0 - 18.5kN
10 cm THICK ALUMINUM HEAD
UNCONFINED 1mm COPPER/ASBESTOS GASKET
CAST IRON BLOCK
PISTON IS 75mm dia & CYL IS 140mm OUTSIDE dia.

SPECIFY # OF BOLTS, PRELOAD, TIGHTENING TORQUE, AND BOLT CIRCLE
MINIMUM FACTOR OF SAFETY OF 1.5 AGAINST ALL FAILURE MODES
USE FINE THREAD

\[
\frac{32.5}{3} = 10.8
\]

\[
C_b = \pi \left(\frac{107.5}{2}\right)
\]

\[
\# \text{bolts} = \frac{\pi \left(\frac{107.5}{2}\right)}{30 \text{mm}} = 11.25
\]

FOR CONVENIENCE, PUT BOLT CIRCLE AT CENTER (107.5mm dia). ASSUME 10 mm
BOLT, SINCE ANY LARGER BOLT WOULD CAUSE EFFECTIVE CYLINDER TO EXIT
THE ENGINE'S CYLINDER WALL (WHICH WOULD VOID CALCULATIONS).
IF THE BOLTS ARE PLACED IN SUCH A WAY TO HAVE THE EFFECTIVE CYLINDERS
TOUCH, IT MIGHT BE A CONVENIENT PLACE TO START.

USING THE DESIGN ASSUMPTIONS ABOVE, CALCULATE FACTORS OF
SAFETY FOR 12 10mm X 1.25 BOLTS.

FIRST COMPUTE THE BOLT STIFFNESS:

\[
K_b = \frac{\pi d^2 E}{4l} = \frac{\pi \left(0.010m\right)^2 206.8 \times 10^9 \text{N/m}^2}{4 \left(0.115m\right)} = 1.41 \times 10^8 \text{N/m}
\]

(Approx 1.5 bolt diameter in blind hole in engine block)

NEXT CALCULATE THE JOINT AND GASKET STIFFNESS:

STIFFNESS OF ALUMINUM

\[
k_{al} = \frac{2\pi d^2 E}{l} = \frac{2\pi \left(0.010m\right)^2 71.7 \times 10^9 \text{N/m}^2}{0.10m} = 4.5 \times 10^8 \text{N/m}
\]

STIFFNESS OF GASKET

\[
k_g = \frac{2\pi d^2 E}{l} = \frac{2\pi \left(0.010m\right)^2 93 \times 10^9 \text{N/m}^2}{0.001m} = 5.8 \times 10^9 \text{N/m}
\]

STIFFNESS OF CAST IRON

\[
k_{fe} = \frac{2\pi d^2 E}{l} = \frac{2\pi \left(0.010m\right)^2 103 \times 10^9 \text{N/m}^2}{0.015m} = 4.3 \times 10^9 \text{N/m}
\]
\[ \frac{1}{K_m} = \frac{1}{K_{br}} + \frac{1}{K_b} + \frac{1}{K_f} = 4.0 \times 10^8 \frac{N}{m} \]

\[ C = \frac{K_b}{K_b + K_m} = \frac{1.41}{4 + 1.41} = 0.26 \]

\[ F_i = 0.60 \quad A_t \quad S_p = 0.60 \times (61.20 \text{mm}) \times 650 \text{MPa} = 23.8 \text{ KN} \]

*Since the F.O.S. in yield must be at least 1.5, we need a relatively low preload, try 60%*

18.5 KN TOTAL EXTERNAL LOAD WITH 12 BOLTS → 1.54 KN/BOLT

\[ P_b = C \cdot P_{ext} + F_i = 0.26 \times (1.54 \text{ KN}) + 23.8 \text{ KN} = 24.2 \text{ KN} \]

\[ N_y = \frac{720 \text{ MPa} \times (61.20 \text{ mm})}{24.2 \text{ KN}} = 1.82 \quad \text{(Factor of Safety in Yield)} \]

CHECK FACTOR OF SAFETY AGAINST JOINT SEPARATION

\[ N_{bep} = \frac{F_i (1-C)}{P} = \frac{23.8 \text{ KN} (1-0.26)}{1.54 \text{ KN}} = 11.4 \]

CHECK FACTOR OF SAFETY IN FATIGUE

\[ F_{by,\text{max}} = 24.2 \text{ KN} \quad \text{and} \quad F_{by,\text{min}} = 23.8 \text{ KN} \]

\[ \sigma_{b,a} = \frac{F_{by,\text{max}} - F_{by,\text{min}}}{2A_t} = 3.3 \text{ MPa} \quad \sigma_{b,m} = \frac{F_{by,\text{max}} + F_{by,\text{min}}}{2A_t} = 3.92 \text{ MPa} \]

\[ S_e = C_{\text{load}} \cdot C_{\text{size}} \cdot C_{\text{surf}} \cdot C_{\text{temp}} \cdot C_{\text{reliab}} \cdot \frac{1}{K_f} \cdot \frac{S_{ut}}{2} = 0.7(95) \cdot 72(1) \cdot \frac{1}{5} \cdot \frac{900}{2} = 72 \text{ MPa} \]

\[ N_f = \frac{S_e (S_{ut} - \sigma_i)}{S_e (\sigma_m - \sigma_i) + S_{ut} \sigma_{\text{all}}} = \frac{72(900 - 390)}{72(3.92 - 3.90) + 900(3.3)} = 11.8 \]

**Note:** How the joint is very overdesigned with massive factors of safety. Most single cylinder gas engines have 6 or 7 6mm bolts, the calculations above are for 12 10mm bolts, so of course, we expect large factors of safety. This problem has an infinite number of solutions since it is a question of design.