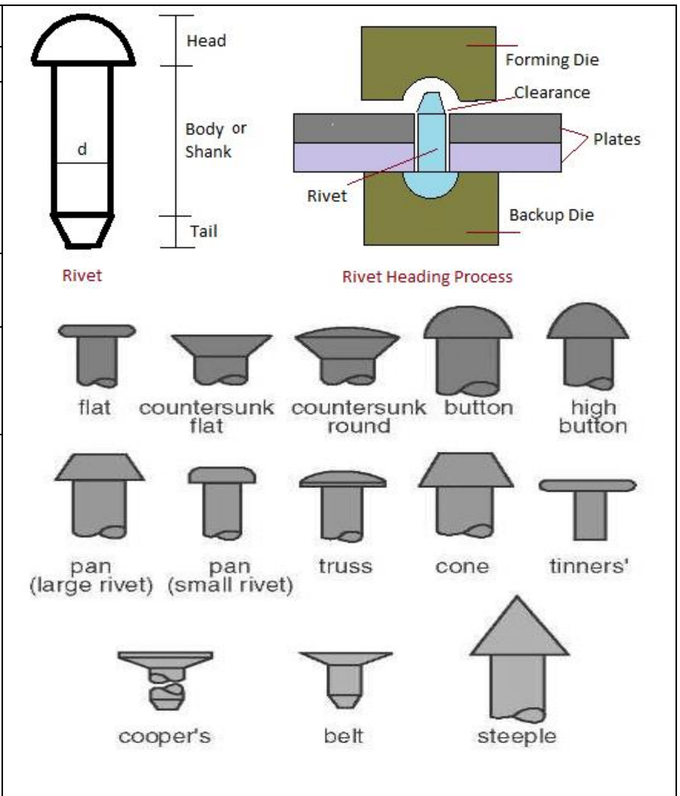
8. JOINTS

JOINT: It's connection between two or more members.

Types of Joints			
Movable Joints		**Im-Movable Joints**	
Translational Joints	Rotational Joints	Permanent Joints	Temporary Joints
Prismatic Joints	Pin Joints	Welded or Riveted Joints	Bolted Joints

RIVET: It's the one-piece fastener used to connect two or more machine members.

PARTS OF RIVET		
HEAD	**SHANK**	**TAIL**
Made using upsetting (Automatic Header machine) Used at less vibrations place.	Shank is always concentric with head and tail axis.	It converts shape after ramming is called point.



TYPES OF RIVETS:

Based on Temperature:	**Based on Hammering:**
1. Cold Riveting: More force	**1.** Hand Riveting:
2. Hot Riveting: Less force	**2.** Machine Riveting:

Based on Head:

1. **Round head rivet:** Used in large structure work where strength is needed. Strong joint, most widely used rivet. It's protrusion joint.
2. **Universal/Pan head rivet:** Used for girders and heavy constructional engineering. Strong joint. It's protrusion joint.
3. **Cone/Pan Head Rivet:** Used for girders and heavy constructional engineering. Strong joint. It's protrusion joint.
4. **Countersunk head rivet:** Ship hulls below the water line. Protrusion is avoided. Less Strong.
5. **Flat/Tinman Smithy Head Rivet:** Used in most general sheet material fabrication.

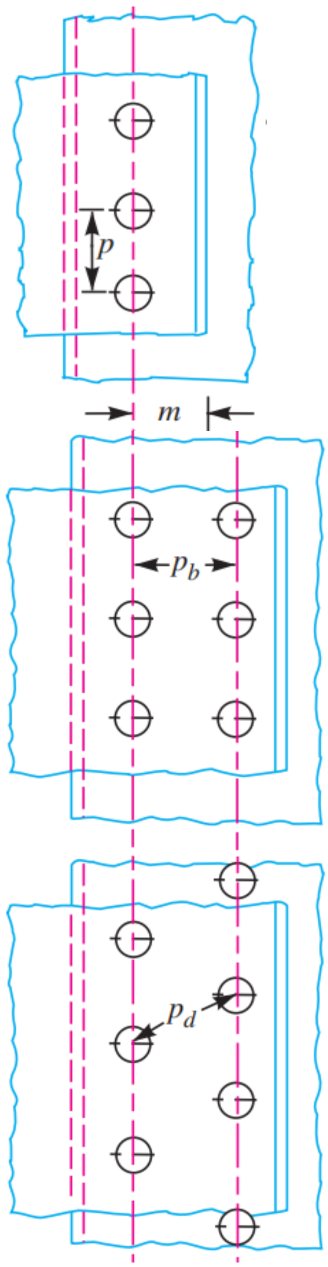
Material Used: Ductile Material. Eg. Steel, Aluminium, Copper.

Important Point:	**Process of Riveting:**
1. Diameter of shank (d): Dimensions of the rivet are specified by shank diameter. 2. Thickness of plates to be joint (t): 3. Unwin's equations: Empirical Relation $d = 6\sqrt{t}, where\ t > 8\ mm.$	1) Making holes using punching and drilling processes. 2) Hammering using hammer and die arrangements.

LAP JOINT	BUTT JOINT
It's joint formed by placing one plate over the another.	It's joint obtained by joining the plates by bringing them together by their edges. We will use additional plate called Strap/ Cover Plate.
1. Single Riveted Lap joint: 1 Raw 2. Double Riveted Lap joint: 2 Raw 3. Triple Riveted Lap joint: 3 Raw 4. Chain Riveted Lap joint: Rivet in a raw is exactly opposite to the rivet in the adjacent raw. (> 1 Rivet) 5. Zig-Zag Riveted Lap joint: Rivet in a raw is at the centre location of the rivets in the adjacent raw. 6. Diamond/ Convergent Zig-Zag Riveted Lap joint: Most economic joint.	1. Single Strap Single Riveted Butt Joint: 2. Double Strap Single Riveted Butt Joint: 3. Double Strap Double Riveted Butt Joint: 4. Double Strap Triple/Chain Riveted Butt Joint: 5. Double Strap Zig-Zag Riveted Butt Joint: 6. Double Strap Diamond/ Convergent Zig-Zag Riveted Butt joint:

TERMINOLOGY USED IN RIVETING:

1. **Centre of Rivet:** It's centroid of cross-section of rivet.
2. **Riveting System:** It's the collection of all rivets.
3. **Centre of Gravity of Riveting system:** It's the centroid of cross-section obtained by joining centre of all rivets.
4. **Row:** It's the line of rivets perpendicular to the direction of loading. Eg. One rows – Single Riveted. Two rows – Double Riveted. Three rows – Triple Riveted.
5. **Pitch (p):** It's the centre distance between two adjacent rivets of the same row.
6. **Back Pitch (p_b):** It's the centre line distance two adjacent row.
7. **Diagonal Pitch (p_d):** It's the centre distance between two rivets of adjacent row.
8. **Margin (m):** It's shortest distance between centre of rivet of edge of plate.



ASSUMPTIONS:

1. When Width of the plate is not specified, consider it as infinite width plate.
2. Load is passing through CG of riveting system.
3. Consider the riveting arrangement only in the pitch region.
4. The load given is the load per pitch length.

NUMBER OF RIVETS PER PITCH (n): It represents the number of rivets per pitch length throughout the parent plate.

Single Riveted: 1 raw => n = 1 Double Riveted: 2 raw => n = 2 Triple Riveted: 3 raw => n = 3	For Chain/ Zig-Zag Lap/Butt Joint

TENSILE FAILURE OF PLATE IN LAP/ BUTT JOINT:

Here, Rivet is stronger than Plate. So, tearing of plates happened.

Length of Tearing $= p - 2r$ $A_t = (p - 2r)t$ $F_t = \sigma_{yt} A_t = \sigma_{yt}(p - 2r)t$	A_t= area of tearing, $F = F_t$ = load acting on the plate in the pitch length = Tearing strength, $\sigma = \sigma_{yt}$= Failure Stress of plate = Yield Stress,

SHEAR FAILURE OF RIVET IN LAP/ BUTT JOINT:

Here, Plate is stronger than Rivet. So, Shearing of Rivet happened. (For Cold Rivet)

$A_s = n\frac{\pi}{4}d^2$ $\boldsymbol{F_s = \tau_{yt} A_s}$ $\boldsymbol{= \tau_{yt}(nk)\frac{\pi}{4}d^2}$	d = Diameter of rivet, A_s= Area of Shearing rivet, $F = F_s$ = load acting over pitch length = Shearing strength, $\tau = \tau_{yt}$= Shear Failure of rivet = Yield Shear Stress, k = No. of Strap Plates in Butt Riveted Joint.

CRUSHING FAILURE OF PLATE IN LAP/ BUTT JOINT:

Both rivet and plates are relatively stronger. So, Compressive failure of plate is happened.

$A_p = ndt$ $\boldsymbol{F_{cr} = \sigma_{cr} A_p = \sigma_{cr} ndt}$	σ_{cr}= Crushing Stress of plate, F_{cr} = Crushing Strength of riveting system,

EFFICIENCY OF THE RIVETED JOINT:

$F_{WOR} = \sigma_{yt} pt, And\ Efficiency\ (\eta) = \frac{F_{WR}}{F_{WOR}}$ Efficiency of joint $\eta = \min\{\eta_t, \eta_s, \eta_c\}$ $\eta = \frac{\min\{F_t, F_s, F_{cr}\}}{F_{WOR}}$	Tearing Efficiency $(\eta_t) = \frac{\sigma_{yt}(p-2r)t}{\sigma_{yt} pt} = 1 - \frac{d}{p}$ Shearing Efficiency $(\eta_s) = \frac{\tau_{ys}(nk)\frac{\pi}{4}d^2}{\sigma_{yt} pt}$ Crushing Efficiency $(\eta_c) = \frac{\sigma_{cr}(n)dt}{\sigma_{yt} pt}$

Plate: 1. $F_t = \sigma_{yt} A_t = \sigma_{yt}(p - d)t$ 2. $F_{cr} = \sigma_{cr} A_p = \sigma_{cr} ndt$ Rivet: 1. $F_s = \tau_{yt} A_s = \tau_{yt}(nk)\frac{\pi}{4}d^2$ $F_{WR} = \min\{F_t, F_s, F_{cr}\}$	$\eta = \frac{\min\{F_t, F_s, F_{cr}\}}{F_{WOR}}$ **Find diameter method 1:** $d = 6\sqrt{t}, where\ t > 8\ mm$ **Find diameter method 2:** $t, \sigma_{cr}, \tau_{yt}$ are known. $F_s = F_{cr}$.	Finding Pitch: $F_t = F_s$ To avoid Shearing of Plate near margin. And Tearing of plate near margin. $m = 1.5d$

TENSILE FAILURE OF FINITE LENGTH PLATE:

Single Riveted	Double Riveted
$A_{min} = (w - xd)t$ $F_t = \sigma_{yt} A_{min} = \sigma_{yt}(w - xd)t$	1. Tearing of first row: equation remains same as single riveted joint. 2. Tearing of Second Row: 1) 1st row should fail by either shear or crushing. 2) after that shearing of 2nd row.

SHEAR FAILURE OF RIVET IN FINITE LENGTH PLATE:

$A_s = nx\frac{\pi}{4}d^2$ $\boldsymbol{F_s = \tau_{yt} A_s = \tau_{yt}(nxk)\frac{\pi}{4}d^2}$	d = Diameter of rivet, x = Number of rivets in a single raw, A_s= Area of Shearing rivet, $F = F_s$ = load acting on plate = Shearing strength, $\tau = \tau_{yt}$= Shear Failure of rivet = Yield Shear Stress, k = No. of Strap Plates in Butt Riveted Joint.

CRUSHING FAILURE OF FINITE LENGTH PLATE IN LAP/ BUTT JOINT:

Both rivet and plates are relatively stronger. So, Compressive failure of plate is happened.

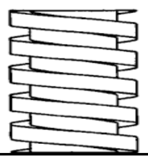
$A_p = xndt$ $\boldsymbol{F_{cr} = \sigma_{cr} A_p = \sigma_{cr} xndt}$	σ_{cr}= Crushing Stress of plate, F_{cr} = Crushing Strength of riveting system, x = Number of rivets in a single raw,

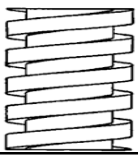
THREADED JOINTS:

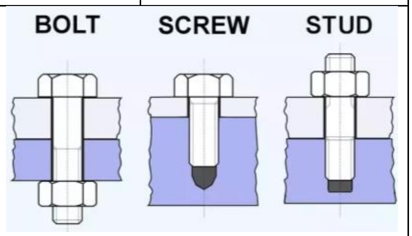
If the joint is made by using threaded fasteners then the obtained joint is said to be threaded/ separable/ detachable/ temporary joint.

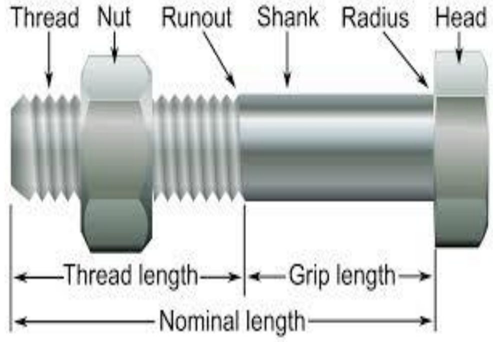
Bolt Nut	Screw	Stud Bolt

Types of Thread:
1. Right hand Thread
2. Left Hand Thread

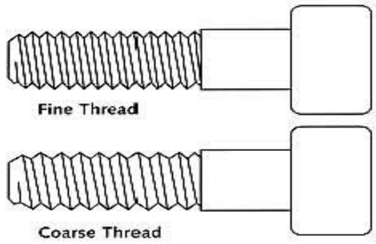


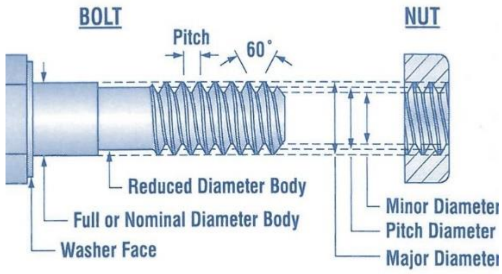






We Will consider Vee thread ISO-Metric Threads throughout study.
Notation: Md Eg. M20, M = Metric,
d = d mm Nominal Diameter
d_c = Minor/ Root/ Core Diameter
d = Major/ Nominal Diameter





TENSILE STRESS IN BOLT: Pre-Load: It's the load comes due to clamping. $Normal\ Stress\ (\sigma_t): {F_i}/{A_{min}}, where\ A_{min} = \frac{\pi}{4}d_c^2$ **SHEAR STRESS IN THREAD:** Assuming there is no bending. $Shear\ Stress\ (\tau) = {F_i}/{A_{Shear\ of\ teeth}}, where\ A_{Shear\ of\ teeth} = \pi d_c tn$ **CRUSHING STRESS IN THREAD:** $Compressive\ Or\ Crushing\ Stress\ (\sigma_c): {F_i}/{A_p},$ $where\ A_p = n\frac{\pi}{4}(d^2 - d_c^2)$	n = number of terns of thread in contact, d_c = core diameter of the bolt, F_i = initial tension/ Pre-load, t = thickness of teeth.

BOLT OF UNIFORM STRENGTH:

$\sigma_{thread} = \sigma_{shank} = {F_i}/{A_{min}} = {F_i}/{A_{shank}} = constant$ $\therefore A_{min} = A_{shank}$	Possibility-I: $d_c = d_{shank}$	Possibility-II: Drilling hole in bolt $d_h = \sqrt{d_{shank}^2 - d_c^2}$

TENSILE STRESS DUE TO EXTERNAL LOAD: Assuming No Pre-load.

$$Normal\ Stress\ (\sigma_t^e): {F_i}/{A_{min}}, where\ A_{min} = \frac{\pi}{4}d_c^2$$

SHEAR STRESS DUE TO EXTERNAL LOAD: Assuming No Pre-load.

Shank undergoes shearing:	**Threaded region undergoes shearing:**
$Shear\ Stress\ (\tau^e): {F_i}/{A_{shank}}, where\ A_{shank} = \frac{\pi}{4} d_{shank}^2$	$Shear\ Stress\ (\tau^e): {F_i}/{A_{min}}, where\ A_{min} = \frac{\pi}{4} d_c^2$

STRESSES IN BOLT DUE TO PRE-LOAD & EXTERNAL LOAD: Assuming Pre-load Condition.

$F_e = F_{cm} + F_b$ $\Delta_m = \frac{F_{cm}}{K_{cm}}, \Delta_b = \frac{F_b}{K_b}$ $\Delta_m = \Delta_b$ $\boldsymbol{F_b = C\, F_e, F_{cm} = (1 - C)\, F_e}$ $\boldsymbol{C = \frac{K_b}{K_b + K_{cm}}}$ $\boldsymbol{R_b = F_i + F_b}$ $\boldsymbol{R_{cm} = -F_i + F_{cm}}$ **Lack Proof Condition:** $\boldsymbol{R_{cm} \le 0}$ **Limiting Condition:** $\boldsymbol{F_i = F_{cm}}$	n = number of terns of thread in contact, d_c = core diameter of the bolt, F_i = initial tension/ Pre-load, F_e = External load acting on **a single bolt** system, F_{cm} = The load acting on connecting member due to external load, F_b = The load acting on the bolt due to external load, Δ_m = deformation of connecting members due to external load, Δ_b = deformation of the bolt due to external load, C = combined Stiffness factor, R_b = Resultant load on bolt, R_{cm} = Resultant load acting on the connecting members.

WELDED JOINTS:

Welding: It's the process of joining two or more members with the application of heat, with or without application of pressure, and with or without filler material.

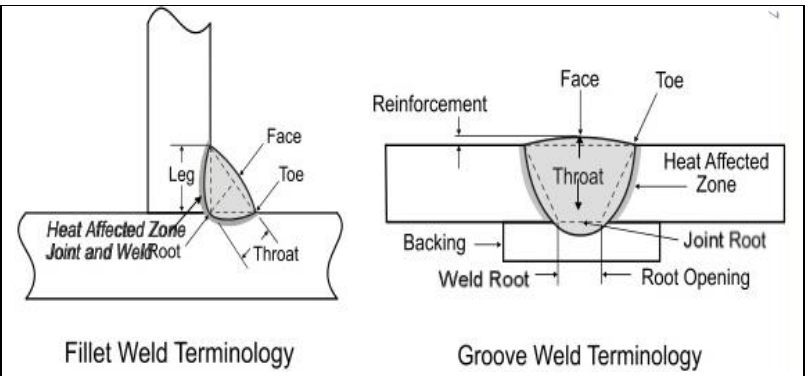
The Joint obtained by welding is called welded joint.

Neglecting Reinforcement:

t = thickness of plate or throat thickness

h = weld size or height of weld or leg size

1. **Butt Weld: Groove Weld: h = t**
2. **Lap Weld: Fillet Weld: h > t**



GROOVE WELD:

$\sigma_{max} = \frac{F}{A_{min}} = \frac{F}{lt}$ Butt joint Strength of groove $F_b = \sigma_{yt} lt = \sigma_{yt} lh$	l = length of plate to be welded, here, h = t

FILLET WELD:

Parallel Fillet Weld: If the length of weld is in the direction of load, then the fillet weld is said to be parallel fillet weld. Assuming leg size is same in both directions. $Shear\ Stress\ (\tau) = \frac{F}{t_\theta l}$ $Where, t_\theta = \frac{h}{\sin\theta + \cos\theta}$ For maximum shear stress $\theta = 45°$, $\tau_{max} = \frac{F}{lt}, where\ t = \frac{h}{\sqrt{2}}$	**Transverse Fillet Weld:** If the length of weld is in the perpendicular direction to load, then the fillet weld is said to be Transverse fillet weld. At the θ angle plane Normal force ($\boldsymbol{F_n}$) and Shear force ($\boldsymbol{F_s}$) acts. $F = \frac{F_n}{\sin(180 - \theta)} = \frac{F_s}{\sin(90 + \theta)}$ $Shear\ Stress\ (\tau_\theta) = \frac{F_s}{t_\theta l}\ and\ Normal\ Stress(\sigma_\theta) = \frac{F_n}{t_\theta l}$ At maximum shear stress $\theta = 22.5°$, $\tau_{max} = \frac{F}{lt}, where\ t = 0.828h$
At Failure: $\boldsymbol{F_p^l = \tau_{yt} lt, where\ t = h/\sqrt{2}}$	**At Failure**: $\boldsymbol{F_t^l = \tau_{yt} lt, where\ t = 0.828h}$
Strength of Fillet Weld $\boldsymbol{F_s = min\,\{F_t^l, F_p^l\} = F_p^l}$	
$\boldsymbol{F_s^l = 1.17 F_p^l}$	
Circumferential Fillet Weld: On axial load Failure is as per Parallel Fillet weld but $\boldsymbol{l = \pi d}$**.**	

AXIALLY LOADED UNSYMMETRICAL FILLET WELD:

$\sum M_{CG} = 0 \Leftrightarrow (tl_1)y_1 = (tl_2)y_2 \Leftrightarrow \frac{l_1}{l_2} = \frac{y_2}{y_1}$ $\frac{l}{l_2} = \frac{y_1 + y_2}{y_1}\ and\ \frac{l}{l_1} = \frac{y_1 + y_2}{y_2}$	Total Length of weld $l = l_1 + l_2$ $y = y_1 + y_2$ Total Axial Force $F = F_1 + F_2$ $F_1 = F\frac{l_1}{l}\ and\ F_2 = F\frac{l_2}{l}$

ECCENTRIC LOADING:

If the load is not passing the centre of gravity of element system then the loading is said to be eccentric loading.

EFFECTS OF ECCENTRIC LOADING			
Primary Effects (Direct Load)		Secondary Effects (Moment or Torsion)	
In the direction of axis of element	In the direction parallel to the cross section of element	In the direction of axis of element	In the direction parallel to the cross section of element
Normal Load	Shear Load	Normal Load	Shear Load

Moment Balance: $M = \sum_i F_{si} r_i \; and \; F_s \propto r$ $\therefore F_s = C\, r_{max}, where\; C = \frac{M}{\sum_i r_i^2}$	r = distance from the element of axis of rotation F_s = Shear Load r_i = distance from the i[th] element of axis of rotation F_{si} = Shear Load on i[th] element

FOR RIVETED AND BOLTED JOINTS:

CASE-I:

$primary\; load\; F_p = F/n$ $Secondary\; load\; F_s = C\, r_{max} = \frac{Fe}{\sum_i r_i^2} r$ $Resultant\; Load\; R = \sqrt{F_p^2 + F_s^2 + 2F_pF_s\cos\theta}$	Effect of primary loading = Shear Stress Effect of Secondary loading = Shear Stress θ = Included Angle between primary and secondary load e = distance between load and axis of rotation of system. r_i = distance between centre of i[th] element to CG of element

Finding Critical Element:

1. The Element should be far away from the axis of rotation of system (CG). ("r" to be maximum)
2. When "r" remains the same, the element with less "θ" is more critical.

$Maximum\; shear\; stress\; \tau_{max} = \frac{R_{max}}{A_{min}} = \frac{\tau_{yt}}{FOS}$	$R_{max} = resultant\; load\; on\; the\; critical\; element.$ $A_{min} = mimimum\; area\; of\; rivet\; shank\; or\; bolt\; core$

CASE-II:

$primary\; load\; F_p = \frac{F}{n}$ $Secondary\; load\; F_s = C\, l_{max} = \frac{Fe}{\sum_i l_i^2} l$ From the theories of Failures (MSST): $\sigma_1 - \sigma_2 = \sigma_{yt}/FOS$ $\frac{1}{A}\sqrt{4F_p^2 + F_s^2} = \frac{\sigma_{yt}}{FOS}$	Effect of primary loading = Shear Stress Effect of Secondary loading = Normal Stress e = distance between Applied load and axis of rotation of system. A_{min} = minimum area of rivet shank or bolt core l_i = distances from the axis of rotation to centre of i[th] element $\sigma_x = F_s/A_{min}$ and $\tau_{xy} = F_p/A_{min}$

CASE-III:

$primary\; load\; F_p = \frac{F}{n}$ $Secondary\; load\; F_s = C\, l_{max} = \frac{Fe}{\sum_i l_i^2} l$ $Resultant\; Load\; R = F_p + F_s$ $Maximum\; Normal\; Stress\; \sigma_{max} = \frac{R_{max}}{A_{min}} = \frac{\sigma_{yt}}{FOS}$	Effect of primary loading = Normal Stress Effect of Secondary loading = Normal Stress R_{max} = resultant load on the critical element. e = distance between Applied load and axis of rotation of system. A_{min} = minimum area of rivet shank or bolt core l_i = distances from the axis of rotation to centre of i[th] element $R_{max} = \frac{F}{n} + Cl_{max}$

FOR WELDED JOINTS:

CASE-I:

$Total\; Area\; A = lt\; and\; Total\; Welding\; length\; l = \sum_i l_i$ $primary\; load\; \tau_p = F/A$ $Secondary\; load\; \tau_s = (M/J)\, r$ $Resultant\; Load\; R = \sqrt{\tau_p^2 + \tau_s^2 + 2\tau_p\tau_s\cos\theta}$	$Total\; Plar\; Moment\; of\; inetia\; J = \sum_i J_i = \sum_i A_i \left[\frac{l_i^2}{12} + h_i^2\right]$ $Maximum\; shear\; stress\; \tau_{max} = \frac{R_{max}}{A_{min}} = \frac{\tau_{yt}}{FOS}$

CASE-II:

$Total\; Area\; A = lt\; and\; Total\; Welding\; length\; l = 2b$ $primary\; load\; \tau_p = F/A,$ $Secondary\; load\; \sigma_s = (M/I)\, y, where\; M = Fe$	From the theories of Failures (MSST): $\sqrt{4\tau_p^2 + \sigma_s^2} = \sigma_{yt}/FOS$