Steel Structures

(Lectures)

Ph.D.

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"Steel Structures"

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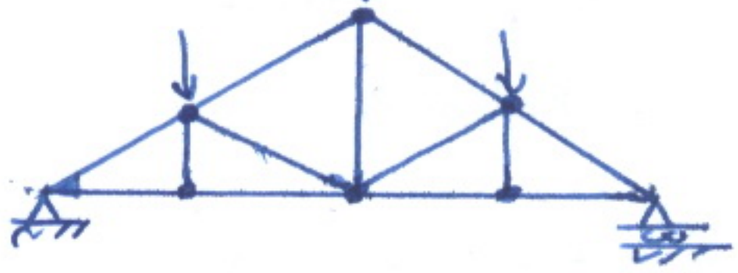
Ch.①

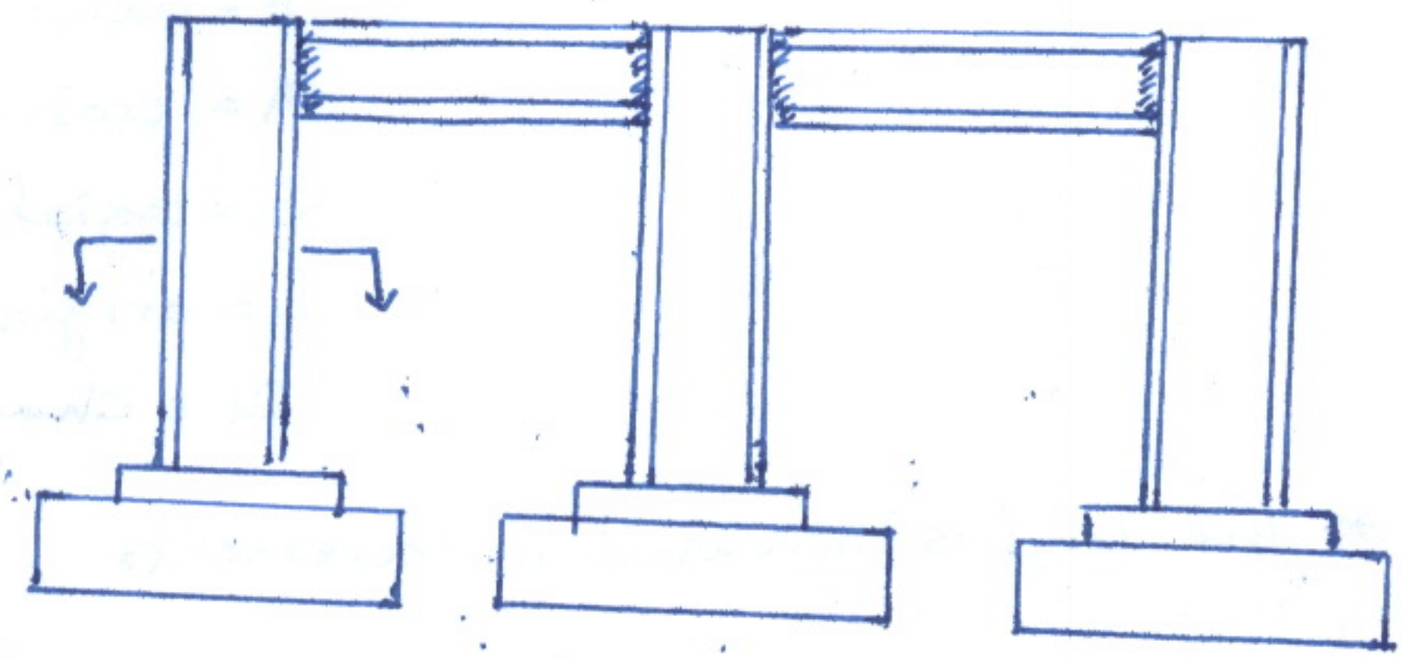
1.1 Structural Design :

The determination of overall proportions & dimensions of the supporting Framework and the selection of the cross sections of the individual members (wether steel structure or reinforced concrete structure).

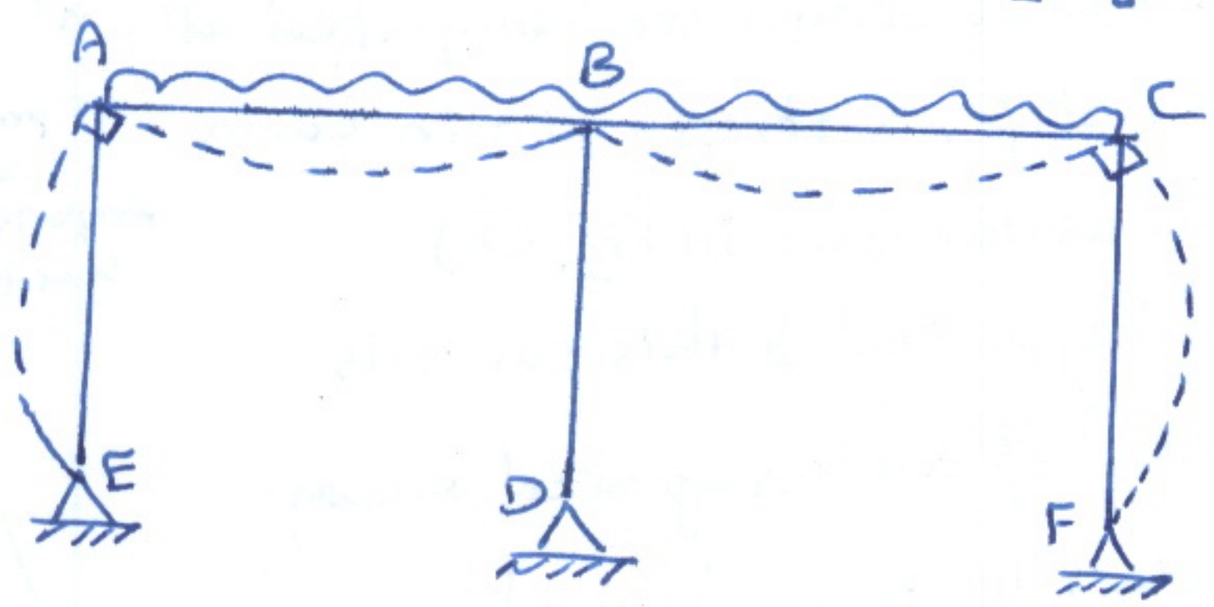
* Type of structure.
  a- Truss
  b- Rigid Frame



- members AB & BC (beams)
- member BD comp. only (Columns)
- members AE & CF axial compression + Bending moment. (beam – column)



Typical Section H



1.2 STRUCTURAL STEEL

* The characteristics of steel are of the most interest to structural Engineers & can be examined by plotting the results of a tensile test.

* The test specimen is subjected to an axial Load (P) as shown in fig. (1)

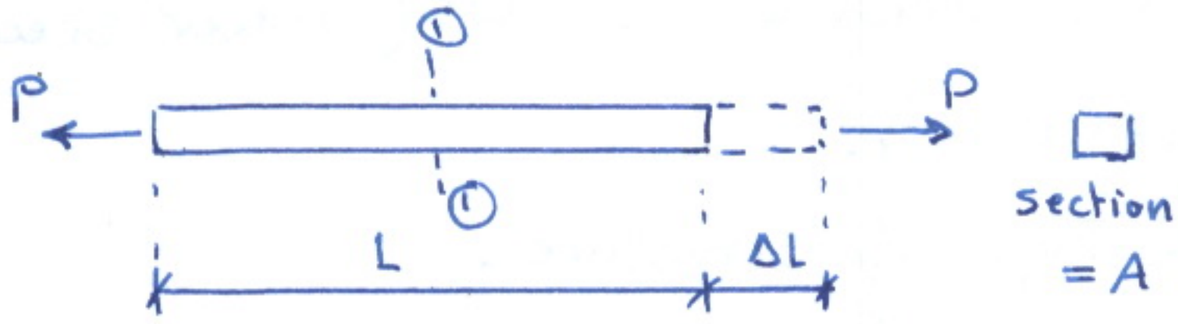


Fig. (1)

The stress & strain can be computed as follows

$$f = \frac{P}{A}, \quad \epsilon = \frac{\Delta L}{L}$$

where:

f = axial tensile stress
P = axial load
A = cross-sectional area
ϵ = axial strain
L = origin length
ΔL = change in length

* The load is increased in increments from zero up to the point of fracture, and stress and strain are computed at each step, a stress-strain curve such as the one in fig. (2) can be plotted & this curve is typical of a class of steel known as ductile or mild steel

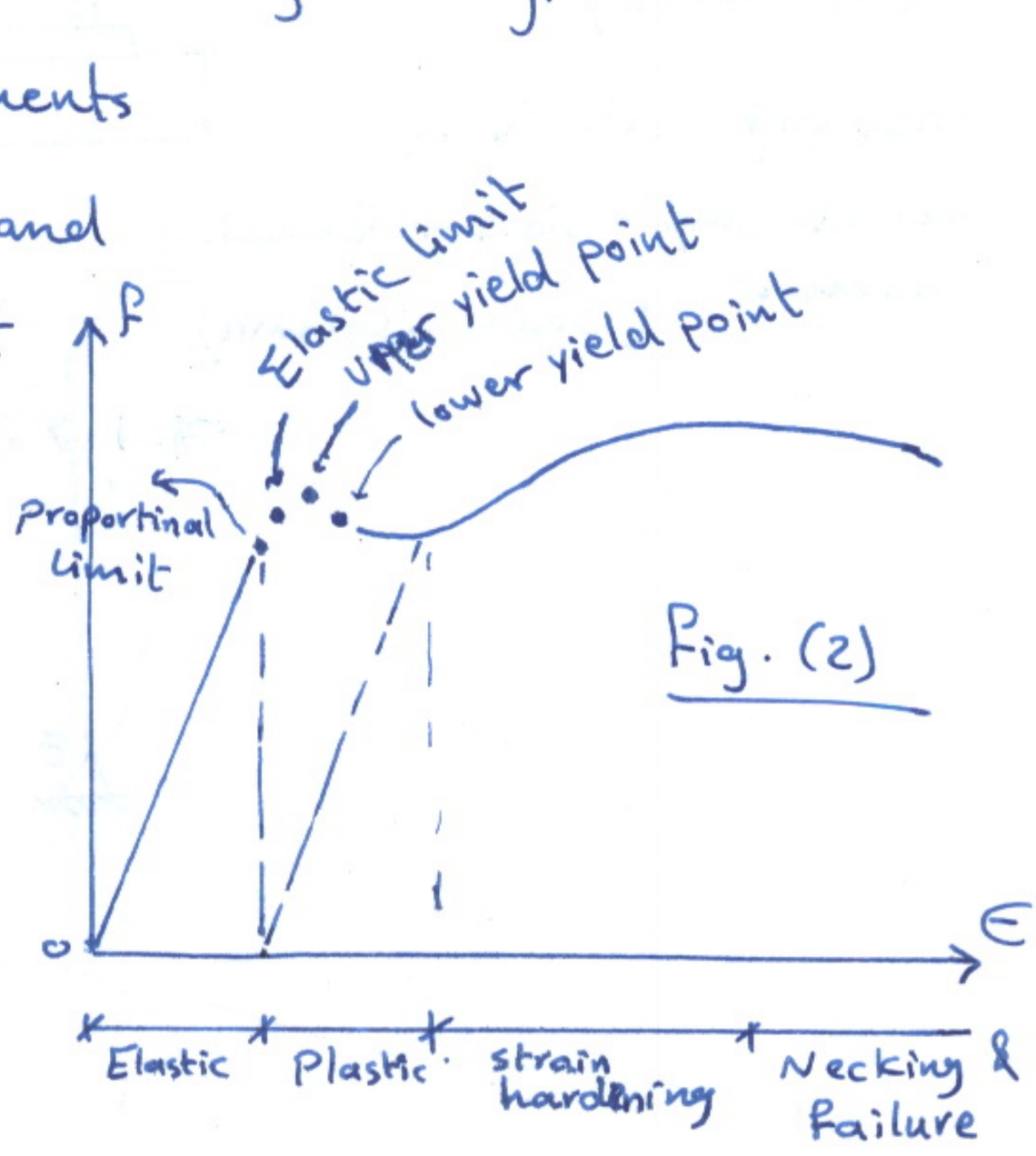


Fig. (2)

* The relationship between stress & strain is linear upto a point called the proportional limit.

The material is said to follow Hook's Law.

* This type of steel is called ductile because of its ability to undergo large deformation before fracturing. Ductility can be measured by the elongation (e) (usually expressed as a percentage)

$$e = \frac{L_f - L_o}{L_o}$$ where L_f = length of speciment at fracture.

L_o = original length of speciment.

Fig (3) shows an idealized version of this stress-strain Curve, in fig (2) the proportional limit, elastic limit and the upper & lower yield points are all very close to one another and are treated as a single point called the yield point defined by the stress (Fy).

The other point of interest to the structural engineer is the max. value of stress that can be attained (تحقيقه / الوصول اليه), called the Ultimate tensile strength (Fu).

The ratio of stress to strain within the elastic range called Young's modulus (E) or modulus of elasticity.

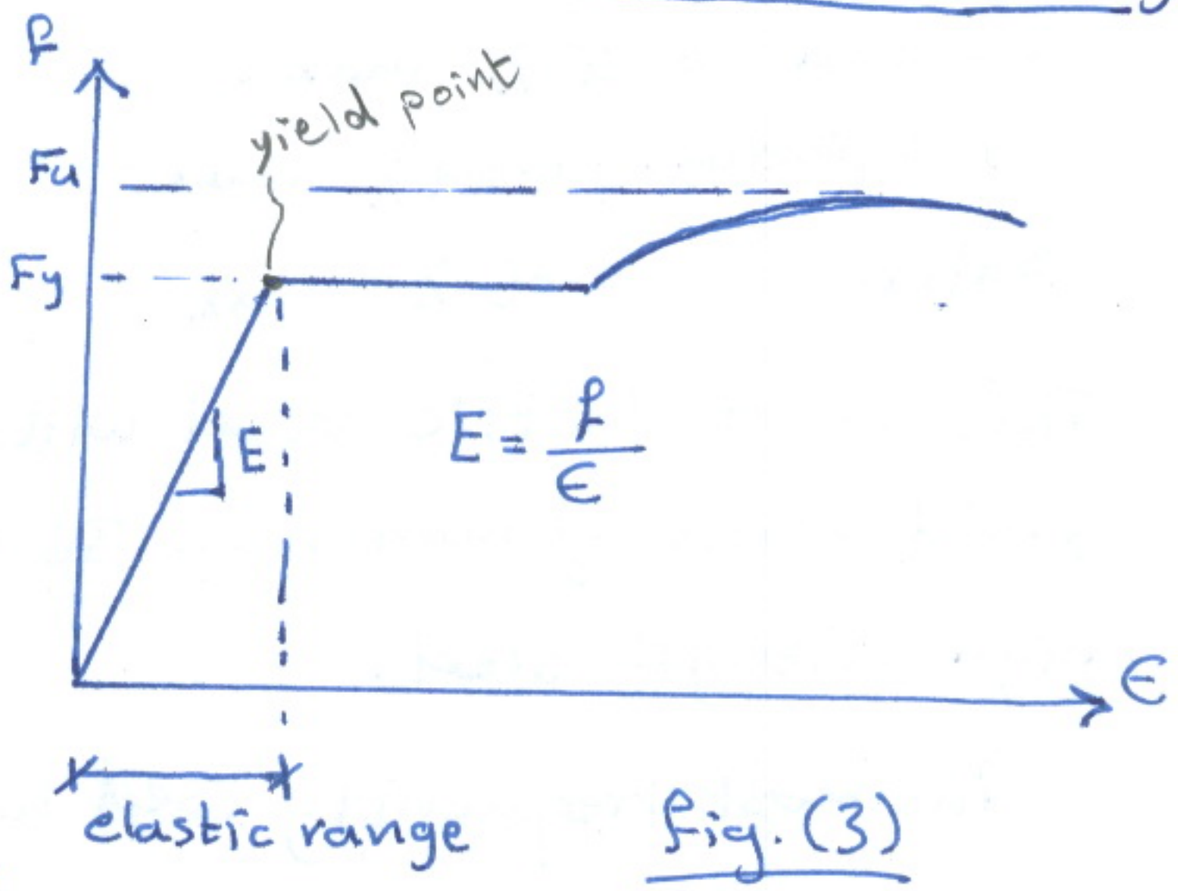


Fig. (3)

structural steels can be grouped according to their composition as follows :-

1- Plain carbon steels : mostly iron and carbon with less than 1% Carbon.

2- Low-alloy (ممزوج) steels : Iron and carbon plus other components usually Comprising (يحتوي) less than 5%

3- high-alloy steels: Similar in composition to the low-alloy steels but with a higher percentage of the other components.

Different grades of structural steel are identified by the American Society for Testing and Materials (ASTM).

The most commonly used structural steel today is a mild steel ASTM A36 (or A36 for short); it has a stress-strain curve of the type shown in Fig.(2) & Fig.(3). and has the following tensile properties.

F_y = 36 000 Psi (36 ksi) yield stress

F_u = 58000 — 80 000 psi (58-80 ksi) Tensile strength

A36 steel is a plain Carbon steel with the following components (other than iron).

Carbon 0.26 % max.
Phosphorous 0.04 % max.
Sulfur 0.05 % max

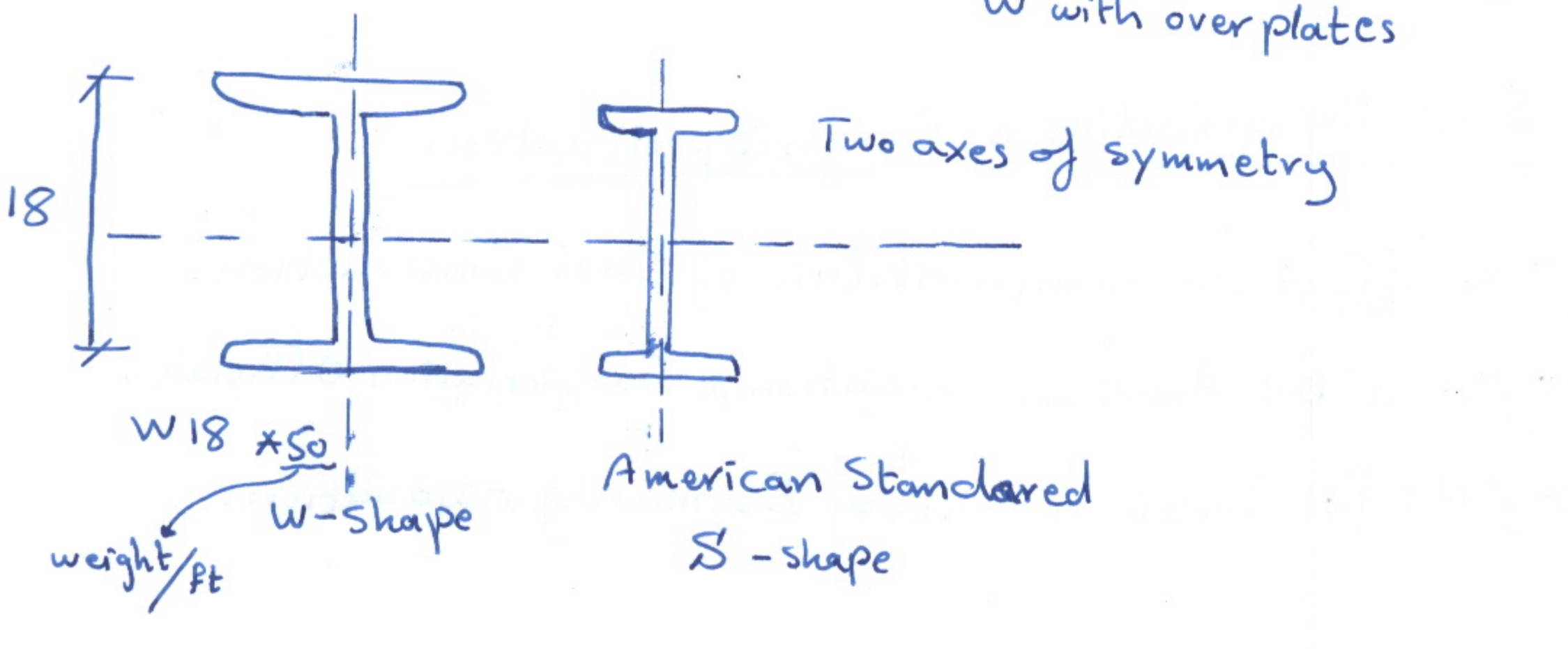
This is a ductile steel with an elongation of 20 %. A steel with yield stress of more than 36 ksi is usually considered to be high strength steel.

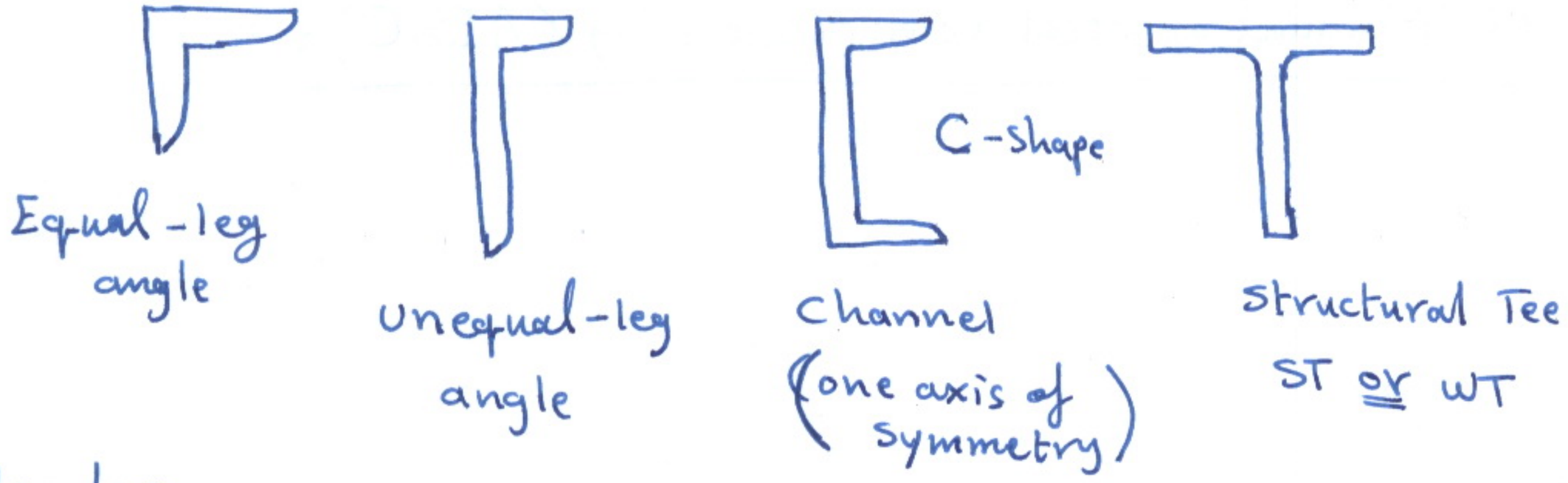
The most frequently used high-strength steels are those with a yield stress of 50 ksi & tensile strength of either 65 ksi or 70 ksi although steel with a yield stress of 100 ksi is available.

* There are two Category of steel products for structural application :

a- hot-rolling (2000 °F) (1093.3 °C) → Standared shape, Built-up Shape (Plate girder, Double angle W with over plates)

b- Cold-formed steel





1.3 loads :

- Dead load.
- Live load → Static, dynamics (impact)
- wind load.
- Earthquake.

1.4 Design Philosophies:

a- allowable stress design - elastic design of working stress design.

b- plastic design.

c- load & resistance Factor design.

1.5 Building Codies & Design Specifications

* AISC : American Institute of steel Construction.
* AASHTO : American Association & Transportation Officials.
* AREA : American Railway Engineering Association.

1.6 Manual of steel Construction by (AISC):

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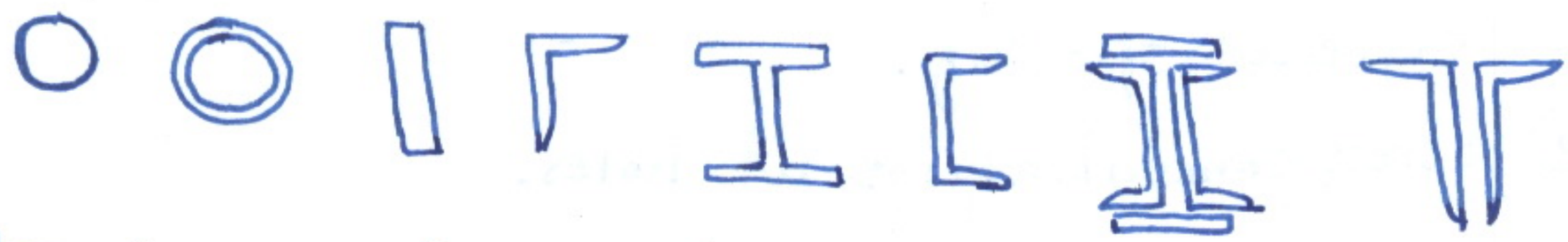
Ch.2

Tension Members

are defined as structural elements that are subjected to axial tensile forces.

* The cross-sectional area is the only determinant of tension member strength for that any cross-sectional configuration may be used as shown in Fig.(1).



The stress in an axially Loaded tension member is given by:

$f = \frac{P}{A}$ where P = magnitude of the load

A = Cross-sectional area normal to the load.

if a tension member has a variable cross section, the stress is a function of the particular section under consideration. The presence of holes in a member also influences the stress at a cross section through the hole & holes. At such allocation the cross-sectional area will be reduced by an amount equal to the area removed by the holles.

Allowable stress (F_t)

$F_t = 0.6\,F_y$ on the gross area (A_g) , F_y = min. yield stress

$F_t = 0.5\,F_u$ on the effective net area (A_e) , F_u = min. tensile strength

The requirement for checking the stress on both the effective net area & the gross area can be explained in terms of two different failure conditions:-

1. excessive deformation - (yielding control)
2. Fracture.

$\frac{Ae}{Ag} < \frac{Fy}{0.833\,Fu}$ the fracture criterion will control.

$\frac{0.5}{0.6}$

$\geq \frac{Fy}{0.833\,Fu}$ failure will be by yielding of the gross section.

The connection almost always weakens the tension member and the measure of its influence is called the joint efficiency, which is a function of:

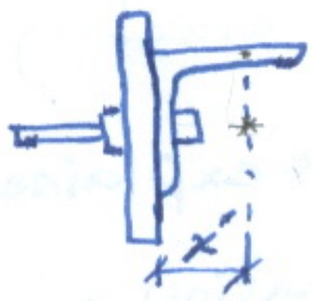
1. the ductility of the material.
2. Fastener spacing.
3. stress concentrations at holes.
4. Fabrication procedure.
5. shear lag (تأخر القص), the most important one.

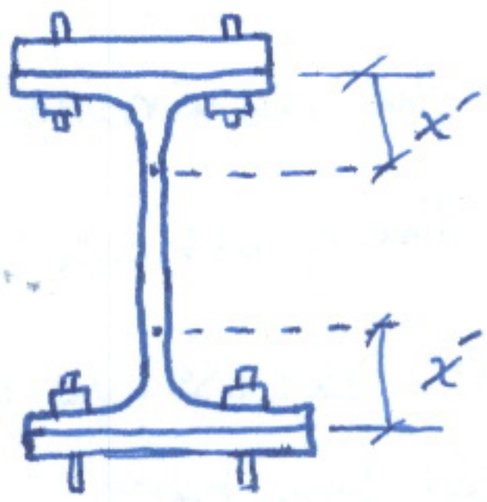
يحدث تأثير القص عندما لا تكون كل اجزاء المقطع مرتبطة بالصفيحة التثبيت وعليه يحدث تشديد للقص في الجزء المربتط
The shear lag occurs when all elements of the cross section are not
من المقطع فقط.
connected. This happens when only for example one leg of an angle is connected to a gusset plate. So the connected element becomes over loaded and the unconnected part is not fully stressed.

The shear lag be accounted for by using a reduced or effective net area, obtained by multiplying the computed net area by the reduced factor $\left(1 - \frac{x'}{L}\right)$ where:

x' : the distance from the centroid of the connected area to the shear plane of the connection.

L : the length of the connection.





$Ae = C_t \cdot An$

where: C_t = reduction coefficient (AISC 1.14.2.2)

An = computed net area.

C_t values are based on connections which falling in to two categories :- either two fasteners per line in direction of the applied load or three or more per line.

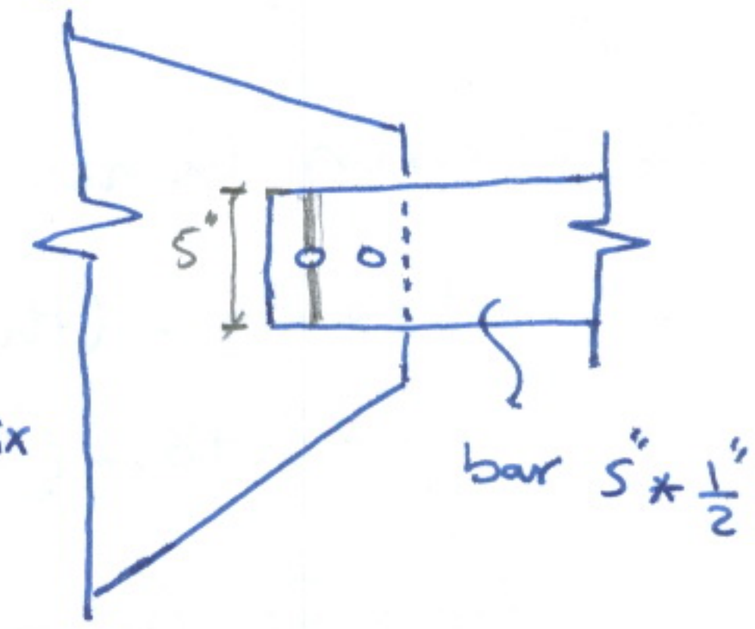
There are three different values for C_t as shown in following :-

① $C_t = 0.9$ for W-shapes, M-shapes and S-shapes that have a flange width to web depth ratio at least $(2/3)$ and are connected through the flanges with at least three fasteners per line in the direction of applied stress.

② $C_t = 0.85$ for all other shapes (including built-up shapes) with at least three fasteners per line or more.

③ $C_t = 0.75$ for all members with only two fasteners per line or less.

Ex,) Find the max. load for the tension member shown in fig. if A36 steel is used. The holes are for $\frac{7}{8}$" dia. bolts.



① stress on the gross section :

$A_g = 0.5(5) = 2.5\ in^2$ gross area for bar.

$F_t = 0.6\,F_y = 0.6(36) = 21.6$ ksi (table 1, Appendix A AISC spec.)

$\therefore P = A_g * F_t = 2.5(21.6) = \cancel{53.5}\ 54^k$

② stress on the net section :

effective hole diameter = $\frac{7}{8}" + \frac{1}{8}" = 1"$ ← Clearance (AISC 1.23 Fabrication)

$A_n = 0.5(5-1) = 2\ in^2$

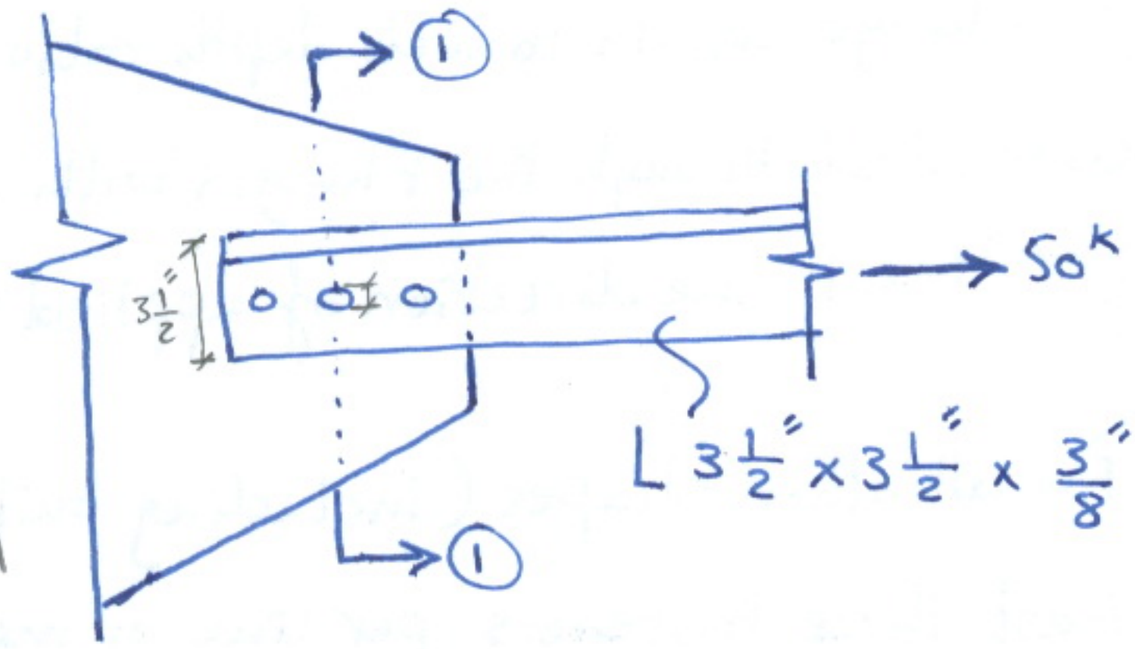
$\therefore A_e = A_n = 2\ in^2$ all elements of cross section are connected.

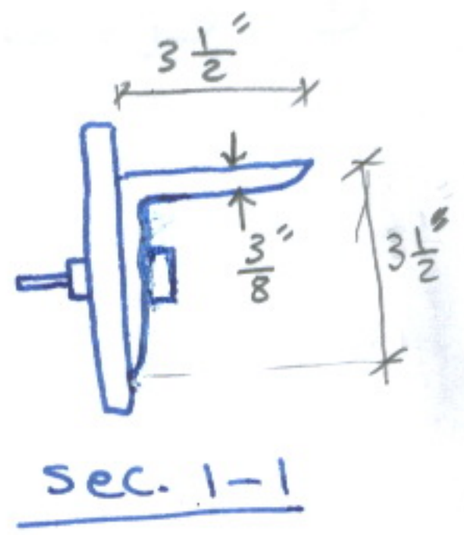
$F_t = 0.5\,F_u = 0.5\,(58) = 29$ ksi

$\therefore P = A_e \cdot F_t = 2\,(29) = 58^k$

$\therefore$ max. permissible load $= \cancel{53.5}\ 54^k$

Ex 2) Check the stresses in the tension member shown in fig. A36 steel is used and the holes are for $\frac{7}{8}$" dia. bolts:





sec. 1–1

$A_g = \left(3\frac{1}{2} + 3\frac{1}{2} - \frac{3}{8}\right) * \frac{3}{8}$

$= 2.48\ in^2$

or from Manual of steel

① Stress on the gross area:

$\boxed{A_g = 2.48\ in^2}$ for L $3\frac{1}{2}$" * $3\frac{1}{2}$" × $\frac{3}{8}$" (AISC Manual)

$F_t = \frac{P}{A_g} = \frac{50}{2.48} = 20.2$ ksi

$F_t = 0.6\,F_y = 21.6$ ksi $\quad\therefore f_t < F_t \quad\therefore$ ok

② Stress on the net area:

$A_n = A_g - (\text{thickness} \times \text{hole diameter})$

$= 2.48 - \left(\frac{3}{8} * \left(\frac{7}{8} + \frac{1}{8}\right)\right) = 2.1\ in^2$

$A_e = C_t \cdot A_n = 0.85\,(2.1) = 1.78\ in^2$

$\therefore f_t = \frac{50}{1.78} = 28.1$ ksi

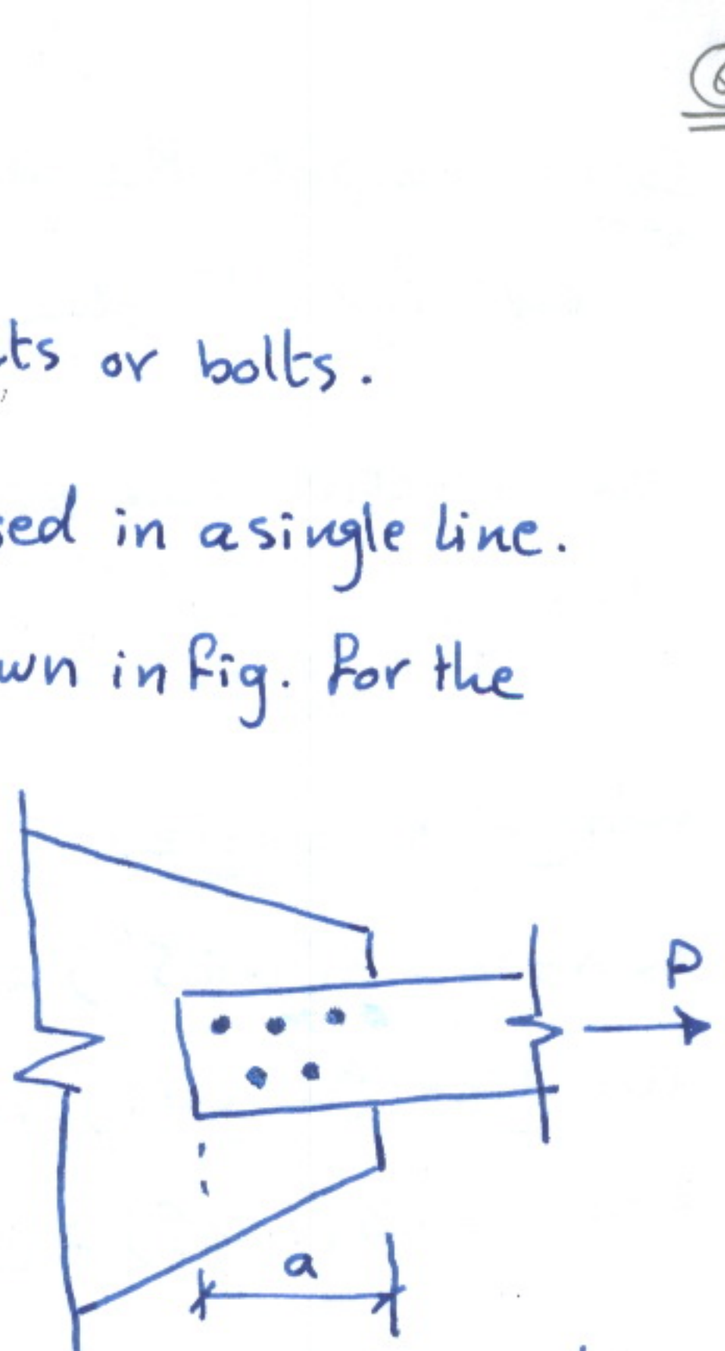
$F_t = 0.5\,F_u = 0.5\,(58) = 29$ ksi

$\therefore f_t < F_t$ o.k

Staggered Fasteners : التثبيت المتراوح

If a tension member connection is made with rivets or bolts.

* The net area will be max. if the fasteners are plased in a single line.
* If there are limitations on dimension (a) as shown in fig. For the connection we need to use more than one line for fasteners if this must be done, the reduction in cross-sectional area is minimized if the fasteners are arranged in staggered pattern as shown.



* Sometimes staggered fasteners are required by the geometry of a connection like the one shown in fig (a).

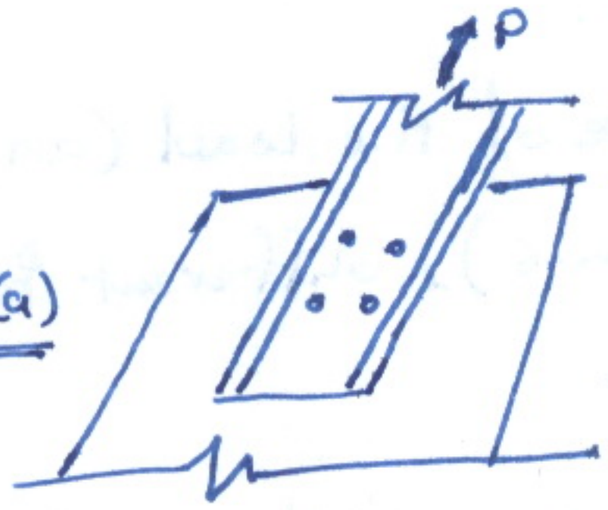


Fig (a)

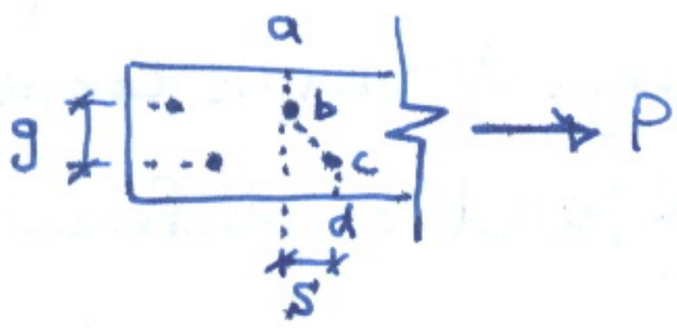


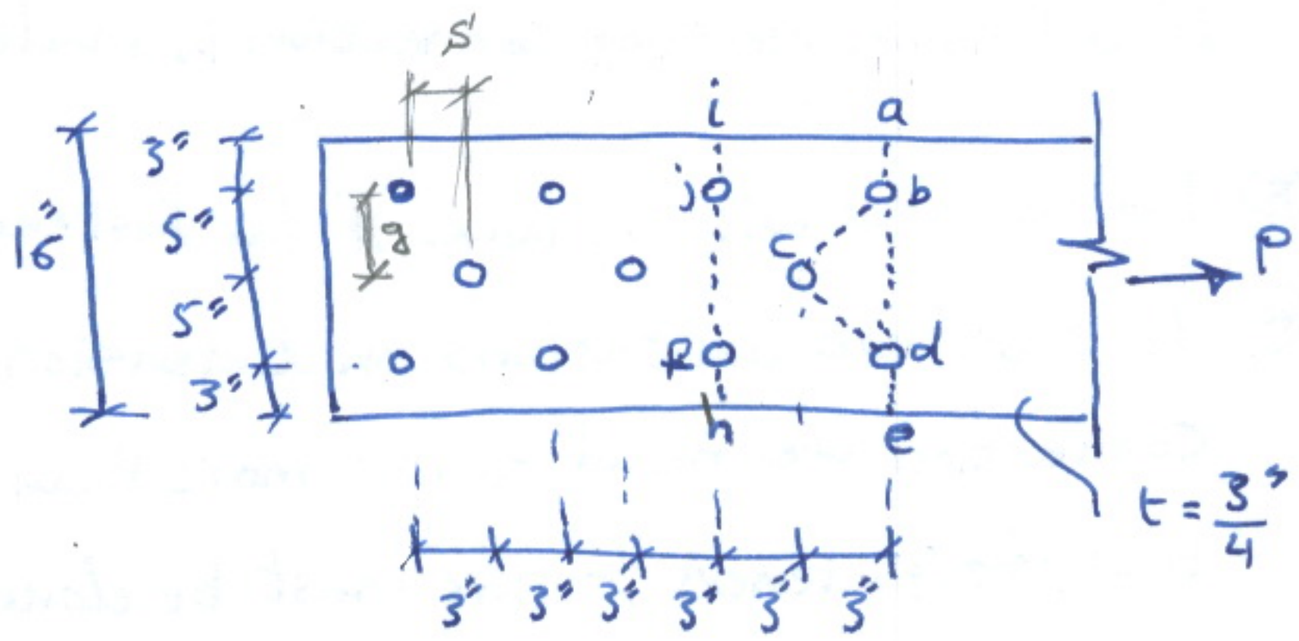
Fig.(b)

* If the amount of stagger is small enough, the influence of an offset holes may be felt by a nerby cross section and failure along an inclined path a b c d such as shown in fig.(b).

In such case the relationship $f = \frac{P}{A}$ does not apply and stresses on the inclined portion (bc) are combination of tensile & shearing stresses. for that the AISC specification use some approximation for measuring the net width (w_n) by subtracting the sum of the hole diameters from the gross width (w_g) and adding for each inclined line in the chain the quantity $\left(\frac{s^2}{4g}\right)$.

$$\therefore w_n = w_g - \Sigma d + \Sigma \frac{s^2}{4g}$$ (AISC specification, sec. 1.14.2.1)

Ex 1) Compute the net area for the plate shown in Fig. The holes are for 1" dia. bolts.



S = 3" , g = 5"

The effective hole diameter is:

$$1" + \underbrace{\left(\frac{1}{8}"\right)}_{\text{clearance}} = 1\frac{1}{8}"$$

Wn Line (abde)

$$W_n = 16 - 2(1.125") = 13.75"$$

Wn Line (abcde) inclined portion

$$W_n = 16 - 3(1.125) + 2\frac{3^2}{4(5)} = 13.52"$$

$$\therefore A_n = W_n \cdot t = (13.52)(0.75) = 10.14 \text{ in}^2$$

Since each fastener resist an equal share of the load (an assumption used in the design of simple connection ch.6), different failure line may be subjected to different loads.

So line (abcde) must resist the full load whereas line (ijfh) will be subjected to $\left(\frac{8}{11}\right)$ of the applied load. This is because $\left(\frac{3}{11}\right)$ of the load will have been transferred from the member before line (ijfh) receives any load.

ثلاثة براغي

11 − 3

عدد البراغي الكلي

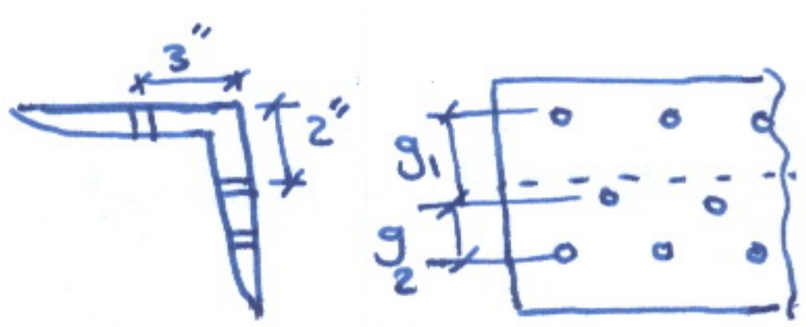
This method will accommodate failure patterns will lines perpendicular to the applied load. if not more complicated theories do provide for this case but the AISC method with its use of reduced effective net areas is adquate.

when lines of fasteners are present in both legs of an angle & the fasteners in these lines are staggered with respect to one another the net area is found by first "unfolding" the angle to obtain an equivalent plate. The unfolding is done along the middle surface.

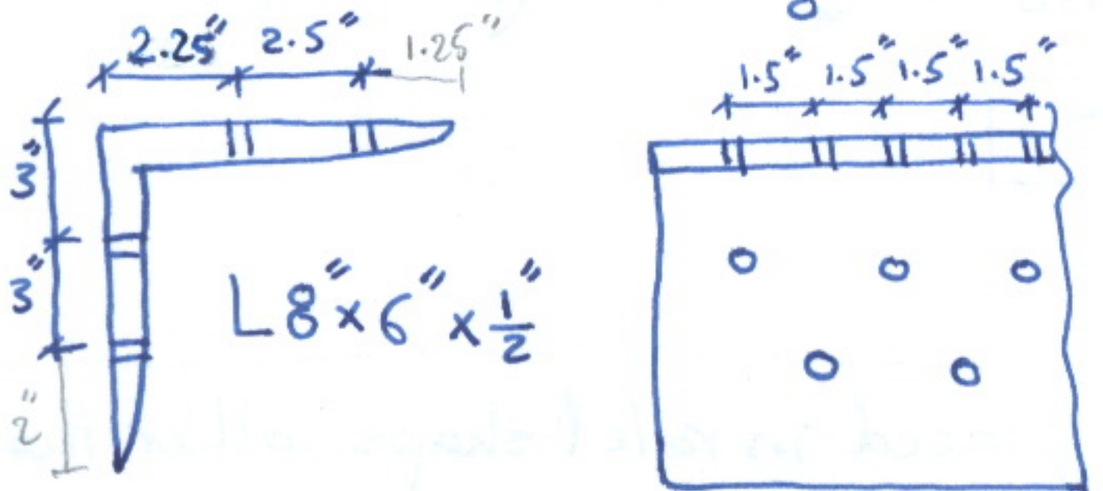
So $\left[w_g = \Sigma \text{ of the leg length} - \text{angle thickness}\right]$ (AISC 1.14.3 specification)

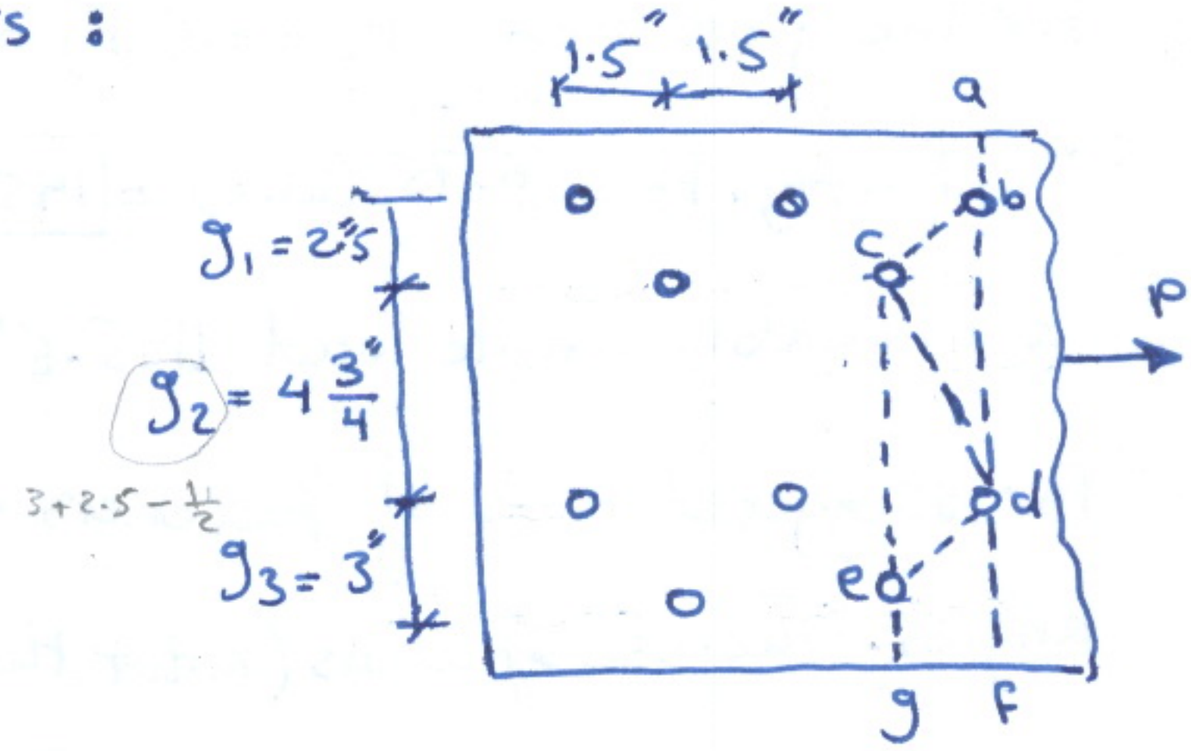
The gage ling crossing the heel of the angle is reduced by an amount equal to the angle thickness.

$\therefore$ The distance $g_1 = 3'' + 2'' - \frac{1}{2}'' = 4\frac{1}{2}''$



Ex) Find the allowable tensile load for the angle shown, A36 steel is used & holes are for $\frac{7}{8}''$ dia. bolts :





$g_2 = 3'' + 2.25'' - \frac{1}{2}'' = 4\frac{3}{4}''$

$w_g = 8'' + 6'' - \frac{1}{2}'' = 13.5''$

effective hole diam. $= \frac{7}{8}'' + \frac{1}{8}'' = 1''$

Line abdf : $w_n = 13.5 - 2(1) = \boxed{11.5''}$

Line abceg : $w_n = 13.5 - 3(1) + \frac{(1.5)^2}{4(2.5)} = 10.73''$

$s = 1.5$

$g_{cb} = 2.5 = g_1$

This line must resist only $\frac{9}{10}$ of the load, because $\frac{1}{10}$ of the load resist by the fastener at (d). Therefore the net width of (10.73") should be multiplied by $\frac{10}{9}$ in order to obtain a net width that can be compared with those lines that resist the full load.

P	$\frac{10}{10}$	$\frac{9}{10}$
w	?	10.73

$? = 10.73 * \frac{10}{9}$

$\therefore w_n = 10.73'' \left(\frac{10}{9}\right) = \boxed{11.97''}$

<u>line abcdeg</u>: $g_2 = g_{cd} = 3 + 2.25 - 0.5 = 4\frac{3}{4}''$

$w_n = w_g - \Sigma d + \Sigma \frac{s^2}{4g}$

$= 13.5 - 4(1) + \frac{(1.5)^2}{4(2.5)} + \frac{(1.5)^2}{4(4.75)} + \frac{(1.5)^2}{4(3)} = \boxed{10.03''}$

$\therefore w_n = 10.03''$, So that $A_n = w_n . t$

$= 10.03 \times 0.5 = 5.02\ in^2$

$A_e = A_n = 5.02\ in^2$, Since both legs of the angle are connected.

$F_t = 0.5\ F_u = 0.5(58) = 29\ ksi$ (allowable stress)

$\therefore P = A_e . F_t = 5.02(29) = \boxed{145.6^k}$

For the gross area $F_t = 0.6\ F_y = 21.6\ ksi$ <u>or</u> 22^{ksi} (AISC specification)

$\therefore P = A_g . F_t = \overbrace{6.75}^{13.5 * 0.5} (21.6) = \boxed{145.8^k}$

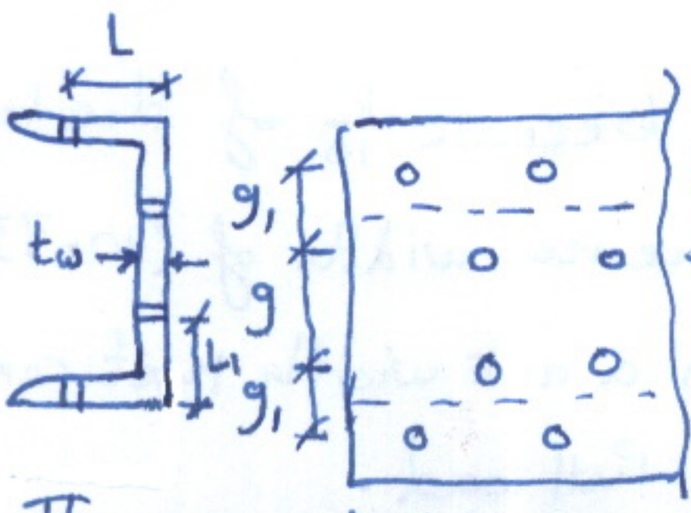
$\therefore$ allowable tensile load 145.6^k

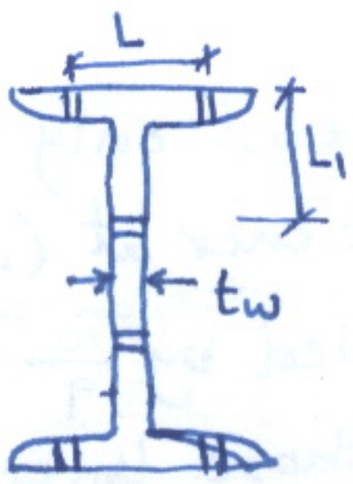
For staggered rows of fasteners are placed in rolled shapes other than angles. The use of areas (rather than widths) and reduced hole diameters (d') given by eq: $d' = d - \frac{s^2}{4g}$

<u>where</u>: d = hole diameter

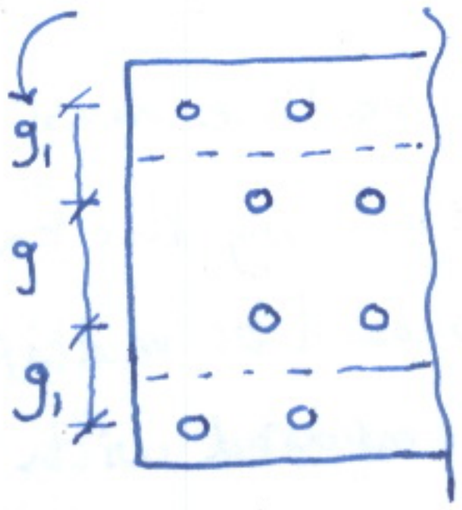
s = pitch, the spacing of two adjacent holes in the direction parallel to the load.

g = gage, the transverse spacing



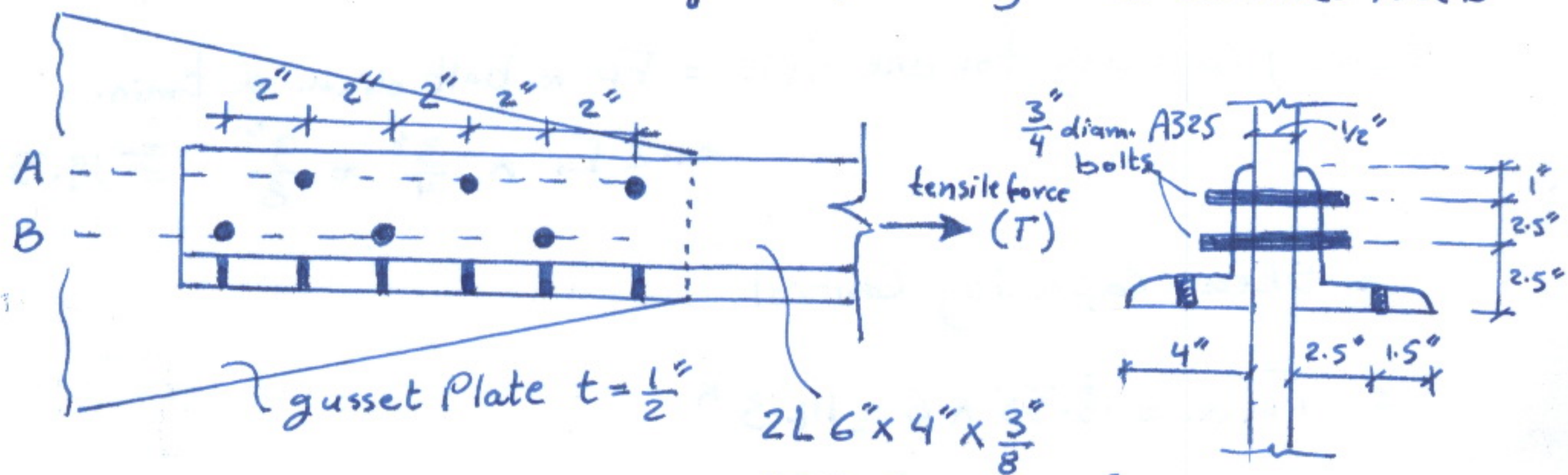


$g_1 = \frac{L}{2} + L_1 - \frac{t_w}{2}$



The gage distances are used as shown in Fig's.

Ex) Determine the tensile Force Permitted by AISC for a pair of L 6" x 4" x $\frac{3}{8}$" angles with the standard distances shown in the fig. if A36 steel & $\frac{3}{4}$" diam. A325 bolts (Threads include) are used and the tensile force is transmitted to the gusset plate by bolts on lines A & B only.



Sol.

$w_g = 6" + 4" - \frac{3}{8}"$

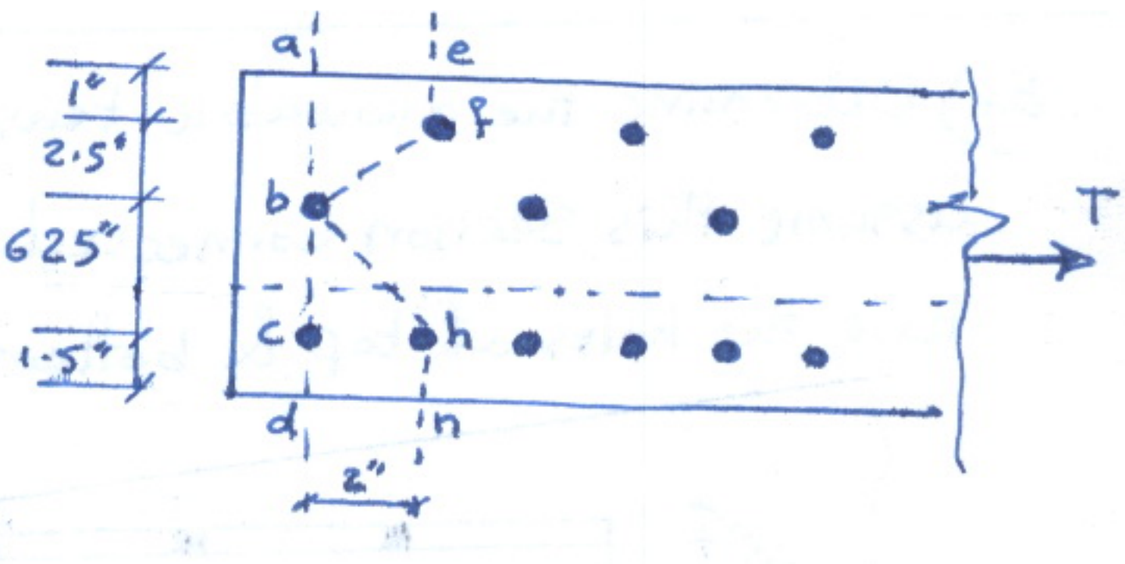
$= 9.625"$

$w_g = 9.625"$

effective hole diam. =

$\frac{3}{4}" + \frac{1}{8}" = 0.875"$

$2.5 + 2.5 - \frac{3}{8} = 4.625"$



Line (abcd): $w_n = 9.625" - 2(0.875") = 7.875"$

Line (efbcd): $w_n = 9.625" - 3(0.875") + \frac{2^2}{4(2.5)} = 7.4"$

Line (efbhn): $w_n = 9.625" - 3(0.875") + \frac{2^2}{4(2.5)} + \frac{2^2}{4(4.625)} = 7.616"$

ملاحظة: لا يتم ضرب $w_n * \frac{12}{11}$ لان البرغي المتروك في ⊆ كغير داخل في تحمل قوة الشد

$\therefore w_n = 7.4"$

$A_n = \overset{\text{Double angle}}{2}(w_n * t) = 2(7.4 * \frac{3}{8}) = 5.55 \text{ in}^2$

$A_e = A_n * C_t = 5.55 * 0.85 = 4.7175 \text{ in}^2$

∴ For gross section $T_{max.} = 0.6 * F_y * A_g = 0.6(36)(7.22) = 156^k$

for net section $T_{max.} = 0.5 * F_u * A_e = 0.5(58)(4.7175) = 136.8^k$

* الجزء الثاني من المثال يخص موضوع الـ Connection

For bolts capacity :-

Shear capacity For one bolt = $F_v * (area)_{bolts} * 2$

$= 21.0 * \frac{\pi(3/4)^2}{4} * 2 = 18.55^k$

bearing Capacity for one bolt = $F_p *$ bolt diam. $* t_{min.}$

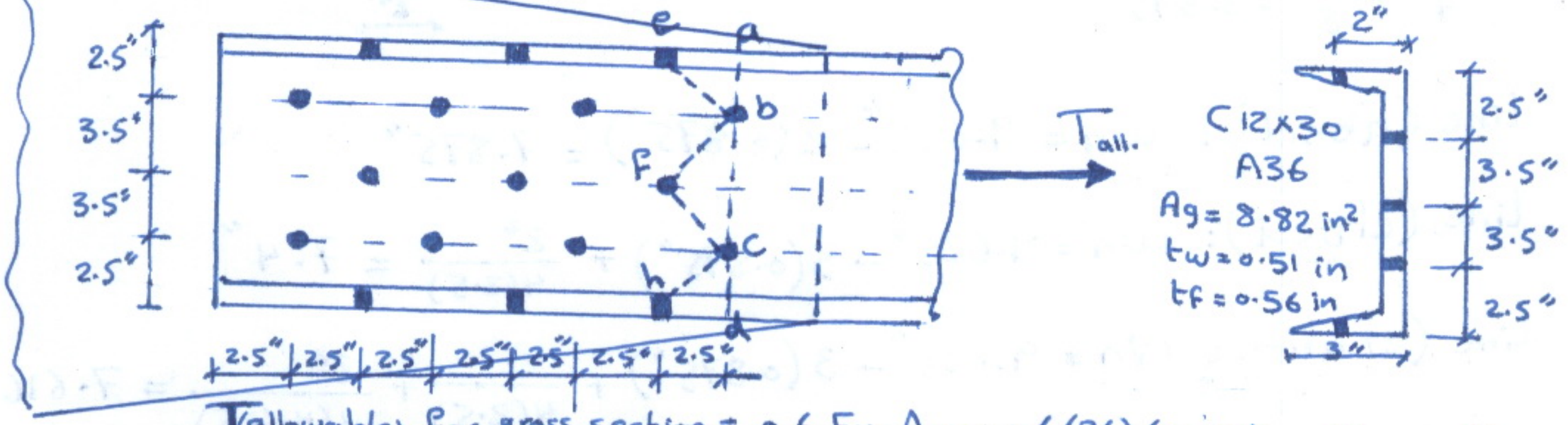
$= 1.2\, F_u * \frac{3''}{4} * \frac{3''}{8} = 19.575^k$

∴ Shear capacity Control

∴ $T_{max.} = 18.55 * 6 = 111.3^k$

∴ The tensile force (T) permitted by AISC $= 111.3^k$

Ex) Determine the allowable tensile load for the C12x30 shown in the fig. assume this section Connected at web side only with 7/8" diam. bolts & have the holes at top & bottom Flange for the same bolt diam. ?



$T_{(allowable)}$ for gross section $= 0.6 \cdot F_y \cdot A_g = 0.6(36)(8.82) = \underline{190.51^k}$

Sol. effective hole diam. $= \frac{7}{8} + \frac{1}{8} = 1''$

g for Flange $= 2 + 2.5 - 0.56 = 3.94''$

line (abcd) : $A_n = A_g - \sum d_{hole} * t_w = 8.82 - (2*1*0.51) = \boxed{7.8\ in^2}$

line (e b c h) : $A_n = A_g - \sum d_{hole} * t_f - \sum d_{hole} * t_w + \sum \frac{s^2}{4g} * t_{min.}$

$= 8.82 - (2*1*0.56) - (2*1*0.51) + 2\,\frac{(2.5)^2 * 0.51}{4 * 3.94} = \boxed{7.084\ in^2}$

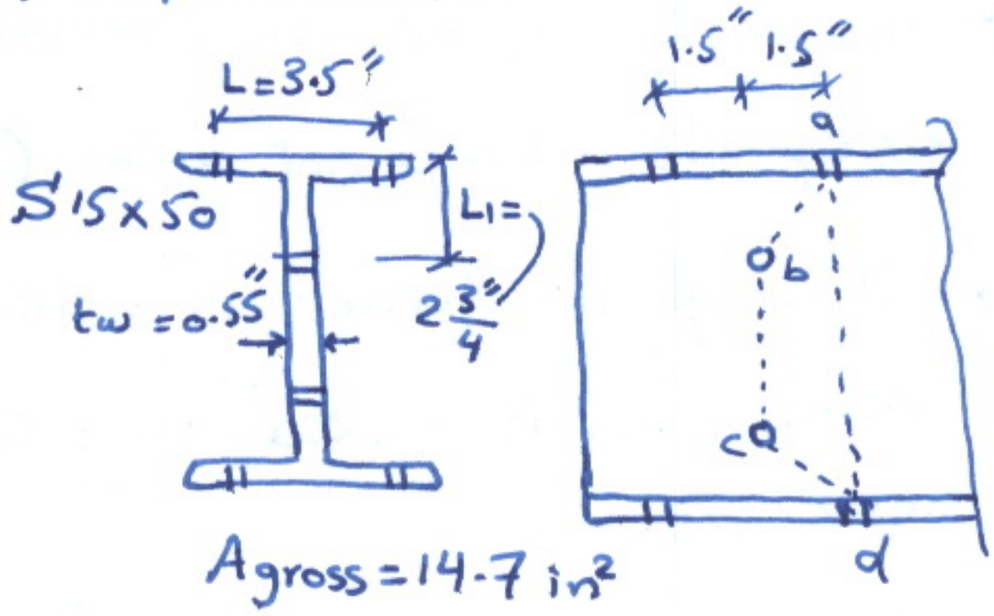
line (e b f c h) : $A_n = 8.82 - (2*1*0.56) - (3*1*0.51) + 2\,\frac{(2.5)^2 0.51}{4*3.94} + 2\,\frac{(2.5)^2 0.51}{4*3.5} = \boxed{7.0299\ in^2}$

∴ $A_{eff.} = A_{net} * C_t = 7.0299 * 0.85 = 5.975\ in^2$

∴ $T_{allowable\ for\ eff.\ section} = 0.5\, F_u \cdot A_e = 0.5(58)(5.975) = \underline{173.29^k}$

∴ allowable tensile load $= \boxed{173.29^k}$

Ex) Find the allowable tensile load for the S-shape shown in fig. the holes are for $\frac{3}{4}$" diameter bolts & A36 steel :



$A_n = A_g - (t * \text{hole diam.})$

effective hole diam. $= \frac{3}{4} + \frac{1}{8} = \frac{7}{8}$"

Line ad : $A_n = A_g - \Sigma d.t$

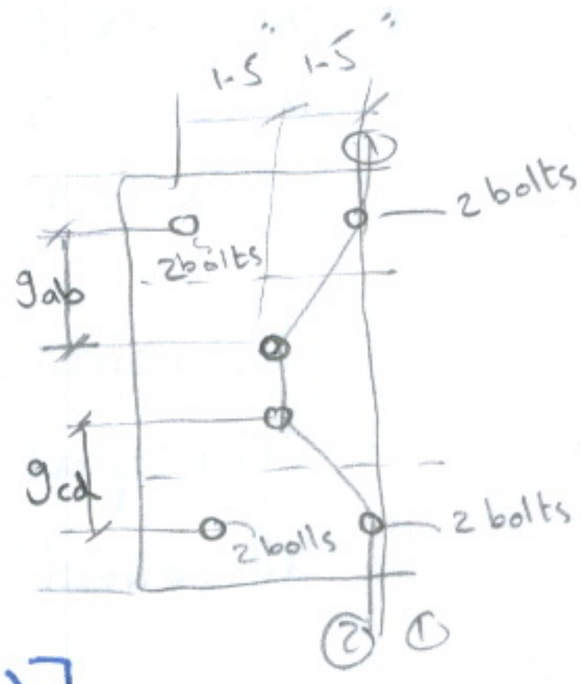
$A_n = 14.7 - (4)(0.622)\frac{7}{8} = 12.52 \text{ in}^2$

(4) عدد البراغي ، t_f

$t_f = 0.622$

$t_w = 0.55$

Line abcd



$g_{\substack{ab \\ cd}} = \frac{L}{2} + L_1 - \frac{t_w}{2} = \frac{3.5"}{2} + 2.75" - \frac{0.55}{2} = 4.22"$

$A_n = A_g - \Sigma d.t_f - \Sigma d.t_w + \sum \frac{S^2.t_w}{4g}$

$= 14.7 - 4(0.622)\frac{7}{8} - 2(0.55)(\frac{7}{8}) + \left[2\frac{(1.5)^2(0.55)}{4(4.22)}\right] = 11.71 \text{ in}^2$

(g_{ab})

$d' = d - \frac{S^2}{4g}$

∴ line abcd Controls

$A_e = A_n = 11.71$ (Since all element of cross section are connected)

$\therefore P = A_e(0.5F_u) = 11.71(0.5 * 58) = 340^k$ for net area

$P = A_g(0.6F_y) = 14.7(22) = 323^k < 340^k$

∴ the allowable tensile load $= 323^k$

Design of Tension Members :

* The design of a tension member involves finding a member with adequate gross & net areas (because of the area lost for holes)

* Although Slenderness is critical to the strength of a compression member, it is a secondary consideration to the strength of tension members.

* The more precise (دقيق) measure of the slenderness is the slenderness ratio which is the ratio of the member length to the minimum radius of gyration of the cross-sectional area.

  The min. radius of gyration is the one corresponding to the minor principal axis of the cross section. (This value is tabulated for all rolled shapes sections. Part 1 AISC manual)

* AISC 1.8.4 suggests a maximum slenderness ratio $\boxed{\frac{L}{r} = 240}$ for main tension members & $\boxed{\frac{L}{r} = 300}$ for lateral bracing and other secondary members. These limits do not apply to cables.

Ex) A main tension member with a length of 5'9" must resist a load of 70 k. Select a member with a rectangular cross section. use A36 steel and assume a connection with one line of $\frac{7}{8}$" diam. bolts :

$$\text{Required } A_g = \frac{P}{0.6\,F_y} = \frac{70}{22} = 3.18 \text{ in}^2$$

$$\text{Required } A_e = \frac{P}{0.5\,F_u} = \frac{70}{29} = 2.41 \text{ in}^2$$

Since $A_e = A_n$ for this member, the gross area corresponding to the required net area is :

$$A_g = A_n + A_{hole} = 2.41 + \left(\frac{7}{8} + \frac{1}{8}\right)t = 2.41 + t$$

Try $t = 1"$ $\therefore A_g = 3.41 \text{ in}^2 > 3.18 \text{ in}^2$ $\therefore$ the required A_g is 3.41 in^2

& $w_g = \frac{A_g}{t} = \frac{3.41}{1} = 3.41"$

Try $1'' \times 3\frac{1}{2}''$ cross section

$$I_{min} = \frac{3.5''(1'')^3}{12} = 0.292 \text{ in}^4$$

$$A = 1(3.5) = 3.5 \text{ in}^2$$

$$r_{min.} = \sqrt{\frac{I_{min}}{A}} = \sqrt{\frac{0.292}{3.5}} = 0.289 \text{ in}$$

$$\therefore \frac{L}{r} = \frac{5.75'(12)}{0.289} = 239 < 240 \quad (O.K)$$

$\therefore$ use a bar $3\frac{1}{2}'' \times 1$ (This member $< 8''$ wide it is classified as a bar rather than a plate)

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when structural shapes or plates are connected to form a built up shape, they must be connected not only at the ends of the member but also at intervals along its length. This type of connection is called stitching (خياطة) and the fasteners used are termed **stitch rivets or bolts**.

* The usual practice is to locate the point of stitching so that $\frac{L}{r}$ for any component part does not exceed $\frac{L}{r}$ for the built-up member.
* AISC 1.18.3.1 requires that built-up shapes whoes component parts are separated by intermittent (متقطع) fillers (حشوة/لحام) be connected at the fillers at intervals such that $\left(\frac{L}{r}\right)_{max.} = 240$.
* For shapes in contact, the spacing of fasteners or welds is limited to $24''$.
* If the components are plates or a combination of plates & shapes, the spacing should not > 24 * the thickness of the thinner plate or $12''$ which is the small one.