MEC

Design of machine element

4/1/2023

AKM sir.

Anbuj Kumar Mitra.

* Review of stress analysis, Theories of failure, Machine design in continuation of strength of materials

* ~~Enumeration~~ General principles and procedure of machine design factor of safety and service factor.

* Design of shaft under torsion, bending and axial loads and combined loads
* Design keys and splines

* Thin and thick cylinders and design of pressure vessels.

Barman

Static load
Period " (fatigue)
Impact "

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* Why machine design is require.
→ Social problem
which can't be done manually that also can't done by machine.

human can't perform work repeatedly with same efficiency so machine is required.

* Every body is deformable.
* If deformation under no-load & max-load is nearly same then deformation is neglected.

* If we neglect & not-neglect analytic result is same.

* When a body is treated as rigid body.

* In solid motion is neglected {frame of reference}
In TOMM deformation is " . {negligible deformation}

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Static force, | fatigue force, dynamic force.

↓

If dirⁿ, magnitude & point of application remain unchanged w.r.t. time is called static force

very-very dificult to get static force

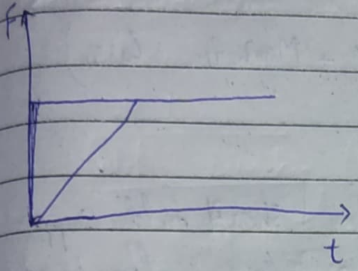
impact force

→ Blast

→ Crane moving on beam (force by tyre).

→ direct impact

→ moving load.



When time of application is very-very low then that force is called dynamic load.

→ Design is done to save from failure.

NEED

1. Qualitative statement
2. Quantitative statement
3. Mathematical statement.

1. kinematic Synthesis
2. kinematic Analysis
3. Force Analysis
4. Selection of materials

1. Analysis of failure
2. Prevention of different modes of failure
3. Manufacturing aspects.
4. Maintainability and Reliability.
5.

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Design Ananlysis
1. Set suitable dimensions
2. failure analysis
3. Suitable prevention of failure
4. Manufacturing consideration

↓

Production drawing

↓

Tentative cost analysis

↓

Manufacturing

↓

Cost analysis

↓

Test

↓

Recomendation for ~~manufacturing~~ mass production

A. Bulk of the component
1. Strength
2. Deflection and deformation
3. Weight
4. Size and shape

B. For the surface of the component
1. Wear
2. Lubrication
3. Friction
4. Friction heat generation

C. Cost.

Modern consideration
1. Safety
2. Ecology
3. Quality of life

Miscellaneous consideration
1. Reliability and maintainability
2. Aesthetics
3. Ergonomics.

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Factor of Safety:

$Y = \frac{Fl}{A\sigma}$

Uncertainties

1. Degree of load uncertainty.
2. Degree of uncertainty in material properties.
3. Degree of uncertainty in stress/deformation analysis method.
4. Degree of uncertainty in theory of failure.
5. Reliability requirement.
6. Manufacturing tolerance in manufacturing.

$$\text{Margin of safety} = \text{failure stress} - \text{Allowable stress}$$
$$= \text{failure stress}\left(1 - \frac{\text{Allowable stress}}{\text{failure stress}}\right)$$
$$= \text{failure stress}\left(1 - \frac{1}{\underbrace{\frac{\text{failure stress}}{\text{allowable stress}}}_{\text{factor of safety} > 1}}\right)$$

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FeE 200 $\sigma_{yield} = 200\,MPa$

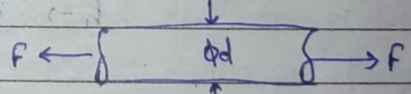
Safety ← F.S. = 3

Allowable stress $= \frac{200}{3} = 66.67\,MPa$

F.S = 4

Near optiminum design ← Allowable stress $= \frac{200}{4} = 50\,MPa$

$\sigma_a = 66.67\,MPa$



F = 25 kN

d = ?

$\Rightarrow \sigma = \frac{F}{A} \Rightarrow A = \frac{F}{\sigma} = \frac{25 \times 10^{3}}{66.67 \times 10^{6}}\ N/mm^2$

$\pi d^2 = 0.37498 \times 10^{-9} \times 10$

$d = 0.01193 \times 10^{-4}\ m$

$d = 0.001193\ mm$

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$1 MPa = 1 \frac{N}{mm^2}$

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Que

$F = 25 kN$

$\sigma = 65 MPa \Rightarrow 65 N/mm^2$

$\frac{\pi d^2}{4} = A = \frac{F}{\sigma} = \frac{25 \times 1000}{65} mm^2 = \frac{5000}{13}$

$d^2 = 122.4268 \times 2 \ mm^2$

$d = 11.0647 \times 2 \ mm$

$d = 22.1294 \ mm$

Que

$d = 25 \ mm$

$A = \frac{\pi d^2}{4} = 490.8738521$

$\sigma_a = \frac{F}{A} = \frac{25 \times 1000}{490.8738521} = 50.92965 \ MPa$

~~$\sigma_{yield} = \sigma_a \times FOS = 152.7887 \ MPa$~~

$FOS = \frac{\sigma_{yield}}{\sigma_a} = \frac{200}{50.9295} = 3.927$

Rounded dim., design dim., Calculated dim.

$$\boxed{F.S_{material} \times F.S_{stress} \times F.S_{failure\ theory} \times F.S_{manufacturing} \times F.S_{Reliability}}$$

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$F.S_{material} = 1.2$

$F.S_{press\text{-}load} = 1.2$

$F.S_{failure\ theory} = 1.2$

$F.S_{manufacturing} = 1.1$

$F.S_{Reliability} = 1.4$ for 99% reliability

$F.S$ = multiplication = 2.66112

$F.S \approx 3.0$

FeE 200 $\sigma_{yt} = \sigma_{yc} = \sigma_{yield} = 200\ MPa$

3 allowable stress = 66.67 MPa

Allowable stress = 50 MPa

$$F.S = \frac{200}{50} = 4$$

3-4

σ_1, σ_2 & σ_3

$\sigma_{max} = \max\{\sigma_1, \sigma_2, \sigma_3\}$

$\sigma_{min} = \min\{\sigma_1, \sigma_2, \sigma_3\}$

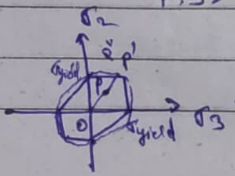
$$\tau_{max} = \max\left\{\frac{|\sigma_1-\sigma_2|}{2}, \frac{|\sigma_2-\sigma_3|}{2}, \frac{|\sigma_3-\sigma_1|}{2}\right\}$$

$$\boxed{\tau_{max} = \frac{\sigma_{max} - \sigma_{min}}{2}}$$

$\sigma_1 > \sigma_2 > \sigma_3$

$$\tau_{max} = \frac{\sigma_1 - \sigma_3}{2} = \frac{\sigma_1 - 0}{2} = \frac{\sigma_1}{2}$$

$$F.S = \frac{\tau_{yield}}{\tau_{max}}, \quad \tau_{yield} = \frac{\sigma_{yield}}{2} = \frac{\sigma_{yield}}{\sqrt{3}} = 0.6\,\sigma_{yield}$$



$$\boxed{F.S = \frac{OP'}{OP}}, \quad \boxed{F.S = \frac{OP''}{OP}}$$

$$\sigma_e = \sqrt{\frac{(\sigma_1-\sigma_2)^2 + (\sigma_2-\sigma_3)^2 + (\sigma_3-\sigma_1^2)}{2}}$$

$$\boxed{F.S = \frac{\sigma_{yield}}{\sigma_e}}$$

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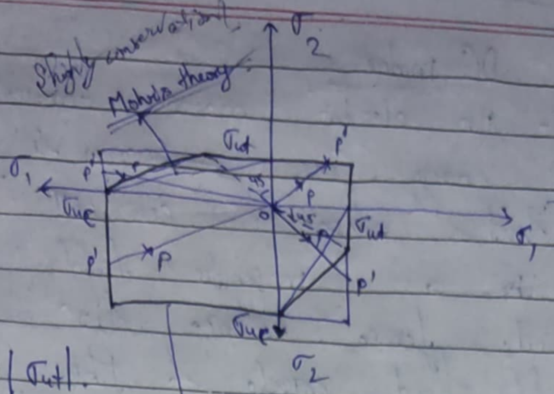


$\sigma_3 = 0$

Rankine Theory

$|\sigma_{uc}| \approx (2 \text{ to } 3)\,|\sigma_{ut}|$.

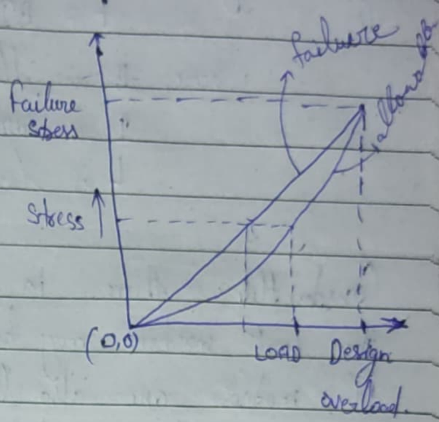
Modified mohr's theory

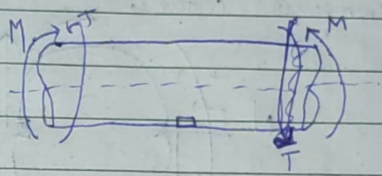
$$\boxed{F.S. = \frac{OP'}{OP}}$$

Load - base F.S.

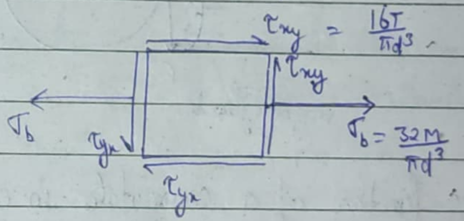
$$F.S. = \frac{\text{Failure stress} \times A}{\text{Allowable stress} \times A}$$

$$= \frac{\text{Design overload}}{\text{Normal Load}}$$





$\sigma_1, \sigma_2 = ?$



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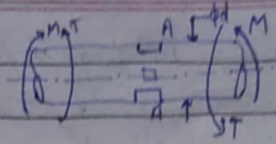
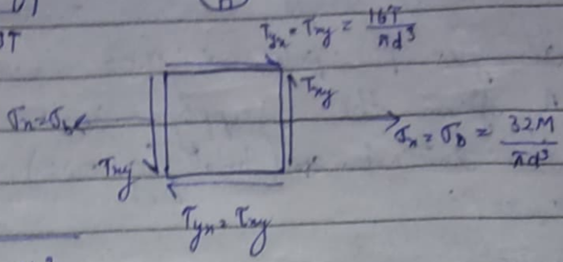




$$\sigma_{1,2} = \frac{\sigma_x}{2} \pm \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + \tau_{xy}^2}$$

$$\left\{\begin{array}{l} \sigma_{max} = \sigma_1 \quad (+ve) \\ \sigma_{min} = \sigma_2 \quad (-ve) \end{array}\right\} \begin{array}{l} \frac{\sigma_x}{2} + \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + \tau_{xy}^2} \\ \frac{\sigma_x}{2} - \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + \tau_{xy}^2} \end{array}$$

$$\tau_{max} = \frac{|\sigma_{max} - \sigma_{min}|}{2} = \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + \tau_{xy}^2}$$

$$= \frac{16}{\pi d^3}\sqrt{M^2 + T^2} = \frac{16 T_e}{\pi d^3}$$

$\left(T_e = \sqrt{M^2 + T^2}\right)$ = equivalent Torque.

$$\tau_{max} \le [\tau]$$

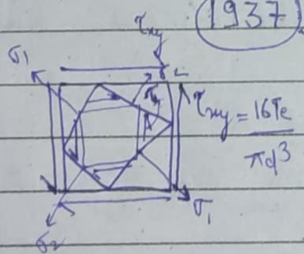
$$\boxed{[\tau] = \frac{\tau_{yield}}{F.O.S}}$$

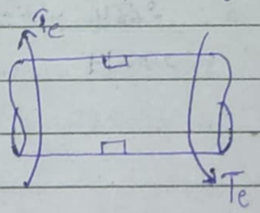
max^m shear stress theory → $\tau_{yield} = \frac{\sigma_{yield}}{2}$

" distortion energy theory → $= \sigma_{yield}/\sqrt{3}$

experimenta $= 0.6\,\sigma_{yield}$ ASME

1937





→ We have to adopt max^m Shear stress theory for design.

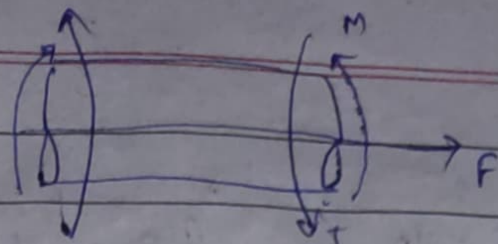
$$\tau_{max} \le [\tau]$$

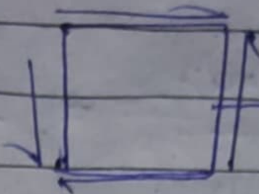
$$\frac{16 T_e}{\pi d^3} \le [\tau]$$

$$d^3 \ge \frac{16 T_e}{\pi [\tau]} \Rightarrow d \ge \sqrt[3]{\frac{16 T_e}{\pi [\tau]}}$$

Hollow ~~shap~~ shaft calculation

next class show





$\tau_{xy} = \frac{16T}{\pi d^3}$

$\sigma_x = \sigma_b + \sigma_t$

$\sigma_b = \frac{32M}{\pi d^3}$

$\sigma_t = \frac{F}{\frac{\pi}{4}d^2} = \frac{4F}{\pi d^2}$

$$\sigma_x = \sigma_b + \sigma_b$$

$$= \frac{32M}{\pi d^3} + \frac{4 \times 8Fd}{\pi d^3 \times 8}$$

$$= \frac{32}{\pi d^3}\left(M + \frac{Fd}{8}\right) \rightarrow \text{modified } M'$$

$$\boxed{T_e = \sqrt{M'^2 + T^2}}$$

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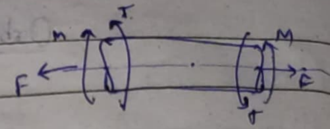
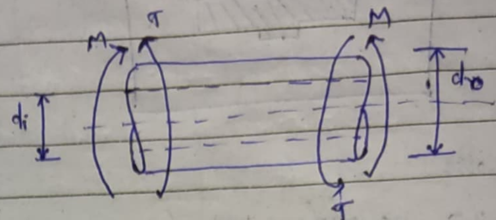
$$d \geq \sqrt[3]{\frac{16 T_e}{\pi[\tau]}}$$

$$T_e = \sqrt{M^2 + T^2}$$



$$\boxed{M = M + \frac{Fd}{8}}$$

Hollow shaft



$$d_o \geq \sqrt[3]{\frac{16\, T_e}{\pi[\tau] f}}$$

$$T_e = \sqrt{M'^2 + T^2}$$

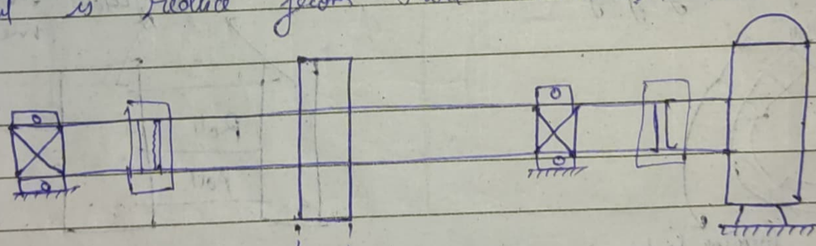
$$M' = M + \frac{F d_o (1 + k^2)}{8}$$

$$f = 1 - k^4 \text{ and } k = \frac{d_i}{d_o}$$

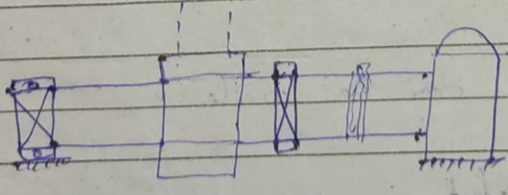
→ As we come inside torsional ~~shear~~ stress less.

→ Centre line is free from torsional & shear stress.

→ Material is reduce from there where stress is less.



Shock



$$T_e = \sqrt{M^2 + T^2}$$

$M \to K_m M$, $T \to K_t T$

[column action factor - αf]

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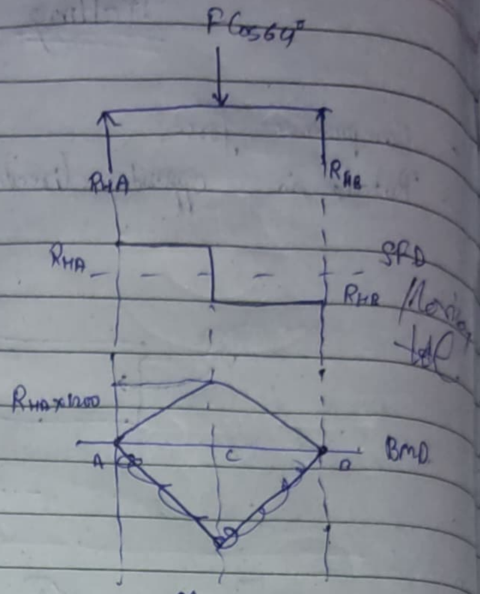
$P\cos 64^\circ = R_{HA} + R_{HB}$



$M = \sqrt{M_{HC}^2 + M_{VC}^2}$

$K_m = 1.6$

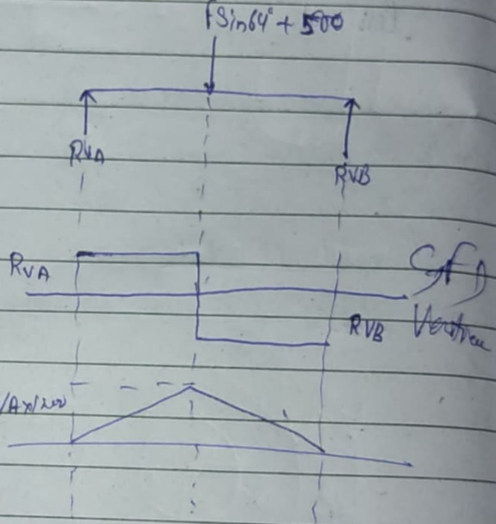
$K_t T =$

$M = 193\ .429$

$T = 240$

$T_e = 3105589.977\ N\text{-}mm$

$M_{HC} = ?$

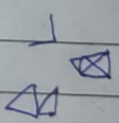


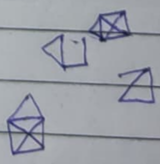
FeE200

$\sigma_{yield} = 200MPa$

$\tau_{yield} = \frac{\sigma_{yield}}{2}$

$[\tau] = \frac{\tau_{yield}}{F.S.} \rightarrow 2.5$





— x — x — x — x —

01/03/2023

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allowable tensile stress

allowable surface stress = 120 x (1.2 to 1.4)

1.28

$d = 82$ mm

Width & height of key

$b = 22, \ h = 14$

tangential force

$$L_e \geq \frac{F_t}{\frac{h}{2} \times [\sigma_{crush}]}$$

w.o $w \times L_e \times [\tau_{allow}] = F_t$

60

$$F_t \times \frac{d_{shaft}}{2} = T \rightarrow 240{,}000\,N$$

82, 41

$\cancel{F_t} = 22 \times \cancel{\ \ } \times 60$

$F_t = 5853.65854$

$$L_e \geq \frac{5853.65854}{\frac{14}{2} \times \cancel{120}\ 60} =$$

$L_e > \cancel{7.434}$ 6.968

$L_e = 7$

$\boxed{F_t \times \frac{d_{shaft}}{2} = T}$

$\boxed{d = \_\_\_}$

$b / h_1 \rightarrow$ from data book

$L \rightarrow \sigma_{crush}$ & τ

$\left.\begin{array}{l} b \times L \times [\tau] \geq F_t \quad (\tau = 60) \quad L \rightarrow 4.43 \text{ min} \\ \frac{h}{2} \times L \times [\sigma_{crush}] \geq F_t \quad (\sigma_{crush} = 150) \quad L \rightarrow 5.8 \text{ mm} \end{array}\right\} \text{max}$

$\boxed{\sigma_{crush} = 1.25 \times 120 = 150}$

Aim is to balance the shaft.

Length of key should not be more then ___

$\frac{L}{1200}$ more then this not permissable

Angle of repose

__Various types of keys__

__Key__

- Saddle key
  - Flat key
- Tangent key
  - Kennedy key
- Sunk key
  - (i) Rectangular key or square key
  - (ii) Gib-head key
  - (iii) Feather key & spline shaft
  - (iv) Woodruff key
- Round key
  - Taper pin

__Pressure vessel__

23,24,25 → SAW
NDT

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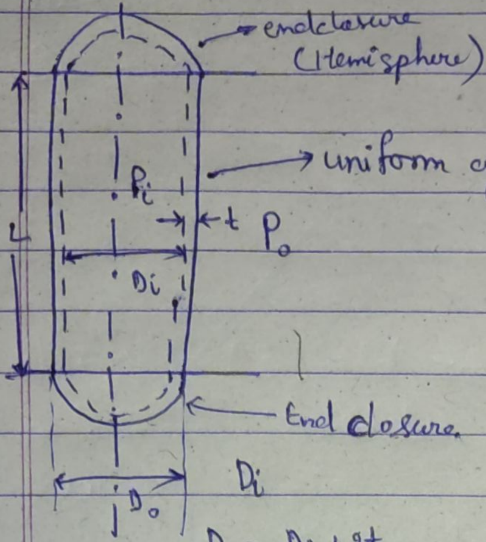
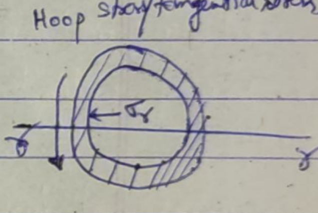
cylinder (pressure vessel)



$D_o = D_i + 2t$

$$\boxed{\frac{D_i}{t} = \text{Ratio value } (K)}$$

$K > 20 \rightarrow$ Thin cylinder
$K \leq 20 \rightarrow$ Thick cylinder



Thin cylinder assumption
1. Effect of radial stress neglegible
2.

$\boxed{\sigma_r \rightarrow \text{neglected},\ P_o = 0}$

$$\sigma_l = \frac{P_i D_i}{4t}$$

t + corrosion allowance

$$\sigma_t = \frac{P_i D_i}{2t}$$

$$\boxed{t \geq \frac{P_i D_i}{2[\sigma_t]}}$$

$$\boxed{t_1 \geq \frac{P_i D_i}{4[\sigma_t]}}$$

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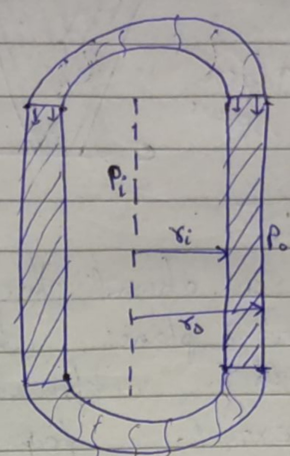
$$\sigma_r = A - \frac{B}{r^2}$$

$$\sigma_t = A + \frac{B}{r^2}$$

Lame's equations for thick cylinder.



at $r = r_i$, $\sigma_r = -P_i$

at $r = r_o$, $\sigma_r = -P_o$

$$-P_i = A - \frac{B}{r_i^2}$$

$$-P_o = A - \frac{B}{r_o^2}$$

$+ \quad - \quad +$

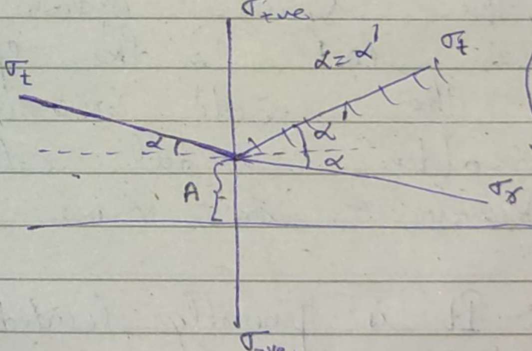
$$P_o - P_i = B\left(\frac{1}{r_o^2} - \frac{1}{r_i^2}\right)$$

$$B = \frac{(P_o - P_i)\, r_i^2 r_o^2}{(r_i^2 - r_o^2)} = \frac{(P_i - P_o)\, r_o^2 r_i^2}{r_o^2 - r_i^2}$$

$$A = \frac{(P_o - P_i)\, r_o^2}{(r_i^2 - r_o^2)} - P_i = \frac{r_i^2 P_i - r_o^2 P_o}{r_o^2 - r_i^2}$$

$$\sigma_l = \frac{r_i^2 P_i - r_o^2 P_o}{r_o^2 - r_i^2}$$

Linearised, $x = \frac{1}{r^2}$

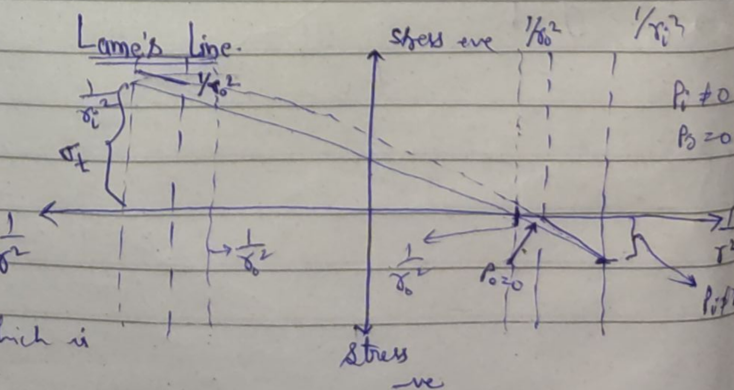


$$\sigma_r = -P_i$$

$$\sigma_l = \frac{r_i^2 P_i}{r_o^2 - r_i^2}$$

$$\sigma_t = \frac{P_i (r_o^2 + r_i^2)}{r_o^2 - r_i^2}$$

$\boxed{\text{To find } \sigma_r \text{ \& } \sigma_t}$



failure will occur at that point which is highly stressed.

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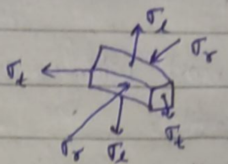
They is need to prevent failure at week point

at $r = r_i$

$$\sigma_l = \frac{P_i r_i^2}{r_o^2 - r_i^2}$$



$P_o = 0$

$P_i \neq 0$

$$\sigma_r = -P_i$$

$$\sigma_t = \frac{P_i(r_o^2 + r_i^2)}{(r_o^2 - r_i^2)}$$

$$\sigma_1 > \sigma_2 > \sigma_3 ; \Rightarrow \sigma_t > \sigma_l > \sigma_r.$$

if we consider brittle material → Rankine theory

σ_t is to be compare with ~~ult~~ ultimate strength in tension

$$[\sigma_t] = \frac{\sigma_{ut}}{FOS}$$

$$[\sigma_t] \geq \sigma_t ; \quad [\sigma_t] \geq \frac{P_i(r_o^2 + r_i^2)}{r_o^2 - r_i^2}$$

$$[\sigma_t](r_o^2 - r_i^2) \geq P_i(r_o^2 + r_i^2)$$

$$[\sigma_t] r_o^2 - [\sigma_t] r_i^2 \geq P_i r_o^2 + P_i r_i^2$$

$$[\sigma_t] r_o^2 - P_i(r_o^2) \geq [\sigma_t] r_i^2 + P_i r_i^2$$

$$\frac{r_o^2}{r_i^2} \geq \frac{[\sigma_t] + P_i}{[\sigma_t] - P_i} ; \quad \boxed{\frac{r_o}{r_i} \geq \sqrt{\frac{[\sigma_t] + P_i}{[\sigma_t] - P_i}}}$$

$$\frac{r_i + t}{r_i} \geq \sqrt{\frac{[\sigma_t] + P_i}{[\sigma_t] - P_i}}$$

$$t \geq r_i \left[\sqrt{\frac{[\sigma_t] + P_i}{[\sigma_t] - P_i}} - 1 \right]$$

for ductile

maxm shear stress theory

$$[\tau] = \frac{\tau_{yield}}{F.S} , \quad \tau_{yield} = \frac{\sigma_{yield}}{2}$$

$$\tau_{max} = \frac{1}{2} \left| \sigma_{max} - \sigma_{min} \right| = \frac{1}{2} \left| \frac{P_i(r_o^2 + r_i^2)}{(r_o^2 - r_i^2)} + P_i \right|$$

$$\tau_{max} = \frac{1}{2} \left| \frac{2 P_i r_o^2}{(r_o^2 - r_i^2)} \right| = \frac{P_i r_o^2}{r_o^2 - r_i^2}$$

$$[\tau] \geq \tau_{max} \quad ; \quad [\tau] \geq \frac{p_i r_o^2}{r_o^2 - r_i^2}$$

$$[\tau](r_o^2 - r_i^2) \geq p_i \cdot r_o^2$$

$$[\tau] r_o^2 - [\tau] r_i^2 \geq p_i \cdot r_o^2$$

$$\frac{r_o}{r_i} \geq \sqrt{\frac{[\tau]}{[\tau] \mp p_i}}$$

$$\frac{r_i + t}{r_i} \geq \sqrt{\frac{[\tau]}{[\tau] \mp p_i}}$$

$$t \geq r_i \left[\sqrt{\frac{[\tau]}{[\tau] \mp p_i}} - 1 \right]$$

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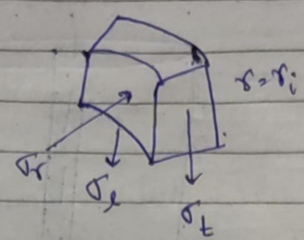
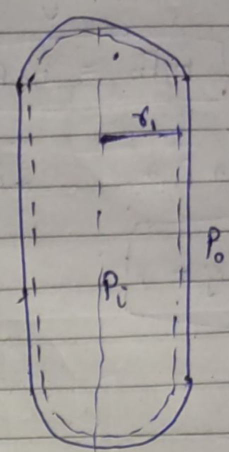
$$[\epsilon_t] = \frac{\sigma_{yield}}{E \times FS} = \frac{[\sigma_t]}{E}$$





at $r = r_i$

$\sigma_r = -P_i$

$\sigma_l = \frac{P_i r_i^2}{r_o^2 - r_i^2}$

$\sigma_t = \frac{P_i(r_o^2 + r_i^2)}{(r_o^2 - r_i^2)}$

$$\epsilon_t = \frac{\sigma_t}{E} - \frac{\mu\sigma_r}{E} - \frac{\mu\sigma_l}{E}$$

$$= \frac{P_i}{E}\left(\frac{r_o^2 + r_i^2}{r_o^2 - r_i^2}\right) + \frac{\mu P_i}{E} - \frac{\mu P_i r_i^2}{E(r_o^2 - r_i^2)}.$$

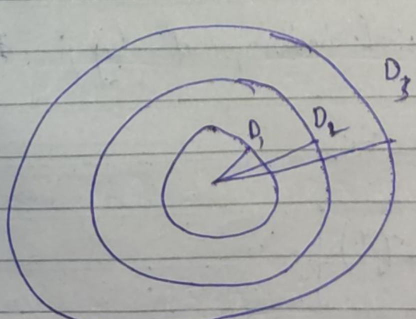
$$= \frac{P_i}{E}\left[r_o^2 + r_i^2 + \mu(r_o^2 - r_i^2) - \mu r_i^2\right] \frac{1}{(r_o^2 - r_i^2)}$$

$$= \frac{P_i}{E(r_o^2 - r_i^2)}\left[(1+\mu) r_o^2 + (1-2\mu) r_i^2\right].$$

$$\left([\sigma_t] - (1+\mu)P_i\right) r_o^2 \geq \left([\sigma_t] + (1-2\mu)P_i\right) r_i^2$$

$$\frac{r_o^2}{r_i^2} \geq \frac{[\sigma_t] + (1-2\mu)P_i}{[\sigma_t] - (1+\mu)P_i}$$

$$t \geq r_i\left[\sqrt{\frac{[\sigma_t] + (1-2\mu)P_i}{[\sigma_t] - (1+\mu)P_i}} - 1\right],$$



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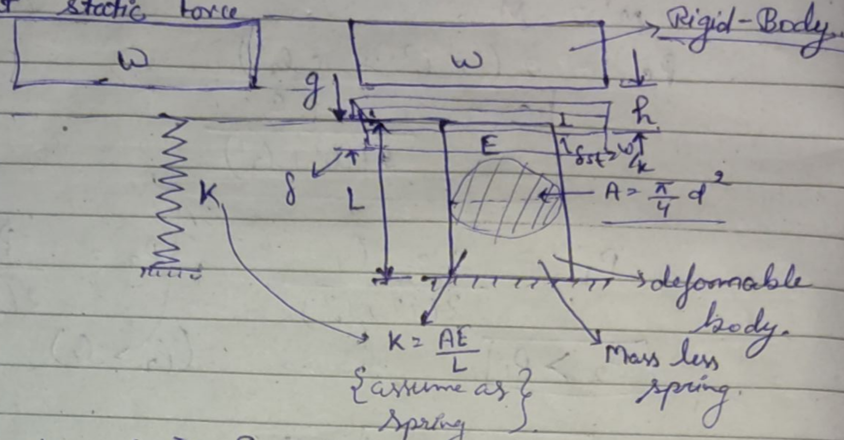
Impact Design procedure

Equivalent static force

damping is absent



Max dynamic deformation, $\delta > \delta_{st}$

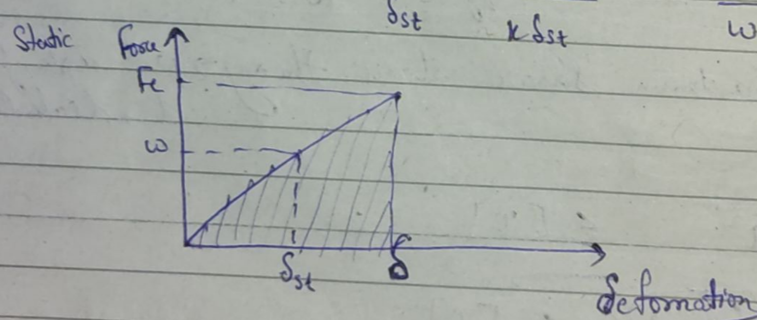
This can ~~deform~~ assume the spring statically.

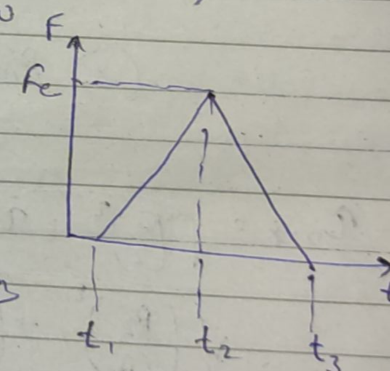
$\hookrightarrow F_e = k\delta$

Impact factor

$\boxed{F_e > W}$

$$\text{Impact factor (I.F.)} = \frac{\delta}{\delta_{st}} = \frac{\delta k}{k\delta_{st}} = \frac{F_e}{W}, \quad > 1$$





$$W(h+\delta) = \frac{1}{2} F_e \delta$$

$$h+\delta = \frac{1}{2} \cdot \frac{F_e}{W} \cdot \delta = \frac{1}{2} \times \frac{\delta}{\delta_{st}} \times \delta$$

$$h+\delta = \frac{1}{2} \times \frac{\delta^2}{\delta_{st}}$$

$$\delta^2 - (2\delta_{st})\delta - 2h\delta_{st} = 0.$$

→ Impact load
→ Direct collision
→ moving load

$$\delta = \frac{2\delta_{st} \pm \sqrt{4\delta_{st}^2 + 8h\delta_{st}}}{2} = \delta_{st} \pm \sqrt{\delta_{st}^2 + 2h\delta_{st}}$$

$$\frac{F_e}{W} = \boxed{\text{I.F.} = \frac{\delta}{\delta_{st}} = \left[1 \pm \sqrt{1 + \frac{2h}{\delta_{st}}}\right]}$$ only positive value will be greater

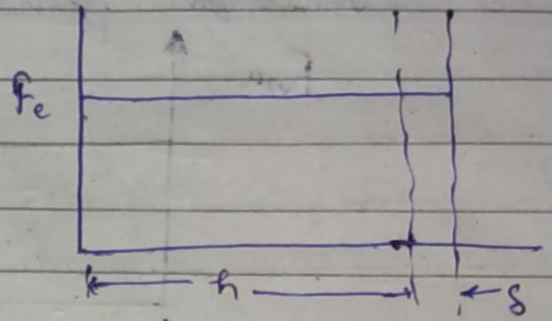
$\boxed{\delta <<< h}$ <u>horizontal</u>

≈ 0

$$w(h+\cancel{\delta}) = \frac{1}{2} F_e \delta_{st}$$

$$wh = \frac{1}{2} F_e \delta_{st}$$

$$\boxed{I.F. = \sqrt{\frac{2h}{\delta_{st}}}}$$



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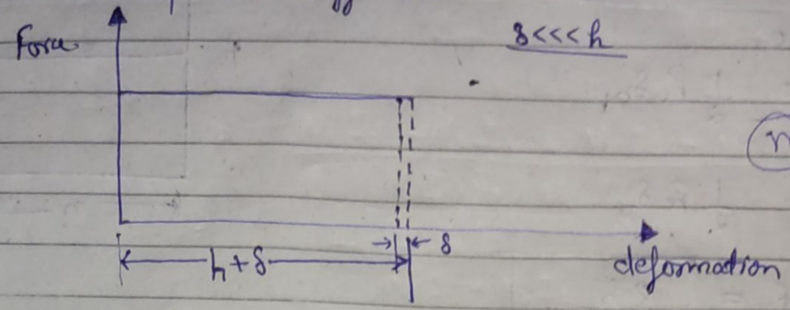
Gravitational potential energy released

$\delta <<< h$



(m) → mass

$\boxed{W = mg}$

$$W(h+\underbrace{\delta}_{\approx 0}) = \frac{1}{2} \underbrace{F_e}_{\text{Equivalent static force}} \delta$$

$$Wh = \frac{1}{2} F_e \delta$$

$$h = \frac{1}{2}\frac{F_e}{W}\cdot\delta = \frac{1}{2}\frac{\delta}{\delta_{st}}\cdot\delta = \frac{1}{2}\frac{\delta^2}{\delta_{st}}$$

$$\delta = \pm\sqrt{2h\delta_{st}}$$

$$\boxed{\delta = \sqrt{2h\delta_{st}}} \qquad \boxed{\delta \longrightarrow +ve}$$

$$\delta = \delta_{st}\sqrt{\frac{2h}{\delta_{st}}}$$

$$\boxed{\delta = \delta_{st}\,(I.F.)} \quad \text{where, } I.F. = \sqrt{\frac{2h}{\delta_{st}}}$$

Velocity just before impact $\Rightarrow V_0 = \sqrt{2gh}$

$$\boxed{2h = \frac{V_0^2}{g}}$$

$$I.F. = \sqrt{\frac{V_0^2}{g\,\delta_{st}}}$$

Assumption:-

1. Stricking body is perfectly rigid {no energy storing capacity in stricking body only ins(}
2. No damping.

Str. has no mass {Stress wave}.

$$\frac{\delta}{\delta_{st}} = \frac{F_e}{W} = \text{Impact factor (I.F.)}$$

Vertical Impact:-

$$\delta = \delta_{st}\times\sqrt{\frac{2h}{\delta_{st}}} = \sqrt{2h\delta_{st}}$$

$$F_e = W\sqrt{\frac{2h}{\delta_{st}}} = \sqrt{\frac{2hW^2}{\delta_{st}}} = \sqrt{2hWk}, \quad \boxed{k = \frac{W}{\delta_{st}}}$$

Horizontal impact:-

$$\delta = \delta_{st} \times \sqrt{\frac{V_0^2}{g\,\delta_{st}}} = \sqrt{\frac{V_0^2\,\delta_{st}}{g}}$$

$$F_e = \omega \times \sqrt{\frac{V_0^2}{g\,\delta_{st}}} = \sqrt{\frac{V_0^2\,\omega^2}{g\,\delta_{st}}} = \sqrt{\frac{V_0^2\,\omega k}{g}}, \quad \boxed{k = \frac{\omega}{\delta_{st}}} = \frac{AE}{L}$$

$$\sigma_{static} = \frac{W}{A}\;;\quad \sigma_{dynamic} = \underbrace{\frac{F_e}{A}}_{\text{maximum value}} = \frac{1}{A}\sqrt{\frac{V_0^2\,\omega k}{g}} = \sqrt{\frac{V_0^2\,\omega k}{A^2 \cdot g}}$$

$F_e \leftarrow k\delta$

$\omega = mg$

$$\sigma_{dynamic} = \sqrt{\frac{m V_0^2 k}{A^2}}$$

$$= \sqrt{2 \times \frac{1}{2} m V_0^2 \times \frac{1}{A^2} \times \frac{AE}{L}}$$

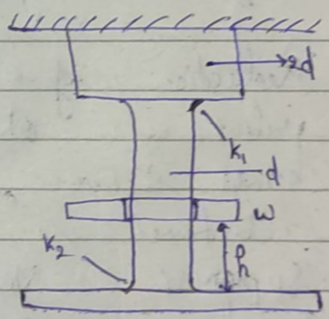
$$= \sqrt{\frac{2UE}{AL}}, \quad U = \frac{1}{2} m V_0^2 = \text{kinetic energy of Impac}$$

Energy failure is used in dynamic impact load.

$$\sigma^2_{dynamic} = \frac{2UE}{AL = V}$$

$$\boxed{U = \frac{1}{2E}\,\sigma^2_{dynamic} \times V}$$

$$U = \int_V \frac{\sigma^2_{dynamic}}{2E}\,dV$$



Change of properties.

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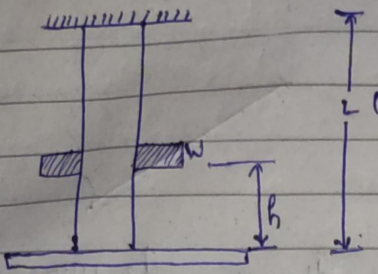
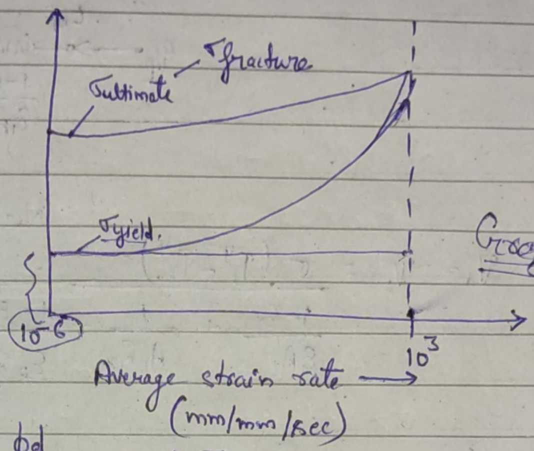


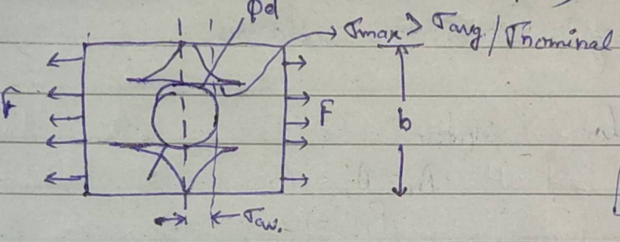
$$\boxed{U = \int_V \frac{\sigma^2_{dynamic}}{2E}\, dv}$$

$\sigma_{dynamic}$



Crazy material

thickness = t.



$\boxed{\sigma_{nom.} = \sigma_{avg.}}$

$$\sigma_{avg.} = \frac{F}{(b-d)t}$$

$\dfrac{\sigma_{max}}{\sigma_{nom}} = K_{th.}$ → theoretical stress ~~state~~ concentration factor.

th K

$$\boxed{K_{eff} = \frac{\sigma_{max}}{\sigma_{nom.}}} \Rightarrow \sigma_{max} = K_{eff} \times \sigma_{nom.}$$

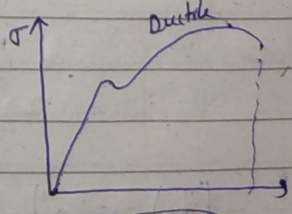
$$\frac{\sigma_{max}}{E} = K_{eff} \times \frac{\sigma_{nom}}{E}$$

below proportional limit

$$\boxed{\epsilon_{max} = K_{eff.} \times \epsilon_{nom.}}$$

diff. w.r.t. time, $\dot{\epsilon}_{max} = K_{eff} \times \dot{\epsilon}_{nom.}$

Modulus of toughness



If loading is very-very slow what will be stress factor (K).

for ductile, $K_{eff} = 1$.

for brittle, $K_{eff} = K_{th}$.

$\boxed{\text{Local yielding}}$

$$\boxed{\left(\frac{U}{V}\right)_{brittle} < \left(\frac{U}{V}\right)_{Ductile}}$$

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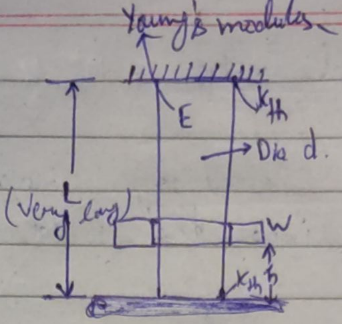
Case-1:



Failure

↳ Stress = σ_{yield}.

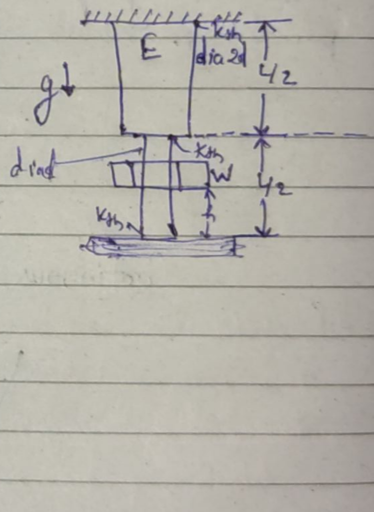
$$Vol. = \frac{\pi}{4} d^2 L.$$

$$\sigma_{nom} = \frac{\sigma_{yield}}{K_{th}}$$

$$U = \frac{\left(\frac{\sigma_{yield}}{K_{th}}\right)^2 \times \frac{\pi}{4} d^2 L}{2E}$$

$$U = \frac{\sigma_{yield}^2 \times \pi d^2 L}{8E \times K_{th}}$$

Case-2:



$$Vol. = \frac{\pi}{4}(2d)^2 \cdot \frac{L}{2} + \frac{\pi}{4} \cdot d^2 \cdot \frac{L}{2}$$

$$Vol. = \left(\frac{5}{2}\right)\frac{\pi}{4} d^2 L$$

$$\boxed{\sigma_{nom,1} = \frac{\sigma_{yield}}{K_{th}}}.$$

$$\text{Total force, } F = \frac{\sigma_{yield}}{K_{th}} \times \frac{\pi}{4} d^2.$$

$$\sigma_{nom,2} = \frac{\frac{\sigma_{yield}}{K_{th}} \times \frac{\pi}{4} d^2}{\frac{\pi}{4}(2d)^2} = \frac{\sigma_{yield}}{4 \times K_{th}}$$

$$U_1 = \frac{\left(\frac{\sigma_{yield}}{K_{th}}\right)^2 \times \frac{\pi d^2 L}{8}}{2E} = \frac{\sigma_{yield}^2 \times \pi d^2 L}{16 E K_{th}^2}.$$

$$U_2 = \frac{\left(\frac{\sigma_{yield}}{4K_{th}}\right)^2 \times \frac{\pi d^2 L}{2}}{2E} = \frac{\sigma_{yield}^2 \times \pi d^2 L}{64 E K_{th}^2}$$

$$U' = U_1 + U_2$$

$$U' = \frac{5}{64}\,\frac{\sigma_{yield}^2 \times \pi d^2 L}{E k_{th}^2}$$

$$U' = \left(\frac{5}{8}\right)\frac{\sigma_{yield}^2 \times \pi d^2 L}{8 E k_{th}^2}$$

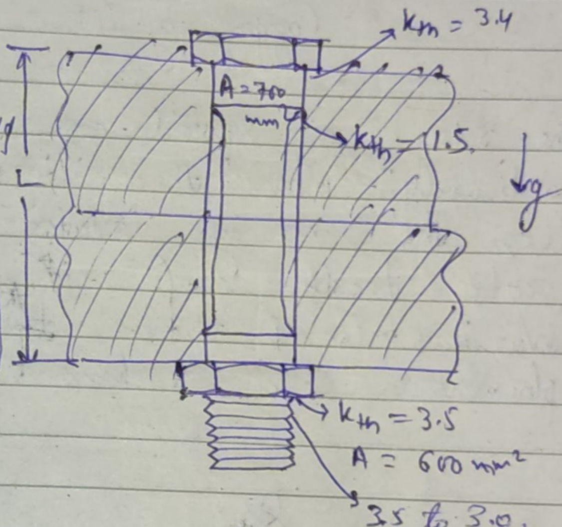
(*) Vol^m in 2nd case is more but energy is less.

$$\frac{P}{700} \times 3.4 = \sigma_{yield}$$

$$P = \frac{700}{3.4}\sigma_{yield} = 205.8823\,\sigma_{yield}$$

$$\frac{P}{600} \times 3.5 = \sigma_{yield}$$

$$\boxed{P = \frac{600}{3.5}\sigma_{yield} = 171.4285\,\sigma_{yield}}$$



$$\frac{P}{600} \times 3.0 = \sigma_{yield}$$

$$\boxed{P = 200\,\sigma_{yield}}$$

$$\frac{\sigma}{A} \times 1.5 = \sigma_{yield}$$

$$\frac{200\,\sigma_{yield} \times 1.5}{A} = \sigma_{yield}$$

$$\boxed{A = 300\ \text{mm}^2}$$