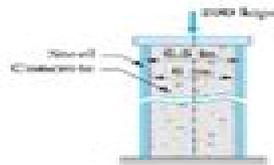# MEMAT/MECH211 – MECHANICS OF DEFORMABLE BODIES
SOLVED STATICALLY INDETERMINATE PROBLEMS

PROBLEM 1

The figure shows the cross section of a circular steel tube that is filled with concrete and topped with a rigid cap. Calculate the stresses in the steel and in the concrete caused by the 200-kip axial load. Use $E_{st} = 29 \times 10^6$ psi and $E_{co} = 3.5 \times 10^6$ psi.

Equilibrium:

$$\sigma_{st} A_{st} + \sigma_{co} A_{co} = P \qquad (a)$$

Compatibility:

$$\epsilon_{st} = \epsilon_{co} \qquad \frac{\sigma_{st}}{E_{st}} = \frac{\sigma_{co}}{E_{co}} \qquad \sigma_{co} = \sigma_{st}\frac{E_{co}}{E_{st}} \qquad (b)$$

Substituting into Eq. (a), we get

$$\sigma_{st}\left(\frac{E_{co}}{E_{st}}A_{co} + A_{st}\right) = P$$

$$\sigma_{st}\left[\frac{3.5}{29}\frac{\pi(5^2)}{4} + \frac{\pi}{4}(6.5^2 - 5^2)\right] = 200 \times 10^3$$

$$\sigma_{st} = 21040 \text{ psi} \blacktriangleleft$$

From Eq. (b):

$$\sigma_{co} = 21040\frac{3.5}{29} = 2900 \text{ psi} \blacktriangleleft$$

PROBLEM 2

A reinforced concrete column 200 mm in diameter is designed to carry an axial compressive load of 320 kN. Determine the required cross-sectional area of the reinforcing steel if the allowable stresses are 6 MPa for concrete and 120 MPa for steel. Use $E_{co} = 14$ GPa and $E_{st} = 200$ GPa.

Compatibility: $\epsilon_{st} = \epsilon_{co}$ gives $(\sigma/E)_{st} = (\sigma/E)_{co}$. If the concrete governs, the stress in the steel would be

$$\sigma_{st} = \frac{E_{st}}{E_{co}}\sigma_{co} = \frac{200}{14}(6) = 85.71 \text{ MPa}$$

Because 85.71 MPa is less than $(\sigma_w)_{st} = 120$ MPa, the concrete governs. Equilibrium gives $P_{st} + P_{co} = 320$ kN:

$$\sigma_{st} A_{st} + \sigma_{co} A_{co} = 320 \text{ kN}$$

$$(85.71 \times 10^6)A_{st} + (6 \times 10^6)\left(\frac{\pi(0.200)^2}{4} - A_{st}\right) = 320 \times 10^3 \text{ N}$$

which gives $A_{st} = 1.650 \times 10^{-3} \text{ m}^2 = 1650 \text{ mm}^2 \blacktriangleleft$

PROBLEM 3

A timber column, 8 in. by 8 in. in cross section, is reinforced on all four sides by steel plates, each plate being 8 in. wide and t in. thick. Determine the smallest value of t for which the column can support an axial load of 300 kips if the working stresses are 1200 psi for timber and 20 ksi for steel. The moduli of elasticity are 1.5×10^6 psi for timber and 29×10^6 psi for steel.

Compatibility: $\epsilon_{st} = \epsilon_{wood}$ gives $(\sigma/E)_{st} = (\sigma/E)_{wood}$.

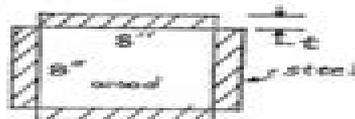If the steel governs, the stress in the wood would be

$$\sigma_{wood} = \frac{E_{wood}}{E_{st}}\sigma_{st} = \frac{1.5}{29}(20 \times 10^3) = 1034 \text{ psi}$$

Because 1034 psi is less than $(\sigma_w)_{wood} = 1200$ psi, the steel governs. Equilibrium gives $P_{st} + P_{wood} = 300$ kips.

$$\sigma_{st} A_{st} + \sigma_{wood} A_{wood} = 300 \times 10^3 \text{ lb}$$

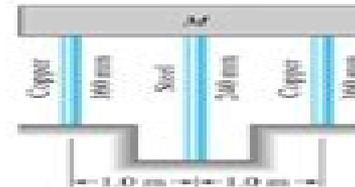$$(20 \times 10^3)(4)(8t) + (1034)(64) = 300 \times 10^3 \text{ lb}$$

which gives $t = 0.365 \text{ in.} \blacktriangleleft$

PROBLEM 4

The rigid block of mass M is supported by the three symmetrically placed rods. The ends of the rods were level before the block was attached. Determine the largest allowable value of M if the properties of the rods are as listed:

	E (GPa)	A (mm²)	σ_w (MPa)
Copper	120	900	70
Steel	200	1200	140

Compatibility: $\delta_{st} = \delta_{co}$ gives $(\sigma L/E)_{st} = (\sigma L/E)_{co}$. If copper governs, the stress in the steel would be

$$\sigma_{st} = \frac{E_{st}L_{co}}{E_{co}L_{st}}\sigma_{co} = \frac{(200)(160)}{(120)(240)}(70) = 77.78 \text{ MPa}$$

Because 77.78 MPa is less than $(\sigma_w)_{st} = 140$ MPa, the copper governs. Equilibrium gives:
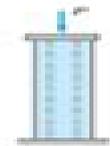
$$3P_{co} + P_{st} = Mg$$
$$2\sigma_{co}A_{co} + \sigma_{st}A_{st} = Mg$$

$$2\left[(70 \times 10^6)(900 \times 10^{-6})\right] + (77.78 \times 10^6)(1200 \times 10^{-6})$$
$$= M(9.81)$$

which yields $M = 22.4 \times 10^3 \text{ kg} \blacktriangleleft$

PROBLEM 5

The concrete column is reinforced by four steel bars of total cross-sectional area 1250 mm². If the working stresses for steel and concrete are 180 MPa and 15 MPa, respectively, determine the largest axial force P that can be safely applied to the column. Use $E_{st} = 200$ GPa and $E_{co} = 24$ GPa.

$$A_{st} = 1250 \times 10^{-6} \text{ m}^2$$
$$A_{co} = (250^2 - 1250) \times 10^{-6} = 61.25 \times 10^{-3} \text{ m}^2$$

Equilibrium:

$$\sigma_{st} A_{st} + \sigma_{co} A_{co} = P \qquad (a)$$

Compatibility:

$$\epsilon_{st} = \epsilon_{co} \qquad \frac{\sigma_{st}}{E_{st}} = \frac{\sigma_{co}}{E_{co}} \qquad \sigma_{st} = \frac{E_{st}}{E_{co}}\sigma_{co} \qquad (b)$$

Substituting into Eq. (a):

$$\sigma_{co}\left(\frac{E_{st}}{E_{co}}A_{st} + A_{co}\right) = P$$

Assuming that concrete governs, we let $\sigma_{co} = (\sigma_w)_{co}$, which yields

$$P = 15 \times 10^6\left[\frac{200}{24}(1250 \times 10^{-6}) + 61.25 \times 10^{-3}\right]$$
$$= 1.075 \times 10^6 \text{ N} = 1.075 \text{ MN} \blacktriangleleft$$

Check stress in steel using Eq. (b):

$$\sigma_{st} = \frac{200}{24}(15) = 125 \text{ MPa} \leq (\sigma_w)_{st} \quad \text{O.K.}$$

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