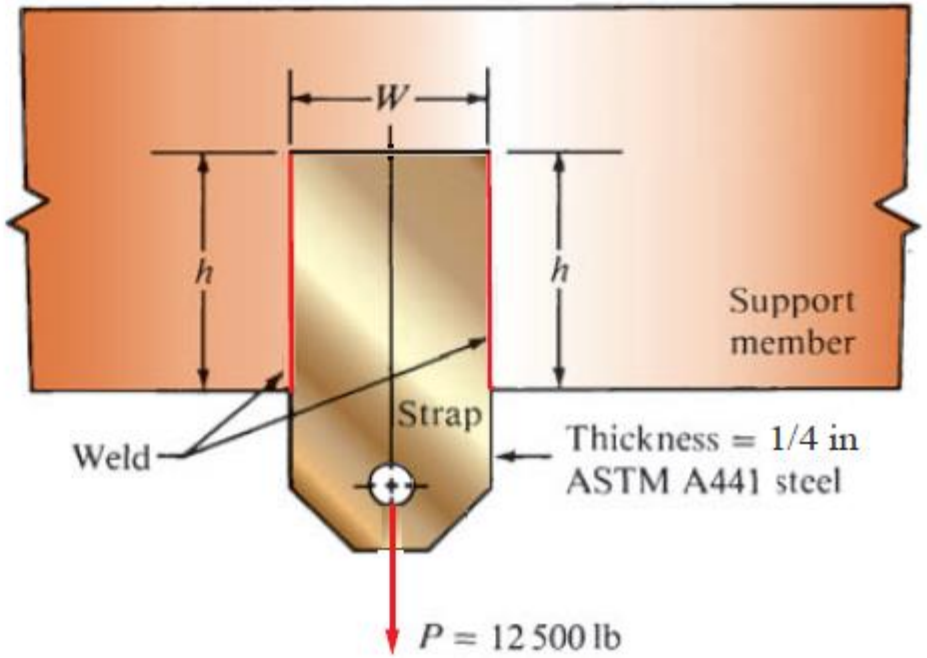
The yield strength of the A441 steel as 42 000 psi. Using a design factor of 2, we can compute an allowable stress of:

$$\sigma_a = 42\,000/2 = 21\,000 \text{ psi}$$

Examples

Then the required area of the strap is:

$$A = \frac{P}{\sigma_a} = \frac{12\ 500\ \text{lb}}{21\ 000\ \text{lb/in}^2} = 0.595\ \text{in}^2$$



But the area is $W * t$, where $t = 0.25$ in. Then the required width W is:

$$W = A/t = 0.595\ \text{in}^2/0.25\ \text{in} = 2.38\ \text{in}$$

Let's specify that $W = 2.50$ in

To compute the required length of the weld *h,* we need the allowable force on the 3/16-in weld. The allowable force on the A441 steel welded with an E70 electrode to be 11 200 lb/in per inch of leg size (from the table). Then:

$$f_a = \frac{11\ 200\ \text{lb/in}}{1.0\text{-in leg}} \times 0.188\text{-in leg} = 2100\ \text{lb/in}$$

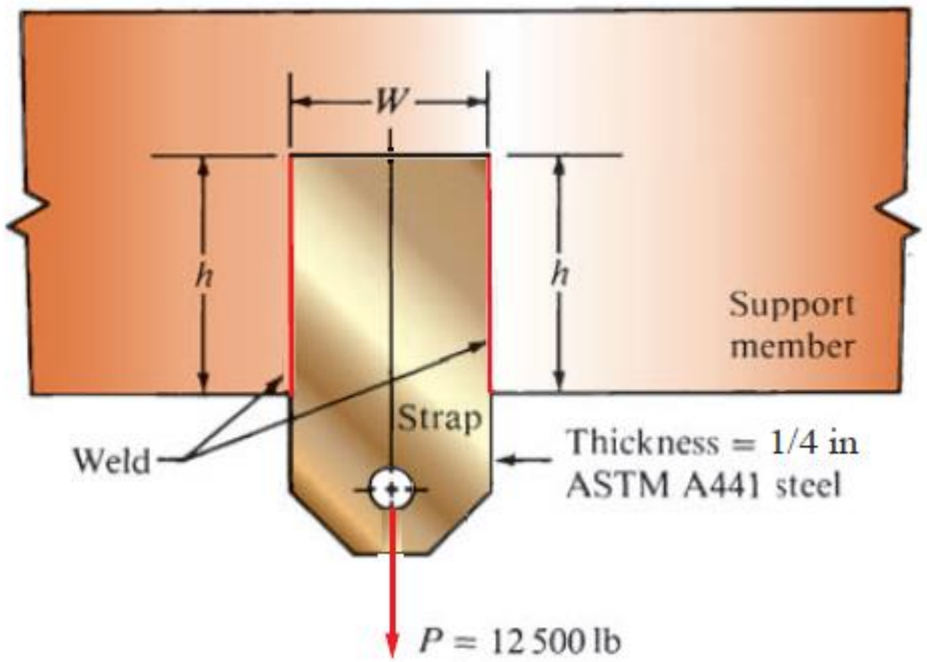
The actual force on the weld is: $f_a = P/A_w = P/2h$

Examples

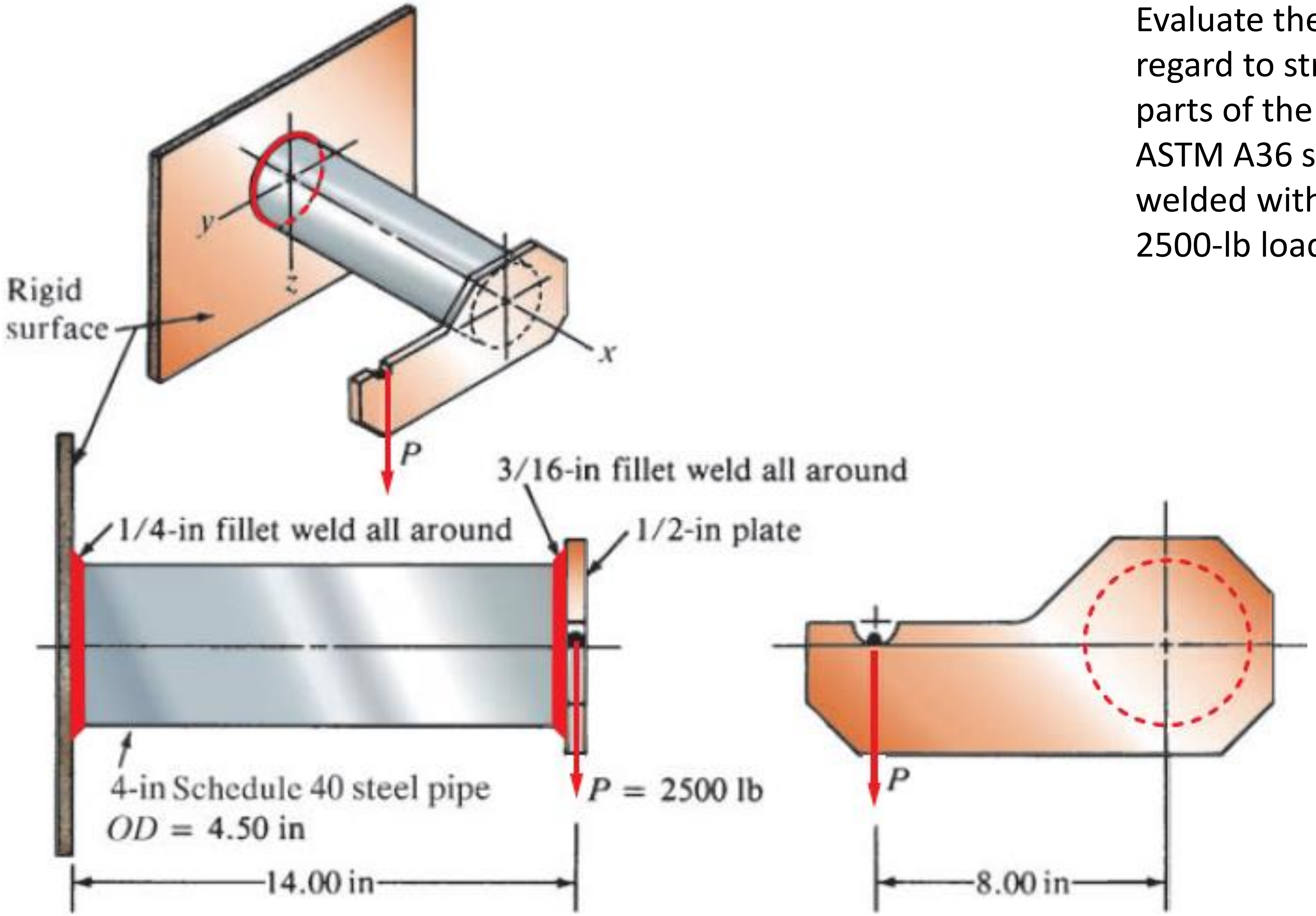
Then solving for *h* gives:

$$h = \frac{P}{2(f_a)} = \frac{12\,500\text{ lb}}{2(2100\text{ lb/in})} = 2.98\text{ in}$$

Let's specify h = 3.00 in.

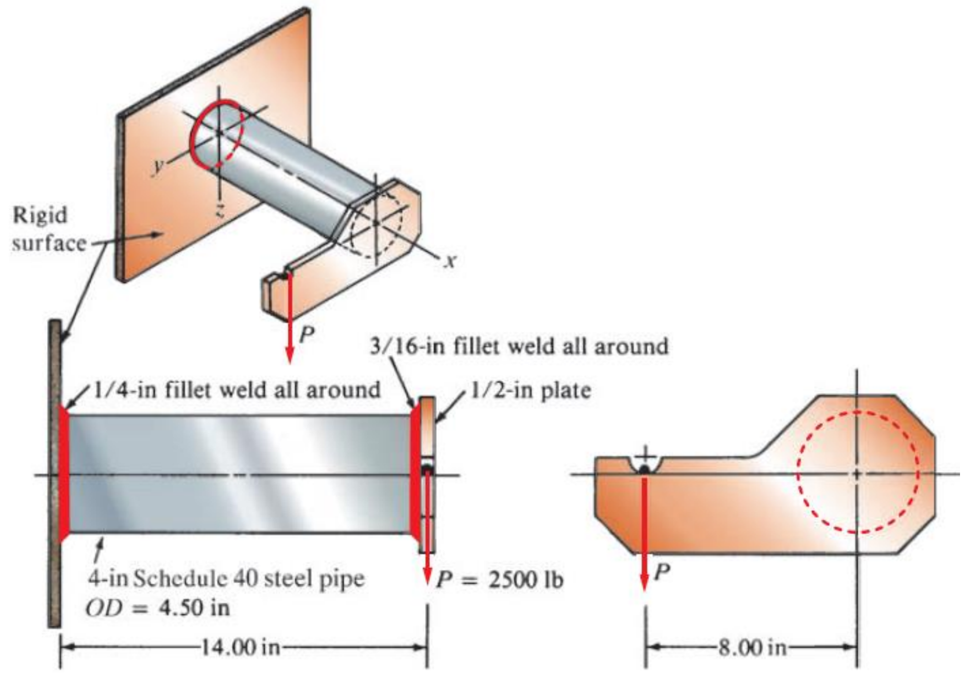


Examples



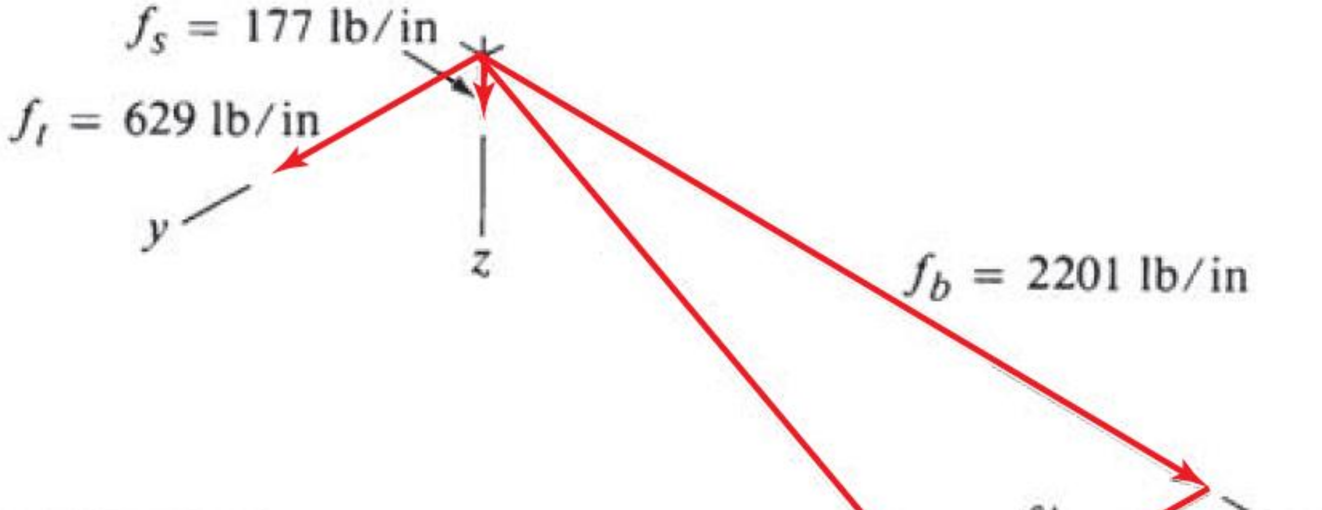
Evaluate the design shown with regard to stress in the welds. All parts of the assembly are made of ASTM A36 structural steel and are welded with an E60 electrode. The 2500-lb load is a dead load.

Examples



The critical point would be the weld at the top of the tube where it is joined to the vertical surface.

At this point, there is a three-dimensional force system acting on the weld, as shown.

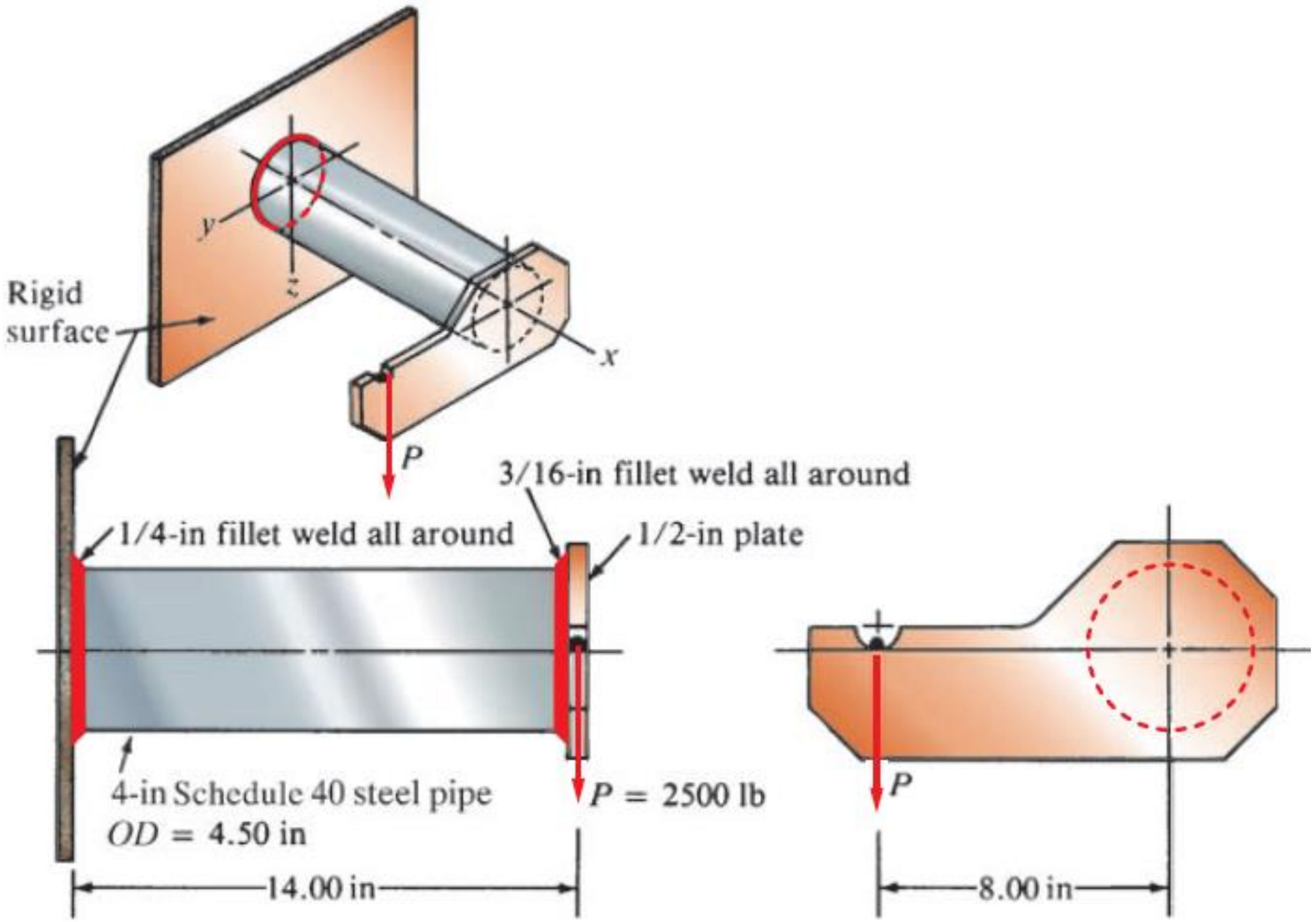


Vector summation:

$$f_R = f_b + f_t + f_s$$

$$|f_R| = \sqrt{f_b^2 + f_t^2 + f_s^2}$$

Examples



The offset location of the load causes a twisting on the weld that produces a force *ft* on the weld toward the left in the *y*-direction. The bending produces a force *fb* acting outward along the *x*-axis.

The vertical shear force *fs* acts downward along the *z*-axis.

From statics, the resultant of the three force components would be

$$f_R = \sqrt{f_t^2 + f_b^2 + f_s^2}$$

Examples

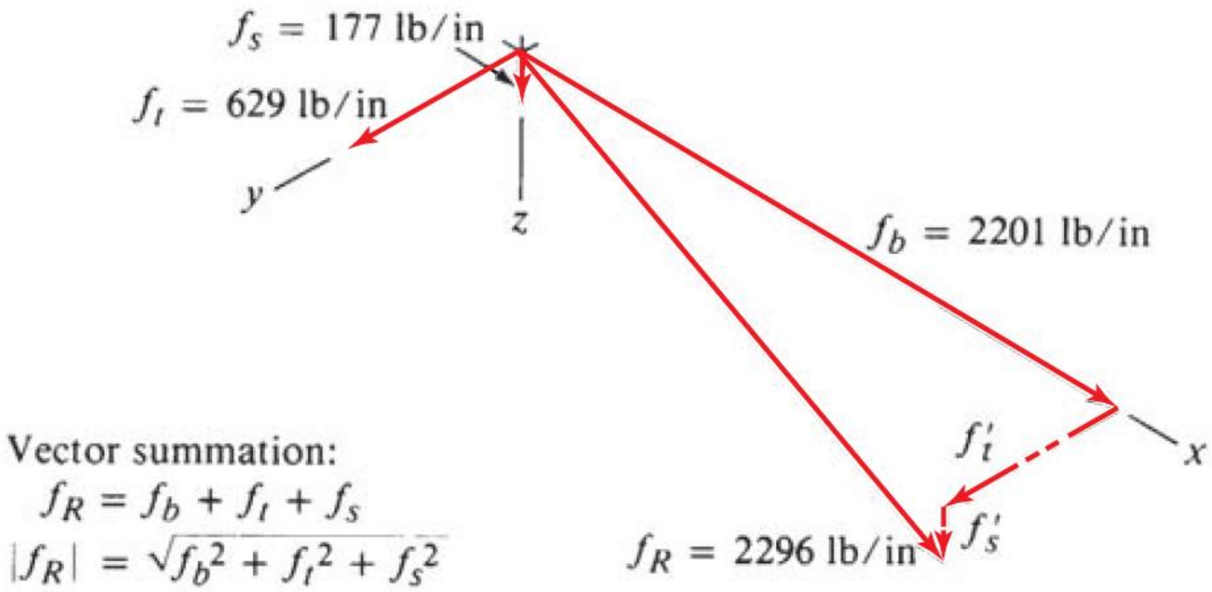
Now each component force on the weld will be computed.
Twisting Force, *ft*

$$f_t = \frac{Tc}{J_w}$$

$$T = (2500 \text{ lb})(8.00 \text{ in}) = 20\,000 \text{ lb} \cdot \text{in}$$

$$c = OD/2 = 4.500 \text{ in}/2 = 2.25 \text{ in}$$

$$J_w = (\pi)(OD)^3/4 = (\pi)(4.500 \text{ in})^3/4 = 71.57 \text{ in}^3$$



Then:

$$f_t = \frac{Tc}{J_w} = \frac{(20\,000 \text{ lb} \cdot \text{in})(2.25 \text{ in})}{71.57 \text{ in}^3} = 629 \text{ lb/in}$$

Examples

Now each component force on the weld will be computed.
Bending Force, *fb*

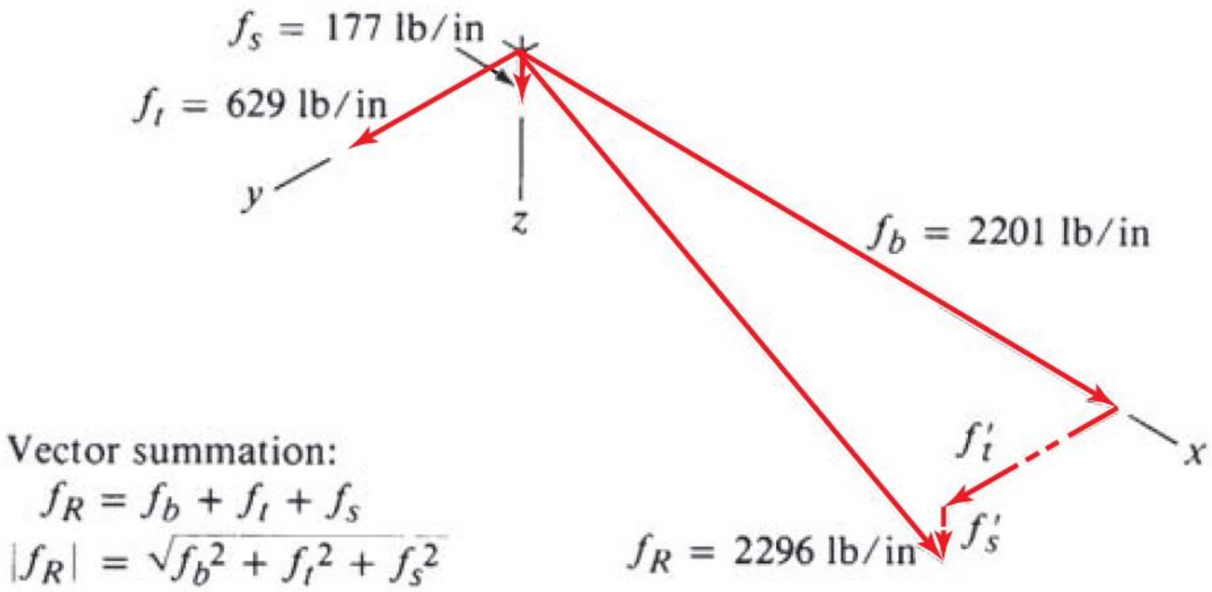
$$f_b = \frac{M}{S_w}$$

$$M = (2500 \text{ lb})(14.00 \text{ in}) = 35\,000 \text{ lb} \cdot \text{in}$$

$$S_w = (\pi)(OD)^2/4 = (\pi)(4.500 \text{ in})^2/4 = 15.90 \text{ in}^2$$

Then:

$$f_b = \frac{M}{S_w} = \frac{35\,000 \text{ lb} \cdot \text{in}}{15.90 \text{ in}^2} = 2201 \text{ lb/in}$$



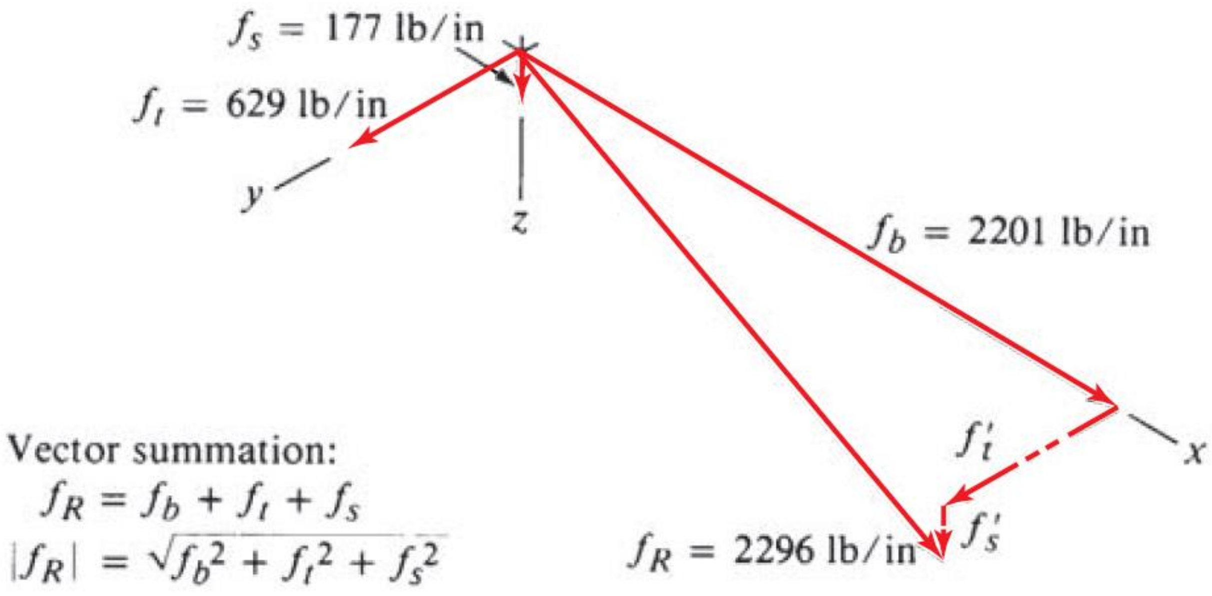
Examples

Now each component force on the weld will be computed.
Vertical Shear Force, *fs*

$$f_s = \frac{P}{A_w}$$

$$A_w = (\pi)(OD) = (\pi)(4.500\ \text{in}) = 14.14\ \text{in}$$

$$f_s = \frac{P}{A_w} = \frac{2500\ \text{lb}}{14.14\ \text{in}} = 177\ \text{lb/in}$$



Now the resultant can be computed:

$$f_R = \sqrt{f_t^{\,2} + f_b^{\,2} + f_s^{\,2}}$$

$$f_R = \sqrt{629^2 + 2201^2 + 177^2} = 2296\ \text{lb/in}$$

Comparing this with the allowable force on a 1.0-in weld gives minimum size for the weld leg to be:

$$w = \frac{2296\ \text{lb/in}}{9600\ \text{lb/in per inch of leg size}} = 0.239\ \text{in}$$

Examples

The 1/4-in fillet specified in is satisfactory.