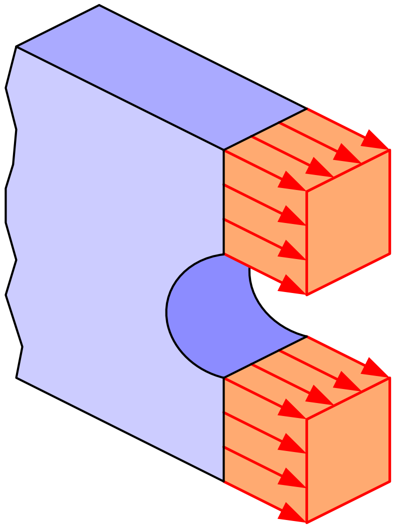
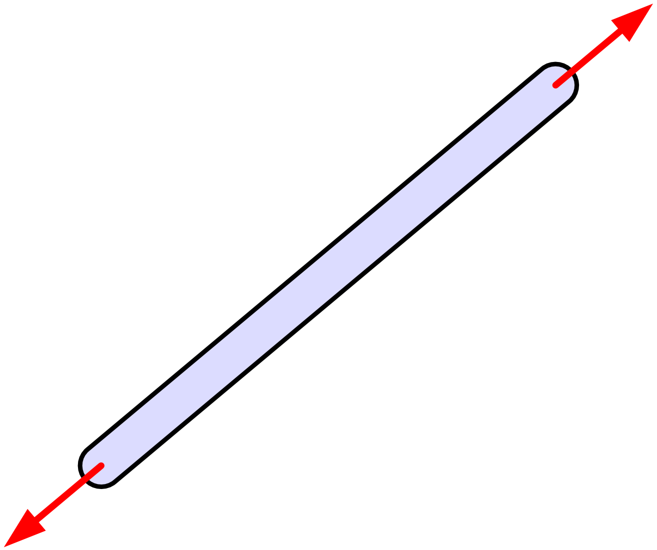


Timber and Steel Design

Lecture 3 - Analysis of Tension Members



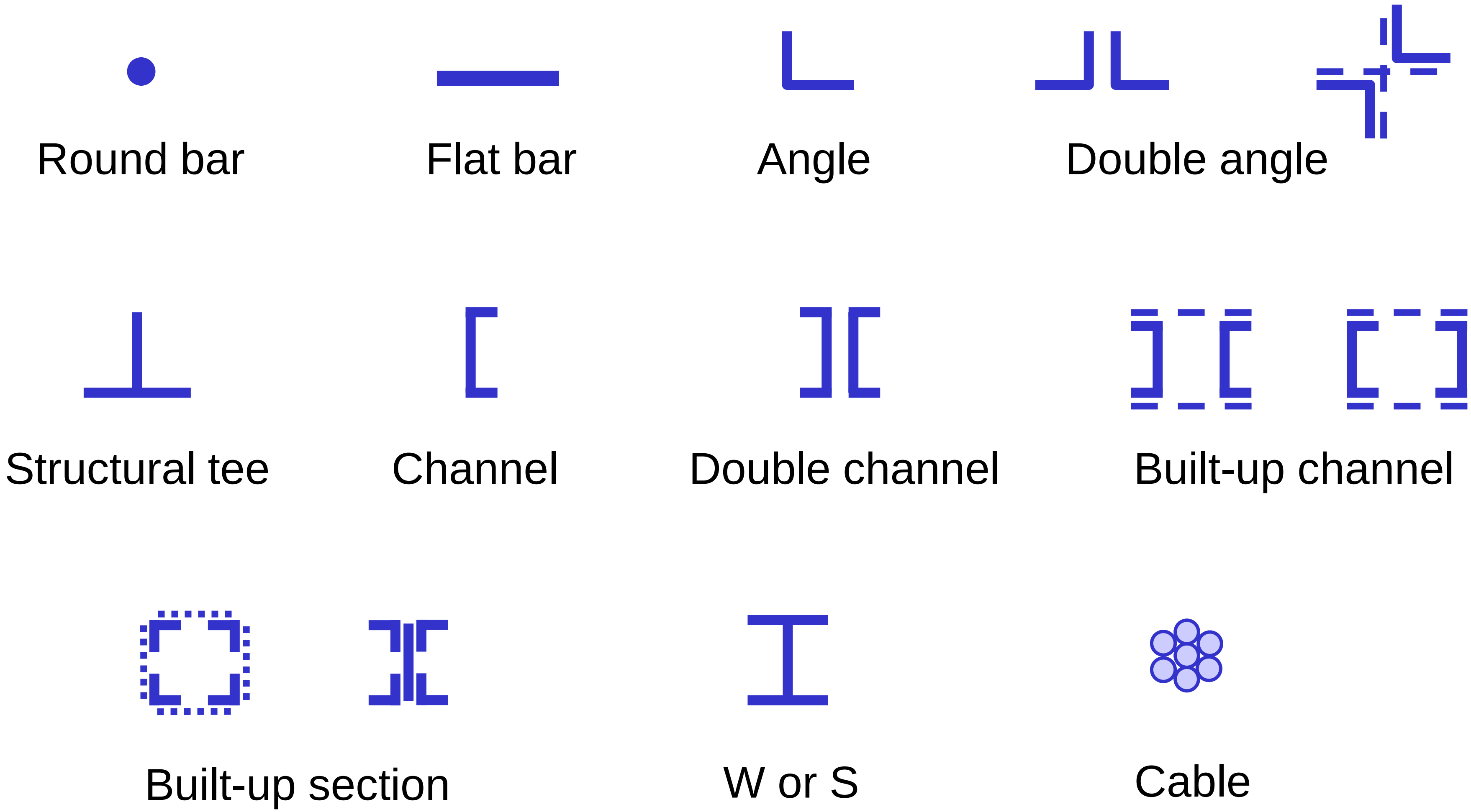
- Tensile Strength
- Net Areas
- Staggered Holes
- Effective Net Area
- Block Shear

Asst.Dr.Mongkol JIRAVACHARADET

S U R A N A R E E INSTITUTE OF ENGINEERING

UNIVERSITY OF TECHNOLOGY SCHOOL OF CIVIL ENGINEERING

Types of Tension Members

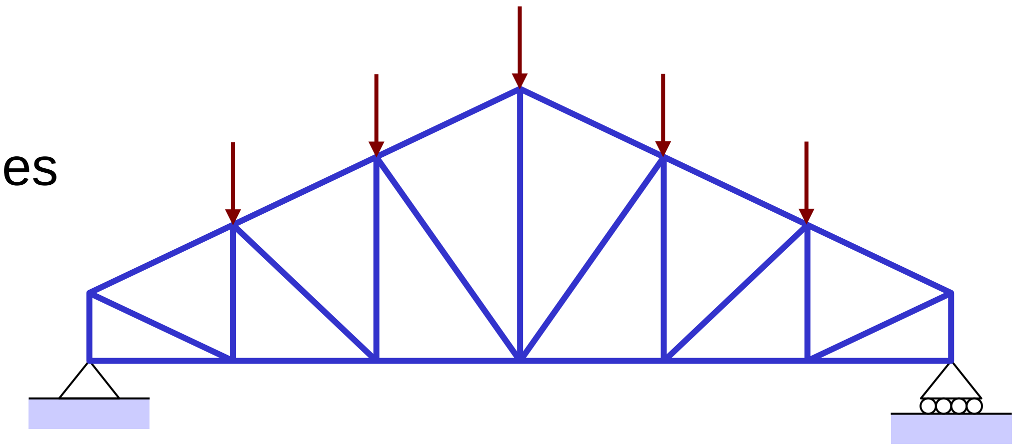


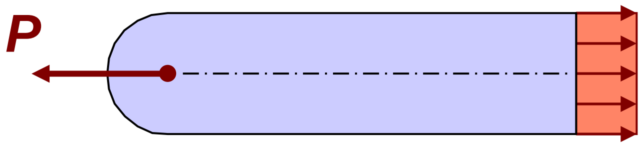
Tension Members subjected to axial tensile forces

- truss members

- bracing for buildings and bridges

- cables in suspended roof and bridges





Stress in an axially loaded tension member:

$$f = \frac{P}{A}$$

The stress in a tension member is uniform throughout the cross-section except:

- near the point of application of load, and

- at the cross-section with holes for bolts or other discontinuities, etc.

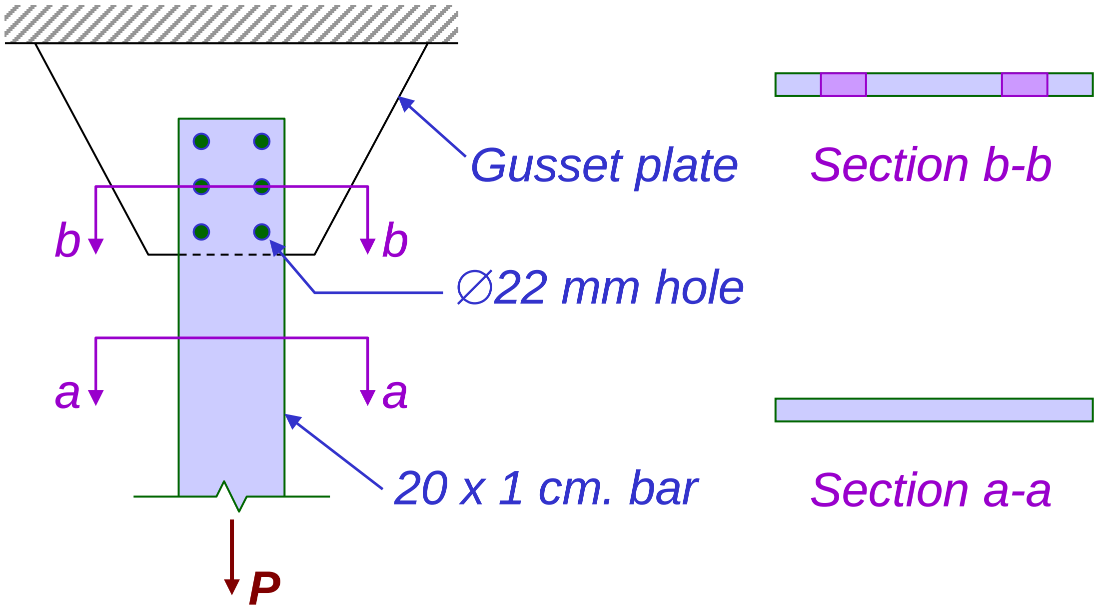
The stress ***P/A*** must be less than a limiting stress ***F*** or

$$\frac{P}{A} < F$$

Thus the load ***P*** must be less than ***FA*** or

$$P < FA$$

For example, consider an 20 x 1 cm. bar connected to a gusset plate and loaded in tension as shown below.



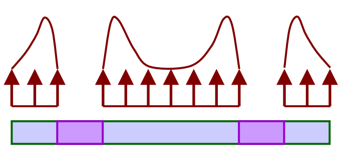
Area of bar = (20 – 2 x 2.2) x 1

= 15.6 cm^2

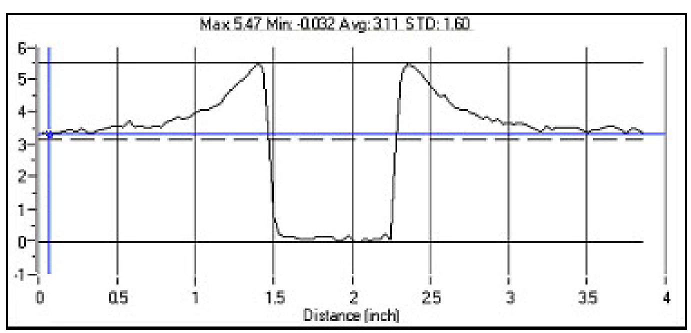
Area of bar = 20 x 1 = 20 cm^2

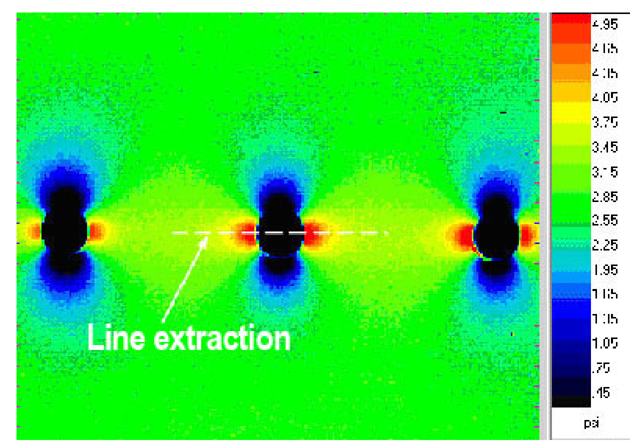
From ***f = P/A***, the reduced area of Section *b – b* will be subjected to higher stresses.

However, the reduced area and therefore the higher stresses will be **localized** around Section b – b.

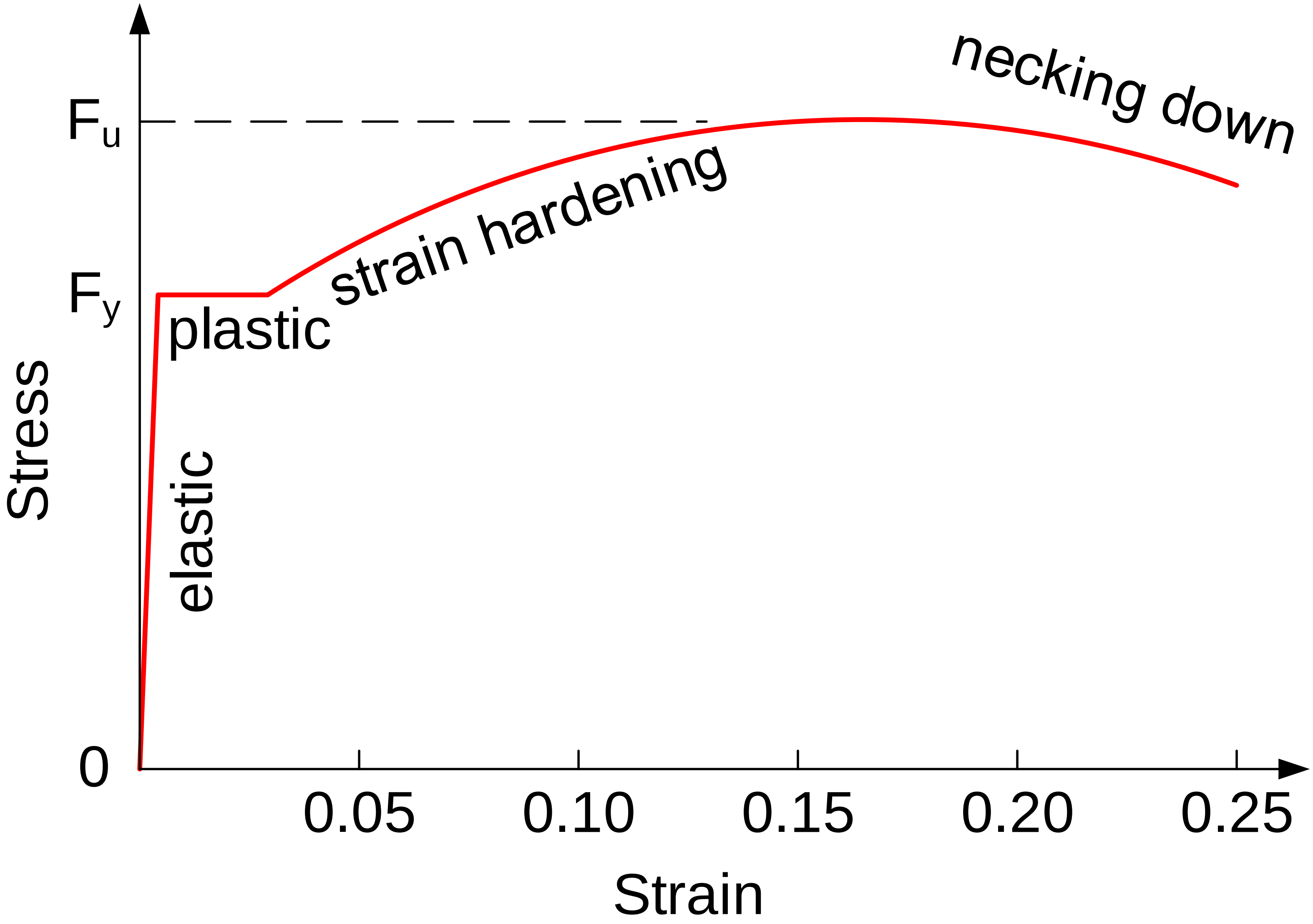


Section b-b





Stress-Strain Curve

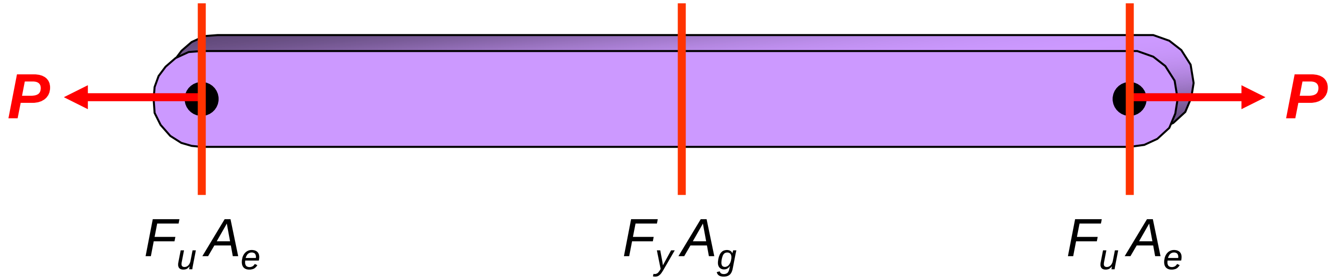


Nominal Tensile Strength

The nominal strength of a tension member P_n is the smaller of

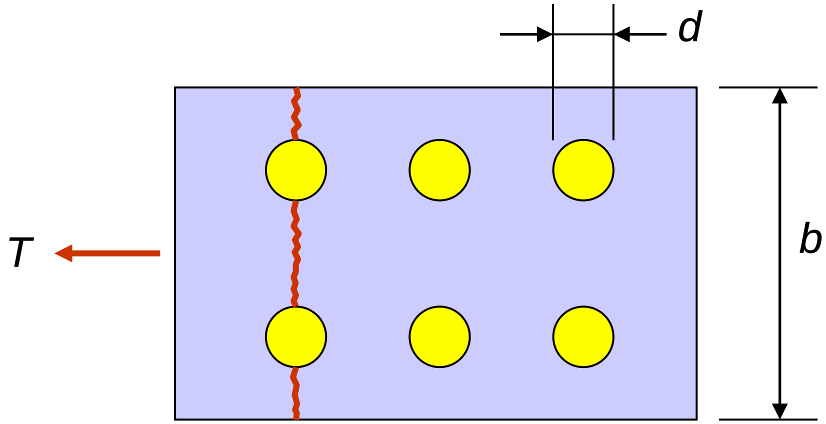
Tensile Yielding : $P_n = F_y A_g$

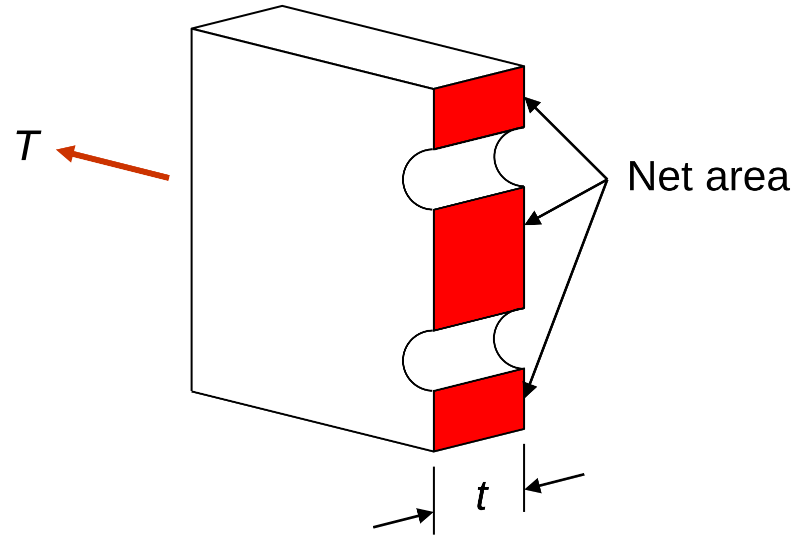
Tensile Rupture : $P_n = F_u A_e$



A_g **Gross Area**	The unreduced area of the member = cross-section total area
A_n **Net Area**	The reduced area of the member = A_g – hole area
A_e **Effective Area**	which may be equal A_n or smaller

Net Area (A_n)

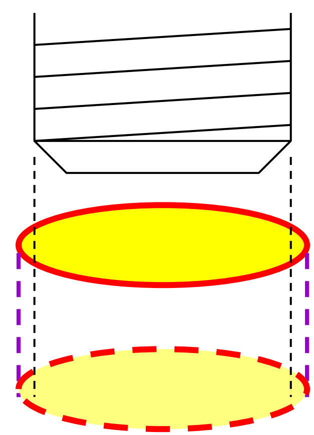




A_g = Gross Area = พื้นที่หน้าตัดทั้งหมด

A_n = Net Area = พื้นที่หน้าตัดสุทธิ

$A_n = A_g$ - พื้นที่รูเจาะ

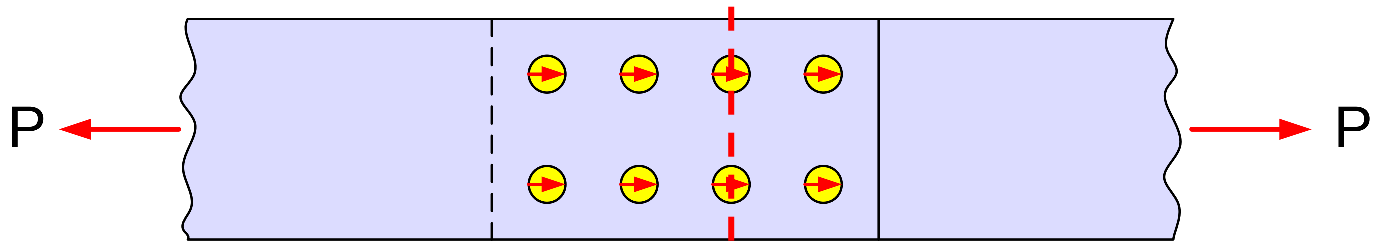


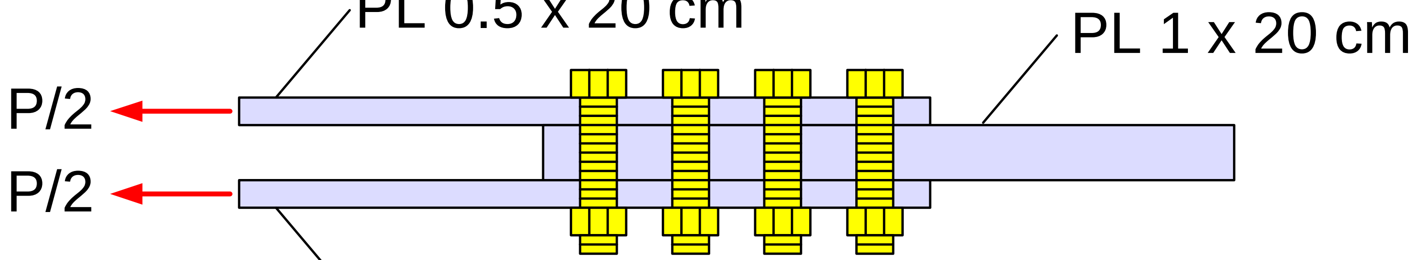
∅Hole = ∅ bolt + punched(1/16” or 1.5 mm)

+ damaged metal (1/16” or 1.5 mm)

= ∅ bolt + 3 mm

Example 3-1: Determine the net area of the 1 x 20 cm plate connected at its end with two lines of 19 mm bolts.





Solution

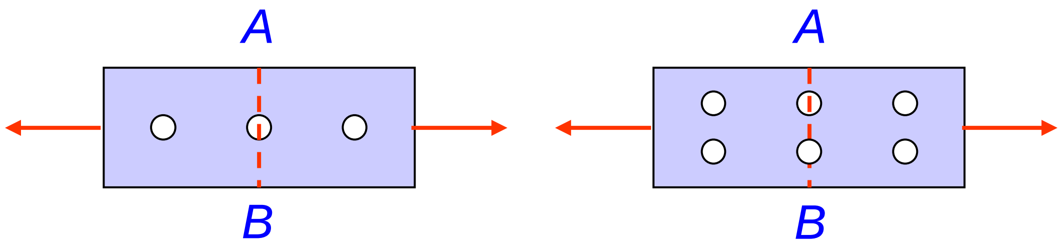
Gross area – Hole area

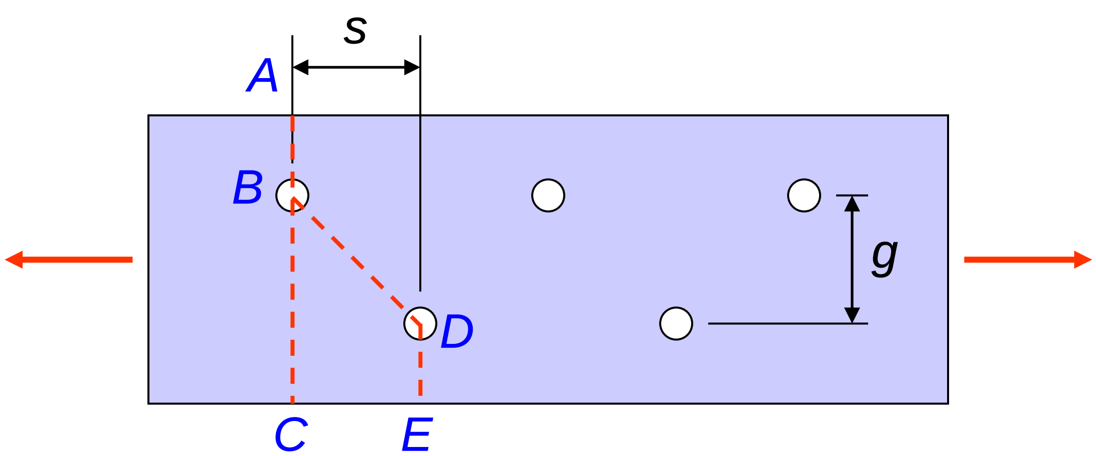
$$A_n = 1 \times 20 - 2(1.9 + 0.3)(1)$$

$$= 15.6 \text{ cm}^2$$ **Ans.**

Staggered Holes

To provide more net area and reduce size of bolt group





s = pitch distance

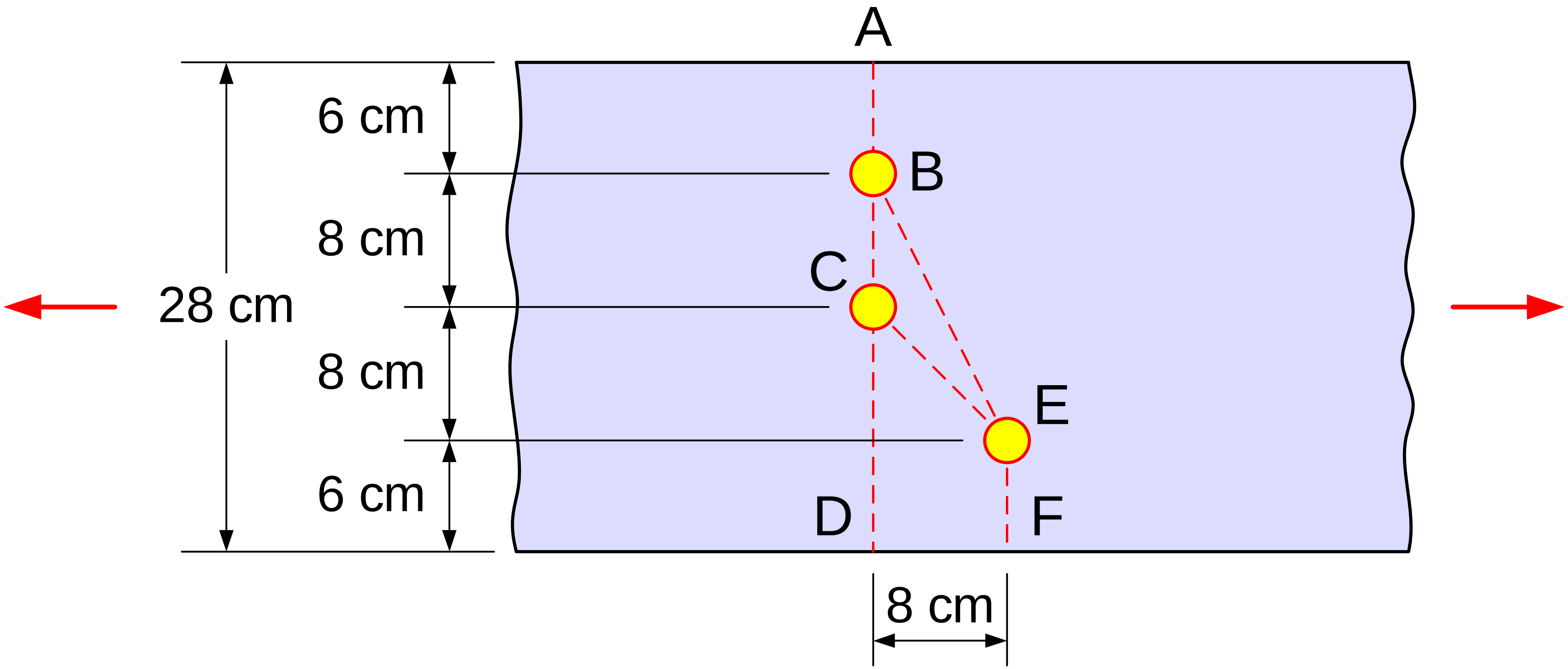
g = gage distance

Possible failure paths: *ABC* or *ABDE*

Compute net area of each path: $$A_n = t_{min}\left[b - n(d + 0.3) + \sum \frac{s^2}{4g}\right]$$

Select the minimum net area

Example 3-2: Determine the critical net area of the 1.2-cm-thick plate. The holes are punched for 19 mm bolts.



Solution Possible critical path are *ABCD*, *ABCEF* or *ABEF*.

Hole diameter to be subtracted is $1.9 + 0.3 = 2.2$ cm

The net areas for each path are as follows:

$$ABCD = (28 - 2(2.2))(1.2) = 28.3 \text{ cm}^2$$

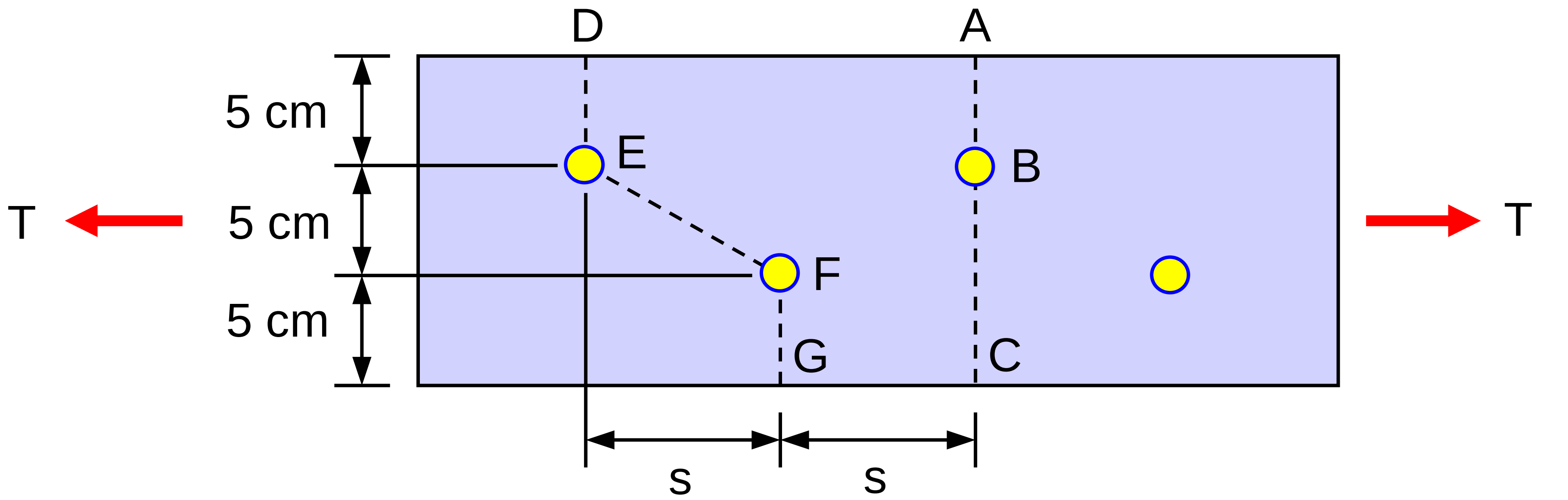
$$ABCEF = \left(28 - 3(2.2) + \frac{8^2}{4(8)}\right)(1.2) = 28.1 \text{ cm}^2$$ **Control**

$$ABEF = \left(28 - 2(2.2) + \frac{8^2}{4(16)}\right)(1.2) = 29.5 \text{ cm}^2$$

It is waste of time to check path *ABEF* for this plate. Two holes need to be subtracted for routes *ABCD* and *ABEF*. As *ABCD* is a shorter routs, it obviously controls over *ABEF*.

How about checking path *ABECD* ?

Example 3-3: Determine the pitch **s** that will give a net area *DEFG* equal to *ABC*. The holes are punched for 19-mm bolts.



Problem: Determine the pitch that give a net area equal to the gross area less one bolt hole.

Solution The hole diameters are 1.9 + 0.3 = 2.2 cm

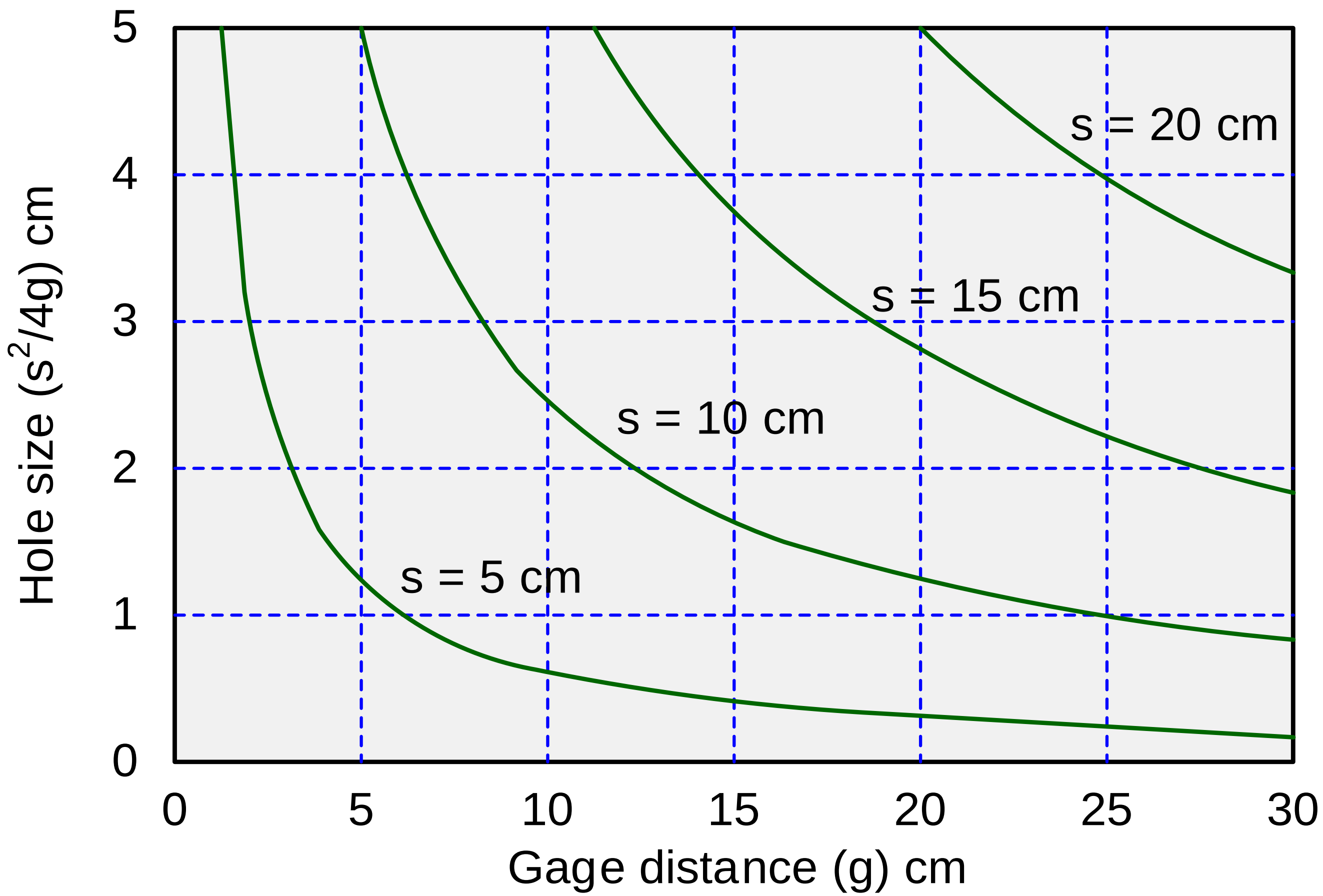
$$ABC = 15 - (1)(2.2) = 12.8 \text{ cm}$$

$$DEFG = 15 - (2)(2.2) + \frac{s^2}{4(5)} = 10.6 + \frac{s^2}{20}$$

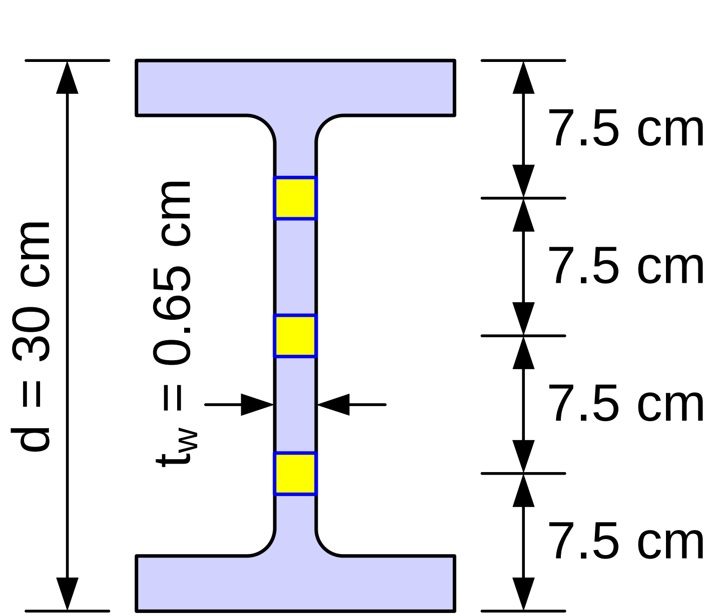
$$ABC = DEFG$$

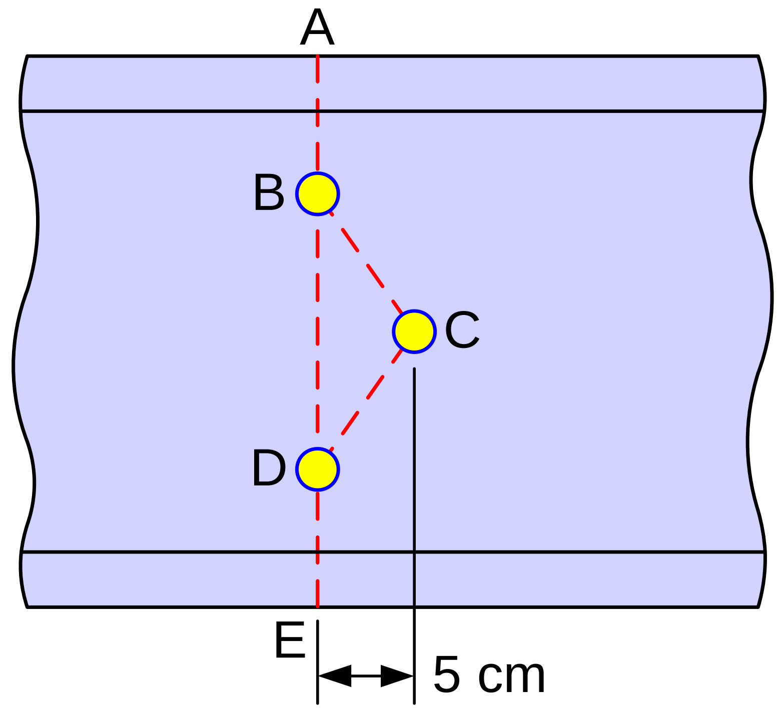
$$12.8 = 10.6 + \frac{s^2}{20}$$

$$s = 6.63 \text{ cm} \leftarrow \text{Minimum pitch}$$



Example 3-4: Determine the net area of the W300 × 36.7 (A_g = 46.78 cm^2). The holes are punched for 22-mm bolts.





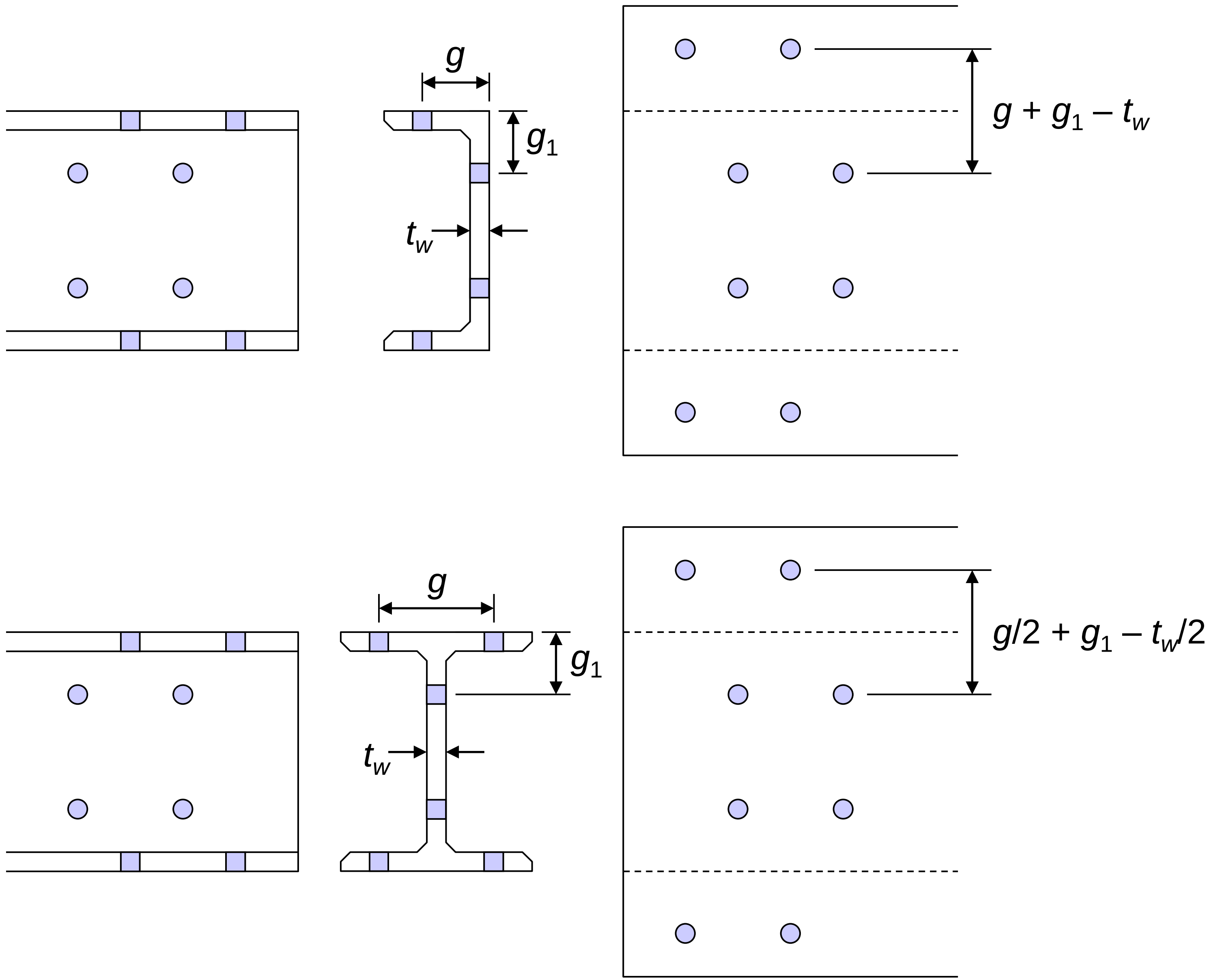
Solution The hole diameters are 2.2 + 0.3 = 2.5 cm

$$ABDE = 46.78 - 2(2.5)(0.65) = 43.53 \text{ cm}^2$$

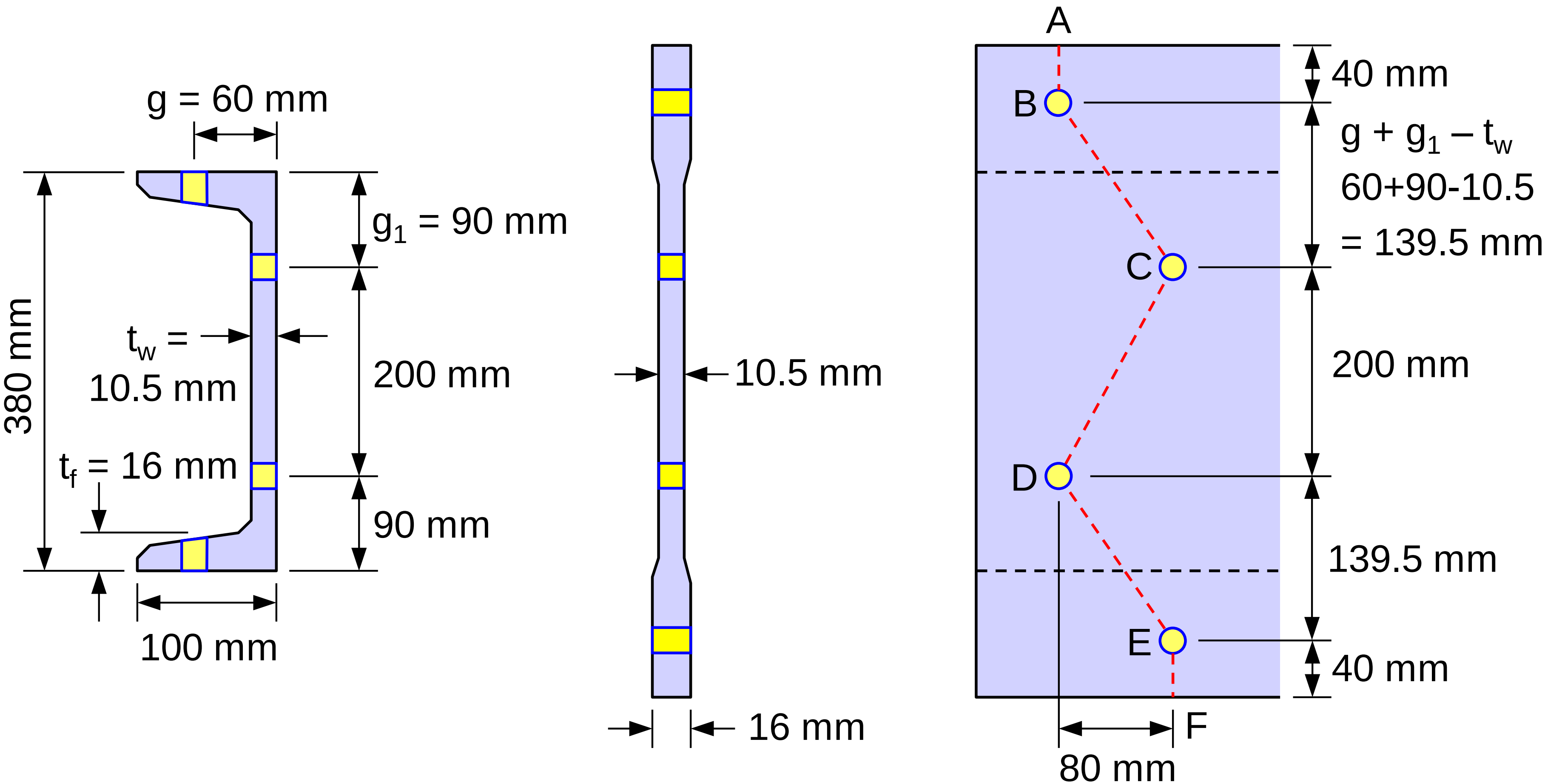
Control

$$ABCDE = 46.78 - 3(2.5)(0.65) + 2\frac{5^2}{4(7.5)} = \boxed{42.99 \text{ cm}^2}$$

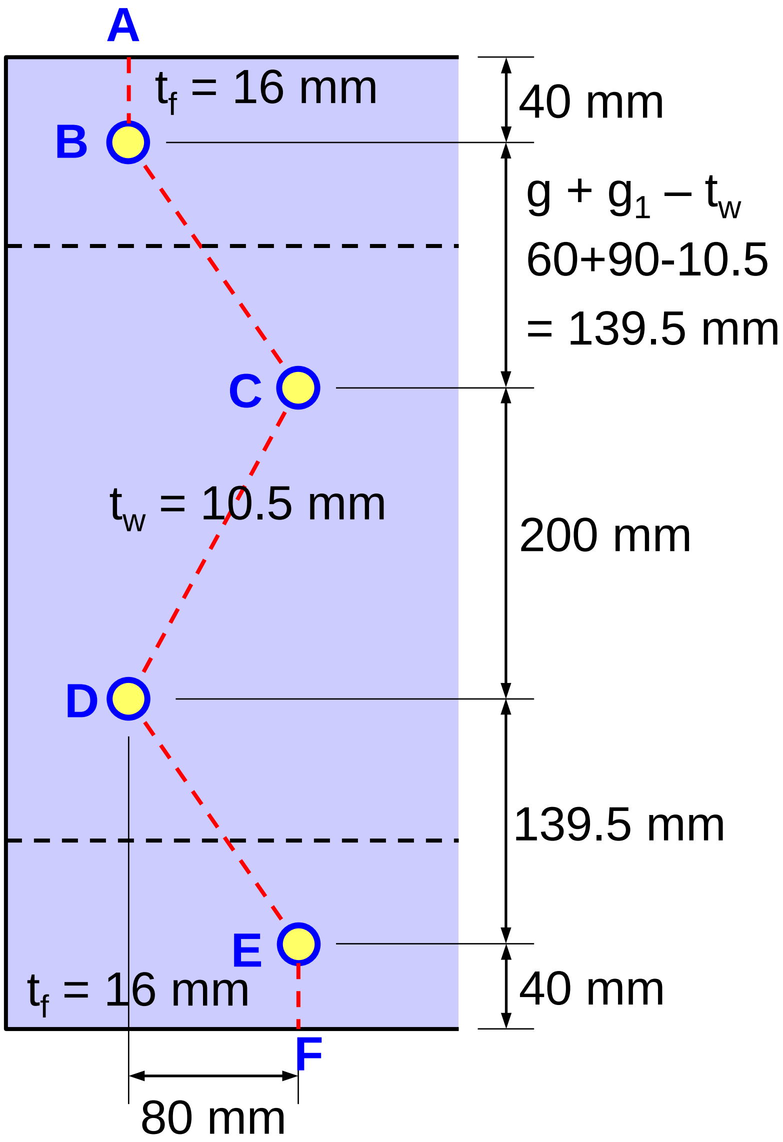
Unfolding of Channel and Wide Flange Sections



Example 3-5: Determine the net area along path ABCDEF for the channel section C380×100×54.5 (A_g = 69.39 cm^2, t_w = 10.5 mm, t_f = 16 mm). The holes are punched for 19-mm bolts.



Solution The hole diameters are 1.9 + 0.3 = 2.2 cm



$$ABCDEF = 69.39 - 2(2.2)(1.6 + 1.05)$$

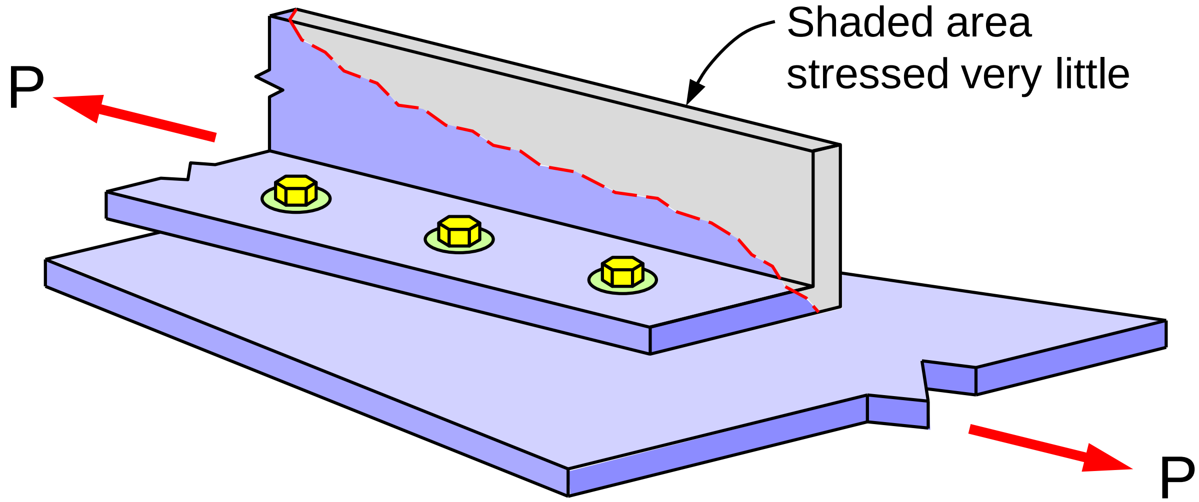
$$+ \frac{8^2}{4(20)}(1.05)$$

$$+ (2)\frac{8^2}{4(13.95)}\left(\frac{1.6 + 1.05}{2}\right)$$

$$= 61.61\ \text{cm}^2$$ Ans.

Effective Net Area (A_e)

When elements of the section are not connected, the actual tensile failure stress will be less than the tensile strength due to nonuniform stress transfer



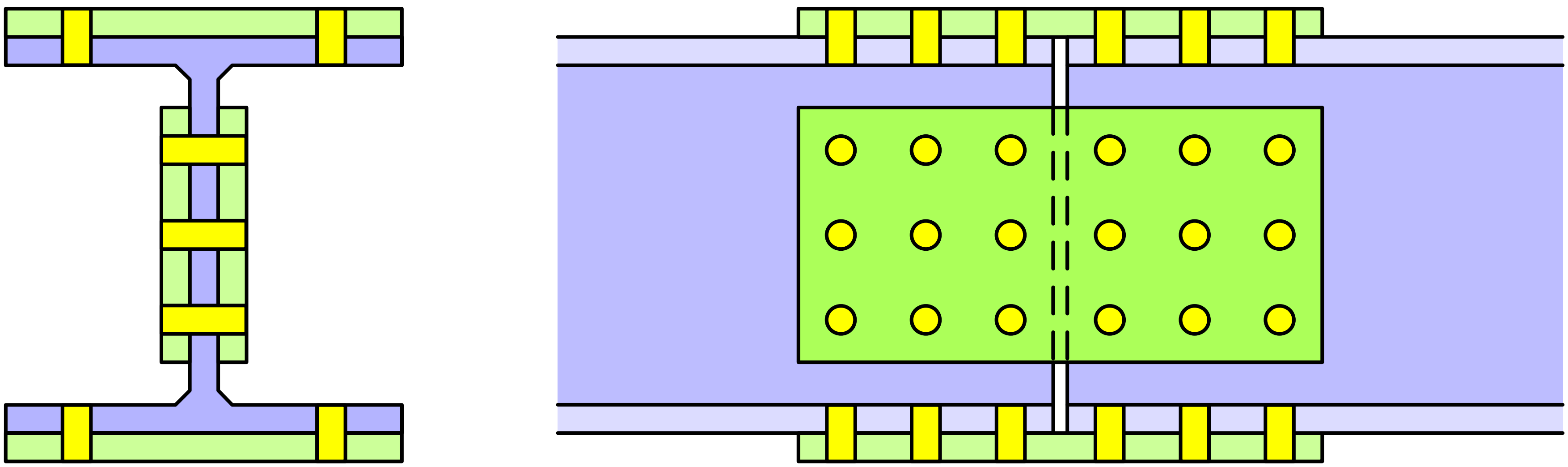
The effective net area of tension members shall be determined as

$$A_e = U A_n$$

where U, the shear lag factor, is determined as shown in Table D3.1.

Effective Net Area (A_e)

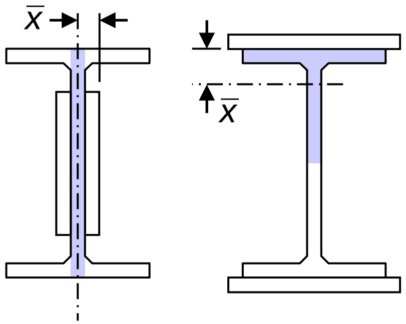
For open sections such as W, C, WT and angle, U need not be less than the ratio of the gross area of the connected elements to the member gross area. (not apply to closed sections such as HSS nor plates)



For bolted splice plates

$$A_e = A_n \leq 0.85A_g$$

TABLE D3.1: Shear Lag Factors for Connections to Tension Members

Case	Description of Element	Shear Lag Factor, U	Example
1	All tension members where the tension load is transmitted directly to each of cross-sectional elements by fasteners or welds (except in Cases 3, 4, 5 and 6)	$U = 1.0$	—
2	All tension members, except plates and HSS, where the tension load is transmitted to some but not all of the cross-sectional elements by fasteners or longitudinal welds (Alternatively, for W, M, S and HP, Case 7 may be used.)	$U = 1 - \bar{x}/L$	
3	All tension members where the tension load is transmitted by transverse welds to some but not all of the cross-sectional elements.	$U = 1.0$ and A_n = area of the directly connected elements	—

$\bar{x}$ = the distance from the centroid of the connected area to the plane of the connection.

L = length of connection.

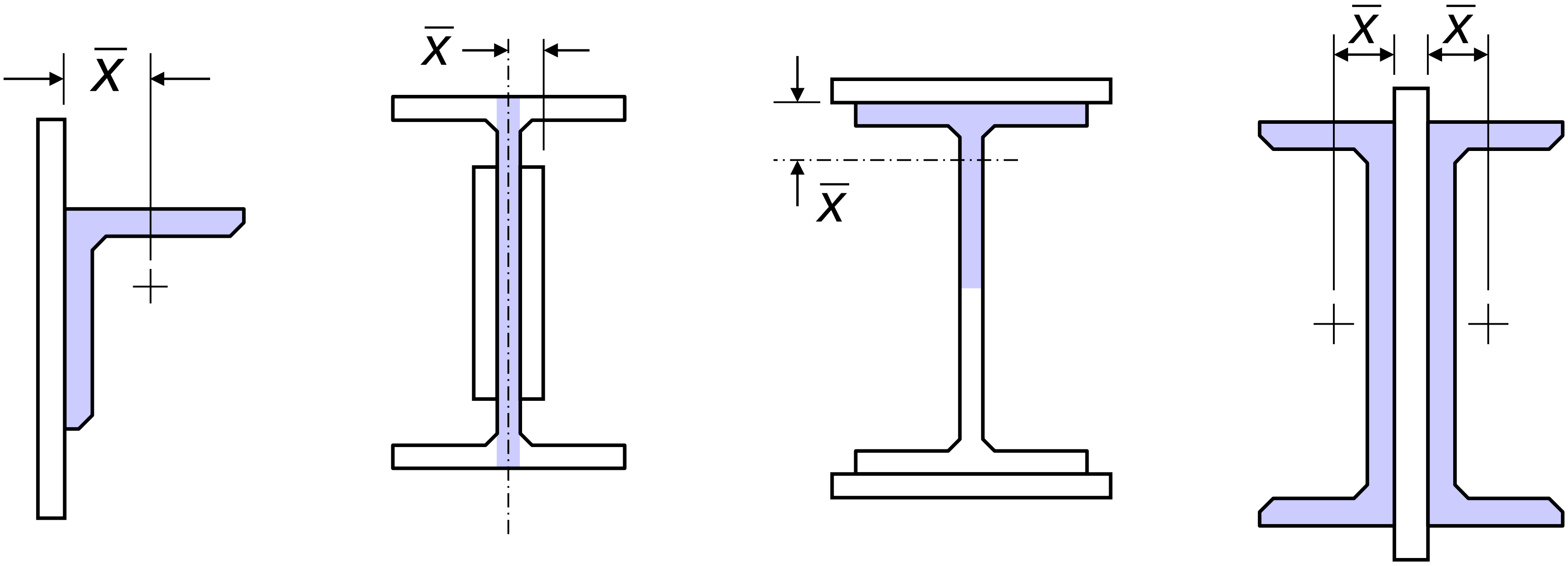
Shear Lag Factor (U)

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

The definition of $\bar{x}$ was formulated by Munse and Chesson (1963).

If a member has two symmetrically located planes of connection,

$\bar{x}$ is measured from the centroid of the nearest one-half of the area.

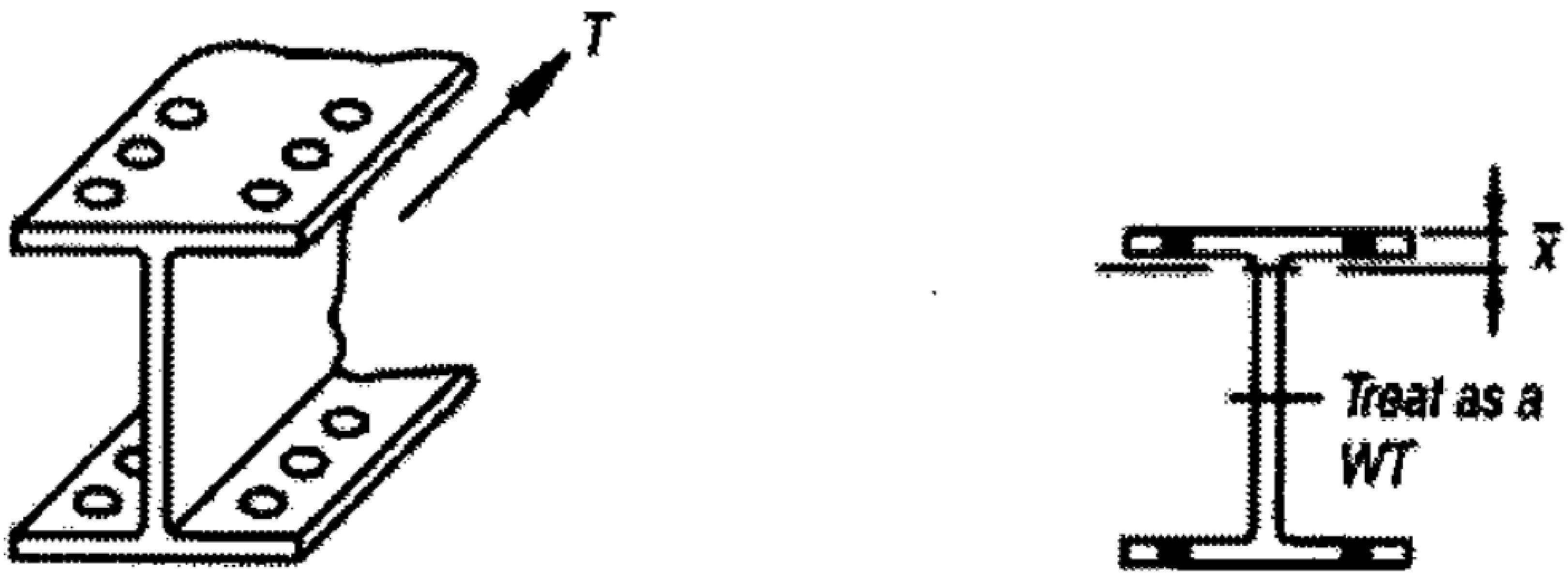


AISC allows to use a larger value of U from other criteria

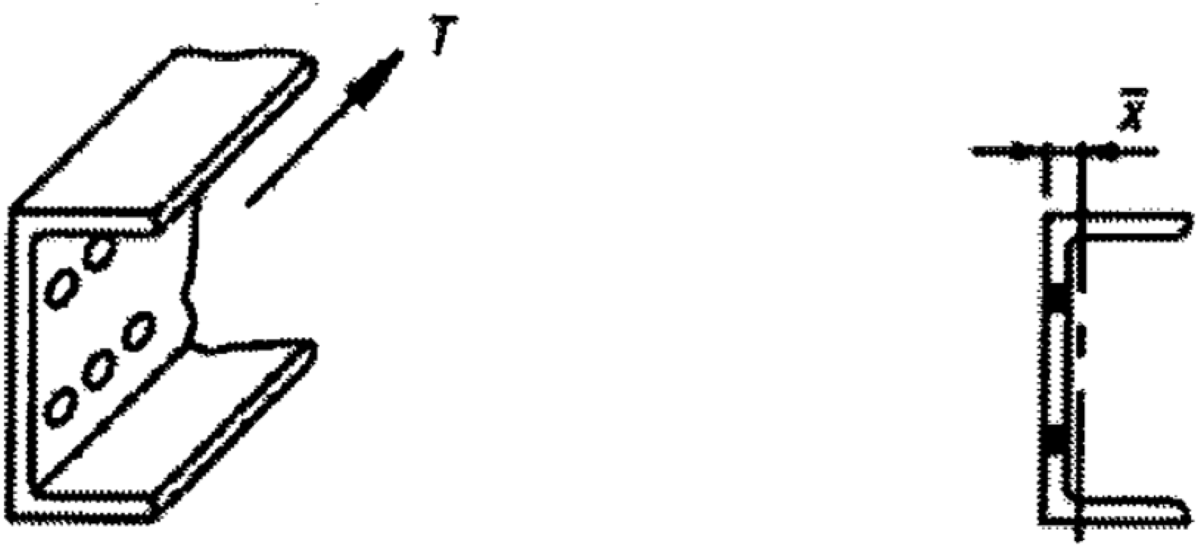
Munse, W.H. and Chesson, E., Jr. 1963. "Riveted and Bolted Joints: Net Section Design." *Journal of the Structural Division*, ASCE 89 (no. ST1): 107-126.

Determination of $\bar{x}$ for U

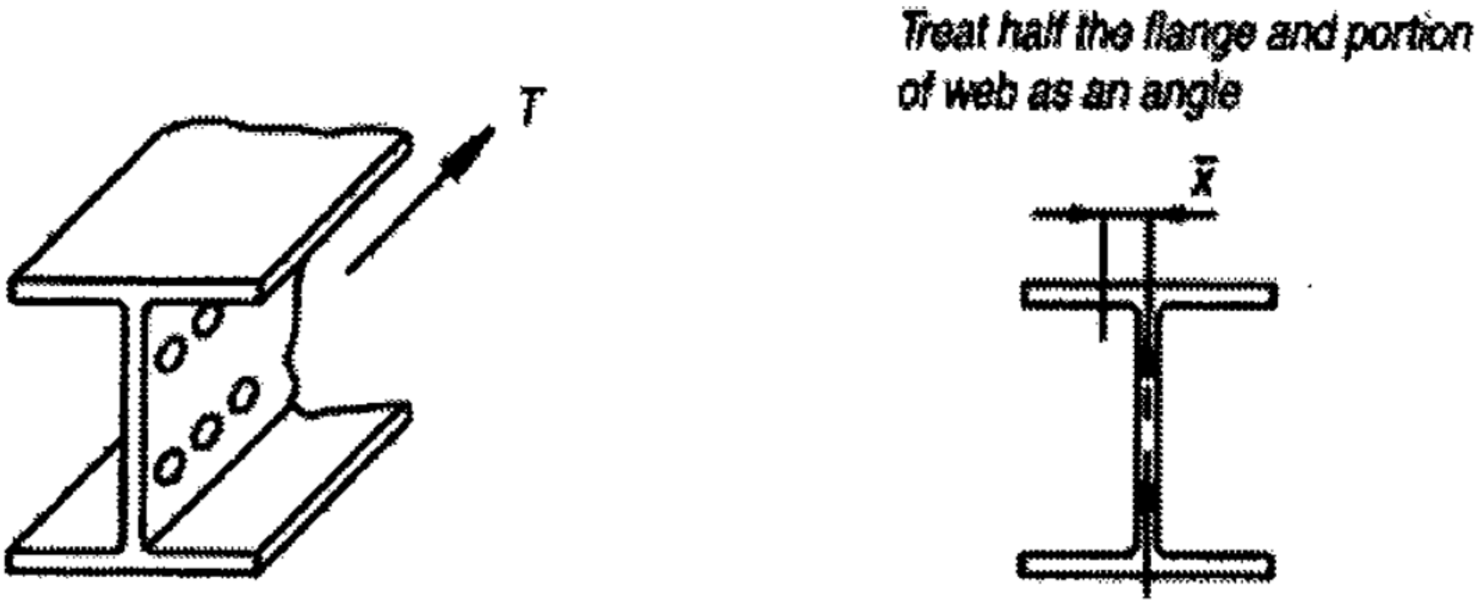
$\bar{x}$ is the perpendicular distance from the connection plane, or face of the member, to the centroid of the member section.



W section with flange connected



Channel section with web connected

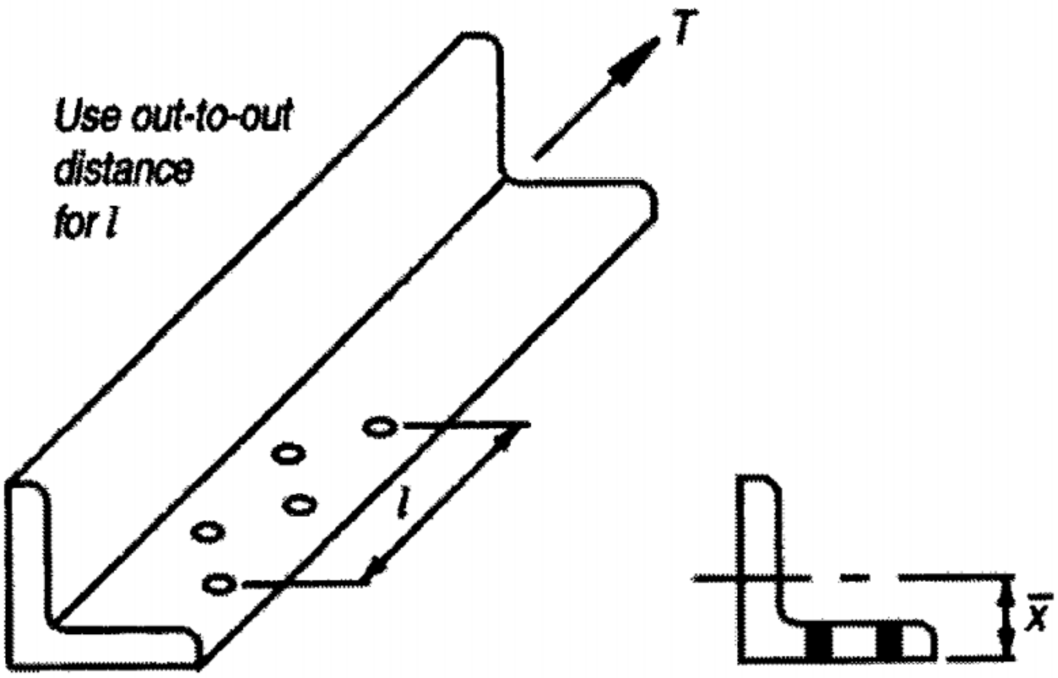


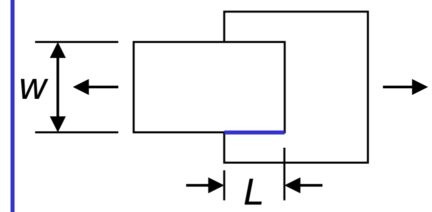
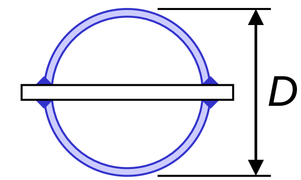
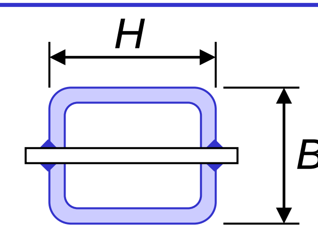
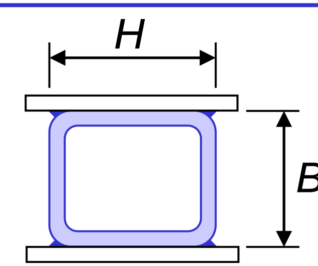
W section with web connected

Determination of L for U

L is the parallel distance to the line of force from the first to the last bolt in the line with maximum number of bolt in the connection or the length of weld.

For staggered bolts, the out-to-out dimension is used for **L**.



Case	Description of Element		Shear Lag Factor, U	Example
4	Plates where the tension load is transmitted by longitudinal welds only.		$L \geq 2w \rightarrow U = 1.0$ $2w > L \geq 1.5w \rightarrow U = 0.87$ $1.5w > L \geq w \rightarrow U = 0.75$	
5	Round HSS with a single concentric gusset plate		$L \geq 1.3D \rightarrow U = 1.0$ $D > L \geq 1.3D \rightarrow U = 1 - \bar{x}/L$ $\bar{x} = D/\pi$	
6	Rectangular HSS	with a single concentric gusset plate	$L \geq H \rightarrow U = 1 - \bar{x}/L$ $\bar{x} = \dfrac{B^2 + 2BH}{4(B+H)}$	
		with two side gusset plates	$L \geq H \rightarrow U = 1 - \bar{x}/L$ $\bar{x} = \dfrac{B^2}{4(B+H)}$	

w = plate width

B = overall width of rectangular HSS measured 90º to the plane of the connection

H = overall height of rectangular HSS measured in the plane of the connection

Case	Description of Element		Shear Lag Factor, *U*	Example
7	W, M, S or HP shapes or tees cut from these shape. (If *U* is calculated per Case 2, the larger value is permitted to be used)	with flange connected with 3 or more fasteners per line in direction of loading	$b_f \geq 2/3d \rightarrow U = 0.90$ $b_f < 2/3d \rightarrow U = 0.85$	—
		with web connected with 4 or more fasteners per line in the direction of loading	$U = 0.70$	—
8	Single angles (If *U* is calculated per Case 2, the larger value is permitted to be used)	with 4 or more fasteners per line in the direction of loading	$U = 0.80$	—
		with 2 or 3 fasteners per line in the direction of loading	$U = 0.60$	—

Eccentric Bracing Connection

Sydney Airport Domestic Terminal - Sydney, Australia

กำลังรับแรงดึง

วสท.

กำลังรับแรงดึงออกแบบ $\phi_t P_n$ และ กำลังรับแรงดึงที่ยอมให้ P_n/Ω ขององค์อาคารรับแรงดึง ต้องมีค่าไม่เกินกำลังรับแรงดึงที่คำนวณโดยกำลังดึงครากบนพื้นที่หน้าตัดรวม และกำลังดึงฉีกขาดบนพื้นที่หน้าตัดสุทธิ

(ก) สำหรับกำลังดึงครากบนพื้นที่หน้าตัดรวม คำนวณโดย

$$P_n = F_y A_g \tag{4.2-1}$$

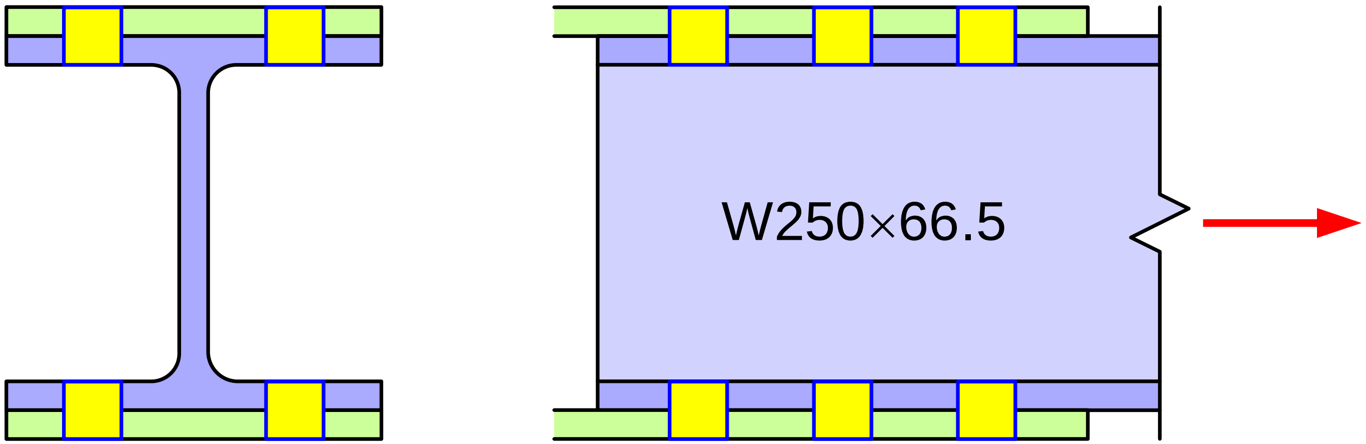
$$\phi_t = 0.90 \text{ (LRFD)} \qquad \Omega_t = 1.67 \text{ (ASD)}$$

(ข) สำหรับกำลังดึงฉีกขาดบนพื้นที่หน้าตัดสุทธิ คำนวณโดย

$$P_n = F_u A_e \tag{4.2-2}$$

$$\phi_t = 0.75 \text{ (LRFD)} \qquad \Omega_t = 2.00 \text{ (ASD)}$$

Example 3-6: Determine the LRFD design tensile strength and the ASD allowable design tensile strength for a W250×66.5 with two lines of 19-mm diameter bolts in each flange using A36 steel with F_y = 2,500 kg/cm^2 and F_u = 4,000 kg/cm^2. There are assumed to be at least three bolts in each line 10-cm on center, and the bolts are not staggered with respect to each other.



Solution W250×66.5 (A_g = 84.7 cm^2, d = 24.8 cm, b_f = 24.9 cm, t_f = 1.3 cm)

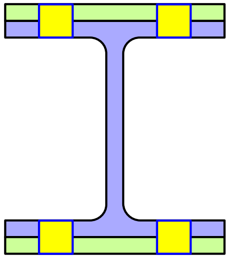
(a) Gross section yielding

$$P_n = F_y A_g$$

$$= (2.5)(84.7) = 212 \text{ tons}$$

LRFD	ASD
$\phi_t = 0.9$ $\phi_t P_n = 0.9(212)$ $= 191 \text{ tons}$	$\Omega_t = 1.67$ $\dfrac{P_n}{\Omega_t} = \dfrac{212}{1.67}$ $= 127 \text{ tons}$

(b) Tensile rupture strength



$$A_n = 84.70 - 4(1.9 + 0.3)(1.3)$$

$$= 73.26 \text{ cm}^2$$

Referring to Appendix A for one-half of a W250×66.5 (WT125×33.2)

$$\bar{x} = 1.98 \text{ cm } (c_x \text{ from Table A-3})$$

Length of connection, $L = 2(10) = 20$ cm

From Table D3.1 (Case 2) $U = 1 - \dfrac{\bar{x}}{L} = 1 - \dfrac{1.98}{20} = 0.90$

But $b_f = 24.9 \text{ cm} > \frac{2}{3}d = \frac{2}{3}(24.8) = 16.5 \text{ cm}$

From Table D3.1 (Case 7) $U = 0.90$ (same value)

$$A_e = U A_n = 0.90(73.26) = 65.93 \text{ cm}^2$$

$$P_n = F_u A_e = (4.0)(65.93) = 264 \text{ tons}$$

LRFD	ASD
$\phi_t = 0.75$ $\phi_t P_n = 0.75(264)$ $= 198 \text{ tons}$	$\Omega_t = 2.00$ $\frac{P_n}{\Omega_t} = \frac{264}{2.00}$ $= 132 \text{ tons}$

Ans. LRFD = 191 tons (Yielding control)

ASD = 127 tons (Yielding control)