# 30 Years

*Previous Solved Papers*

# Civil Services Main Examination

(1995-2024)

# Civil Engineering

## Paper-I

*Topicwise Presentation*

*Also useful for*
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**Civil Services Main Examination Previous Years Solved Papers : Civil Engineering (Paper-I)**



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# Preface

B. Singh (Ex. IES)

**Civil Service** is considered as the most prestigious job in India and it has become a preferred destination by all engineers. In order to reach this estimable position every aspirant has to take arduous journey of Civil Services Examination (CSE). Focused approach and strong determination are the pre-requisites for this journey. Besides this, a good book also comes in the list of essential commodity of this odyssey.

I feel extremely glad to launch the revised edition of such a book which will not only make CSE plain sailing, but also with 100% clarity in concepts.

MADE EASY team has prepared this book with utmost care and thorough study of all previous years papers of CSE. The book aims to provide complete solution to all previous years questions with accuracy.

On doing a detailed analysis of previous years CSE question papers, it came to light that a good percentage of questions have been asked in Engineering Services, Indian Forest Service and State Services exams. Hence, this book is a one stop shop for all CSE, ESE, IFS and other competitive exam aspirants.

I would like to acknowledge efforts of entire MADE EASY team who worked day and night to solve previous years papers in a limited time frame and I hope this book will prove to be an essential tool to succeed in competitive exams and my desire to serve student fraternity by providing best study material and quality guidance will get accomplished.

With Best Wishes

**B. Singh (Ex. IES)**

CMD, MADE EASY Group

Previous Years Solved Papers of

# Civil Services Main Examination

# Civil Engineering : Paper-I

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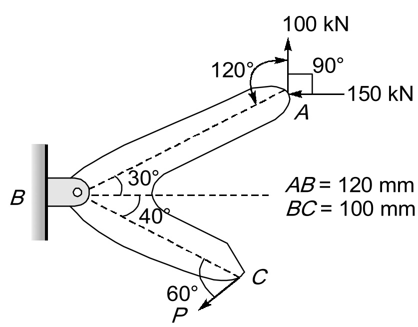
# 1 Engineering Mechanics

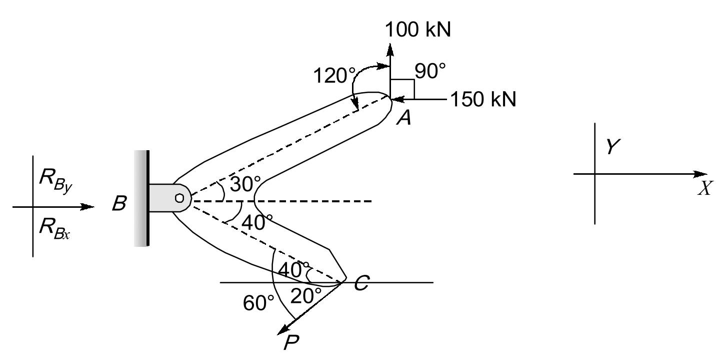
## 1. Composition, Resolution and Equilibrium of Forces

1.1 A component of a machine is subjected to a system of coplanar forces shown in the figure. Neglecting friction, determine the magnitude of force *P* to keep the component in equilibrium. Also determine the magnitude and direction of the reaction at the hinge at *B*.




[2005 : 12 Marks]

Solution:




Let $R_{Bx}$ and $R_{By}$ be the reaction component at *B* in *X* and *Y* direction respectively.

For equilibrium $\Sigma F_x = 0$

$$-150 - P\cos 20° + R_{Bx} = 0 \quad \text{...(i)}$$

$$\Sigma F_y = 0$$

$$100 + R_{By} - P\sin 20° = 0 \quad \text{...(ii)}$$

$$\Sigma M_B = 0$$

$$\Rightarrow \quad -100 \times (AB\cos 30°) - 150 \times (AB\sin 30°) + P\cos 20°\,(BC\sin 40°) + P\sin 20°\,(BC\cos 40°) = 0 \quad \text{...(iii)}$$

Given, $AB = 120$ mm

$BC = 100$ mm

In equation (iii), put value of *AB*, *BC*

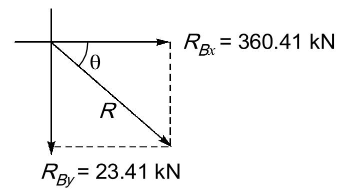
we get, $P = 223.92$ kN

Now, from eqn. (i) and (ii), $R_{Bx} = 150 + P\cos 20°$

$= 150 + 223.92 \times \cos 20° = 360.41$ kN

$$R_{By} = -100 + P \sin 20° = -100 + 223.92 \times \sin 20° = -23.41 \text{ kN}$$

Now, At hinge $B$,



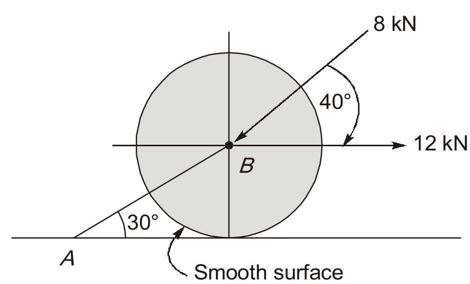

Resultant reaction, $R = \sqrt{(R_{B_x})^2 + (R_{B_y})^2}$

$$= \sqrt{(360.41)^2 + (23.41)^2} = 361.17 \text{ kN}$$

Direction of resultant force, $\tan\theta = \dfrac{R_{B_y}}{R_{B_x}} = \dfrac{23.41}{360.41} = 0.065$

$$\theta = \tan^{-1}(0.065) = 3.72° \simeq 3°43'8.38'' \text{ clockwise from } x\text{-axis}$$

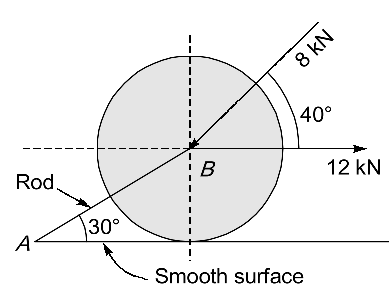
1.2 A roller of weight 20 kN rests on a smooth horizontal floor and is connected to the floor by the bar *AB* as shown in figure. Determine the force in the bar *AB* and reaction from the floor, if the roller is subjected to a horizontal force of 12 kN and inclined force of 8 kN as shown in the figure.




[2006 : 12 Marks]

**Solution:**

Given: Weight of roller = 20 kN




Let $F_{AB}$ be the force in the rod *AB* and *R* be the reaction from floor.

Consider equation of roller

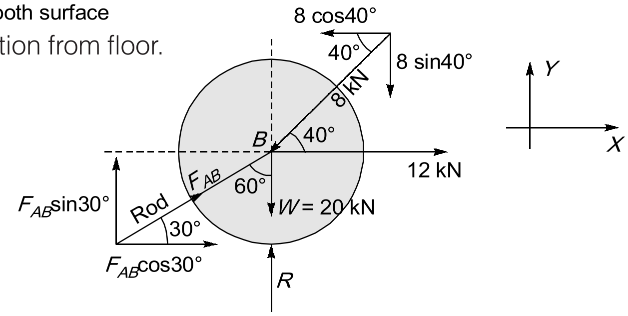
Resolving the forces horizontally, $\Sigma F_x = 0$

$$12 - 8\cos 40° + F_{AB}\cos 30° = 0$$

$$F_{AB} = -6.78 \text{ kN}$$

Resolving the forces vertically

$$\Sigma F_y = 0$$



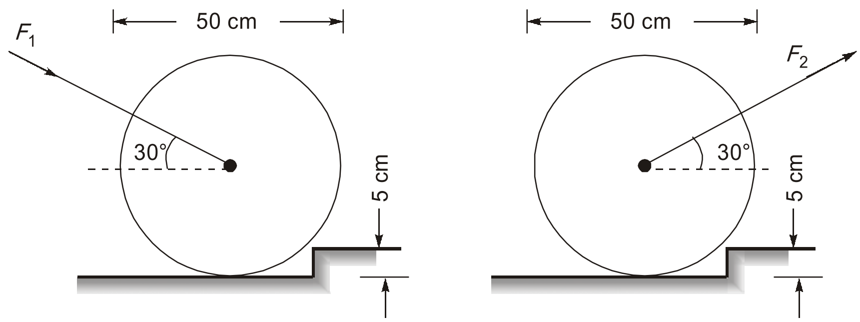
$$8 \sin 40° + 20 - F_{AB} \sin 30° = R$$

$$R = 5.14 + 20 - (-6.78) \sin 30°$$

$$R = 28.53 \text{ kN}$$

Hence, force in road $AB$ is 6.78 kN (Tensile) and reaction from the floor is 28.53 kN. (Upwards)

1.3



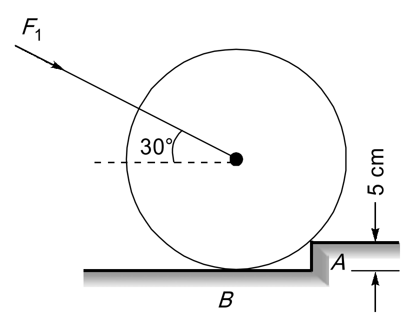

Compute the forces $F_1$ and $F_2$ required to just start a 100 kg lawn mower over a 5 cm step when

(b) the mower is pushed and

(c) the mower is pulled. (Above Figure)

[2007 : 20 Marks]

**Solution:**



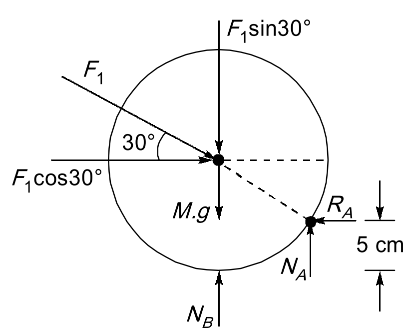

Given: Mass of lawn mower = 100 kg

Height of step = 5 cm

Dia. of mower = 50 cm

**Case-I**: When the mower is pushed

F.B.D




In limiting case $N_B = 0$ and $\Sigma M_A = 0$

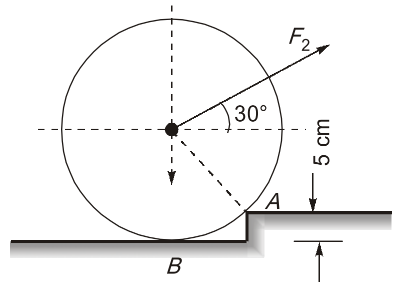
Computing $\Sigma M_A = 0$

$$F_1 \cos 30° \times (25-5) = (F_1 \sin 30° + 100 \times 9.8) \times \sqrt{(25)^2 - (25-5)^2}$$

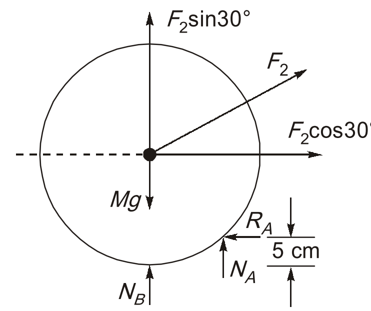
$$F_1 \times \frac{\sqrt{3}}{2} \times 20 = \left(\frac{F_1}{2} + 980\right) \times 15$$

$\Rightarrow$ $$F_1 = 1496.86 \text{ N} = 1.496 \text{ kN}$$

**Case-II**: When the mower is pulled




F.B.D.




In limiting case $N_B = 0$ and $\Sigma M_A = 0$

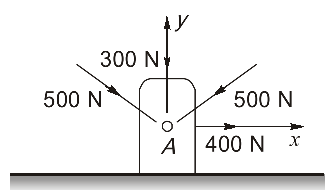
Computing $\Sigma M_A = 0$

$$F_2 \cos 30° \times (25-5) = (mg - F_2 \sin 30°) \times \sqrt{25^2 - (20)^2}$$

$$F_2 \times \frac{\sqrt{3}}{2} \times 20 = \left(980 - \frac{F_2}{2}\right) \times 15$$

$$F_2 = 592.25 \text{ N} = 0.592 \text{ kN}$$

1.4

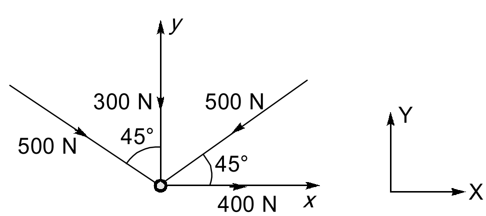



What are the orthogonal total force components in *x* and *y* directions of the force transmitted to pin A of a roof truss by the four members (above figure)

[2007 : 12 Marks]

**Solution:**

Here, angle between the forces acting is not given, so assuming inclination is 45° w.r.t. $x$ and y-axis




Considering the equilibrium of forces,

$$\Sigma F_x = 0$$

$$F_x = 400 - 500 \cos 45° + 500 \sin 45°$$

$$F_x = 400 \text{ N} (\rightarrow)$$

$$\Sigma F_y = 0$$

$$F_y = 300 + 500 \sin 45° + 500 \cos 45°$$

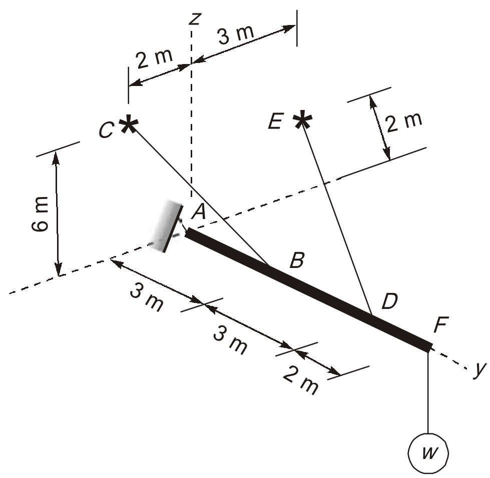
$$= 300 + 1000 \times \frac{1}{\sqrt{2}} = 1007.11 \text{ N} (\downarrow)$$

Hence, force transmitted to pin $A$ of a roof truss

in $x$-direction $F_x = 400\ \text{N}(\rightarrow)$

in $y$-direction $F_y = 1007.11\ \text{N}(\downarrow)$

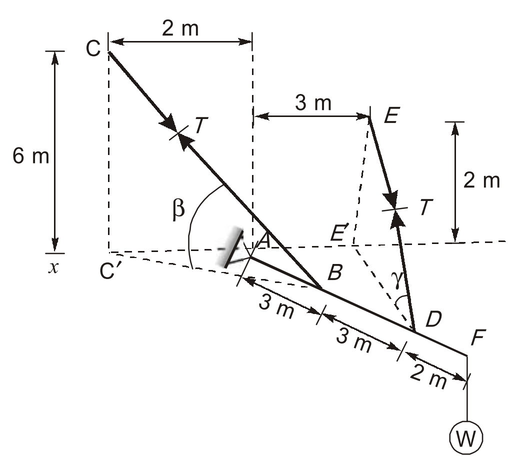
1.5




Cables $BC$ and $DE$ can hold a maximum tension of 280 kN before failure. Determine the maximum weight W that can be suspended from the end of the boom $ABDF$. (Above figure)

[2007 : 20 Marks]

Solution:




From the given figure $BC' = \sqrt{AB^2 + (AC')^2} = \sqrt{3^2 + 2^2} = \sqrt{13}$

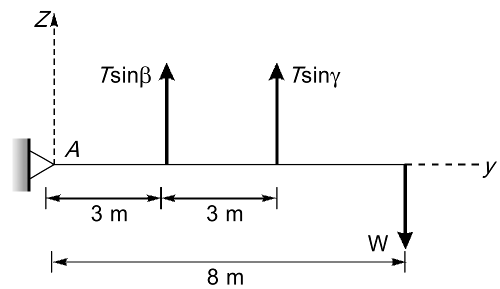
Hence, $\beta = \tan^{-1}\left(\dfrac{6}{\sqrt{13}}\right)$ $\left[\because \tan\beta = \left(\dfrac{CC'}{C'B}\right)\right]$

Also $DE' = \sqrt{AD^2 + (AE')^2} = \sqrt{6^2 + 3^2} = \sqrt{45}$

Hence, $\gamma = \tan^{-1}\left(\dfrac{2}{\sqrt{45}}\right)$ $\left[\because \tan\gamma = \left(\dfrac{EE'}{E'D}\right)\right]$

Now let the structure is loaded with the maximum weight W then the tension in both the cable will be equal to $T = 280$ kN

Now making the diagram in 2-D i.e. y-z plane. Force acting on the body will be




For equilibrium $\Sigma M_A = 0$

$\Rightarrow$ $W \times 8 = T\sin\beta \times 3 + T\sin\gamma \times 6$

$W \times 8 = 280\sin\beta \times 3 + 280\sin\gamma \times 6$ (writing values of β and γ)

$$\tan\beta = \frac{6}{\sqrt{13}}$$

$$\sin\beta = \frac{6}{\sqrt{(36)+13}} = \frac{6}{7}$$

$$\tan\gamma = \frac{2}{\sqrt{45}}$$

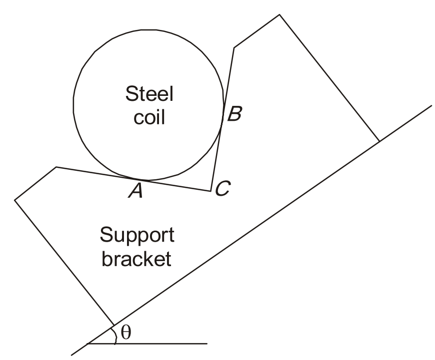
$$\sin\gamma = \frac{2}{\sqrt{45+4}} = \frac{2}{7}$$

$$W = 280 \times \frac{6}{7} \times 3 + 280 \times \frac{2}{7} \times 6$$

$$W = 150 \text{ kN}$$

1.6 A steel coil of diameter 2.5 m and weighing 700 kN has been supported on a bracket as shown. The supporting surfaces of the bracket are at right angles to each other at *C*. The bracket is fixed to an inclined slope and its angle of inclination with horizontal is **θ**. At what angle of inclination **θ**, will the contact force at B to one-half of the contact force at *A*?

Assume frictionless contact between the steel coil and the bracket. Note that only the end view is shown in the figure.




**[2002 : 12 Marks]**

**Solution:**

**Given:** Diameter of steel coil ($D$) = 2.5 m

Weight, (W) = 700 kN

By geometry, $\angle CDE = \angle CED = 45°$

$\phi + \theta = 45°$

$\angle DOG = 90 - \theta$

$\angle DOA = 45°$

$\Rightarrow$ $\angle AOG = 90 - \theta - 45 = 45 - \theta = \phi$

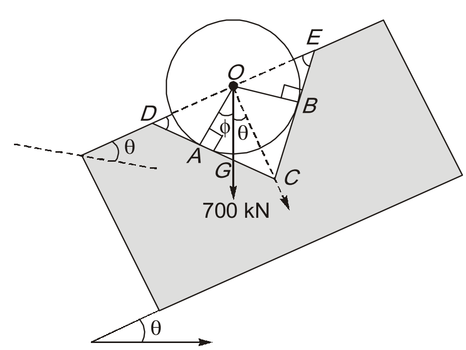
Considering the equilibrium at joint '0'

$\Sigma F_x = 0$

$W\cos\phi = N_A$ (i)

$\Sigma F_y = 0$

$W\sin\phi = N_B$ (ii)



Given,

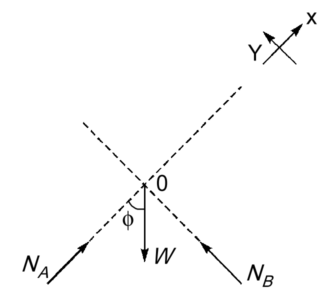
$$N_B = \frac{1}{2}N_A$$

$$700 \sin (45 - \theta) = \frac{700}{2}\cos(45 - \theta)$$

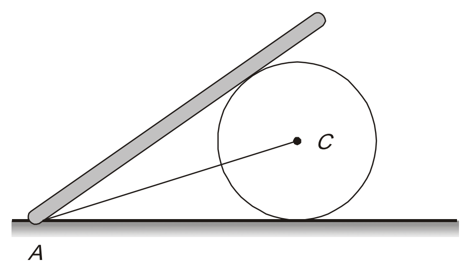
$$\Rightarrow \quad \tan(45 - \theta) = \frac{1}{2}$$

$$\Rightarrow \quad (45 - \theta) = 26.565°$$

$$\Rightarrow \quad \theta = 18.435°$$




1.7 A smooth right circular cylinder of radius 0.5 m rests on a horizontal plane and is kept from rolling by an inclined string AC of length 1.0 m. A prismatic bar of length 1.5 m and weight 125 N is hinged at point A and leans against the cylinder as shown in the figure below. Find the tension S that will be induced in the string AC.



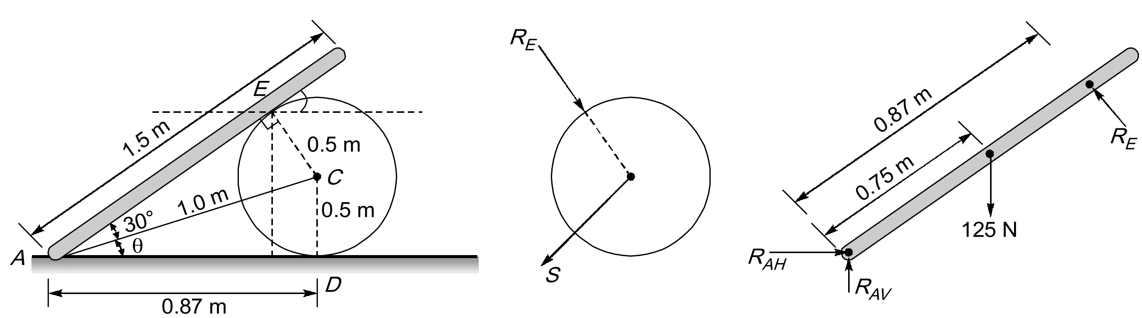

[2009 : 12 Marks]

Solution:

$$\sin\theta = \frac{0.5}{1}$$

$$\theta = 30°$$

FBD of roller:




$$\text{Length of } AD = \sqrt{1^2 - 0.5^2} = 0.866 \text{ m}$$

$$AD = AE = 0.866 \text{ m} \approx 0.87 \text{ m}$$

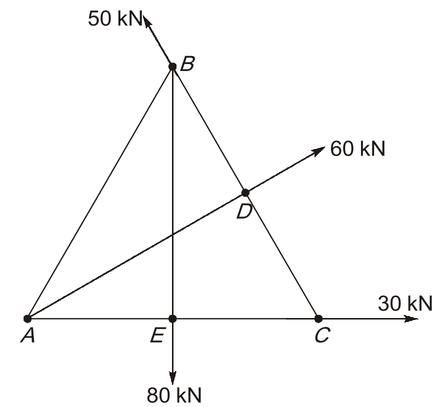
$\Sigma F_A = 0$ (i) $\quad R_E \times 0.87 = 125\,(0.75 \times \cos 60°)$

$$R_E = 54.13 \text{ N}$$

$\Sigma F_{cylinder} = 0; \quad -S\cos 30° + R_E \cos 30° = 0$

$$S = R_E = 54.13 \text{ N}$$

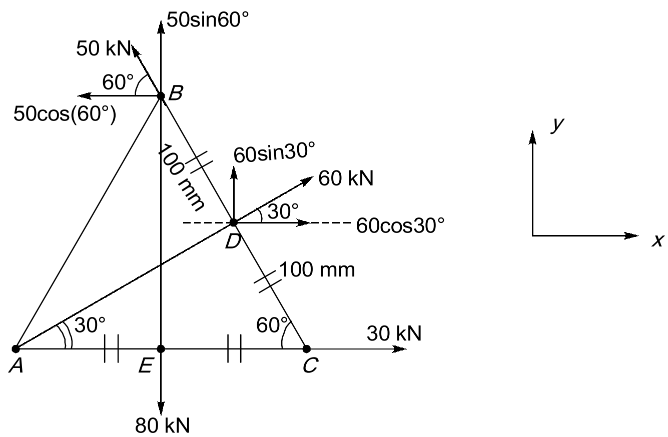
1.8 Find the resultant of the force system acting on a Lamina of equilateral triangle of sides 200 mm. Find also its direction and position w.r.t. point A as shown in the figure, D and E are mid points of BC and AC respectively.




[2013 : 12 Marks]

Solution:

Given is the following force system,




Given, triangle is equilateral with side 200 mm.

To find the resultant force:

$$\Sigma H = 30 + 60\cos 30° - 50\cos 60° = 56.96 \text{ kN } (\rightarrow)$$

$$\Sigma V = 50\sin 60° + 60\sin 30° - 80 = 6.7 \text{ kN } = 6.7 \text{ kN}(\downarrow)$$

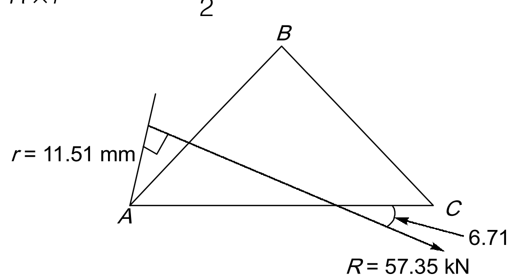
$\Rightarrow$ $$\text{Resultant (R)} = \sqrt{(\Sigma H)^2 + (\Sigma V)^2} = 57.35 \text{ kN}$$

$\Rightarrow$ Angle of resultant with horizontal = $\tan^{-1}\left(\dfrac{-6.7}{56.96}\right) = -6.71°$

To find distance of resultant from A

$\Rightarrow$ Taking moment about A $[\Sigma(M_A)] = 0$

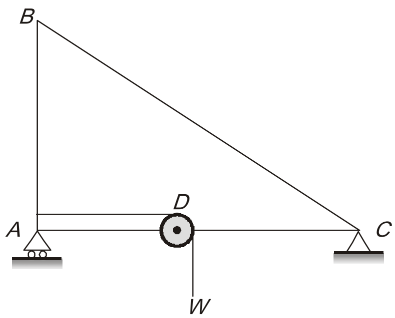
$\Rightarrow$ $$R \times \vec{r} = -80 \times \frac{200}{2} + 50 \times 200 \sin 60°$$




$$\vec{r} = \frac{660.25}{57.35} = 11.51 \text{mm}$$

Hence, the final resultant value and position diagram is shown in figure.

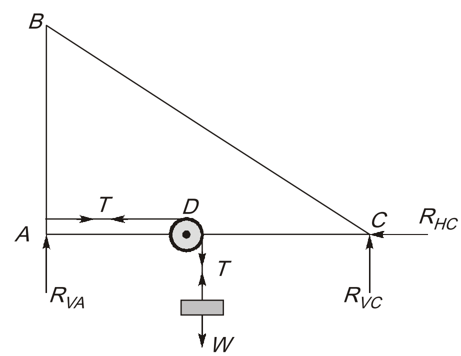
1.9 Draw free body diagram (FBD) of the whole system as shown in the figure. Neglecting self weight of its parts AB, BC, AC and D, draw FBDs of individual parts also. The wheel at D is frictionless.

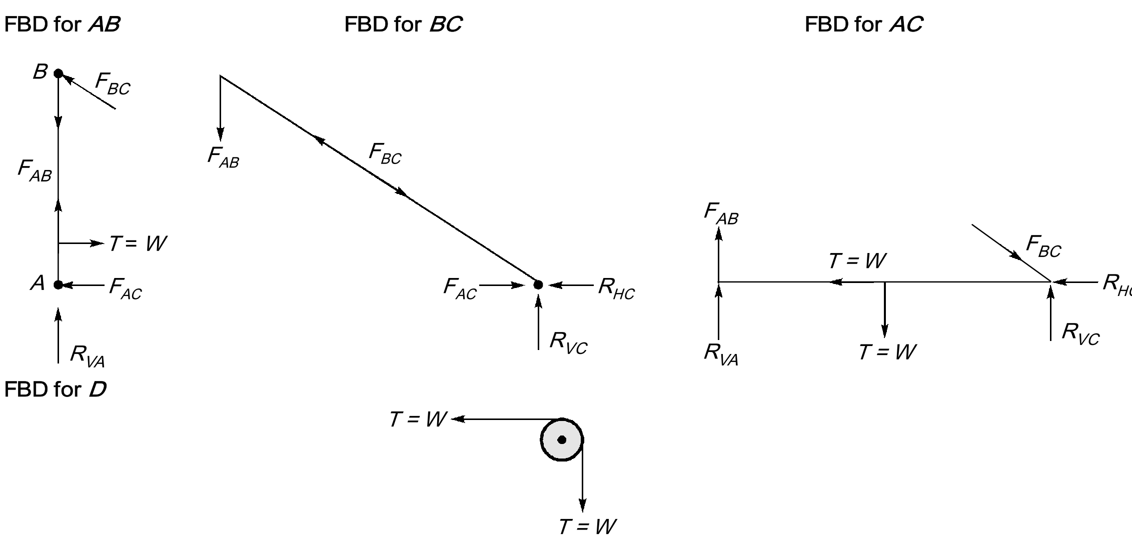



[2013 : 10 Marks]

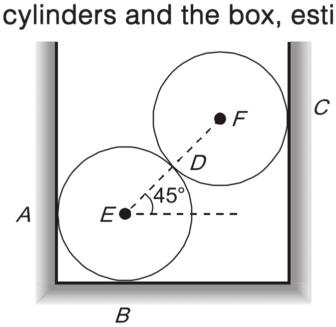
Solution:

FBD of whole structure




1.10 Two equal cylinders, $E$ and $F$, each weighing 1000 N are placed in a box as shown in the figure. Neglecting friction between the cylinders and the box, estimate reactions at $A$, $B$ and $C$.

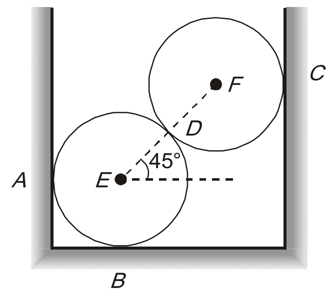



[2013 : 10 Marks]

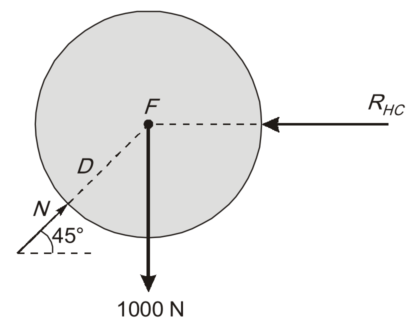
Solution:

Given two cylinders $E$ and $F$ each weighing 1000 N

Also, there is no friction between the cylinder and box.




FBD for cylinder $F$



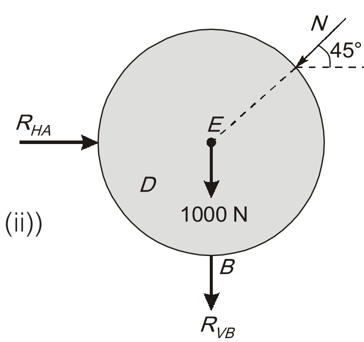

Hence, $N \cos 45° = R_{HC}$

$N \sin 45° = 1000$ ...(i)

$\Rightarrow$ $N = 1000\sqrt{2}$ N ...(ii)

From (i), $R_{HC} = \dfrac{1000\sqrt{2}}{\sqrt{2}} = 1000$ N

Free body diagram for cylinder $E$




For equilibrium, $R_{HA} = N\cos 45° = 1000\sqrt{2}\dfrac{1}{\sqrt{2}}$ (using (ii))

$= 1000$ N

$R_{VB} = 1000 + N\sin 45°$

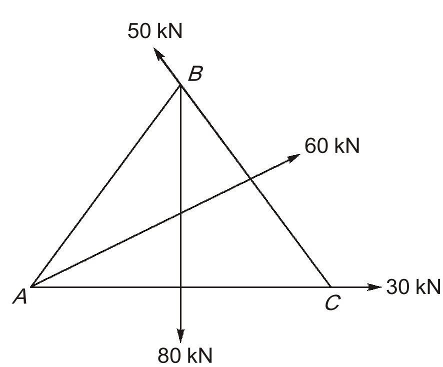
$= 1000 + 1000 + 1000\sqrt{2} \times \dfrac{1}{\sqrt{2}} = 2000$ N

Hence, Reaction at $A = R_{HA} = 1000$ N (Horizontal)

Reaction at $B = R_{VB} = 2000$ N (Vertical)

Reaction at $C = R_{HC} = 1000$ N (Horizontal)

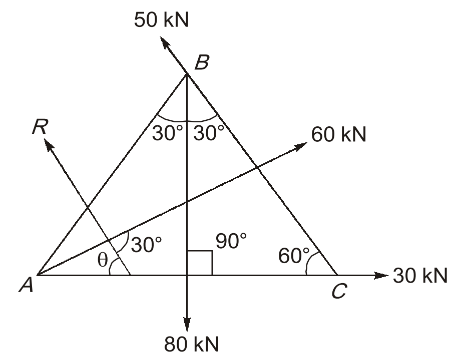
**1.11 Find the resultant of the force system acting on a lamina of equilateral triangle of sides 200 mm shown in figure. Also find the direction and position with respect to *A*.**




[2014 : 10 Marks]

Solution:

Considering equilibrium of forces acting on lamina




$$\Sigma F_H = 0$$

$$R_x + 30 + 60\cos 30° + 50\cos 120° = 0$$

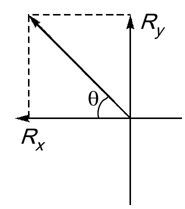
$\Rightarrow$ $R_x + 56.96 = 0$

$\Rightarrow$ $R_x = -56.96$ kN

$$\Sigma F_V = 0$$

and $R_y - 80 + 60\sin 30 + 50\sin 120 = 0$

$\Rightarrow$ $R_y = 6.698$ kN




$\Rightarrow$ Resultant, $R = \sqrt{R_x^2 + R_y^2} = \sqrt{(56.96)^2 + (6.698)^2} = 57.35$ kN

Direction, $\tan\theta = \dfrac{R_y}{R_x} = \dfrac{6.698}{56.96} = 0.1175$

$\Rightarrow$ $\theta = 6°42'$

Let $R$ is located $x$ distance from $A$

Moment about A of all forces must be zero

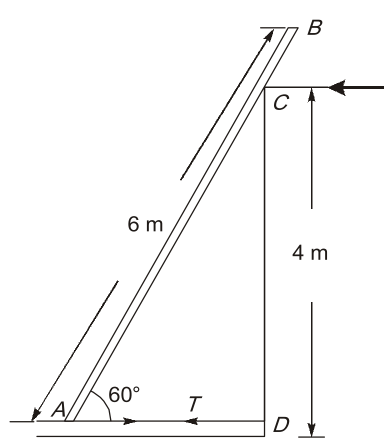
$\therefore$ $\Sigma M_A = 0$

$\Rightarrow$ $50 \times 200\sin 60 - 80 \times 200\cos 60 + 57.35 \times x \sin 6°42 = 0$

$\Rightarrow$ $50 \times 200\sin 60 - 80 \times 200\cos 60 + 57.35 \times x \sin 6°42' = 0$

$\Rightarrow$ $x = 98.65$ mm (Left of point A)

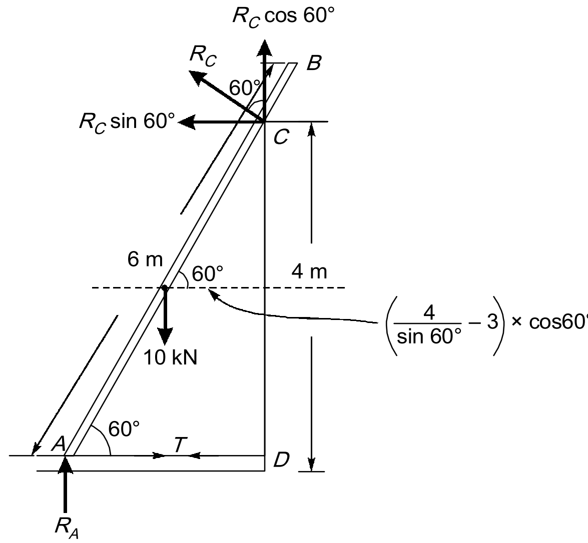
1.12 A rod AB 6 m long is held against sliding by a string AD. The rod weighs 10 kN. Determine the tension is the string AD assuming that all surfaces are smooth.




[2015 : 10 Marks]

Solution:

Considering the equilibiurm of forces acting on string $AD$.




$$\Sigma F_V = 0$$

$\Rightarrow$ $$R_A + R_C \cos 60° = 10 \quad ...(i)$$

$$\Sigma F_H = 0$$

$\Rightarrow$ $$R_C \sin 60° = T \quad ...(ii)$$

$$\Sigma M_C = 0$$

$\Rightarrow$ $$T \times 4 + 10 \times \left(\frac{4}{\sin 60°} - 3\right) \cos 60° - R_A \times \frac{4}{\tan 60°} = 0$$

$\Rightarrow$ $$4T + 8.09 - 2.13 R_A = 0 \quad ...(iii)$$

Using equation (i) and (ii),

$$R_A = 10 - R_C \cos 60°$$

$$= 10 - \frac{T}{\sin 60°} \cos 60°$$

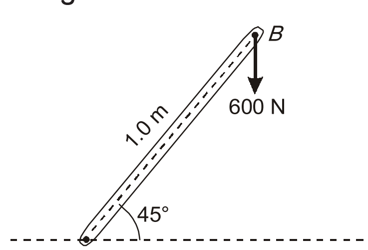
$$R_A = 10 - 0.5773T$$

Put value of $R_A$ in equation (iii)

$$4T + 8.09 - 2.31\,(10 - 0.5773T) = 0$$

$\Rightarrow$ $$T = 2.81 \text{ kN}$$

1.13 A lever is loaded as shown in the figure.




(i) Calculate the moment of force at Point A.

(ii) Calculate the amount of horizontal force to be applied at B to produce the same amount of moment of force as calculated above.

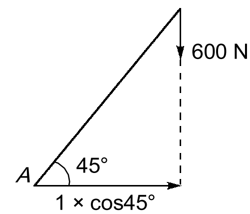
(iii) Calculate smaller amount of force to be applied at B, to produce the same amount of moment of force as calculated in part (i).

(iv) Calculate the distance of point on lever where 1.20 kN vertical force to be applied to produce same amount of moment of force as calculated in part (i).

[2017 : 10 Marks]

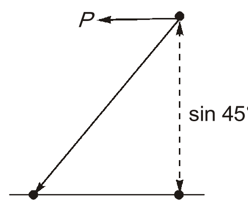
Solution:

(i) Moment of force at $A$,



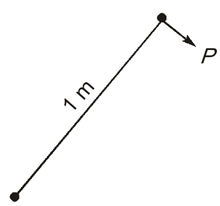

$$M_A = 1 \times \cos 45 \times 600 = 424.26 \text{ N-m}$$

(ii) Horizontal force at B that can produce moment = 424.26 N-m



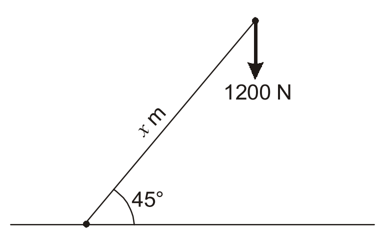

$$1 \times \sin 45 \times P = 424.26$$
$$P = 600 \text{ N}$$

(iii) Smallest force will generate the equivalent moment when it is applied perpendicular to rod.



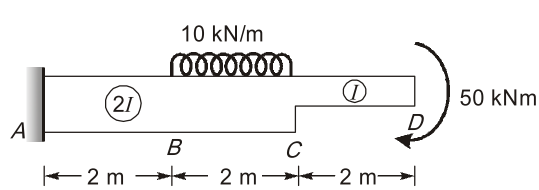

So, $$1 \times P = 424.26$$
$$P = 424.26 \text{ N}$$

(iv) Distance of point on lever



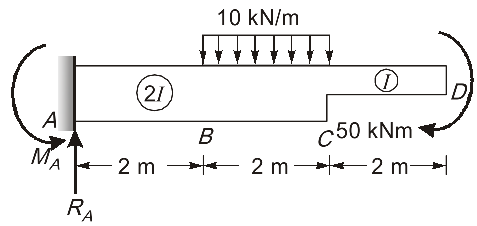

So, $$x \times \cos 45° \times 1200 = 424.26$$
$$x = 0.5 \text{ m}$$

1.14 A cantilever beam $ABCD$, as shown in the figure below, is carrying a uniformly distributed load of 10 kN/m between $B$ and C and a clockwise moment of 50 kN-m at free end $D$. Draw the free body diagram for $A$, $D$ and for the member BC only.




[2024 : 10 Marks]

Solution:

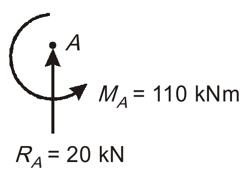



Let reactive moment induced at $A$ is $M_A$ and vertical reaction developed at $A$ is $R_A$.

$$\Sigma\text{Moments at } A = 0$$

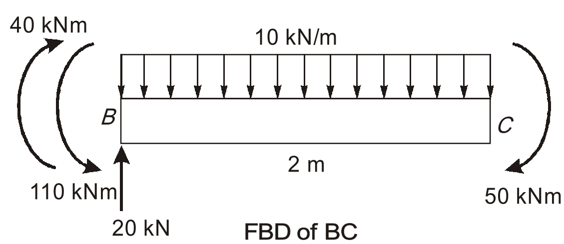
$\Rightarrow$
$$M_A = 10 \times 2 \times 3 + 50 = 110 \text{ kNm (ACW)}$$

Also,
$$R_A = 10 \times 2 = 20 \text{ kN}$$




FBD of joint $A$


FBD of free end $D$



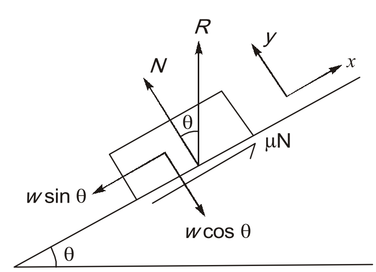

FBD of BC

## 2. Friction

2.1 Explain angle of friction and angle of repose.

[2006 : 3 Marks]

Solution:




**Angle of friction:** Angle made by the resultant of normal reaction and limiting frictional force with normal reaction is called angle of friction. It is denoted by '$\phi$'.

**Angle of Repose:** The minimum angle of plane at which the body placed on it starts to slide due to its own weight is called angle of repose. It is denoted by '$\theta$'.

Relation between angle of friction and angle of repose.

Consider the equilibrium equation in $x$ and $y$-direction when object about to slide.

$$\Sigma F_x = 0$$

$$\mu N - w\sin\theta = 0$$

$$N = \frac{w}{\mu}\sin\theta \qquad \text{...(i)}$$

$$\Sigma F_y = 0$$

$$N - w\cos\theta = 0$$

$$N = w\cos\theta \quad ...(ii)$$

From (i) and (ii) $\mu = \tan\theta$ ...(iii)

and from definition of angle of friction

$$\tan\phi = \frac{\mu w\cos\theta}{w\cos\theta} = \mu \quad ...(iv)$$

From (iii) and (iv) $\tan\phi = \tan\theta \Rightarrow \phi = \theta$

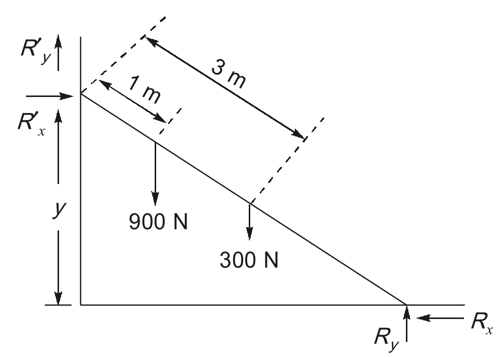
2.2 A ladder is 6 m long and is supported by a horizontal floor and vertical wall. The coefficient of friction between the floor and the ladder is 0.4 and between the wall and the ladder is 0.2. The weight of the ladder is 300 N acting through its centre. The ladder also supports a vertical load of 900 N at a distance of 1 m from the contact point of the ladder with the wall.

Determine the least value of 'α' at which the ladder may be placed without slipping. Determine the reaction at that stage.

[2006 : 9 Marks]

Solution:

Considering F.B.D. of ladder




$\Sigma F_y = 0$

$R_y + R_y' = 1200$ N (i)

$\Sigma F_x = 0$

Also,

$R_x' = R_x$ (ii)

$R_x = \mu R_y;\ \mu = 0.4$ (iii)

$R_y' = \mu' R_x';\ \mu' = 0.2$ (iv)

From equation (ii), (iii) and (iv)

$$\frac{R'_y}{\mu'} = \mu R_y$$

$$R'_y = \mu' \mu R_y$$

$$R'_y = 0.4 \times 0.2 \times R_y$$

$$R'_y = 0.08\ R_y$$

From equation (i)

$$0.08R_y + R_y = 1200$$

$$1.08R_y = 1200$$

$$\Rightarrow \quad R_y = 1111.11 \text{ N}$$

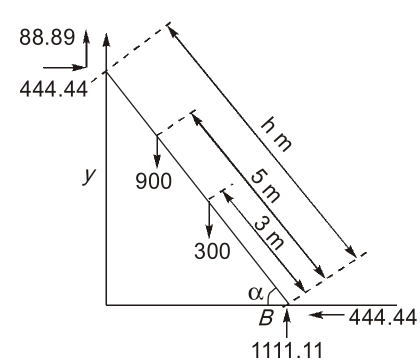
$$R'_y = 1200 - 1111.11 \text{ kN} = 88.89 \text{ N}$$

$R_y = 1111.11$ N

$R'_y = 88.89$ N

$R_x = 0.4 \times 1111.11 = 444.44$ N

$$R'_x = \frac{88.89}{0.2} = 444.44 \text{ N}$$




Now, calculation of least 'α'

From figure,

$$\Rightarrow \quad \sin\alpha = \frac{y}{h}$$

$$\Rightarrow \quad y = h\sin\alpha$$

$$\Sigma M_B = 0$$

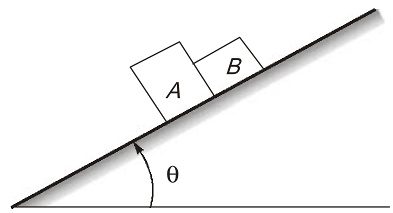
$$\Rightarrow \quad 444.44 \times 6\sin\alpha + 88.89 \times 6\cos\alpha - 900 \times 5\cos\alpha - 300 \times 3\cos\alpha = 0$$

$$\Rightarrow \quad 2666.64\sin\alpha - 4866.66\cos\alpha = 0$$

$$\Rightarrow \quad \tan\alpha = \frac{4866.66}{2666.64}$$

$$\Rightarrow \quad \alpha = 61.28°$$

2.3

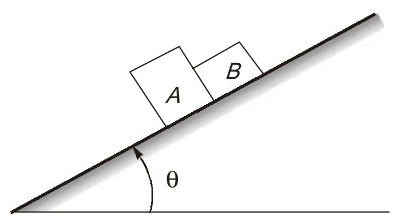



**Bodies A and B weigh 500 N and 300 N respectively. The platform on which they are placed is raised from the horizontal position to an angle θ. What is the maximum angle that can be reached before the bodes slip down the inclined? Use value of $\mu_s$ = 0.20 for all contact surfaces. (Above figure)**

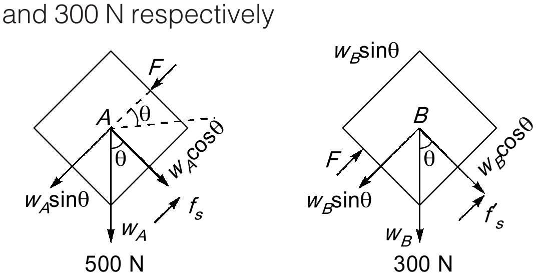
**[2007 : 20 Marks]**

**Solution:**

Given:




Bodies *A* and *B* weigh 500 N and 300 N respectively




Assuming no friction acts between *A* and *B* as no relative movement takes place between them.

For Block *A*

$$W_A\sin\theta + F - f_s = 0$$

$$500\sin\theta + F - 500\cos\theta \times 0.2 = 0 \qquad (f_s = \mu_s \cdot w_A\cos\theta) \qquad \text{...(i)}$$

for Block *B*

$$W_B\sin\theta - F - f'_s = 0 \qquad (f'_s = \mu_s \cdot w_B\cos\theta)$$

$$300\sin\theta - F - 300\cos\theta + 0.2 = 0 \qquad \text{...(ii)}$$

Adding equation (i) and (ii) we get

$$800\sin\theta - 800\cos\theta \times 0.2 = 0$$

$$800\sin\theta - 160\cos\theta = 0$$

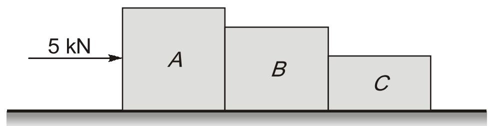
$$800\tan\theta = 160$$

$$\tan\theta = \frac{160}{800}$$

$$\theta = 11.31°$$

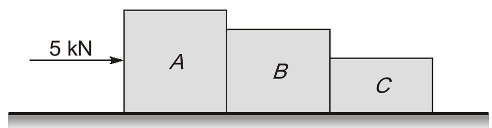
Hence, the maximum angle that can be reached before the bodies slip down the inclinded.

**2.4 Three bodies A, B and C of masses 50 kg, 30 kg and 20 kg respectively are under a force of 5 kN as shown. Calculate the force transferred between A and B, B and C. Assume all the frictionless surfaces.**




[2012 : 12 Marks]

Solution:




Given: $m_A = 50$ kg, $m_B = 30$ kg, $m_C = 20$ kg

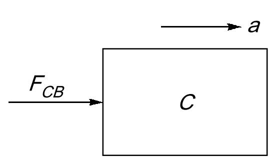
After action of 5 KN, all three blocks will move with same acceleration so, considering $A$, $B$, $C$ together in a system and applying Newton's 2nd law

$$\Sigma F = (m_A + m_B + m_C) \,.\, a$$

$$5 \times 10^3 = (50 + 30 + 20) \times a$$

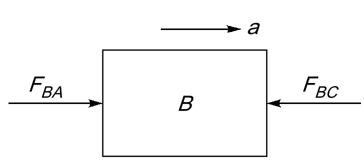
$$a = 50 \text{ m/s}^2$$

Now, equation of block $C$




$$F_{CB} = m_C a = 20 \times 50 = 1000 \text{ N}$$

Now, equation of block $B$




$$\Sigma F = m_B a$$

$$(F_{BA} - F_{CB}) = m_B \,.\, a$$

$$F_{BA} = m_B \,.\, a + F_{CB} \qquad [F_{BC} = F_{CB} = 1000 \text{ N}]$$

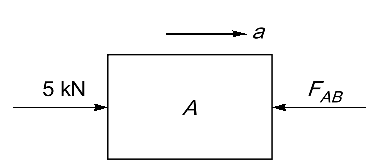
$$= 30 \times 50 + 1000 = 2500 \text{ N}$$

Now, equation of block $A$

$$\Sigma F = ma$$

$$5 \times 10^3 - F_{AB} = m_B \,.\, a = 50 \times 50 = 2500$$

$$\therefore \quad F_{AB} = 2500 \text{ N}$$

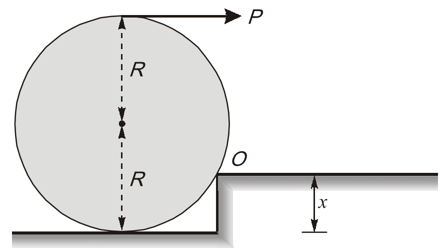



Hence, contact forces transferred between

$A$ and $B$, $F_{AB} = 2500$ N

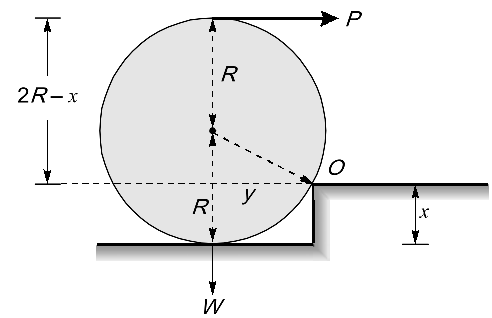
$B$ and $C$, $F_{BC} = 1000$ N

2.5 What is the maximum height x of a step in the figure so that a force P will roll a cylinder of radius R weighing W over the step with no slippage at all. The coefficient static friction is $\mu_s$.




[2013 : 10 Marks]

Solution:




Given, Coefficient of static friction = $\mu_s$
Weight of cylinder = W

For no slipage

$$P \le \mu_s W$$

or
$$\frac{W}{P} \ge \frac{1}{\mu_s} \quad \text{...(i)}$$

Since there is no slippage in the limiting case clockwise moment about "O" of weight "W" should be equal to anticlockwise moment of force "P" about O

i.e.
$$\Sigma M_O = O$$

$$P \times (2R - x) = W \times y$$

$$\left( y = \sqrt{R^2 - (R-x)^2} \right)$$

$$P \times (2R - x) = W \times \sqrt{2Rx - x^2}$$

$$P^2 (2R - x)^2 = W^2 \times (2R - x)$$

$$(2R - x)\left[\frac{P^2}{w^2}(2R - x) - x\right] = 0$$

$$x \ne 2R$$

Hence,
$$\frac{P^2}{W^2}(2R - x) - x = 0$$

$$x = \frac{2RP^2}{P^2 + W^2}$$

$$\Rightarrow \quad x = \frac{2R}{\left(1 + \frac{W^2}{P^2}\right)} \quad \text{...(ii)}$$

Now $x$ will be maximum when $\frac{W}{P}$ is minimum

∴ from equation (i)

$$\frac{W}{P} = \frac{1}{\mu_s}$$

from equation (ii)

Hence, putting
$$\frac{W}{P} = \frac{1}{\mu_s}$$

$$x = \frac{2R\mu_s^2}{1 + \mu_s^2}$$