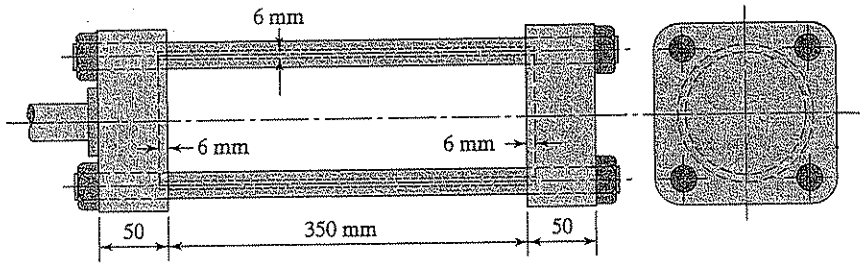
ME 325 – Exam 2
April 13, 2009

1.(*60 pts.*) The bolts shown in the figure below are M20, ISO grade 8.8 steel, coarse-pitch with rolled threads. The steel cylinder is 100 mm inside diameter (ID). Fluid pressure inside the cylinder varies between 0 and 14 MPa. Assume the end plates are rigid. Find the value of the initial preload on the bolts, F_i, in order to ensure a factor of safety of four against fatigue failure.



2.(*40 pts.*) A 7/16-in-dia UNC SAE grade 7 bolt is preloaded to 70% of its proof strength when clamping a 2.75-in thick sandwich of solid steel. Find the safety factors against bolt yielding and joint separation when the external load fluctuated between 0 and 5,000 lb. Assume that the bolt is completely threaded and no washers are used in the connection.

① M20 grade 8.8 steel bolts :

$S_p = 600\ MPa \quad S_{ut} = 830\ MPa \quad A_t = 245\ mm^2$

$$K_b = 4 \cdot \frac{A_t \cdot E_b}{L_b}$$

$E_b = 207\ GPa \quad L_b = 350 + 2 \cdot 50 = 0.45\ m$

$$K_b = 4 \cdot \frac{245 \cdot 10^{-6} \cdot 207 \cdot 10^{9}}{0.45} = 451 \cdot 10^{6}\ \frac{N}{m} = 451\ \frac{MN}{m}$$

$$K_m = \frac{A_m E_m}{L_m}$$

$$A_m = \frac{\pi}{4}\left(OD^2 - ID^2\right) = \frac{\pi}{4}\left[(0.1 + 2 \cdot 0.006)^2 - 0.1^2\right] = 0.001998\ m^2$$

$E_m = 207\ GPa$

$L_m = 350 + 2 \cdot 6 = 362\ mm = 0.362\ m$

$$K_m = \frac{0.001998 \cdot 207 \cdot 10^{9}}{0.362} = 1143\ \frac{MN}{m}$$

$$C = \frac{K_b}{K_m + K_b} = \frac{451}{451 + 1143} = 0.283$$

External load due to fluid pressure varies between 0 and p_{max}.

$$P_{max} = p_{max} \cdot A_{ID} = p_{max} \cdot \frac{\pi}{4} ID^2 = 14 \cdot 10^{6} \cdot \frac{\pi}{4} \cdot (0.1)^2 = 0.11 \cdot 10^{6}\ N$$

$= 0.11\ MN$ (applied to all four bolts)

$$\sigma_b = \frac{F_b}{A_t} = \frac{F_i + C\,P/4}{A_t} \quad \text{with} \quad 0 \le P \le P_{max}$$

$$\sigma_{ba} = \frac{C\,\frac{P_{max}}{4}}{2A_t} = \frac{0.283 \cdot \frac{0.11 \cdot 10^6}{4}}{2 \cdot 245 \cdot 10^{-6}} = 15.9 \text{ MPa}$$

$$\sigma_{bm} = \frac{F_i}{2A_t} + \frac{C\,P_{max}/4}{2A_t} = \frac{F_i}{2A_t} + 15.9$$

Modified Goodman

$$\frac{\sigma_{ba}}{S_e} + \frac{\sigma_{bm}}{S_{ut}} = \frac{1}{n} \qquad n = 4$$

$S_e = 129$ MPa $S_{ut} = 830$ MPa

$$\frac{15.9}{129} + \frac{F_i}{2A_t} \cdot \frac{1}{830} + \frac{15.9}{830} = \frac{1}{4} \Rightarrow$$

$$\Rightarrow F_i = 2A_t \cdot 830 \left(\frac{1}{4} - \frac{15.9}{129} - \frac{15.9}{830} \right) = 43{,}760 \text{ N} = 43.8 \text{ kN}$$

(2) $\frac{7}{16}$" UNC, class 7, rolled threads

$F_i = 0.7 \cdot S_p \cdot A_t = 0.7 \cdot 105 \cdot 10^3 \cdot 0.1063 = 7813$ lb

$S_p = 105$ ksi , $A_t = 0.1063$ in^2

Assuming a bolt completely threaded, and no washers.

$$k_b = \frac{A_t \cdot E_b}{L_b} = \frac{0.1063 \cdot 30 \cdot 10^6}{2.75} = 1.16 \cdot 10^6 \frac{lb}{in}$$

$E_b = 30 \cdot 10^6$ psi $\quad L_b = 2.75$ in

$$k_m = \frac{0.577\pi \cdot E_m \cdot d}{2 \ln\left(5 \cdot \frac{0.577l + 0.5d}{0.577l + 2.5d}\right)} = \frac{0.577 \cdot \pi \cdot 30 \cdot 10^6 \cdot 0.438}{2 \ln\left(5 \cdot \frac{0.577 \cdot 2.75 + 0.5 \cdot 0438}{0.577 \cdot 2.75 + 2.5 \cdot 0.438}\right)} =$$

$$= 9.8 \cdot 10^6 \frac{lb}{in}$$

$E_m = 30 \cdot 10^6$ psi

$l = 2.75 \quad d = \frac{7}{16} = 0.438$ in

$$C = \frac{k_b}{k_m + k_b} = \frac{1.16}{1.16 + 9.8} = 0.106$$

Factor of safety against bolt yielding

$$n = \frac{S_p A_t - F_i}{C \cdot P_{max}} = \frac{105 \cdot 10^3 \cdot 0.1063 - 7813}{0.106 \cdot 5000} = 6.31$$

Factor of safety against separation

$$n = \frac{F_i}{(1-C)P} = \frac{7813}{(1-0.106) \cdot 5000} = 1.74$$