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Force systems and its resultants



PREVIOUS YEAR QUESTION (2024 PATTERN)

5. Resolution and Composition of Forces

- Find the resolve components of the force 300 N acting along the axis u and v as shown in Fig. 2a. [Apr 2025]

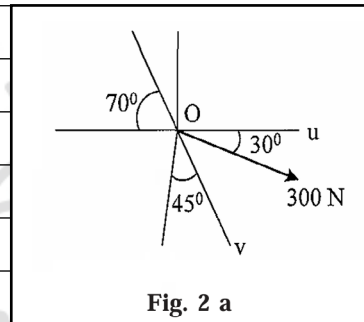


Fig. 2 a

6. Resultant of Concurrent Force System

- Find magnitude and direction of the resultant force with respect to origin 'O' for concurrent force system shown in Fig. 2a. [Nov 2024]

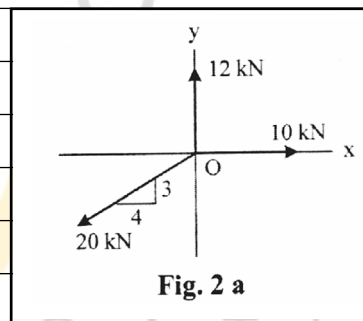


Fig. 2 a

- Determine the magnitude F and angle θ of force F as shown in Fig. 2b so that the resultant of the three forces acting on the point O is zero. [Apr 2025]

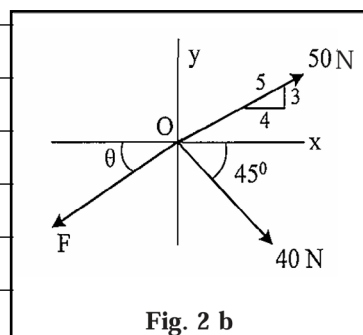
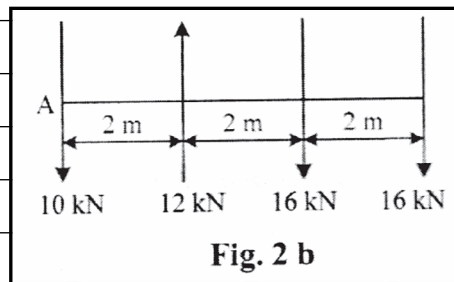


Fig. 2 b

9. Resultant of Parallel Force System

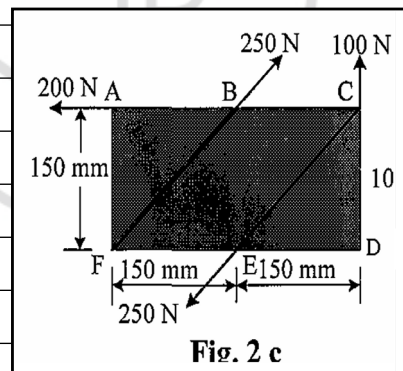
- Determine magnitude, direction and point of application of the resultant with reference to point A for the force system as shown in Fig. 2b.

[Nov 2024]



- A 150×300 mm plate is subjected to four forces as shown in Fig. 2c. Determine the resultant of the four forces with respect to point F.

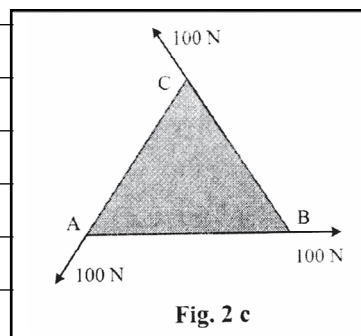
[Apr 2025]



10. Couple and Resultant of General Force System

- Determine the magnitude and direction of resultant with reference to point A for the force system shown in Fig. 2c if side of equilateral triangle is 1 m.

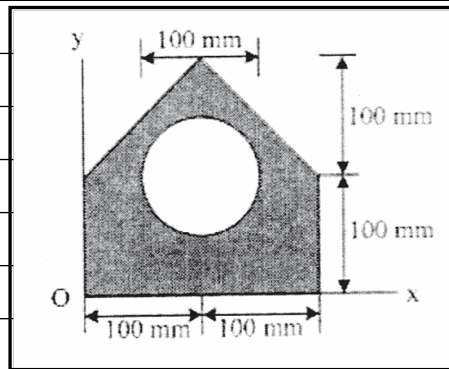
[Nov 2024]



11. Centroid of Basic Figures

- Determine the y-coordinate of centroid of the shaded area as shown in Fig. 2d.

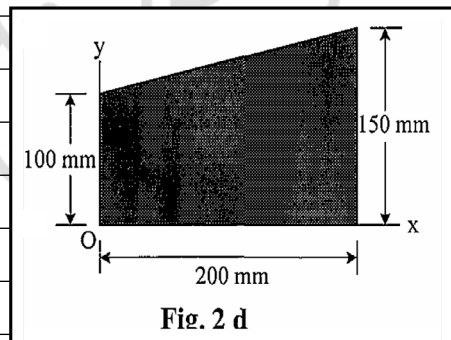
[Nov 2024]



12. Centroid of Composite Figure

- Locate the centroid of the shaded plane lamina with respect to origin O as shown in Fig. 2d.

[Apr 2025]



◀ Introduction ▶

Engineering Mechanics is a branch of applied science that deals with the effect of forces on bodies, whether the bodies are at rest or in motion. It provides the foundation for understanding how machines, structures, and mechanical systems behave under various conditions of loading.

Mechanics aims to answer questions like:

- Why does a bridge remain stable under heavy load?
- How much force is required to lift an object?
- What happens when a car suddenly stops or turns?

In simple words, Engineering Mechanics helps us predict the motion or equilibrium of a body when forces act on it. It is based on physical laws and mathematical logic, primarily Newton's Laws of Motion.

Mechanics is not only theoretical; it is deeply practical. Every field of engineering civil, mechanical, electrical, or computer simulation uses mechanics concepts to analyze and design systems that can perform safely and efficiently.

(a) What is a Body?

- A body in mechanics means any object (solid, rigid, or flexible) whose motion or equilibrium we study.
- It can be a small part like a bolt, or a large system like an aircraft.

(b) Assumptions in Mechanics

- The body is considered rigid (it does not deform under applied forces).
- The effect of air resistance and friction may be neglected unless necessary.
- The forces acting are represented by vectors, having both magnitude and direction.

(c) Branches of Mechanics

- Mechanics is broadly divided into two main parts:

1. Statics:

Statics deals with bodies that are at rest under the action of forces.

In statics, the sum of all forces and moments on the body is zero.

Example – Calculating the support reactions of a beam, the tension in a rope, or the stability of a ladder.

2. Dynamics:

- Dynamics deals with bodies in motion. It is further divided into:

Kinematics: The study of motion without considering the forces that cause it (only displacement, velocity, and acceleration are studied).

Kinetics: The study of motion along with the forces and torques that cause it.

(d) Subdivisions Based on Nature of Matter

Rigid Body Mechanics – Assumes bodies do not deform.

Deformable Body Mechanics – Considers deformation and elasticity.

Fluid Mechanics – Studies liquids and gases in motion or rest.

(e) Scope of Engineering Mechanics

Engineering Mechanics connects theory with application.

It is used to:

- Design stable and safe structures.
- Analyze machine components and their motion.
- Understand dynamic systems like vehicles and robots.
- Simulate real-world physical systems using software (in fields like robotics, computer graphics, and game development).

Formula

- At the introductory level, the most fundamental relation in mechanics is Newton's Second Law of Motion:

$$F = m \times a$$

Where,

F = Force (in Newtons)

m = Mass (in kilograms)

a = Acceleration (in m/s^2)

This equation forms the foundation of both statics and dynamics.

In Statics,

$a=0$, so the net force is zero (the body is in equilibrium).

In Dynamics,

$a \neq 0$, meaning forces produce acceleration or motion.

Solved Example

Example : A car of mass 800 kg accelerates at 2.5 m/s^2 . Find the force required.

Solution:

Given,

$m = 800 \text{ kg}$

$a = 2.5 \text{ m/s}^2$

Using

$$F = m \times a$$

$$F = 800 \times 2.5 = 2000\text{N}$$

Hence, the force required is 2000 Newtons.

Common Mistakes

1. Confusing mass and weight:

- Mass is the amount of matter (kg).

- Weight is the gravitational force acting on the mass (N).

Relation:

$$W = m \times g,$$

where $g = 9.81 \text{ m/s}^2$.

Ignoring direction:

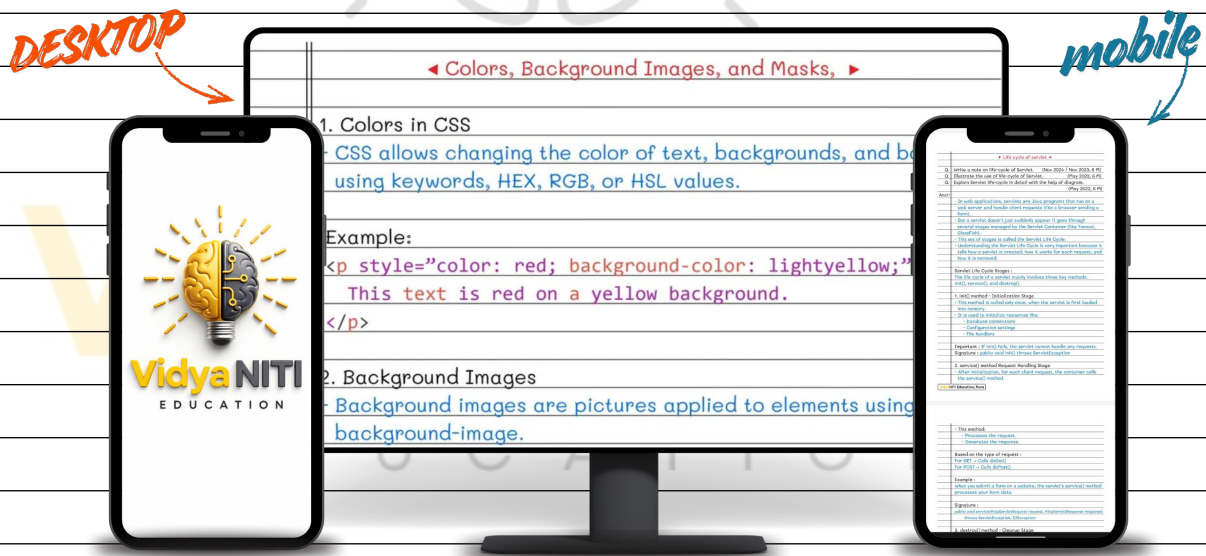
- Every force has both magnitude and direction; it must be treated as a vector.

Forgetting units:

Always express quantities in SI units N, m, kg, s.

Thinking mechanics is purely mathematical:

Mechanics is about reasoning physically why the body moves or stays still and then representing it mathematically.

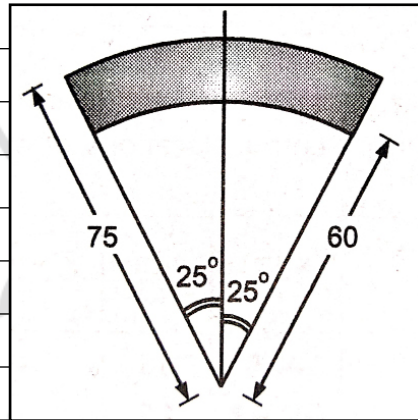


[CLICK HERE](#)

◀ Centroid of Composite Figure ▶

Solved problems

Example 1: Locate the centroid of the shaded area (all dimensions are in mm).



Solution:

(a) For the larger sector:

$$A_1 = r^2 \alpha = (75)^2 \times (0.436) = 2454.37 \text{ mm}^2$$

$$y_1 = \frac{2rs \sin \alpha}{3\alpha} = \frac{2 \times 75 \times \sin 25^\circ}{3 \times (0.436)} = 48.465 \text{ mm}$$

(b) For the smaller sector (to be subtracted):

$$A_2 = r^2 \alpha = (60)^2 \times (0.436) = 1569.6 \text{ mm}^2$$

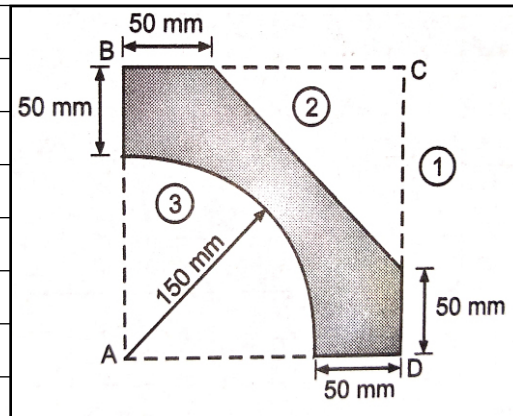
$$y_2 = \frac{2rs \sin \alpha}{3\alpha} = \frac{2 \times 60 \times \sin 25^\circ}{3 \times (0.436)} = 38.77 \text{ mm}$$

Now, the position of centroid y of the shaded area:

$$\bar{y} = \frac{A_1 y_1 - A_2 y_2}{A_1 - A_2} = \frac{(2454.37)(48.465) - (1569.6)(38.77)}{2454.37 - 1569.6} = 65.66 \text{ mm}$$

Final Answer: Centroid = (0, 65.66)

Example 2: Locate the centroid of the shaded lamina as shown in Figure



Solution:

We divide the figure into 3 parts:

Sr. No.	Area (A)	$\bar{x}$ (from A)	$\bar{y}$ (from A)	A_x	A_y
1	200×200	100	100	4×10^6	4×10^6
2	150×150	150	150	-1.69×10^6	-1.69×10^6
3	$\frac{1}{4}\pi(150)^2$	$\frac{4 \times 150}{3\pi}$	Same as $\bar{x}$	-1.12×10^6	-1.12×10^6

Summation:

$$\sum A = 11078.54$$

$$\sum A_x = 1.19 \times 10^6$$

$$\sum A_y = 1.19 \times 10^6$$

Coordinates of Centroid:

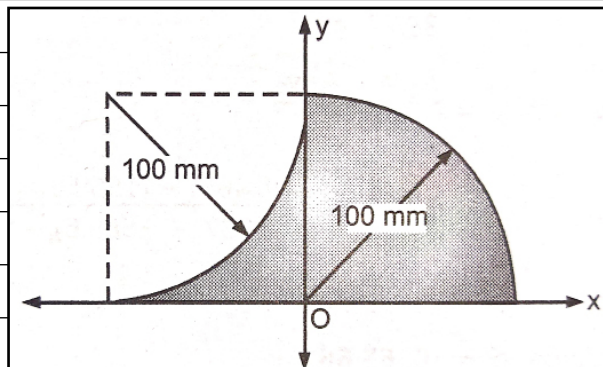
$$\bar{x} = \frac{\sum A_x}{\sum A} = \frac{1.19 \times 10^6}{11078.54} = 107.41 \text{ mm from A}$$

$$\bar{y} = \frac{\sum A_y}{\sum A} = \frac{1.19 \times 10^6}{11078.54} = 107.41 \text{ mm from A}$$

Final Answer:

Centroid = (107.41, 107.41)

Example 3: Locate the centroid of the shaded area with respect to the given axis



Solution:

We divide the area into 3 parts:

Sr. No.	Area (A)	$\bar{x}$	$\bar{y}$	A_x	A_y
1	$\frac{\pi r^2}{4}$	$\frac{4r}{3\pi}$	$\frac{4r}{3\pi}$	$0.3333 r^2$	$0.3333 r^2$
2	r^2	$-\frac{1}{2}$	$-\frac{1}{2}$	$-0.5 r^2$	$0.5 r^2$
3	$\frac{\pi r^2}{4}$	$-\frac{4r}{3\pi}$	$-\frac{4r}{3\pi}$	$+0.4515 r^2$	$-0.4515 r^2$

Summation:

$$\sum A = r^2$$

$$\sum A x = +0.2848 r^2$$

$$\sum A y = +0.3818 r^2$$

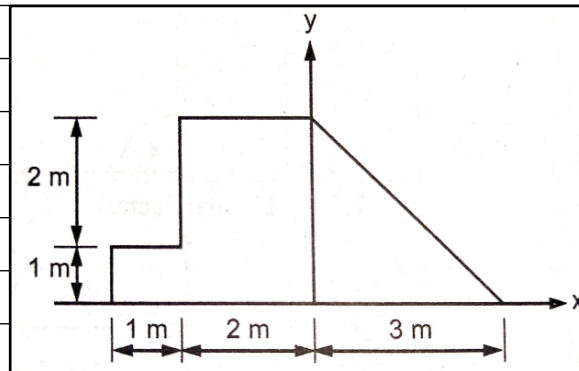
Coordinates of Centroid:

$$\bar{x} = \frac{\sum Ax}{\sum A} = \frac{0.2848 r^2}{r^2} = 0.2848r = 28.48 \text{ mm}$$

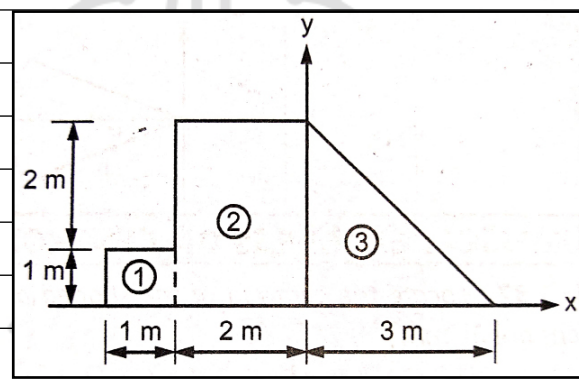
$$\bar{y} = \frac{\sum Ay}{\sum A} = \frac{0.3818 r^2}{r^2} = 0.3818r = 38.18 \text{ mm}$$

Final Answer: Centroid = (28.48, 38.18)

Example 4: Locate the centroid of the plate as shown in Figure



Solution:



- The composite area is divided into 3 elementary shapes as shown in Figure

Centroid Data Table:

Part	Area A (m ²)	$\bar{x}$ (m)	$\bar{y}$ (m)	$x\bar{A}$ (m ³)	$y\bar{A}$ (m ³)
1	1.0	-2.5	0.5	-2.5	0.5
2	2.0	-1.0	1.5	-2.0	3.0
3	4.5	0.0	1.0	0.0	4.5
Total	7.5			-4.5	8.0

Coordinates of Centroid:

$$\bar{x} = \frac{\sum x\bar{A}}{\sum A} = \frac{-4}{11.5} = -0.3478 \text{ m}$$

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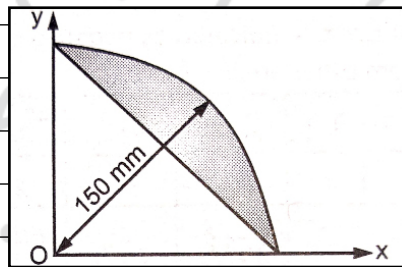
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$$\bar{y} = \frac{\sum yA}{\sum A} = \frac{14}{11.5} = 1.2174 \text{ m}$$

Final Answer: Centroid = (-0.3478, 1.2174)

Example 5: Determine the position of the centroid of the shaded area as shown in Figure with respect to origin O.



Solution:

The composite area is divided into:

- A quarter circle
- A triangle (subtracted from the circle, so its area is taken as negative)

Centroid Data Table:

Part	Area A (mm ²)	$\bar{x}$ (mm)	$\bar{y}$ (mm)	$\bar{x} \cdot A$ (mm ³)	$\bar{y} \cdot A$ (mm ³)
Quarter Circle	$\pi r^2/4 = 17671.46$	$4r/3\pi = 63.66$	$4r/3\pi = 63.66$	1125×10^3	1125×10^3
Triangle	-11250	$150/3 = 50$	$150/3 = 50$	-562.5×10^3	-562.5×10^3
Total	6421.46			562.5×10^3	562.5×10^3

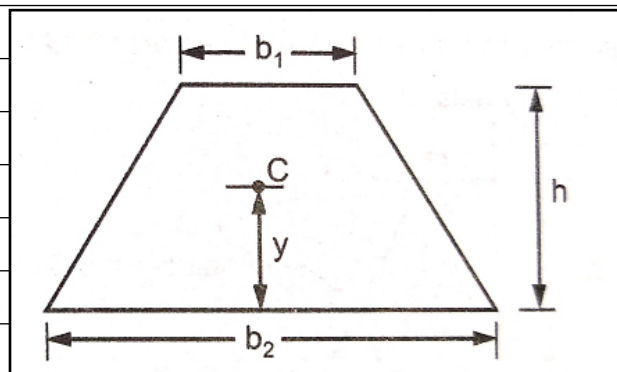
Coordinates of Centroid:

$$\bar{x} = \frac{\sum xA}{\sum A} = \frac{562.5 \times 10^3}{6421.46} = 87.59 \text{ mm}$$

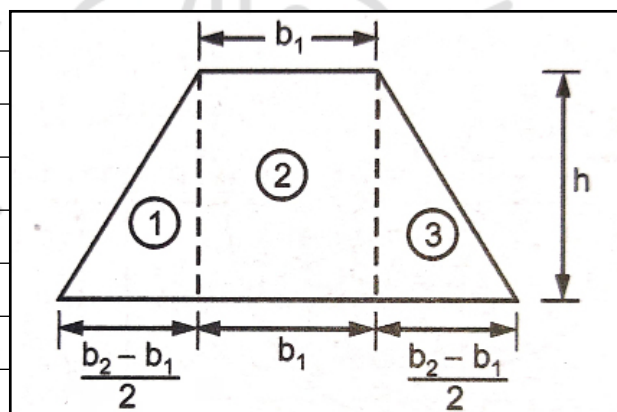
$$y = x = 87.59 \text{ mm}$$

Final Answer: Centroid = (87.59, 87.59)

Example 6: Determine the distance y to the centroid of the trapezoidal area in terms of the given dimensions in Figure



Solution:



The trapezoid is divided into:

- Two right-angled triangles (parts 1 and 3)
- One rectangle (part 2)

Centroid Data Table:

Part	Area A (unit ²)	$\bar{y}$ (unit)	$\bar{y} \cdot A$ (unit ³)
1 and 3	$(b_2 - b_1) \cdot h / 2$	$h / 3$	$(1/6) \cdot (b_2 - b_1) \cdot h^2$
2	$b_1 \cdot h$	$h / 2$	$(b_1 \cdot h^2) / 2$

Total Area:

$$\Sigma A = \left[\frac{(b_2 - b_1)}{2} \right] h + b_1 h = \frac{h}{2} (b_2 + b_1)$$

Total $\sum A y$:

$$\sum A y = \frac{h^2}{6}(b_2 - b_1) + \frac{b_1 h^2}{2} = \frac{h^2}{6}(b_2 - b_1 + 3b_1) = \frac{h^2}{6}(b_2 + 2b_1)$$

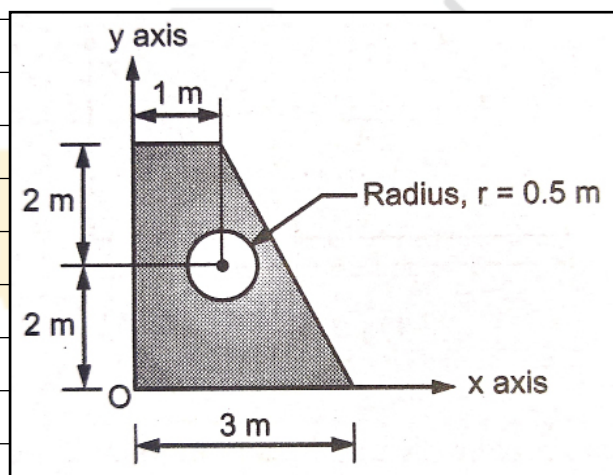
Coordinates of Centroid:

$$\bar{y} = \frac{\sum A y}{\sum A} = \frac{\frac{h^2}{6}(b_2 + 2b_1)}{\frac{h}{2}(b_2 + b_1)} = \frac{h(b_2 + 2b_1)}{3(b_2 + b_1)}$$

Final Answer:

$$\bar{y} = \frac{h(b_2 + 2b_1)}{3(b_2 + b_1)}$$

Example 7: Determine the position of the centroid of the shaded area as shown in Figure with respect to origin O.



Solution:

The composite area consists of:

- Rectangle
- Triangle
- A circular segment (subtracted)

Centroid Data Table:

Part	Area A (m ²)	$\bar{x}$ (m)	$\bar{y}$ (m)	$\bar{A} \cdot \bar{x}$ (m ³)	$\bar{A} \cdot \bar{y}$ (m ³)
Rectangle	$4 \times 1 = 4$	2	0.5	8	2
Triangle	$(1/2) \times 2 \times 2 = 2$	$2 + (2/3) = 2.667$	1.333	5.334	2.666
Circle	$-\pi/4 \times (0.5)^2 = -0.196$	0.5	$2 - (4r)/(3\pi) = 1.787$	-0.098	-0.35

Summation:

$$\sum A = 4 + 2 - 0.196 = 5.804 \text{ m}^2$$

$$\sum A \bar{x} = 7.8826 \text{ m}^3$$

$$\sum A \bar{y} = 7.2164 \text{ m}^3$$

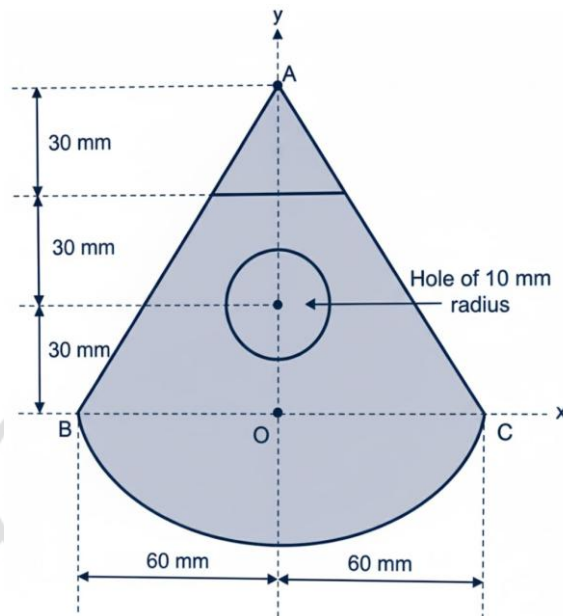
Coordinates of Centroid:

$$\bar{x} = \frac{\sum A \bar{x}}{\sum A} = \frac{7.8826}{5.804} = 1.358 \text{ m}$$

$$\bar{y} = \frac{\sum A \bar{y}}{\sum A} = \frac{7.2164}{5.804} = 1.243 \text{ m}$$

Final Answer: Centroid = (1.358 m, 1.243 m)

Example 4: If ABC represents sector of a circle, locate the centroid of shaded portion with reference to given 'x' and 'y' axes. (Dec. 03, 8 Marks)



Solution :

The given Fig. P. 5.8.23(b) is symmetrical about y-axis.

$\therefore$ x-coordinate of centroid,

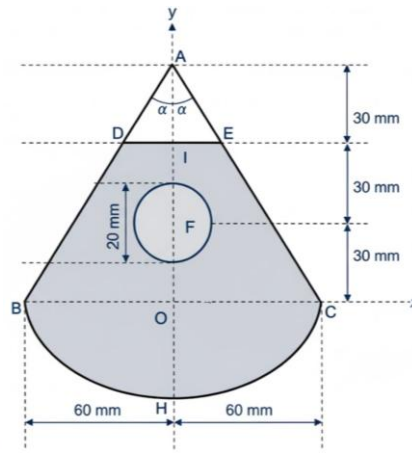
$$\bar{x} = 0$$

To find $\bar{y}$, divide the figure into 3 parts :

- ① Sector of a circle ABHC
- ② $\triangle ADE$ (to be removed)
- ③ Circle 'F' (to be removed)

From $\triangle AOB$,

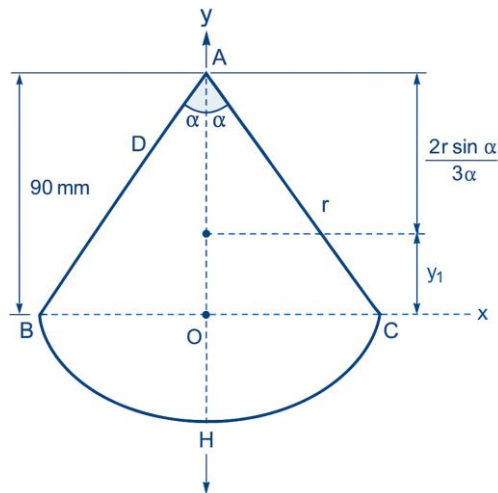
$$\tan \alpha = \frac{OB}{OA} = \frac{60}{90} \quad \therefore \alpha = 33.7^\circ$$



For $\triangle AGD$,

$$\tan \alpha = \frac{DI}{AI} = \frac{60}{90} \Rightarrow DI = 20 \text{ mm}$$

$$DE = DI + IE = 20 + 20 = 40 \text{ mm } (\because \triangle AID \text{ and } \triangle AIE \text{ are symmetric})$$



From $\triangle AOB$,

$$\cos \alpha = \frac{OA}{AB} \quad \cos 33.7^\circ = \frac{90}{AB}$$

$$\therefore AB = 108.18 \text{ mm}$$

Radius, $r = AB = 108.18 \text{ mm}$

$$\alpha = 33.7^\circ = 33.7^\circ \times \frac{\pi}{180^\circ} = 0.588 \text{ rad}$$

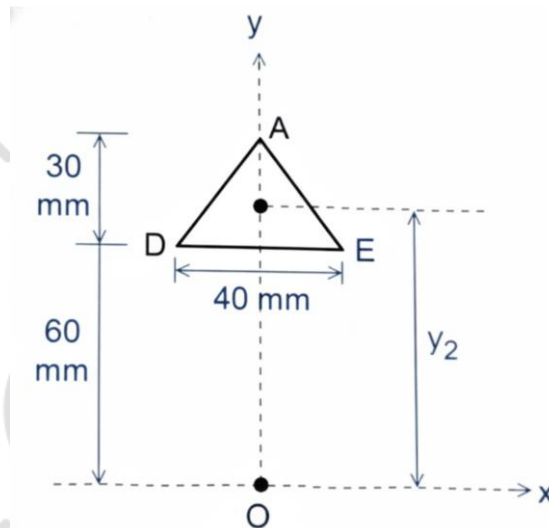
For ① Sector of a circle ABHC :

$$A_1 = \alpha r^2 = 0.588 \times 108.18^2 = 6881.31 \text{ mm}^2$$

$$y_1 = 90 - \frac{2rs\sin\alpha}{3\alpha}$$

$$= 90 - \frac{2 \times 108.18 \times \sin 33.7^\circ}{3 \times 0.588} = 21.95 \text{ mm}$$

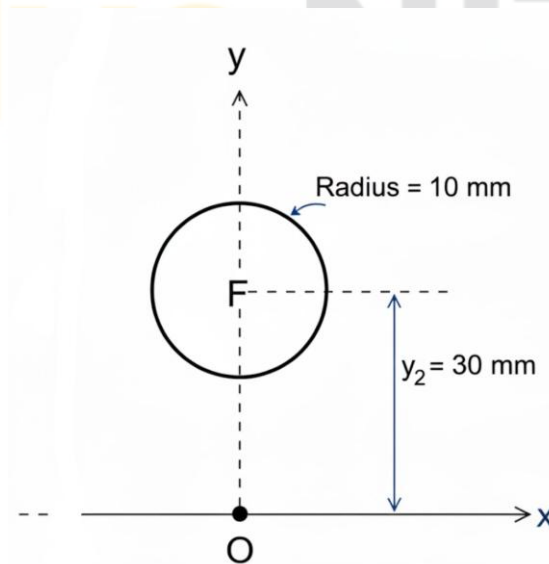
For ② $\triangle ADE$:



$$A_2 = 1/2 \times 40 \times 30 = 600 \text{ mm}^2$$

$$y_2 = 60 + 1/3 \times 30 = 70 \text{ mm}$$

For ③ Circle 'F' :



Radius = 10 mm

$$A_3 = \pi r^2 = \pi \times 10^2 = 314.16 \text{ mm}^2$$

$$y_3 = 30 \text{ mm}$$

$$\begin{aligned}\bar{y} &= \frac{\sum Ay}{\sum A} = \frac{A_1 y_1 - A_2 y_2 - A_3 y_3}{A_1 - A_2 - A_3} \\ &= \frac{6881.31 \times 21.95 - 600 \times 70 - 314.16 \times 30}{6881.31 - 600 - 314.16} \\ &= 16.69 \text{ mm}\end{aligned}$$

∴ The position of centroid of the shaded portion w.r.t x and y axes is :

$$(\bar{x}, \bar{y}) = (0, 16.69) \text{ mm}$$

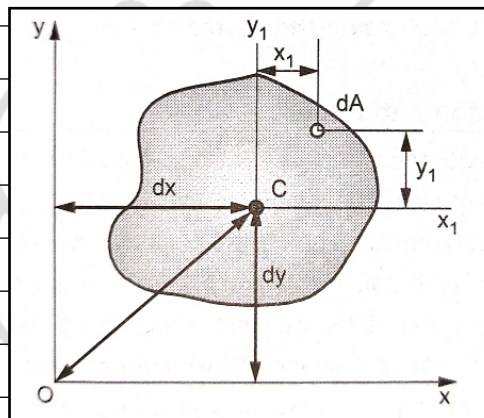


◀ Parallel Axis Theorem ▶

Statement:

- The Moment of Inertia of an area about any axis parallel to the centroidal axis is equal to the Moment of Inertia about the centroidal axis plus the product of the area and the square of the distance between the two axes.

$$I = IG + Ad^2$$



Where:

- I = Moment of Inertia about the new (parallel) axis
- IG = Moment of Inertia about the centroidal axis
- A = Area of the section
- d = Distance between the centroidal axis and the new axis

Derivation:

Let:

- x be the centroidal axis
- x' be the new axis, at a distance d from x
- y be the perpendicular distance of a small area element dA from centroidal axis x

Then, the distance from the new axis $x' = y + d$

Now,

$$I = \int (y + d)^2 dA$$

Expanding:

$$I = \int (y^2 + 2yd + d^2) dA$$

$$I = \int y^2 dA + 2d \int y dA + d^2 \int dA$$

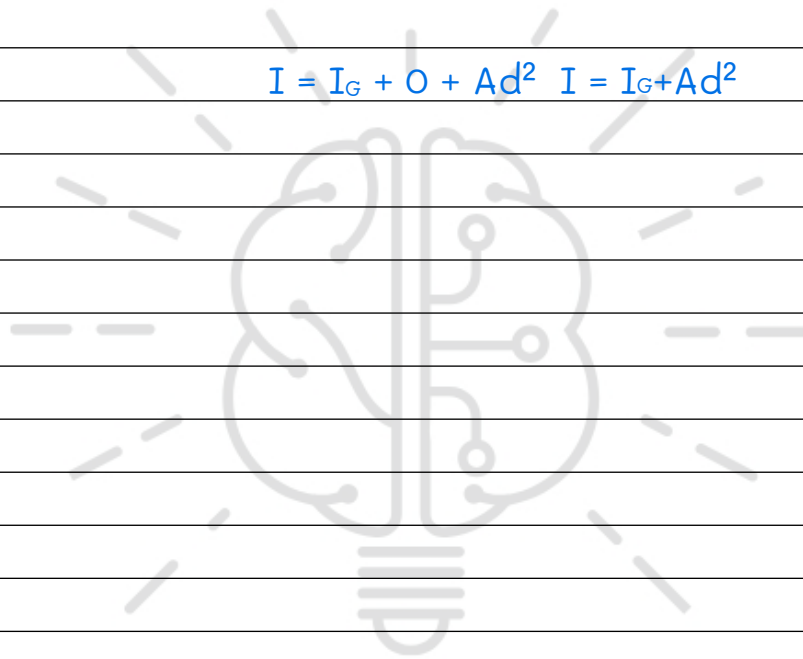
$$\int y^2 dA = I_G \text{ (Moment of Inertia about centroidal axis)}$$

$$\int y dA = 0 \text{ (since centroidal axis passes through centroid)}$$

$$\int dA = A$$

So,

$$I = I_G + 0 + Ad^2 \quad I = I_G + Ad^2$$



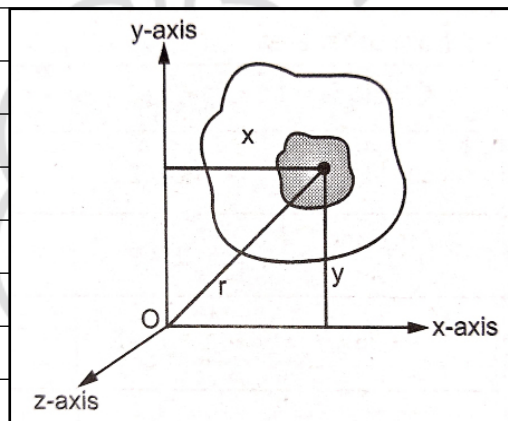
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◀ Perpendicular Axis Theorem ▶

Statement:

- For a planar lamina (2D figure) lying in the XY-plane, the Moment of Inertia about an axis perpendicular to the plane (Z-axis) is equal to the sum of the Moments of Inertia about the two perpendicular axes (X and Y) in the plane:

$$I_z = I_x + I_y$$



Where:

- I_z = Moment of Inertia about the z-axis (perpendicular to the plane)
- I_x, I_y = Moments of Inertia about x and y axes in the plane

Derivation:

Let:

- r be the distance from the origin to an elemental area dA
 - x, y be the coordinates of that element,
- so: $r^2 = x^2 + y^2$

Now, moment of inertia about the z-axis is:

$$I_z = \int r^2 dA = \int (x^2 + y^2) dA$$

Splitting:

$$I_z = \int x^2 dA + \int y^2 dA$$

$$I_z = I_x + I_y$$

Important Notes:

- The Parallel Axis Theorem applies to any area, even 3D bodies.
- The Perpendicular Axis Theorem applies only to plane (2D) figures.



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