Lecture # 13-15

Welded Joints - Direct Loading

Welded Joints - Direct Loading

1. Welded Joints and their advantages:

Welding is a very commonly used permanent joining process. It can be defined as a process of joining metallic parts by heating to a suitable temperature with or without the application of pressure.

A welded joint has following advantages:

(i) Compared to other type of joints, the welded joint has higher efficiency. An efficiency > 95 % is easily possible.

(ii) Since the added material is minimum, the joint has lighter weight.

(iii) Welded Joints have smooth appearances.

(iv) Due to flexibility in the welding procedure, alteration and addition are possible.

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1. Welded Joints and their advantages:

(v) It is less expensive.

(vi) Forming a joint in difficult locations is possible through welding.

The advantages have made welding suitable for joining components in various machines and structures.

Some typically welded machine components are listed below.

Pressure vessels, steel structures,

Flanges welded to shafts and axles, Crank shafts,

Heavy hydraulic turbine shafts, Large gears, pulleys, flywheels, Gear housing, Machine frames and bases Housing and mill-stands.

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2. Basic types of welding processes:

Welding can be broadly classified in two groups

i) Liquid state (fusion) welding where heat is added to the base metals until they melt.

Added metal (filler material) may also be supplied.

Upon cooling strong joint is formed.

Depending upon the method of heat addition this process can be further subdivided, namely

Electrical heating: Arc welding, Resistance welding, Induction welding and Chemical welding: Gas welding, Thermit welding, Laser welding, Electron beam welding

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ii) Solid state welding:

Here mechanical force is applied until materials deform to plastic state.

Bonds are then formed through molecular interaction.

Solid state welding may be of various kinds, namely,

Cold welding

Diffusion welding

Hot forging

we can refer detailed descriptions of the individual welding processes in any standard textbook on welding.

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3. Strength of Welded Joints:

Adequate care must be taken to enhance strength of the welded joint.

It is seen that strength of a welded joint gets affected mainly by the following factors.

(i) Crack initiation: it is possible that cracks form while cooling a melted metal.

(ii) Residual stresses: due to inhomogeneous heating of the base metals, residual stresses may exist upon cooling.

(iii) Metallurgical transformation: in heat affected zone (HAZ) metallurgical properties may change leading to weakening of the joint.

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3. Strength of Welded Joints:

(iv) Defects: of various kinds like incomplete penetration, porosity, slag inclusion which affect the strength of a welded joint.

(v) Stress concentration: abrupt change in the geometry after welding may introduce stress concentration in the structure.

4. Types of Welded Joints:

Welded Joints - Direct Loading are primarily of two kinds

(a) Lap or fillet joint: obtained by overlapping the plates and welding their edges.

The fillet joints may be single transverse fillet, double transverse fillet or parallel fillet joints

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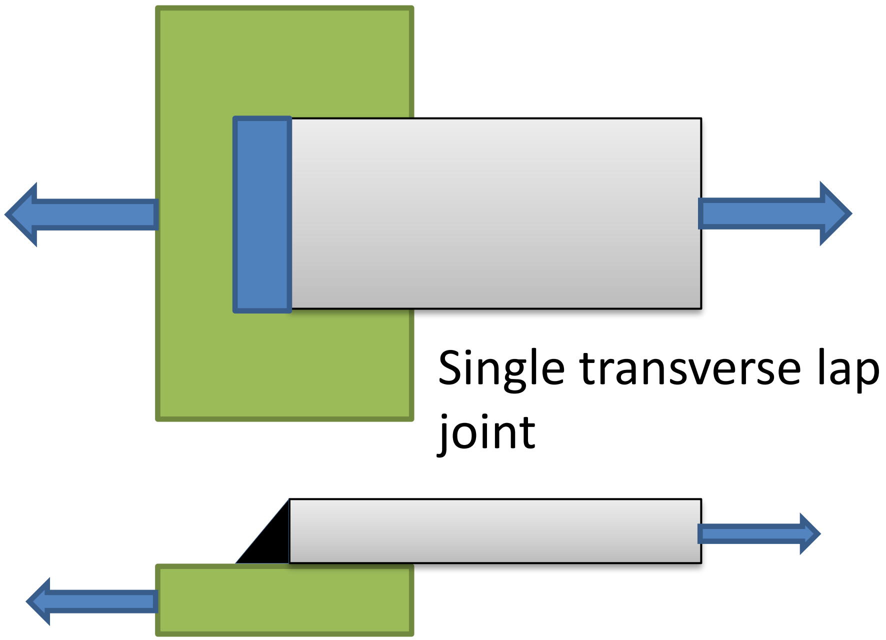
4. Types of Welded Joints:

(a) Lap or fillet joint: obtained by overlapping the plates and welding their edges.

The fillet joints may be single transverse fillet,



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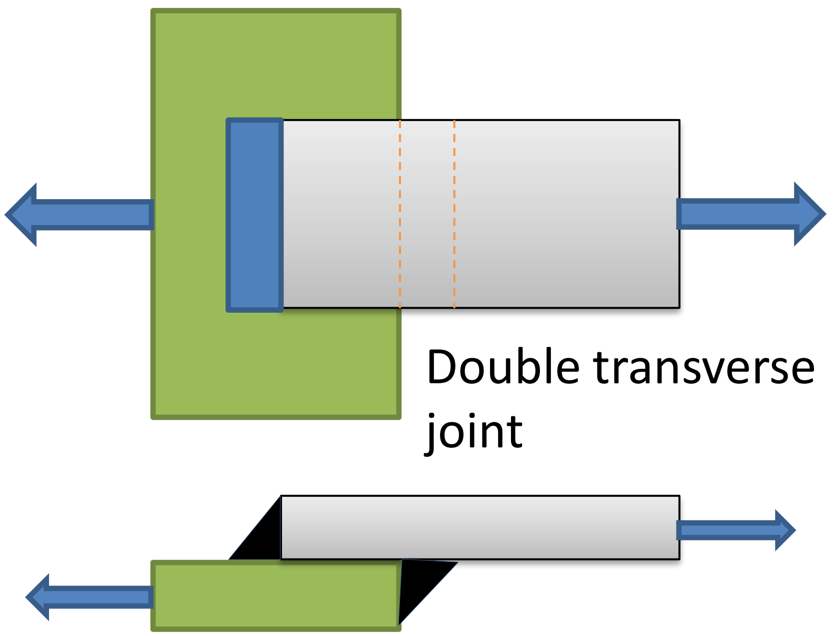
4. Types of Welded Joints:

(a) Lap or fillet joint: obtained by overlapping the plates and welding their edges.

The fillet joints may be double transverse fillet or



Double transverse lap joint

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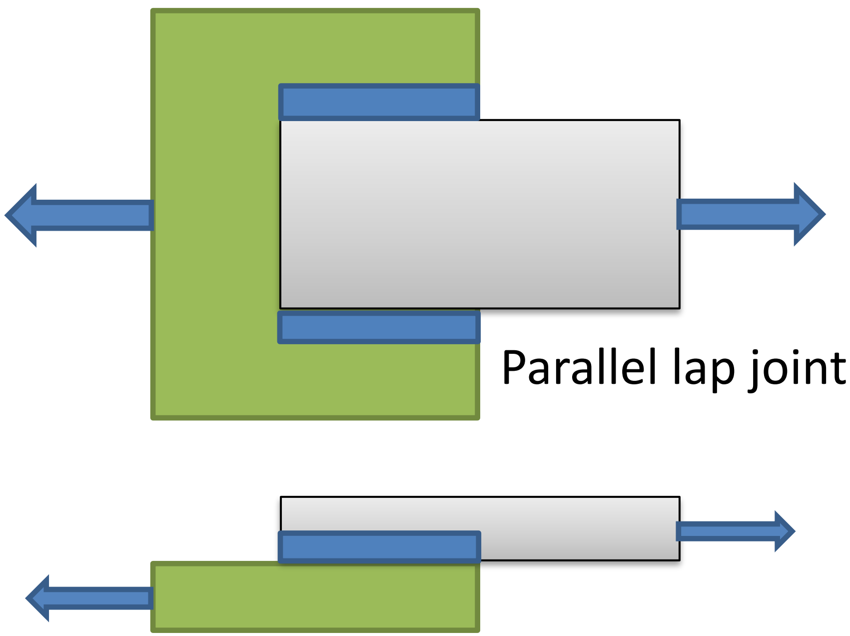
4. Types of Welded Joints:

(a) Lap or fillet joint: obtained by overlapping the plates and welding their edges.

The fillet joints may be parallel fillet joints,



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4. Types of Welded Joints:

(b) Butt joints: formed by placing the plates edge to edge and welding them.

Grooves are sometimes cut (for thick plates) on the edges before welding.

According to the shape of the grooves, the butt joints may be of different types, e.g.,

Square butt joint

Single V-butt joint, double V-butt joint

Single U-butt joint, double U-butt joint

Single J-butt joint, double J-butt joint

Single bevel-butt joint, double bevel butt joint

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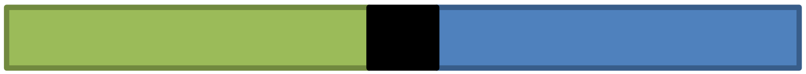
4. Types of Welded Joints:

(b) Butt joints:



Square butt joint

Single V butt joint

Double V butt joint

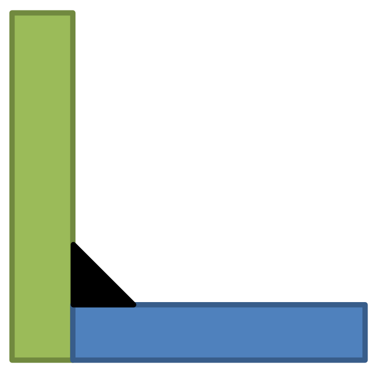
There are other types of Welded Joints - Direct Loading

for example,

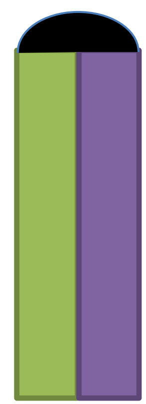
Corner joint

Edge or seal joint

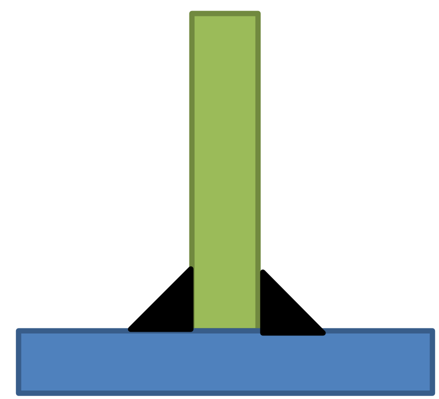
T-joint



Corner Joint



Edge Joint



T - Joint

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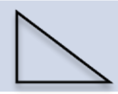
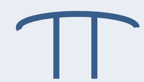
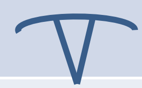
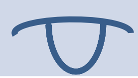
4. Types of Welded Joints:

Each type of joint has its own symbol.

The basic weld symbols are shown in Table 1

S. No.	Type of weld	Welding Symbol
1	Fillet Joint	
2	Square Butt Joint	
3	Single V- butt joint	
4	Double V- butt joint	
5	Single U – butt joint	
6	Single bevel butt joint	

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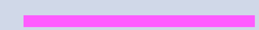
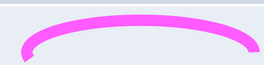
4. Types of Welded Joints: After welding is done the surface is properly finished. The contour of the welded joint may be flush, concave or convex and the surface finish may be grinding finish, machining finish or chipping finish.

The symbols of the contour and the surface finish are shown in Table below

S. No.	Particular	Weld Symbol
1	Flush contour	
2	Convex contour	
3	Concave contour	
4	Grinding finish	G
5	Machining finish	M
6	Chipping finish	C

Welded Joints - Direct Loading

5. Welding symbol:

A welding symbol has following basic elements:

1. Reference line
2. Arrow
3. Basic weld symbols (like fillet, butt joints etc.)
4. Dimensions
5. Supplementary symbols
6. Finish symbols
7. Tail
8. Specification processes.

These welding symbols are placed in standard locations as shown in next slide.

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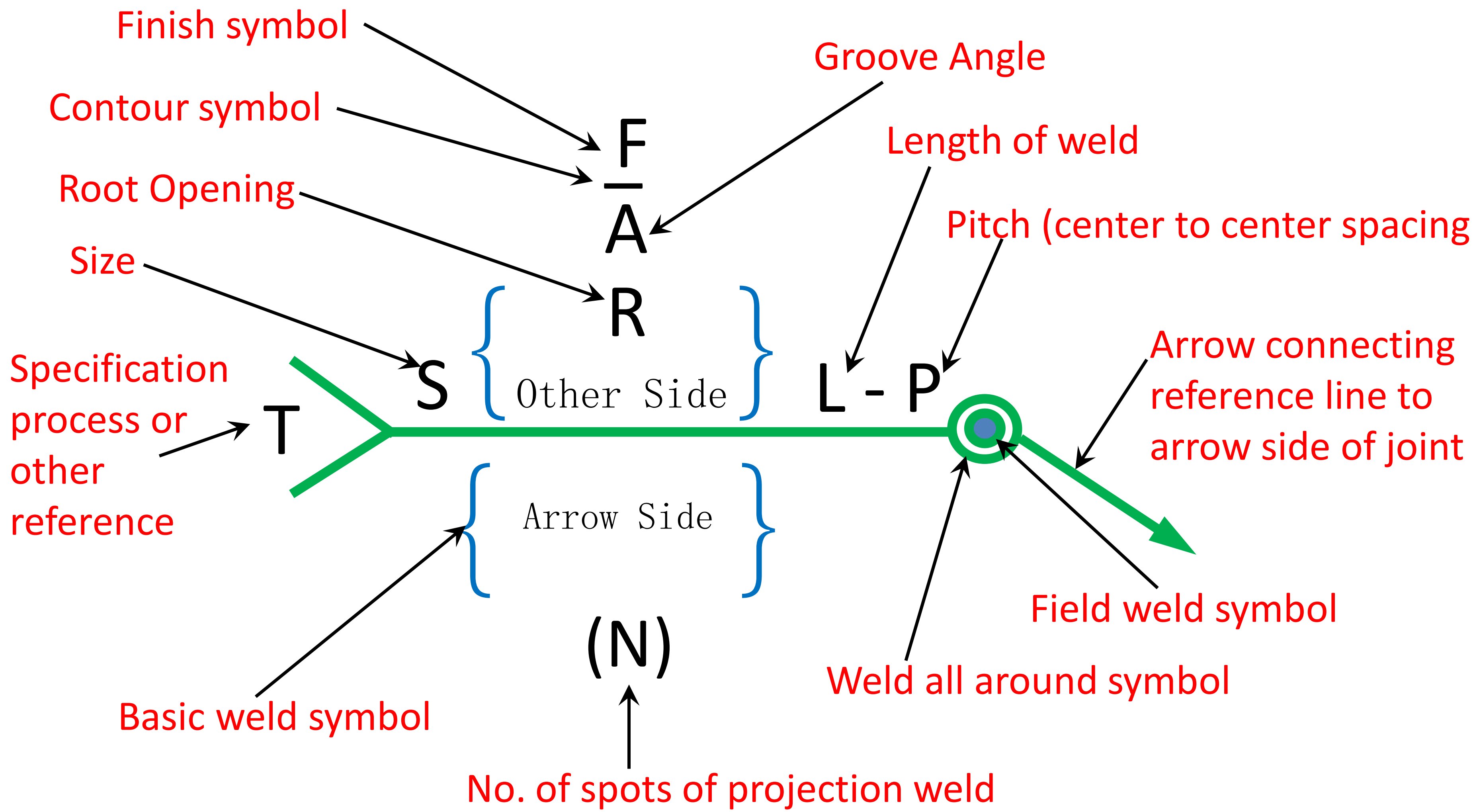

Welding symbols placement in standard locations.

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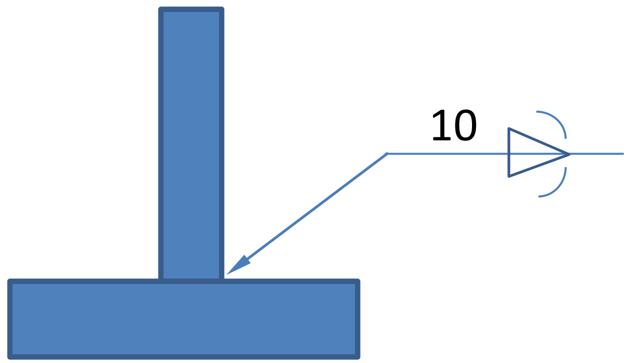
Example - If the desired weld is a fillet weld of size 10 mm to be done on each side of Tee joint with convex contour, the weld symbol will be as following.



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1. Strength of Butt Welded Joints

In case of butt joint, the length of leg or size of weld is equal to the throat thickness which is equal to thickness of plates.

∴ Tensile strength of the butt joint

(single-V or square butt joint), $P = t \times l \times \sigma_t$

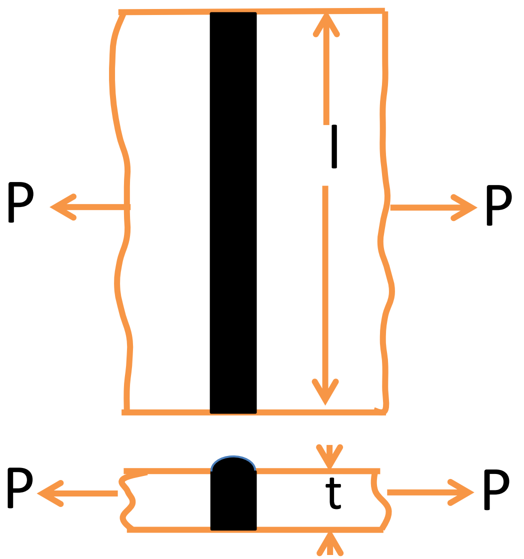
where l = Length of weld (mm)

t = thickness of weld plate (mm)

P = Tensile force on plates (N)

σ_t = Tensile stress in the plate (N/mm^2)

It is generally equal to the width of plate



Welded Joints - Direct Loading

1. Strength of Butt Welded Joints

and tensile strength for double-V butt joint is given by

$P = (t_1 + t_2)\, l \times \sigma_t$

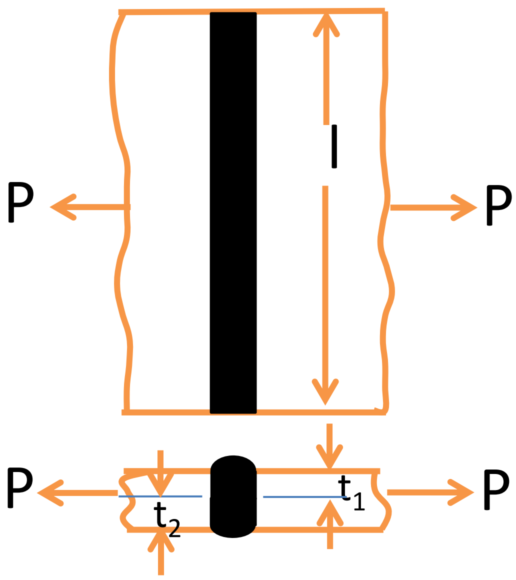
where t_1 = Throat thickness at the top, and

t_2 = Throat thickness at the bottom

l = Length of weld (mm)

P = Tensile force on plates (N)

σ_t = Tensile stress in the plate (N/mm^2)

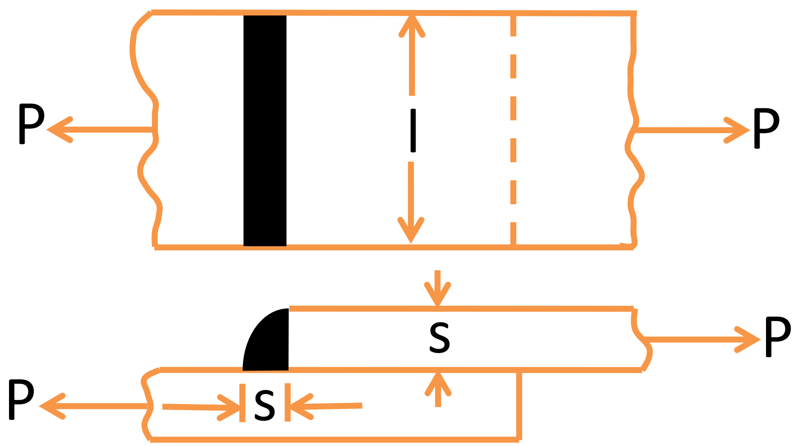


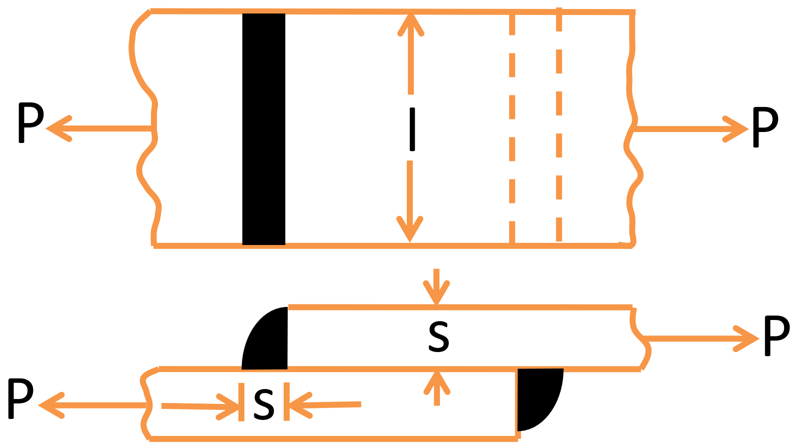
Welded Joints - Direct Loading

2. Strength of Transverse Fillet Welded Joints

The transverse fillet welds are designed for tensile strength.

Let us consider a single and a double transverse fillet weld as shown in figure.



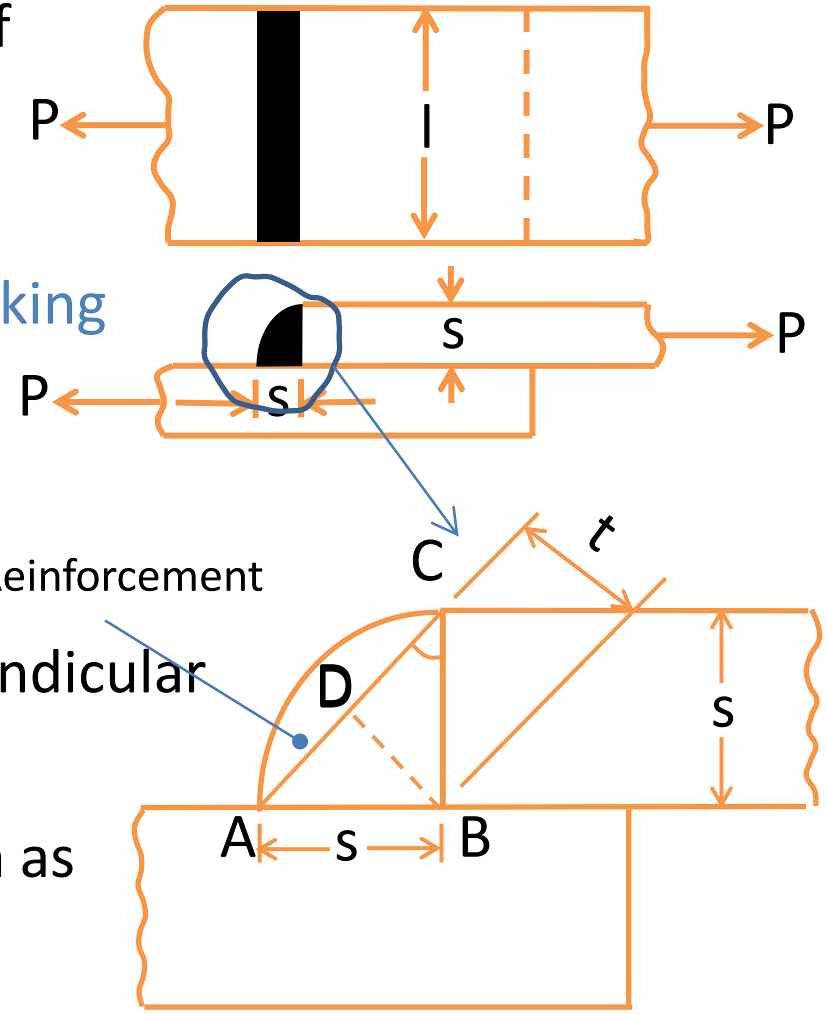


Welded Joints - Direct Loading

2. Strength of Transverse Fillet Welded Joints

In order to determine the strength of the fillet joint, it is assumed that the section of fillet is a right angled triangle ABC with hypotenuse AC making equal angles with other two sides AB and BC.

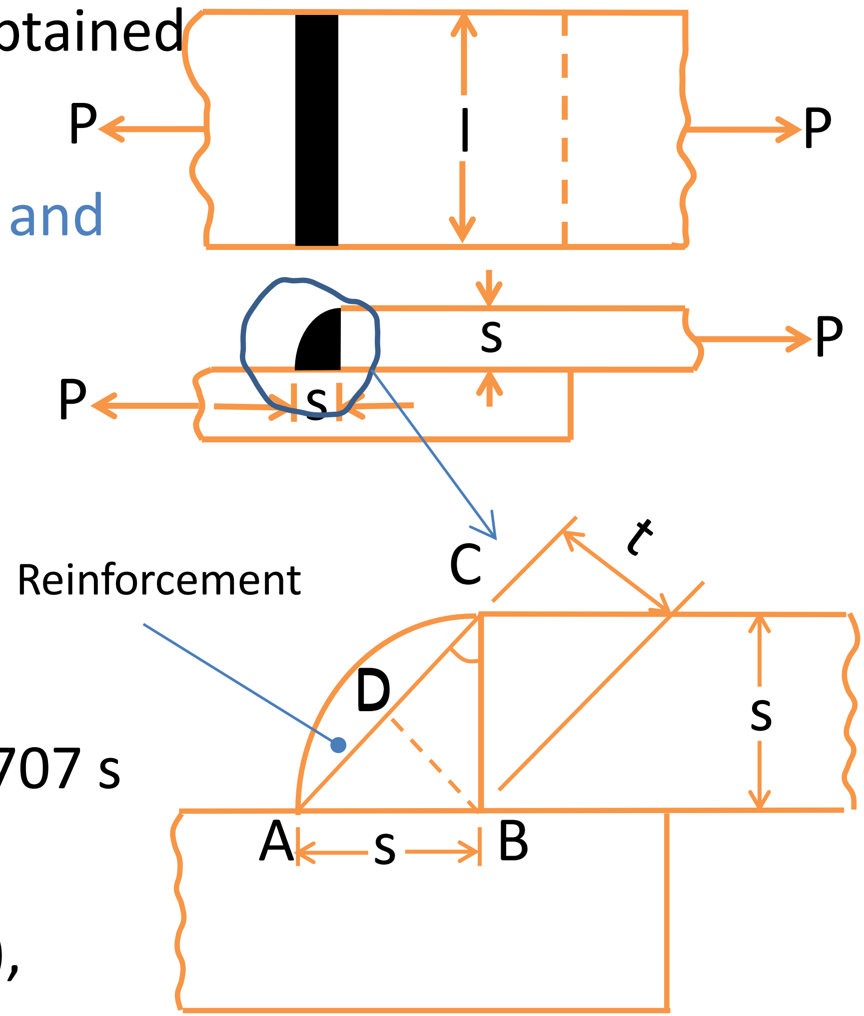
The length of each side is known as leg or size of the weld and the perpendicular distance of the hypotenuse from the intersection of legs (i.e. BD) is known as throat thickness.



Welded Joints - Direct Loading

2. Strength of Transverse Fillet Welded Joints

The minimum area of the weld is obtained at the throat BD, which is given by the product of the throat thickness and length of weld.



Let t = Throat thickness (BD),

s = Leg or size of weld,

t= Thickness of plate, and

l = Length of weld, we find that the throat thickness, $t = s \times \sin 45° = 0.707\, s$

∴ Minimum area of the weld or throat area (maximum stress place),

Welded Joints - Direct Loading

2. Strength of Transverse Fillet Welded Joints

A = Throat thickness × Length of weld

$= t \times l = 0.707\ s \times l$

If σ_t is the allowable tensile stress for the weld metal, then the tensile strength of the joint for single fillet weld,

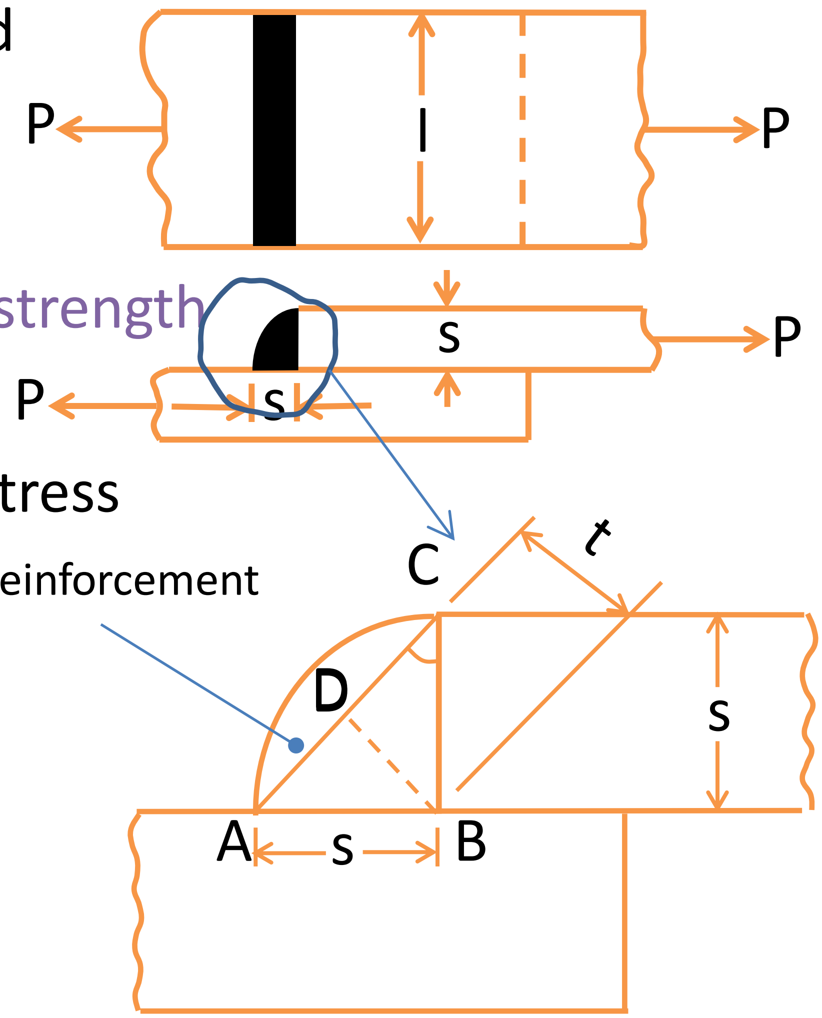
P = Throat area × Allowable tensile stress

$= 0.707\ s \times l \times \sigma_t$

and tensile strength of the joint for double fillet weld,

$P = 2 \times 0.707\ s \times l \times \sigma_t$

$= 1.414\ s \times l \times \sigma_t$

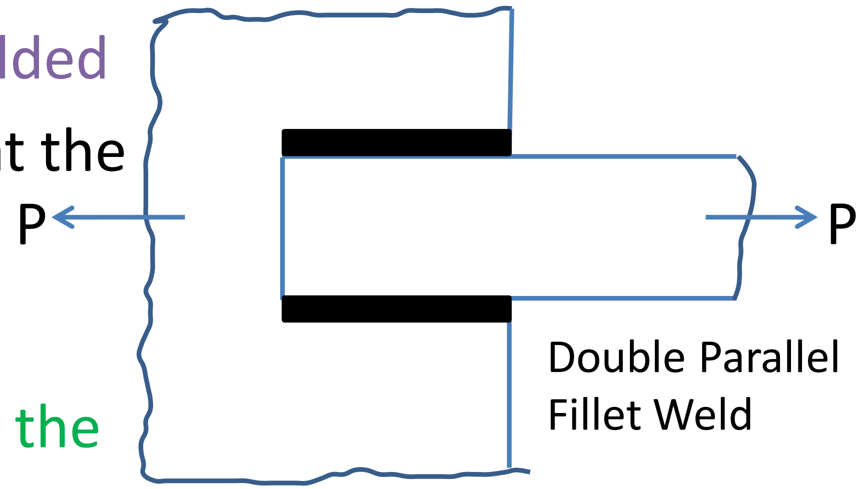


Welded Joints - Direct Loading

3. Strength of Parallel Fillet Welded Joints

The parallel fillet welded joints are designed for shear strength.

Consider a double parallel fillet welded joint as shown in Fig. We know, that the minimum area of weld or the throat area, $A = 0.707 \, s \times l$



If τ is the allowable shear stress for the weld metal, then

the shear strength of the joint for single parallel fillet weld,

P = Throat area × Allowable shear stress = $0.707 \, s \times l \times \tau$

and shear strength of the joint for double parallel fillet weld,

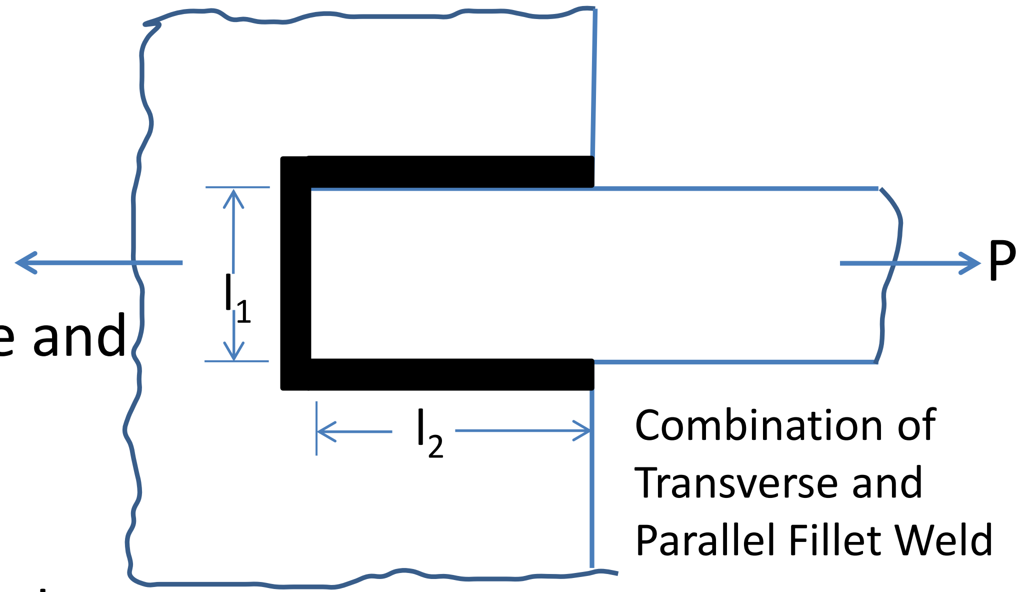
$P = 2 \times 0.707 \times s \times l \times \tau = 1.414 \, s \times l \times \tau$

Welded Joints - Direct Loading

4. Strength of Parallel and Transverse Fillet Welded Joints

If there is a combination of single transverse and double parallel fillet welds,

then the strength of the joint is given by the sum of strengths of single transverse and double parallel fillet welds.



Combination of Transverse and Parallel Fillet Weld

Mathematically,

$$P = 0.707s \times l_1 \times \sigma_t + 1.414\, s \times l_2 \times \tau$$

where l_1 is normally the width of the plate.

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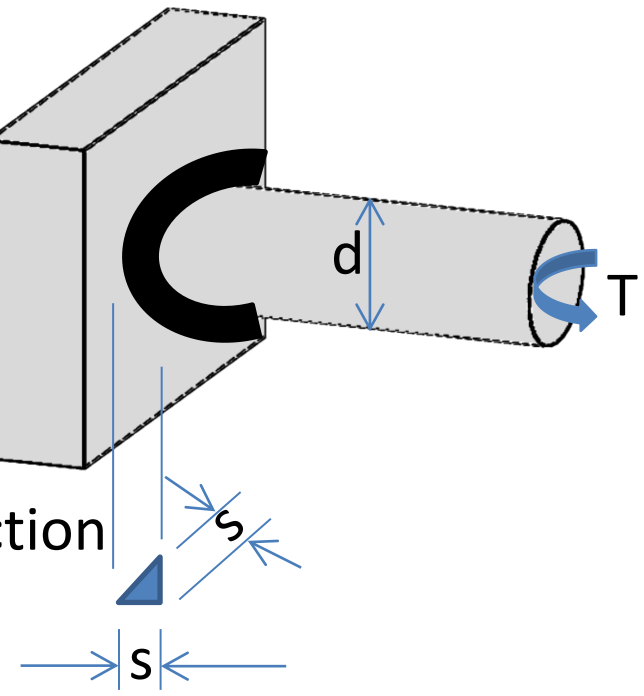
Example 1.

A plate 100 mm wide and 10 mm thick is to be welded to another plate by means of double parallel fillets. The plates are subjected to a static load of 80 kN. Find the length of weld if the permissible shear stress in the weld does not exceed 55 MPa.

Welded Joints - Direct Loading

5. Circular fillet weld subjected to torsion.

Consider a circular rod connected to a rigid plate by a fillet weld as shown in Fig.



Let d = Diameter of rod,

r = Radius of rod,

T = Torque acting on the rod,

s = Size (or leg) of weld,

t = Throat thickness,

J = Polar moment of inertia of the weld section

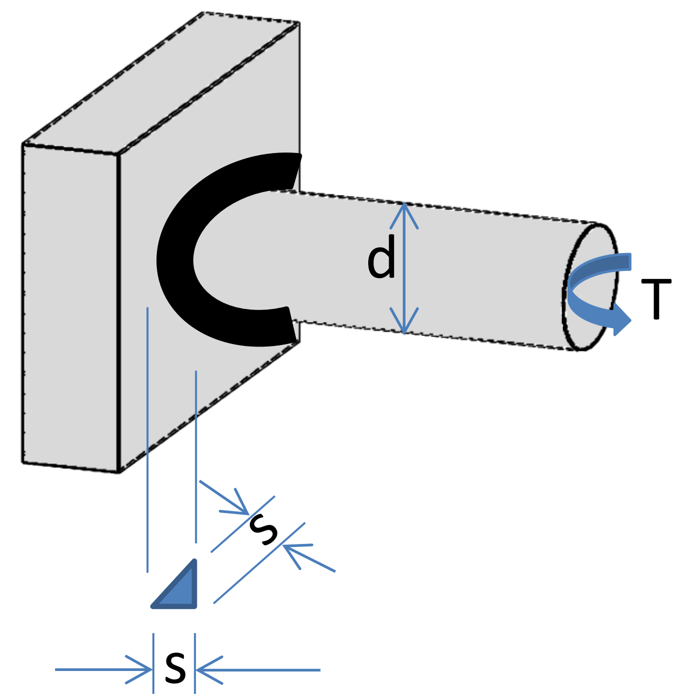
$$J = \frac{\pi t d^3}{4}$$

Welded Joints - Direct Loading

5. Circular fillet weld subjected to torsion.

We know that the shear stress for the material is given by

$$\tau = \frac{T\,r}{J} = \frac{T \times (d/2)}{J} = \frac{T \times (d/2)}{\pi t d^3/4} = \frac{2T}{\pi t d^2}$$



This shear stress occurs in a horizontal plane along a leg of the fillet weld.

The maximum shear occurs on the throat of weld which is inclined at 45° to the horizontal plane.

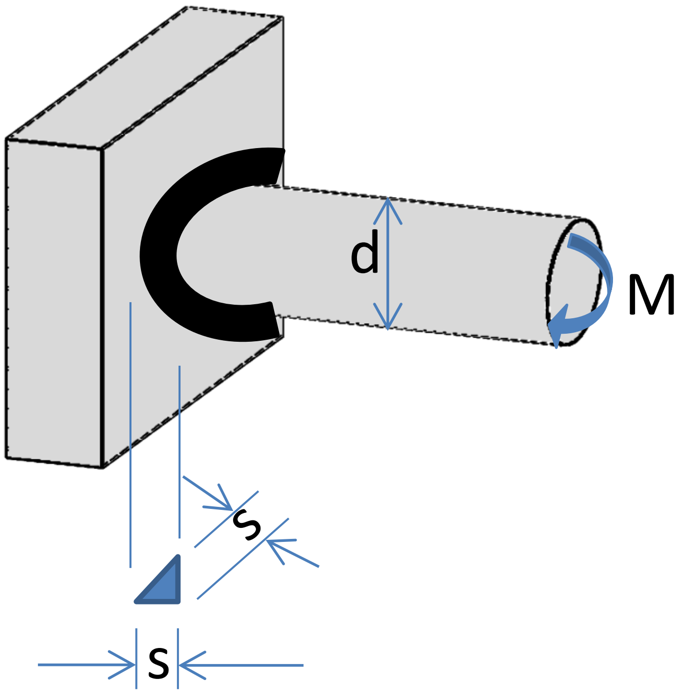
∴ Length of throat, t = s sin 45° = 0.707 s

and maximum shear stress, $$\tau_{max} = \frac{2T}{\pi \times 0.707 s \times d^2} = \frac{2.83T}{\pi\, s\, d^2}$$

Welded Joints - Direct Loading

6. Circular fillet weld subjected to bending moment.

Consider a circular rod connected to a rigid plate by a fillet weld as shown in Fig.



Let d = Diameter of rod,

M = Bending moment acting on the rod,

s = Size (or leg) of weld,

t = Throat thickness,

Z = Section modulus of the weld section

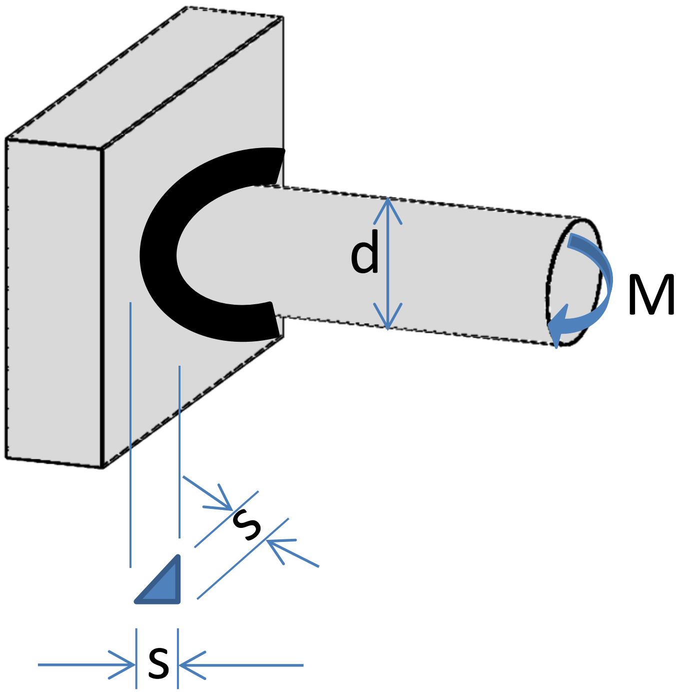
$$= \frac{\pi t d^2}{4}$$

Welded Joints - Direct Loading

6. Circular fillet weld subjected to bending moment.

We know that the bending stress for the material is given by

$$\sigma_b = \frac{M}{Z} = \frac{M}{\pi d^2/4} = \frac{4M}{\pi d^2}$$



This bending stress occurs in a horizontal plane along a leg of the fillet weld.

The maximum bending stress occurs on the throat of the weld which is inclined at 45° to the horizontal plane.

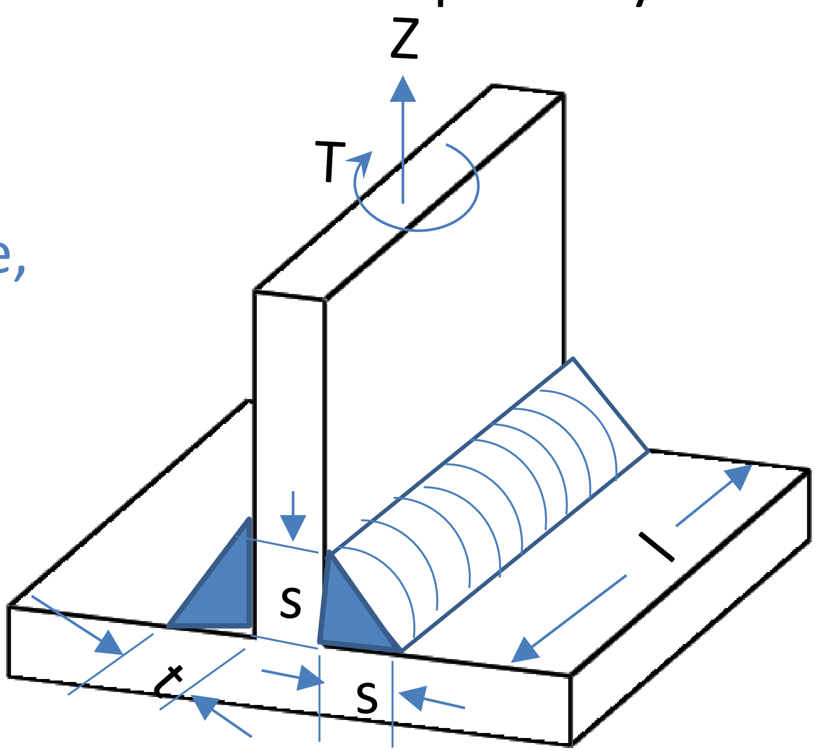
∴ Length of throat, $t = s \sin 45° = 0.707\, s$

and maximum bending stress, $$\sigma_{b(\max)} = \frac{4M}{\pi \times 0.707\, s \times d^2} = \frac{5.66\, M}{\pi\, s\, d^2}$$

Welded Joints - Direct Loading

7. Long fillet weld subjected to torsion.

Consider a vertical plate attached to a horizontal plate by two identical fillet welds as shown in Fig.



Let

T = Torque acting on the vertical plate,

l = Length of weld,

s = Size (or leg) of weld,

t = Throat thickness, and

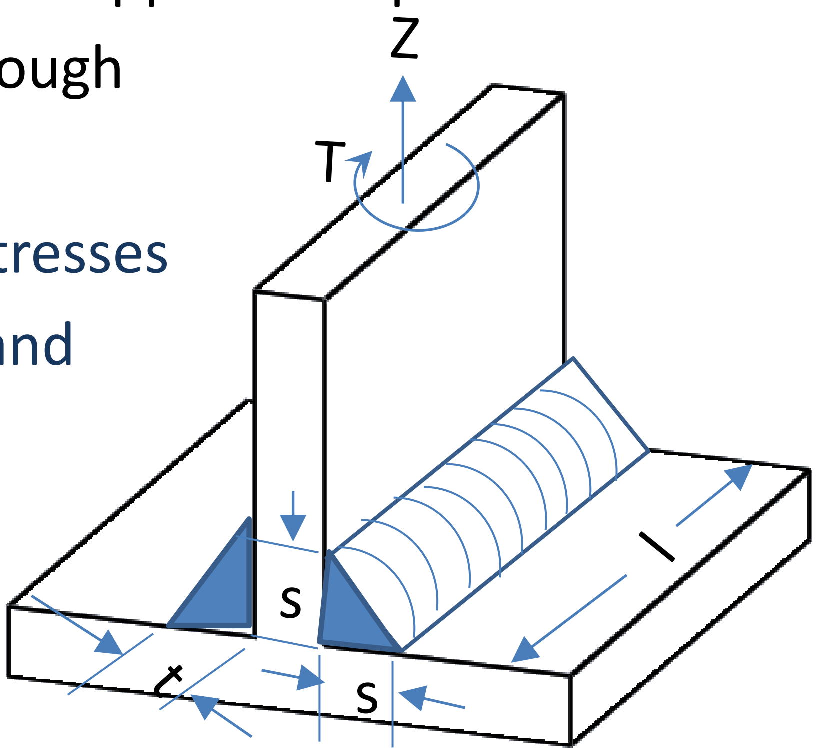
J = Polar moment of inertia of the weld section

$$J = 2 \times \frac{t \times l^3}{12} = \frac{t \times l^3}{6}$$

Welded Joints - Direct Loading

7. Long fillet weld subjected to torsion.

It may be noted that the effect of the applied torque is to rotate the vertical plate about the Z-axis through its mid point.



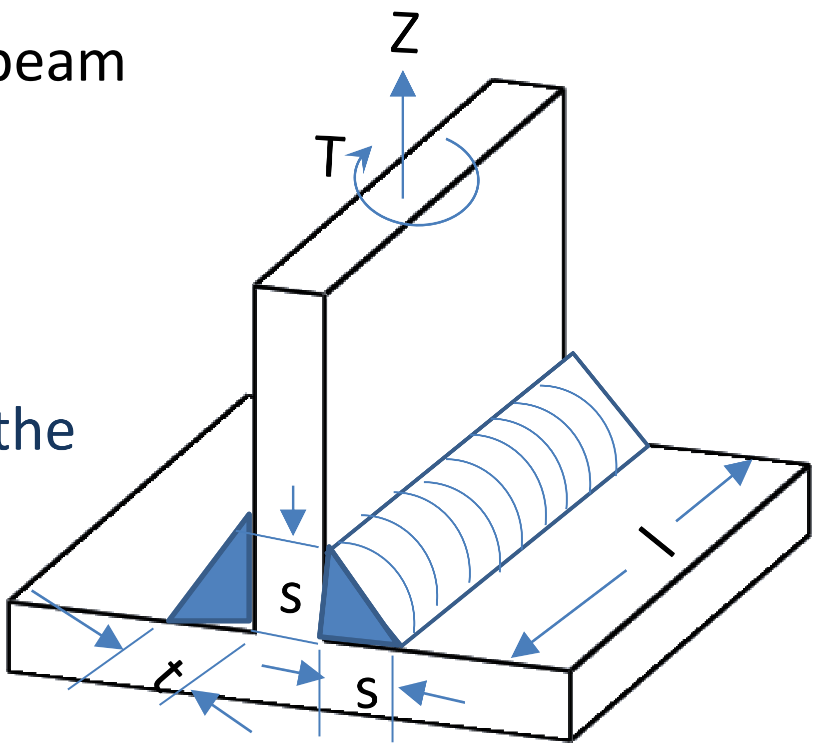
This rotation is resisted by shearing stresses developed between two fillet welds and the horizontal plate.

It is assumed that these horizontal shearing stresses vary from zero at the Z-axis and maximum at the ends of the plate.

Welded Joints - Direct Loading

7. Long fillet weld subjected to torsion.

This variation of shearing stress is analogous to the variation of normal stress over the depth (l) of a beam subjected to pure bending.



$$\therefore \text{Shear stress, } \tau = \frac{T \times (l/2)}{t \times l^3/6} = \frac{3T}{t \times l^2}$$

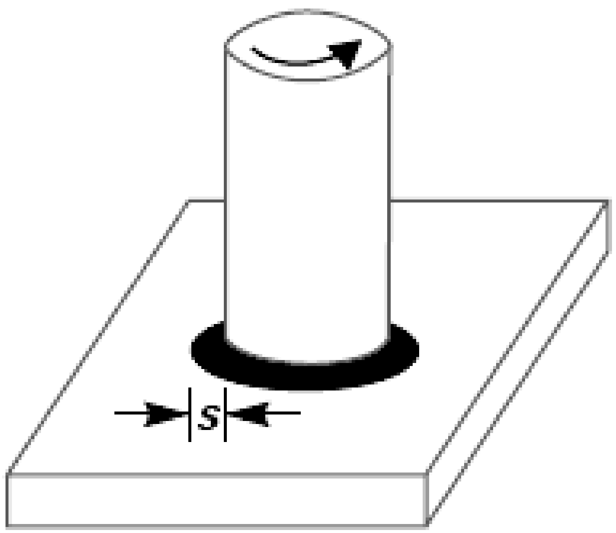
The maximum shear stress occurs at the throat and is given by

$$\tau_{\max} = \frac{3T}{0.707\ s \times l^2} = \frac{4.242\ T}{s \times l^2}$$

Welded Joints - Direct Loading

Example 2.

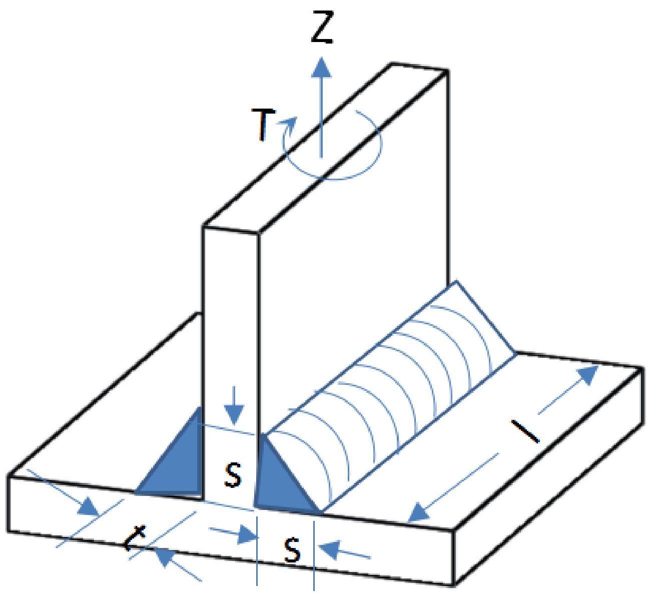
A 50 mm diameter solid shaft is welded to a flat plate by 10 mm fillet weld as shown in Fig. Find the maximum torque that the welded joint can sustain if the maximum shear stress intensity in the weld material is not to exceed 80 MPa.



Welded Joints - Direct Loading

Example 3.

A plate 1 m long, 60 mm thick is welded to another plate at right angles to each other by 15 mm fillet weld, as shown in Fig. Find the maximum torque that the welded joint can sustain if the permissible shear stress intensity in the weld material is not to exceed 80 MPa.



Welded Joints - Direct Loading

Stresses for Welded Joints

The stresses in Welded Joints are difficult to determine because of the variable and unpredictable parameters like

homogenuity of the weld metal,

thermal stresses in the welds,

changes of physical properties due to high rate of cooling etc.

The stresses are obtained, on the following assumptions:

1. The load is distributed uniformly along the entire length of the weld, and
2. The stress is spread uniformly over its effective section.

Welded Joints - Direct Loading

Stresses for Welded Joints

The following table shows the stresses for Welded Joints for joining ferrous metals with mild steel electrode under steady and fatigue or reversed load.

Type of weld	Bare electrod	Column1	Coated electrod	Column2
	Steady Load (Mpa)	Fatigue Load (Mpa)	Steady Load (Mpa)	Fatigue Load (Mpa)
1. Fillet Welds (All types)	80	21	98	35
2. Butt welds				
Tension	90	35	110	55
Compression	100	35	125	55
Shear	55	21	70	35

Welded Joints - Direct Loading

Stress Concentration Factor for Welded Joints

The reinforcement provided to the weld produces stress concentration at the junction of the weld and the parent metal.

When the parts are subjected to fatigue loading, the stress concentration factor should be taken into account.

Type of joint	Stress concentration factor
1. Reinforced butt welds	1.2
2. Toe of transverse fillet welds	1.5
3. End of parallel fillet weld	2.7
4. T - Butt joint with sharp corner	2
For static and any type of joint, stress concentration factor is 1.0	

Welded Joints - Direct Loading

Example 4.

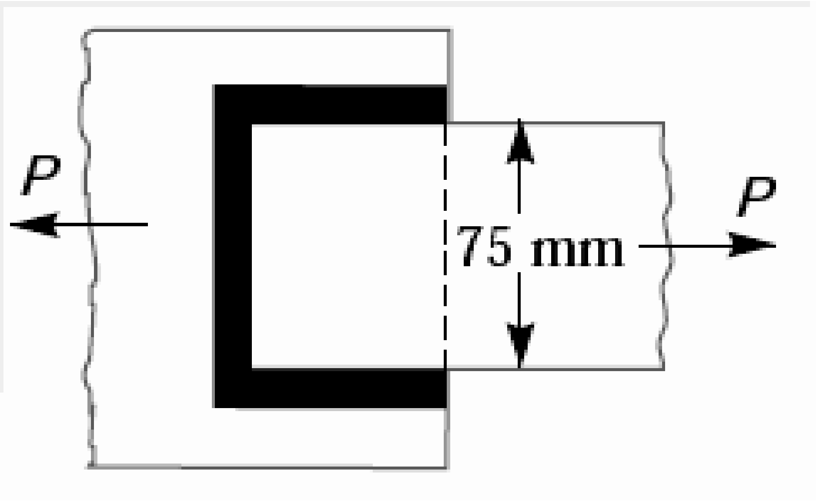
A plate 100 mm wide and 12.5 mm thick is to be welded to another plate by means of parallel fillet welds. The plates are subjected to a load of 50 kN. Find the length of the weld so that the maximum stress does not exceed 56 MPa. Consider the joint first under static loading and then under fatigue loading.

Welded Joints - Direct Loading

Example 5.

A plate 75 mm wide and 12.5 mm thick is joined with another plate by a single transverse weld and a double parallel fillet weld as shown in Fig. The maximum tensile and shear stresses are 70 MPa and 56 MPa respectively.

Find the length of each parallel fillet weld, if the joint is subjected to both static and fatigue loading.

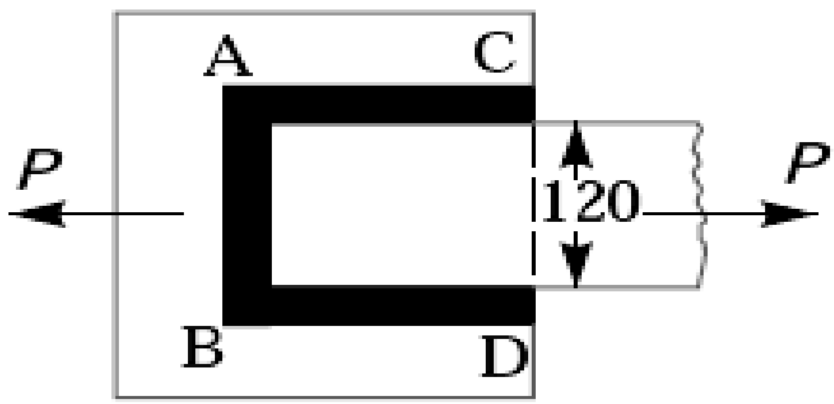


Welded Joints - Direct Loading

Example 6.

Determine the length of the weld run for a plate of size 120 mm wide and 15 mm thick to be welded to another plate by means of

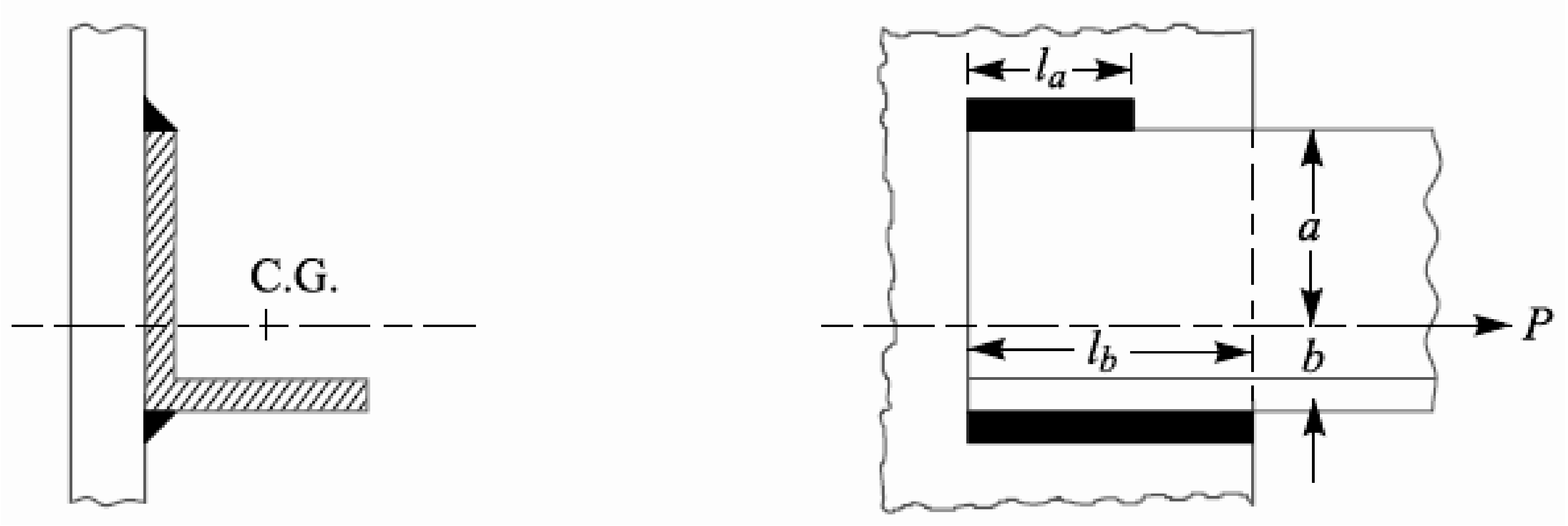
1. A single transverse weld; and
2. Double parallel fillet welds when the joint is subjected to variable loads.



Welded Joints - Direct Loading

Axially Loaded Unsymmetrical Welded Sections

Sometimes unsymmetrical sections such as angles, channels, T-sections etc., welded on the flange edges are loaded axially. In such cases, the lengths of weld should be proportioned in such a way that the sum of resisting moments of the welds about the gravity axis is zero. Consider an angle section as shown in Fig.



Welded Joints - Direct Loading

Axially Loaded Unsymmetrical Welded Sections

Let

l_a = Length of weld at the top,

l_b = Length of weld at the bottom,

l = Total length of weld = $l_a + l_b$,

P = Axial load,

a = Distance of top weld from gravity axis,

b = Distance of bottom weld from gravity axis, and

f = Resistance offered by the weld per unit length.

$$\therefore \text{moment of the top weld about gravity axis} = l_a \times f \times a$$

[illegible]

Welded Joints - Direct Loading

Axially Loaded Unsymmetrical Welded Sections

Since the sum of the moments of the weld about the gravity axis must be zero, therefore,

$$l_a \times f \times a - l_b \times f \times b = 0 \text{ or } l_a \times f \times a = l_b \times f \times b$$

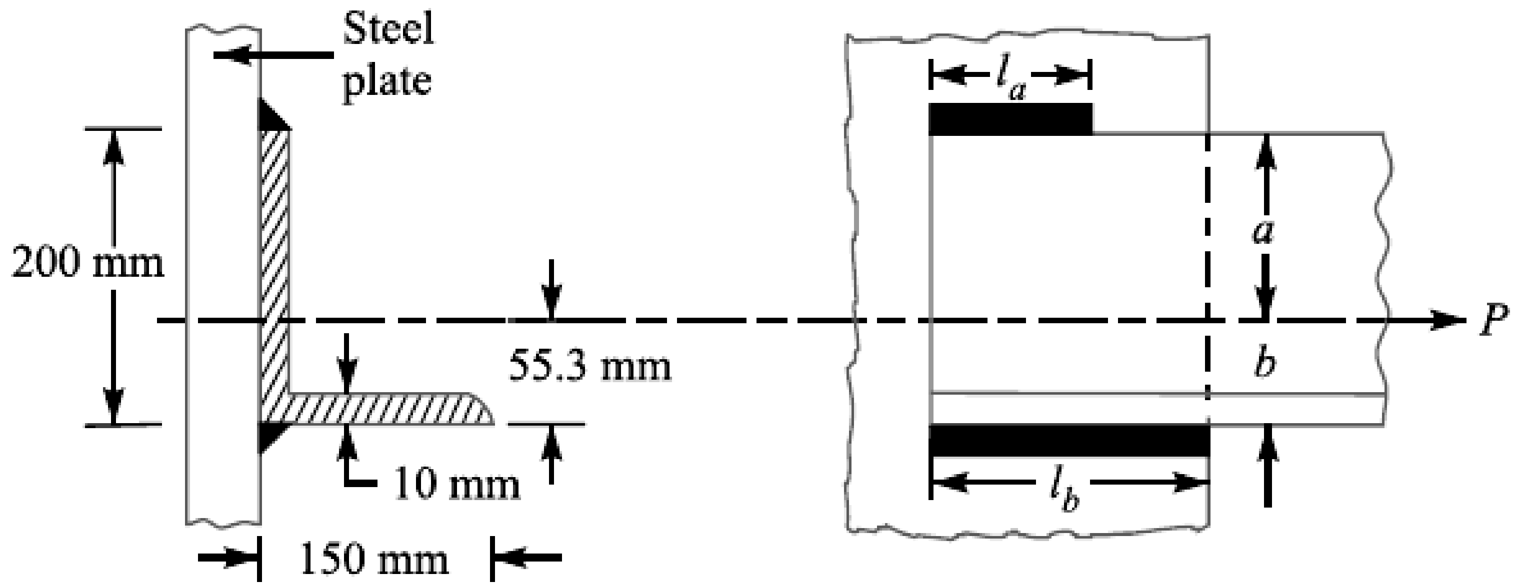
since $l = l_a + l_b$

$$\therefore \text{ we have } l_a = \frac{l \times b}{a+b}, \text{ and } l_b = \frac{l \times a}{a+b}$$

Welded Joints - Direct Loading

Example 7.

A 200 × 150 × 10 mm angle is to be welded to a steel plate by fillet welds as shown in Fig. If the angle is subjected to a static load of 200 kN, find the length of weld at the top and bottom. The allowable shear stress for static loading may be taken as 75 MPa.



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Welded Joints - Direct Loading