Department of Civil Engineering, IIT Bombay
CE 102 Engineering Mechanics – Mid-Semester Exam

Date: February 22, 2006 **Max. Marks: 100**

Note: State clearly all assumptions you have made, if any. Draw clear Free body Diagram(s). If you make multiple attempts, cancel out the one(s) you don't want to be graded. Only the first non-cancelled one encountered will be graded. **Time: 2 hours**

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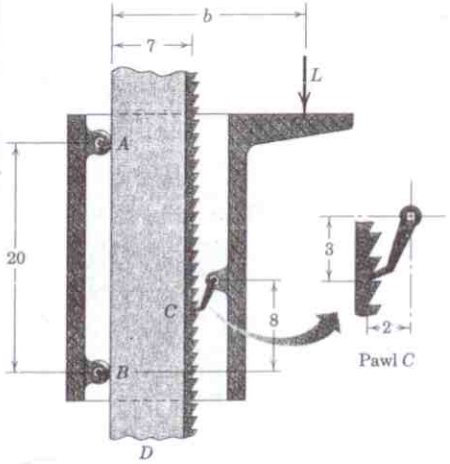
1. The device shown in section (**Fig. 1**) can support the load ***L*** at various heights by re-setting the pawl ***C*** in another tooth at the desired height on the fixed vertical column ***D***. Determine the distance ***b*** at which the load should be positioned in order for the two rollers ***A*** and ***B*** to support equal forces. The weight of the device is negligible compared with ***L***. **(25 marks)**

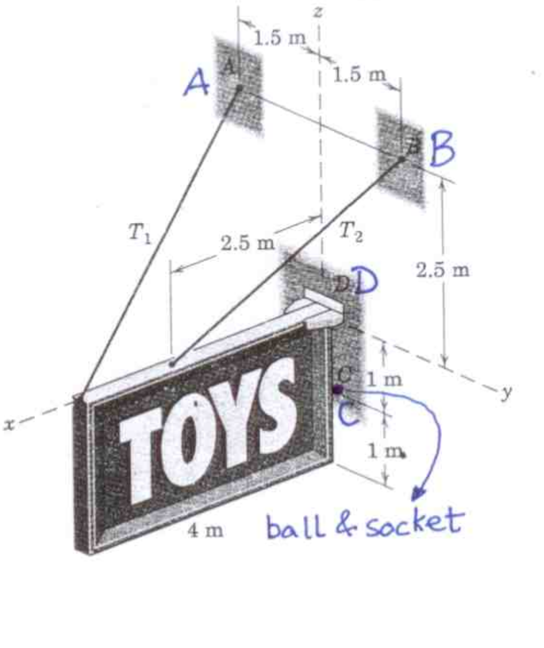
Fig. 1 ⇒

ALL DIMENSIONS IN cm



2. A rectangular signboard over a store (**Fig. 2**) weighs **1000 N**, with the center of mass in the center of the rectangle. The support against the wall at ***C*** may be treated as a ball-and-socket joint. At corner ***D*** support is provided in the *y*-direction only. Calculate the tensions T_1 and T_2 in the supporting wires, and the reactions supported at ***C*** and ***D***. **(25 marks)**

Fig. 2 ⇒



3. The movable gantry is used to erect and prepare a **5000 kN** rocket for firing. The primary structure of the gantry is approximated by the symmetrical plane truss shown in **Fig. 3**, which is statically indeterminate. As the gantry is positioning a **600 kN** section of the rocket suspended from *A*, strain-guage measurements indicate a compressive force of ***50 kN*** in member ***AB*** and a tensile force of ***120 kN*** in member ***CD*** due to the ***600 kN*** load. Calculate the corresponding forces in members ***BF*** and ***EF*** **using the method of joints.** **(25 marks)**

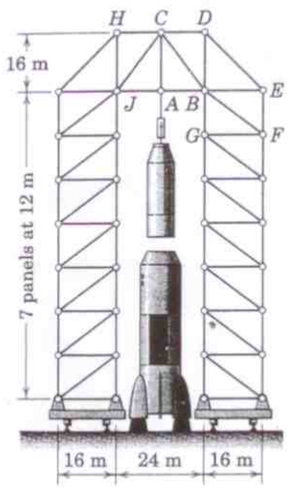


Fig. 3

4. The truss supports a ramp (shown with a dashed line) which extends from a fixed approach level near joint ***F*** to a fixed exit level near joint ***J*** as shown in **Fig. 4**. The loads shown represent the weight of the ramp. Determine the forces in members ***BH***, ***CD***, and ***CH*** **using the method of sections.** **(25 marks)**

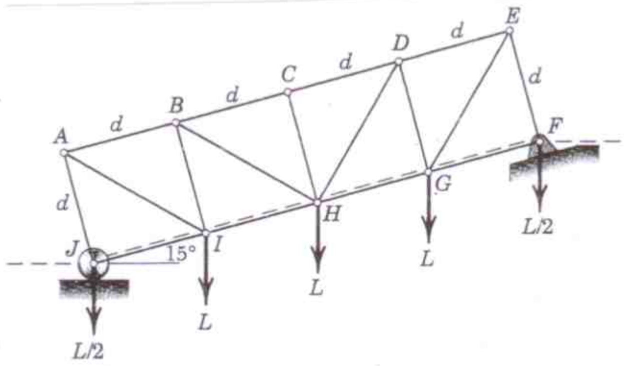
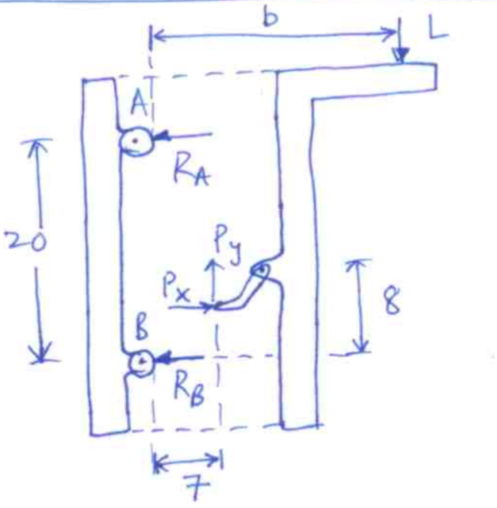


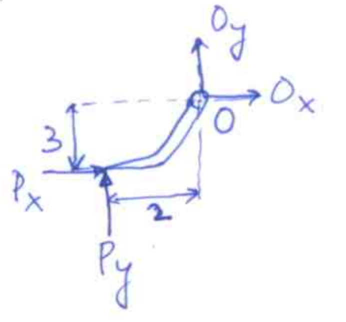
Fig. 4

CE102 – Midsem solution – 2006.

P①



FBD of entire device



FBD of Pawl.

Small rollers at A, B, so no friction

6 unknowns (b, R_A, P_x, P_y, O_x, O_y)
2 FBD's. (Pawl, device)
⇒ SD.

From device FBD : $\Sigma F_y = 0 \rightarrow P_y = L$

From Pawl FBD : $\Sigma M_O = 0 \rightarrow P_x(3) = P_y(2) \rightarrow P_x = \frac{2}{3}L$

From device FBD : $\Sigma F_x = 0 \rightarrow R_A + R_B = P_x$ (put $R_A = R_B$)

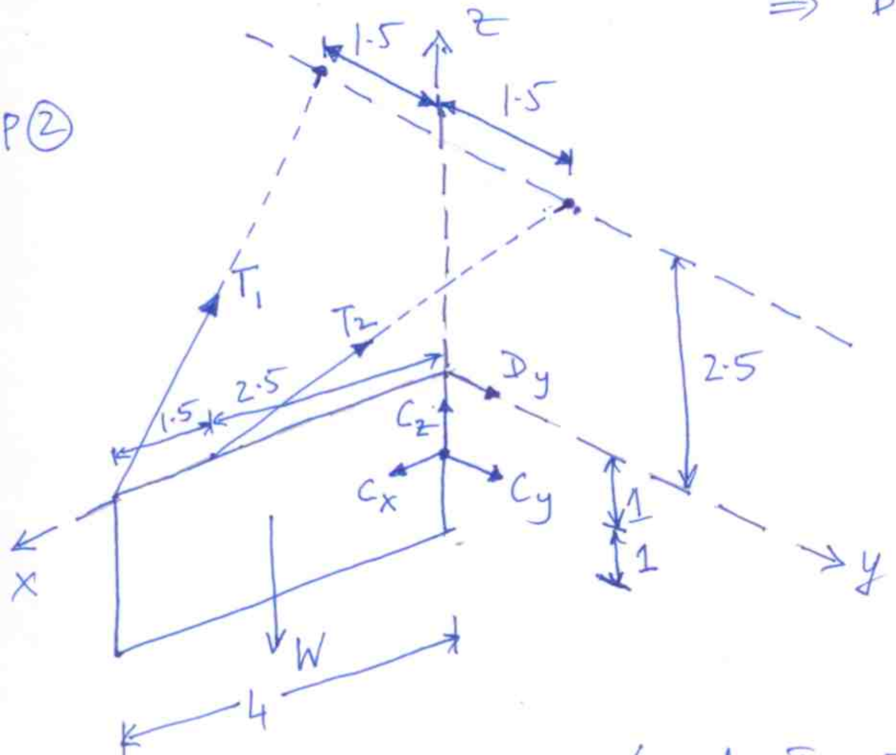
$$2R_B = \frac{2}{3}L \rightarrow R_B = \frac{L}{3}$$

$$\Sigma M_A = 0 \rightarrow Lb + R_B(20) - P_y(7) - P_x(20-8+3) = 0$$

($R_B = L/3$, $P_y = L$, $P_x = 2/3\,L$)

$$\Rightarrow b = \frac{2}{3}(15) + 7 - \frac{20}{3} = 10.33\text{ cm}$$

P②



Unit vectors along $\underline{T}_2$, $\underline{T}_1$ are :

$$\underline{e}_{T_1} = \frac{-4\underline{i} - 1.5\underline{j} + 2.5\underline{k}}{\sqrt{24.5}}$$

$$\underline{e}_{T_2} = \frac{-2.5\underline{i} + 1.5\underline{j} + 2.5\underline{k}}{\sqrt{14.75}}$$

Moment about z-axis (only T_{1y}, T_{2y} involved) :

$$-T_1\left(\frac{1.5}{\sqrt{24.5}}\right)(4) + T_2\left(\frac{1.5}{\sqrt{14.75}}\right)(2.5) = 0 \longrightarrow ①$$

Moment about axis parallel to y-axis thru C: (only $W, T_{1x}, T_{2x}, T_{1z}, T_{2z}$ involved).

$$-T_1\left(\frac{4}{\sqrt{24.5}}\right)(1) - T_2\left(\frac{2.5}{\sqrt{14.75}}\right)(1) - T_1\left(\frac{2.5}{\sqrt{24.5}}\right)(4) - T_2\left(\frac{2.5}{\sqrt{14.75}}\right)(2.5) + W(2) = 0 \rightarrow (2)$$

(1), (2) $\rightarrow$ $T_1 = 346.835\,N$, $T_2 = 430.583\,N$ ◄

Moment about axis parallel to x-axis thru C: (only T_{1y}, T_{2y}, D_y, involved).

$$T_1\left(\frac{1.5}{\sqrt{24.5}}\right)(1) - T_2\left(\frac{1.5}{\sqrt{14.75}}\right)(1) - D_y(1) = 0 \rightarrow (3)$$

$\Rightarrow D_y = 63.06\ N$ ◄

$$\Sigma F_x = 0 \rightarrow C_x = -T_{1x} - T_{2x} = -\left[T_1\left(\frac{-4}{\sqrt{24.5}}\right) + T_2\left(\frac{-2.5}{\sqrt{14.75}}\right)\right]$$

$C_x = 560.57\,N$ ◄

$$\Sigma F_y = 0 \rightarrow C_y = -T_{1y} - T_{2y} - D_y = -\left[T_1\left(\frac{-1.5}{\sqrt{24.5}}\right) + T_2\left(\frac{1.5}{\sqrt{14.75}}\right) + D_y\right]$$

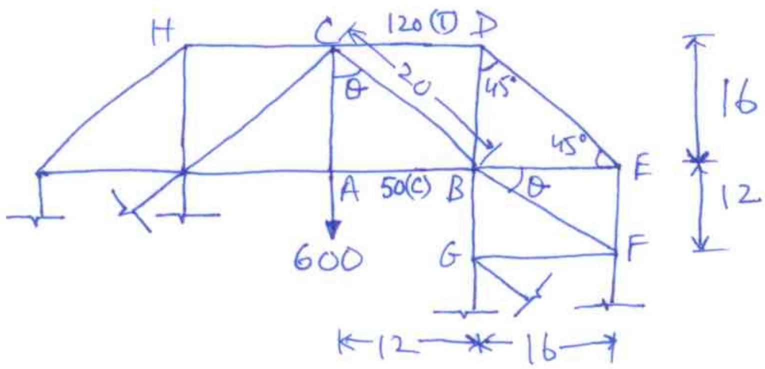
$C_y = 0$ ◄ (can see it also from eqn (3)).

$$\Sigma F_z = 0 \rightarrow C_z = W - T_{1z} - T_{2z} = W - \left(T_1\left(\frac{2.5}{\sqrt{24.5}}\right) + T_2\frac{2.5}{\sqrt{14.75}}\right)$$

$C_z = 525.536\ N$ ◄

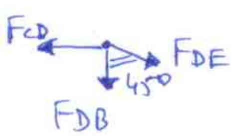
$$C = \sqrt{C_x^2 + C_y^2 + C_z^2} = 768.393\,N$$ ◄

P(3)



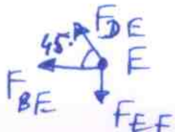
Note: Symmetry — use it. (in geometry & loading).

Jt. D:



$F_{DE} = \frac{F_{CD}}{\cos 45}$, $F_{DB} = -F_{DE}\cos 45 = -F_{CD} = -120$

Jt. E:



$F_{EF} = F_{DE}\cos 45 = 120 = 120(T)$ ◄

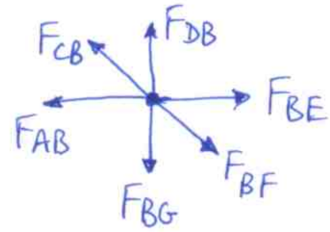
$F_{BE} = -F_{DE}\cos 45 = -120$

Jt. A: $F_{CA} = 600$

Jt C: (use symmetry in geometry & loading)

$$2F_{CB}\cos\theta = -F_{CA} \rightarrow F_{CB} = -\frac{600}{2 * \frac{16}{20}} = -375$$

Jt B:

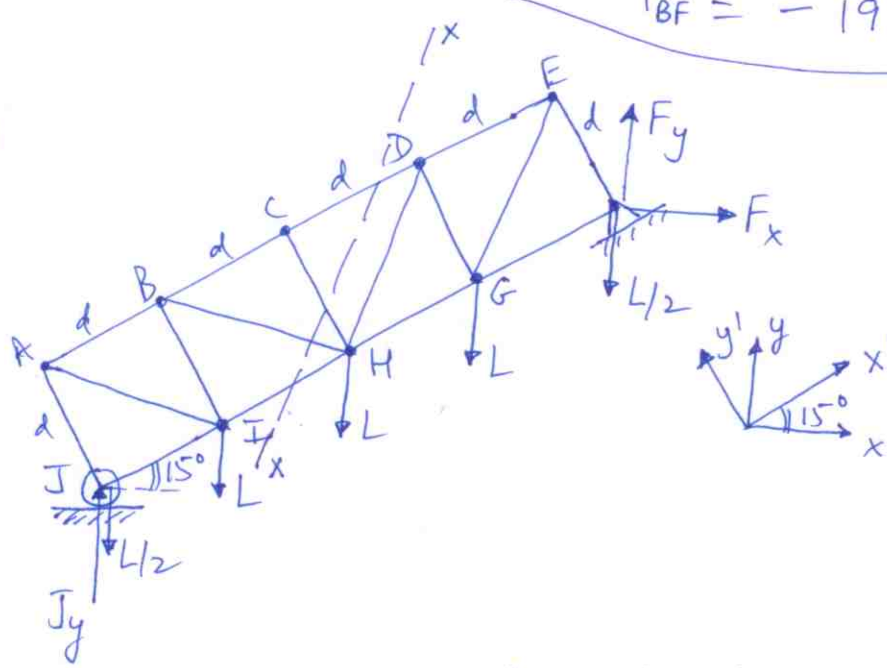


$$F_{BF}\cos\theta = F_{CB}\sin\theta + F_{AB} - F_{BE}$$

$$F_{BF} = \frac{(-375)\left(\frac{12}{20}\right) + (-50) - (-120)}{(16/20)}$$

$$F_{BF} = -193.75 = 193.75\,(C)$$

P(4)



$F_{CH} = 0$ by inspection of Jt. C.

$$\Sigma M_F = 0 \rightarrow J_y = \frac{L\left(\frac{1}{2}*4 + 3+2+1\right)\cancel{d\cos 15}}{4\,\cancel{d\cos 15}} = 2L$$

consider FBD to the left of section xx:

$$\Sigma M_H = 0 \longrightarrow F_{CD} \times d + J_y(2d\cos 15) - \frac{L}{2}(2d\cos 15) - Ld\cos 15 = 0$$

$$\Rightarrow F_{CD} = \frac{2Ld\cos 15 - 4Ld\cos 15}{d} = -2L\cos 15 = -1.932L$$

(i.e. compressive) (1.932L)

$$\Sigma F_{y'} = 0 \longrightarrow -F_{BH}\cos 45 - \left(L + \frac{L}{2}\right)\cos 15 + J_y\cos 15 = 0$$

$$\Rightarrow F_{BH} = \frac{\frac{L}{2}\cos 15}{\cos 45} = 0.683L \text{ (Tensile)}$$