Ashur University College

Civil Engineering Department

STRENGTH OF MATERIALS

CHAPER ONE – INTRODUCTION

Second Class

2018 – 2019

First Semester

prepared by:

Dr. Sabah Noory Al Ani

Details of Lecturer

Course Lecturer: Dr. Sabah Al Ani •

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1.1 COURSE GOALS

- This course has two specific goals:
- (i) To introduce students to concepts of stresses and strain; shearing force and bending; as well as torsion and deflection of different structural elements.

- (ii) To develop theoretical and analytical skills relevant to the areas mentioned in (i) above.

1.2 COURSE Syllabus

Ch1. Introduction

Ch2. Stress,

Axial Loads ,The concept of the stress, General stresses in a space element , Types of stresses, Riveted (Bolted) Joints, Allowable stresses; Factor of Safety,

Ch3. Strain,

Hooke's Law, Axial Load Problems True Stress- strain diagram, Ductile and Brittle Materials, Deflection of Axially Loaded Rods (applied within elastic range only), Statically indeterminate members (axially loaded only), Problems Involving Temperature Changes (Thermal changes), Poisson's Ratio, Generalized Hooke's Law, Shear Strain Hooke's Law in Shear,

Ch4. Axial Force,

Shear and Bending moment ,Types of supports, Types of loadings Classification of beams according to their supporting system, Classification of beams according to their analysis procedure, Calculations of beams' reactions, Internal forces and moments in beams, Shear and moment diagrams by equations, Shear and moment diagrams by summation approach,

Ch5. Torsion :

Torsion formula of circular sections, Polar moment of inertia, Hollow circular sections, Statically Indeterminate Problems, Torsion of Noncircular Members, Thin-walled members with open cross sections Thin-walled members with open cross sections

Ch6. Pure Bending of Beams

Curvature of a beam, Bending formula, Elastic section modulus, Beams of Two Materials, Stress Distribution in Composite Sections (Method of Transformed section).

1.3 **Course Objectives**

Strength of Materials answers two questions:

- *Is the material strong enough?*
- *Is the material stiff enough?*

- If the material is not strong enough, your design will **break**.
- D If the material isn't stiff enough, your design probably won't function the way it's intended to .

- The main objective of the study of strength of materials (or mechanics of materials) is to provide the engineer with methods of analyzing various machines and structural members .
- Design and analysis of a given structure involve the determination of stresses and deformation

Upon successful completion of this course, students should be able to:

(i) Understand and solve simple problems involving stresses and strain in two and three dimensions. •

(ii) Understand the difference between statically determinate and indeterminate problems. •

(iii) Understand and carry out simple experiments illustrating properties of materials in tension, compression as well as hardness and impact tests. •

COURSE OBJECTIVES CONTD.

- (iv) Analyze stresses in two dimensions and understand the concepts of principal stresses and the use of Mohr circles to solve two-dimensional stress problems.
- (v) Draw shear force and bending moment diagrams of simple beams and understand the relationships between loading intensity, shearing force and bending moment.
- (vi) Compute the bending stresses in beams with one or two materials.
- (vii) Calculate the deflection of beams using the direct integration and moment-area method.
- (viii) Apply sound analytical techniques and logical procedures in the solution of engineering problems.

1.4 Teaching Strategies

The course will be taught via Lectures. Lectures will also involve the solution of tutorial questions. Tutorial questions are designed to complement and enhance both the lectures and the students appreciation of the subject.

Course work assignments will be reviewed with the students.

Lecture Times

- Sunday: 8.30 to 10.30 a.m.
- Monday: 12.30 a.m. to 02.30 p.m

COURSE WORK

- 1. One Mid-Semester Test (10%);
- 2. Quizzes and H.W (20%) and
- 3. End of Semester 1 Examination (70%).

More Course Details

- **Textbook :** Mechanics of Materials, second edition (SI version), by: E. Popov, 1978, Prentice-Hall International.
- References :

✓ Strength of Materials , Professor Dr. Nabeel Al-BayatiY, University of Technology, Building and Construction Engineering Department.

✓ Strength of Materials, fifth edition,(SI units), Schaum's outlines, by: W. Nash and M. Potter, 2011.

✓ Mechanics of Materials, sixth edition (U.S. customary and SI units), by: F. Beer, E. Johnston Jr, J. DeWolf and D. Mazurek, 2012

✓ Elements of Strength of Materials, by: Timoshenko

✓ Strength of Materials, by: Singer

✓ Mechanics of Materials by: Ferdinand P. Beer, E. Russell Johnston, Jr. and John T. De Wolf, Third Edition.

1. 5 INTRODUCTION

Strength of materials is a branch of applied mechanics that deals with the behavior of solid bodies subjected to various types of loading. Other names for this field of study are mechanics of materials and solid mechanics. The solid bodies considered in this book include bars with axial loads, shafts in torsion, beams in bending, and columns in compression. The principal objective of mechanics of materials is to determine the stresses, strains, and displacements in structures and their components due to the loads acting on them. If we can find these quantities for all values of the loads up to the loads that cause failure, we will have a complete picture of the mechanical behavior of these structures

1.6 SYMBOLS AND SI UNITS

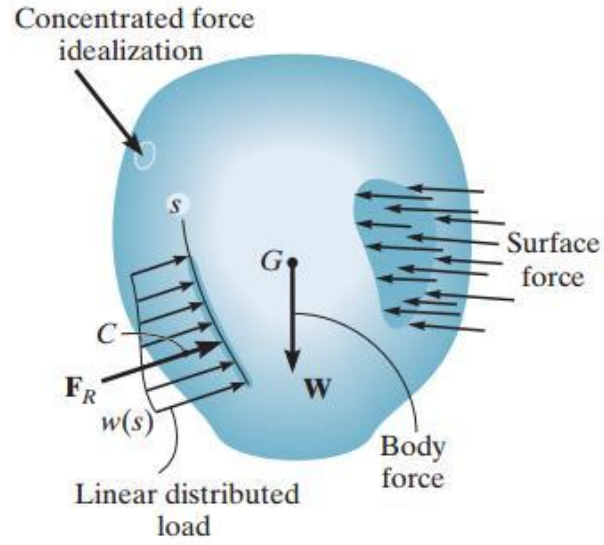
	British	Metric	S.I. (System International)
1- Force (1 N = 4.448 lb)	Ib(lebra), kip, Ton 1 kip = 1000 Ib 1 ton = 2240 Ib	g(gram), kg 1 kg = 1000 g 1 Ton = 1000 kg	N(Newton), kN 1 kN = 1000 N 1 kg = 10 N
2- Length (1 in = 2.54 cm)	In (inch), ft 1 ft = 12 in	mm, cm, m 1 cm = 10 mm 1 m = 100 cm 1 m =1000 mm	mm, cm, m 1 cm = 10 mm 1 m = 100 cm 1 m =1000 mm
3-Stress (=Force/Area) kPa = 6.894 psi	psi (lb/in^2) ksi (kip/in^2)	Pa[Pascal] (N/m^2), kPa, MPa, GPa MPa[Mega Pascal] = 10^6 Pa (N/mm^2) GPa[Giga Pascal] = 10^9 Pa (kN/mm^2)	

Best units used in these lectures: mm or in. [length], N or Pa (lb) [Force], MPa(N/mm^2), psi (lb/in^2) [Stress]

1.7 Forces in Strength of Materials

There are several types of forces that act on solid bodies. These consist of forces applied to the mass of the body and to the surface of the body, forces at restraints, and internal forces. In Figure 1 we show a general three dimensional body with forces depicted acting on its surface and on its mass.

- **External Loads: A body is subjected to only two types of external** loads; namely, surface forces or body forces.
- **Surface Forces: Surface forces are caused by the direct contact of** one body with the surface of another. In all cases these forces are distributed over the area of contact between the bodies.
- **Body Forces: A body force is developed when one body exerts a** force on another bod without direct physical contact between the bodies.



1.8 Classification of Materials:

A. Elastic Material مادة مرنه

If material undergoes (يخضع) deformation (تشويه) on external loading and the deformation disappear (يختفي) on removal the load. Example – steel and rubber

B. Plastic Material مادة طيعه، لينة، لدائنية

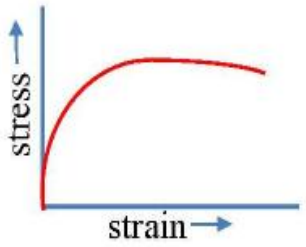
If material undergoes deformation on external loading and the deformation does not disappear at all on removal load. Example – lead and gold

C. Elastic-plastic Material

If material undergoes deformation on external loading and the deformation disappear partially (جزئيا) on removal of the load. Hence, a permanent (دائمي) deformation remain even after removal of the load in elasto-plastic material.

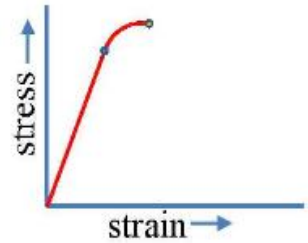
D. Ductile Material مادة لدنة قابلة للسحب

Material can undergo large deformation before failure. In other word, a material which can be drawn into wires is known as ductile material. Example – Aluminium, copper, magnesium, etc. An advantage of ductility is that visible distortion may occur if the loads become too large, thus providing an opportunity (فرصه) to take remedial (علاجي) action before an actual fracture (كسر) occurs.



E. Brittle Material مادة هشة

A material in which no deformation take place when external load is applied and it fails by rupture. In other word, materials that fail in tension at relatively low values of strain known as brittle materials. Example – concrete, cast-iron, glass, ceramic materials.

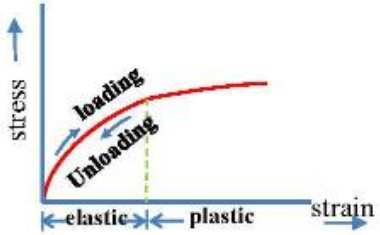


1.9 Mechanical Properties of Materials:

A. **Hardness**: The hardness of a material is a measure of its resistance to penetration by an identer. It is also measure of strength and often has the units of stress. The identer is fabricate to a hard material and the shape of tip may conical, spherical or pyramidal.

B. **Elasticity**: Is the property of a material by virtue (ميزة) of which it returns to its original dimension during unloading.

C. **Plasticity**: Is the property of a material by virtue (ميزة) of which permanent (دائم) deformation of the material take place after removal of load.



D. **Ductility**: Is the property of a material by virtue of which it can be drawn into wires before rupture. It is measured by the percentage of elongation and percentage of reduction of area of a test piece before rupture. Ductile materials are capable of absorbing large amount of energy prior to fracture. With increasing carbon content, steel become less ductile but has a higher yield stress and higher ultimate stress.

E. **Brittleness** قابلية الهشاشة: Lack of ductility is brittleness.

F. **Toughness** قابلية القساوة: The property of a metal by virtue of which it can be bent, twisted or stretched under a high stress before rupture is called toughness.

G. **Malleability** قابلية التطريق: The property of a metal by virtue of which it can be beaten or rolled into their sheets without rupture is called malleability.

H. **Strength**: It is the ability of a material to resist the action of external force without breaking. The tensile strength, compressive strength and shear strength represents the strength of a material.

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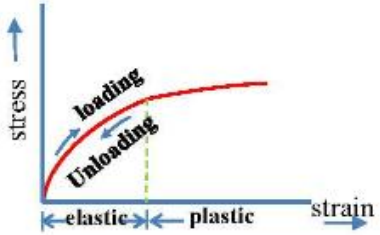

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1.11 Design Considerations

The most two factors that should be consider when making any type of design are:

- **Safety**
- **Economy**

Design of engineering systems is usually a trade-off between maximizing safety and minimizing cost.

1.12 Typical Approach to an Engineering Solution

- Identify the problem
- State the objective
- Develop alternative solutions
- Evaluate the alternatives, and
- Use the best alternative

1.13 Elements of structure:

Below are the main element for each stricter as shown in Fi. 2

A. Roof or Floor Slabs (one-way or two-way)
B. Beams (simple or continues span)
C. Columns (Concrete or steel section)
D. Walls (Bricks or Concrete)
E. Foundations (isolated, combined or strip)

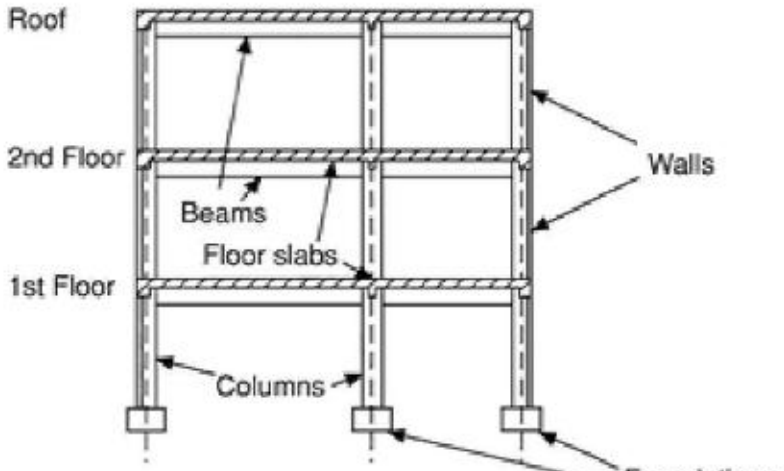


Fig. 2 Some elements of a structure.

1.14 Types of Supports:

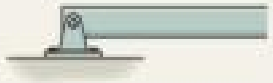
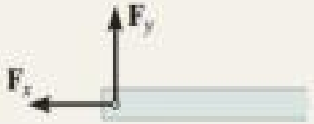
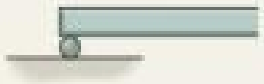
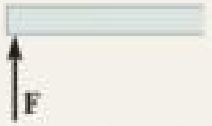
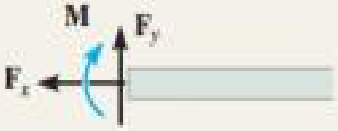
Type of connection	Reaction	Type of connection	Reaction
 Cable	 One unknown: F	 External pin	 Two unknowns: F_x, F_y
 Roller	 One unknown: F	 Internal pin	 Two unknowns: F_x, F_y
 Smooth support	 One unknown: F	 Fixed support	 Three unknowns: F_x, F_y, M







Photo of different types of Roller Bearings





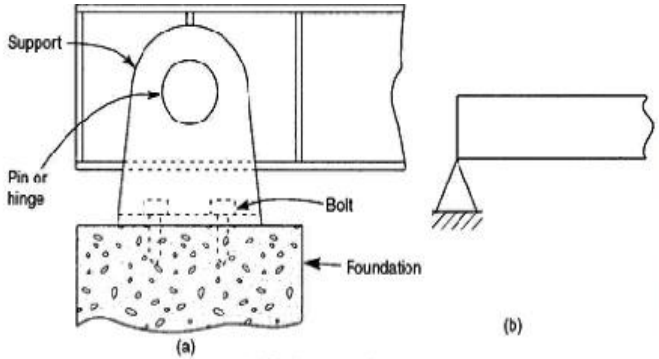


FIGURE 4 Idealization of a pinned support



Photo showing a Hinged Bearing



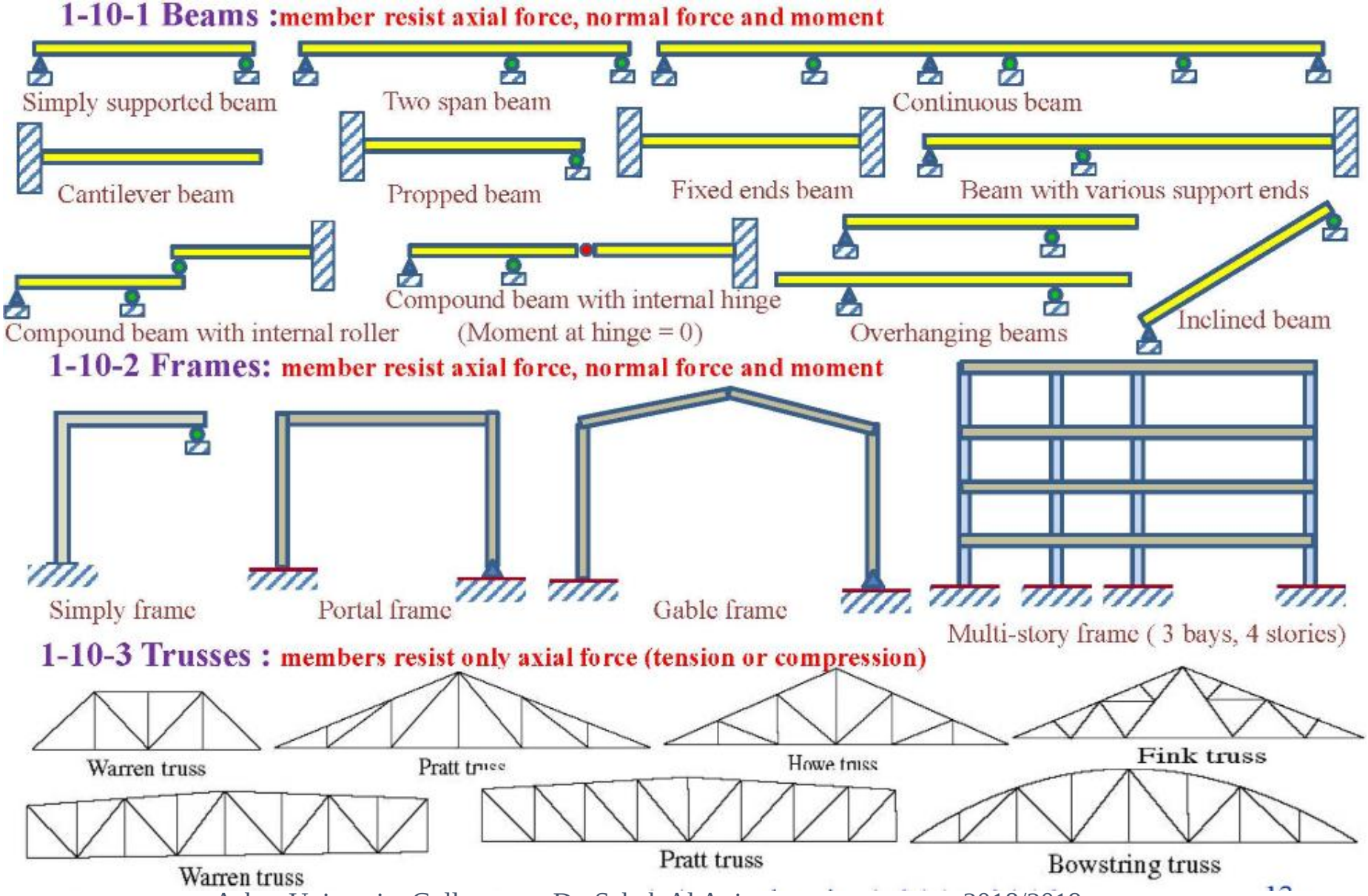






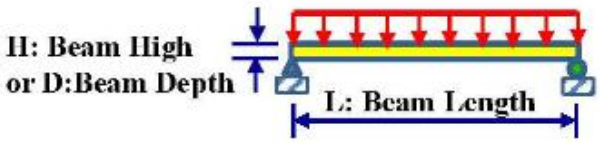


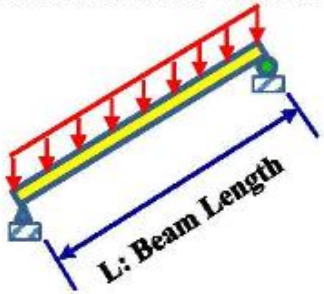
1.15 Kinds of Supports:

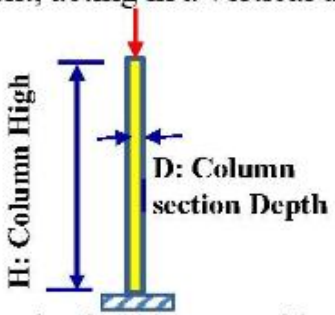


1.16 Types of Loadings:

1.16.1 **:Selfweight load**: Calculate from unit mass of material and volume of element, acting in a vertical direction.







Example-1-1: Calculate the selfweight of a reinforced concrete beam of breadth 300 mm, depth 600 mm and length 6000mm. unit mass of reinforced concrete is 2400 kg/ m^3. Assuming that the gravitational constant is 10 m/ sec^2 (strictly 9.807 m/ sec^2), the unit weight of reinforced concrete, ρ, is

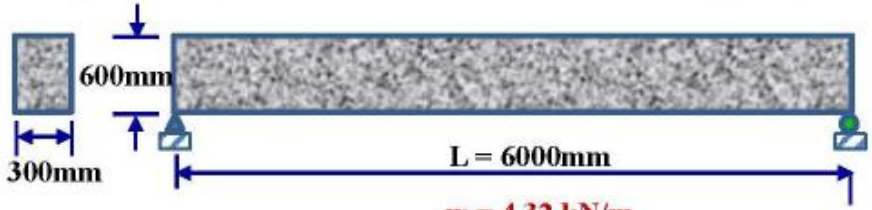
$\rho = 2400 \times 10 = 24\,000\ N/m^3 = 24\ kN/m^3$

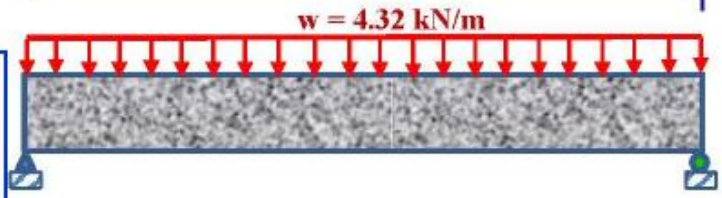
Hence,

the selfweight of beam = volume × unit weight

$= (0.3 \times 0.6 \times 6)24 = 25.920\ kN$

selfweight per unit length of beam = 25.92 / 6 = 4.320 kN/m





Hint: force(weight) = mass × acceleration (Newton's Second Law)
For mass = 1 kg, Gravity acceleration= 9.807 m/ sec^2
So force(weight) = 1 × 9.807 = 9.807 ≈ 10 or 1kg = 10N (which means that it would require a force of 9.807N to produce an acceleration of 9.8071m/s^2 in a mass of 1 kg)

Example-1-2: Calculate the selfweight of a reinforced concrete column of circular section with 350 mm radius, and height 3000mm, the unit weight (density) of reinforced concrete, ρ, is

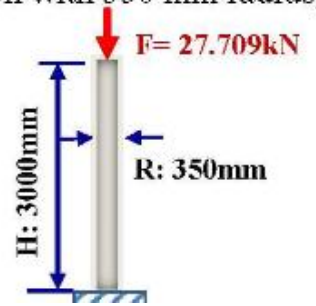
$\rho = 2400 \times 10 = 24\,000\ N/m^3 = 24\ kN/m^3$

Hence,

the selfweight of column= volume × unit weight

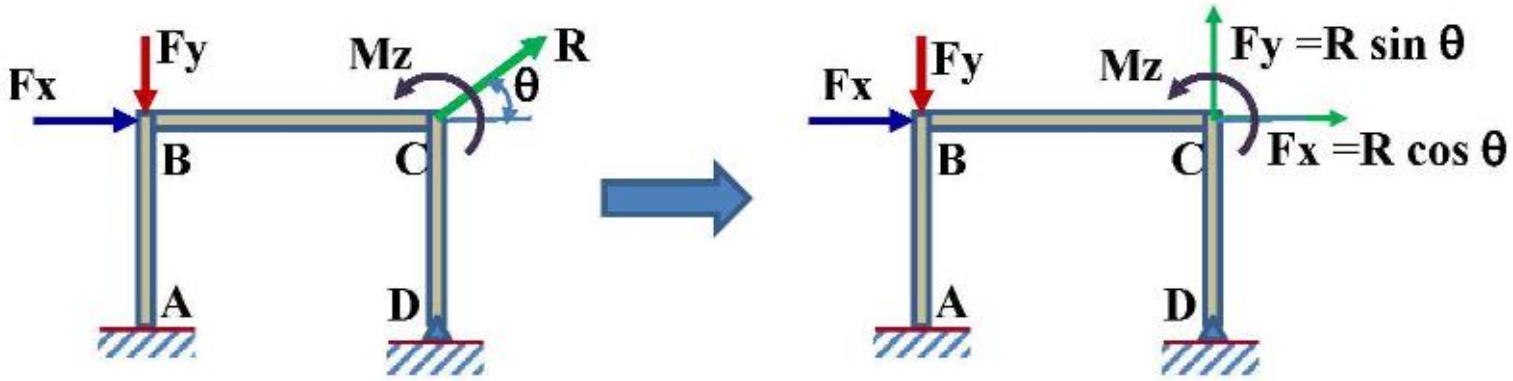
$= ([\pi * 0.35^2] \times 3)24 = 27.709\ kN$

Where π = 3.1415926

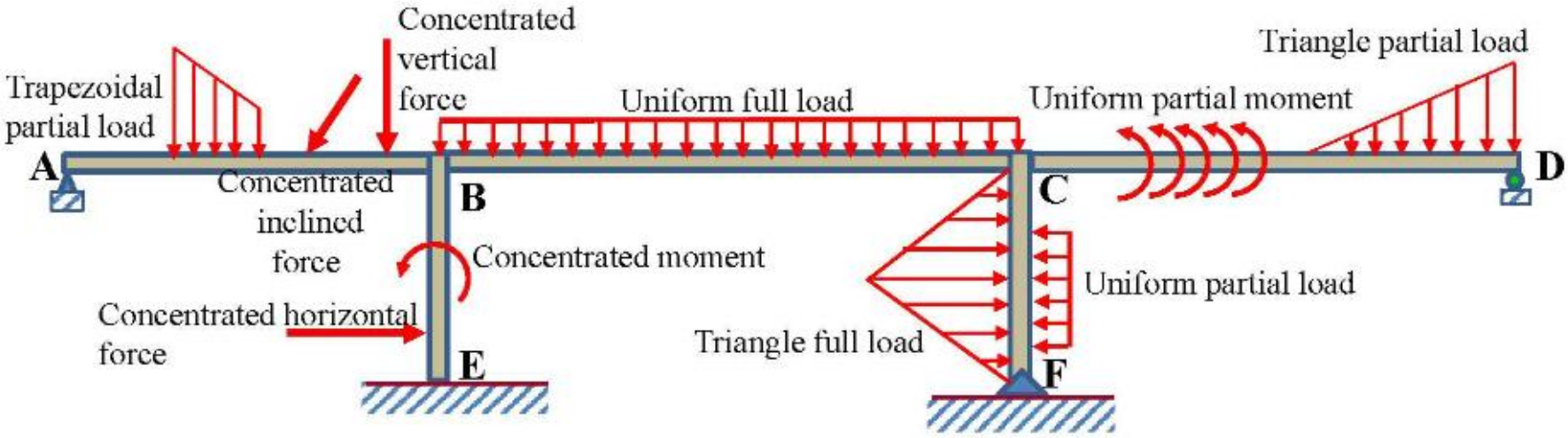


1.16.2 External Loads:

1.16.2.1 : **Joint load**: (**Force or Moment**), acting at the joint only, vertical, horizontal or inclined direction.



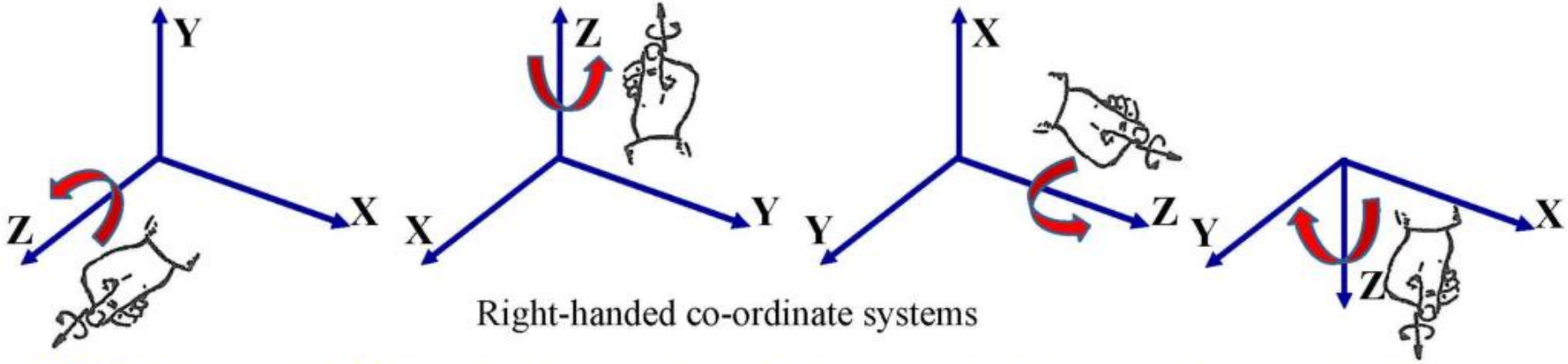
1.16.2.2 : **Member load**: (**Load means Force or Moment**) Acting along member, vertical, horizontal or inclined direction.



1-12 Sign Conventions:

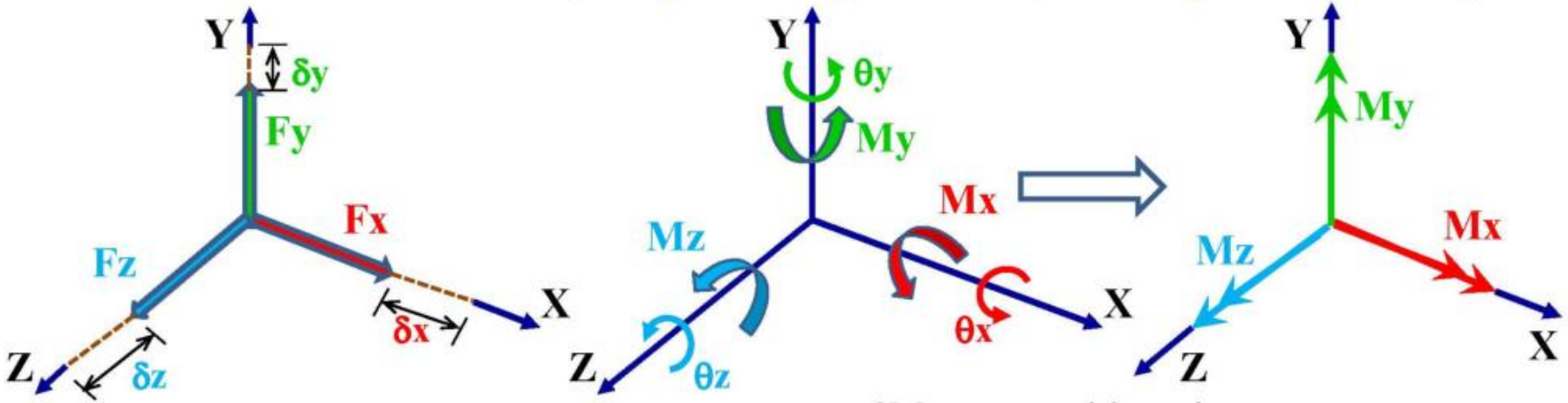
1-12-1 Axes:

Throughout this subject we will use the Cartesian co-ordinate system of three mutually perpendicular axes. Only right-handed systems will be used, which means the following:



Right-handed co-ordinate systems

1-12-2 Forces and Moments: (force produce displacements δ, Moment produce rotation θ)

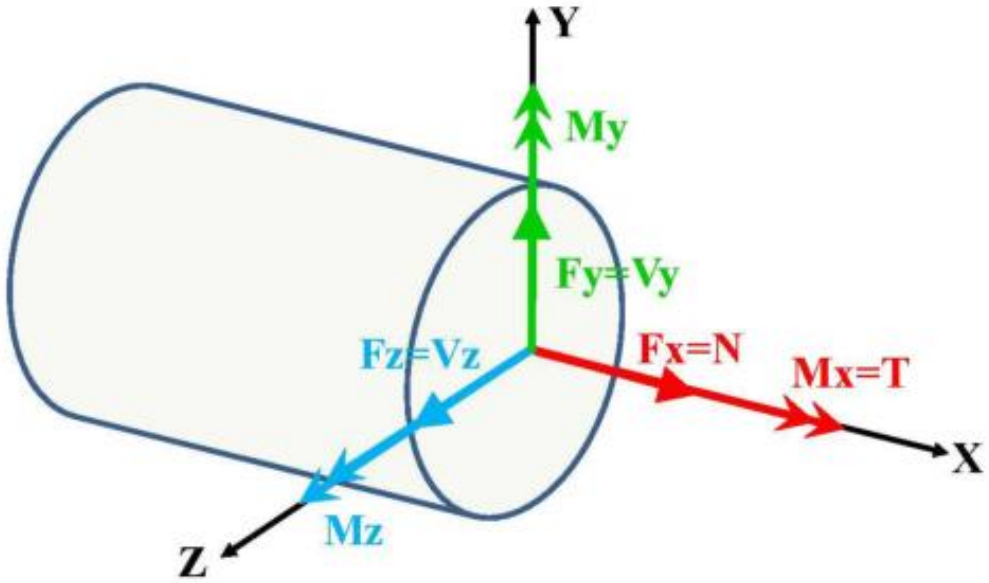


3Forces and 3displacements system

3Moments and 3rotations system

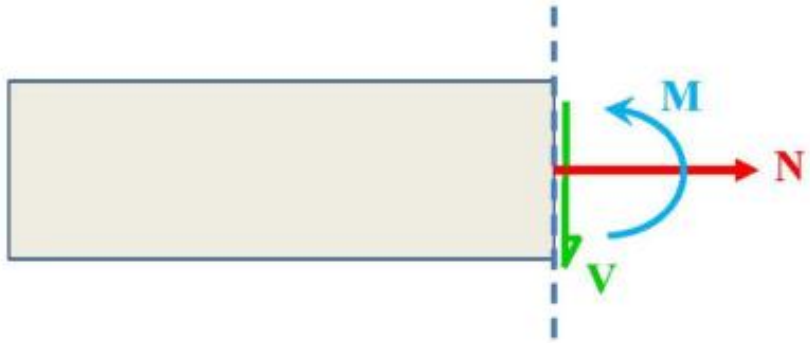
+ Positive direction of forces and moments system

In general, for a three dimensional problem, there are six loads on any cross section (3 Forces & 3 Moments)



N = Normal Force
V = Shear Force
T = Torque
M = Bending Moment

For two dimensional problems, this can be reduced to three loads (2 forces & 1 moment).



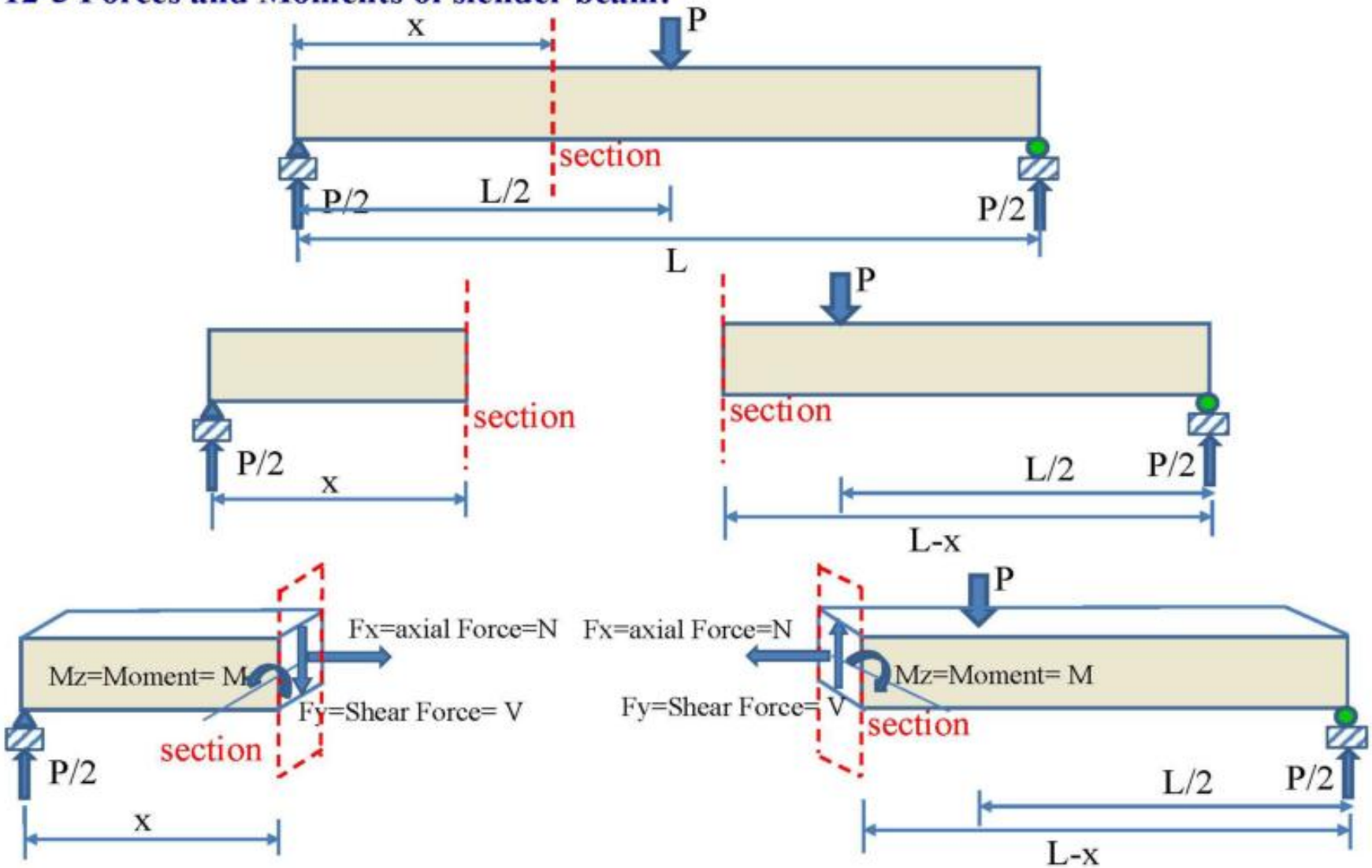
Positive Sign Conventions:

Tension axial force on the section

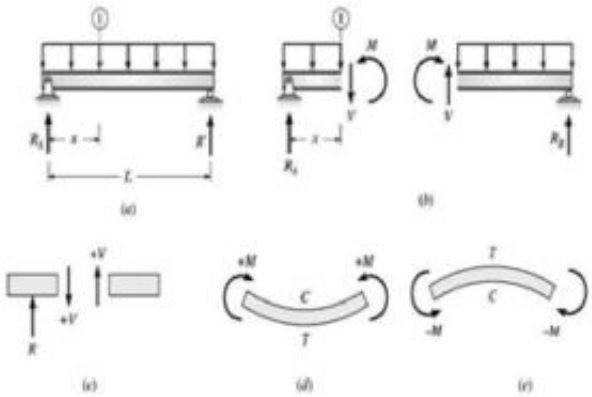
Shears that produces clockwise moments

Bending moments that produce compression in the top fibers and tension in the bottom fibers of the beam

1-12-3 Forces and Moments of slender beam:



+ Positive direction of axial force, shear force and moments at beam section for equilibrium system

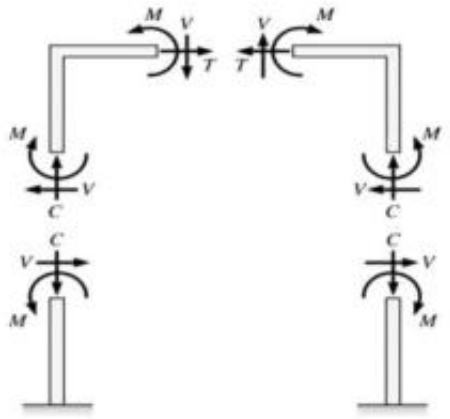


Beam Sign Convention for Shear and Moment

Following our positive beam sign convention, a positive bending moment bends a beam concave upward (or toward the positive y direction), whereas a negative bending moment bends a beam concave downward (or towards the negative y direction).

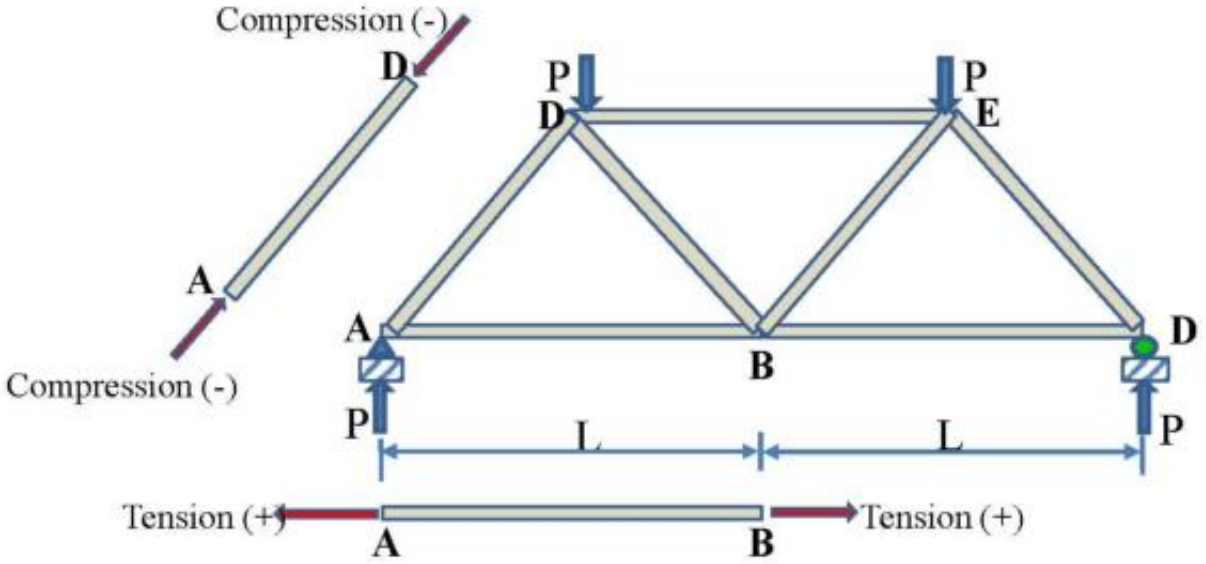
Positive Bending

Negative Bending



Positive Internal Forces Acting on a Portal Frame

1-12-4 Forces truss bar element: resist axial force only, tension or compression

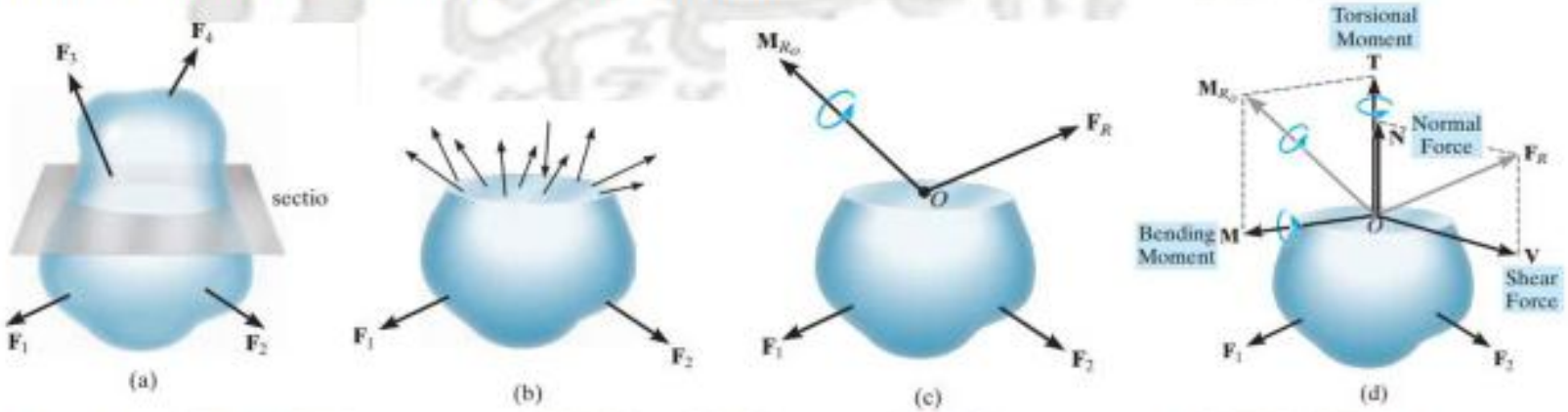


1.17 Review OF Statics:

Equations of Equilibrium: Equilibrium of a body requires both a **balance of forces**, to prevent the body from translating or having accelerated motion along a straight or curved path, and a **balance of moments**, to prevent the body from rotating.

$$\Sigma F_x = 0 \quad \Sigma F_y = 0 \quad \Sigma F_z = 0$$
$$\Sigma M_x = 0 \quad \Sigma M_y = 0 \quad \Sigma M_z = 0$$

Internal Resultant Loadings and free body diagram



Normal force, N. This force acts perpendicular to the area. It is developed whenever the external loads tend to push or pull on the two segments of the body.

Shear force, V. The shear force lies in the plane of the area and it is developed when the external loads tend to cause the two segments of the body to slide over one another.

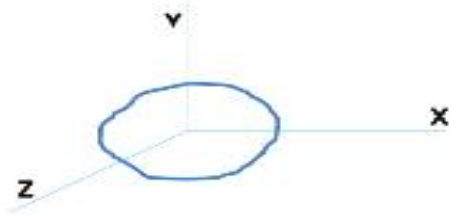
Torsional moment or torque, T. This effect is developed when the external loads tend to twist one segment of the body with respect to the other about an axis perpendicular to the area.

Bending moment, M. The bending moment is caused by the external loads that tend to bend the body about an axis lying within the plane of the area.

1.18 Determinate and Indeterminate Problems :

- The equation of static equilibrium for the three dimensional problems are :-

$$\sum Fx = 0 \quad , \sum Mx = 0$$
$$\sum Fy = 0 \quad , \sum My = 0$$
$$\sum Fz = 0 \quad , \sum Mz = 0$$



If the number of the unknowns is greater than 6 the problem is of indeterminate type .

- In the planar problems the equations of static equilibrium,

$$\sum Fx = 0$$
$$\sum Fy = 0$$
$$\sum Ma = 0$$



Where (a) is any point on the xy plane at which a normal axis to this plane passes .
If the number of unknown reactions is greater than three the problem is of indeterminate type .

Examples

Statically determinate to the 1st degree



No. of unknowns =5

No. of static equilibrium equations=3

Indeterminate to the 2nd degree .

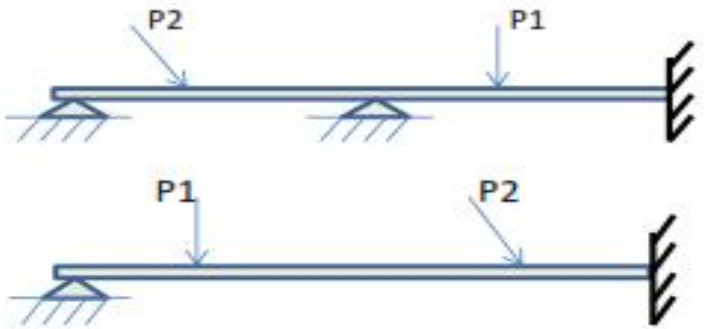


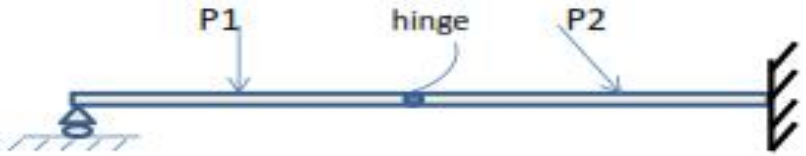
No.of unknowns =7

No.of equations =3

Indeterminate to the 4th degree.

Indeterminate to the 2nd degree .





The hinge will now add another equation (equation of condition) and the beam is now determinate.

No. of unkowns =6

No.of equations =3+2

3 static equilibrium equations

2 equations of condition (2-hinges)

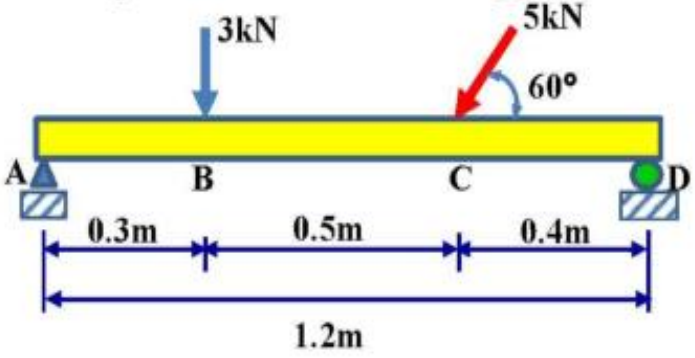
So the beam is indeterminate to the 1st degree.

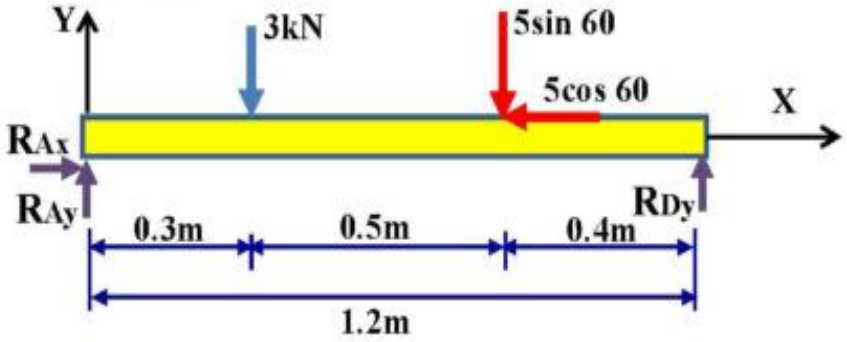


1.19 Calculation of Support Reactions:

The conditions of statically equilibrium, are used to calculate reactions at supports in structures so long as the support system is **statically determinate**, (there are a number of unknowns equal to the number of equations of statically equilibrium).

Example 1-1: Calculate the support reactions in the simply supported beam **ABCD** shown below:





Structure Free-Body Diagram

Solution:

$\Sigma F_x = 0 \Rightarrow R_{Ax} - 5*\cos 60 = 0, \quad R_{Ax} = 2.5\ kN \rightarrow$

$\Sigma M_D = 0$

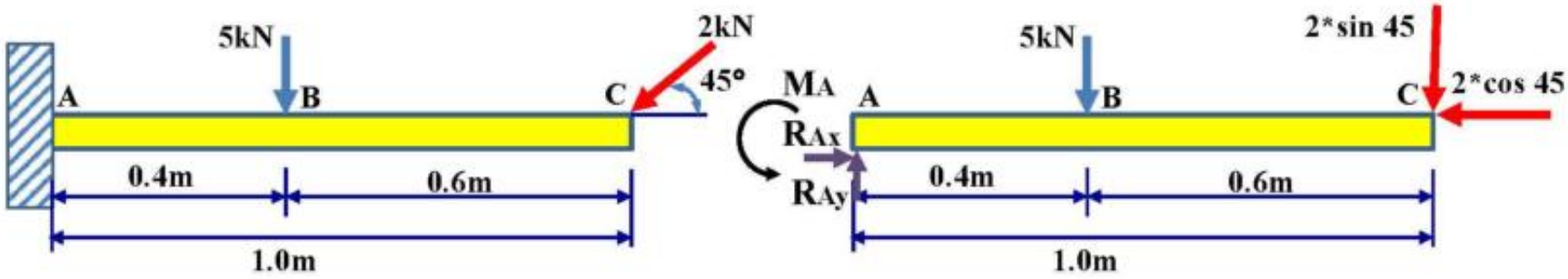
$-R_{Ay} * (1.2) + 3 * (0.9) + 5 \sin 60 * (0.4) = 0, \quad R_{Ay} = 3.7\ kN \uparrow$

$\Sigma F_y = 0 \quad , R_{Ay} + R_{Dy} - 3 - 5 \sin 60 = 0$

$3.7 + R_{Dy} - 3 - 5 \sin 60 = 0$

$R_{Dy} = 3.6\ kN \uparrow$

Example 1-2: Calculate the support reactions in the cantilever beam **ABC** shown below:



Structure Free-Body Diagram

Solution:

$\Sigma F_x = 0 \Rightarrow R_{Ax} - 2*\cos 45 = 0, \quad R_{Ax} = 1.4 \text{ kN} \rightarrow$

$\Sigma F_y = 0 \uparrow +, \quad R_{Ay} - 5 - 2 \sin 45 = 0, \quad R_{Ay} = 6.4 \text{ kN} \uparrow$

$\Sigma M_A = 0 \circlearrowleft +, \quad M_A - 5 * (0.4) - 2 \sin 45 * (1.0) = 0, \quad M_A = 3.4 \text{ kN-m}$

the resultant reaction at a support is:

$R_A^2 = R_{Ax}^2 + R_{Ay}^2$

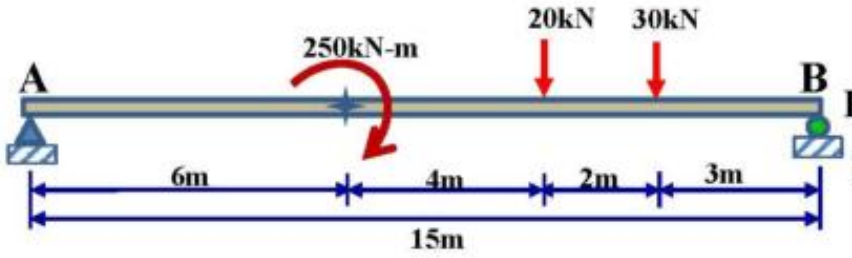
$R_A^2 = 1.4^2 + 6.4^2, \quad R_A = 4.5 \text{ kN}$

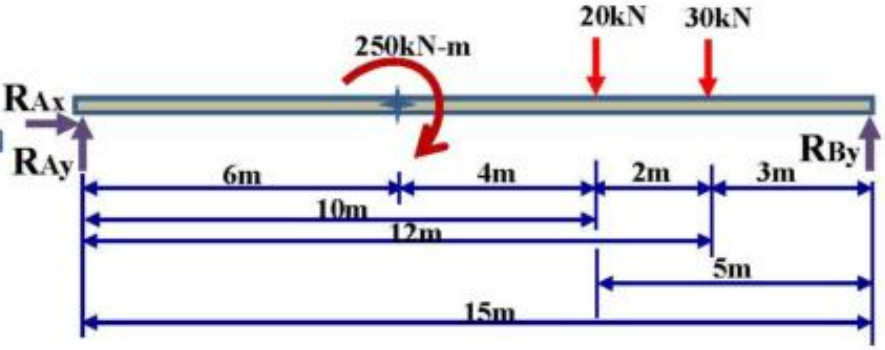
The inclination of **R,** to

$$\tan \theta = R_{Ax} / R_{Ay}$$
$$= 1.4 / 6.4 = 0.676$$

From which $\theta = 34.0°$

Example 1-3: Find reactions of simply supported beam shown below:





Structure Free-Body Diagram

Solution:

$\Sigma F_x = 0 \Rightarrow R_{Ax} = 0$

$\Sigma M_A = 0$

$R_{By} * (15) - 30 * (12) - 20 * (10) - 250 = 0$

$R_{By} = 54$ kN ↑ Positive sign means assumed direction of reaction was corrected

$\Sigma M_B = 0$

$-R_{Ay} * (15) - 250 + 20 * (5) + 30 * (3) = 0$

$R_{Ay} = -4$ kN Negative sign means assumed direction of reaction was not corrected

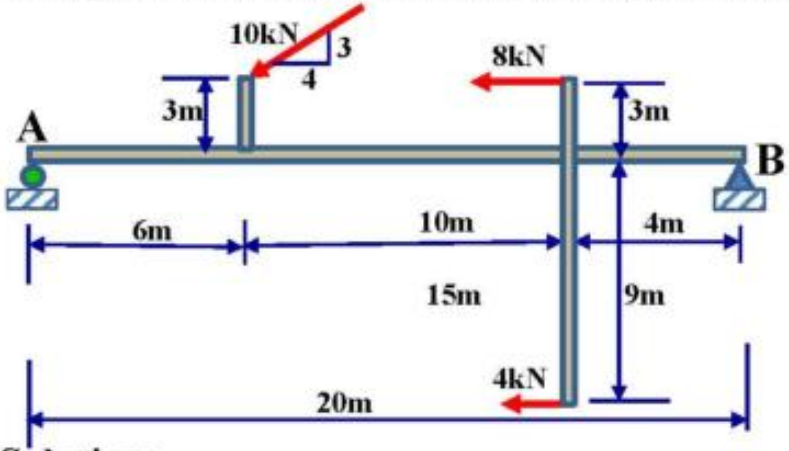
$\therefore R_{Ay} = 4$ kN ↓

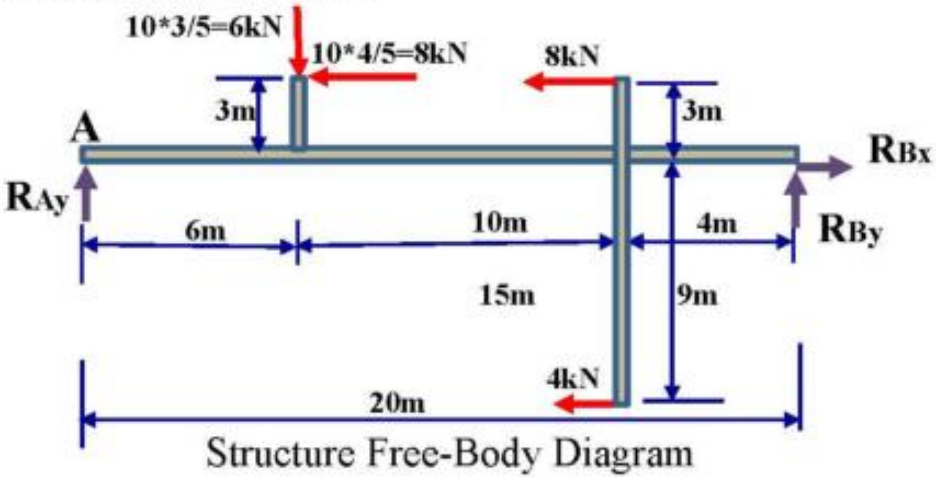
Check: $\Sigma F_y = 0$ ↑+

$54 - 20 - 30 - 4 = 0$

$54 - 54 = 0 \quad \therefore$ OK

Example 1-4: Calculate reactions at supports for the beam shown below:





Structure Free-Body Diagram

Solution:

$\Sigma F_x = 0 \rightarrow$, $-8 - 8 - 4 + R_{Bx} = 0$, $R_{Bx} = 20$ kN

$\Sigma M_A = 0$ ↻

$+ R_{By} * (20) + 8 * (3) + 8 * (3) - 4 * (9) - 6 * (6) = 0$

$R_{By} = 1.2$ kN ↑ Positive sign means assumed direction of reaction was corrected

$\Sigma M_B = 0$ ↻

$-R_{Ay} * (20) + 6 * (14) + 8 * (3) + 8 * (3) - 4 * (9) = 0$

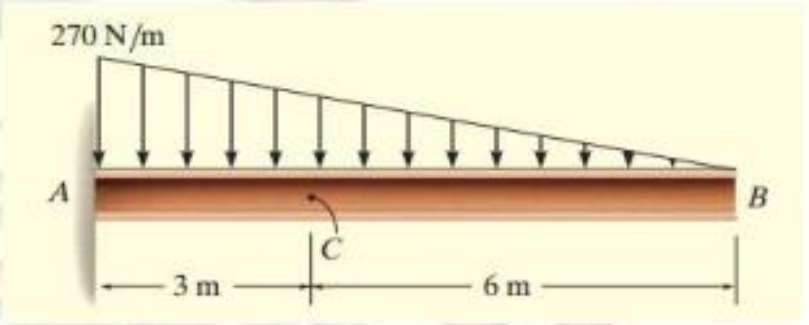
$R_{Ay} = 4.8$ kN ↑

Check: $\Sigma F_y = 0$ ↑ , $4.8 - 6 + 1.6 = 0$, $6 - 6 = 0$, ∴ OK

Check: $\Sigma F_x = 0$ →, $20 - 8 - 8 - 4 = 0$, $20 - 20 = 0$ ∴ OK

Example 1.5

Determine the resultant internal loadings acting on the cross section at C of the cantilevered beam shown in the Figure.



$$\frac{w}{6}=\frac{270}{9}\rightarrow w=180N/m$$

$$F=\frac{1}{2}\times 180\times 6=540N$$

$$(+)\rightarrow \sum F_x=0$$

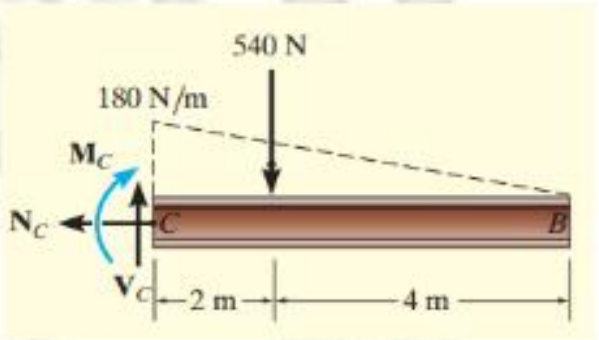
$$-N_c=0$$

$$(+)\uparrow \sum F_y=0$$

$$V_c-540=0\rightarrow V_c=540N$$

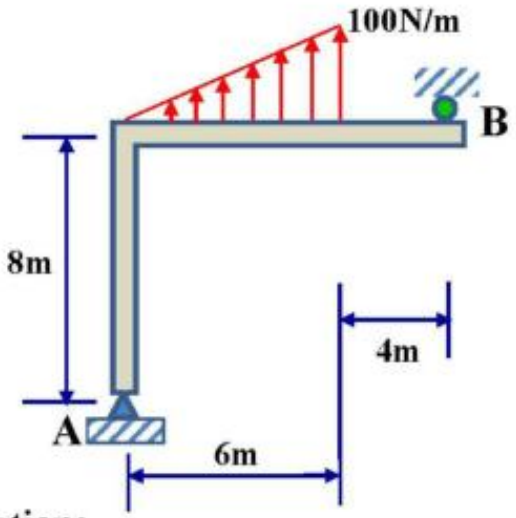
$$\circlearrowleft(+)\sum M_c=0\rightarrow -M_c-540\times 2=0$$

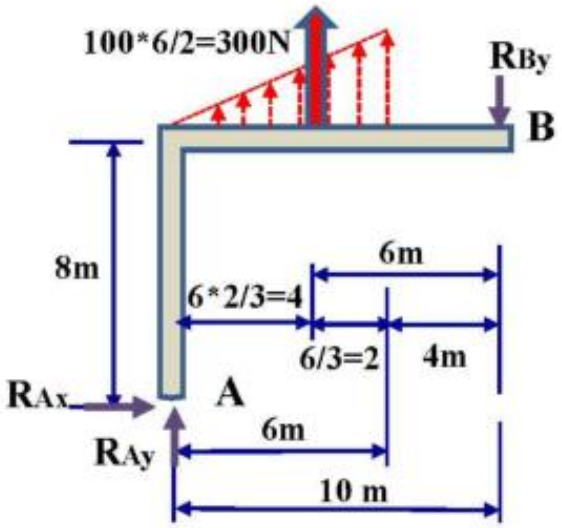
$$M_c=-1080N.m$$



The negative sign indicates that acts in the opposite direction to that shown on the free-body diagram.

Example 1.6 : Calculate reactions at supports for the frame shown below:





Structure Free-Body Diagram

Solution:

$\Sigma F_x = 0 \Rightarrow R_{Ax} = 0$

$\Sigma M_A = 0$ ⟲+

$-R_{By} * 10 + 300 * 4 = 0$

$R_{By} = 120$ N ↓ Positive sign means assumed direction of reaction was corrected

$\Sigma M_B = 0$ ⟲+

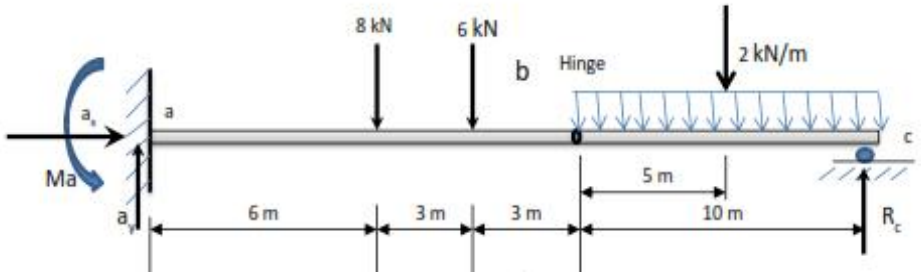
$-R_{Ay} * 10 - 300 * 6 = 0$

$R_{Ay} = -180$ N Negative sign means assumed direction of reaction was not corrected

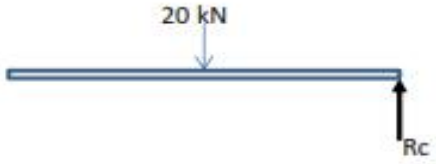
$\therefore R_{Ay} = 180$ N ↓

Check: $\Sigma F_y = 0$ ↑+ , $-120 + 300 - 180 = 0$, $-300 + 300 = 0$, $\therefore$ OK

Example 1.7 : Find the forces in all reaction for the frame?



member bc as F.B.D



$\sum Mb = 0$ Type equation here.

20*5 =10 Rc

Rc = 10 KN

The whole frame as F.B.D

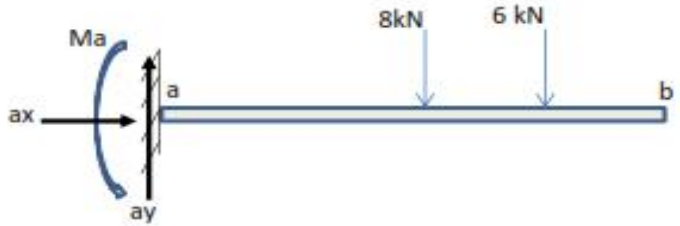
$\sum Fx = 0$, $\sum Fy = 0$ Type equation here.

ax =0

ay -8-6-20+10 =0

ay = 24 kN

Member ab as F.B.D



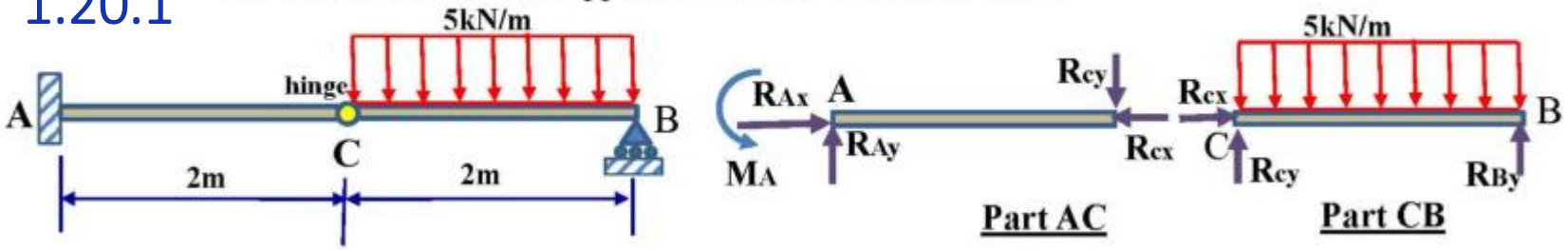
$\sum Mb = 0$

Ma +8*6 +6*3 -24*12 = 0

Ma = 222 kN.m

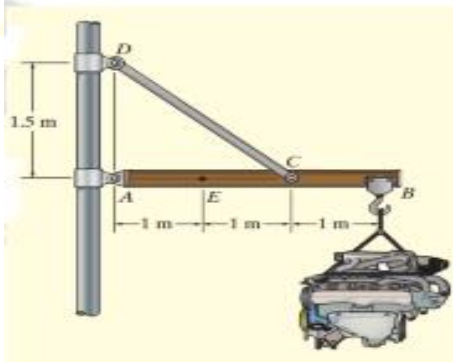
1.20 H.W No.1

1.20.1 : Calculate reactions at supports for the beam shown below:

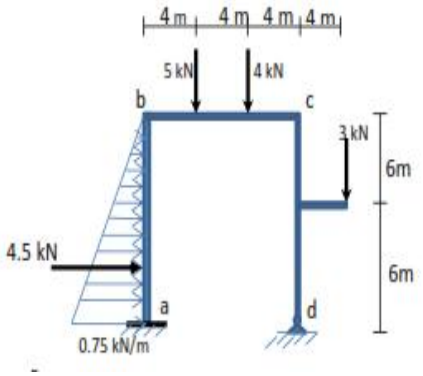


1.20.2

The 500-kg engine is suspended from the crane boom in the Figure. Determine the resultant internal loadings acting on the cross section of the boom at point E.



1.20.3 For the frame shown , find the reactions .



Note: As agreed next lecture you have to submitted your H.W and a Quiz will be done !!!!