Statics and Mechanics of Materials SI 1st edition Goodno Solutions Manual

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Chapter 2 Solutions

Problem 2.1-1

Part (a)

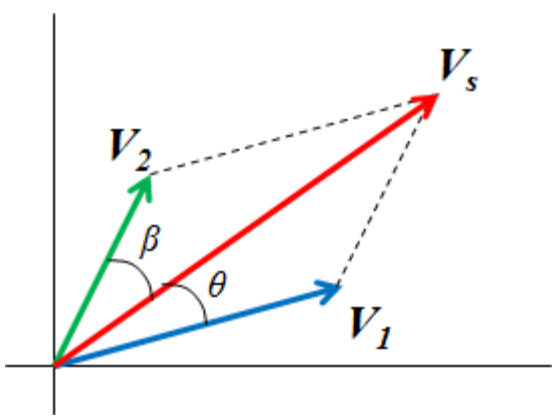
$$V_1 = \begin{pmatrix} 4 \\ 1 \end{pmatrix} \qquad V_2 = \begin{pmatrix} 2 \\ \alpha \end{pmatrix} \qquad V_1 \cdot V_2 = 0 \text{ solve}, \alpha \rightarrow -8$$

Part (b)

$$\gamma = \text{atan}\left(\frac{1}{4}\right) = 14.036\,\text{deg} \qquad \varphi = 30\text{deg} \qquad \beta = \varphi + \gamma = 44.036\,\text{deg}$$

$$\tan(\beta) = \frac{\alpha}{2} \left| \begin{array}{l} \text{solve}, \alpha \\ \text{float}, 4 \end{array} \right. \rightarrow 1.934$$

Part (c)



$$V_1 = 4 \qquad V_2 = 8 \qquad V_s = 12$$

Law of Cosines

$$\theta = \text{acos}\left(\frac{V_1^2 + V_s^2 - V_2^2}{2 \cdot V_1 \cdot V_s}\right) = 0 \cdot \text{deg}$$

Next, Law of Sines

$$\beta = \text{asin}\left(\frac{V_1}{V_2} \cdot \sin(\theta)\right) = 0 \cdot \text{deg}$$

$$\phi = \theta + \beta = 0 \cdot \text{deg}$$

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Problem 2.1-2

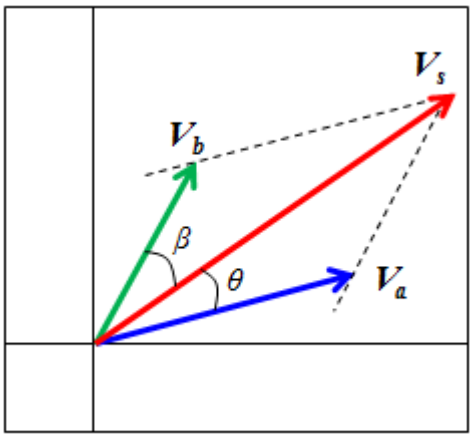

Fig. 2 – Vectors V_a and V_b in Part (c)

$$V_a = 5 \qquad V_b = 7 \qquad V_s = 10$$

Law of Cosines

$$\theta = \operatorname{acos}\left(\frac{V_a^{\,2} + V_s^{\,2} - V_b^{\,2}}{2 \cdot V_a \cdot V_s}\right) = 40.5 \cdot \text{deg}$$

Next, Law of Sines

$$\beta = \operatorname{asin}\left(\frac{V_a}{V_b} \cdot \sin(\theta)\right) = 27.7 \cdot \text{deg}$$

$$\phi = \theta + \beta = 68.2 \cdot \text{deg}$$

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Problem 2.1-3

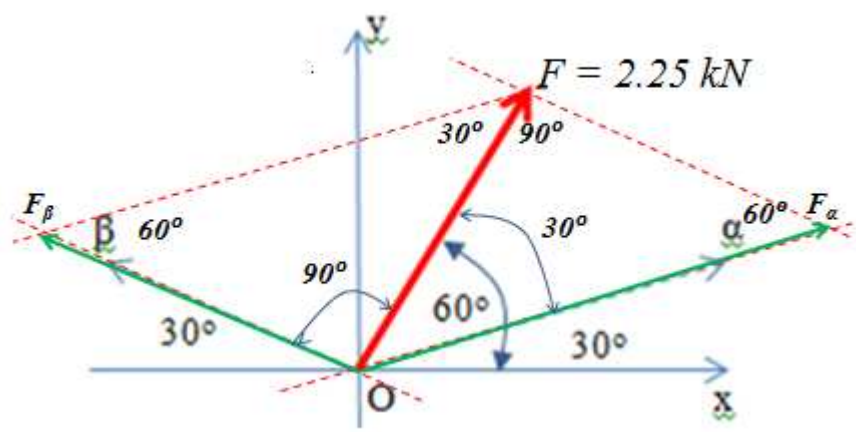
$F = 2.25kN$ $\qquad$ $ORIGIN = 1$

Part (a)

$$F_{xy} = F\cdot\begin{pmatrix}\cos(60deg)\\ \sin(60deg)\end{pmatrix} = \begin{pmatrix}1.125\\ 1.949\end{pmatrix}\cdot kN \qquad F_x = F_{xy_1} = 1.125\cdot kN \qquad F_y = F_{xy_2} = 1.949\cdot kN$$

Part (b) - components

parallelogram law



Law of Cosines

$$\frac{F_\alpha}{\sin(90deg)} = \frac{F}{\sin(60deg)}$$

$$F_\alpha = F\cdot\left(\frac{\sin(90deg)}{\sin(60deg)}\right)$$

$$F_\alpha = 2.598kN$$

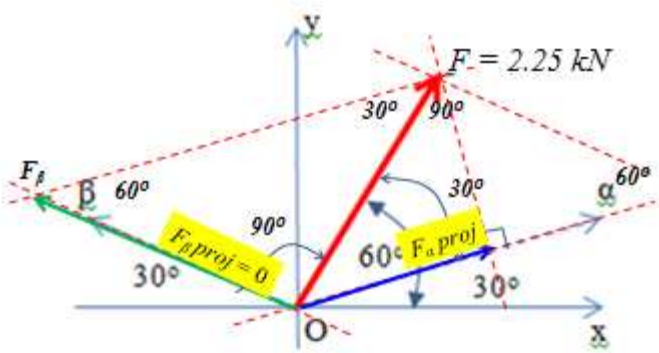
$$\frac{F_\beta}{\sin(30deg)} = \frac{F}{\sin(60deg)}$$

$$F_\beta = F\cdot\left(\frac{\sin(30deg)}{\sin(60deg)}\right)$$

$$F_\beta = 1.299kN$$

Law of cosines check $\qquad \sqrt{F_\alpha^{\,2} + F_\beta^{\,2} - 2\cdot F_\alpha\cdot F_\beta\cdot\cos(60deg)} = 2.25\cdot kN$

Part (c) - projections



$$F_{\alpha proj} = F\cdot\cos(30deg) = 1.949kN$$

$$F_{\beta proj} = F\cdot\cos(90deg) = 0\cdot kN$$

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Problem 2.1-4

Move the coordinate system from O to A then find component of F in x-y or n-t systems

$$F = 2.5kN \qquad \alpha = 45deg$$

Part (a)

$$F_x = -F \cdot \cos(\alpha) = -1.768 \cdot kN$$

$$F_y = F \cdot \sin(\alpha) = 1.768 \cdot kN$$

Part (b)

$$\theta = 60deg - 45deg = 15 \cdot deg$$

$$F_n = -F \cdot \cos(\theta) = -2.415 \cdot kN$$

$$F_t = -F \cdot \sin(\theta) = -0.647 \cdot kN$$

(a) $F_x = -1.768 \cdot kN \qquad F_y = 1.768 \cdot kN$

(b) $F_n = -2.415 \cdot kN \qquad F_t = -0.647 \cdot kN$

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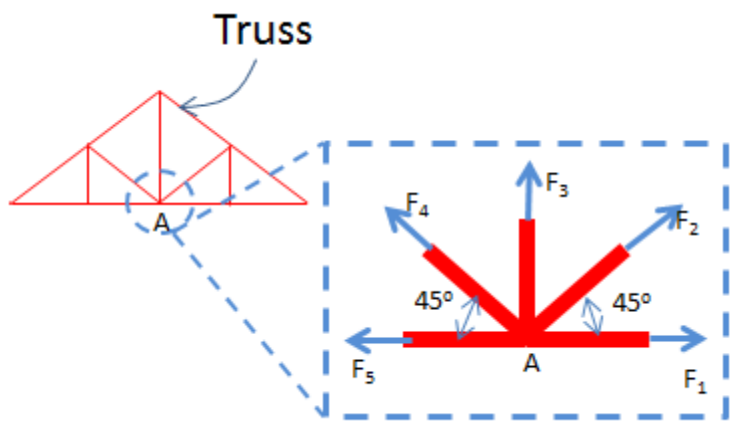
Problem 2.1-5



$F_1 = 450N \qquad F_3 = 90N \qquad F_5 = 670N \qquad \alpha = 45deg$

$\Sigma F_x = 0$

$F_1 + F_2 \cdot \cos(\alpha) - F_4 \cdot \cos(\alpha) - F_5 = 0$ ... (1) so $F_4 = \frac{1}{\cos(\alpha)} \cdot \left(F_1 + F_2 \cdot \cos(\alpha) - F_5\right)$

$\Sigma F_y = 0$

$F_2 \cdot \sin(\alpha) + F_4 \cdot \sin(\alpha) + F_3 = 0$ ... (2) so $F_2 = \frac{1}{\sin(\alpha)} \cdot \left(-F_3 - F_4 \cdot \sin(\alpha)\right)$

Substitute expression for F_4 into Eq. (2)

$$F_2 = \frac{F_5 - F_1 - F_3}{(\cos(\alpha) + \sin(\alpha))} = 91.9 \cdot N \qquad \text{and} \qquad F_4 = \frac{-F_3 - F_2 \cdot \sin(\alpha)}{\sin(\alpha)} = -219.2 \cdot N$$

<u>CHECK</u> that resultant is zero

$\Sigma F_x = F_1 + F_2 \cdot \cos(\alpha) - F_4 \cdot \cos(\alpha) - F_5 = 0 \cdot lb$

$\Sigma F_y = F_2 \cdot \sin(\alpha) + F_3 + F_4 \cdot \sin(\alpha) = 0 \cdot lb$

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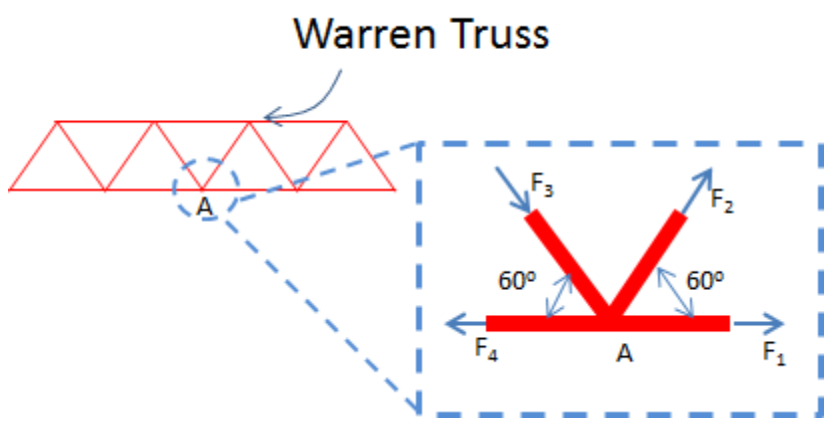
Problem 2.1-6



Part (a): units = kN

$$F_1 = \begin{pmatrix} 100 \\ 0 \end{pmatrix} \quad F_2 = \begin{pmatrix} 60\cdot\cos(60deg) \\ 60\cdot\sin(60deg) \end{pmatrix} = \begin{pmatrix} 30 \\ 51.962 \end{pmatrix} \qquad R_{12} = F_1 + F_2 = \begin{pmatrix} 130 \\ 52 \end{pmatrix} \qquad |R_{12}| = 140$$

Law of sines: β_{12} = angle that R_{12} makes with x axis

$$\beta_{12} = \operatorname{asin}\left(\frac{|F_2|}{|R_{12}|}\cdot\sin(120deg)\right) = 21.79\cdot deg \qquad \beta_{12} = 21.8\cdot deg$$

Part (b)

$$F_3 = \begin{pmatrix} 60\cdot\cos(60deg) \\ -60\cdot\sin(60deg) \end{pmatrix} = \begin{pmatrix} 30 \\ -51.962 \end{pmatrix} \qquad F_4 = \begin{pmatrix} -100 \\ 0 \end{pmatrix} \quad R_{34} = F_3 + F_4 = \begin{pmatrix} -70 \\ -51.96 \end{pmatrix} \quad |R_{34}| = 87.18$$

γ_{34} = angle that R_{34} makes with (-x) axis

$$\gamma_{34} = \operatorname{asin}\left(\frac{|F_3|}{|R_{34}|}\cdot\sin(60deg)\right) = 36.587\cdot deg \qquad \text{so} \qquad \beta_{34} = 180deg + \gamma_{34} = 217\cdot deg$$

Part (c)

$$F_1 + F_2 + F_3 + F_4 = \begin{pmatrix} 60 \\ 0 \end{pmatrix} \qquad R_{12} + R_{34} = \begin{pmatrix} 60 \\ 0 \end{pmatrix} \qquad |F_1 + F_2 + F_3 + F_4| = 60$$

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Problem 2.1-6 - cont'd

Solution #2

$F_1 = 100kN \qquad F_2 = 60kN \qquad \alpha = 60deg \qquad F_4 = 100kN$

Part (a)

Use parallelogram rule & law of cosines

$$R_{12} = \sqrt{F_1^2 + F_2^2 + 2 \cdot F_1 \cdot F_2 \cdot \cos(\alpha)} = 140 \cdot kN \qquad \beta = \operatorname{asin}\left(\frac{F_2}{R_{12}} \cdot \sin(120deg)\right) = 21.787 \cdot deg$$

Part (b)

$F_3 = 60kN \qquad F_4 = 100kN \qquad \alpha = 120deg \qquad 60deg - \beta = 38.213 \cdot deg$

$$R_{34} = \sqrt{F_3^2 + F_4^2 + 2 \cdot F_3 \cdot F_4 \cdot \cos(\alpha)} = 87.2 \cdot kN \qquad \gamma = \operatorname{asin}\left(\frac{F_3}{R_{34}} \cdot \sin(60deg)\right) = 36.587 \cdot deg$$

Part (c): Sum of resultant forces at point A $\qquad \alpha = 60deg$

$$\Sigma F_x = F_1 - F_4 + F_2 \cdot \cos(\alpha) + F_3 \cdot \cos(\alpha) = 60 \cdot kN$$

$$\Sigma F_y = F_2 \cdot \sin(\alpha) - F_3 \cdot \sin(\alpha) = 0\,N$$

$$\Sigma F = \sqrt{\Sigma F_x^2 + \Sigma F_y^2} = 60 \cdot kN$$

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Problem 2.1-7

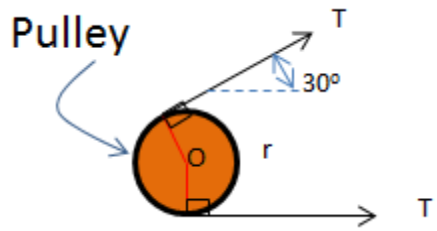
$T = 350N \qquad r = 100mm$

The tension force of the cable will induce no moment resultant at O.

The resultant of the cable forces is

$$R = \sqrt{T^2 + T^2 + 2 \cdot T \cdot T \cdot \cos(30deg)} = 676.1 \cdot N$$

$$\alpha = \operatorname{atan}\left(\frac{T \cdot \sin(30deg)}{T + T \cdot \cos(30deg)}\right) = 15 \cdot deg$$



or

$$\Sigma F_x = T \cdot \cos(30deg) + T = 653.109N$$

$$\Sigma F_y = T \cdot \sin(30deg) = 175 \cdot N$$

$$R = \sqrt{\Sigma F_x^{\,2} + \Sigma F_y^{\,2}} = 676.1 \cdot N$$

$$\alpha = \operatorname{atan}\left(\frac{\Sigma F_y}{\Sigma F_x}\right) = 15 \cdot deg$$

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Problem 2.1-8

Part (a) magnitudes > $N_1 = 200N$ $N_2 = 347N$

vectors: $N_1 = N_1 \cdot \begin{pmatrix} \cos(30deg) \\ \sin(30deg) \\ 0 \end{pmatrix} = \begin{pmatrix} 173.2 \\ 100 \\ 0 \end{pmatrix} N$ $N_2 = N_2 \cdot \begin{pmatrix} -\sin(30deg) \\ \cos(30deg) \\ 0 \end{pmatrix} = \begin{pmatrix} -173.5 \\ 300.5 \\ 0 \end{pmatrix} N$

Resultant: $R = N_1 + N_2 = \begin{pmatrix} -0.3 \\ 400.5 \\ 0 \end{pmatrix} N$

angle with x axis:

$$180 \cdot deg + atan\left(\frac{R_2}{R_1}\right) = 90.042 \cdot deg$$

Part (b) $n = \begin{pmatrix} -\cos(60deg) \\ \sin(60deg) \\ 0 \end{pmatrix} = \begin{pmatrix} -0.5 \\ 0.866 \\ 0 \end{pmatrix}$ $t = \begin{pmatrix} \cos(30deg) \\ \sin(30deg) \\ 0 \end{pmatrix} = \begin{pmatrix} 0.866 \\ 0.5 \\ 0 \end{pmatrix}$

$R_n = R \cdot n = 347\,N$ = N_2 $R_t = R \cdot t = 200\,N$ = N_1

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Problem 2.1-9

Cartesian vectors

$$T_1 = 3.6kN \cdot \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \qquad T_2 = 2.7kN \cdot \begin{pmatrix} \cos(30deg) \\ \sin(30deg) \\ 0 \end{pmatrix} = \begin{pmatrix} 2.3 \\ 1.4 \\ 0 \end{pmatrix} \cdot kN \qquad T_3 = 5.3kN \cdot \begin{pmatrix} \sin(30deg) \\ -\cos(30deg) \\ 0 \end{pmatrix} = \begin{pmatrix} 2.7 \\ -4.6 \\ 0 \end{pmatrix} \cdot kN$$

Resultant

$$R = T_1 + T_2 + T_3 = \begin{pmatrix} 4.988 \\ 0.36 \\ 0 \end{pmatrix} \cdot kN \qquad |R| = 5.001 \cdot kN$$

Angle with x axis

$$i = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \qquad \theta_x = acos\left(\frac{R}{|R|} \cdot i\right) = 4.13 \cdot deg$$

or direction cosines of R:

$$n_R = \frac{R}{|R|} = \begin{pmatrix} 1 \\ 0.07 \\ 0 \end{pmatrix}$$

$$\theta_x = acos\left(n_{R_1}\right) = 4.13 \cdot deg$$

$$atan\left(\frac{0.36}{4.988}\right) = 4.13 \cdot deg$$

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Problem 2.1-10

Use Law of Cosines and Law of Sines to find lengths of each cable segment & angles between cables and line OB

$$L_1 = \sqrt{2.5^2 + 1.5^2 - 2(2.5)\cdot(1.5)\cdot\cos(60deg)} = 2.179 \quad m \qquad L_2 = \sqrt{2.5^2 + 3^2 - 2(2.5)\cdot(3)\cdot\cos(60deg)} = 2.784 \quad m$$

$$\frac{L_1}{\sin(60deg)} = \frac{2.5}{\sin(\theta_1)} \qquad \theta_1 = \operatorname{asin}\left(\frac{2.5}{L_1}\cdot\sin(60deg)\right) = 83.413\cdot deg \qquad \theta_2 = \operatorname{asin}\left(\frac{2.5}{L_2}\cdot\sin(60deg)\right) = 51.052\cdot deg$$

Subtract 30 deg. from each angle theta to find angles between each cable segment & x axis.

$$\theta_{1x} = \theta_1 - 30deg = 53.413\cdot deg \qquad \theta_{2x} = \theta_2 - 30deg = 21.052\cdot deg$$

Cartesian components for each cable

$$T_1 = (440N)\cdot\begin{pmatrix} -\cos(\theta_{1x}) \\ \sin(\theta_{1x}) \end{pmatrix} = \begin{pmatrix} -262.257 \\ 353.3 \end{pmatrix} N \qquad T_2 = (560N)\cdot\begin{pmatrix} -\cos(\theta_{2x}) \\ \sin(\theta_{2x}) \end{pmatrix} = \begin{pmatrix} -522.624 \\ 201.158 \end{pmatrix} N$$

Resultant

$$R = T_1 + T_2 = \begin{pmatrix} -785 \\ 554 \end{pmatrix} N$$

Direction cosines of R

$$n_R = \frac{R}{|R|} = \begin{pmatrix} -0.817 \\ 0.577 \end{pmatrix} \qquad \theta_x = \operatorname{acos}(n_{R_1}) = 144.8\cdot deg \qquad 180deg - \theta_x = 35.238\cdot deg$$

^ between θ_{1x} and θ_{2x}

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Problem 2.1-11

$\theta = 80\text{deg}$ $\alpha = 25\text{deg}$ $T = 22.25\text{kN}$ $a = 4.6\text{m}$ $b = 7.6\text{m}$

Geometry

$\beta = 180\text{deg} - (\theta + \alpha) = 75\cdot\text{deg}$

Resultant acts in y dir. so $T\cdot\sin(\beta_1) = T\cdot\sin(\beta_2)$ and $\beta_2 = \beta_1$ which gives $\beta_1 = \frac{\beta}{2} = 37.5\cdot\text{deg}$

Resultant of cable force T = 22.25 kN at B (in -y dir.)

$R = T\cdot(\cos(\beta_1) + \cos(\beta_2))$ $R = 35.304\text{kN}$

Check that resultant component in x-dir. is zero $R_x = T\cdot(-\sin(\beta_1) + \sin(\beta_2)) = 0\cdot\text{lb}$

$-T\cdot\sin(\beta_1) = -14\cdot\text{kN}$ $T\cdot\sin(\beta_2) = 14\cdot\text{kN}$

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Problem 2.1-12

$$F_1 = 250\text{N}\cdot\begin{pmatrix} -\cos(30\text{deg}) \\ \sin(30\text{deg}) \end{pmatrix} = \begin{pmatrix} -216.506 \\ 125 \end{pmatrix}\text{N} \qquad F_3 = 250\text{N}\cdot\begin{pmatrix} \cos(30\text{deg}) \\ -\sin(30\text{deg}) \end{pmatrix} = \begin{pmatrix} 216.506 \\ -125 \end{pmatrix}\text{N} \qquad F_2 = 180\text{N}\cdot\begin{pmatrix} 0 \\ -1 \end{pmatrix}$$

$$R = F_1 + F_2 + F_3 = \begin{pmatrix} 0 \\ -180 \end{pmatrix}\text{N}$$

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Problem 2.1-13

$F_{EB} = 20kN \qquad \alpha = 80deg \qquad \beta = 60deg$

Part (a) - Cartesian components

$$F_{EB} = F_{EB} \cdot \begin{pmatrix} -\cos(\alpha) \\ \sin(\alpha) \\ 0 \end{pmatrix} = \begin{pmatrix} -3.47 \\ 19.7 \\ 0 \end{pmatrix} \cdot kN$$

Part (b) - projection on CA

$$n_{CA} = \begin{pmatrix} -\cos(\beta) \\ \sin(\beta) \\ 0 \end{pmatrix} = \begin{pmatrix} -0.5 \\ 0.866 \\ 0 \end{pmatrix} \qquad F_{CA} = F_{EB} \cdot n_{CA} = 18.79kN$$

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Problem 2.1-14

$F = 8N \qquad T = 9N$

Fig. (a) $\qquad A = \begin{pmatrix} 3 \\ 0 \\ 2 \end{pmatrix} \qquad E = \begin{pmatrix} 2 \\ 2 \\ 0 \end{pmatrix}$

$$n_{AE} = \frac{E - A}{|E - A|} = \begin{pmatrix} -0.333 \\ 0.667 \\ -0.667 \end{pmatrix} \qquad R_a = F \cdot \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} + T \cdot n_{AE} = \begin{pmatrix} -3 \\ 6 \\ 2 \end{pmatrix} N$$

Fig. (b) $\qquad R_b = F \cdot \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix} + T \cdot \left(-n_{AE}\right) = \begin{pmatrix} -5 \\ -6 \\ 6 \end{pmatrix} N$

Fig. (c) $\qquad E = \begin{pmatrix} 0 \\ 2 \\ 0 \end{pmatrix}$

$$n_{AE} = \frac{E - A}{|E - A|} = \begin{pmatrix} -0.728 \\ 0.485 \\ -0.485 \end{pmatrix} \qquad R_c = F \cdot \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} + T \cdot n_{AE} = \begin{pmatrix} 1.45 \\ 4.37 \\ -4.37 \end{pmatrix} N$$

Answers

$$R_a = \begin{pmatrix} -3 \\ 6 \\ 2 \end{pmatrix} N \qquad R_b = \begin{pmatrix} -5 \\ -6 \\ 6 \end{pmatrix} N \qquad R_c = \begin{pmatrix} 1.45 \\ 4.37 \\ -4.37 \end{pmatrix} N$$

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Problem 2.1-15

$$A = \begin{pmatrix} 1.5 \\ 6 \\ 9 \end{pmatrix} \cdot m \qquad n_{OA} = \frac{A}{|A|} = \begin{pmatrix} 0.137 \\ 0.549 \\ 0.824 \end{pmatrix} \qquad T = 12.5 kN \qquad T = T \cdot n_{OA} = \begin{pmatrix} 1.72 \\ 6.87 \\ 10.3 \end{pmatrix} \cdot kN \qquad |T| = 12.5 \cdot kN$$

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Problem 2.1-16

$$\alpha = \operatorname{atan}\left(\frac{34}{27}\right) = 51.546 \cdot \text{deg} \qquad \beta = \operatorname{atan}\left(\frac{17}{27}\right) = 32.196 \cdot \text{deg}$$

For resultant to be vertical, horizontal components of cable forces must sum to zero

$$T = \frac{6\text{kN} \cdot (\cos(\alpha)) + 4\text{kN} \cdot (\cos(\beta)) - 3.6\text{kN} \cdot (\cos(\beta))}{\cos(\alpha)} = 6.54 \cdot \text{kN}$$

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Problem 2.1-17

$TCE = 1.67kN \qquad a = 6m \qquad b = 2.4m \qquad c = 1.8m$

Position and unit vectors

$$r_{CE} = \begin{pmatrix} \frac{-a}{2} \\ c \\ -b \end{pmatrix} = \begin{pmatrix} -3 \\ 1.8 \\ -2.4 \end{pmatrix} \cdot m \qquad n_{CE} = \frac{r_{CE}}{|r_{CE}|} = \begin{pmatrix} -0.707 \\ 0.424 \\ -0.566 \end{pmatrix} \qquad r_{CA} = \begin{pmatrix} 0 \\ 0 \\ 0 - b \end{pmatrix} \qquad n_{CA} = \frac{r_{CA}}{|r_{CA}|} = \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix}$$

$$T_{CE} = TCE \cdot n_{CE} = \begin{pmatrix} -1.181 \\ 0.709 \\ -0.945 \end{pmatrix} \cdot kN \qquad |T_{CE}| = 1.67 \cdot kN$$

Angle between CE and line CA (= -z axis) $\qquad \theta = acos\left(n_{CE_3}\right) = 124.45 \cdot deg \qquad acos\left[n_{CE} \cdot \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix}\right] = 55.55 \cdot deg$

$124.45 + 55.55 = 180$

Projection onto line CA $\qquad TCE \cdot cos(55.55deg) = 0.945 \cdot kN$

^ in this case, projection = component (except for sign)

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Problem 2.1-18

$a = 10m \qquad b = 4m \qquad c = 3m \qquad T_{CE} = 1700N \qquad T_{CF} = T_{CE}$

Symmetry about yz plane so R will lie in yz plane (x component is zero)

Joint coordinates

$$C = \begin{pmatrix} 0 \\ 0 \\ b \end{pmatrix} \qquad E = \begin{pmatrix} \frac{-a}{2} \\ c \\ 0 \end{pmatrix} \qquad F = \begin{pmatrix} \frac{a}{2} \\ c \\ 0 \end{pmatrix}$$

unit vectors

$$n_{CE} = \frac{E - C}{|E - C|} = \begin{pmatrix} -0.707 \\ 0.424 \\ -0.566 \end{pmatrix} \qquad n_{CF} = \frac{F - C}{|F - C|} = \begin{pmatrix} 0.707 \\ 0.424 \\ -0.566 \end{pmatrix}$$

cable force vectors and resultant

$$T_{CE} = T_{CE} \cdot n_{CE} = \begin{pmatrix} -1202 \\ 721 \\ -962 \end{pmatrix} N \qquad T_{CF} = T_{CF} \cdot n_{CF} = \begin{pmatrix} 1202 \\ 721 \\ -962 \end{pmatrix} N \qquad R = T_{CE} + T_{CF} = \begin{pmatrix} 0 \\ 1442 \\ -1923 \end{pmatrix} N$$

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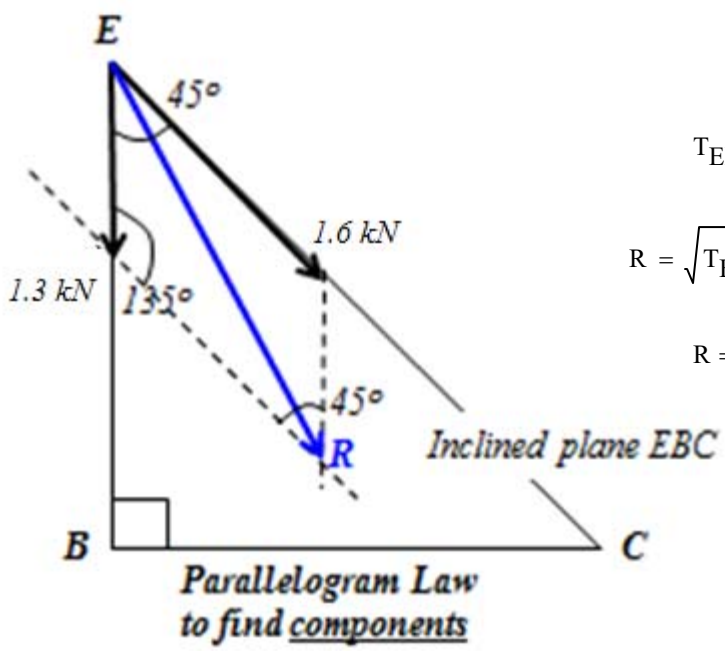
Problem 2.1-19

1. Note that EBC is a right angle
2. Length of EB is 3 m = a/2 so angle CEB is 45 deg.
3. Use Parallelogram Law to find R (start with sketch)

Dimensions (m)

$a = 6m \qquad b = 2.4m \qquad c = 1.8m$

PART (a) - Parallelogram Law and Law of Cosines



$T_{EB} = 1.3kN \qquad T_{EC} = 1.6kN$

$$R = \sqrt{T_{EB}^2 + T_{EC}^2 - 2\cdot(T_{EC})\cdot(T_{EB})\cdot\cos(135deg)} = 2.682\cdot kN$$

$R = 2.682\cdot kN$ < magnitude of resultant

Vectors

$$r_{EB} = \begin{pmatrix} 0 \\ -c \\ b \end{pmatrix} \qquad r_{EC} = \begin{pmatrix} \frac{a}{2} \\ -c \\ b \end{pmatrix} \qquad n_{EB} = \frac{r_{EB}}{|r_{EB}|} = \begin{pmatrix} 0 \\ -0.6 \\ 0.8 \end{pmatrix} \qquad n_{EC} = \frac{r_{EC}}{|r_{EC}|} = \begin{pmatrix} 0.707 \\ -0.424 \\ 0.566 \end{pmatrix}$$

$$r_{FC} = \begin{pmatrix} \frac{-a}{2} \\ -c \\ b \end{pmatrix} \qquad r_{FD} = \begin{pmatrix} 0 \\ -c \\ b \end{pmatrix} \qquad n_{FC} = \frac{r_{FC}}{|r_{FC}|} = \begin{pmatrix} -0.707 \\ -0.424 \\ 0.566 \end{pmatrix} \qquad n_{FD} = \frac{r_{FD}}{|r_{FD}|} = \begin{pmatrix} 0 \\ -0.6 \\ 0.8 \end{pmatrix}$$

$$T_{EB} = T_{EB}\cdot n_{EB} \qquad T_{EC} = T_{EC}\cdot n_{EC} \qquad R = T_{EB} + T_{EC} = \begin{pmatrix} 1.131 \\ -1.459 \\ 1.945 \end{pmatrix}\cdot kN \qquad |R| = 2.682\cdot kN$$

< agrees with above result

$|T_{EB}| = 1.3\cdot kN \qquad |T_{EC}| = 1.6\cdot kN$

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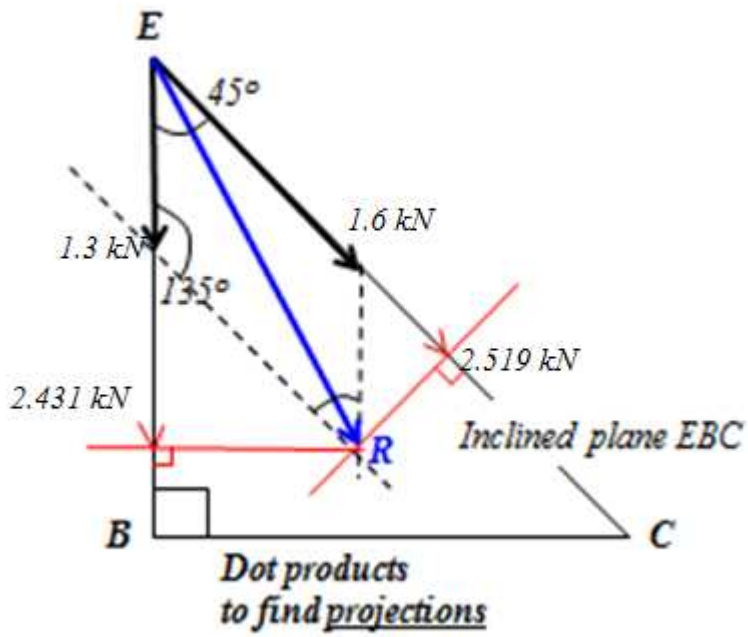
Problem 2.1-19 - PART (b) - Projections of R onto lines EB and EC - use dot product

$R_{EB} = R \cdot n_{EB} = 2.431 \cdot kN$ < not equal to component of R along EB (i.e., 1.3 kN)

$R_{EC} = R \cdot n_{EC} = 2.519 \cdot kN$ < not equal to component of R along EC (i.e., 1.6 kN)



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Problem 2.1-20

$F_s = 154N \qquad h = 660mm \qquad d = 150mm \qquad H = 1041mm \qquad c = 506mm$

Joint coordinates

$$A = \begin{pmatrix} h \\ h - H \\ d \end{pmatrix} = \begin{pmatrix} 660 \\ -381 \\ 150 \end{pmatrix} \cdot mm \qquad B = \begin{pmatrix} h \\ h \\ c \end{pmatrix} = \begin{pmatrix} 660 \\ 660 \\ 506 \end{pmatrix} \cdot mm$$

Unit vector

$$n_{AB} = \frac{B - A}{|B - A|} = \begin{pmatrix} 0 \\ 0.946 \\ 0.324 \end{pmatrix}$$

Part (a)

$$F_s = F_s \cdot n_{AB} = \begin{pmatrix} 0 \\ 145.7 \\ 49.8 \end{pmatrix} N \qquad |F_s| = 154\,N$$

Part (b)

$$n_{AD} = \frac{-A}{|A|} = \begin{pmatrix} -0.85 \\ 0.491 \\ -0.193 \end{pmatrix} \qquad F_{AD} = F_s \cdot n_{AD} = 61.9\,N \qquad \theta = \operatorname{acos}\left(\frac{F_s \cdot n_{AD}}{|F_s|}\right) = 66.3 \cdot deg$$

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Problem 2.1-21

$F = 1.5kN \qquad r = 0.75m \qquad h = 2.25m \qquad A = \begin{pmatrix} -r \cdot \sin(60deg) \\ r \cdot \cos(60deg) \\ h \end{pmatrix} = \begin{pmatrix} -0.65 \\ 0.375 \\ 2.25 \end{pmatrix} \cdot m$

Part (a)

$n_{OA} = \frac{A}{|A|} = \begin{pmatrix} -0.274 \\ 0.158 \\ 0.949 \end{pmatrix} \qquad F = F \cdot n_{OA} = \begin{pmatrix} -410.79 \\ 237.17 \\ 1423.02 \end{pmatrix} \cdot N \qquad |F| = 1.5 \cdot kN$

Part (b)

$n_{BC} = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \qquad F_{BC} = F \cdot n_{BC} = 237.2 \cdot N \qquad \theta = \operatorname{acos}\left(\frac{F \cdot n_{BC}}{|F|}\right) = 80.9 \cdot deg$

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Problem 2.1-22

$T_B = 3700N$

Joint coordinates $\quad B = \begin{pmatrix} -0.5 \\ -1 \\ 0 \end{pmatrix} \cdot m \qquad C = \begin{pmatrix} 0 \\ 0 \\ 2.5 \end{pmatrix} \cdot m$

Unit vector along cable B: $\quad n_{BC} = \dfrac{C - B}{|C - B|} = \begin{pmatrix} 0.183 \\ 0.365 \\ 0.913 \end{pmatrix}$

Cable force vector: $\quad T_B = T_B \cdot n_{BC} = \begin{pmatrix} 676 \\ 1351 \\ 3378 \end{pmatrix} \cdot N \qquad |T_B| = 3700 \cdot N$

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Problem 2.1-23

$T_{AB} = 67N$

Joint coordinates: $A = \begin{pmatrix} 200mm \\ 500mm - 500mm \cdot \cos(60deg) \\ -500mm \cdot \sin(60deg) \end{pmatrix} = \begin{pmatrix} 200 \\ 250 \\ -433.013 \end{pmatrix} \cdot mm \quad B = \begin{pmatrix} 150 \\ 0 \\ 0 \end{pmatrix} \cdot mm \quad C = \begin{pmatrix} 0 \\ 500 \\ 0 \end{pmatrix} \cdot mm$

Part (a) $n_{AB} = \frac{B - A}{|B - A|} = \begin{pmatrix} -0.1 \\ -0.498 \\ 0.862 \end{pmatrix} \qquad T_{AB} = T_{AB} \cdot n_{AB} = \begin{pmatrix} -6.667 \\ -33.334 \\ 57.736 \end{pmatrix} \cdot N$

Part (b) $n_{CD} = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \qquad T_{CD} = T_{AB} \cdot n_{CD} = -6.667 \cdot N$

Part (c) $n_{CB} = \frac{B - C}{|B - C|} = \begin{pmatrix} 0.287 \\ -0.958 \\ 0 \end{pmatrix} \qquad T_{CB} = T_{AB} \cdot n_{CB} = 30.01 \cdot N$

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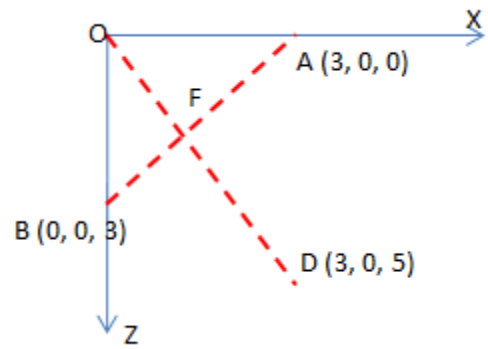
Problem 2.1-24

Find the intersection line between OD and AB/ coordinate F in X-Z plane



line OD

$z(x) = \frac{5}{3} \cdot x \quad \ldots (1)$

line AB

$z(x) = 3 - x \quad \ldots. (2)$

equating equation (1) & (2)

Hence, $x = 3 \cdot \frac{3}{8} = 1.125 \qquad z(x) = 1.875$

Part (a)

$$F = \begin{pmatrix} 1.125 \\ 0 \\ 1.875 \end{pmatrix} \qquad C = \begin{pmatrix} 0 \\ 3 \\ 0 \end{pmatrix} \qquad E = \begin{pmatrix} 3 \\ 3 \\ 5 \end{pmatrix} \qquad A = \begin{pmatrix} 3 \\ 0 \\ 0 \end{pmatrix} \qquad B = \begin{pmatrix} 0 \\ 0 \\ 3 \end{pmatrix}$$

$$n_{CE} = \frac{E - C}{|E - C|} = \begin{pmatrix} 0.514 \\ 0 \\ 0.857 \end{pmatrix} \qquad n_{FE} = \frac{E - F}{|E - F|} = \begin{pmatrix} 0.397 \\ 0.636 \\ 0.662 \end{pmatrix}$$

$$P = (3kN) \cdot n_{CE} = \begin{pmatrix} 1.543 \\ 0 \\ 2.572 \end{pmatrix} \cdot kN \qquad Q = (4kN) \cdot n_{FE} = \begin{pmatrix} 1.589 \\ 2.542 \\ 2.648 \end{pmatrix} \cdot kN$$

Part (b)

$$R = P + Q = \begin{pmatrix} 3.13 \\ 2.54 \\ 5.22 \end{pmatrix} \cdot kN \qquad Y = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \qquad \theta_Y = \operatorname{acos}\left(\frac{R \cdot Y}{|R|}\right) = 67.3 \cdot deg$$

Part (c)

$$n_{CA} = \frac{A - C}{|A - C|} = \begin{pmatrix} 0.707 \\ -0.707 \\ 0 \end{pmatrix} \qquad P_{CApar} = P \cdot n_{CA} = 1.091 \cdot kN \qquad P_{CApar} \cdot n_{CA} = \begin{pmatrix} 0.772 \\ -0.772 \\ 0 \end{pmatrix} \cdot kN$$

$$P_{CAper} = P - P_{CApar} \cdot n_{CA} = \begin{pmatrix} 0.77 \\ 0.77 \\ 2.57 \end{pmatrix} \cdot kN$$

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Problem 2.1-24 - cont'd

Part (d)

$$n_{BA} = \frac{A - B}{|A - B|} = \begin{pmatrix} 0.707 \\ 0 \\ -0.707 \end{pmatrix} \qquad Q_{BApar} = Q \cdot n_{BA} = -0.749 \cdot kN \qquad Q_{BApar} \cdot n_{BA} = \begin{pmatrix} -0.53 \\ 0 \\ 0.53 \end{pmatrix} \cdot kN$$

$$Q_{BAper} = Q - Q_{BApar} \cdot n_{BA} = \begin{pmatrix} 2.12 \\ 2.54 \\ 2.12 \end{pmatrix} \cdot kN$$

Part (e)

$$\theta = \operatorname{acos}\left(\frac{P \cdot Q}{|P| \cdot |Q|}\right) = 39.5 \cdot deg$$

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Problem 2.1-25

$T_2 = 23kN$ $\quad B = \begin{pmatrix} 3.6 \\ 0 \\ 0 \end{pmatrix} \cdot m$ $\quad D = \begin{pmatrix} 1.5 \\ 3.6 \\ 0 \end{pmatrix} \cdot m$ $\quad Q = \begin{pmatrix} 1.5 \\ 1.5 \\ 2.1 \end{pmatrix} \cdot m$

Unit vector along cable 2 $\quad n_{BQ} = \dfrac{Q - B}{|Q - B|} = \begin{pmatrix} -0.631 \\ 0.451 \\ 0.631 \end{pmatrix}$

Components of vector T_2 $\quad T_2 = T_2 \cdot n_{BQ} = \begin{pmatrix} -14.52 \\ 10.37 \\ 14.52 \end{pmatrix} \cdot kN$ $\quad |T_2| = 23 \cdot kN$

Projection on line BD

$n_{BD} = \dfrac{D - B}{|D - B|} = \begin{pmatrix} -0.504 \\ 0.864 \\ 0 \end{pmatrix}$ $\quad T_{BD} = T_2 \cdot n_{BD} = 16.27 \cdot kN$

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Problem 2.1-26

$$O = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \qquad A = \begin{pmatrix} 3 \\ 3 \\ 4 \end{pmatrix} \qquad x = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \qquad y = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \qquad z = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

$$r_{OA} = A - O = \begin{pmatrix} 3 \\ 3 \\ 4 \end{pmatrix} \qquad n_{OA} = \frac{r_{OA}}{|r_{OA}|} = \begin{pmatrix} 0.514 \\ 0.514 \\ 0.686 \end{pmatrix}$$

Part (a)

$$F = (25kN) \cdot n_{OA} = \begin{pmatrix} 12.86 \\ 12.86 \\ 17.15 \end{pmatrix} \cdot kN$$

Part (b)

$$n_{OA} = \begin{pmatrix} 0.514 \\ 0.514 \\ 0.686 \end{pmatrix}$$

Part (c)

$$x_p = \begin{pmatrix} \cos(30deg) \\ -\sin(30deg) \\ 0 \end{pmatrix} \qquad y_p = \begin{pmatrix} \sin(30deg) \\ \cos(30deg) \\ 0 \end{pmatrix} \qquad z_p = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

$$F_{xp} = F \cdot x_p = 4.71 \cdot kN \qquad F_{yp} = F \cdot y_p = 17.57 \cdot kN \qquad F_{zp} = F \cdot z_p = 17.15 \cdot kN$$

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Problem 2.1-27

$$H = \begin{pmatrix} 0 \\ 0 \\ 75 \end{pmatrix} \cdot mm \qquad B = \begin{pmatrix} 100 \\ 125 \\ 0 \end{pmatrix} mm \qquad C = \begin{pmatrix} 100 \\ 0 \\ 0 \end{pmatrix} \cdot mm \qquad P = 45kN$$

$$r_{HB} = B - H = \begin{pmatrix} 100 \\ 125 \\ -75 \end{pmatrix} \cdot mm \qquad n_{HB} = \frac{r_{HB}}{|r_{HB}|} = \begin{pmatrix} 0.566 \\ 0.707 \\ -0.424 \end{pmatrix} \qquad x = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \qquad y = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \qquad z = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

Part (a)

$$P = P \cdot n_{HB} = \begin{pmatrix} 25.456 \\ 31.82 \\ -19.092 \end{pmatrix} \cdot kN \qquad P = \begin{pmatrix} 25.46 \\ 31.82 \\ -19.09 \end{pmatrix} \cdot kN$$

Part (b)

$$n_{HC} = \frac{C - H}{|C - H|} = \begin{pmatrix} 0.8 \\ 0 \\ -0.6 \end{pmatrix} \qquad P_{HCpar} = P \cdot n_{HC} = 31.82 \cdot kN$$

$$P_{HCper} = P - P_{HCpar} \cdot n_{HC} = \begin{pmatrix} 0 \\ 31.82 \\ 0 \end{pmatrix} \cdot kN \qquad |P_{HCper}| = 31.82 \cdot kN$$

Part (c)

$$D = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \qquad G = \begin{pmatrix} 100 \\ 0 \\ 75 \end{pmatrix} \cdot mm \qquad n_{DG} = \frac{G - D}{|G - D|} = \begin{pmatrix} 0.8 \\ 0 \\ 0.6 \end{pmatrix}$$

$$P_{DG} = P \cdot n_{DG} = 8.91 \cdot kN \qquad \theta = acos\left(\frac{P \cdot n_{DG}}{|P|}\right) = 78.6 \cdot deg$$

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Problem 2.1-28

$$O = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \quad A = \begin{pmatrix} 0 \\ 0 \\ 6 \end{pmatrix} \quad B = \begin{pmatrix} 0 \\ 3 \\ 6 \end{pmatrix} \quad C = \begin{pmatrix} 3 \\ 4 \\ 0 \end{pmatrix} \quad x = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \quad y = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \quad z = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

$$n_{BC} = \frac{C - B}{|C - B|} = \begin{pmatrix} 0.442 \\ 0.147 \\ -0.885 \end{pmatrix}$$

Part (a)

$$P = \begin{pmatrix} 30 \\ 25 \\ -75 \end{pmatrix} \cdot kN$$

Part (b)

$$P \cdot n_{BC} = 83.3 \cdot kN$$

Part (c)

$$\theta = \operatorname{acos}\left(\frac{P \cdot n_{BC}}{|P|}\right) = 9.88 \cdot deg$$

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Problem 2.1-29

$$E = \begin{pmatrix} 1.2 \\ 0 \\ 0 \end{pmatrix} m \qquad F = \begin{pmatrix} 1.2 \\ 0 \\ 1.2 \end{pmatrix} m \qquad D = \begin{pmatrix} 1.2 \\ 0.6 \\ 0.6 \end{pmatrix} m \qquad C = \begin{pmatrix} 0.3 \\ 1.2 \\ 1.2 \end{pmatrix} m \qquad B = \begin{pmatrix} 0.3 \\ 1.2 \\ 0 \end{pmatrix} m$$

$$n_{DB} = \frac{B - D}{|B - D|} = \begin{pmatrix} -0.728 \\ 0.485 \\ -0.485 \end{pmatrix} \qquad n_{DC} = \frac{C - D}{|C - D|} = \begin{pmatrix} -0.728 \\ 0.485 \\ 0.485 \end{pmatrix} \qquad n_{DE} = \frac{E - D}{|E - D|} = \begin{pmatrix} 0 \\ -0.707 \\ -0.707 \end{pmatrix}$$

$$n_{DF} = \frac{F - D}{|F - D|} = \begin{pmatrix} 0 \\ -0.707 \\ 0.707 \end{pmatrix}$$

$$T_{DB} = 45kN \qquad T_{DC} = 45kN \qquad T_{DE} = 67kN \qquad T_{DF} = 67kN$$

Part (a)

$$T_{DB} = T_{DB} \cdot n_{DB} = \begin{pmatrix} -32.7 \\ 21.8 \\ -21.8 \end{pmatrix} \cdot kN \qquad T_{DC} = T_{DC} \cdot n_{DC} = \begin{pmatrix} -32.7 \\ 21.8 \\ 21.8 \end{pmatrix} \cdot kN$$

$$T_{DE} = T_{DE} \cdot n_{DE} = \begin{pmatrix} 0 \\ -47.4 \\ -47.4 \end{pmatrix} \cdot kN \qquad T_{DF} = T_{DF} \cdot n_{DF} = \begin{pmatrix} 0 \\ -47.4 \\ 47.4 \end{pmatrix} \cdot kN$$

Part (b)

$$R = T_{DB} + T_{DC} + T_{DE} + T_{DF} = \begin{pmatrix} -65.5 \\ -51.1 \\ 0 \end{pmatrix} \cdot kN \qquad |R| = 83.1 \cdot kN$$

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Problem 2.1-30

$$mass = 450kg \qquad P = 20kN \qquad D = \begin{pmatrix} 0 \\ 9 \\ 9\cdot\tan(55deg) \end{pmatrix}\cdot m = \begin{pmatrix} 0 \\ 9 \\ 12.853 \end{pmatrix}\cdot m \qquad E = \begin{pmatrix} 3 \\ 13 \\ 0 \end{pmatrix}\cdot m$$

Part (a)

$$W = mass\cdot g\cdot\begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ -4413 \end{pmatrix}\cdot N \qquad n_{DE} = \frac{E - D}{|E - D|} = \begin{pmatrix} 0.218 \\ 0.29 \\ -0.932 \end{pmatrix} \qquad P = P\cdot n_{DE} = \begin{pmatrix} 4350 \\ 5801 \\ -18639 \end{pmatrix}\cdot N$$

Part (b)

$$R = W + P = \begin{pmatrix} 4350 \\ 5801 \\ -23052 \end{pmatrix}\cdot N \qquad |R| = 24.2\cdot kN$$

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Problem 2.2-1

$P = 45kN \qquad M = 2.8kN\cdot m \qquad L = 1.8m \qquad \theta = 45deg$

Resultant force

$$R_A = P\cdot\begin{pmatrix}0\\-1\\0\end{pmatrix} + P\cdot\begin{pmatrix}\cos(\theta)\\-\sin(\theta)\\0\end{pmatrix} = \begin{pmatrix}31.82\\-76.82\\0\end{pmatrix}\cdot kN \qquad |R_A| = 83.15\cdot kN \qquad \alpha = \operatorname{atan}\left(\frac{R_{A_0}}{R_{A_1}}\right) = -22.5\cdot deg$$

Resultant moment

$$M_A = \begin{pmatrix}\frac{3\cdot L}{4}\\0\\0\end{pmatrix}\times\left[P\cdot\begin{pmatrix}0\\-1\\0\end{pmatrix}\right] + M\cdot\begin{pmatrix}0\\0\\-1\end{pmatrix} + \begin{pmatrix}\frac{3\cdot L}{2}\\0\\0\end{pmatrix}\times\left[P\cdot\begin{pmatrix}\cos(\theta)\\-\sin(\theta)\\0\end{pmatrix}\right] = \begin{pmatrix}0\\0\\-149\end{pmatrix}\cdot kN\cdot m$$

x intercept $\qquad$ Given $\qquad x = L$

$$\begin{pmatrix}x\\0\\0\end{pmatrix}\times R_A = M_A$$

$$x = \mathrm{Find}(x) = 1.95\cdot m \qquad d = \frac{|M_A|}{|R_A|} = 1.798\cdot m \qquad \frac{d}{\cos(|\alpha|)} = 1.95\cdot m \qquad x = \frac{|M_A|}{|R_y|} = 1.946\cdot m$$

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Problem 2.2-2

$$\theta = \operatorname{atan}\left(\frac{3}{4}\right) = 36.87\cdot\text{deg} \qquad P_B = 25\text{kN}\cdot\begin{pmatrix}\cos(45\text{deg}-\theta)\\ -\sin(45\text{deg}-\theta)\\ 0\end{pmatrix} = \begin{pmatrix}24.749\\ -3.536\\ 0\end{pmatrix}\cdot\text{kN} \qquad P_H = \begin{pmatrix}0\\ -50\text{kN}\\ 0\end{pmatrix} \qquad P_F = \begin{pmatrix}0\\ -75\text{kN}\\ 0\end{pmatrix}$$

$$P_D = 50\text{kN}\cdot\begin{pmatrix}\cos(60\text{deg}-\theta)\\ \sin(60\text{deg}-\theta)\\ 0\end{pmatrix} = \begin{pmatrix}45.981\\ 19.641\\ 0\end{pmatrix}\cdot\text{kN}$$

Resultants

$$R_A = P_B + P_D + P_H + P_F = \begin{pmatrix}70.7\\ -108.9\\ 0\end{pmatrix}\cdot\text{kN} \qquad \left|R_A\right| = 129.8\cdot\text{kN}$$

$$M_A = \begin{pmatrix}2\text{m}\\ \frac{3}{4}\cdot 2\text{m}\\ 0\end{pmatrix}\times P_B + \begin{pmatrix}2\text{m}\\ 0\\ 0\end{pmatrix}\times P_H + \begin{pmatrix}6\text{m}\\ 0\\ 0\end{pmatrix}\times P_F + \begin{pmatrix}6\text{m}\\ \frac{3}{4}\cdot 2\text{m}\\ 0\end{pmatrix}\times P_D = \begin{pmatrix}0\\ 0\\ -545\end{pmatrix}\cdot\text{kN}\cdot\text{m} \qquad \left|M_A\right| = 545\cdot\text{kN}\cdot\text{m}$$

y intercept

$$y = \frac{\left|M_A\right|}{R_x} = 7.71\text{ m}$$

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Problem 2.2-3

$L = 3.6\text{m} \qquad \theta = 60\text{deg}$

$$R_A = \begin{pmatrix} 90 - 333\cdot\cos(\theta) \\ -200 - 333\cdot\sin(\theta) \\ 0 \end{pmatrix}\cdot\text{kN} = \begin{pmatrix} -76.5 \\ -488.4 \\ 0 \end{pmatrix}\cdot\text{kN} \qquad \left|R_A\right| = 494.3\,\text{kN}$$

$$M_A = \begin{pmatrix} 0 \\ 0 \\ -200\cdot\text{kN}\cdot\frac{L}{2} - 333\cdot\text{kN}\cdot\sin(\theta)\cdot\frac{3\cdot L}{4} - 135\cdot\text{kN}\cdot\text{m} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ -1273.643 \end{pmatrix}\cdot\text{kN}\cdot\text{m}$$

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Problem 2.2-4

$\theta = 60\text{deg}$

$$R_O = \begin{pmatrix} 2 - 1 \\ 2 - 1 \\ 0 \end{pmatrix} \cdot F \qquad R_O = \begin{pmatrix} 1 \\ 1 \\ 0 \end{pmatrix} F$$

$$M_{Oz} = -2 \cdot F \cdot (r \cdot \sin(60\text{deg})) - 2 \cdot F \cdot (r \cdot \cos(60\text{deg})) - F \cdot r \qquad M_{Oz} = -\left(2 + \sqrt{3}\right) \cdot F \cdot r$$

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Problem 2.2-5

$F_{EB} = 11kN \qquad \alpha = 80deg \qquad \beta = 45deg \qquad BC = 5.4m$

$$F_{EB} = F_{EB} \cdot \begin{pmatrix} -\cos(\alpha) \\ \sin(\alpha) \\ 0 \end{pmatrix} = \begin{pmatrix} -2 \\ 11 \\ 0 \end{pmatrix} \cdot kN \qquad r_{CB} = \begin{pmatrix} -BC \cdot \cos(\beta) \\ BC \cdot \sin(\beta) \\ 0 \end{pmatrix} = \begin{pmatrix} -3.818 \\ 3.818 \\ 0 \end{pmatrix} \cdot m$$

Part (a)

$$M_C = r_{CB} \times F_{EB} = \begin{pmatrix} 0 \\ 0 \\ -34 \end{pmatrix} \cdot kN \cdot m$$

Part (b)

$$M_{Cz} = \left(\left|F_{EB}\right|\right) \cdot [\cos(\alpha) \cdot (BC \cdot \sin(\beta)) - \sin(\alpha) \cdot (BC \cdot \cos(\beta))] = -34 \cdot kN \cdot m$$

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Problem 2.2-6

$$F = 110kN \qquad A = \begin{pmatrix} -3 \\ -1 \\ 0 \end{pmatrix} \cdot m \qquad B = \begin{pmatrix} 3 \\ 1 \\ 0 \end{pmatrix} \cdot m \qquad r_{OA} = A \qquad r_{OB} = B$$

$$F_A = F \cdot \begin{pmatrix} -\cos(30deg) \\ -\sin(30deg) \\ 0 \end{pmatrix} = \begin{pmatrix} -95.263 \\ -55 \\ 0 \end{pmatrix} \cdot kN \qquad F_B = F \cdot \begin{pmatrix} \cos(30deg) \\ \sin(30deg) \\ 0 \end{pmatrix} \qquad R_O = F_A + F_B = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} N$$

$$M_O = r_{OA} \times F_A + r_{OB} \times F_B = \begin{pmatrix} 0 \\ 0 \\ 139.5 \end{pmatrix} \cdot kN \cdot m$$

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Problem 2.2-7

$F = 45kN \qquad A = \begin{pmatrix} 75 \\ 75 \\ 100 \end{pmatrix} \cdot mm \qquad B = \begin{pmatrix} 125 \\ 0 \\ 0 \end{pmatrix} \cdot mm \qquad C = \begin{pmatrix} 0 \\ 0 \\ 75 \end{pmatrix} \cdot mm$

Part (a)

$$n_{OA} = \frac{A}{|A|} = \begin{pmatrix} 0.514 \\ 0.514 \\ 0.686 \end{pmatrix} \qquad F_{OA} = F \cdot n_{OA} = \begin{pmatrix} 23.152 \\ 23.152 \\ 30.87 \end{pmatrix} \cdot kN \qquad r_{BO} = -B$$

$$M_B = r_{BO} \times F_{OA} = \begin{pmatrix} 0 \\ 3.9 \\ -2.9 \end{pmatrix} \cdot kN \cdot m \qquad |M_B| = 4.8 \cdot kN \cdot m$$

Part (b)

$$r_{CO} = -C \qquad M_C = r_{CO} \times F_{OA} = \begin{pmatrix} 1.74 \\ -1.74 \\ 0 \end{pmatrix} \cdot kN \cdot m$$

Part (c)

$$n_{CB} = \frac{B - C}{|C - B|} = \begin{pmatrix} 0.857 \\ 0 \\ -0.514 \end{pmatrix} \qquad M_{CB} = M_B \cdot n_{CB} = 1.49 \cdot kN \cdot m \qquad = \qquad M_C \cdot n_{CB} = 1.49 \cdot kN \cdot m$$

Vectors

$$M_{CBpar} = M_B \cdot n_{CB} \cdot n_{CB} = \begin{pmatrix} 1.28 \\ 0 \\ -0.77 \end{pmatrix} \cdot kN \cdot m \qquad M_{CBper} = M_B - M_{CBpar} = \begin{pmatrix} -1.28 \\ 3.86 \\ -2.13 \end{pmatrix} \cdot kN \cdot m$$

$$|M_{CBpar}| = 1.49 \cdot kN \cdot m$$

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Problem 2.2-8

$$P = \begin{pmatrix} 30 \\ 25 \\ -75 \end{pmatrix} \cdot kN \qquad A = \begin{pmatrix} 0 \\ 0 \\ 6 \end{pmatrix} \cdot m \qquad B = \begin{pmatrix} 0 \\ 3 \\ 6 \end{pmatrix} \cdot m \qquad C = \begin{pmatrix} 3 \\ 4 \\ 0 \end{pmatrix} \cdot m$$

Part (a)

$$r_{BA} = A - B = \begin{pmatrix} 0 \\ -3 \\ 0 \end{pmatrix} m \qquad M_B = r_{BA} \times P = \begin{pmatrix} 225 \\ 0 \\ 90 \end{pmatrix} \cdot kN \cdot m$$

Part (b)

$$M_{Bx} = (75kN) \cdot (3m) = 225 \cdot kN \cdot m \qquad M_{By} = 0 \qquad M_{Bz} = (30kN) \cdot (3m) = 90 \cdot kN \cdot m$$

Part (c)

$$n_{BC} = \frac{C - B}{|C - B|} = \begin{pmatrix} 0.442 \\ 0.147 \\ -0.885 \end{pmatrix} \qquad M_{BC} = M_B \cdot n_{BC} = 19.9 \cdot kN \cdot m$$

Vectors

$$M_{BCpar} = M_B \cdot n_{BC} \cdot n_{BC} = \begin{pmatrix} 8.8 \\ 2.93 \\ -17.61 \end{pmatrix} \cdot kN \cdot m \qquad M_{BCper} = M_B - M_{BCpar} = \begin{pmatrix} 216.2 \\ -2.9 \\ 107.6 \end{pmatrix} \cdot kN \cdot m$$

$$|M_{BCpar}| = 19.9 \cdot kN \cdot m$$

Part (d)

$$r_{OA} = A \qquad M_O = r_{OA} \times P = \begin{pmatrix} -150 \\ 180 \\ 0 \end{pmatrix} \cdot kN \cdot m \qquad n_{OB} = \frac{B}{|B|} = \begin{pmatrix} 0 \\ 0.447 \\ 0.894 \end{pmatrix}$$

$$M_{OBpar} = M_O \cdot n_{OB} \cdot n_{OB} = \begin{pmatrix} 0 \\ 36 \\ 72 \end{pmatrix} \cdot kN \cdot m \qquad M_{OBper} = M_O - M_{OBpar} = \begin{pmatrix} -150 \\ 144 \\ -72 \end{pmatrix} \cdot kN \cdot m$$

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Problem 2.2-9

Part (a)

$$P = \begin{pmatrix} 25 \\ 50 \\ -75 \end{pmatrix} kN \quad A = \begin{pmatrix} 0 \\ 0 \\ 6 \end{pmatrix} m \quad D = \begin{pmatrix} x_D \\ y_D \\ 0 \end{pmatrix} \quad C = \begin{pmatrix} 4.5 \\ 3 \\ 0 \end{pmatrix} m \quad r_{OA} = A \quad r_{OD} = D \quad M_O = r_{OA} \times P = \begin{pmatrix} -300 \\ 150 \\ 0 \end{pmatrix} \cdot kN \cdot m$$

Also $\quad r_{OD} \times P = M_O \quad r_{OD} \times P \rightarrow \begin{pmatrix} -75 \cdot kN \cdot y_D \\ 75 \cdot kN \cdot x_D \\ 50 \cdot kN \cdot x_D - 25 \cdot kN \cdot y_D \end{pmatrix}$ so

$$x_D = \frac{150 kN \cdot m}{75 kN} = 2 \cdot m$$

$$y_D = \frac{-300 kN \cdot m}{-75 kN} = 4 \cdot m$$

(or use a geometry solution)

$$50 kN \cdot x_D - 25 kN \cdot y_D = 0 \cdot kN \cdot m$$

Part (b)

$$P_A = P \quad P_O = -P \quad D = \begin{pmatrix} x_D \\ y_D \\ 0 \end{pmatrix} = \begin{pmatrix} 2 \\ 4 \\ 0 \end{pmatrix} \cdot m \quad |M_O| = 335 \cdot kN \cdot m$$

$$M_A = -r_{OA} \times P_O \quad |M_A| = 335 \cdot kN \cdot m$$

$$r_{DO} = -D \quad M_D = r_{DO} \times P_O \quad |M_D| = 335 \cdot kN \cdot m$$

$$r_{CO} = -C \quad r_{CD} = D - C \quad M_C = r_{CD} \times P_A + r_{CO} \times P_O \quad |M_C| = 335 \cdot kN \cdot m$$

Part (c)

$$d = \frac{|M_O|}{|P|} = 3.59 \cdot m$$

Part (d)

Varignon's theorem

$$M_{Ox} = -(50kN) \cdot (6m) = -300 \cdot kN \cdot m$$

$$M_{Oy} = (25kN) \cdot (6m) = 150 \cdot kN \cdot m$$

$$M_{Oz} = 0$$ since P has line of action through z axis

$$M_O = \begin{pmatrix} -300 \\ 150 \\ 0 \end{pmatrix} \cdot kN \cdot m$$

Part (e)

$$P = \begin{pmatrix} 25 \\ 50 \\ -75 \end{pmatrix} \cdot kN \quad Q = 0.8 \cdot P = \begin{pmatrix} 20 \\ 40 \\ -60 \end{pmatrix} \cdot kN \quad |P| = 93.541 \cdot kN \quad |Q| = 74.833 \cdot kN \quad \frac{|Q|}{|P|} = 0.8$$

$$B = \begin{pmatrix} 0 \\ 0 \\ z_Q \end{pmatrix} \quad r_{OB} = B \quad r_{OB} \times Q = M_O \quad |M_O| = 335.41 \cdot kN \cdot m$$

$$\left| \begin{pmatrix} 0 \\ 0 \\ z_Q \end{pmatrix} \times \begin{pmatrix} 20 \\ 40 \\ -60 \end{pmatrix} \right| = 335.41 \quad \left| \begin{pmatrix} 0 \\ 0 \\ z_Q \end{pmatrix} \times \begin{pmatrix} 20 \\ 40 \\ -60 \end{pmatrix} \right| \rightarrow 20 \cdot \sqrt{5} \cdot |z_Q| = 335.41 \quad \frac{335.41}{20\sqrt{5}} = 7.5 \ m$$

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Problem 2.2-10

$$P_A = \begin{pmatrix} 30 \\ 25 \\ -75 \end{pmatrix} kN \qquad P_O = -P_A = \begin{pmatrix} -30 \\ -25 \\ 75 \end{pmatrix} \cdot kN \qquad \left|P_A\right| = 84.558 \cdot kN \qquad F_C = \left|P_A\right| \cdot \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} -84.558 \\ 0 \\ 0 \end{pmatrix} \cdot kN$$

$$A = \begin{pmatrix} 0 \\ 0 \\ 6 \end{pmatrix} m \qquad C = \begin{pmatrix} 6 \\ 4 \\ 0 \end{pmatrix} m \qquad r_{OA} = A \qquad r_{OC} = C$$

<u>Resultants at O</u>

$$R_O = P_A + P_O + F_C = \begin{pmatrix} -84.6 \\ 0 \\ 0 \end{pmatrix} \cdot kN \qquad M_O = r_{OA} \times P_A + r_{OC} \times F_C = \begin{pmatrix} -150 \\ 180 \\ 338 \end{pmatrix} \cdot kN \cdot m$$

<u>Wrench resultant - components of M_O (kN-m) along & perpend. to R_O</u>

$$n_R = \frac{R_O}{\left|R_O\right|} = \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix} \qquad M_{Rpar} = M_O \cdot n_R \cdot n_R = \begin{pmatrix} -150 \\ 0 \\ 0 \end{pmatrix} \cdot kN \cdot m \qquad M_{Rper} = M_O - M_{Rpar} = \begin{pmatrix} 0 \\ 180 \\ 338 \end{pmatrix} \cdot kN \cdot m$$

positive wrench resultant in (-x) direction

<u>Coordinates (meters) of pt at which wrench pierces yz plane</u>

$$\begin{pmatrix} 0 \\ y \\ z \end{pmatrix} \times R_O = M_{Oper} \text{ float}, 5 \rightarrow 0.0$$

$$y = \frac{338230.0 \cdot N \cdot m}{84558.0 \cdot N} = 4\,m$$

$$z = \frac{180000 \cdot N \cdot m}{-84558.0 \cdot N} = -2.13\,m$$

$$d = \frac{\left|M_{Rper}\right|}{\left|R_O\right|} = 4.53\,m$$

< perpend. dist. (m) from O to line of action of wrench

$$\sqrt{z^2 + y^2} = 4.53\,m$$

< same as d since wrench is perpendicular to yz plane

Answers

$$R_O = \begin{pmatrix} -84.6 \\ 0 \\ 0 \end{pmatrix} \cdot kN \qquad M_{Rpar} = \begin{pmatrix} -150 \\ 0 \\ 0 \end{pmatrix} \cdot kN \cdot m \qquad y = 4\,m \qquad z = -2.13\,m$$

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Problem 2.2-11

$F = 1.5kN \quad r = 0.75m \quad h = 2.25m \quad A = \begin{pmatrix} -r\cdot\sin(60deg) \\ r\cdot\cos(60deg) \\ h \end{pmatrix} = \begin{pmatrix} -0.65 \\ 0.375 \\ 2.25 \end{pmatrix}\cdot m \quad B = \begin{pmatrix} 0 \\ -r \\ h \end{pmatrix} \quad C = \begin{pmatrix} 0 \\ r \\ h \end{pmatrix} \quad D = \begin{pmatrix} 0 \\ r \\ 0 \end{pmatrix}$

$$n_{OA} = \frac{A}{|A|} = \begin{pmatrix} -0.274 \\ 0.158 \\ 0.949 \end{pmatrix}$$

Part (a)

$$F = F\cdot n_{OA} = \begin{pmatrix} -0.411 \\ 0.237 \\ 1.423 \end{pmatrix}\cdot kN \qquad r_{BO} = -B \qquad r_{BA} = A - B \qquad F_x = F_1 \quad F_y = F_2 \quad F_z = F_3$$

$$M_B = r_{BO} \times F = \begin{pmatrix} 1.601 \\ 0.924 \\ 0.308 \end{pmatrix}\cdot kN\cdot m = r_{BA} \times F = \begin{pmatrix} 1.601 \\ 0.924 \\ 0.308 \end{pmatrix}\cdot kN\cdot m$$

Part (b)

$$M_{Bx} = F_y\cdot h + F_z\cdot r = 1.601\cdot kN\cdot m \qquad M_{By} = -F_x\cdot h = 0.924\,kN\cdot m \qquad M_{Bz} = -F_x\cdot r = 0.308\,kN\cdot m$$

Part (c)

$$r_{DO} = -D \qquad r_{DA} = A - D \qquad M_D = r_{DO} \times F = \begin{pmatrix} -1.067 \\ 0 \\ -0.308 \end{pmatrix}\cdot kN\cdot m = r_{DA} \times F = \begin{pmatrix} -1.067 \\ 0 \\ -0.308 \end{pmatrix}\cdot kN\cdot m$$

$$n_{BD} = \frac{D - B}{|D - B|} = \begin{pmatrix} 0 \\ 0.555 \\ -0.832 \end{pmatrix} \qquad M_{BDpar} = M_D\cdot n_{BD}\cdot n_{BD} = \begin{pmatrix} 0 \\ 0.142 \\ -0.213 \end{pmatrix}\cdot kN\cdot m$$

$$M_{BDper} = M_D - M_{BDpar} = \begin{pmatrix} -1.067 \\ -0.142 \\ -0.095 \end{pmatrix}\cdot kN\cdot m$$

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Problem 2.2-12

$F = 520N \qquad A = \begin{pmatrix} 0 \\ 9 \\ 4 \end{pmatrix} m \qquad B = \begin{pmatrix} 0 \\ 0 \\ 4 \end{pmatrix} m \qquad C = \begin{pmatrix} 5 \\ 0 \\ 0 \end{pmatrix} m \qquad D = \begin{pmatrix} 5 \\ 9 \\ 0 \end{pmatrix} m \qquad n_{CA} = \frac{A - C}{|A - C|} = \begin{pmatrix} -0.453 \\ 0.815 \\ 0.362 \end{pmatrix}$

Part (a)

$F = F \cdot n_{CA} = \begin{pmatrix} -235.39 \\ 423.71 \\ 188.31 \end{pmatrix} N \qquad r_{BC} = C - B = \begin{pmatrix} 5 \\ 0 \\ -4 \end{pmatrix} m \qquad r_{BA} = A - B = \begin{pmatrix} 0 \\ 9 \\ 0 \end{pmatrix} m$

$M_B = r_{BC} \times F = \begin{pmatrix} 1695 \\ 0 \\ 2119 \end{pmatrix} \cdot N \cdot m$ check $r_{BA} \times F = \begin{pmatrix} 1695 \\ 0 \\ 2119 \end{pmatrix} \cdot N \cdot m$

Part (b)

$F_x = -235.39N \qquad F_y = 423.71N \qquad F_z = 188.31N$

$M_{Bx} = F_y \cdot (4m) = 1695 \cdot N \cdot m \qquad M_{By} = -F_z \cdot (5m) - F_x \cdot (4m) = 0 \cdot N \cdot m \qquad M_{Bz} = F_y \cdot (5m) = 2119 \cdot N \cdot m$

Part (c)

$n_{BD} = \frac{D - B}{|D - B|} = \begin{pmatrix} 0.453 \\ 0.815 \\ -0.362 \end{pmatrix} \qquad M_{BDpar} = M_B \cdot n_{BD} \cdot n_{BD} = \begin{pmatrix} -0 \\ -0 \\ 0 \end{pmatrix} \cdot N \cdot m \qquad M_{BDper} = M_B - M_{BDpar} = \begin{pmatrix} 1695 \\ 0 \\ 2119 \end{pmatrix} \cdot N \cdot m$

Part (d)

$r_{OC} = C \qquad M_O = r_{OC} \times F = \begin{pmatrix} 0 \\ -942 \\ 2119 \end{pmatrix} \cdot N \cdot m$

$n_{OD} = \frac{D}{|D|} = \begin{pmatrix} 0.486 \\ 0.874 \\ 0 \end{pmatrix} \qquad M_{ODpar} = M_O \cdot n_{OD} \cdot n_{OD} = \begin{pmatrix} -400 \\ -720 \\ 0 \end{pmatrix} \cdot N \cdot m \qquad M_{ODper} = M_O - M_{ODpar} = \begin{pmatrix} 400 \\ -222 \\ 2119 \end{pmatrix} \cdot N \cdot m$

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Problem 2.2-13

$T_{AB} = 67N$

Joint coordinates: $A = \begin{pmatrix} 200 \\ 500 - 500 \cdot \cos(60deg) \\ -500 \cdot \sin(60deg) \end{pmatrix} \cdot mm = \begin{pmatrix} 200 \\ 250 \\ -433.013 \end{pmatrix} \cdot mm \quad B = \begin{pmatrix} 150 \\ 0 \\ 0 \end{pmatrix} \cdot mm \quad C = \begin{pmatrix} 0 \\ 500 \\ 0 \end{pmatrix} \cdot mm$

Part (a) $n_{AB} = \frac{B - A}{|B - A|} = \begin{pmatrix} -0.1 \\ -0.498 \\ 0.862 \end{pmatrix} \quad T_{AB} = T_{AB} \cdot n_{AB} = \begin{pmatrix} -6.667 \\ -33.334 \\ 57.736 \end{pmatrix} \cdot N \quad r_{OB} = B \quad r_{OA} = A$

$M_O = r_{OB} \times T_{AB} = \begin{pmatrix} 0 \\ -8.66 \\ -5 \end{pmatrix} \cdot N \cdot m$ or as a check $r_{OA} \times T_{AB} = \begin{pmatrix} -0 \\ -8.66 \\ -5 \end{pmatrix} \cdot N \cdot m$

Part (b) $T_{ABx} = -6.667N \quad T_{ABy} = -33.334N \quad T_{ABz} = 57.736N$

$M_{Ox} = 0 \quad M_{Oy} = -T_{ABz} \cdot (200mm) - T_{ABx} \cdot (500mm \cdot \sin(60deg)) = -8.66 \cdot N \cdot m$

$M_{Oz} = -T_{ABx} \cdot (500mm - 500mm \cdot \cos(60deg)) + T_{ABy} \cdot (200mm) = -5 \cdot N \cdot m$

Part (c)

$r_{CA} = A - C = \begin{pmatrix} 200 \\ -250 \\ -433.013 \end{pmatrix} \cdot mm \quad M_C = r_{CA} \times T_{AB} = \begin{pmatrix} -28.9 \\ -8.7 \\ -8.3 \end{pmatrix} \cdot N \cdot m \quad n_{CD} = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$

$M_{CDpar} = M_C \cdot n_{CD} \cdot n_{CD} = \begin{pmatrix} -29 \\ 0 \\ 0 \end{pmatrix} \cdot N \cdot m \quad M_{CDper} = M_C - M_{CDpar} = \begin{pmatrix} 0 \\ -8.7 \\ -8.3 \end{pmatrix} \cdot N \cdot m$

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Problem 2.2-14

$F_{DO} = 2.5N \qquad T_{AE} = 4N \qquad M_y = 5N\cdot m \qquad A = \begin{pmatrix} 1.8 \\ 0 \\ 2.1 \end{pmatrix} m \qquad E = \begin{pmatrix} 2.6 \\ 0 \\ 0 \end{pmatrix} m \qquad r_{OA} = A$

$n_{AE} = \frac{E - A}{|E - A|} = \begin{pmatrix} 0.356 \\ 0 \\ -0.934 \end{pmatrix} \qquad T_{AE} = T_{AE}\cdot n_{AE} = \begin{pmatrix} 1.424 \\ 0 \\ -3.738 \end{pmatrix} N \qquad T_{AEx} = 1.424N \qquad T_{AEy} = 0 \qquad T_{AEz} = -3.738N$

<u>Part (a)</u>

$$M_O = M_y\cdot\begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} + r_{OA} \times T_{AE} = \begin{pmatrix} 0 \\ 14.72 \\ 0 \end{pmatrix}\cdot N\cdot m$$

<u>Part (b)</u>

$M_{Ox} = 0 \qquad M_{Oy} = M_y + T_{AEx}\cdot(2.1m) - T_{AEz}\cdot(1.8m) = 14.72\cdot N\cdot m \qquad M_{Oz} = 0$

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Problem 2.2-15

Part (a)

$$P = 175N \qquad F_C = P\cdot\begin{pmatrix}0\\0\\-1\end{pmatrix} \qquad R_O = F_C = \begin{pmatrix}0\\0\\-175\end{pmatrix}\cdot N \qquad C = \begin{pmatrix}125mm\cdot\cos(40deg)\\31.25mm + 50mm\\125mm\cdot\sin(40deg)\end{pmatrix} = \begin{pmatrix}95.756\\81.25\\80.348\end{pmatrix}\cdot mm$$

$$r_{OC} = C \qquad M_O = r_{OC}\times F_C = \begin{pmatrix}-14.2\\16.8\\0\end{pmatrix}\cdot N\cdot m$$

Part (b)

$$A = \begin{pmatrix}0\\31.25mm\\0\end{pmatrix} \qquad B = \begin{pmatrix}125mm\cdot\cos(40deg)\\31.25mm\\125mm\cdot\sin(40deg)\end{pmatrix} = \begin{pmatrix}95.756\\31.25\\80.348\end{pmatrix}\cdot mm \qquad n_{AB} = \frac{B - A}{|B - A|} = \begin{pmatrix}0.766\\0\\0.643\end{pmatrix}$$

$$r_{AC} = C - A$$

$$M_A = r_{AC}\times F_C = \begin{pmatrix}-8.8\\16.8\\0\end{pmatrix}\cdot N\cdot m \qquad M_{AB} = M_A\cdot n_{AB}\cdot n_{AB} = \begin{pmatrix}-5.1\\0\\-4.3\end{pmatrix}\cdot N\cdot m \qquad M_A\cdot n_{AB} = -6.7\cdot N\cdot m$$

$$|M_{AB}| = 6.7\cdot N\cdot m$$

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Problem 2.2-16

$F_{DO} = 2.5N \qquad T_{AB} = 4N \qquad M_y = 5N \cdot m$

$$A = \begin{pmatrix} 1.8 \\ 0 \\ 2.1 \end{pmatrix} m \qquad B = \begin{pmatrix} 2.6 \\ 1.4 \\ 0 \end{pmatrix} m \qquad C = \begin{pmatrix} 1.8 \\ 1.4 \\ 0 \end{pmatrix} m \qquad D = \begin{pmatrix} 0 \\ 0 \\ 2.1 \end{pmatrix} m \qquad r_{OA} = A$$

$$n_{AB} = \frac{B - A}{|B - A|} = \begin{pmatrix} 0.302 \\ 0.529 \\ -0.793 \end{pmatrix} \qquad T_{AB} = T_{AB} \cdot n_{AB} = \begin{pmatrix} 1.209 \\ 2.115 \\ -3.173 \end{pmatrix} N \qquad \text{so} \qquad T_{ABx} = 1.209N \qquad T_{ABy} = 2.115N$$

$$T_{ABz} = -3.173N$$

Part (a)

$$M_O = M_y \cdot \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} + r_{OA} \times T_{AB} = \begin{pmatrix} -4.44 \\ 13.25 \\ 3.81 \end{pmatrix} \cdot N \cdot m$$

Part (b)

$$M_{Ox} = -T_{ABy} \cdot (2.1m) = -4.44 \cdot N \cdot m \qquad M_{Oy} = M_y + T_{ABx} \cdot (2.1m) + \left(-T_{ABz}\right) \cdot (1.8m) = 13.25 \cdot N \cdot m$$

$$M_{Oz} = T_{ABy} \cdot (1.8m) = 3.81 \cdot N \cdot m$$

Part (c)

$$n_{OC} = \frac{C}{|C|} = \begin{pmatrix} 0.789 \\ 0.614 \\ 0 \end{pmatrix} \qquad M_{OCpar} = M_O \cdot n_{OC} \cdot n_{OC} = \begin{pmatrix} 3.65 \\ 2.84 \\ 0 \end{pmatrix} \cdot N \cdot m \qquad M_{OCper} = M_O - M_{OCpar} = \begin{pmatrix} -8.09 \\ 10.41 \\ 3.81 \end{pmatrix} \cdot N \cdot m$$

Part (d)

$$M_O = M_O - M_y \cdot \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} = \begin{pmatrix} -4.442 \\ 8.249 \\ 3.807 \end{pmatrix} N \cdot m$$

$$d = \frac{|M_O|}{|T_{AB}|} = 2.53m$$

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Problem 2.2-17

$F = 67N \qquad A = \begin{pmatrix} 540 \\ 0 \\ 630 \end{pmatrix} \cdot mm \qquad D = \begin{pmatrix} 0 \\ 0 \\ 630 \end{pmatrix} \cdot mm \qquad d = 540mm$

Varignon's theorem

$M_{Ay} = -F \cdot d = -36.18 \cdot N \cdot m \qquad M_{Dy} = M_{Ay} \qquad M_{Oy} = M_{Ay}$ < same moment about any point for force couple

Vector algebra

$F_A = F \cdot \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \qquad F_D = -F_A$

$r_{AD} = D - A = \begin{pmatrix} -0.54 \\ 0 \\ 0 \end{pmatrix} \cdot m \qquad M_A = r_{AD} \times F_D = \begin{pmatrix} 0 \\ -36.18 \\ 0 \end{pmatrix} \cdot N \cdot m$

$r_{DA} = -r_{AD} = \begin{pmatrix} 0.54 \\ 0 \\ 0 \end{pmatrix} \cdot m \qquad M_D = r_{DA} \times F_A = \begin{pmatrix} 0 \\ -36.18 \\ 0 \end{pmatrix} \cdot N \cdot m$

$r_{OA} = A \qquad M_O = r_{OA} \times F_A = \begin{pmatrix} 0 \\ -36.18 \\ 0 \end{pmatrix} \cdot N \cdot m$

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Problem 2.2-18

$$r_{CB} = \begin{pmatrix} -3 \\ -8 \\ 3 \end{pmatrix} \cdot m \qquad r_{CA} = \begin{pmatrix} -3 \\ 0 \\ 9 \end{pmatrix} \cdot m \qquad r_{BA} = \begin{pmatrix} 0 \\ 8 \\ 6 \end{pmatrix} \cdot m \qquad r_{DC} = \begin{pmatrix} -12 \\ 8 \\ -9 \end{pmatrix} \cdot m$$

$$F = 500N \qquad F_{BA} = F \cdot \frac{r_{BA}}{|r_{BA}|} = \begin{pmatrix} 0 \\ 400 \\ 300 \end{pmatrix} \cdot N$$

a) Find moment of F about point C

$$M_C = r_{CB} \times F_{BA} = \begin{pmatrix} -3600 \\ 900 \\ -1200 \end{pmatrix} \cdot N \cdot m \qquad r_{CA} \times F_{BA} = \begin{pmatrix} -3600 \\ 900 \\ -1200 \end{pmatrix} \cdot N \cdot m$$

< can use any pt along line of action of F

b) Find moment of F about line CD using a cross product

$$n_{CD} = \frac{r_{DC}}{|r_{DC}|} = \begin{pmatrix} -0.706 \\ 0.471 \\ -0.529 \end{pmatrix}$$

$$M_{CD} = M_C \cdot n_{CD} \cdot n_{CD} = \begin{pmatrix} -2541 \\ 1694 \\ -1906 \end{pmatrix} \cdot N \cdot m \qquad |M_{CD}| = 3600 \cdot N \cdot m$$

c) Find the shortest distance d between component F_{per} (perpendicular to line CD) and line CD

$$F_{parCD} = F_{BA} \cdot n_{CD} \cdot n_{CD} = \begin{pmatrix} -20.761 \\ 13.841 \\ -15.571 \end{pmatrix} \cdot N \qquad F_{perCD} = F_{BA} - F_{parCD} = \begin{pmatrix} 20.761 \\ 386.159 \\ 315.571 \end{pmatrix} \cdot N \qquad r_{DC} \times F_{parCD} = \begin{pmatrix} -0 \\ 0 \\ 0 \end{pmatrix} \cdot N \cdot m$$

^ component of F which is parallel to CD has no moment about CD

$$d = \frac{|M_{CD}|}{|F_{perCD}|} = 7.21 \cdot m \qquad |F_{perCD}| \cdot d = 3600 \cdot N \cdot m$$

< same as $|M_{CD}|$

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Problem 2.2-19

$F = 90N \qquad M = 5.7N\cdot m \qquad r_{DB} = \begin{pmatrix} 75 \\ -100 \\ 0 \end{pmatrix}\cdot mm \qquad n_{DB} = \frac{r_{DB}}{|r_{DB}|} = \begin{pmatrix} 0.6 \\ -0.8 \\ 0 \end{pmatrix} \qquad F_{DB} = F\cdot n_{DB} = \begin{pmatrix} 54 \\ -72 \\ 0 \end{pmatrix}\cdot N$

<u>Find unit vector normal to plane ABC</u>

$r_{BC} = \begin{pmatrix} 0 \\ 100 \\ 0 \end{pmatrix}\cdot mm \qquad r_{BA} = \begin{pmatrix} -75 \\ 0 \\ 125 \end{pmatrix}\cdot mm \qquad r_{AB} = -r_{BA}$

$n_{BCA} = \frac{r_{BC} \times r_{BA}}{|r_{BC} \times r_{BA}|} = \begin{pmatrix} 0.857 \\ 0 \\ 0.514 \end{pmatrix} \qquad M = M\cdot n_{BCA} = \begin{pmatrix} 4.888 \\ 0 \\ 2.933 \end{pmatrix}\cdot N\cdot m$

<u>a) Find M_A due to both F and M</u>

$M_A = M + r_{AB} \times F_{DB} = \begin{pmatrix} -4.1 \\ -6.8 \\ -2.5 \end{pmatrix}\cdot N\cdot m$

<u>b) Find moment about line AC</u>

$r_{AC} = \begin{pmatrix} 75 \\ 100 \\ -125 \end{pmatrix}\cdot mm \qquad n_{AC} = \frac{r_{AC}}{|r_{AC}|} = \begin{pmatrix} 0.424 \\ 0.566 \\ -0.707 \end{pmatrix} \qquad M_{AC} = M_A\cdot n_{AC}\cdot n_{AC} = \begin{pmatrix} -1.62 \\ -2.16 \\ 2.7 \end{pmatrix}\cdot N\cdot m$

<u>c) What is the perpendicular distance d (mm) from force F to line AC?</u>

$d = \frac{|(M_A)\cdot n_{AC}\cdot n_{AC}|}{|F|} = 42.426\,mm$ < as expected distance is less than 1/2 of diagonal dist. at base (= 125/2 = 62.5)

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Problem 2.2-20

<u>Find unit vectors in directions of three couples</u> Let $b = 1$

$$n_1 = \frac{\begin{pmatrix} 0 \\ \frac{3\cdot b}{2} \\ 0 \end{pmatrix} \times \begin{pmatrix} -2\cdot b \\ 0 \\ 3\cdot b \end{pmatrix}}{\left|\begin{pmatrix} 0 \\ \frac{3\cdot b}{2} \\ 0 \end{pmatrix} \times \begin{pmatrix} -2\cdot b \\ 0 \\ 3\cdot b \end{pmatrix}\right|} \rightarrow \begin{pmatrix} \frac{3\cdot\sqrt{13}}{13} \\ 0 \\ \frac{2\cdot\sqrt{13}}{13} \end{pmatrix} = \begin{pmatrix} 0.832 \\ 0 \\ 0.555 \end{pmatrix}$$

$$n_2 = \frac{\begin{pmatrix} -2\cdot b \\ 0 \\ 0 \end{pmatrix} \times \begin{pmatrix} -2\cdot b \\ \frac{-3\cdot b}{2} \\ 3\cdot b \end{pmatrix}}{\left|\begin{pmatrix} -2\cdot b \\ 0 \\ 0 \end{pmatrix} \times \begin{pmatrix} -2\cdot b \\ \frac{-3\cdot b}{2} \\ 3\cdot b \end{pmatrix}\right|} \rightarrow \begin{pmatrix} 0 \\ \frac{2\cdot\sqrt{5}}{5} \\ \frac{\sqrt{5}}{5} \end{pmatrix} = \begin{pmatrix} 0 \\ 0.894 \\ 0.447 \end{pmatrix} \qquad n_3 = \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix}$$

^ by inspection

$$M_1 = M_0\cdot n_1 = \begin{pmatrix} 0.832 \\ 0 \\ 0.555 \end{pmatrix} M_0 \qquad M_2 = M_0\cdot n_2 = \begin{pmatrix} 0 \\ 0.894 \\ 0.447 \end{pmatrix} M_0 \qquad M_3 = M_0\cdot n_3 = \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix} M_0$$

Single couple is sum of three vectors

$$M_{SE} = M_1 + M_2 + M_3 = \begin{pmatrix} 0.832 \\ 0.894 \\ 0.002 \end{pmatrix} M_0$$

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Problem 2.2-21

(a) Moment of force $F_1 = 54$ N about E

$$r_{EG} = \begin{pmatrix} 1.2 \\ 1.2 \\ -0.9 \end{pmatrix} \cdot m \qquad F_1 = 54 \cdot N \cdot \frac{\begin{pmatrix} 0 \\ -1.2 \\ 0.9 \end{pmatrix}}{\left|\begin{pmatrix} 0 \\ -1.2 \\ 0.9 \end{pmatrix}\right|} = \begin{pmatrix} 0 \\ -43.2 \\ 32.4 \end{pmatrix} \cdot N \qquad M_{EF1} = r_{EG} \times F_1 = \begin{pmatrix} 0 \\ -38.88 \\ -51.84 \end{pmatrix} \cdot N \cdot m$$

(b) Moment of force $F_2 = 80$ N about E

$$F_2 = 80N \cdot \frac{\begin{pmatrix} -1.2 \\ 0 \\ 0.9 \end{pmatrix}}{\left|\begin{pmatrix} -1.2 \\ 0 \\ 0.9 \end{pmatrix}\right|} = \begin{pmatrix} -64 \\ 0 \\ 48 \end{pmatrix} \cdot N \qquad M_{EF2} = r_{EG} \times F_2 = \begin{pmatrix} 57.6 \\ 0 \\ 76.8 \end{pmatrix} \cdot N \cdot m$$

(c) Moment of couple C = 19 N-m about E

$$r_{OG} = \begin{pmatrix} 1.2 \\ 1.2 \\ 0 \end{pmatrix} \cdot m \qquad r_{OB} = \begin{pmatrix} 0 \\ 1.2 \\ 0.9 \end{pmatrix} \cdot m$$

$$C = 19N \cdot m \cdot \frac{r_{OG} \times r_{OB}}{\left|r_{OG} \times r_{OB}\right|} = \begin{pmatrix} 9.775 \\ -9.775 \\ 13.034 \end{pmatrix} \cdot N \cdot m \qquad M_{EC} = C = \begin{pmatrix} 9.78 \\ -9.78 \\ 13.03 \end{pmatrix} \cdot N \cdot m$$

(d) Moment of resultant of F_1, F_2 and C about line EG

$$n_{EG} = \frac{r_{EG}}{\left|r_{EG}\right|} = \begin{pmatrix} 0.625 \\ 0.625 \\ -0.469 \end{pmatrix} \qquad r_{EG} = \begin{pmatrix} 1.2 \\ 1.2 \\ -0.9 \end{pmatrix} \cdot m$$

resultant moment about pt. E

$$M_{ER} = M_{EF1} + M_{EF2} + M_{EC} = \begin{pmatrix} 67.4 \\ -48.7 \\ 38 \end{pmatrix} \cdot N \cdot m \qquad M_{EG} = M_{ER} \cdot n_{EG} n_{EG} = \begin{pmatrix} -3.81 \\ -3.81 \\ 2.86 \end{pmatrix} \cdot N \cdot m$$

(e) Moment of resultant of F_1, F_2 and C about line EB

$$n_{EB} = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$$

$$M_{EB} = M_{ER} \cdot n_{EB} \cdot n_{EB} = \begin{pmatrix} 0 \\ -48.7 \\ 0 \end{pmatrix} \cdot N \cdot m$$ < y component of M_{ER} above

and $$\left(M_{EF1} + C\right) \cdot n_{EB} \cdot n_{EB} = \begin{pmatrix} 0 \\ -48.7 \\ 0 \end{pmatrix} \cdot N \cdot m$$ < F_2 passes through line EB so offers no contribution to M_{EB}

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Problem 2.2-22

Part (a) Resultant force (N)

$$R = (50 + 75 + 95 + 65 + 70)\cdot N\cdot\begin{pmatrix}0\\1\\0\end{pmatrix} = \begin{pmatrix}0\\355\\0\end{pmatrix} N$$

Part (b)

Moment (N.m) about pt. B: note that r x F = -(F x r)

$$M_B = -\left[\begin{pmatrix}0\\50\\0\end{pmatrix}N\times\begin{pmatrix}0\\0\\\frac{3}{2}\end{pmatrix}m + \begin{pmatrix}0\\75\\0\end{pmatrix}N\times\begin{pmatrix}0\\\frac{6}{2}\\0\end{pmatrix}m + \begin{pmatrix}0\\95\\0\end{pmatrix}N\times\begin{pmatrix}\frac{5}{2}\\6\\0\end{pmatrix}m + \begin{pmatrix}0\\65\\0\end{pmatrix}N\times\begin{pmatrix}5\\6\\\frac{4}{2}\end{pmatrix}m + \begin{pmatrix}0\\70\\0\end{pmatrix}N\times\begin{pmatrix}5\\6-2\\4\end{pmatrix}m\right]$$

$$M_B = \begin{pmatrix}-485\\0\\913\end{pmatrix}\cdot N\cdot m$$

< all forces are parallel to y-axis so moment has x and z components only, as expected

Part (c) $|R| = 355\,N$ $\quad |M_B| = 1033\cdot N\cdot m$ $\quad d = \frac{|M_B|}{|R|} = 2.91\,m$

$$\begin{pmatrix}x\\0\\z\end{pmatrix}\times R = M_B \;\Big|\begin{matrix}\text{solve}, x, z\\ \text{float}, 4\end{matrix} \rightarrow (2.57\cdot m \quad 1.366\cdot m) \qquad \sqrt{2.57^2 + 1.366^2} = 2.9105$$

^ move resultant R (acting in +y-dir.) a dist. d from B so that it pierces (x, z) plane at coordinates x = 2.57m, z = 1.366m

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Problem 2.2-23

Part (a)

$$R_{Ax} = -22.5N \qquad R_{Ay} = -13.5N + 9N = -4.5 \cdot N \qquad R_{Az} = 0$$

$$M_{Ax} = 13.5N \cdot (100mm) = 1.35 \cdot N \cdot m \qquad M_{Ay} = -22.5N \cdot (100mm) = -2.25 \cdot N \cdot m$$

$$M_{Az} = (9 - 13.5)N \cdot (25mm) = -0.113 \cdot N \cdot m$$

Part (b)

$$r_{AB} = \begin{pmatrix} 25 \\ 0 \\ 100 \end{pmatrix} mm \qquad F_B = \begin{pmatrix} -22.5 \\ -13.5 \\ 0 \end{pmatrix} N \qquad R_A = F_B + \begin{pmatrix} 0 \\ 9N \\ 0 \end{pmatrix} = \begin{pmatrix} -22.5 \\ -4.5 \\ 0 \end{pmatrix} \cdot N$$

$$M_A = r_{AB} \times F_B + \begin{pmatrix} 0 \\ 0 \\ 9 \cdot 25 \end{pmatrix} N \cdot mm = \begin{pmatrix} 1.35 \\ -2.25 \\ -0.113 \end{pmatrix} \cdot N \cdot m$$

Part (c)

$$n_R = \frac{R_A}{|R_A|} = \begin{pmatrix} -0.981 \\ -0.196 \\ 0 \end{pmatrix} \qquad M_{Rpar} = M_A \cdot n_R \cdot n_R = \begin{pmatrix} 0.865 \\ 0.173 \\ 0 \end{pmatrix} \cdot N \cdot m \qquad M_{Rper} = M_A - M_{Rpar} = \begin{pmatrix} 0.485 \\ -2.423 \\ -0.113 \end{pmatrix} \cdot N \cdot m$$

$$\begin{pmatrix} 0 \\ y \\ z \end{pmatrix} \times R_A = M_{Rper} \qquad \begin{pmatrix} 0 \\ y \\ z \end{pmatrix} \times R_A \rightarrow \begin{pmatrix} 4.5 \cdot N \cdot z \\ -22.5 \cdot N \cdot z \\ 22.5 \cdot N \cdot y \end{pmatrix}$$

$$y = \frac{-0.113N \cdot m}{22.5N} = -5.022 \cdot mm \qquad z = \frac{-2.423N \cdot m}{-22.5 \cdot N} = 107.689mm$$

$$\begin{pmatrix} 0 \\ -5.022 \\ 107.689 \end{pmatrix} mm \times R_A = \begin{pmatrix} 0.485 \\ -2.423 \\ -0.113 \end{pmatrix} \cdot N \cdot m = M_{Rper}$$

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Problem 2.2-24

Position and unit vectors

$$r_{AC} = \begin{pmatrix} 3 \\ 7 \\ 0 \end{pmatrix} m \qquad r_{AB} = \begin{pmatrix} 0 \\ 7 \\ -5 \end{pmatrix} m \qquad r_{CD} = \begin{pmatrix} 0 \\ -7 \\ -5 \end{pmatrix} m \qquad n_{AC} = \frac{r_{AC}}{|r_{AC}|} = \begin{pmatrix} 0.394 \\ 0.919 \\ 0 \end{pmatrix} \qquad n_{AB} = \frac{r_{AB}}{|r_{AB}|} = \begin{pmatrix} 0 \\ 0.814 \\ -0.581 \end{pmatrix}$$

$$n_{CD} = \frac{r_{CD}}{|r_{CD}|} = \begin{pmatrix} 0 \\ -0.814 \\ -0.581 \end{pmatrix}$$

Resultant force (N) and unit vector along R

$$R = 75N \cdot n_{AC} + 50N \cdot n_{AB} + 90N \cdot n_{CD} = \begin{pmatrix} 29.5 \\ 36.4 \\ -81.4 \end{pmatrix} N \qquad n_R = \frac{R}{|R|} = \begin{pmatrix} 0.315 \\ 0.387 \\ -0.867 \end{pmatrix}$$

Moment (N.m) about pt. O

$$M_O = \begin{pmatrix} 0 \\ 0 \\ 5 \end{pmatrix} m \times \left(75N \cdot n_{AC} + 50N \cdot n_{AB}\right) + \begin{pmatrix} 3 \\ 0 \\ 0 \end{pmatrix} m \times \left(90N \cdot n_{CD}\right) = \begin{pmatrix} -548.1 \\ 304.7 \\ -219.7 \end{pmatrix} \cdot N \cdot m$$

Components of M_O along & perpend. to R

$$M_{Rpar} = M_O \cdot n_R \cdot n_R = \begin{pmatrix} 42.8 \\ 52.7 \\ -117.8 \end{pmatrix} \cdot N \cdot m \qquad M_{Rper} = M_O - M_{Rpar} = \begin{pmatrix} -590.9 \\ 252 \\ -101.9 \end{pmatrix} \cdot N \cdot m \qquad \left|M_{Rper}\right| = 650.4 \cdot N \cdot m$$

Coordinates (meters) of pt P where wrench pierces xy plane

$$\begin{pmatrix} x \\ y \\ 0 \end{pmatrix} \times R = M_{Rper} \text{ float}, 5 \rightarrow \begin{pmatrix} -81.373 \cdot N \cdot y \\ 81.373 \cdot N \cdot x \\ 36.387 \cdot N \cdot x + -29.544 \cdot N \cdot y \end{pmatrix} = \begin{pmatrix} -590.9 \cdot J \\ 251.96 \cdot J \\ -101.87 \cdot J \end{pmatrix}$$

$$x = \frac{251.96 N \cdot m}{81.373 N} = 3.1\,m \qquad y = \frac{590.9 N \cdot m}{81.373 N} = 7.26\,m$$

$$36.387 N \cdot x + -29.544 N \cdot y = -101.87 \cdot N \cdot m$$

$$d = \frac{\left|M_{Rper}\right|}{|R|} = 6.93\,m$$

< perpend. dist. (m) from O to line of action of wrench (note that R is not perpendicular to xy plane)

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Problem 2.2-25

$$P = \begin{pmatrix} 25 \\ 50 \\ -75 \end{pmatrix} kN \qquad P_A = P \qquad P_O = -P \qquad R_O = P_A + P_O = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \cdot kN$$

$$M_C = (275 kN \cdot m) \cdot \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} -275 \\ 0 \\ 0 \end{pmatrix} \cdot kN \cdot m$$

$$M_O = \begin{pmatrix} 0 \\ 0 \\ 6 \end{pmatrix} m \times P_A + M_C = \begin{pmatrix} -575 \\ 150 \\ 0 \end{pmatrix} \cdot kN \cdot m$$

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Problem 2.2-26

$$R_A = \begin{pmatrix} -140 \\ 80 \\ -120 \end{pmatrix} \text{ N} \qquad M_A = \begin{bmatrix} -80\cdot(2) \\ 120\cdot(5) - 140\cdot(2) + 30 - 25 \\ 80\cdot(5) + 140\cdot(7) \end{bmatrix} = \begin{pmatrix} -160 \\ 325 \\ 1380 \end{pmatrix} \text{ N}\cdot\text{m} \qquad n_R = \frac{R_A}{|R_A|} = \begin{pmatrix} -0.697 \\ 0.398 \\ -0.597 \end{pmatrix}$$

Wrench resultant (here, a negative wrench)

$$M_{Rpar} = M_A\cdot n_R\cdot n_R = \begin{pmatrix} 406 \\ -232 \\ 348 \end{pmatrix} \qquad M_{Rper} = M_A - M_{Rpar} = \begin{pmatrix} -566 \\ 557 \\ 1032 \end{pmatrix}$$

$$d = \frac{|M_{Rper}|}{|R_A|} = 6.479 \quad \text{m} \qquad \begin{pmatrix} 0 \\ y \\ z \end{pmatrix} \times R_A = M_{Rper} \text{ float}, 5 \rightarrow \begin{pmatrix} -120\cdot y - 80\cdot z \\ -140\cdot z \\ 140\cdot y \end{pmatrix} = \begin{pmatrix} -566.14 \\ 557.08 \\ 1031.9 \end{pmatrix}$$

$$y_P = \frac{1031.9}{140} = 7.37\,\text{m} \qquad z_P = \frac{557.08}{-140} = -3.98\ \text{m}$$

$$-120\cdot y_P - 80\cdot z_P = -566.154$$

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Problem 2.2-27

$$R_O = (5)\cdot(775N)\cdot\begin{pmatrix}0\\-1\\0\end{pmatrix} = \begin{pmatrix}0\\-3.875\times 10^3\\0\end{pmatrix}\cdot N \qquad \beta = 120deg$$

Use Varignon's theorem

$$M_{Ox} = 775N\cdot(1.2m + 3.6m + 6m) - 775N\cdot(3m\cdot\sin(\beta - 90deg) + 6.6m\cdot\sin(\beta - 90deg)) = 4650\cdot N\cdot m$$

$M_{Oy} = 0$ since all forces are parallel to y axis

$$M_{Oz} = -775N\cdot(3m\cdot\cos(\beta - 90deg) + 6.6m\cdot\cos(\beta - 90deg)) = -6443\cdot N\cdot m$$

$$M_O = \begin{pmatrix}M_{Ox}\\M_{Oy}\\M_{Oz}\end{pmatrix} = \begin{pmatrix}4650\\0\\-6443\end{pmatrix}\cdot N\cdot m$$

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Problem 2.2-28

Joint coordinates (meters)

$$A = \begin{pmatrix} 0 \\ 5 \\ 0 \end{pmatrix} \quad B = \begin{pmatrix} 4 \\ 5 \\ 0 \end{pmatrix} \quad E = \begin{pmatrix} 0 \\ 5 \\ 3 \end{pmatrix} \quad F = \begin{pmatrix} 4 \\ 5 \\ 3 \end{pmatrix} \quad G = \begin{pmatrix} 4 \\ 0 \\ 3 \end{pmatrix} \quad D = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \quad n_{DB} = \frac{B}{|B|} = \begin{pmatrix} 0.625 \\ 0.781 \\ 0 \end{pmatrix}$$

Resultants

$$R_D = \begin{pmatrix} 25 \\ 30 \\ -10 \end{pmatrix} + 15 \cdot n_{DB} = \begin{pmatrix} 34.4 \\ 41.7 \\ -10 \end{pmatrix} \text{ kN} \qquad M_D = \begin{pmatrix} 0 \\ 0 \\ 5 \end{pmatrix} + A \times \begin{pmatrix} 0 \\ 0 \\ -10 \end{pmatrix} + E \times \begin{pmatrix} 25 \\ 0 \\ 0 \end{pmatrix} + G \times \begin{pmatrix} 0 \\ 30 \\ 0 \end{pmatrix} = \begin{pmatrix} -140 \\ 75 \\ 0 \end{pmatrix} \text{ kN}\cdot\text{m}$$

Moments about and perpendicular to line DF

$$n_{DF} = \frac{F}{|F|} = \begin{pmatrix} 0.566 \\ 0.707 \\ 0.424 \end{pmatrix} \qquad M_{DFpar} = M_D \cdot n_{DF} \cdot n_{DF} = \begin{pmatrix} -14.8 \\ -18.5 \\ -11.1 \end{pmatrix} \text{ kN}\cdot\text{m} \qquad M_{DFper} = M_D - M_{DFpar} = \begin{pmatrix} -125.2 \\ 93.5 \\ 11.1 \end{pmatrix} \text{ kN}\cdot\text{m}$$

Wrench resultant (have negative wrench here)

$$n_R = \frac{R_D}{|R_D|} = \begin{pmatrix} 0.625 \\ 0.759 \\ -0.182 \end{pmatrix} \qquad M_{Rpar} = M_D \cdot n_R \cdot n_R = \begin{pmatrix} -19.15 \\ -23.24 \\ 5.57 \end{pmatrix} \text{ kN}\cdot\text{m} \qquad M_{Rper} = M_D - M_{Rpar} = \begin{pmatrix} -120.8 \\ 98.2 \\ -5.6 \end{pmatrix} \text{ kN}\cdot\text{m}$$

$$d = \frac{|M_{Rper}|}{|R_D|} = 2.84 \text{ m} \qquad \begin{pmatrix} x \\ y \\ 0 \end{pmatrix} \times R_D = M_{Rper} \text{ float}, 5 \rightarrow \begin{pmatrix} -10 \cdot y \\ 10 \cdot x \\ 41.713 \cdot x + -34.37 \cdot y \end{pmatrix} = \begin{pmatrix} -120.85 \\ 98.241 \\ -5.5717 \end{pmatrix}$$

$$x = 9.82 \text{ m} \qquad y = 12.08 \text{ m}$$

$$41.713 \cdot x + -34.37 \cdot y = -5.568$$

Answers

$$R_D = \begin{pmatrix} 34.4 \\ 41.7 \\ -10 \end{pmatrix} \text{ kN} \qquad M_D = \begin{pmatrix} -140 \\ 75 \\ 0 \end{pmatrix} \text{ kN}\cdot\text{m} \qquad M_{DFpar} = \begin{pmatrix} -14.8 \\ -18.5 \\ -11.1 \end{pmatrix} \text{ kN}\cdot\text{m}$$

$$M_{DFper} = \begin{pmatrix} -125.2 \\ 93.5 \\ 11.1 \end{pmatrix} \text{ kN}\cdot\text{m} \qquad x = 9.82 \text{ m} \qquad y = 12.08 \text{ m}$$

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Problem 2.2-29

$$A = \begin{pmatrix} 32 \\ 0 \\ 0 \end{pmatrix} mm \qquad B = \begin{pmatrix} 32 \\ 190 \\ 0 \end{pmatrix} mm \qquad F = 112N \cdot \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ -112 \end{pmatrix} \cdot N \qquad N_A = 67N \cdot \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} -67 \\ 0 \\ 0 \end{pmatrix} \cdot N$$

$$r_{OB} = B$$

Part (a)

$$R_O = F + N_A = \begin{pmatrix} -67 \\ 0 \\ -112 \end{pmatrix} \cdot N \qquad M_O = r_{OB} \times F = \begin{pmatrix} -21.28 \\ 3.584 \\ 0 \end{pmatrix} \cdot N \cdot m$$

Part (b)

$$n_R = \frac{R_O}{|R_O|} = \begin{pmatrix} -0.513 \\ 0 \\ -0.858 \end{pmatrix}$$

$$M_{Rpar} = M_O \cdot n_R \cdot n_R = \begin{pmatrix} -5.6 \\ 0 \\ -9.4 \end{pmatrix} \cdot N \cdot m \qquad M_{Rper} = M_O - M_{Rpar} = \begin{pmatrix} -15.672 \\ 3.584 \\ 9.375 \end{pmatrix} \cdot N \cdot m$$

$$\begin{pmatrix} x \\ y \\ 0 \end{pmatrix} \times R_O = M_{Rper} \qquad \begin{pmatrix} x \\ y \\ 0 \end{pmatrix} \times R_O \text{ float}, 5 \rightarrow \begin{pmatrix} -112.0\,N \cdot y \\ 112.0\,N \cdot x \\ 67.0\,N \cdot y \end{pmatrix}$$

$$x = \frac{3.584N \cdot m}{112.0\,N} = 32 \cdot mm$$

$$y = \frac{-15.672N \cdot m}{-112N} = 139.929\,mm$$

$$\frac{9.375N \cdot m}{67N} = 139.925\,mm$$

$$d = \frac{|M_{Rper}|}{|R_O|} = 142.6\,mm$$

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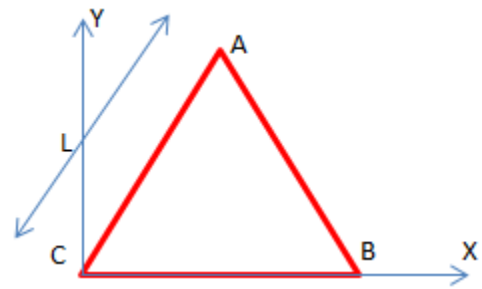
Problem 2.2-30

$F_1 = 150N \qquad F_2 = F_1 \qquad F_3 = 75N$ ABC is an equilateral triangle



$$R = F_1 + F_2 + F_3 = 375\,N \qquad R = R\cdot\begin{pmatrix}0\\0\\1\end{pmatrix}$$

Joint coordinates (assume that L = 1m) $\quad C = \begin{pmatrix}0\\0\\0\end{pmatrix} \qquad B = \begin{pmatrix}1\\0\\0\end{pmatrix} \qquad A = \begin{pmatrix}\cos(60deg)\\ \sin(60deg)\\ 0\end{pmatrix} = \begin{pmatrix}0.5\\0.866\\0\end{pmatrix}$

$$M_C = B\times\begin{pmatrix}0\\0\\F_2\end{pmatrix} + A\times\begin{pmatrix}0\\0\\F_3\end{pmatrix} \qquad M_C \rightarrow \begin{pmatrix}64.951905283832895\cdot N\\ -37.50000000000000825\cdot N - 150\cdot N\\ 0\end{pmatrix} = \begin{pmatrix}64.952\\-187.5\\0\end{pmatrix}N$$

$$\begin{pmatrix}x\\y\\0\end{pmatrix}\times R = M_C \;\Big|\begin{matrix}\text{solve},x,y\\ \text{float},4\end{matrix} \rightarrow (0.5 \quad 0.1732)$$

so resultant R passes through point with coordinates

$$x = \frac{L}{2} \qquad y = \frac{\sqrt{3}}{10}\cdot L$$

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Problem 2.2-31

Joint coordinates

$$A = \begin{pmatrix} 0 \\ 0 \\ 300 \end{pmatrix} mm \quad B = \begin{pmatrix} 0 \\ 87.5 \\ 300 \end{pmatrix} mm \quad C = \begin{pmatrix} 87.5 \\ 87.5 \\ 300 \end{pmatrix} mm \quad r_{OA} = A \quad r_{OC} = C$$

Part (a)

$$R_{Ox} = -45N \quad R_{Oy} = (31.5 - 22.5)N = 9 \cdot N \quad R_{Oz} = 0$$

$$M_{Ox} = -31.5N \cdot (150mm) + 22.5N \cdot (300mm) = 2.025 \cdot N \cdot m$$

$$M_{Oy} = -45N \cdot (300mm) = -13.5 \cdot N \cdot m$$

$$M_{Oz} = 1.6 \cdot N \cdot m - 22.5N \cdot (87.5mm) = -0.369 \cdot N \cdot m$$

Part (b)

$$R_O = \begin{pmatrix} -45 \\ 31.5 - 22.5 \\ 0 \end{pmatrix} \cdot N = \begin{pmatrix} -45 \\ 9 \\ 0 \end{pmatrix} \cdot N$$

$$M_O = \left[\begin{pmatrix} 0 \\ 0 \\ 150 \end{pmatrix} mm\right] \times \left[\begin{pmatrix} 0 \\ 31.5 \\ 0 \end{pmatrix} N\right] + r_{OA} \times \left[\begin{pmatrix} -45 \\ 0 \\ 0 \end{pmatrix} N\right] + r_{OC} \times \begin{pmatrix} 0 \\ -22.5 \\ 0 \end{pmatrix} N + \begin{pmatrix} 0 \\ 0 \\ 1.6 \end{pmatrix} N \cdot m = \begin{pmatrix} 2.025 \\ -13.5 \\ -0.369 \end{pmatrix} \cdot N \cdot m$$

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Problem 2.2-32

$$R_O = \begin{bmatrix} 0 \\ -2\cdot(300N) \\ 2\cdot(50N) - 2\cdot(50N) \end{bmatrix} = \begin{pmatrix} 0 \\ -600 \\ 0 \end{pmatrix} N$$

$$M_{Ox} = 4\cdot(50N)\cdot(1.5m) - 2\cdot(800N\cdot m) = -1300\cdot N\cdot m \qquad M_{Oy} = 0 \qquad M_{Oz} = 0 \qquad M_O = \begin{pmatrix} M_{Ox} \\ M_{Oy} \\ M_{Oz} \end{pmatrix} = \begin{pmatrix} -1300 \\ 0 \\ 0 \end{pmatrix}\cdot N\cdot m$$

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Problem 2.2-33

Joint coordinates

$$C = \begin{pmatrix} 3.6 \\ 1.2 \\ 1.2 \end{pmatrix} m \qquad D = \begin{pmatrix} 0 \\ 0.9 \\ 0 \end{pmatrix} m$$

Unit vector

$$n_{CD} = \frac{D - C}{|D - C|} = \begin{pmatrix} -0.946 \\ -0.079 \\ -0.315 \end{pmatrix}$$

Force F

$$F_{CD} = (110 kN) \cdot n_{CD} = \begin{pmatrix} -104.03 \\ -8.67 \\ -34.68 \end{pmatrix} \cdot kN$$

$$R_O = F_{CD} = \begin{pmatrix} -104.03 \\ -8.67 \\ -34.68 \end{pmatrix} \cdot kN \qquad M_x = (11 \cdot kN \cdot m) \cdot \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \qquad r_{OD} = D$$

$$M_O = M_x + r_{OD} \times F_{CD} = \begin{pmatrix} -20.2 \\ 0 \\ 93.6 \end{pmatrix} \cdot kN \cdot m$$

<u>Part (b)</u> - select x and z components of M_O

<u>Part (a)</u>

$$M_{OApar} = M_O \cdot \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \cdot \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} -20.2 \\ 0 \\ 0 \end{pmatrix} \cdot kN \cdot m \qquad M_{OAper} = M_O - M_{OApar} = \begin{pmatrix} 0 \\ 0 \\ 94 \end{pmatrix} \cdot kN \cdot m$$

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Problem 2.2-34

Joint coordinates

$$F = \begin{pmatrix} 1.125 \\ 0 \\ 1.875 \end{pmatrix} m \qquad C = \begin{pmatrix} 0 \\ 3 \\ 0 \end{pmatrix} m \qquad E = \begin{pmatrix} 3 \\ 3 \\ 5 \end{pmatrix} m \qquad A = \begin{pmatrix} 3 \\ 0 \\ 0 \end{pmatrix} m \qquad B = \begin{pmatrix} 0 \\ 0 \\ 3 \end{pmatrix} m \qquad D = \begin{pmatrix} 3 \\ 0 \\ 5 \end{pmatrix} m$$

$$n_{CE} = \frac{E - C}{|E - C|} = \begin{pmatrix} 0.514 \\ 0 \\ 0.857 \end{pmatrix} \qquad n_{FE} = \frac{E - F}{|E - F|} = \begin{pmatrix} 0.397 \\ 0.636 \\ 0.662 \end{pmatrix}$$

$$P = (3kN) \cdot n_{CE} = \begin{pmatrix} 1.543 \\ 0 \\ 2.572 \end{pmatrix} \cdot kN \qquad Q = (4kN) \cdot n_{FE} = \begin{pmatrix} 1.589 \\ 2.542 \\ 2.648 \end{pmatrix} \cdot kN$$

<u>Part (a)</u>

$$R_O = P + Q = \begin{pmatrix} 3.13 \\ 2.54 \\ 5.22 \end{pmatrix} \cdot kN \qquad r_{OE} = E \qquad M_O = r_{OE} \times (P + Q) = \begin{pmatrix} 2.95 \\ 0 \\ -1.77 \end{pmatrix} \cdot kN \cdot m$$

<u>Part (b)</u>

$$r_{AE} = E - A = \begin{pmatrix} 0 \\ 3 \\ 5 \end{pmatrix} m \qquad M_A = r_{AE} \times (P + Q) = \begin{pmatrix} 2.95 \\ 15.66 \\ -9.4 \end{pmatrix} \cdot kN \cdot m$$

$$n_{AD} = \frac{D - A}{|D - A|} = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \qquad M_{ADpar} = M_A \cdot n_{AD} \cdot n_{AD} = \begin{pmatrix} 0 \\ 0 \\ -9.4 \end{pmatrix} \cdot kN \cdot m \qquad M_{ADper} = M_A - M_{ADpar} = \begin{pmatrix} 2.95 \\ 15.66 \\ 0 \end{pmatrix} \cdot kN \cdot m$$

Answers

a) $R_O = \begin{pmatrix} 3.13 \\ 2.54 \\ 5.22 \end{pmatrix} \cdot kN \qquad M_O = \begin{pmatrix} 2.95 \\ 0 \\ -1.77 \end{pmatrix} \cdot kN \cdot m$

b) $M_{ADpar} = \begin{pmatrix} 0 \\ 0 \\ -9.4 \end{pmatrix} \cdot kN \cdot m \qquad M_{ADper} = \begin{pmatrix} 2.95 \\ 15.66 \\ 0 \end{pmatrix} \cdot kN \cdot m$

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Problem 2.2-35

$$H = \begin{pmatrix} 0 \\ 0 \\ 75 \end{pmatrix} \cdot mm \qquad B = \begin{pmatrix} 100 \\ 125 \\ 0 \end{pmatrix} mm \qquad C = \begin{pmatrix} 100 \\ 0 \\ 0 \end{pmatrix} \cdot mm \qquad G = \begin{pmatrix} 100 \\ 0 \\ 75 \end{pmatrix} \cdot mm \qquad A = \begin{pmatrix} 0 \\ 125 \\ 0 \end{pmatrix} \cdot mm \qquad P = 45kN$$

$$n_{HB} = \frac{B - H}{|B - H|} = \begin{pmatrix} 0.566 \\ 0.707 \\ -0.424 \end{pmatrix} \qquad n_{DG} = \frac{G}{|G|} = \begin{pmatrix} 0.8 \\ 0 \\ 0.6 \end{pmatrix} \qquad r_{DH} = H \qquad r_{DB} = B$$

Part (a)

$$P = P \cdot n_{HB} = \begin{pmatrix} 25.456 \\ 31.82 \\ -19.092 \end{pmatrix} \cdot kN \qquad R_D = P = \begin{pmatrix} 25.46 \\ 31.82 \\ -19.09 \end{pmatrix} \cdot kN$$

$$M_D = r_{DH} \times P = \begin{pmatrix} -2.39 \\ 1.91 \\ 0 \end{pmatrix} \cdot kN \cdot m$$

< no z component since P acts through z axis and

$$r_{DB} \times P = \begin{pmatrix} -2.39 \\ 1.91 \\ 0 \end{pmatrix} \cdot kN \cdot m$$

Part (b)

$$M_{DGpar} = M_D \cdot n_{DG} \cdot n_{DG} = \begin{pmatrix} -1.53 \\ 0 \\ -1.15 \end{pmatrix} \cdot kN \cdot m \qquad |M_{DGpar}| = 1.91 \cdot kN \cdot m$$

$$M_{DGper} = M_D - M_{DGpar} = \begin{pmatrix} -0.86 \\ 1.91 \\ 1.15 \end{pmatrix} \cdot kN \cdot m$$

Part (c)

$$r_{AB} = \begin{pmatrix} 100 \\ 0 \\ 0 \end{pmatrix} \cdot mm \qquad M_A = r_{AB} \times P = \begin{pmatrix} 0 \\ 1.909 \\ 3.182 \end{pmatrix} \cdot kN \cdot m \qquad d = \frac{|M_A|}{|P|} = 82.46\,mm$$

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Problem 2.2-36

$T_{CE} = 50kN \qquad a = 10m \qquad b = 4m \qquad c = 3m$

Position and unit vectors

$$r_{CE} = \begin{pmatrix} \frac{-a}{2} \\ c \\ -b \end{pmatrix} = \begin{pmatrix} -5 \\ 3 \\ -4 \end{pmatrix} \cdot m \qquad n_{CE} = \frac{r_{CE}}{|r_{CE}|} = \begin{pmatrix} -0.707 \\ 0.424 \\ -0.566 \end{pmatrix} \qquad r_{CA} = \begin{pmatrix} 0 \\ 0 \\ 0 - b \end{pmatrix} \qquad n_{CA} = \frac{r_{CA}}{|r_{CA}|} = \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix}$$

$$T_{CE} = T_{CE} \cdot n_{CE} = \begin{pmatrix} -35.4 \\ 21.2 \\ -28.3 \end{pmatrix} \cdot kN \qquad |T_{CE}| = 50 \cdot kN$$

Part (a)

$$R_A = T_{CE} = \begin{pmatrix} -35.4 \\ 21.2 \\ -28.3 \end{pmatrix} \cdot kN \qquad r_{AC} = \begin{pmatrix} 0 \\ 0 \\ b \end{pmatrix} \qquad M_A = r_{AC} \times T_{CE} = \begin{pmatrix} -84.9 \\ -141.4 \\ 0 \end{pmatrix} \cdot kN \cdot m$$

Part (b)

$$D = \begin{pmatrix} \frac{a}{2} \\ 0 \\ b \end{pmatrix} = \begin{pmatrix} 5 \\ 0 \\ 4 \end{pmatrix} m \qquad n_{AD} = \frac{D}{|D|} = \begin{pmatrix} 0.781 \\ 0 \\ 0.625 \end{pmatrix}$$

$$M_{ADpar} = M_A \cdot n_{AD} \cdot n_{AD} = \begin{pmatrix} -51.7 \\ 0 \\ -41.4 \end{pmatrix} \cdot kN \cdot m \qquad M_{ADper} = M_A - M_{ADpar} = \begin{pmatrix} -33.1 \\ -141.4 \\ 41.4 \end{pmatrix} \cdot kN \cdot m$$

$$|M_{ADpar}| = 66.3 \cdot kN \cdot m$$

Answers

a) $R_A = \begin{pmatrix} -35.4 \\ 21.2 \\ -28.3 \end{pmatrix} \cdot kN \qquad M_A = \begin{pmatrix} -84.9 \\ -141.4 \\ 0 \end{pmatrix} \cdot kN \cdot m$

b) $M_{ADpar} = \begin{pmatrix} -51.7 \\ 0 \\ -41.4 \end{pmatrix} \cdot kN \cdot m \qquad M_{ADper} = \begin{pmatrix} -33.1 \\ -141.4 \\ 41.4 \end{pmatrix} \cdot kN \cdot m$

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Problem 2.2-37

Solution

$$E = \begin{pmatrix} 1.2 \\ 0 \\ 0 \end{pmatrix} m \quad F = \begin{pmatrix} 1.2 \\ 0 \\ 1.2 \end{pmatrix} m \quad D = \begin{pmatrix} 1.2 \\ 0.6 \\ 0.6 \end{pmatrix} m \quad C = \begin{pmatrix} 0.3 \\ 1.2 \\ 1.2 \end{pmatrix} m \quad B = \begin{pmatrix} 0.3 \\ 1.2 \\ 0 \end{pmatrix} m \quad A = \begin{pmatrix} 0.3 \\ 0 \\ 0.6 \end{pmatrix} m \quad G = \begin{pmatrix} 0.3 \\ 0.6 \\ 0.6 \end{pmatrix} m$$

$$n_{DB} = \frac{B - D}{|B - D|} = \begin{pmatrix} -0.728 \\ 0.485 \\ -0.485 \end{pmatrix} \qquad n_{DC} = \frac{C - D}{|C - D|} = \begin{pmatrix} -0.728 \\ 0.485 \\ 0.485 \end{pmatrix} \qquad n_{DE} = \frac{E - D}{|E - D|} = \begin{pmatrix} 0 \\ -0.707 \\ -0.707 \end{pmatrix}$$

$$n_{DF} = \frac{F - D}{|F - D|} = \begin{pmatrix} 0 \\ -0.707 \\ 0.707 \end{pmatrix} \qquad n_{AG} = \frac{G - A}{|G - A|} = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$$

$$T_{DB} = 45kN \qquad T_{DC} = 45kN \qquad T_{DE} = 67kN \qquad T_{DF} = 67kN$$

Part (a)

$$T_{DB} = T_{DB} \cdot n_{DB} = \begin{pmatrix} -32.74 \\ 21.83 \\ -21.83 \end{pmatrix} \cdot kN \qquad T_{DC} = T_{DC} \cdot n_{DC} = \begin{pmatrix} -32.74 \\ 21.83 \\ 21.83 \end{pmatrix} \cdot kN$$

$$T_{DE} = T_{DE} \cdot n_{DE} = \begin{pmatrix} 0 \\ -47.38 \\ -47.38 \end{pmatrix} \cdot kN \qquad T_{DF} = T_{DF} \cdot n_{DF} = \begin{pmatrix} 0 \\ -47.38 \\ 47.38 \end{pmatrix} \cdot kN$$

$$R_A = T_{DB} + T_{DC} + T_{DE} + T_{DF} = \begin{pmatrix} -65.48 \\ -51.1 \\ 0 \end{pmatrix} \cdot kN \qquad |R_A| = 83.1 \cdot kN$$

$$r_{AD} = D - A = \begin{pmatrix} 0.9 \\ 0.6 \\ 0 \end{pmatrix} m \qquad M_A = r_{AD} \times R_A = \begin{pmatrix} 0 \\ 0 \\ -6.7 \end{pmatrix} \cdot kN \cdot m \qquad |M_A| = 6.7 \cdot kN \cdot m$$

Part (b)

$$M_A \cdot n_{AG} = 0 \cdot kN \cdot m$$

$T_{DB} = T_{DC}$ and $T_{DE} = T_{DF}$ so **symmetry** of loading (with respect to a vertical plane through ADG) means there is no moment component about AG axis

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Problem 2.2-38

$F_s = 154N \quad h = 660mm \quad d = 150mm \quad H = 1041mm \quad c = 506mm \quad a = 760mm \quad h_o = 490mm \quad b = 254mm$

$mass = 20kg \quad g = 9.807\frac{m}{s^2}$

Joint coordinates

$$A = \begin{pmatrix} h \\ h - H \\ d \end{pmatrix} = \begin{pmatrix} 660 \\ -381 \\ 150 \end{pmatrix} \cdot mm \qquad B = \begin{pmatrix} h \\ h \\ c \end{pmatrix} = \begin{pmatrix} 660 \\ 660 \\ 506 \end{pmatrix} \cdot mm \qquad C = \begin{pmatrix} 0 \\ 0 \\ a + b + c \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 1520 \end{pmatrix} \cdot mm \qquad D = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} mm \qquad O = \begin{pmatrix} h_o \\ \text{unknown} \\ b + c \end{pmatrix}$$

Unit vectors

$$n_{AB} = \frac{B - A}{|B - A|} = \begin{pmatrix} 0 \\ 0.946 \\ 0.324 \end{pmatrix} \qquad n_{CD} = \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix} \qquad n_{AC} = \frac{C - A}{|C - A|} = \begin{pmatrix} -0.421 \\ 0.243 \\ 0.874 \end{pmatrix}$$

Part (a)

$$W = mass \cdot g \cdot \begin{pmatrix} 0 \\ -1 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ -196.13 \\ 0 \end{pmatrix} N \qquad F_s = F_s \cdot n_{AB} = \begin{pmatrix} 0 \\ 145.71 \\ 49.83 \end{pmatrix} N \qquad R_A = W + F_s = \begin{pmatrix} 0 \\ -50.4 \\ 49.8 \end{pmatrix} N \qquad |R_A| = 70.9\,N$$

$$M_{Ax} = mass \cdot g \cdot (b + c - d) = 119.6 \cdot N \cdot m \qquad M_{Ay} = 0 \qquad M_{Az} = -mass \cdot g \cdot (h - h_o) = -33.3 \cdot N \cdot m$$

$$M_A = \begin{pmatrix} M_{Ax} \\ M_{Ay} \\ M_{Az} \end{pmatrix} = \begin{pmatrix} 119.6 \\ 0 \\ -33.3 \end{pmatrix} \cdot N \cdot m$$

Part (b)

$$r_{CA} = A - C = \begin{pmatrix} 660 \\ -381 \\ -1370 \end{pmatrix} \cdot mm \qquad M_C = r_{CA} \times F_s + \begin{bmatrix} -mass \cdot g \cdot (a) \\ 0 \\ -mass \cdot g \cdot (h_o) \end{bmatrix} = \begin{pmatrix} 31.58 \\ -32.89 \\ 0.07 \end{pmatrix} \cdot N \cdot m \qquad n_{CD} = \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix}$$

$$M_{CD} = M_C \cdot n_{CD} = -0.067 \cdot N \cdot m$$

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Problem 2.2-39

$P = 20kN \qquad W = 450kg \cdot g = 4.413 \cdot kN$

$$D = \begin{pmatrix} 0 \\ 9 \\ 9 \cdot \tan(55deg) \end{pmatrix} \cdot m = \begin{pmatrix} 0 \\ 9 \\ 12.853 \end{pmatrix} m \qquad E = \begin{pmatrix} 3 \\ 13 \\ 0 \end{pmatrix} m \qquad C = \begin{pmatrix} 0 \\ 5 \\ 5 \cdot \tan(55deg) \end{pmatrix} m = \begin{pmatrix} 0 \\ 5 \\ 7.141 \end{pmatrix} m \qquad r_{OC} = C$$

$$n_{DE} = \frac{E - D}{|E - D|} = \begin{pmatrix} 0.218 \\ 0.29 \\ -0.932 \end{pmatrix} \qquad P = P \cdot n_{DE} = \begin{pmatrix} 4 \\ 6 \\ -19 \end{pmatrix} \cdot kN \qquad W = W \cdot \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ -4.413 \end{pmatrix} \cdot kN \qquad r_{OE} = E$$

<u>Resultants</u>

$$R_O = P + W = \begin{pmatrix} 4.35 \\ 5.8 \\ -23.05 \end{pmatrix} \cdot kN \qquad M_O = r_{OC} \times W + r_{OE} \times P = \begin{pmatrix} -264.38 \\ 55.92 \\ -39.15 \end{pmatrix} \cdot kN \cdot m \qquad M_O = \begin{pmatrix} -264.4 \\ 55.9 \\ -39.2 \end{pmatrix} \cdot kN \cdot m$$

$$|R_O| = 24 \cdot kN \qquad |M_O| = 273 \cdot kN \cdot m$$

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