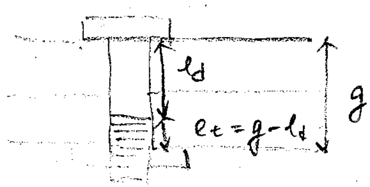
Note: if P is steadily increased to a value above

$$P_{critical} = \frac{k_b + k_m}{k_m} F_i$$

at $P = P_{critical}$, the members "seperate" and the bolt must suddenly carry the full load P instead of just $\underline{CP}$, $\Rightarrow$ a sufficient preload is very important

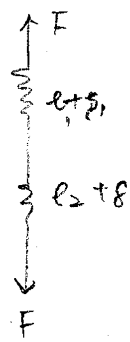
· estimate k_b & k_m



regard threaded & unthreaded porsions as springs in series

$$F = k_1 \delta_1 = k_2 \delta_2$$

so $\delta_1 = \frac{F}{k_1}$ & $\delta_2 = \frac{F}{k_2}$

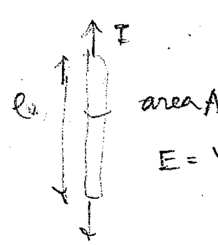


$$F = k\delta = k(\delta_1 + \delta_2)$$

$$\Rightarrow F = k\left(\frac{F}{k_1} + \frac{F}{k_2}\right)$$

$$\therefore \frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2}$$

· Stiffness of a rod



E = Young's modulus

$$\sigma = E\epsilon$$

$$\frac{F}{A} = E\frac{\delta}{l}$$

$$\rightarrow k = \frac{F}{\delta} = \frac{AE}{l}$$

for bolt $\frac{1}{k_b} = \frac{l_d}{A_d E} + \frac{l_t}{A_t E}$

where $A_d = \frac{\pi d^2}{4}$ d = "major diameter"

A_t = "tensile stress Area"

$$\rightarrow k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d}$$

- for members

$$\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2} + \cdots \frac{1}{k_N} \quad \text{if there are } N \text{ members}$$

Note: if there is any member which is "soft" than others

$\Rightarrow$ $\frac{1}{k_m}$ is dertermined by $\frac{1}{k_{soft}}$

$\Rightarrow$ $\frac{1}{k_m}$ is "large"

$\Rightarrow$ k_m is "small" $\rightarrow$ we want $k_m \uparrow$

recall we want

$c \ll 1$

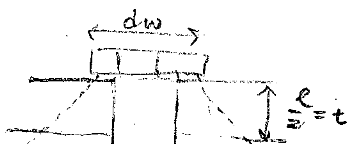
$\Rightarrow$ $F_b = P \cdot C$ is small

$\Rightarrow$ $F_m = P \cdot (1-c)$ is large

$\Rightarrow$ most P acts on member

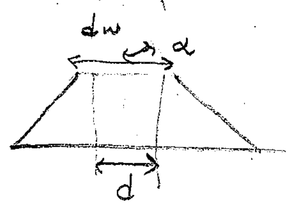
Estimate k_m is not easy { experiments
finite element
approximate model based on "pressure cone" text 8.5

Text 8.5



why not easy?

changes when the area of material subject to the bolt pressure changes with distance into the bolt.



dw : diameter of washer face
d : diamete of bolt shate
α = 30° in general
t : member thickness
= $\frac{l}{2}$ (two member case)

$\alpha = 30°$ in this course unless specified

↓ calculation in 8.5

$$k = \frac{P}{\delta} = \frac{\pi E d \tan\alpha}{\ln \frac{(1.15t + d_w - d)(d_w + d)}{(1.15t + d_w + d)(d_w - d)}}$$

$l = 2t$

↓ 2 member, same material, geometry

diameter of washer face is about 50% greater than the fastener diameter for standard hexagon-head bolts & cap screws $\Rightarrow d_w = 1.5d$

$$k_m = \frac{k}{2} = \frac{0.577\pi E d}{2\ln\left(5\,\frac{0.577l + 0.5d}{0.577l + 2.5d}\right)}$$

- Specification of Preload

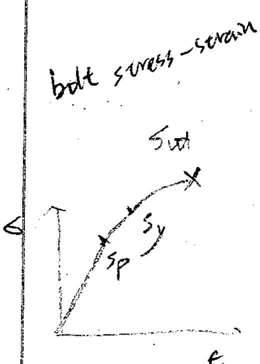
force on bolt $F_b = F_i + CP$

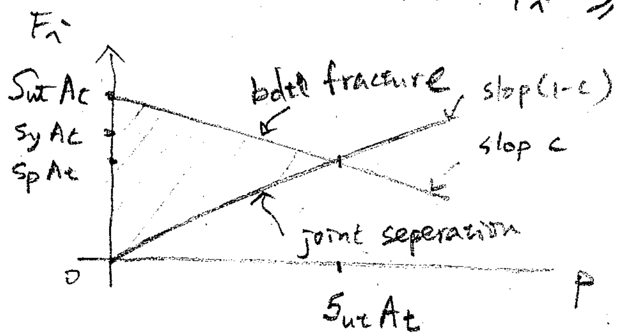
Stress $\sigma = \frac{F_b}{A_t} = \frac{F_i + CP}{A_t} \leq S_{ut}$

to prevent fracture (yielding), require $F_i \leq S_{ut} \cdot A_t - CP$

Recall: to prevent seperation $F_m = -F_i + (1-c)P \leq 0$

also want $F_i \geq (1-c)P$





S_p = "proof" stress

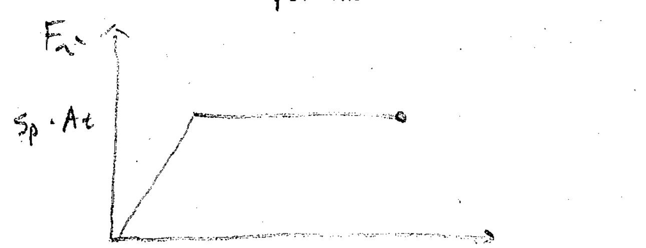
S_pA_t = "proof" load

(max. load without permanent bolt extension)

table 8.9~8.11

Standard practice

- If bolt reuse after disassembly : $F_i \approx 0.75\, S_pA_t$
- ~~relaced~~ permanent connections : $F_i \approx 0.9\, S_pA_t$



$S_p \approx 0.85\, S_y$

idealized behavior of ductile bolt (exhibits significant plastic deformation brefore fracture)

If bolt is not stretched into plastic regime ($F_i = S_pA_t$)

→ there will be greater variability in