DESIGN PROJECT # 2

Due to Saturday, January 1, 2022

Use the following numbers in your calculations

If only one person is doing the project

Your school ID →

a ←

b ←

If two people are doing the project together

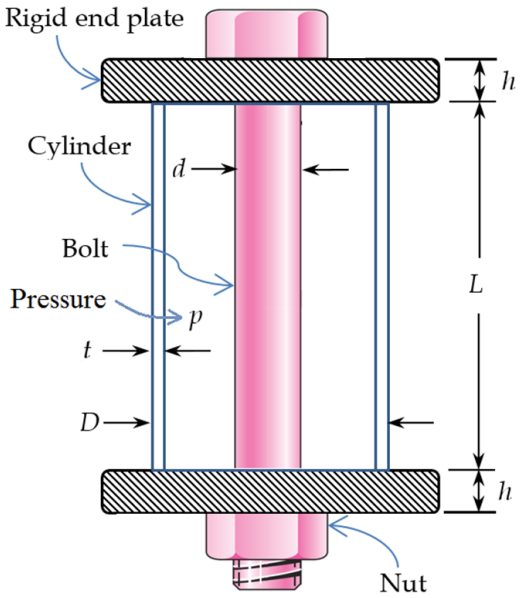
First person's school ID →

a ←

Second person's school ID →

b ←

Consider a thin - walled cylinder placed between two rigid end plates. A bolt is inserted through the holes in the end plates. The nut is snugly tightened so that no appreciable stress develops in the bolt and cylinder. Instead of applying a specific torque via a torque wrench to give a certain preload in the bolt, the nut is rotated by a certain number of turns, n, after snugly tightening the nut to induce a certain preload in the bolt. **(*a*)** Derive the relation between the number of turns, n, which may not be an integer number, and the preload, F_i. Hint: Use equilibrium and compatibility principles. You may consider that the pre-tensioning is achieved in two steps: The positions of the end plates are fixed; the nut is turned and the bolt is elongated while cylinder remains undeformed; then the plates are released. **(*b*)** Inside the cylinder, a fluid is introduced with a pressure of $(12 + 0.5b)$ MPa. Derive the relation between the pressure and the tension in the bolt and compression in the cylinder. Consider also the axial extension in the bolt due to pressure and axial contraction in the cylinder due to hoop stress.



(*c*) Develop a computer code to design the bolted joint by choosing a suitable property class, diameter, and preload for the bolt such that the lowest of the safety factors for the possible failure modes is above 1.6 and the cost is minimum. The bolt should be standard. The segments of the bolt in tension can be assumed to be mostly unthreaded. The preload factor, K_i, should be chosen between 0.50 and 0.90. Both the bolt and the cylinder are made of steel with $E = 207$ GPa and $\nu = 0.3$. $t = (4 + 0.3a)$ mm, $D = (120 - 4b)$ mm, $L = (240 + 12a)$ mm (length of the cylinder), $h = 20$ mm (thickness of the end plates). Note that the length of the bolt under stress is $L + 2h$. Fluid pressure varies from 0 MPa to $(12 + 0.5b)$ MPa. 5×10^5 cycles of fatigue life with 99.9% reliability is required. In the failure analysis of the bolt, pressure applied on the bolt shank should be taken into account. In order to prevent leakage, contained gaskets (not shown) are used between the rigid plates and nut and bolt head, but because their thickness is small, there is no need to include them in the stiffness analysis. Note: In the failure analysis, consider the safety factor as a factor of the pressure, p_{max}, for example do not define SF_{yield}

as $SF_{yield} = S_y/\sigma_{max}$, but define as $S_y = f(SF_{yield}\ p_{max})$

The computer code should read the inputs from an input file or within the program and find the values of the design variables without user intervention through iterations. Print out your program and output file; also return a softcopy of the code. The output file should include the following **in the given order**: Major diameter of the bolt (d), pitch (p), pitch diameter (d_p), tensile stress area (A_t), property class of the material, number of turns of the nut for preload (n), initial load (F_i), preload factor (K_i), tensile stress in the bolt after preload (σ_{bi}), compressive stress in the clamped member after preload (σ_{ci}), maximum external separating force (F_e), maximum tension in the bolt (F_b), minimum compression in the clamped member (F_c), the increase in the axial stress of the bolt due to the pressure ($\Delta\sigma_b$), the decrease in the axial stress of the cylinder due to the pressure ($\Delta\sigma_c$), safety factor against yielding, safety factor against leakage, alternating force in the bolt (F_a), mean force in the bolt (F_m), standard endurance limit (S_n'), load factor (C_{load}), gradient (or size) factor (C_{size}), surface factor (C_{surf}), reliability factor (C_{rel}), corrected endurance limit (S_n), fatigue strength for 5×10^5 reversed cycles (S_f), fatigue stress concentration factor (K_f), alternating axial stress of the bolt (σ_a), alternating equivalent stress of the bolt (σ_{ea}), maximum allowable alternating stress (S_a), safety factor against fatigue failure, cost.

(*d*) Completely describe the problem, derivations, your solution method, and calculations.

Note: Two people may form a project group and work on the project together. However, project groups may not get any help from each other. Do not show your code to another group. Any similarity in the algorithm and computer code will be presumed as cheating.

Prices of bolt classes

Class	Price
4.6	$1.0 + 0.2 \times d$ (mm)
4.8	$1.1 + 0.22 \times d$ (mm)
5.8	$1.3 + 0.26 \times d$ (mm)
8.8	$3 + 0.6 \times d$ (mm)
9.8	$6 + 1.2 \times d$ (mm)
10.9	$9 + 1.8 \times d$ (mm)
12.9	$11 + 2.2 \times d$ (mm)