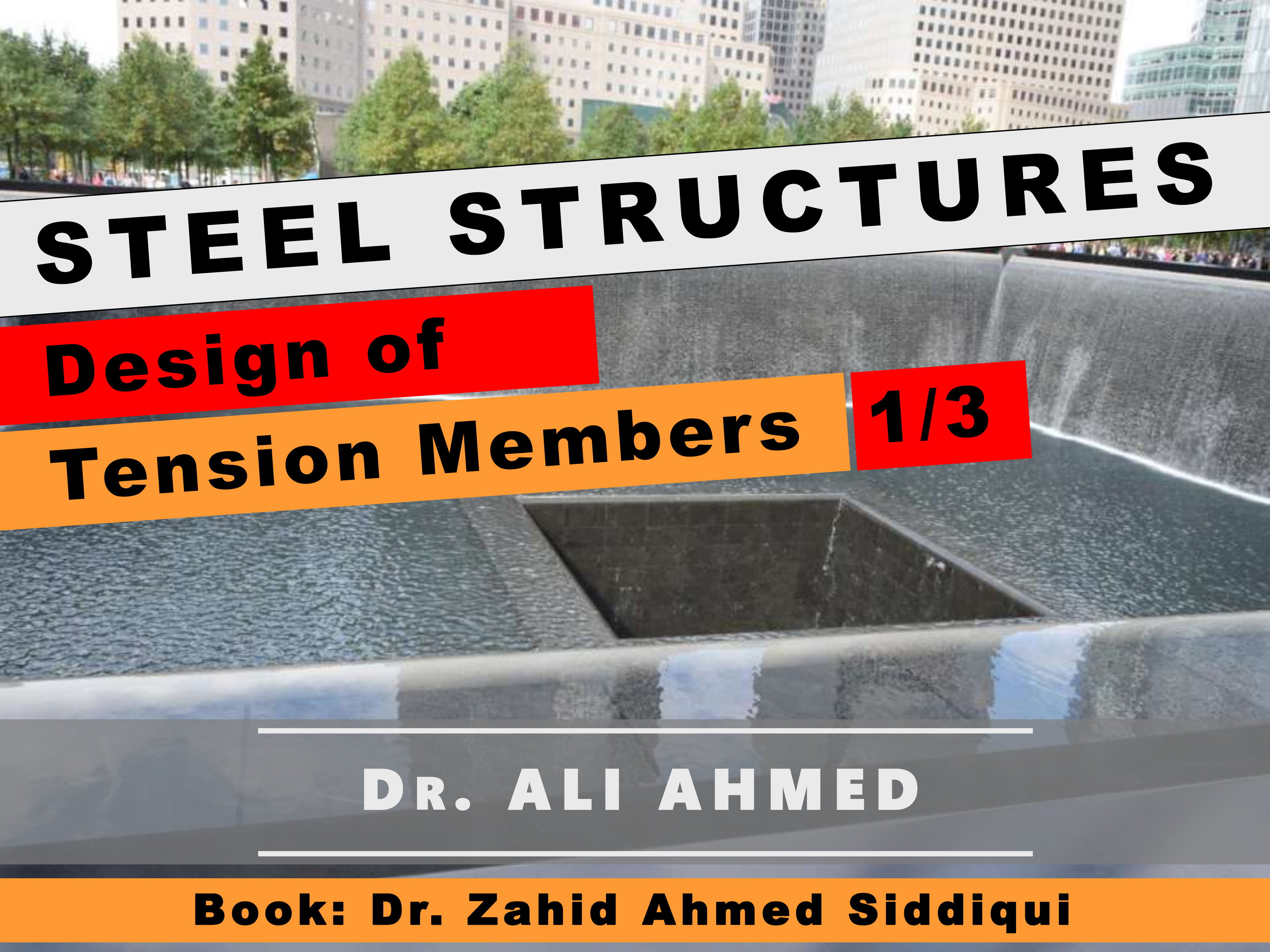

STEEL STRUCTURES

Design of Tension Members 1/3

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Book: Dr. Zahid Ahmed Siddiqui

DESIGN OF TENSION MEMBERS

Members subjected to axial tensile forces are called *Tension Members*.

These members tend to elongate on the application of load.

Bending due to simultaneous transverse loads and buckling are significantly reduced and a initially non-straight member tends to straighten up.

Typical examples are main members of trusses subjected to tension.

However, some secondary members like tie rods and certain braces may also be subjected to tensile loads.

In general, the use of single structural shape is more economical than the built-up section in case of a tension member. However, built-up members may be required in the following situations:

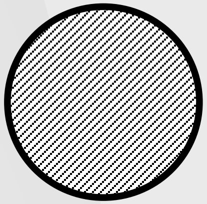
a. The tensile capacity of a single rolled section is not sufficient.

b. The slenderness ratio (KL/r) does not provide sufficient rigidity.

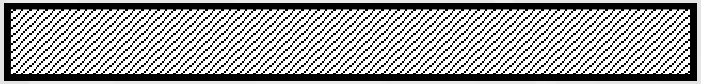
c. The effect of bending combined with the tensile behaviour requires a larger lateral stiffness.

d. Unusual connection details require a particular cross-section.

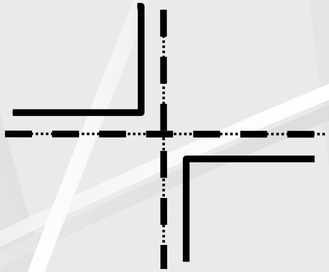
e. Aesthetics dictates a particular cross-sectional shape.



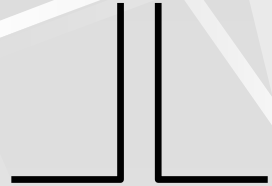
Round Bar



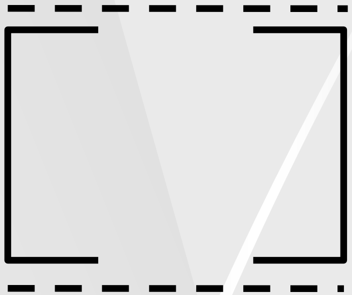
Flat Bar



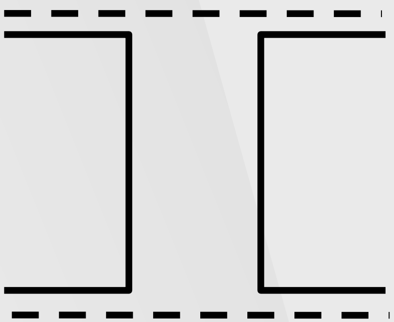
Built-up Section



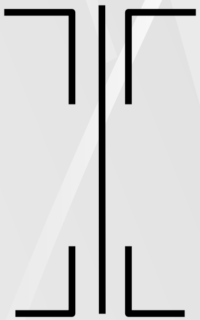
Double Angle



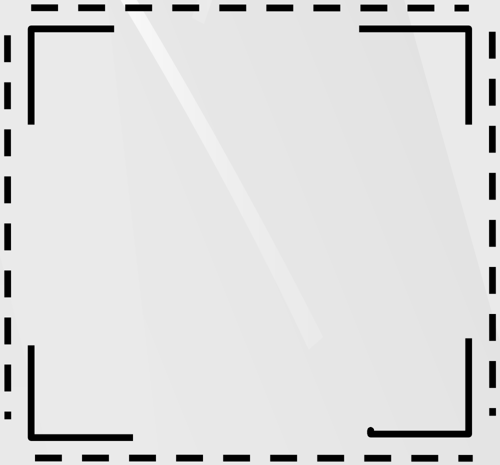
Double Channel Box Section



Double Channel Built-up Section



Built-up I-Section



4-Angle Box Section

GROSS AREA OF CROSS-SECTION (A_g)

It is the total area of cross-section present throughout the length of the member.
(AISC – D3.1).

The elements that are discontinued lengthwise are not included in the gross area.

For example, area of lacing elements and spacer plates is not included in gross area.

The gross area for rolled steel shapes is directly available in the properties tables.

According to AISC – D3.2, the **gross area** of a member is the sum of the products of the thickness and the net width of each element.

NET AREA OF CROSS-SECTION (A_n)

When tension members have holes punched in them for rivets or bolts, the minimum reduced area after the holes are taken out is called the net area.

Failure of a tension member always occurs at the weakest section where area of cross-section is minimum.

SHEAR LAG FACTOR (*U*)

Bearing pressure due to bolts acting over smaller areas and transferring forces only near the weld produce *stress concentrations* at some points within the member cross-section.

Further, *eccentricity in connection* may produce extra stresses due to unwanted moments.

Similarly, at a connection, if one part of the section is connected while the other is left free, all the forces have to pass only through the connected part at the joint.

Shear Lag Effect

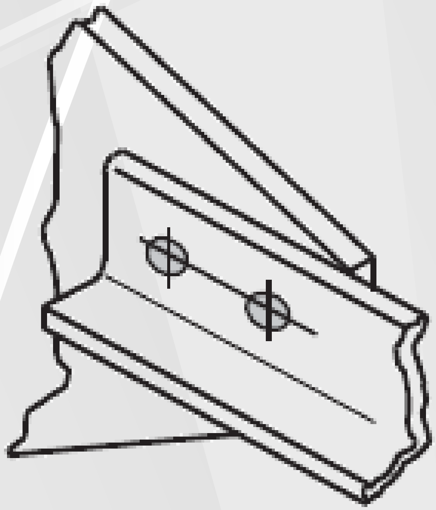
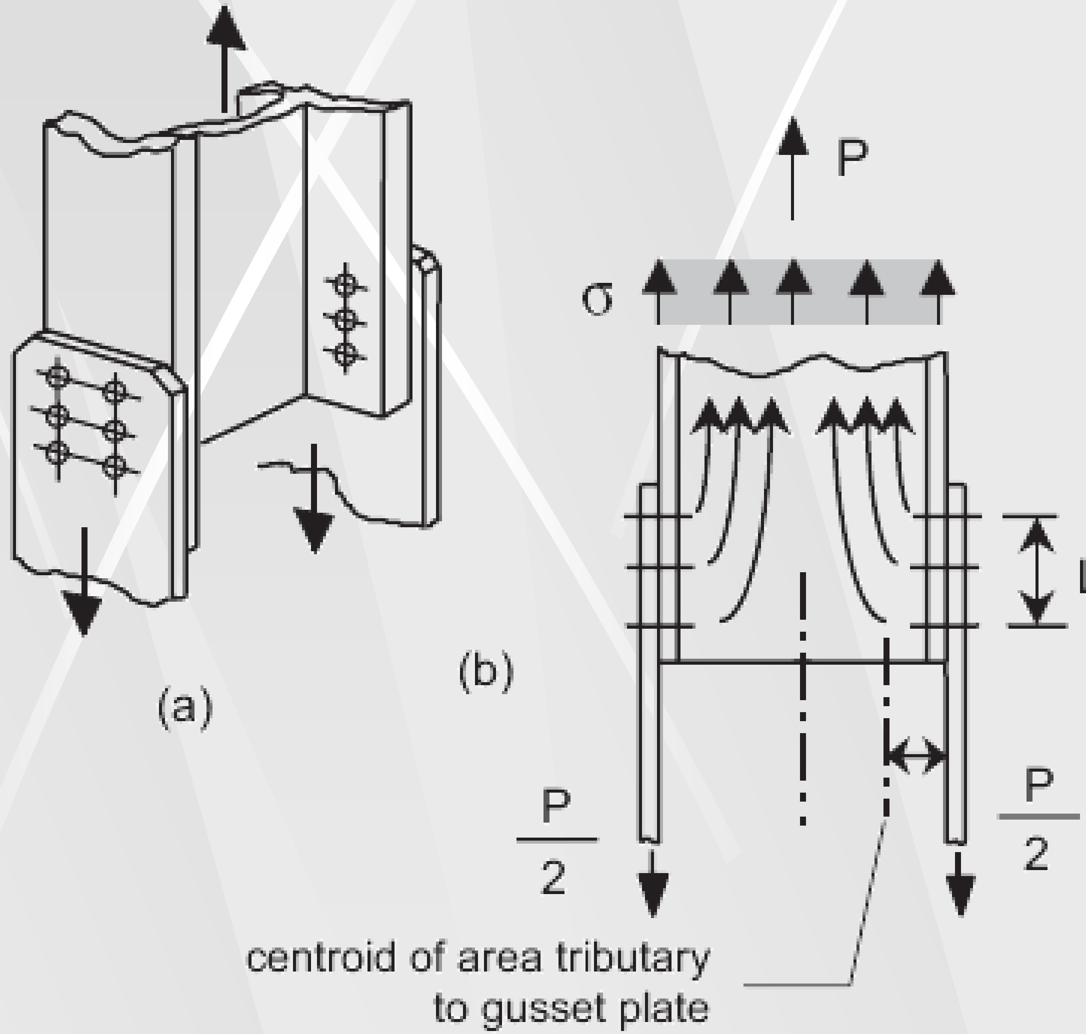


Fig. 5.7 Shear Lag in Angle Connection



Away from the joint, these stresses spread to give a uniform stress distribution.

Efficiency of a joint **is defined as how well the stresses are distributed to transfer the applied forces.**

If the joint is not fully efficient, *premature failure* can occur reducing the member strength.

This expected reduction is usually applied on the area of cross-section to get *effective net area* used to calculate the reduced member strength.

SHEAR LAG FACTOR (*U*)

Shear lag factor (*U*) is the factor by which net area of a section is reduced for shear lag, stress concentrations and eccentricity at the joints.

$$A_e = U\,A_n$$

The approximate values of this factor for various joining conditions are given below.

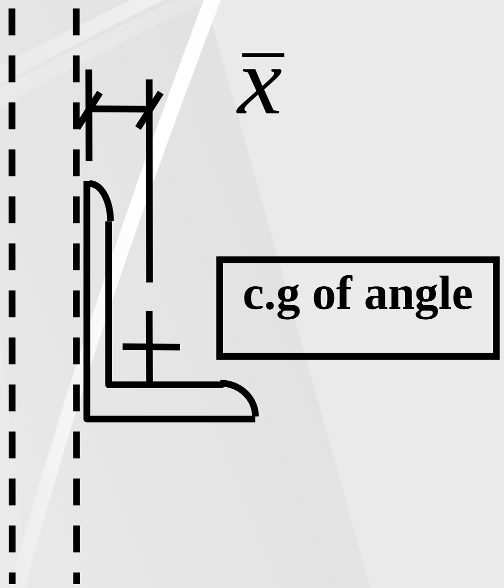
a. When tension load is transmitted through each of the cross-sectional elements by fasteners or welds, *U* = 1.0.

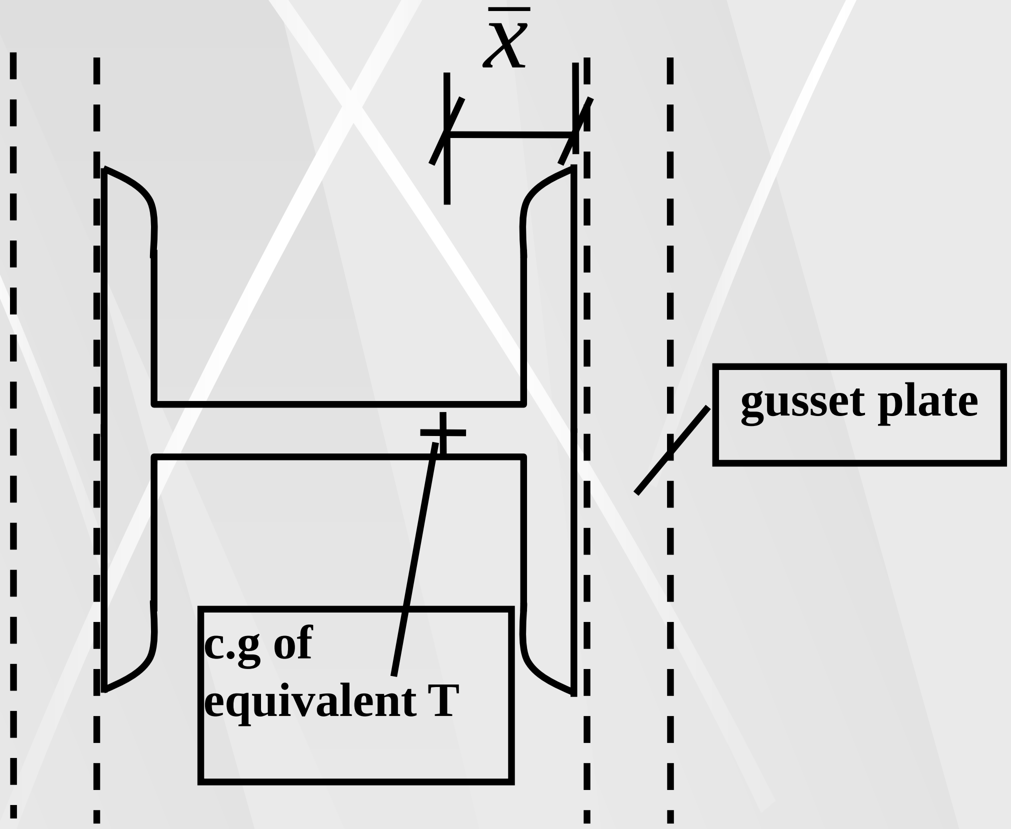
b. The preferable expression for *U* for all tension members, except plates and HSS, where load is not transferred by all elements of the section, is as follows:

$$U = 1 - \frac{\bar{x}}{\ell}$$

$\bar{x}$ = distance from centroid of element being connected eccentrically to plane of load transfer, called connection eccentricity.

ℓ = length of connection, centre-to-centre of the outer rivet holes or actual length of weld.


$\bar{x}$
c.g of angle


$\bar{x}$
gusset plate
c.g of
equivalent T

c. **When tension load is transferred by transverse welds,**

$$A_e = A_n . U$$

where, A **= area of directly connected elements**

and $U = 1.0$

d. **When two separate plates are connected by longitudinal welds,**

For $l_w \geq 2B$ — $U = 1.00$

For $2B > l_w \geq 1.5B$ — $U = 0.87$

For $1.5B > l_w \geq B$ $U = 0.75$

where, l_w = length of weld

B = width of plate equal to distance between welds

e. For W, M, S, HP or tees with flange connected with 3 or more fasteners per line in the direction of loading, the following values may approximately be considered.

a) $b_f \geq {}^2/_3\, d$ $U = 0.90$

b) $b_f < {}^2/_3\, d$ $U = 0.85$

f. For W, M, S, HP or tees with web connected with 4 or more fasteners per line in the direction of loading, $U = 0.70$.

g. For single angle section with 4 or more fasteners per line in the direction of loading, $U = 0.80$.

h. For single angle section with 2 or 3 fasteners per line in the direction of loading, $U = 0.60$.

i. For double angles, the same value as given by AISC for single angles may approximately be used.

CALCULATION OF NET AREA

Reduction in Area for One Fastener

In fabricating structural steel, which is to be connected with rivets or bolts, the holes are usually punched larger than the diameter of the rivet or bolt.

Furthermore, the punching of hole is assumed to damage or even destroy 0.75 mm or more of the surrounding metal beyond the drilled hole.

The nominal holes for bolts are given in Table 2.1.

Table 2.1. Nominal Bolt Hole Dimensions, mm.

Bolt Diameter (d)	Standard Hole Diameter (d_h)	Oversize Diameter
15	17	19
18	20	22
20	22	24
22	24	28
25	28	31
28	31	36
30	33	38
≥ 35	$d + 3$	$d + 8$

Diameter of holes considered for strength calculations

= (diameter of the rivet + 1.5 + 1.5) mm

= (diameter of standard bolt hole, d_h + 2) mm

The diameter of hole for the rivet is *d* + 1.5, whereas another 1.5 mm is to be added because this extra portion around the hole may be damaged due to drilling of the hole.

The area of hole to be subtracted from width of the cross section is rectangular and equals the diameter of the hole times the thickness of metal.

Reduction in area for one fastener

$= (d + 3)\, t$;for rivets

$= (d_h + 2)\, t$;for standard bolt holes

Where

d = diameter of rivet and

d_h = diameter of hole for the bolt.

Reduction in Area for More than One Holes

Reduction in area

= $n\,(d + 3)\,t$ for rivets

= $n\,(d_h + 2)\,t$ for standard bolt holes

where n = number of holes in the critical failure path

d = diameter of fastener, and

t = thickness of plate

$$A_n = A_g - n\,(d + 3)\,t$$

for vertical failure planes when rivets are used

Example 2.1: Determine the net area of a **10 x 200 mm** plate joined with **two 6 x 200 mm plates** as shown in Figure 2.3. The plates are connected to each other with two lines of **20 mm rivets**.

Solution:

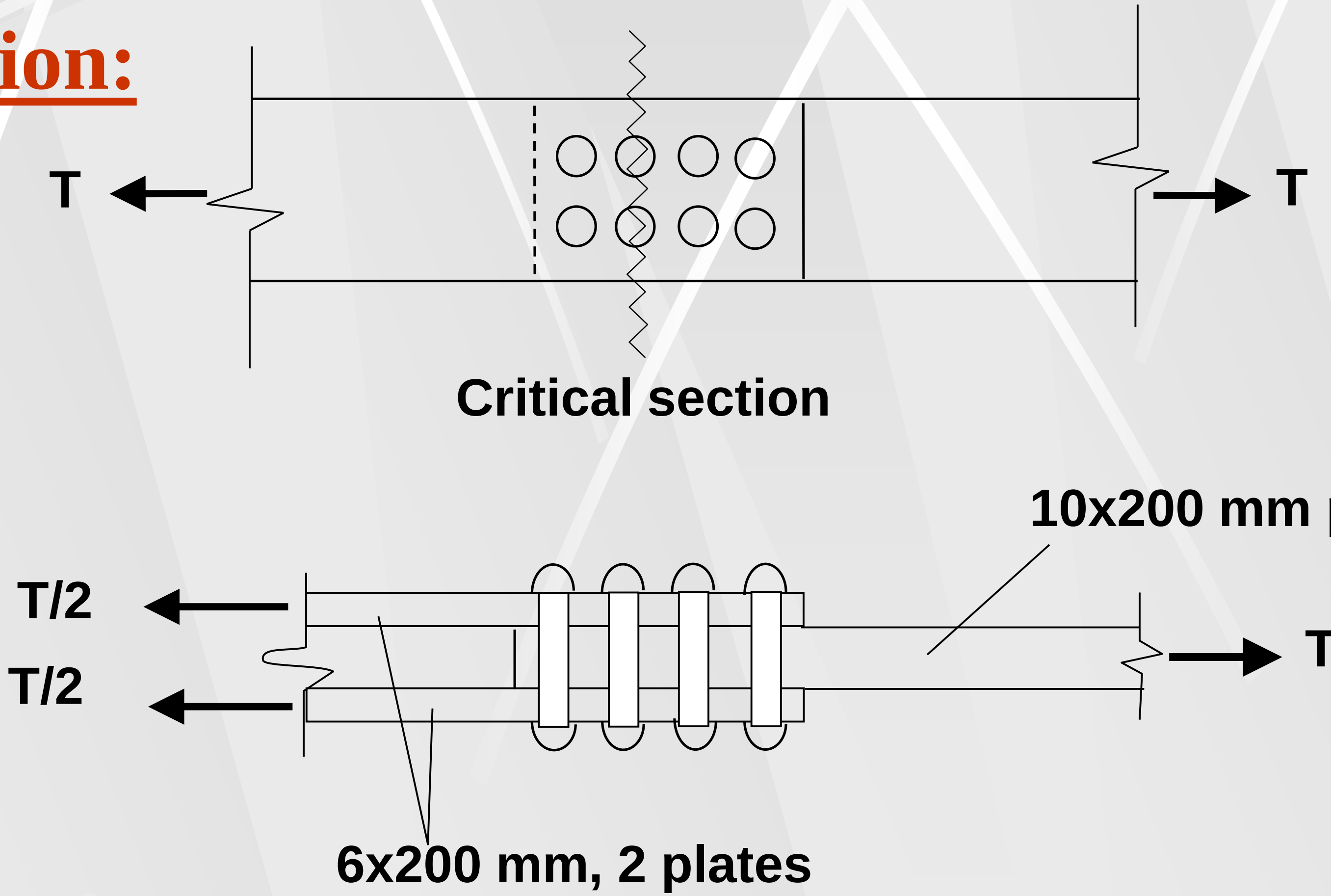


Figure 2.3. Connection of Three Plates By Rivets.

$$A_g = \text{smaller of} \begin{cases} 10 \times 200 = 2000 \text{ mm}^2 \\ 2 \times 6 \times 200 = 2400 \text{ mm}^2 \end{cases}$$

$$= 2000 \text{ mm}^2$$

The failure plane is vertical having two holes in its path, n = 2.

$$A_n = A_g - n\,(d + 3)\,t$$

$$= 2000 - (2).(20 + 3).(10)$$

$$= 1540 \text{ mm}^2$$

FASTENER SPACING

Pitch of fasteners

The centre-to-centre distance of the fasteners along the longitudinal axis of the member is called pitch and is denoted by *p*, as shown in Figure 2.4.

Gage distance of fasteners

The centre-to-centre distance between the fasteners along the transverse direction is called gage denoted by *g*; refer to Figure 2.4.

Stagger of fasteners

The longitudinal distance between two nearest rivets lying in two adjacent layers of rivets is called stagger denoted by *s* and shown in Figure 2.4.

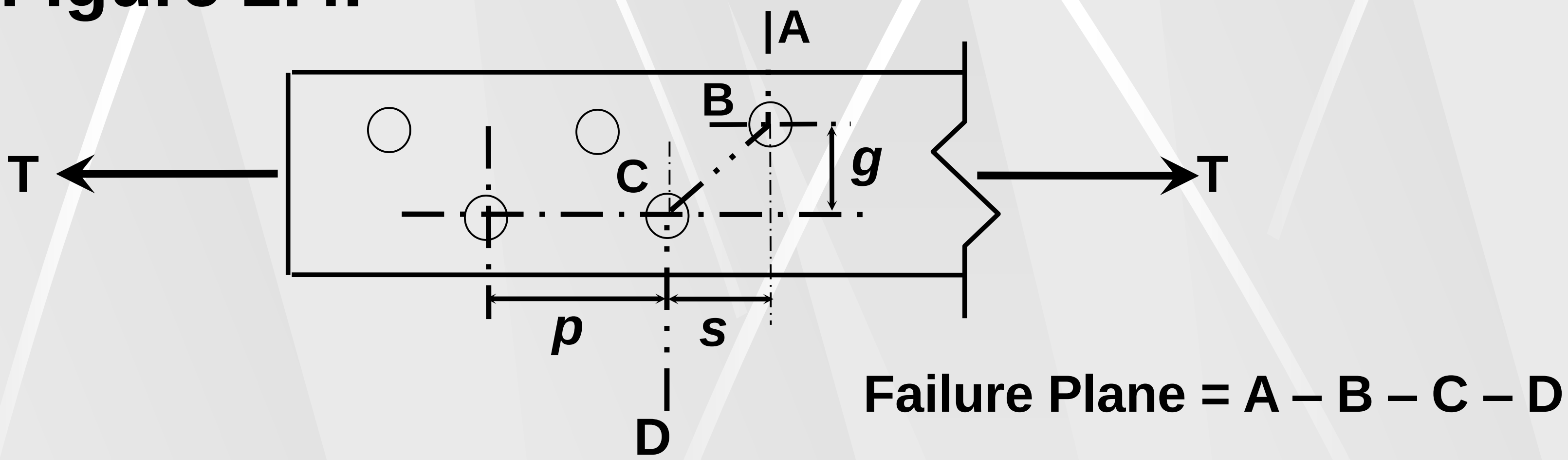


Figure 2.4. Fastener Spacing In Various Directions.

Standard gage distances for angles and channels are given in Figures 2.5 and 2.6.

Leg Dimension (mm)	203	178	152	127	102	89	76	64	51	44	38	35	32	25
g	114	102	89	76	64	51	44	35	29	25	22	22	19	16
g_1	76	64	57	51										
g_2	76	76	64	44										

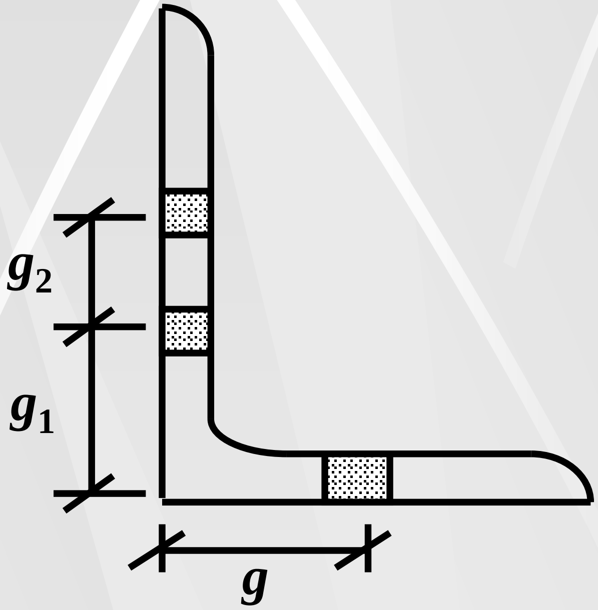
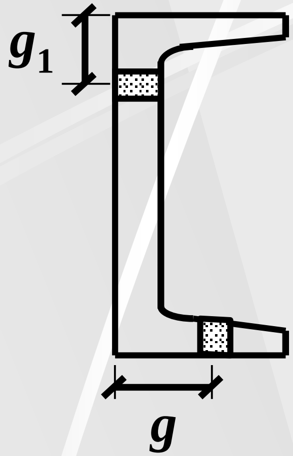


Figure 2.5. Usual Gages For Angles.



Actual flange width b_f (mm)	g (mm)
< 46	25
46-51	29
52-64	33
65-70	38
71-81	44
82-90	51
91-100	57
> 100	64

Actual depth d (mm)	g_1 (mm)
240-460	64
150-239	57
100-149	51

Figure 2.6. Usual Gages For Channels.

Additional Area Due To Inclined Failure Plane

Just like each hole in the path of failure plane reduces net area, area equal to $\left(\frac{s^2}{4g} \times t\right)$ is added to the net area for each inclined line in the assumed failure plane.

Total Net Area (An)

$$A_n = A_g - (d + 3)\, t + \left(\sum \frac{s^2}{4g}\right) t \qquad \text{for rivets}$$

or $W_n = W_g - n\,(d + 3) + \sum \frac{s^2}{4g}$ for rivets

***Note:* The net area must be calculated for all the possible critical failure planes and the least value must be taken.**

A typical truss connection is shown in Figure 2.7 to explain the position of gusset plate and the fasteners.

Gusset plate is a plate to which all the truss members are connected at a joint.

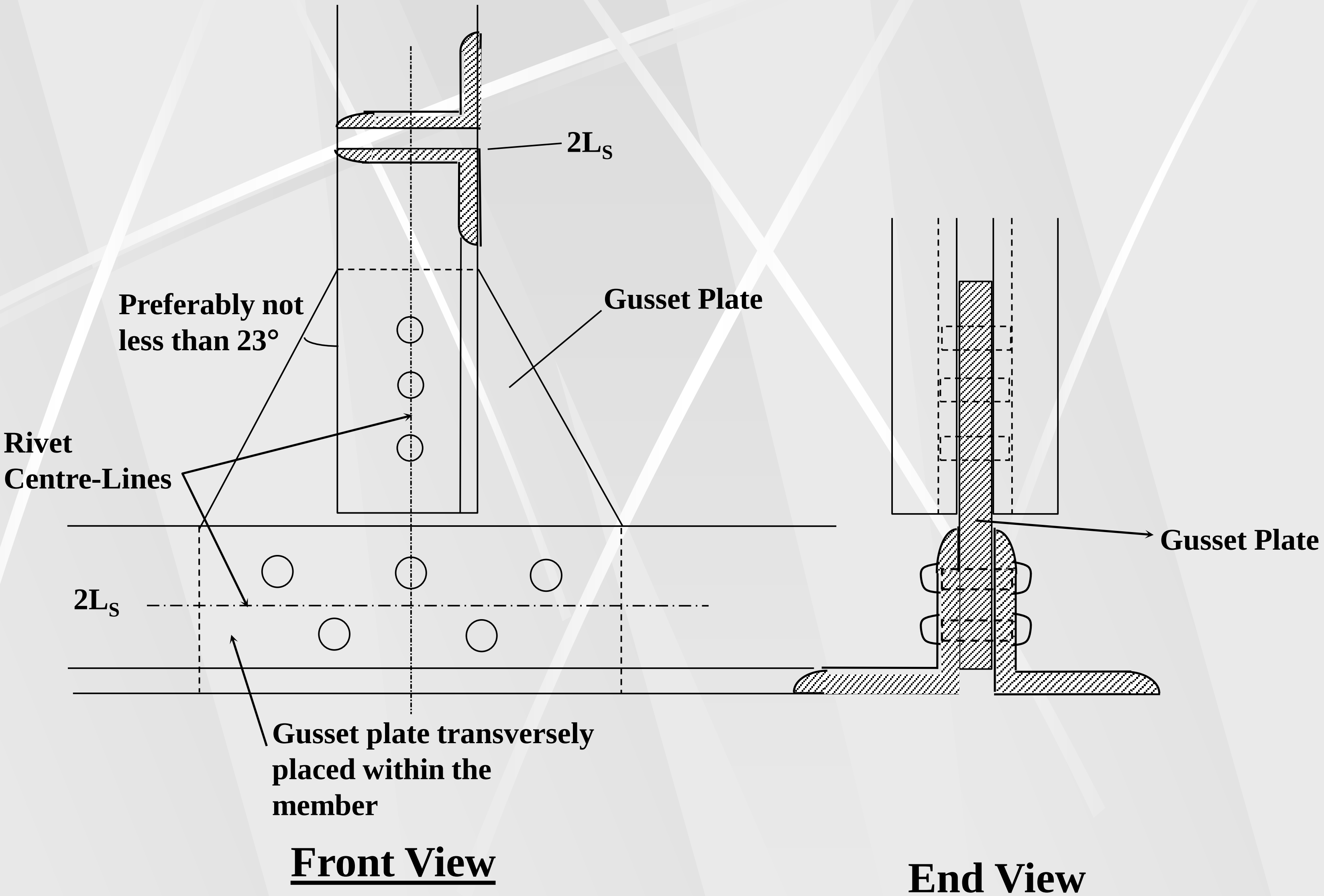


Figure 2.7. A Typical Riveted Truss Connection.

Total Net Area For Welded Connections

In case of welded members, net area and effective net area can both be considered equal to the gross area with *U* = 1.

Example - 2.2: **Determine the minimum net area of plate shown in Figure 2.8 where the location of 20 mm diameter fasteners is also indicated.**

Solution:

Path AD

$$A_n = A_g - n\,(d + 3)\,t$$

$$= (6)(305) - 2(20 + 3)(6) = 1554 \text{ mm}^2$$

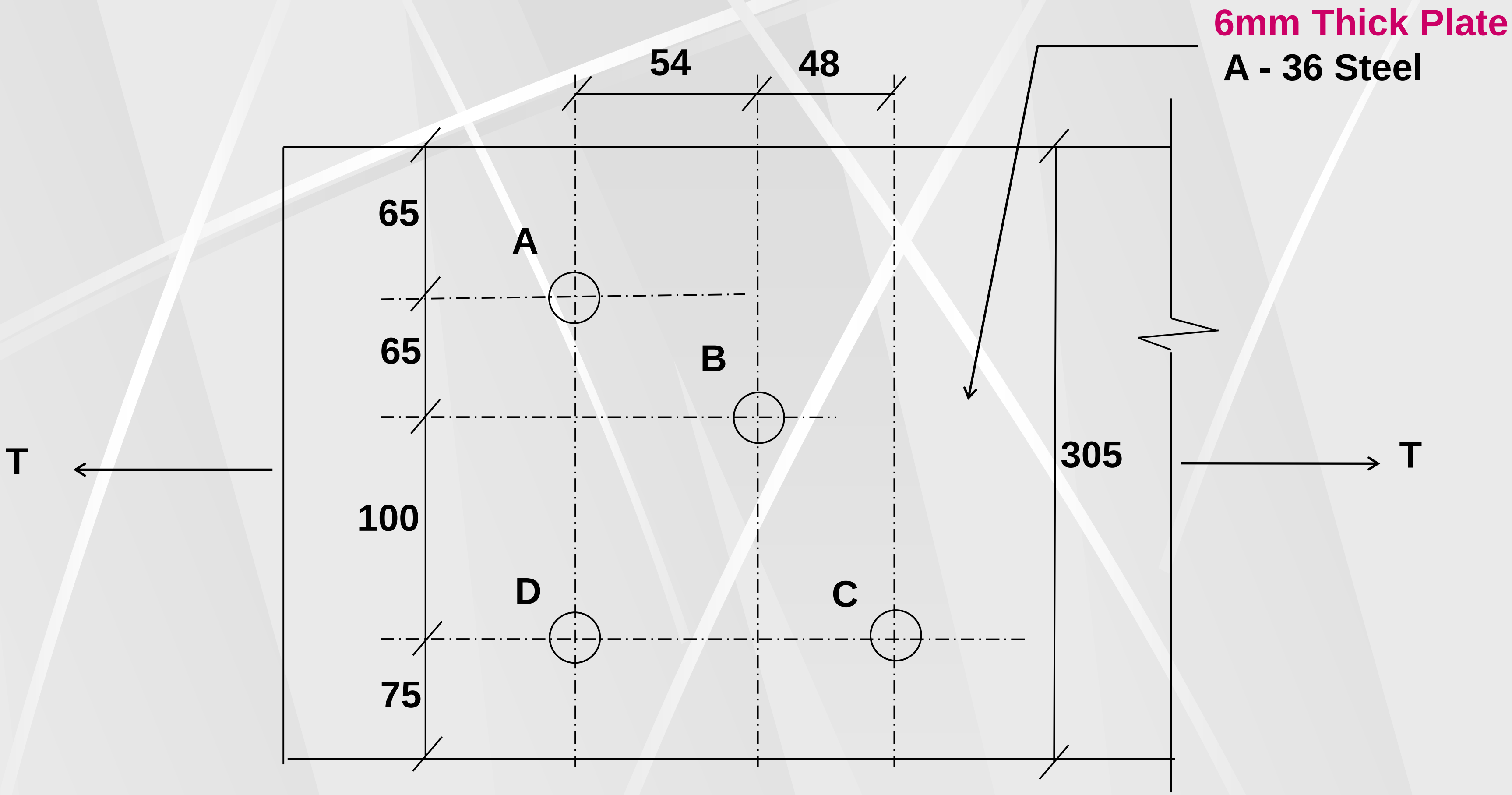


Figure 2.8. Connection Details For Data of Example 2.2.

Path ABD

$$A_n = A_g - n\,(d + 3)\,t + \left(\sum \frac{s^2}{4g}\right)t$$

$$= (6)(305) - 3(20 + 3)(6) + \left[\frac{54^2}{(4)(65)} + \frac{54^2}{(4)(100)}\right](6)$$

$$= 1527 \text{ mm}^2$$

Path ABC

$$A_n = (6)(305) - 3(20 + 3)(6) + \left[\frac{54^2}{(4)(65)} + \frac{48^2}{(4)(100)}\right](6)$$

$\approx 1518 \text{ mm}^2$ $\Leftarrow$ **Controls**

NET AREA OF STRUCTURAL SHAPES

The structural shapes are assumed to be flattened out into single plates.

The horizontal plates are rotated until these become in the same vertical plane (refer to Figure 2.9).

The general procedure may then be used to calculate the net area in which all possible failure planes are considered.

A great care is required to use the thickness of various parts in the formulas, because it may be double of the actual thickness of that part.

For example, in Figure 2.9, thickness of the flange is to be considered double in the analogous section.

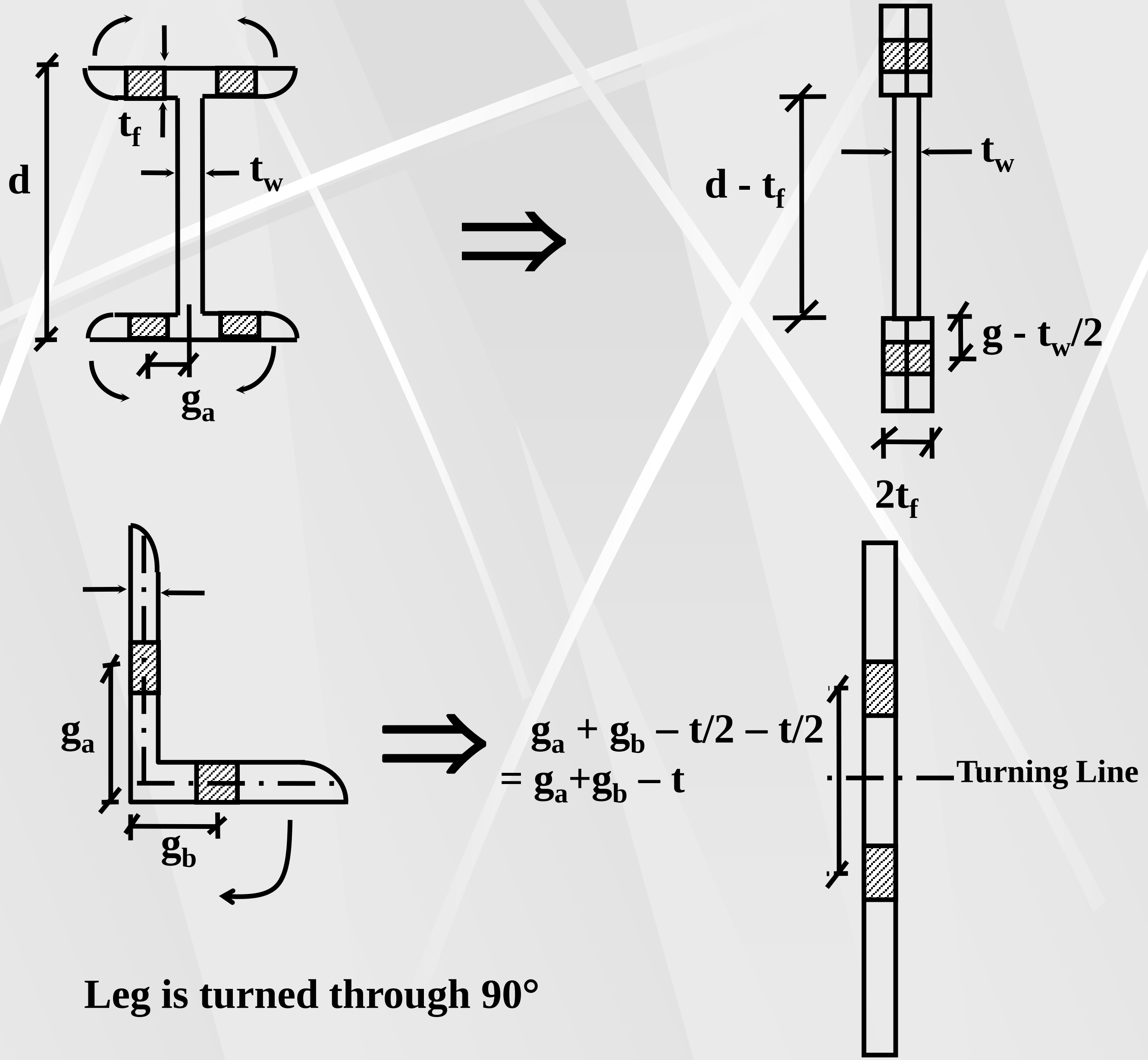


Figure 2.9. Net Area of Structural Shapes.

Example - 2.3: **Determine the net area A_n for the angle given in Figure 2.10 if 18 mm diameter fasteners are used.**

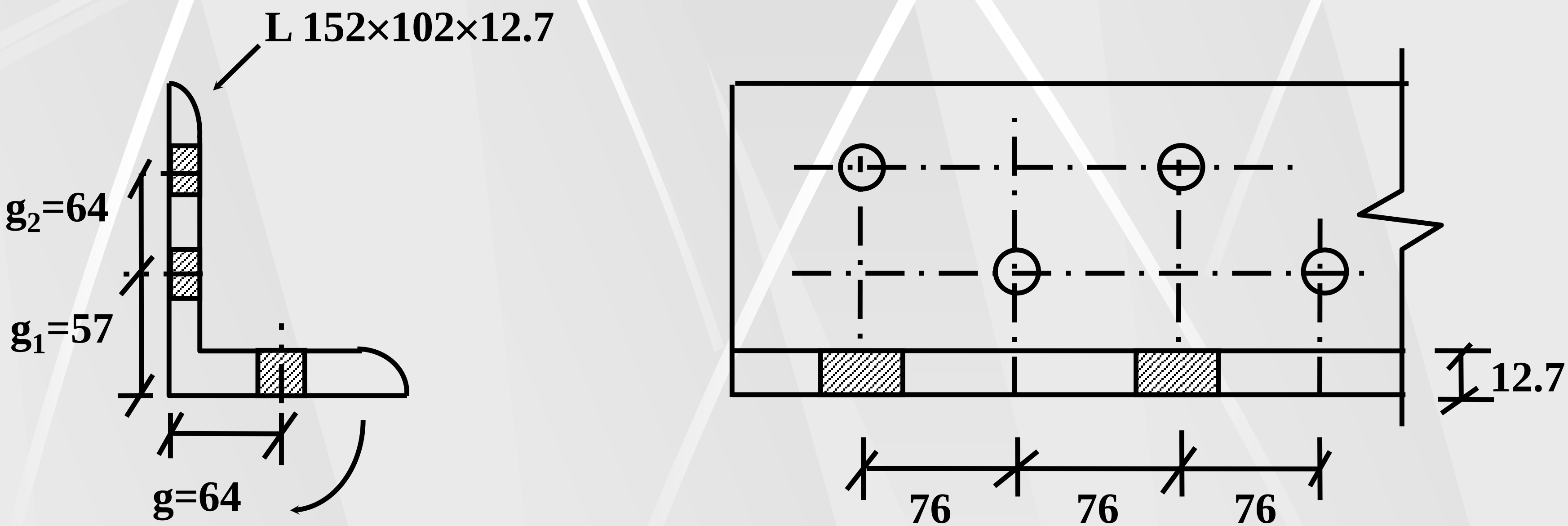
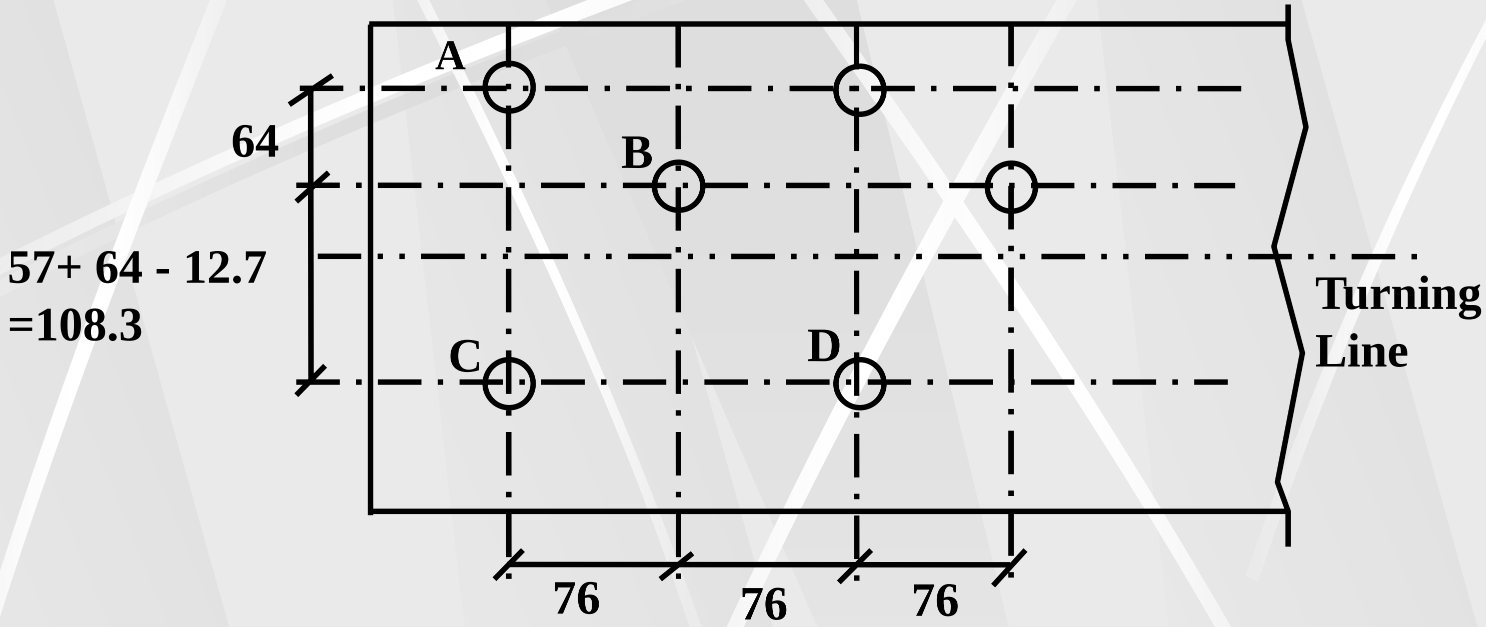


Figure 2.10. Connection Details For Angle Section of Example 2.3.

Solution:



After opening the section, a single plate is obtained. Calculations for net area can now be made for various failure planes like AC, ABC and ABD, etc., and minimum value can be selected as the final answer (See book for details).

Minimum Spacing Of Bolts In Line Of Transmitted Force

The distance between the centres of standard, oversized or slotted holes should be greater than or equal to 2.67 *d*, however, a distance of 3 *d* is preferred.

Minimum End Distance In Direction Of Transmitted Force

The prevention of splitting out at the end bolt of a series of bolts in a line requires a certain minimum edge distance of 1.5 *d*

	Minimum Edge Distance Using Standard Hole	
d (mm)	At Sheared Edges (mm)	At Rolled Edges (mm)
12	22	19
15	27	21
18	32	24
20	34	26
22	38	28
25	43	31
28	49	35
30	52	38
32	57	41
35	63	45
Over 35	1.75 d	1.25 d

The distance from the centre of a standard hole to an edge of a connected part in any direction is given in Table 2.2.

It is not permitted to be less than the value evaluated by the following expression (when deformation at the bolt hole due to service load is not a design consideration):

$$L_c \geq \frac{P_u}{0.75 \times 1.2 \times F_u t} \quad \text{and} \quad d_{min} = \frac{P_u}{0.75 \times 2.4 \times F_u t} \quad \text{(LRFD)}$$

$$L_c \geq \frac{2P}{1.2 \times F_u t} \quad \text{and} \quad d_{min} = \frac{2P}{2.4 \times F_u t} \quad \text{(ASD)}$$

where

L_c = clear distance of end bolt to edge measured in the line of force,

P_u = factored load on end bolt,

P = service load on end bolt, and

d_{min} = minimum diameter of the bolt.

For oversized and slotted holes, the correction is given in AISC Specification.

When deformation at the bolthole due to service load is a design consideration, the expressions are modified as under:

$$L_c \geq \frac{P_u}{0.75 \times 1.5 \times F_u t} \quad \textbf{and } d_{min} = \frac{P_u}{0.75 \times 3 \times F_u t} \quad \text{(LRFD)}$$

$$L_c \geq \frac{2P}{1.5 \times F_u t} \quad \textbf{and } d_{min} = \frac{2P}{3 \times F_u t} \quad \text{(ASD)}$$

Maximum Edge Distance

The maximum distance from the centre of a bolt to the nearest edge is smaller of 12t and 150mm, where *t* is the thickness of the connected part.

The purpose is to make sure that the painted pieces cannot have excessive separation with the resulting corrosion due to entering moisture.

Maximum Longitudinal Spacing

In case of members not subjected to corrosion, the maximum longitudinal spacing is lesser of the following:

a) 24 times the thickness of thinner plate
b) 305 mm

In case of members subjected to atmospheric corrosion, the maximum longitudinal spacing is lesser of the following:

a) 14 times the thickness of thinner plate
b) 180 mm

MINIMUM CONNECTED LEG WIDTH

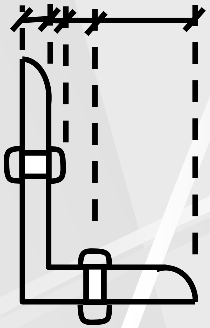


Figure 2.10. Various Clearances Required For Fasteners.

b_{min} ≅ Transverse edge distance from the centre of hole
+ clearance to the bolt head on other leg from centre of hole
+ thickness of other leg along with dimension of bolt on it

≅ $1.5d + (d+6) + (t_a + 0.75d + 2)$

b_{min} ≅ $3.25d + 18$ *if bolt is present on the perpendicular leg,*

or ≅ $2.5d + 16$ *if no bolt is present on the perpendicular leg.*

For welded connections b_{min} should be greater than or equal to 50 mm.

Design Practice: For L = 2 – 3 m, $b_{min} = L/40$

MAXIMUM SLENDERNESS RATIO

According to AISC – D1, there is no maximum slenderness limit for design of members in tension.

Even though stability is not a criterion in the design of tension members, it is still preferable to limit their length in order to prevent a member from becoming too flexible both during erection and final use of the structure.

Two main factors controlling slenderness ratio in tensions members are:

a) Tension members that are too long may sag excessively due to their own weight.

b) They may vibrate when subjected to wind forces or when these are supporting vibrating equipment such as fans or compressors.

For members whose design is based on tensile force, the slenderness ratio *L/r* preferably should not exceed 300 where *L* is the actual and not the effective length.

The above limitation does not apply to rods in tension where *L/r* may be kept up to 500.

AISC-D1, means that the Specification is given by American Institute of Steel Construction, D is the chapter no. and 1 is the article no. of that chapter.