RRB-JE 2024

Railway Recruitment Board
Junior Engineer Examination

Civil Engineering

Engineering Mechanics

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

MADE EASY PUBLICATIONS

Engineering Mechanics

Contents

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Composition, Resolution and Equilibrium of Forces

1.1 Force

Force is the action of one body on another. It may be defined as an action which changes or tends to change the state of rest or of uniform motion of body. For representing the force acting on the body, the magnitude of the force, its point of action and direction of its action should be known. There are different types of forces such as gravitational, frictional, magnetic, inertia or those caused by mass and acceleration.

According to Newton's second law of motion, we can write force as

$$F = ma = \text{mass} \times \frac{\text{length}}{\text{time}^2}$$

One Newton force is defined as that which gives an acceleration of 1 m/s^2 to a body of mass of 1 kg in the direction of force.

Thus, $\qquad\qquad$ 1 N = 1 kg × 1 m/s^2 = 1 kg-m/s^2

The action of one body and another, which changes or tends to change the state of rest or of uniform motion of body is called as force.

The three requisites for representing the force acting on the body are:
- Magnitude of force
- Its point of action, and
- Direction of its action

1.2 Effects of a Force

A force may produce the following effects in a body, on which it acts:
1. It may change the motion of a body i.e. if a body is at rest, the force may set it in motion. And if the body is already in motion, the force may accelerate or retard it.
2. It may retard the forces, already acting on a body, thus bringing it to rest or in equilibrium.
3. It may give rise to the internal stresses in the body, on which it acts.

1.3 Characteristics of a Force

To know the effect of force on a body, the following elements of force should be known.
1. Magnitude (i.e. 2 N, 5 kN, 10 kN etc.)
2. Direction or line of action.
3. Sense or nature (push or pull).
4. Point of application.

1.4 Force Systems

A force system is collection of forces acting on a body in one or more planes. According to the relative position of the lines of action of the forces, the forces may be classified as follows:

1. **Collinear:** The forces whose lines of action lie on the same line are known as collinear forces.
2. **Concurrent:** The forces, which meet at one point, are known as concurrent forces. Concurrent forces may or may not be collinear.
3. **Coplanar:** The forces whose line of action lie on the same plane are known as coplanar forces.
4. **Coplanar concurrent:** The forces, which meet at one point and their line of action lie on the same plane, are known as coplanar concurrent forces.
5. **Non-coplanar concurrent:** The forces, which meet at one point but their lines of action do not lie on the same plane, are known as coplanar non-concurrent forces.
6. **Coplanar non-concurrent:** The forces, which do not meet at one point but their line of action lie on the same plane, are known as coplanar non-concurrent forces.
7. **Non-coplanar non-concurrent:** The forces, which do not meet at one point and their line of action do not lie on the same plane, are known as non-coplanar non-concurrent forces.

1.5 Resultant Force

A single force which produces same effect on the body as the system of forces is called as resultant force.

1.6 Parallelogram Law of Forces

This law is used for finding the resultant of two forces acting at a point.

If two forces F_1 and F_2 are acting at a point and are represented in magnitude and direction by two sides of a parallelogram, then their resultant is represented by the diagonal of the parallelogram both in magnitude and direction.

Consider a parallelogram $OACB$ as shown in figure 1.1 where sides OA and OB represent the forces F_1 F_2 acting at a point O. According to the parallelogram law of forces, the resultant R is represented by a diagonal OC.

Let θ be the angle between the forces F_1 and F_2 and α be the angle made by R with force F_1.

From the figure 1.1 we can write

$$BC = OA = F_1$$
$$AC = OB = F_2$$
$$\angle BOA = \theta = \angle CAD$$

and ΔODC and ΔADC are right angle triangles.

From triangle ADC, we can write

$$AD = AC \cos\theta = F_2 \cos\theta$$
$$CD = AC \sin\theta = F_2 \sin\theta$$

Fig. 1.1

From triangle ODC, we can write

$$OC^2 = OD^2 + CD^2 = (OA + AD)^2 + CD^2$$
$$R^2 = (F_1 + F_2 \cos\theta)^2 + (F_2 \sin\theta)^2$$

$$= F_1^2 + 2F_1F_2 \cos\theta + F_2^2 \cos^2\theta + F_2^2 \sin^2\theta$$

$$= F_1^2 + 2F_1F_2 \cos\theta + F_2^2(\cos^2\theta + \sin^2\theta)$$

$$= F_1^2 + 2F_1F_2 \cos\theta + F_2^2$$

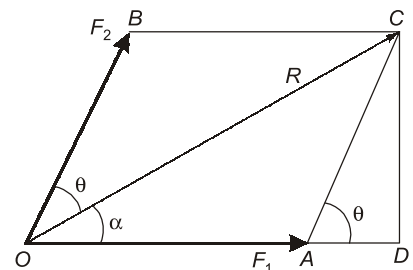$$R = \sqrt{F_1^2 + 2F_1F_2 \cos\theta + F_2^2} \qquad \qquad \text{... (i)}$$

From triangle *ODC*,

$$\tan\alpha = \frac{CD}{OD} = \frac{CD}{OA + AD} = \frac{F_2 \sin\theta}{F_1 + F_2 \cos\theta} \qquad \text{... (ii)}$$

Thus

$$R = \sqrt{F_1^2 + 2F_1F_2 \cos\theta + F_2^2}$$

and

$$\tan\alpha = \frac{F_2 \sin\theta}{F_1 + F_2 \cos\theta}$$

1.7 Triangle Law of Forces

This law states that:

If two forces acting simultaneously on a body are represented in magnitude and direction by two sides of a triangle taken in order then their third side will represent the resultant of two forces in the direction and magnitude taken in opposite order.
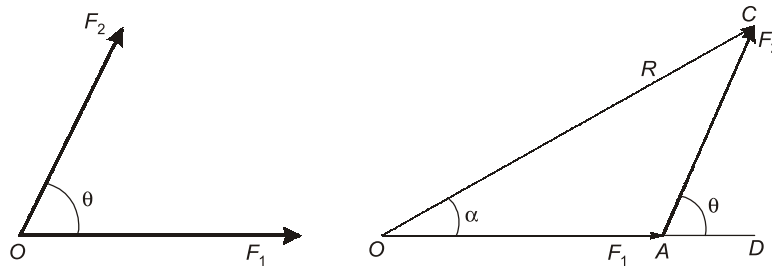

Fig. 1.2

If three forces are acting on a body and they are represented by three sides of the triangle in magnitude and direction, then the body will be in equilibrium condition.

1.8 Polygon Law of Forces

When two more forces are acting on the body, the triangle law can be extended to polygon law.

If a number coplanar concurrent forces acting simultaneously on a body are represented in magnitude and direction by the sides of a polygon, taken in order, then their resultant can be represented by closing side of the polygon in magnitude and direction in the opposite order.
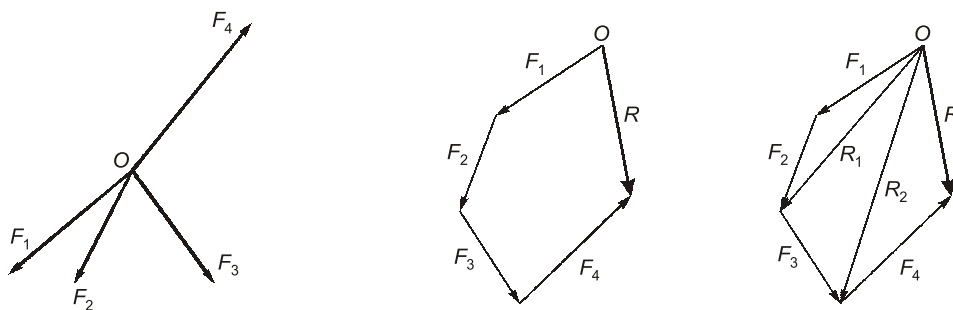

Fig. 1.3

Consider the forces F_1, F_2 and F_3 acting at a point *O* as shown in figure 1.3. As per the polygon law of forces the resultant force *R* is as shown in figure 1.3. According to parallelogram law, then the resultant of F_1 and F_2 is represented by R_1 and resultant of R_1 and F_3 is represented by R_2. The resultant *R* is the resultant of F_4 and R_2. This procedure can be extended to any number of forces acting at a point in a plane.