Tutorial 3.1: Fastener

In-Class activity

1. State the class number of the steel bolts if the proof strength is 315 MPa.
   Answer: From table 2.2, select the next higher proof strength (380MPa). Therefore,Class 5.8 is selected.

2. Determine the preload necessary to be applied on the bolt of class 4.8 with a 6 mm diameter to form a permanent joint.

   Answer: For permanent joint, use $F_i = 0.9F_p$.
   where, $F_p = S_pA_t$
   From Table 2.2, class 4.8 has $S_p = 310MPa$
   From Table 2.1, diameter 6mm has $A_t = 20.1mm^2 = 20.1 \times 10^{-6}m^2$
   Therefore, $F_p = 310 \times 10^6 \times 20.1 \times 10^{-6} = 6.23N$
   Finally, $F_i = 0.9F_p = 0.9 \times 6.23 = 5.61N$

Theory

1. Proof strength of the steel bolts is obtained from table of specifications and strengths for steel bolts. Explain how to determine the proof strength of the bolt other than steel.

2. If the external load acting on the bolt is increasing, list ONE (1) improvement that can be done to prevent the joint from separating by assuming the diameter and class number of the bolt areunchanged.

Calculation

Question 1

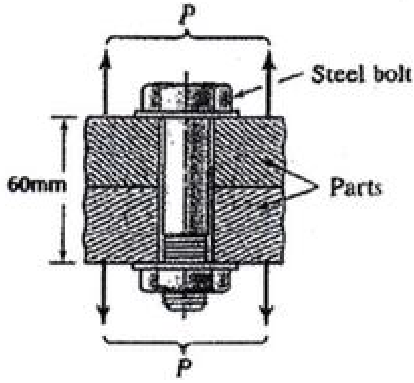

Figure 1: Figure Q1

The bolt of connnection M20 x 2.5, ISO coarse thread having Sy = 630 Mpa. The joint carries an external load of P = 40 kN. The bolt were made of steel of modulus elasticity Es and the parts are cast iron with modulus of elasticity Ec = Es/2. Determine

(i) The total force on the bolt if the joint is reusable

(ii) The tightening torque if the bolts are lubricated

Example Solution

$d = 0.02m$
$p = 2.5mm$
$Sy = 630 \times 10^6$Pa
$Load, P = 40 \times 10^3$N
Engagement length between bolt and nut,
$L = 0.06m$

i - The total force on the bolt if the joint is reusable
Total force on bolt equation

$$F_b = CP + F_i \tag{1}$$

where $F_i = 0.75F_p$ for reusable joint
First, find joint stiffness factor.

$$C = \frac{k_b}{k_b + k_p} \tag{2}$$

Find bolt stiffness factor, k_b

$$k_b = \frac{A_b E_b}{L} \tag{3}$$

Change $E_b = E_s$ (steel)
Then, substitue diameter of bolt, d=0.02m and grip distance, L=0.06m to find kb.

$$
\begin{aligned}
k_b &= \frac{(\frac{\pi d^2}{4})E_s}{L} \\
&= \frac{(\frac{\pi 0.02^2}{4})E_s}{0.06} \\
&= 5.236 \times 10^{-3} E_s
\end{aligned}
$$

Left E_s as unknown.

Then, find Part stiffness factor, k_p.

$$
k_p = \frac{0.58\pi E_p d}{2\ln\left(5\frac{0.58l+0.5d}{0.58l+2.5d}\right)} \tag{4}
$$

Use $E_p = E_c = \frac{E_s}{2}$
Substitute $E_p = E_s/2$ to kp equation so it can cancel out when finding C in Equation 2.

$$
\begin{aligned}
k_p &= \frac{0.58\pi(\frac{E_s}{2})d}{2\ln\left(5\frac{0.58l+0.5d}{0.58l+2.5d}\right)} \\
&= \frac{0.58\pi(\frac{E_s}{2})(0.02)}{2\ln\left(5\frac{0.58(0.06)+0.5(0.02)}{0.58(0.06)+2.5(0.02)}\right)} \\
&= 9.379 \times 10^{-3} E_s
\end{aligned}
$$

Substitute into joint stiffness factor equation, C (Eq. 2)

$$
\begin{aligned}
C &= \frac{k_b}{k_b + k_p} \\
&= \frac{5.236 \times 10^{-3} E_s}{5.236 \times 10^{-3} E_s + 9.379 \times 10^{-3} E_s} \\
&= \frac{5.236 \times 10^{-3}}{5.236 \times 10^{-3} + 9.379 \times 10^{-3}} \\
&= \frac{5.236}{5.236 + 9.379} \\
&= 0.3583
\end{aligned}
$$

For reusable joint, $F_i = 0.75F_p$ and Proof Strength, $F_p = S_p A_t$.
If Yield strength is given, use $S_p = 0.9Sy$.
Therefore, the Preload equation become,

$$
\begin{aligned}
F_i &= 0.75F_p \\
&= 0.75(S_p A_t) \\
&= 0.75(0.9S_y A_t)
\end{aligned}
$$

A_t is the tensile stress area of the bolt.
From Table 2.1, diameter of M20 bolt, $A_t = 245 \times 10^{-6} mm^2$.
Convert to m^2.

$$\begin{aligned}
A_t &= 245mm^2 \\
&= 245mm^2 \times (\frac{1m}{1000mm})^2 \\
&= 245 \times 1 \times 10^{-6} \\
&= 245 \times 10^{-6} m^2
\end{aligned}$$

Substitute into Preload equation,

$$\begin{aligned}
&= 0.75(0.9 S_y A_t) \\
&= 0.75(0.9)(630 \times 10^6)(245 \times 10^{-6}) \\
&= 1.042 \times 10^5 N
\end{aligned}$$

Substitute into Total force on bolt equation (Eq. 1)

$$\begin{aligned}
F_b &= CP + F_i \\
&= 0.3583(40 \times 10^3) + 1.042 \times 10^5 \\
&= 1.185 \times 10^5 N
\end{aligned}$$

ii- The tightening torque if the bolts are lubricated
If joint are lubricated, k=0.15

$$\begin{aligned}
T &= kdF_i \\
&= (0.15)(20 \times 10^{-3})(1.042 \times 10^5) \qquad (5) \\
&= 312.56 N.m
\end{aligned}$$

Question 2

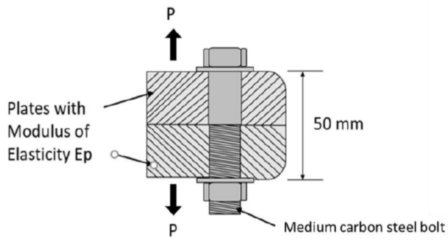

Figure 2: Figure Q1

A section of connection illustrated in Figure 1 forms a reusable connection. A total of 4 bolts are used to resist an external load 150 kN. The bolt connection is M14 x 1.5 ISO fine threadclass 5.8, made from medium carbon steel with modulus of elasticity of 200 GPa. The stress in each bolt is 406.2MPa. Determine;

(i) The joint stiffness factor.

(ii) Stiffness constant for bolt and plates.

(iii) Modulus of elasticity of plate Ep

(iv) Suggest suitable material used for plates (Based on answer in iii)

Question 3

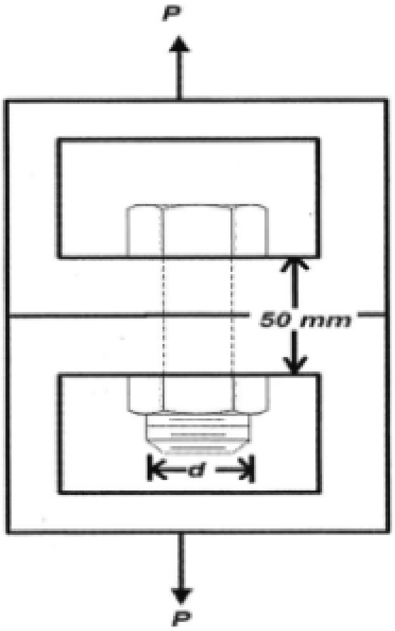

Figure 3: Figure Q3

A bolted assembly of two parts is shown in Figure Q3, is to support an external load, P = 80 kN. The steel bolt is fine thread and the modulus of elasticity is 200 GPa and reused connection. The joint stiffness factor for the design is 0.286. The parts are made of cast iron with a modulus of elasticity of 70 GPa. Assume the factor of safety for the joint is 2. Determine;

(i) The stiffness constant for the part of the effective area of the part is 2500 mm^2

(ii) The stiffness constant for the bolt and size of the bolt, d.

(iii) The suitable metric specification class number for the bolt.

Question 4

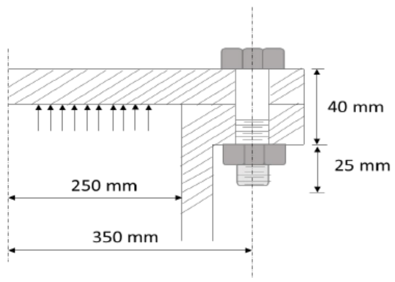

Figure 4: Figure Q4

Given M10 x 1.5 grade 5.8 bolts used to create a permanent joint connection for a pressure cylinder. A total of 2 number of bolts of modulus of elasticity 200 GPa is used to carries external load P = 8kN. The joint parts are cast iron ASTM A-48 with modulus of elasticity of 70 GPa. Determine;

(i) The stiffness constant for bolts, parts and joint's stiffness factor

(ii) Proof strength of the bolt

(iii) Yield strength of the bolt

(iv) The preload on the bolt

(v) The forces on the bolt and will the part be separated under load P?

(vi) The forces on the part

(vii) The torque on the bolt if the joint is lubricated

(viii) Pressure of gas on the cylinder if the diameter of the cylinder is 250 mm.

Well-defined problem
1. If the external load is increased by 60%, suggest improvements need to be done to avoid separation?
2. Recommend the maximum pressure if the number of bolts is increased to 6
3. Is the joint safe or fail if the pressure is increased 30%. Prove your answer.
4. If the external load is increased by 30%, suggest the suitable metric specification class number for the bolt.

Answer

Q2
i- The joint stiffness factor, $C = 0.1793$
ii- Stiffness constant for bolt, $k_b = 6.158 \times 10^8 N/m$ and plates, $k_p = 2.817 \times 10^9 N/m$
iii- Modulus of elasticity of plate, $E_p = 228.4GPa$
iv- Suggest suitable material used for plates (Based on answer in iii)
Structural steel ASTM A-36, High-strength Steel ASTM A-242

Q3
i- The stiffness constant for the part of the effective area of the part is $k_p = 3.5 \times 10^9$
ii- The stiffness constant for the bolt is $k_b = 1.402 \times 10^9 N/m$ and size of the bolt, d=22mm
iii- Minimum proof strength for the design is 476.67MPa. From Table 2.2, the next higher Proof strength is 600MPa. The suitable metric specification class number for the bolt is 8.8.

Q4
i- The stiffness constant for bolts, $k_b = 3.927 \times 10^8 N/m$, parts, $k_p = 5.941 \times 10^8 N/m$ and joint's stiffness factor, $C = 0.3986$
ii- Refer to Table 2.2, Class 5.8 has Proof strength, $S_p = 380MPa$
iii- Yield strength of the bolt, $S_y = 422.22MPa$
iv- The preload on the bolt, $F_i = 1.9836 \times 10^4 N$
v- The forces on the bolt, $F_b = 21.428kN$ and the part will not be separated under load P.
vi- The forces on the part, $F_p = -17.428kN$
vii- The torque on the bolt if the joint is lubricated, $T = 29.754N.m$
viii- Pressure of gas on the cylinder if the diameter of the cylinder is 250 mm, $P_{max} = 163kPa$
Well-defined problem
1. Option 1: Increase the number of bolts to reduce the load on each bolt.
Number of bolts, n = 3

Option 2: Increase size of bolt to increase effective cross-sectional area.
The next larger A_t is 84mm. The new bolt size will be M12.
Option 3: Use higher class of bolt. Maintain the same size of bolt and number of bolts.
The next higher Proof strength is 600MPa. The suitable metric specification class number for the bolt is 8.8.

2. The maximum pressure if the number of bolts is increased to 6 is $P_{max} = 676.9kPa$
3. The joint is safe if the pressure is increased 30%.
New Pressure, $P_{new} = 1.3 \times 8000 = 10400N$