MECHANIC OF CIVIL ENGINEERING STRUCTURES

Volume 1

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POLITEKNIK MALAYSIA PORT DICKSON

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We hereby declare that this module is our original work. To the best of our knowledge, its contains no material previously written or published by another person. However, if there is any, due acknowledgement and credit are mentioned accordingly in the e-book.

PREFACE



This e-book written specially for polytechnic student, who are pursuing DCC20053 Mechanic in Civil Engineering Structures, Diploma in Civil Engineering. The content are the latest syllabus prescribed in Malaysia polytechnics, covers knowledge of facts and basic principles of types of forces, strength of materials and behavior of loaded structures. This course provides exposure to the impact of loaded structures on direct and shear stresses.

This book version cover three chapter out of six chapter that have been designed in Mechanic in Civil Engineering Structures syllabus. Chapter 1 Introduction to Mechanic of Civil Engineering Structures will be covering the types of load, beam, structures and relationship between reaction, pressure and gravity. Whereas Chapter 2 Equilibrium forces, shear force and bending moment will comprise all the calculation in beam includes shear force and bending moment diagram. Meanwhile Chapter 3 Direct Stress will be cover the fundamental of material including stress-strain, deformation of stress and also Modulus of Elasticity.

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CHAPTER 1

INTRODUCTION TO:

MECHANICS OF CIVIL ENGINEERING STRUCTURES

CHAPTER 1

INTRODUCTION TO MECHANICS OF CIVIL ENGINEERING STRUCTURES

INTRODUCTION

Structural mechanics, or solid mechanics, is a field of applied mechanics in which you compute deformations, stresses, and strains in solid materials. Often, the purpose is to determine the strength of a structure, such as a bridge, in order to prevent damage or accidents. Other common goals of structural mechanics analysis include determining the flexibility of a structure and computing dynamic properties, such as natural frequencies and responses to time-dependent loads.

The subject matter includes such fundamental concepts as stresses and strains, deformations and displacements, elasticity and inelasticity, strain energy, and load-carrying capacity. These concepts underlie the design and analysis of a huge variety of structural systems.

In this book version, **MECHANICS OF CIVIL ENGINEERING STRUCTURES** covers knowledge of facts and basic principles of types of forces, strength of materials and behavior of loaded structures.

01 **MECHANICS** : Study or analysis of object movement.

02 **STRUCTURES** : Formed made from various part to be particular form.

03 **MECHANIC STRUCTURES** : associated with study OR analysis on qualities and structure behaviors when it imposed load or force.

1.1 : TYPES OF STRUCTURE

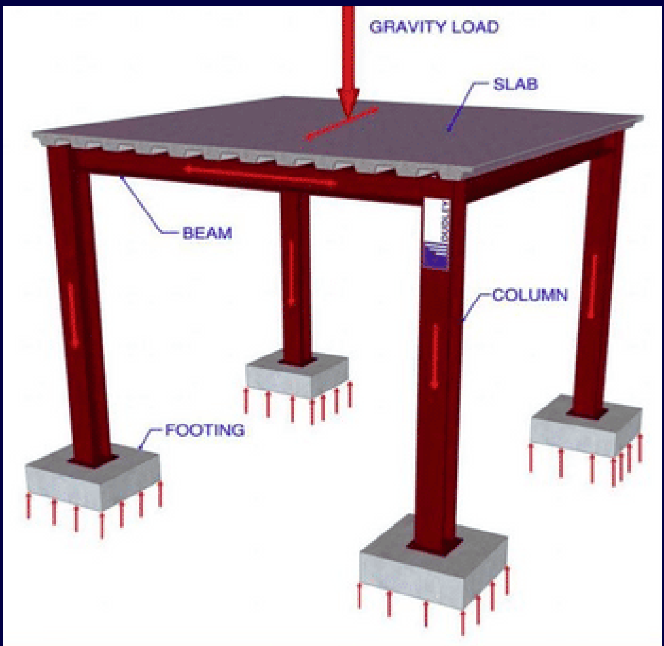


Figure 1.1 : Structure Members

STRUCTURE MEMBERS?

TYPES OF STRUCTURE MEMBERS

Structure was one extension system structure member's designs to bear force to maintain form and stability.

Example : Building - combination a few structural member such as column, beam, slab and framework.

TYPICAL STRUCTURES MEMBERS

BEAM

Straight horizontal members are used generally to carry vertical loads. Beams may be designed from several of element and materials – concrete, metal etc. with rectangular or other cross section.

Figure 1.2 : Beam

COLUMN

Members are generally vertical and resist axial compressive loads. Columns are elements similar to the tie rods but they carry vertical loads

Figure 1.3 : Column

SLAB

Constructed to provide flat surfaces, usually horizontal, in building floors, roofs, bridges, and other types of structures. The slab may be supported by walls AND reinforced concrete beams

Figure 1.4 : Slab

1.2 : TYPES OF INTERNAL AND EXTERNAL FORCES

WHAT IS INTERNAL AND EXTERNAL FORCES?

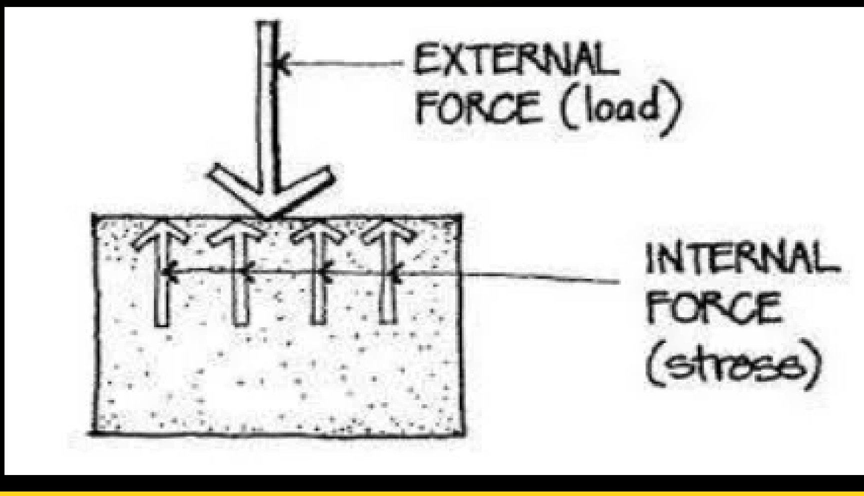


Figure 1.5 : Internal Load

The forces and couples to which a structure may be subjected can be classified into two types, external forces and internal forces.

3 TYPES OF INTERNAL FORCES

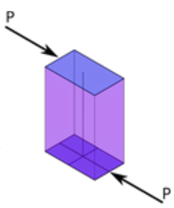
Internal forces are produced from the external forces acting on structure members such as pole, beam or column.

???

Axial force, sometimes called 'normal force,' is a compression or tension force acting aligned with the extension of a structure member.

???

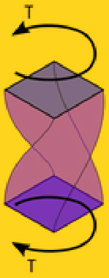
Shear force is a force acting in a direction perpendicular to the alignment of the member.



???

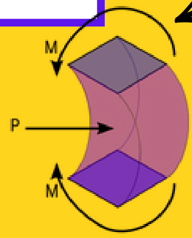
Moment force, lastly, is a turning result of a force multiplied by the distance from its acting location to the turning point. The number of these components varies in one-dimensional, two-dimensional and three-dimensional.

TORSION



Force comprising two equivalence moment which acted in direction oppositional in both his end.

Force comprising two equivalence moment which acted in direction oppositional in both his end.



BENDING

1.2 : TYPES OF INTERNAL AND EXTERNAL FORCES

EXTERNAL FORCES

- Load imposed on structures.

What is exactly means by External Forces?

External forces are the actions of other bodies on the structure under consideration. For the purposes of analysis, it is usually convenient to further classify these forces as applied forces and reaction forces.

Examples of external forces include dead loads, such as the weight of the structure itself and the non-structural materials it supports, and live loads, which include moving loads, such as occupants, goods, and furniture, as well as wind loads, seismic loads, and impact loads among others are shown in Figure 1.6 (a) and (b).

Dead Load

Dead loads consist of self-weight of the structure (weight of walls, floors, roofs etc).

Live Load

Live loads consist of moving or variable loads like people, furniture, temporary stores etc. It is also called super-imposed load.

Wind Load

The Wind acts horizontally on the surfaces of the walls, roofs and inclined roof of the structure.

Seismic Load

These loads are internal forces which act on the structure due to earthquake developed ground movements.

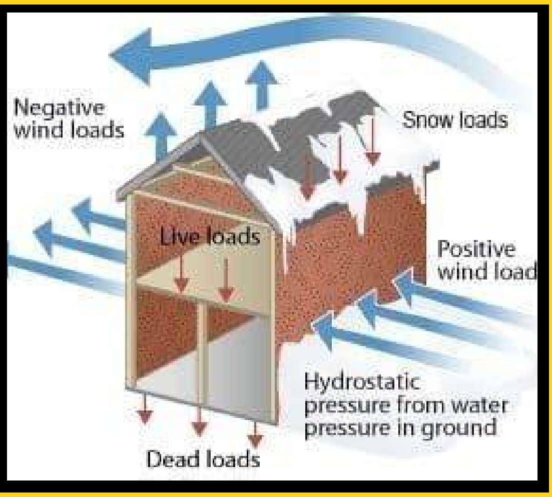


Figure 1.6 (a) : External Load

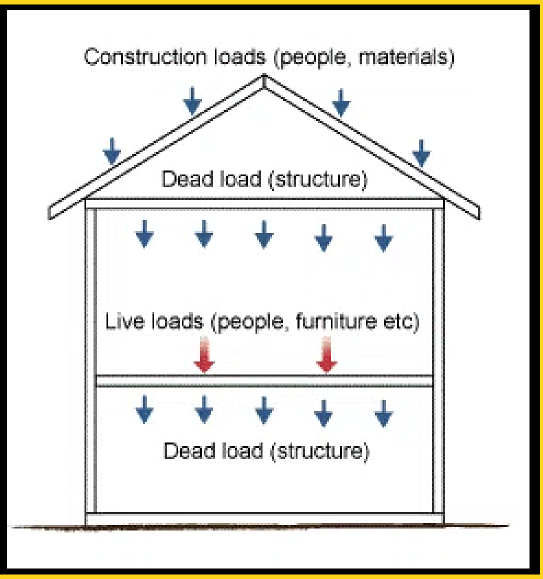


Figure 1.6 (b) : External Load

1.3 : TYPES OF SUPPORT, INTERNAL REACTION AND ITS DIRECTION IN STRUCTURE

DID YOU KNOW WHAT IT IS SUPPORT?

Support in a structure is a member which helps others member to resist loads. Different types of supports, their reactions and applications for structures and their details is discussed. Supports in a structure transfers the load to the ground and provides stability to the structure supported on it. These are the types of support in structures:

TYPES OF SUPPORT

ROLLER

this support carry only shear forces between jointed members. The roller support allows rotation and one displacement of the support point.

PINNED

this support carry shear and axial forces but not moment between different members.

FIXED END

this support carry moment, shear and axial forces between different members. This kind of support doesn't allow any displacements of the support point.

Figure 1.7 : Roller Support at end of bridge

Figure 1.8: Pinned/Hinged Support at Sydney Harbor bridge

Figure 1.9: Fixed End Support - Beam Fixed in Wall

1.4 : TYPES OF BEAM, LOAD AND REACTION

TYPES OF BEAM

Structural members are usually classified according to the types of beam and loads that they support. There are 4 types of beam will be considered in this chapter:

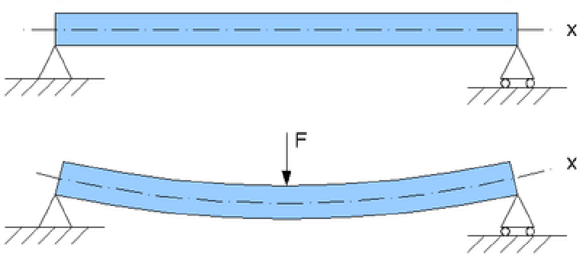


Figure 1.10 : Simply Supported Beam

Simply Supported Beam

- Beams are structural members subjected to lateral loads, that is, forces or moments having their vectors perpendicular to the axis of the bar.
- at both end are support either by pinned or roller

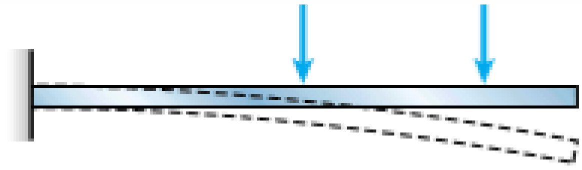


Figure 1.11 : Cantilever Beam

Cantilever Beam

- The beam which has fixed at one end and free at the other support, is called a cantilever beam.
- It is used one as support and the other one is freely unsupportly.

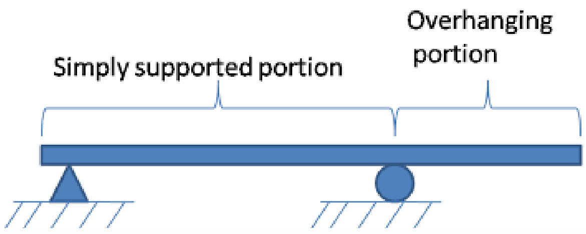


Figure 1.12 : Overhanging Beam

Overhanging Beam

- The supports are not placed at the ends i.e. supports are placed beyond the ends. One or both ends may be overhang.
- Support used either roller and pinned or combination of both.

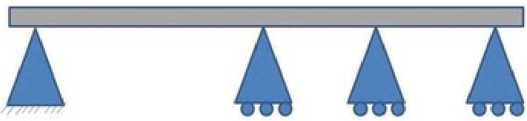


Figure 1.13 : Continuous Beam

Continuous Beam

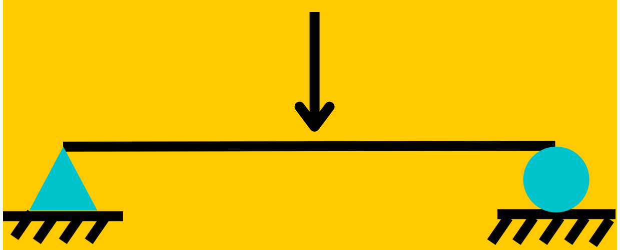
- The statically indeterminate multi span beam supported on hinges is known as continuous beam.
- These beams are supported by two or more supports.

1.4 : TYPES OF BEAM, LOAD AND REACTION

TYPES OF LOAD

Loads are classified according to the method on its being distributed on structures. There are three types of load and normally loads are carried by combination of various type of these loads. The three types loads are:

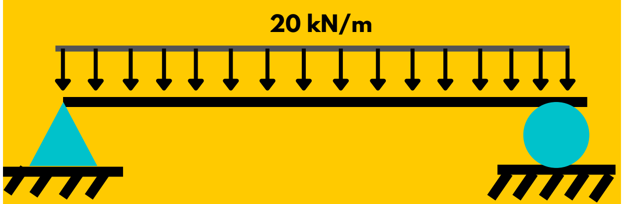
1 Point Load/ Concentrated Load



Point load is that load which acts over a small distance. Because of concentration over small distance this load can may be considered as acting on a point.

Normally, Point load is denoted by P and symbol of point load is arrow heading downward (↓) with unit Newton (N) or Kilo Newton (KN).

2 Uniformly Distributed Load (UDL)



Distributed load is that acts over a considerable length or "over a length which is measurable. Distributed load is measured as per unit length and its unit in N/m or KN/m etc.

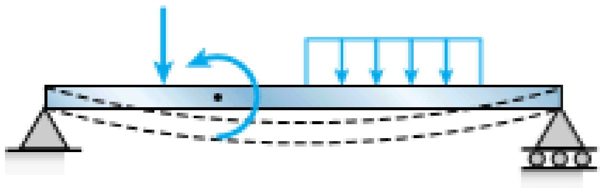
To simplify the reaction analysis, its consider the total load carried and assumed it acting at the middle of the span.

The UDL load also can be find by simply multiplying the intensity of UDL with its loading length.

The answer will be the point load which can also be pronounced as Equivalent concentrated load (E.C.L). Concentric because converted load will acts at the center of span length.

1.4 : TYPES OF BEAM, LOAD AND REACTION

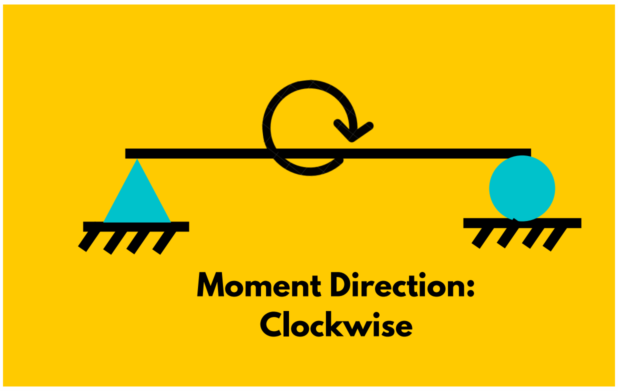
TYPES OF LOAD

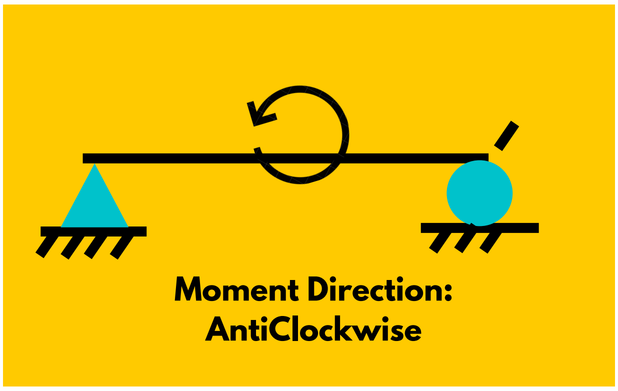


Examples of beams subjected to various of loads.

3 Moment

Moment is generate from a pair of forces. These forces are acting from a certain point and its causes turning or twist at that particular point. Its act either in direction clockwise or anti clockwise. If the direction turn into clockwise it is assume as positive and conversely in negative if the the direction turn anti-clockwise. Moment is measure in Nm or kNm etc. Moment are represented in two direction as below:





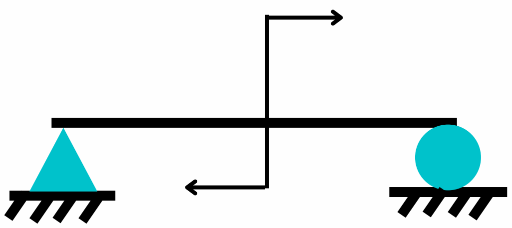


Figure 1.14 : Clockwise Moment Direction

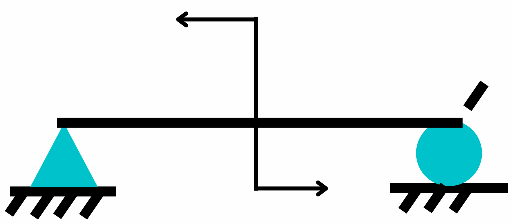


Figure 1.15: AntiClockwise Moment Direction

1.4 : TYPES OF BEAM, LOAD AND REACTION

REACTIONS AND ITS DIRECTION

Tips & Tricks

Symbol of reactions:
M = Moment
Fx = Horizontal forces
Fy = Vertical forces

In Mechanics in Civil Engineering Structures supports are basically of 4 types. Simple support, Roller support, pin support and fixed support. When the beam is loaded these supports resist the load by producing reaction. These supports allow or resist vertical reaction, horizontal reaction or a moment depending on type of support. The table below show the diagram and the direction of reaction at support:

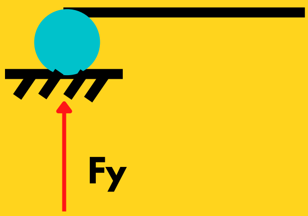
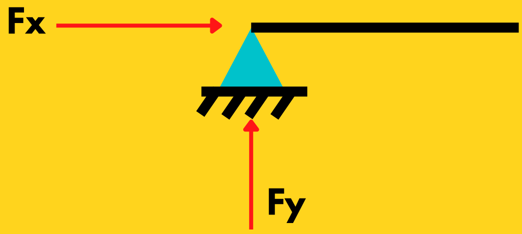
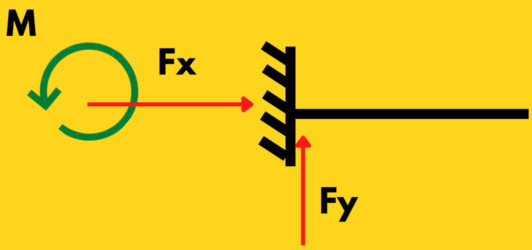
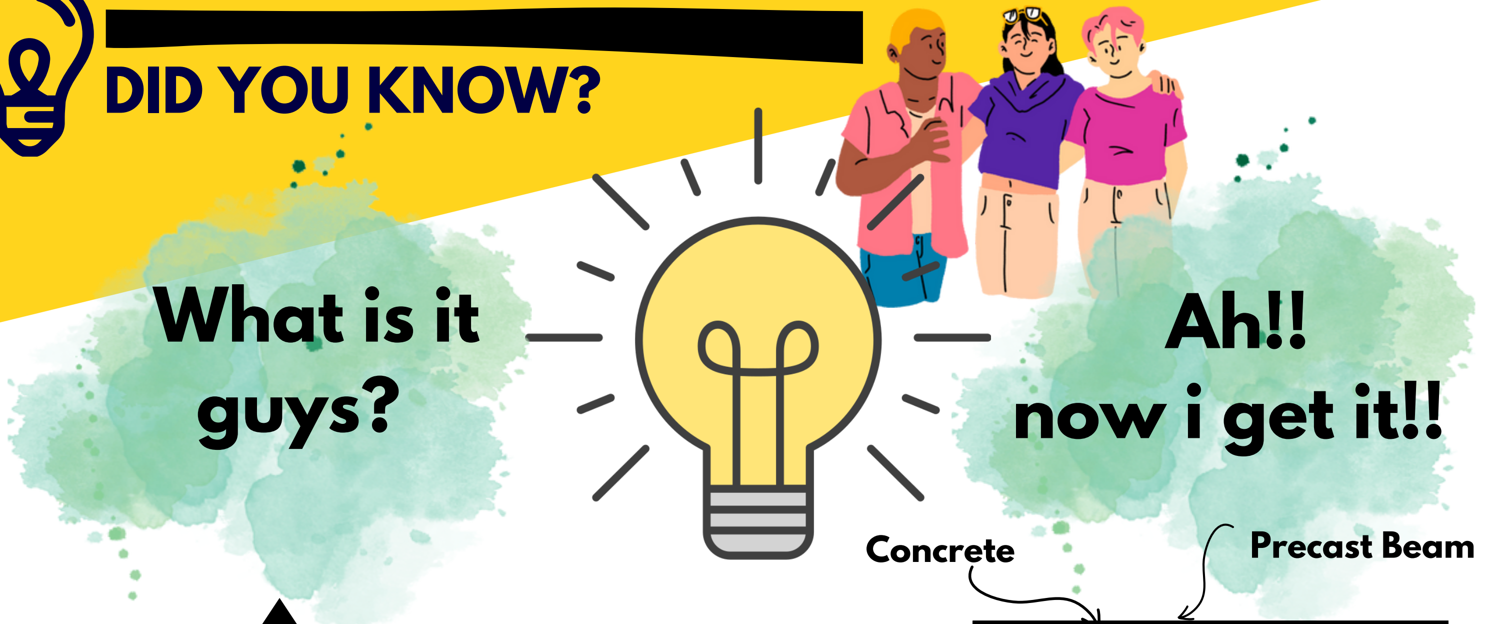
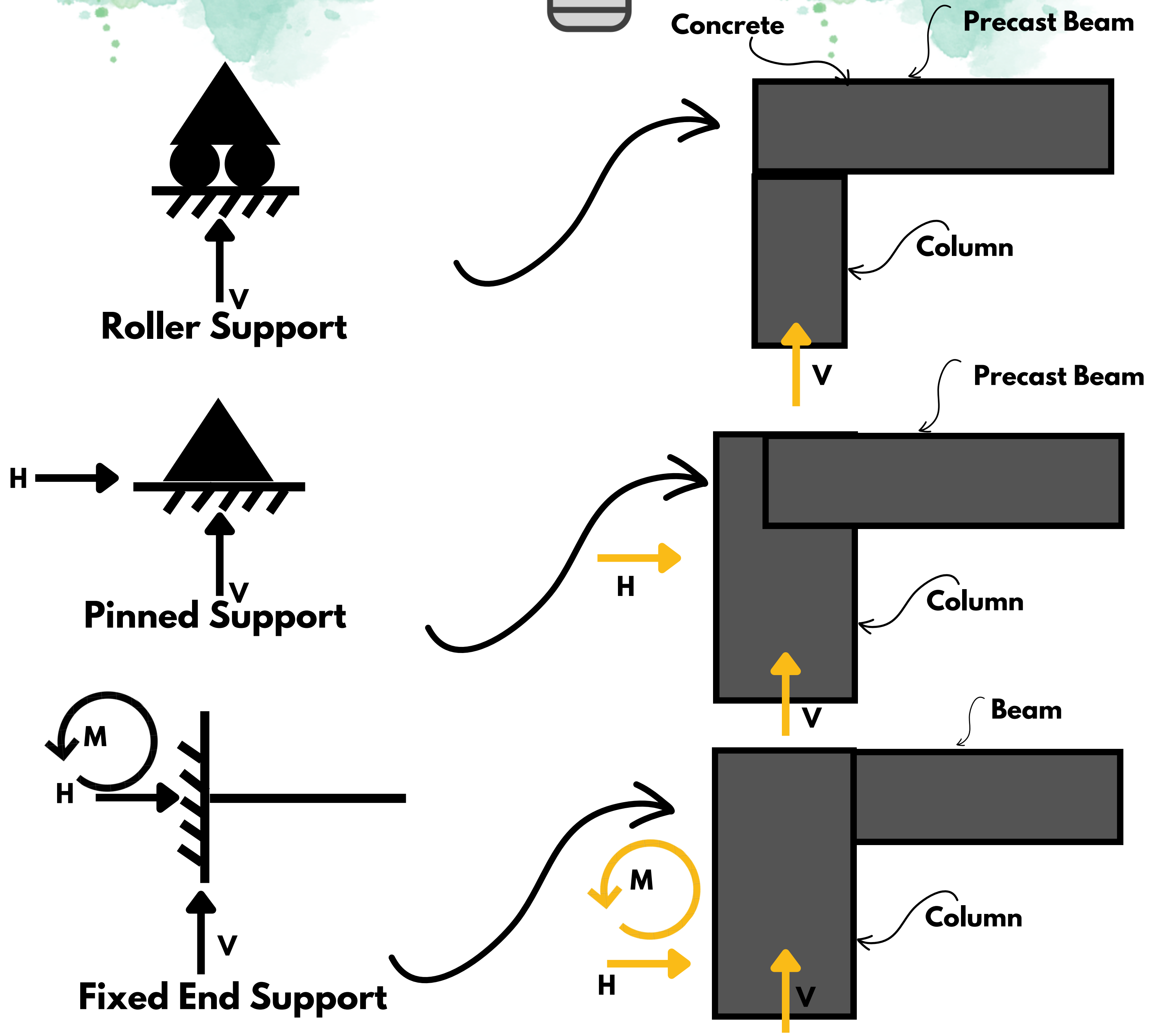
SUPPORT	DIAGRAM & DIRECTON OF REACTION	NO OF UKNOWN
Roller		1
Pinned		2
Fixed End		3

Table 1.0 : Types of Support and their direction

1.4 : TYPES OF BEAM, LOAD AND REACTION

DID YOU KNOW?





1.4 : TYPES OF BEAM, LOAD AND REACTION

CATEGORIES OF BEAM

1

Statically Determinate Beam

Statically determinate Beam; reaction forces not more than 3 and equation can be solve based on basic equation static.

Figure 1.16: 3 reaction @ Statically Determinate Beam

2

Statically Indeterminate Beam

Statically Indeterminate Beam; reaction forces have more than 3, magnitude cannot be solved by the basic equation static.

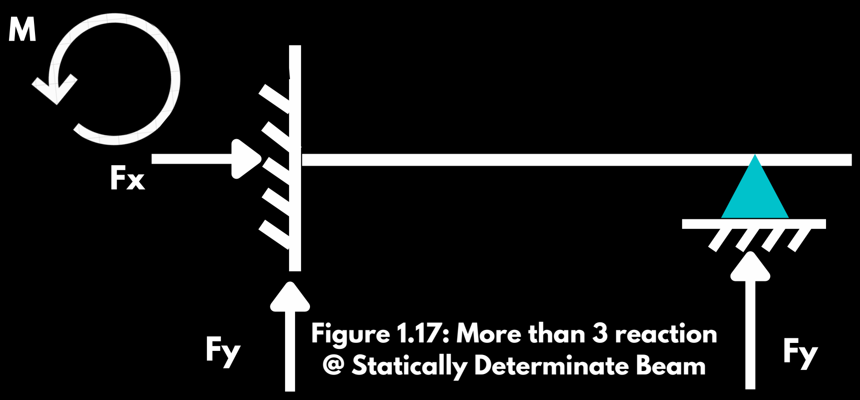


Figure 1.17: More than 3 reaction @ Statically Determinate Beam

1.5: RELATIONS BETWEEN GRAVITY, PRESSURE, LOAD AND REACTION.

GRAVITY AND PRESSURE

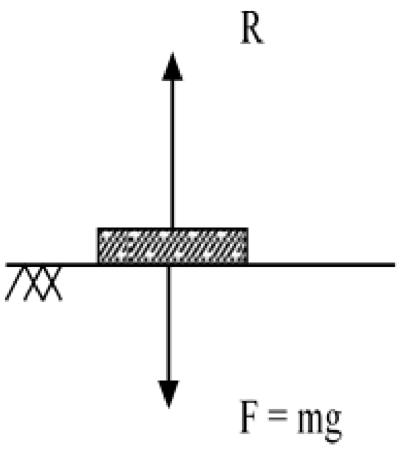
Gravity, pressure and load reaction HAVE one force action. All the three having relation to produce equilibrium in force action.

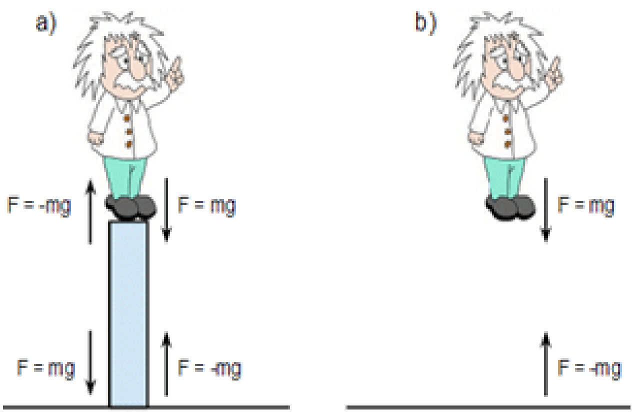
GRAVITY

01

For an example, a box placed on top a horizontal plane. If the box having mass, m and gravitational attraction, g then that box force is product between mass and gravitational attraction.

Gravity : the force that causes two particular to pull towards each other





Force, F = Mass x gravity

= Mg

$g = 9.81\ ms^{-2}$

Unit = Newton @ $kgms^{-2}$

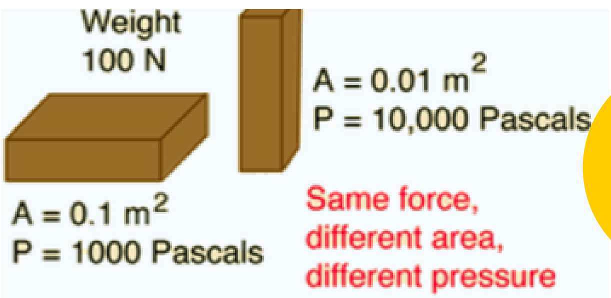
PRESSURE

02

If touch surface area between boxes with plane is A, then pressure, p experienced by surface in touch was per wide unit.

Pressure, = Force / unit area = F/A

Unit = N/ms^2 @ Pascal



1.5: RELATIONS BETWEEN GRAVITY, PRESSURE, LOAD AND REACTION.

RELATION BETWEEN LOAD AND REACTION

Relationship between load and reaction:

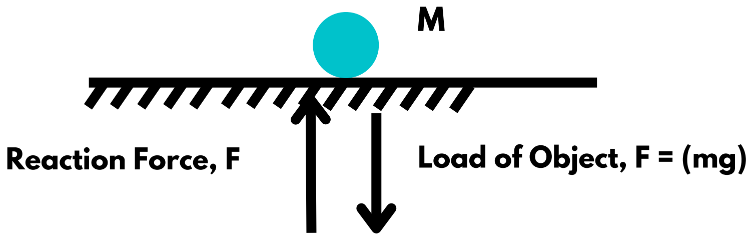
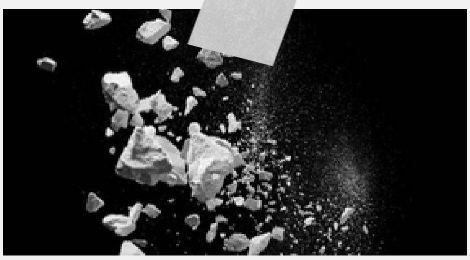


Figure : Examples of Forces and reaction

Every object has their own mass and its magnitude is different according to the material characteristic. Each object has specific mass with unit is in kilogram (kg).



Force is the product of mass and pull of gravity. An object with specific mass have weight if its influenced by gravitational pull.

Sign of reaction:

Sum of Forces to the Right (Positive)

→(+ve)

Sum of Forces to the Left (negative)

(-ve) ←

Sum of Forces vertically up (Positive)

↑(+ve)

Sum of Forces vertically down (negative)

↓(-ve)

Sum of clockwise moment (Positive) ↻ (+ve)

Sum of anticlockwise moment (negative)

↺ (-ve)

TUTORIAL QUESTION

TRY TO ANSWER THIS QUESTION (CHAPTER 1)

1. Define the type of structure in civil engineering.

Answer: Section 1.1

2. Identify TWO (2) types of support and its reaction.

Answer: Section 1.3

3. Define terms of Mechanic Structure in civil engineering.

Answer: Section 1.0

4. Draw the reaction support diagram.

Answer: Section 1.4

5. Identify the types of beam in civil engineering.

6. Identify types of load in civil engineering.

CHAPTER 2

EQUILIBRIUM FORCES, SHEAR FORCES AND BENDING MOMENT

2.0 EQUILIBRIUM FORCES

BASIC KNOWLEDGE OF EQUILIBRIUM FORCES

Tips & Tricks

A structural beam is in the static condition when all the unknown reaction can be determine by using 3 basic static equation.

A structure is considered to be in equilibrium if, initially at rest, it remains at rest when subjected to a system of forces and couples. If a structure is in equilibrium, then all its members and parts are also in equilibrium.

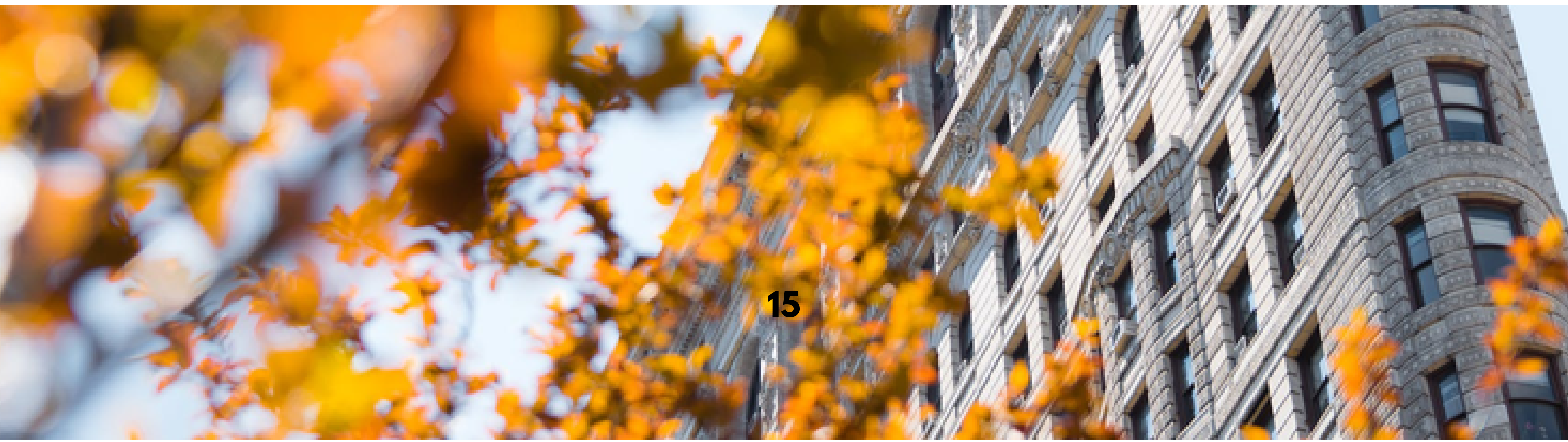
In order for a structure to be in equilibrium, all the forces and couples (including support reactions) acting on it must balance each other, and there must neither be a resultant force nor a resultant couple acting on the structure.

BASIC STATIC EQUATION

1. Algebraic sum of vertical forces = 0, $\Sigma fy = 0$
2. Algebraic sum of horizontal forces = 0, $\Sigma fx = 0$
3. Algebraic sum of moment forces = 0, $\Sigma M = 0$

These three equations are referred to as the equations of equilibrium of plane structures. The first two of the three equilibrium equations express, respectively, that the algebraic sums of the x components and y components of all the forces are zero, thereby indicating that the resultant force acting on the structure is zero.

The third equation indicates that the algebraic sum of the moments of all the forces about any point in the plane of the structure and the moments of any couples acting on the structure is zero, thereby indicating that the resultant couple acting on the structure is zero. All the equilibrium equations must be satisfied simultaneously for the structure to be in equilibrium.



2.1: FREE BODY DIAGRAM (FBD)

HOW TO DRAW FBD?

Free Body Diagrams (FBD) are useful aids for representing the relative magnitude and direction of all forces acting upon an object in a given situation.

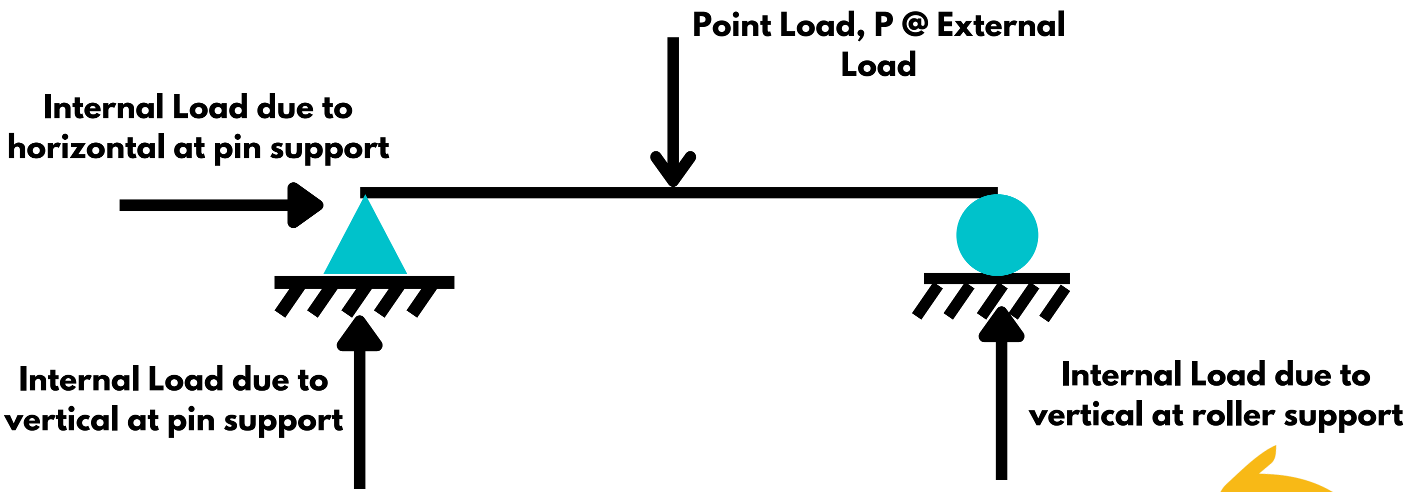


Figure 2.0 : Examples of Free Body Diagram

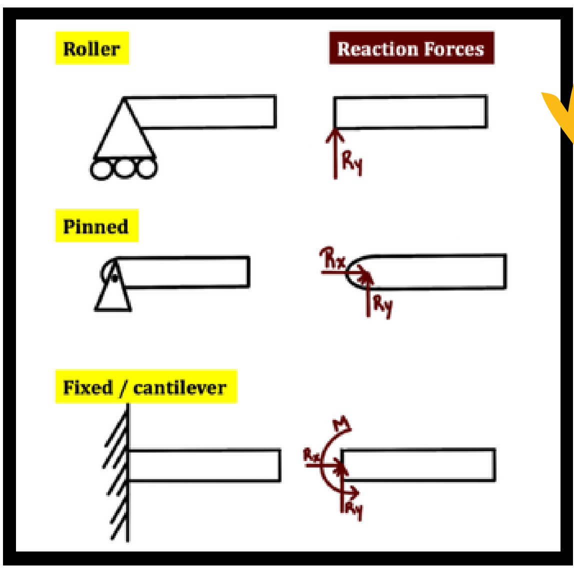


Figure 2.1 : Reaction force sign based on types of support

FBD are sketch based on their support reaction. The common mistakes student always make is forget to sketch FBD.

2.1: FREE BODY DIAGRAM (FBD)

HOW TO DRAW FBD?

Before we go how to draw the Free Body diagram, we should know the concept of Internal and External forces as is explained in Chapter 1 before.

Consider a beam as below is cut into section XX plane and separated apart as AX and XB in order to meet the equilibrium principles:

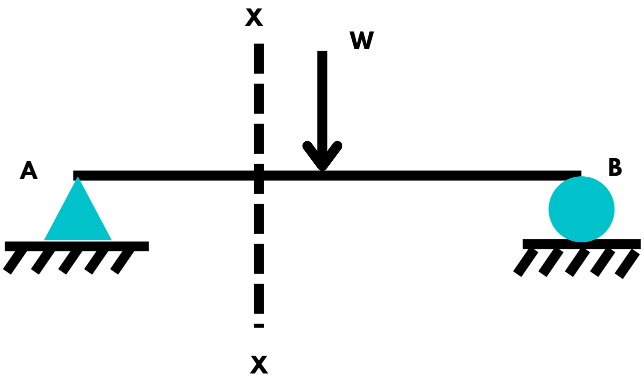


Figure 2.2 : Beam section at plane XX

MAGNITUDE AND DIRECTION OF THE REACTIONS

There are standard magnitude and direction of the reactions for the internal and external forces that important before calculate the reactions. A supported beam have several unknown (related to reactions at support given in a beam). The number of unknown will depends on the support given.

There are Internal forces exist, a force V and a moment that acting as shown in free body diagram below:

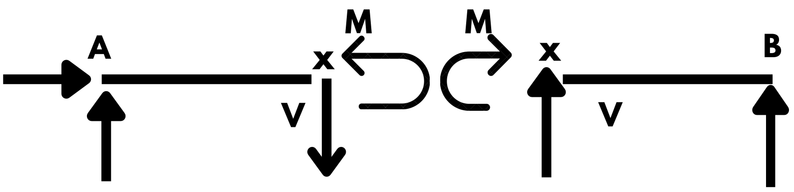
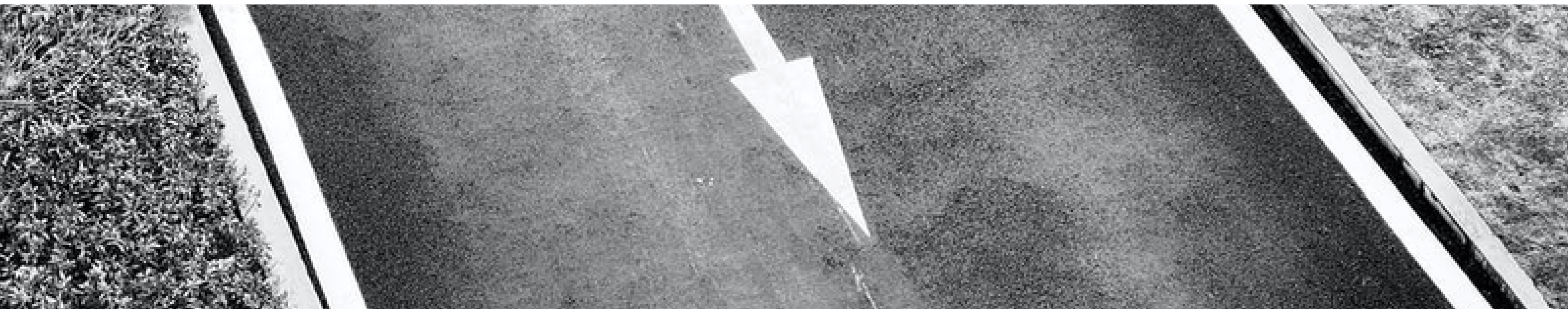


Figure 2.3 : Examples of free body diagram

This vertical V force is known as shear forces at acting point X. The moment, M also acting at point X and known as bending moment. This moment cause the beam to bend in vertical plane that contains the longitudinal axis of the beam.

The moment of all the forces, i.e., load and reaction to the left of section X-X is Clockwise. The moment of all the forces, i.e., load and reaction to the right of section X-X are Anti-Clockwise.



2.2: CALCULATION OF REACTION FORCES

HOW TO DETERMINE REACTION FORCES?

Did YOU Know?

Simply Supported Beam in real !!

Below are the guidelines to determine the reaction forces at beam:

- Determine the number of reaction at every support.
- Sketch the beam Free Body Diagram and assume the direction of reaction.
- Determine the magnitude of the reaction using basic static equation.

EXAMPLES 2.1: Simply Supported Beam With Point Load

Figure show the simply supported beam with point load of 15 KN with pinned at A and roller at support B. Determine the magnitude of reaction at the support.

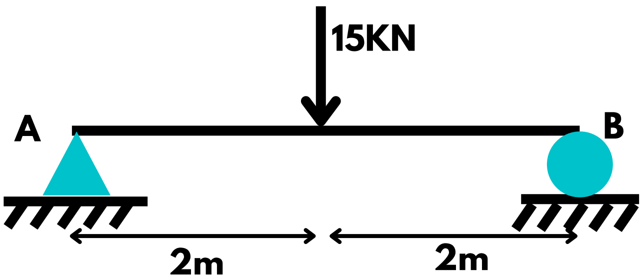


Figure 2.4 : Simply Supported Beam With Point Load

2.2: CALCULATION OF REACTION FORCES

HOW TO DETERMINE REACTION FORCES? continued

Solution:

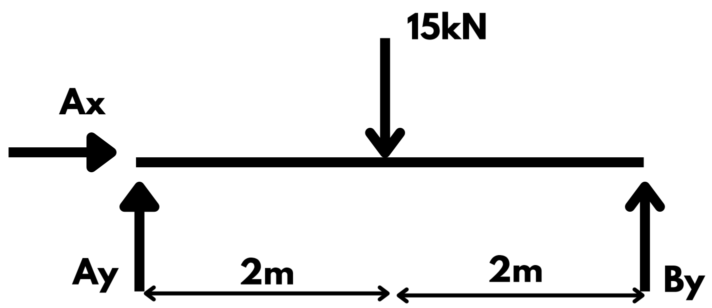
Step 1 : Determine the number of reaction at every support.

There are two reaction forces at pinned support A and one reaction at support Roller B. Figure below show the force system exists.

Solution:

Step 2 : Sketch the Free Body Diagram. (load and forces position)

There are two reaction forces at pinned support A and one reaction at support Roller B. Figure below show the force system exists.



Step 3 : Determine reaction forces by using basic static equilibrium equation

Solution:

1. **Forces to the Right (Positive) & Forces to the Left (negative)**

$\rightarrow \Sigma fx = 0$

$Ax = 0$

2. **Forces vertically up (Positive) & Forces vertically down (negative)**

$\uparrow \Sigma fy = 0$

$Ay + By - 15 = 0$

$Ay + By = 0 + 15$

$Ay + By = 15$ kN---------- eqn(i)

2.2: CALCULATION OF REACTION FORCES

HOW TO DETERMINE REACTION FORCES? Continued..

3 Clockwise moment (Positive) & Anticlockwise moment (negative)

Tips: Moment may be taken at point/support A or B, if moment taken at point A, magnitude at point By have to determined.

Take Moment at Point A:

(+ve) ↻ $\Sigma MA = 0$

$15(2) - By\,(4) = 0$

$By = 30/4$

$By = 7.5\text{ kN } (\uparrow)$

Upward arrow show due to positive answer

<u>Solution:</u>

From Equation (i): insert By into eqn (i)

$Ay + By = 15\text{ kN}$---------- eqn(i)

$Ay + 7.5 = 15\text{ kN}$

$Ay = 15 - 7.5$

$Ay = 7.5\text{ kN } (\uparrow)$

Checking at Point B, take moment at support B, find Ay:

Take Moment at Point B:

(+ve) ↻ $\Sigma MB = 0$

$-15(2) + Ay\,(4) = 0$

$Ay = 30/4$

$Ay = 7.5\text{ kN}$ (ok)

2.2: CALCULATION OF REACTION FORCES

EXAMPLES 2.2: Simply Supported Beam With Inclined Point Load

Figure 2.5 show the simply supported beam with pinned at A and roller at support B. Determine the magnitude of reaction at the support.

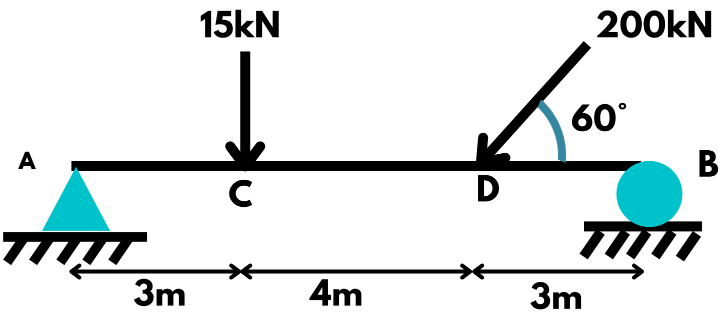
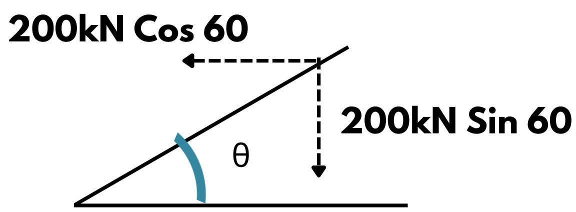


Figure 2.5: Simply Supported Beam With inclined Pont Load

Solution:

Step 1 : Determine the number of reaction at every support.

There are two reaction forces at pinned support A and one reaction at support Roller B. Inclined forces should be transform into two components of forces (vertically and horizontally)



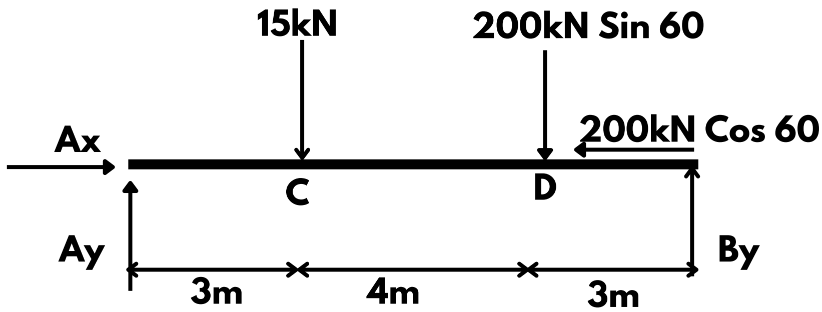
Tips: Transforming inclined point load into vertical and horizontal.

2.2: CALCULATION OF REACTION FORCES

EXAMPLES 2.2: Simply Supported Beam With Inclined Point Load

Continued..

Step 2 : Sketch the Free Body Diagram. (load and forces position)



Step 3 : Determine reaction forces by using basic static equilibrilium equation

Solution:

(1) Forces to the Right (Positive) & Forces to the Left (negative)

→ Σfx = 0
Ax - 200 Cos 60 = 0
Ax = 100 kN

(2) Forces vertically up (Positive) & Forces vertically down (negative)

↑ Σfy = 0
Ay + By - 15 - 200 sin 60 = 0
Ay + By = 0 + 15 + 173.205
Ay + By= 188.205 kN---------- eqn(i)

(3) Clockwise moment (Positive) & Anticlockwise moment (negative)

Take Moment at Point A:

↻ (+ve) ΣMA = 0
15(3) + 200 sin 60 (7) - By (10) = 0
By = 1257.43/10
By = 125 .74 kN (↑)

From Equation (i): insert By into eqn (i)
Ay + By = 188.205 kN---------- eqn(i)
Ay + 125.74 = 188.205 kN
Ay = 62.46 kN (↑)

Tips & Tricks

Tips: Now, you can try checking value Ay by taking moment at point B.

2.2: CALCULATION OF REACTION FORCES

EXAMPLES 2.3: Simply Supported Beam With Uniformly Distributed Load

Figure 2.6 show the simply supported beam subjected to a Uniformly Distributed Load. Determine the reaction at the support.

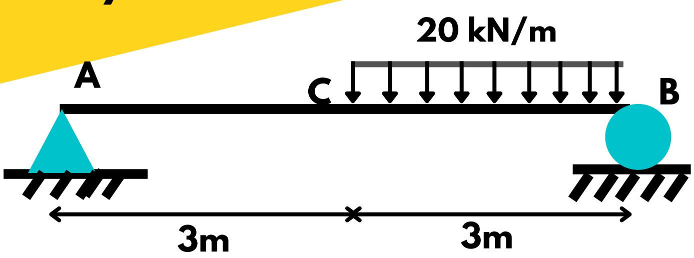
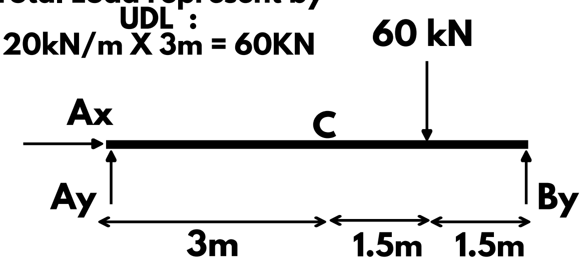


Figure 2.6 : Simply Supported Beam With UDL Load

Solution (Method 1):

Total Load represent by UDL :
20kN/m X 3m = 60KN



1 Take Moment at Point A:

(+ve) $\Sigma MA = 0$

$60(4.5) - By\ (6) = 0$

$By = 270/6$

$By = 45$ kN (↑)

2 Horizontal force :

→ $\Sigma fx = 0$

$Ax = 0$

3 Vertical force :

↑ $\Sigma fy = 0$

$Ay + By - 60 = 0$

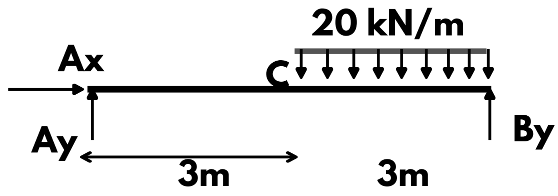
$Ay + By = 60$ ---------- eqn(i)

4 From Equation (i): insert By into eqn (i)Ay + By = 60 kN---------- eqn(i)

$Ay + 45 = 60$ kN

$Ay = 15$ kN (↑)

Solution (Method 2):



1 Take Moment at Point A:

(+ve) $\Sigma MA = 0$

$20(3)(3/2 + 3) - By\ (6) = 0$

$By = 270/6$

$By = 45$ kN (↑)

2 Horizontal force :

Same value as method 1 for Horizontal force

3 Vertical force :

↑ $\Sigma fy = 0$

$Ay + By - 20(3) = 0$

$Ay + By = 60$ ---------- eqn(i)

4 Same value as method 1 for this step.

2.2: CALCULATION OF REACTION FORCES

EXAMPLES 2.4 (a): Simply Supported Beam With Uniformly Distributed Load and Moment

Figure 2.7 show the simply supported beam subjected to a Uniformly Distributed Load and moment. Determine the magnitude and reaction at the support.

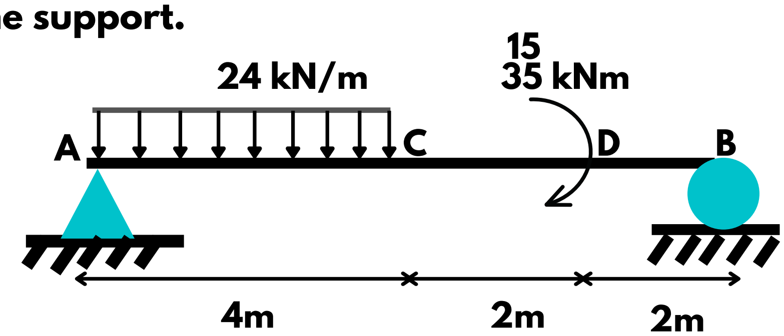
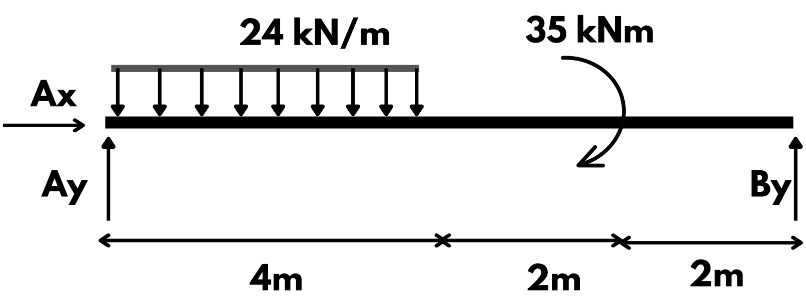


Figure 2.7: Simply Supported Beam With UDL and Moment Load

Tips & Tricks

UDL is given in the form of load per unit length. To get the total load, the load per unit length should be multiplied with the length represented.



Free Body Diagram

UDL load also can determine by consider the total load carried and multiplied with the length given and assumed it acting at the middle of the span.

Horizontal force :

$\rightarrow \quad \Sigma fx = 0$

$Ax = 0$

Take Moment at Point A :

(+ve) $\Sigma MA = 0$

$35 + 24(4)(4/2) - By(8) = 0$

$By = 227/8$

$By = 28.375$ kN ($\uparrow$)

Vertical force :

$\uparrow \quad \Sigma fy = 0$

$Ay + By - 24(4) = 0$

$Ay + By = 96$ ---------- eqn(i)

From Equation (i): insert By into eqn (i)

$Ay + By = 96$ kN---------- eqn(i)

$Ay + 28.375 = 96$ kN

$Ay = 67.625$ kN ($\uparrow$)

2.2: CALCULATION OF REACTION FORCES

EXAMPLES 2.4 (b) : Simply Supported Beam With Uniformly Distributed Load (UDL) and Moment (AntiClockwise Direction)

Figure 2.8 show the simply supported beam subjected to a Uniformly Distributed Load and moment. Determine the magnitude and reaction at the support.

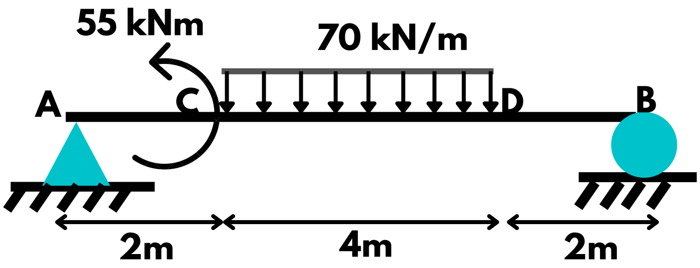
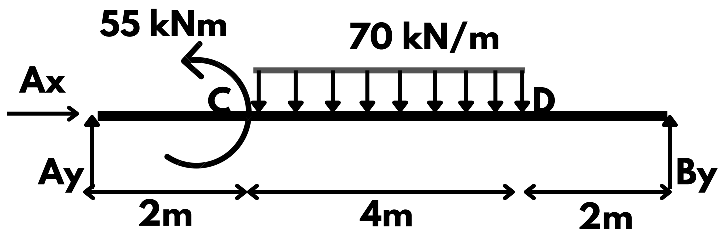


Figure 2.8: Simply Supported Beam With UDL and Moment Load



Free Body Diagram

Horizontal force :

$\rightarrow \Sigma fx = 0$

$Ax = 0$

Take Moment at Point A :

(+ve) $\Sigma MA = 0$

$-55 + 70(4)(4/2+2) - By\ (8) = 0$

$By = 1625/8$

$By = 203.125\ kN\ (\uparrow)$

Vertical force :

$\uparrow \Sigma fy = 0$

$Ay + By - 70(4) = 0$

$Ay + By = 280$ ---------- eqn(i)

From Equation (i): insert By into eqn (i)

$Ay + By = 280\ kN$---------- eqn(i)

$Ay + 203.125 = 280\ kN$

$Ay = 76.875\ kN\ (\uparrow)$

2.2: CALCULATION OF REACTION FORCES

EXAMPLES 2.5 : Simply Supported Beam With (Point Load, Inclined Point Load, Uniformly Distributed Load and Moment)

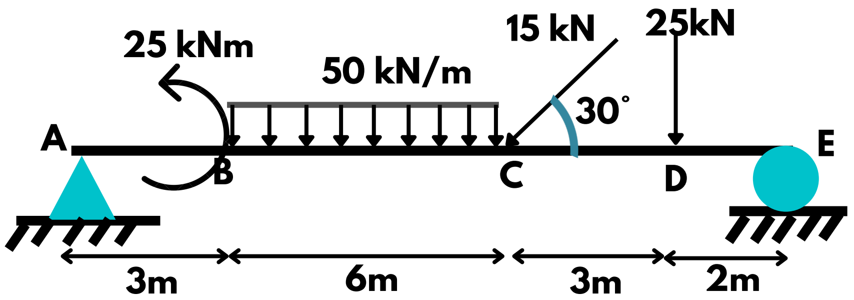
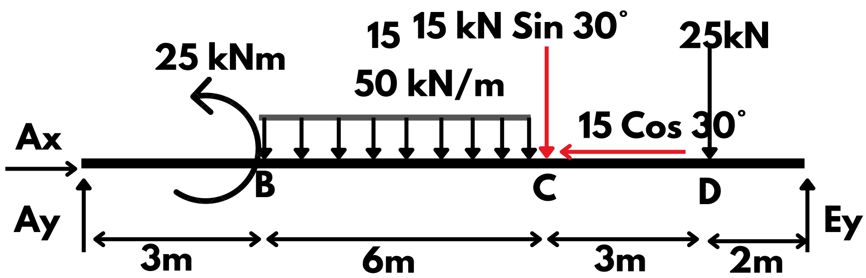


Figure 2.9: Simply Supported Beam With Multiple Load

Free Body Diagram



Horizontal force :

$\rightarrow \Sigma fx = 0$

Ax - 15 Cos 30 = 0

Ax = 12.99 kN

Vertical force :

$\uparrow \Sigma fy = 0$

Ay + Ey - 50(6) - 15 Sin 30 - 25 = 0

Ay + Ey = 332.5--- eqn(i)

Take Moment at Point A :

(+ve) $\Sigma MA = 0$

-25 + 50(6)(6/2+3) + 15 Sin 30(9) + 25(12) - Ey (14) = 0

Ey = 2142.5/14

Ey = 153.04 kN ($\uparrow$)

From Equation (i): insert By into eqn (i)

Ay + Ey = 332.5kN---------- eqn(i)

Ay + 153.04 = 332.5kN

Ay = 179.46kN ($\uparrow$)

Tips & Tricks

Checking at Point B, take moment at support B, to find Ay. If your answer is equal and same, so the answer is correct.

2.2: CALCULATION OF REACTION FORCES

EXAMPLES 2.6 : Overhanging Beam With (Point Load and Uniformly Distributed Load and Moment)

Figure 2.10 show the overhanging beam subjected to a Point and UDL Load. Determine the magnitude and reaction at the support.

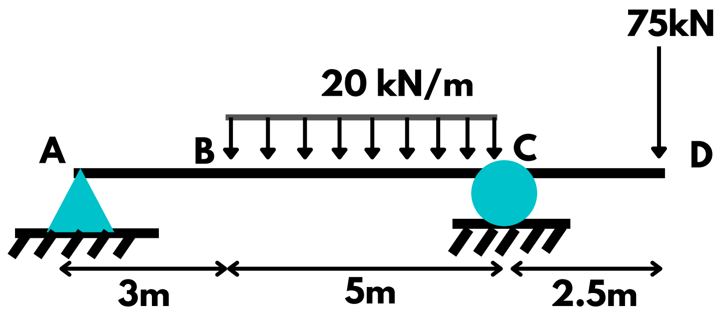
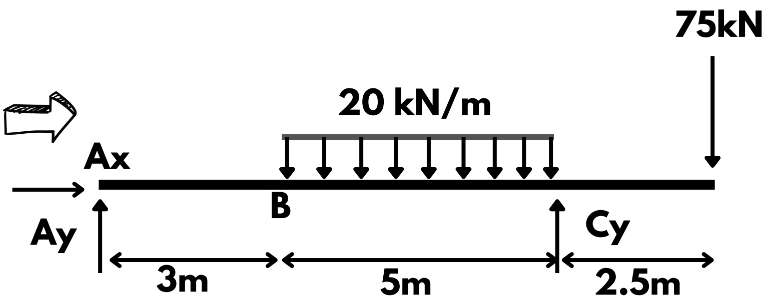


Figure 2.10: Overhanging Beam with one end hanging

Free Body Diagram



Horizontal force :

$\rightarrow \Sigma fx = 0$

$Ax = 0$

Take Moment at Point A :

(+ve) $\Sigma MA = 0$

$20(5)(5/2+3) + 75(10.5) - Cy\,(8) = 0$

$Cy = 1337.5/8$

$Cy = 167.19\text{ kN } (\uparrow)$

Vertical force :

$\uparrow \Sigma fy = 0$

$Ay + Cy - 20(5) - 75 = 0$

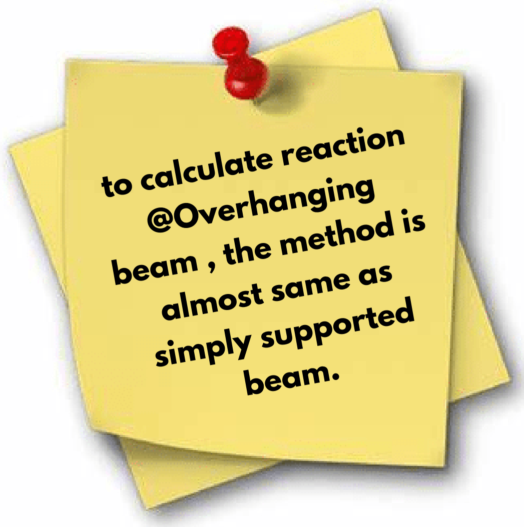
$Ay + Cy = 175kN$ --------- eqn(i)

From Equation (i): insert By into eqn (i)

$Ay + Cy = 175kN$ ---------- eqn(i)

$Ay + 167.19 = 175kN$

$Ay = 7.81kN\ (\uparrow)$



2.2: CALCULATION OF REACTION FORCES

EXAMPLES 2.7 : Overhanging Beam With Point Load and Uniformly Distributed Load. (both end hanging)

Figure 2.11 show the overhanging beam subjected to a Point and UDL Load. Determine the magnitude and reaction at the support.

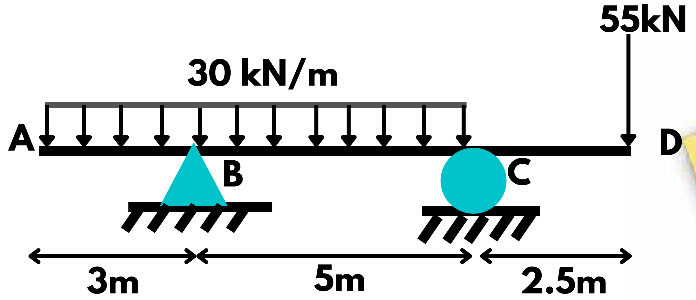
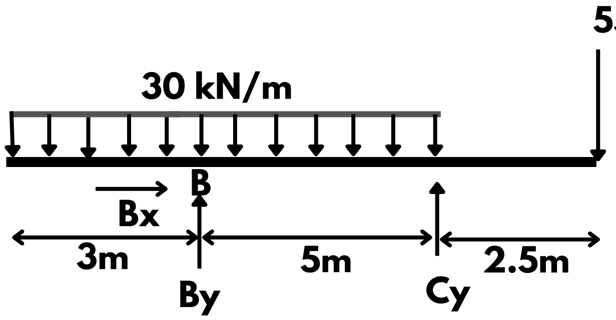


Figure 2.11: Overhanging Beam with both end hanging

> If beam are overhanging at both end, to calculate reaction beam, moment are taken at support pinned or roller.

Free Body Diagram



Horizontal force :

$\rightarrow \Sigma fx = 0$

$Ax = 0$

Vertical force :

$\uparrow \Sigma fy = 0$

$By + Cy - 30(8) - 55 = 0$

By + Cy = 295kN--------- eqn(i)

Take Moment at Point A :

$(+ve)\Sigma MB = 0$

$-30(3)(3/2) + 30(5)(5/2) + 55(7.5) - Cy(5) = 0$

$Cy = 652.5/5$

$Cy = 130.5\ kN\ (\uparrow)$

From Equation (i): insert By into eqn (i)

By + Cy = 295 kN---------- eqn(i)

$By + 130.5 = 295\ kN$

$By = 164.5\ kN\ (\uparrow)$

> **Checking at Point C, take moment at support C, find By:**
>
> $(+ve)\quad \Sigma MC = 0$
>
> $-30(8)(8/2) + 55(2.5) + By(5) = 0$
>
> $By = 822.5/5$
>
> By = 164.5 kN (ok!)

2.2: CALCULATION OF REACTION FORCES

EXAMPLES 2.8 : Cantilever Beam With Point Load and Uniformly Distributed Load.

Figure 2.12 show the Cantilever beam with fixed end support subjected to a Point and UDL Load. Determine the magnitude and reaction at the support.

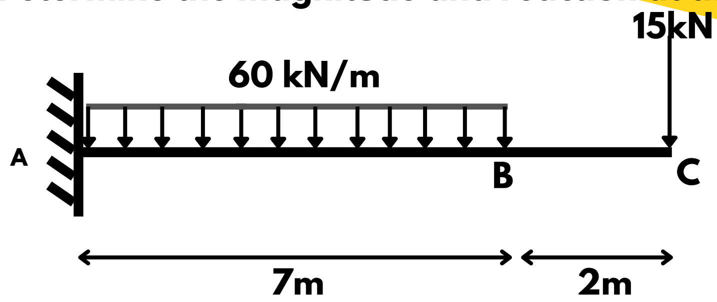


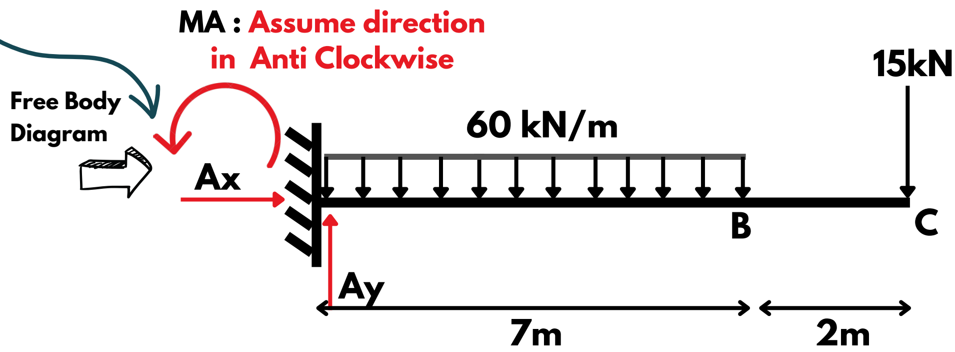
Figure 2.12 : Cantilever Beam with fixed end support

Tips & Tricks

Notes : Moment for this support are assume in anticlockwise direction. So, the value is in negative (-ve).

At fixed end support, there are 3 unknown reaction:

- Moment @support, M
- Horizontal force, Fx
- Vertical force , Fy



Horizontal force :

$\longrightarrow \Sigma fx = 0$

$Ax = 0$

Take Moment at Point A (at fixed support) :

(+ve) $\Sigma MA = 0$

$- MA + 60(7)(7/2) + 15(9) = 0$

$- MA = -1605 \text{ kNm}$

$MA = 1605 \text{ kNm}$

Direction: anticlockwise

Notes : The direction of moment value is depends on the first moment assumption. If the value in positive, so the direction of moment will act same.

Vertical force :

$\uparrow \Sigma fy = 0$

$Ay - 60 (7) - 15 = 0$

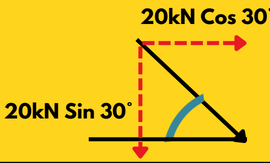
$Ay = 435\text{kN} (\uparrow)$

2.2: CALCULATION OF REACTION FORCES

EXAMPLES 2.9 : Cantilever Beam With Inclined Point Load and Uniformly Distributed Load.

Figure 2.13 show the Cantilever beam with fixed end support subjected to a Inclined Point and UDL Load. Determine the magnitude and reaction at the support.

Converting incline points load into two components.



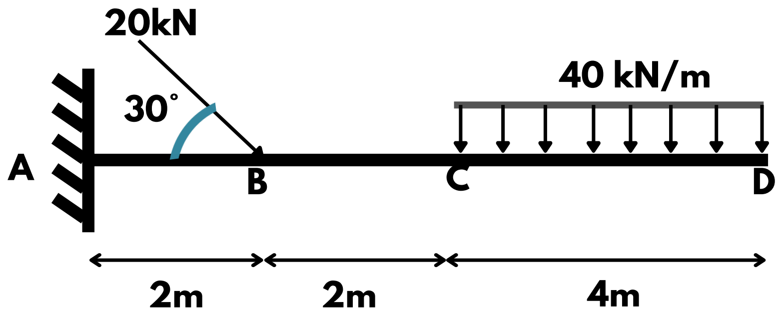
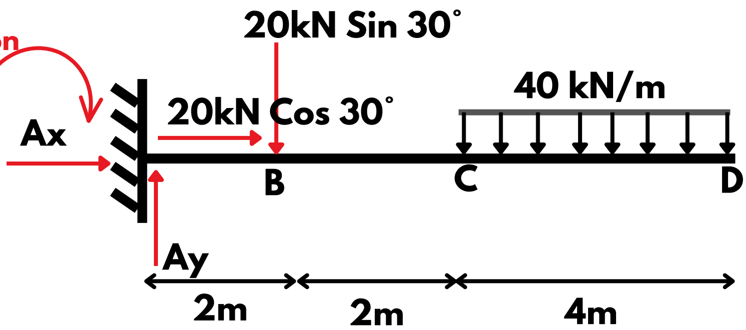


Figure 2.13: Cantilever Beam with fixed end support

Free Body Diagram

MA : Assume direction in Clockwise



Horizontal force :

$\rightarrow$ $\Sigma fx = 0$

$Ax + 20 \cos 30^\circ = 0$

$Ax = -17.32kN$ ($\leftarrow$)

Notes : The direction of Ax value is in negative, so the direction of forces will act oppositely with the first assumption.

Take Moment at Point A (at fixed support) :

(+ve) $\Sigma MA = 0$

$MA + 20 \sin 30^\circ (2) + 40(4)(4/2 + 4) + 15(9) = 0$

$MA = - 1115$ kNm

Direction: anticlockwise

Vertical force :

$\uparrow$ $\Sigma fy = 0$

$Ay - 20 \sin 30^\circ - 40 (4) = 0$

$Ay = 150kN$ ($\uparrow$)

2.2: CALCULATION OF REACTION FORCES

EXAMPLES 2.10 : Cantilever Beam With Inclined Point Load and Uniformly Distributed Load.

Figure 2.14 show the Cantilever beam with fixed end support subjected to a Point and UDL Load. Determine the magnitude and reaction at the support.

> Notes : Cantilever beam /fixed end support can be illustrate in two position, either free end in right or left side.

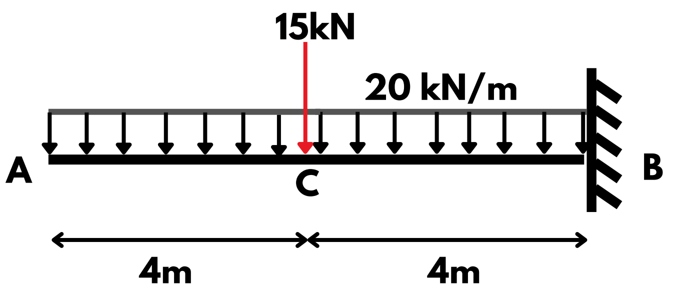
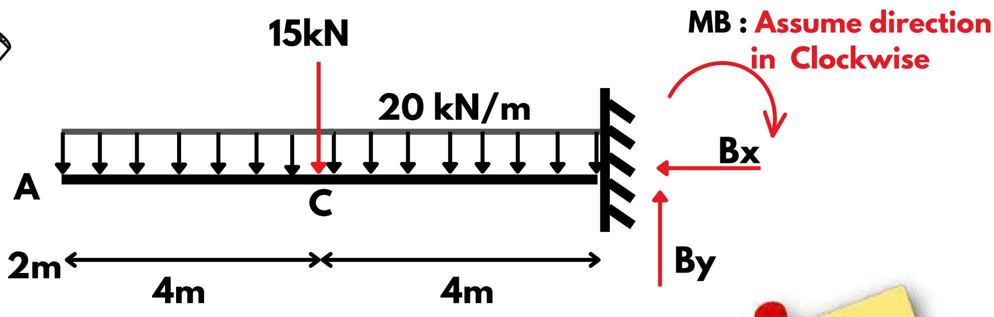


Figure 2.14: Cantilever Beam with fixed end support

Free Body Diagram



Horizontal force : (→)

$\Sigma fx = 0$

$Bx = 0$

Take Moment at Point A (at fixed support) :

(+ve) $\Sigma MB = 0$

$MB - 20\,(8)\,(8/2) - 15(4) = 0$

$MB = 700$ kNm (+ve)

> Notes : Moment for this support are assume in clockwise direction. So, the value is in positive (+ve).

Vertical force : (↑)

$\Sigma fy = 0$

$By - 20\,(8) - 15 = 0$

$By = 175$kN (↑)

2.3: SHEAR FORCE AND BENDING MOMENT

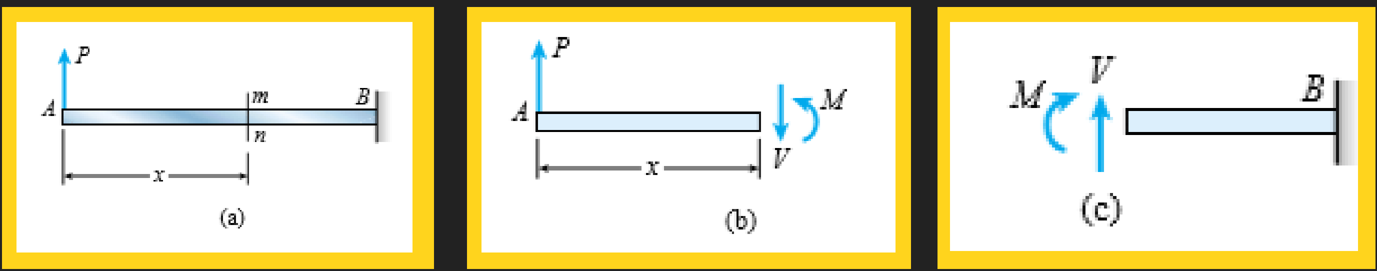
INTRODUCTION

In this chapter we will discuss shear forces and bending moments in beams, and know how these quantities are related to each other and to the loads.

Shear forces and bending moments is an essential step in the design of any beam. We need to know not only the maximum values of these quantities, but also the manner in which they vary along the axis.

When a beam is loaded by forces or couples, stresses and strains are created throughout the interior of the beam. To determine these stresses and strains, we first must find the internal forces and internal couples that act on cross sections of the beam.

As an illustration of how these internal quantities are found, consider a cantilever beam AB loaded by a force P at its free end as per figure below:



We cut through the beam at a cross section mn located at distance x from the free end and isolate the left-hand part of the beam as a free body.

The free body is held in equilibrium by the force P and by the stresses that act over the cut cross section. From statics, we know that the resultant of the stresses acting on the cross section can be reduced to a shear force V and a bending moment M

2.3: SHEAR FORCE AND BENDING MOMENT

SIGN CONVENTION

SHEAR STRESS

Shear stress at any beam section is in algebraic sum (force acting vertically at left or right support). This shear forces acting in vertically (direction in y axis.)

Sign Conventions Shear Force :

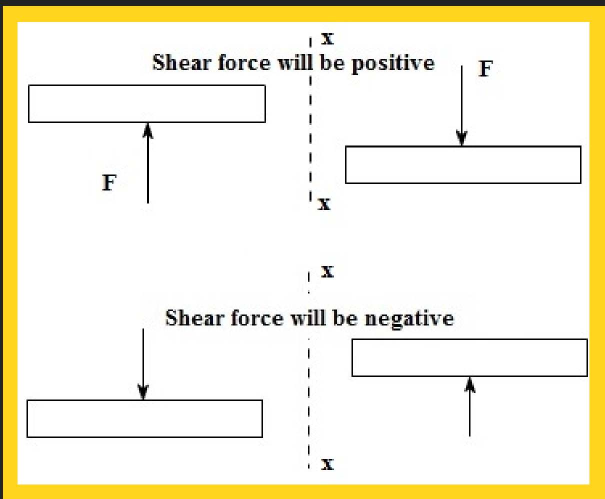


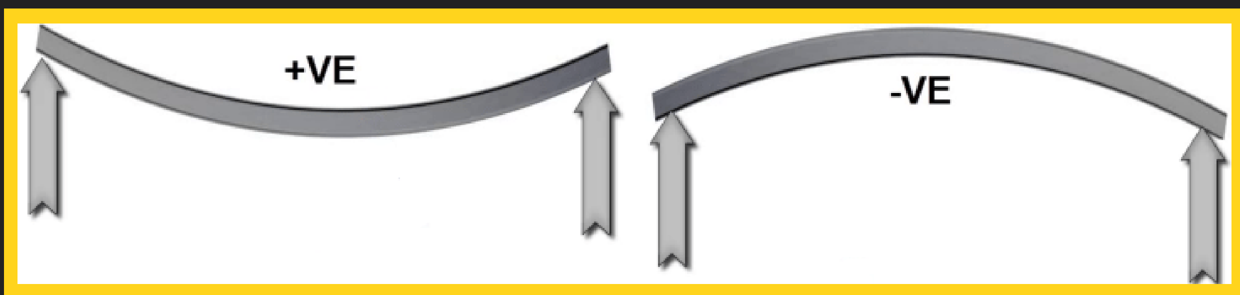
Figure 2.15 : Sign Conventions Shear Force

Similarly for Shear force is positive when the left portion of the section goes upwards or the right portion of the section goes downwards.

Shear force is Negative when left portion of the section goes downwards, or the right portion of the section goes upwards.

BENDING MOMENT

Bending moment at every beam section is defined as in algebraic sum of moment on the left and right section of the beam. This bending moment is cause by bending/flexure.



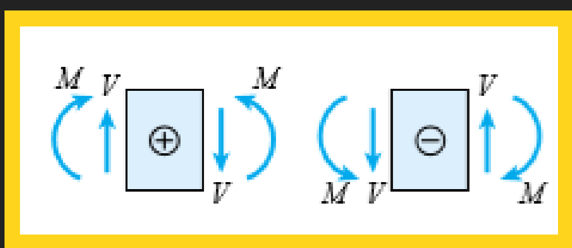


Figure 2.16 : Sign conversion for shear force, V and bending

2.4: SHEAR FORCE AND BENDING MOMENT DIAGRAM

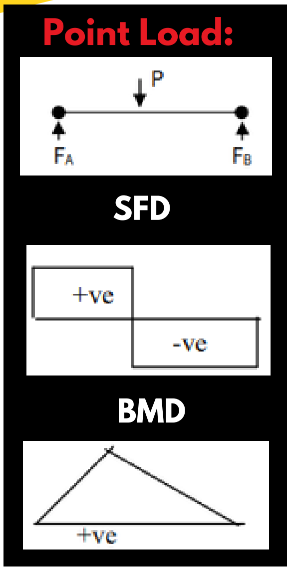
WHAT IT IS SFD & BMD?

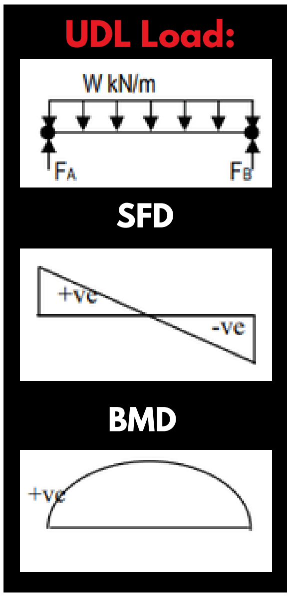
Shear force and Bending moment diagram in beams can be useful to determine the maximum absolute value of the shear force and the bending moment of the beams with respect to the relative load.

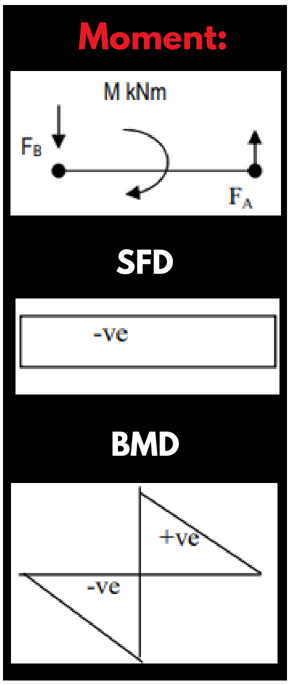
HOW TO DRAW SHEAR FORCE DIAGRAM (SFD) AND BENDING MOMENT DIAGRAM (BMD)

The listed points below are very important to consider while drawing the SFD and BMD:

- ☑ Consider the left or the right portion of the section.
- ☑ Add the forces(including reactions) normal to the beam on the one of the portion.
- ☑ If the right portion of the section is chosen, then the force acting downwards is positive and the force acting upwards is negative.
- ☑ If the Left portion of the section is chosen, then the force acting downwards is negative and the force acting upwards is positive.
- ☑ The positive values of Shear force and Bending moment are plotted above the baseline the negative values are plotted below the baseline.
- ☑ Shear force diagram will increase or decrease suddenly. I.e., By vertical straight line at a section where there is a vertical point load.
- ☑ Shear force between any two vertical loads will be constant. And hence the shear force between the two vertical loads will be horizontal.
- ☑ The bending moment at the two ends of the simply supported beam and at the free end of a cantilever will be zero.

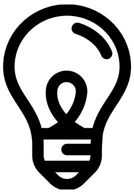






2.4: SHEAR FORCE AND BENDING MOMENT DIAGRAM

Before draw SFD and BMD, we needs to calculate Shear force and bending moment first. The examples below show how to calculate Shear force and bending moment:



EXAMPLES 2.11 : Simply Supported Beam (Point Load).

Figure 2.17 below show the Simply Supported Beam subjected to 10kN Point Load . Determine value of Shear Force and Bending Moment and draw the diagram.

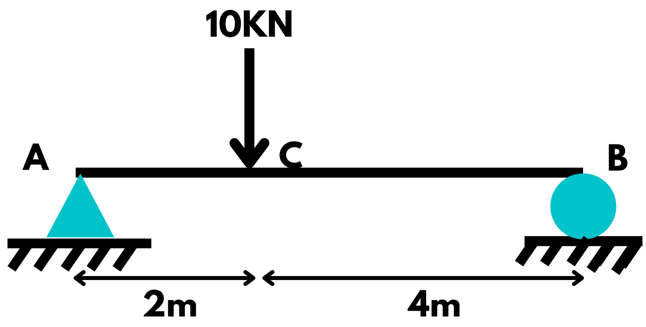
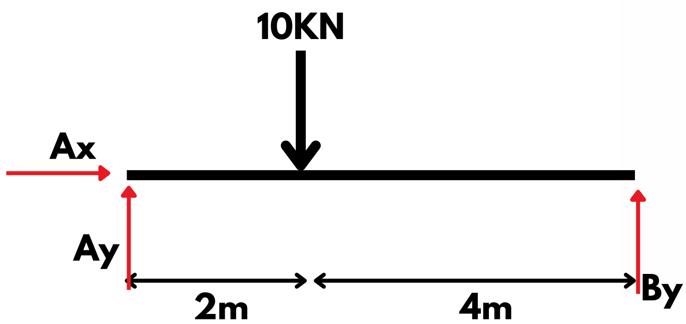


Figure 2.17 : Simply Supported Beam With Point Load

Before we calculate the Shear Force and bending moment, the reaction at support must be find first.

Step 1 :

Determine the reaction force at support



Horizontal force :

$\rightarrow \Sigma fx = 0$

$Ax = 0$

Vertical force :

$\uparrow \Sigma fy = 0$

$Ay + By - 10 = 0$

$Ay + 3.33 = 10$

$Ay = 6.67kN$

Take Moment at Point A :

$\circlearrowright (+ve)\ \Sigma MA = 0$

$10(2) - By(6) = 0$

$By = 20/6$

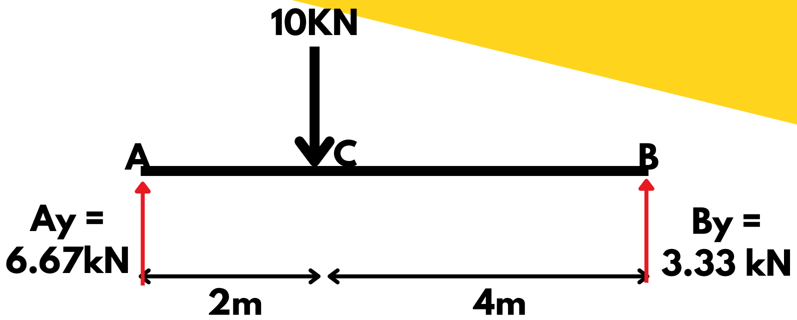
$By = 3.33\ kN\ (\uparrow)$

2.4: SHEAR FORCE AND BENDING MOMENT DIAGRAM

EXAMPLES 2.11 : Simply Supported Beam (Point Load).

Step 2 :

Determine the Shear Force by observing every section point from left to right . At each shear force point must remark as, F. For an example, point A, will remarks as FA and etc.



Shear Force value are find from left to right by point to another point.

- at point A, FA :

There is a value Ay = 6.67kN (acting upward), so the value is positive. Then it is written as, FA = 6.67kN

- at point C, FC :

There is a value at point C = 10kN (acting downward), so the value is negative. By taking value at point A, here it is written as;

FC = 6.67 - 10kN

FC = - 3.33 kN

- at point B, FB :

The sum of shear forces at ends must be equal to zero.

There is a value at point B = 3.33kN (acting upward), so the value is positive. By taking value at point C, here it is written as;

FB = - 3.33 + 3.33kN

FB = 0 kN

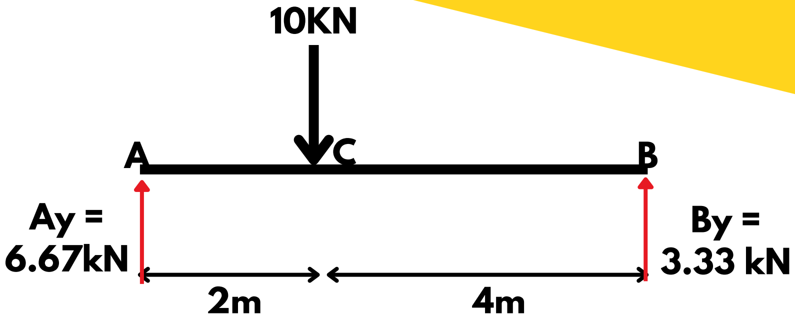
2.4: SHEAR FORCE AND BENDING MOMENT DIAGRAM

EXAMPLES 2.11 : Simply Supported Beam (Point Load).

Step 3 :

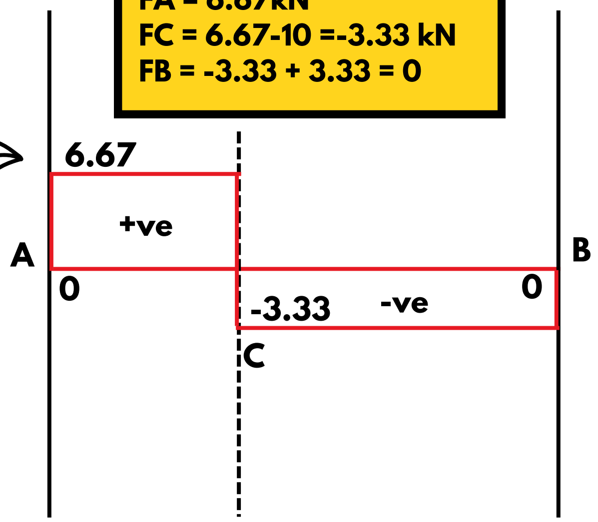
Drawing/sketching Shear Force Diagram:

- marks and connect all the shear force values from left to right.



Shear Force diagram/shape are depends on the types of load. It is draw from left to right by point to another point.

Shear Force Value:
FA = 6.67kN
FC = 6.67-10 =-3.33 kN
FB = -3.33 + 3.33 = 0



As mentioned before, point load shape for Shear Force is in constant.

Value of SF vertically upward is positive, and vertically downward is negative

Step 4 :

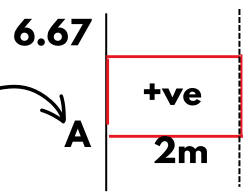
- Determine the Bending Moment by observing every section point from left to right . At each bending point must remark as, M. For an example, point A, will remarks as MA and etc.

- at point A, MA : 0 kNm

FA =
6.67 kN

- at point C, MC : (use Area Method), shape of FA to point C is rectangular, so area of rectangular is define as below:

- MC = 6.67 (2)
  = 13.34kNm



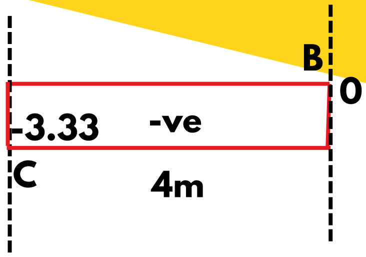
2.4: SHEAR FORCE AND BENDING MOMENT DIAGRAM

EXAMPLES 2.11 : Simply Supported Beam (Point Load).

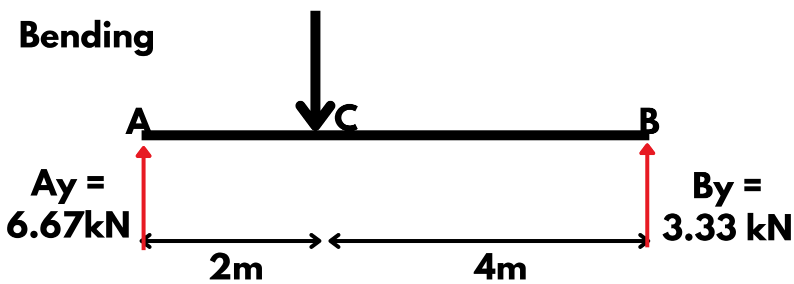
- at point B, MB : (use Area Method), by taking moment value from left, MB is define as below:

- MB = 13.34 - 3.33(4)
  = 0kNm

consideration of rectangular area value (distance X shear force) for bending moment



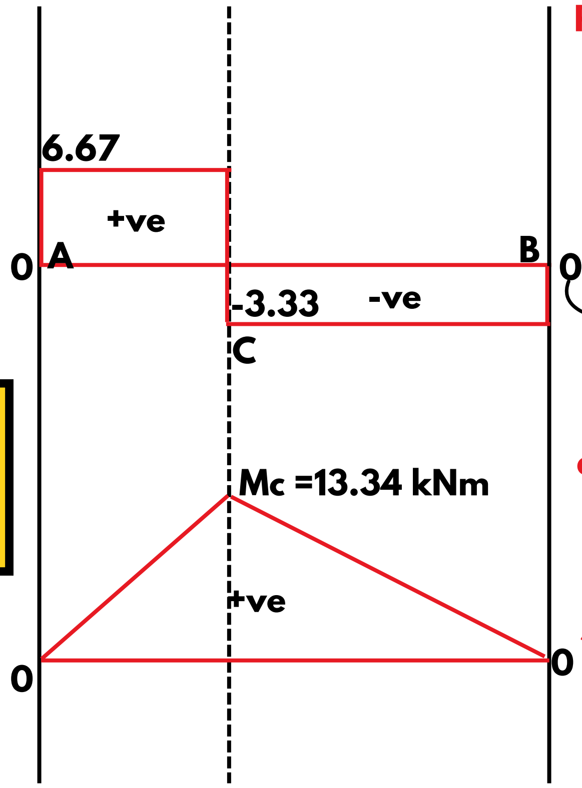
Step 5 : Drawing/sketching Bending Moment Diagram:



Shear Force Value:
FA = 6.67kN
FC = 6.67-10 =-3.33 kN
FB = -3.33 + 3.33 = 0

Bending Moment Value:
MA = 0
MC = 6.67(2) =13.34kNm
MB = 13.34 - 3.33(4) = 0

The sum of shear forces and bending moment at ends of support must be equal to zero.



Point load shape for Bending Moment is in linear.

The shape of SFD and BMD are depends on the type of load;
Point Load;
SFD = Constant
BMD = linear

2.4: SHEAR FORCE AND BENDING MOMENT DIAGRAM

EXAMPLES 2.12 : Simply Supported Beam (UDL Load).

Determine the reaction at figure 2.18 below. Sketch the Shear Force and Bending Moment diagram.

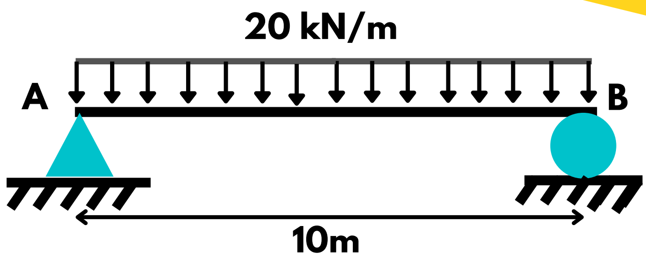
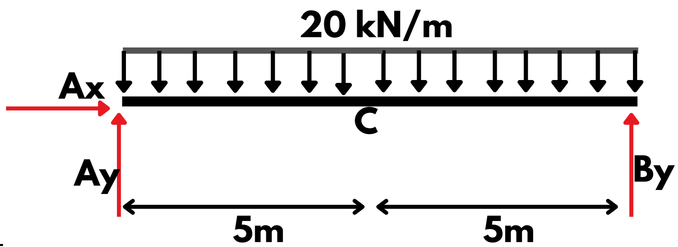


Figure 2.18 : Simply Supported Beam With UDL

Step 1 :

Determine the reaction force at support



Lets say the value of reaction are as below:
Ax = 0kN
Ay = 100kN
By = 100kN

Step 2 :

Determine the shear force value

Shear Force Value:

FA = 100 kN

FC = 100 - 20(5) = 0 kN

FB = 0 - 20 (10) = -100 kN

FB'= -100 + 100 = 0 kN

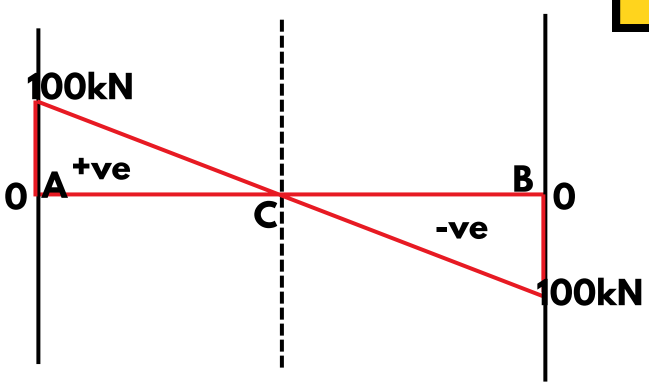
Sum of force at point C, (at middle of span of UDL load) multiplied with distance. (act downward (-ve) value.

Sum of force at point C to B, (UDL load) multiplied with 10 m distance. (act downward (-ve) value.

Forces By acting upward. (+ve) value.

Step 3 :

Drawing/Sketching the SFD



Watch & Learn how to draw SFD & BMD @ youtube:

2.4: SHEAR FORCE AND BENDING MOMENT DIAGRAM

EXAMPLES 2.12 : Simply Supported Beam (UDL Load). Continued..

Step 4 :

Determine the bending moment value

Bending Moment Value:

MA = 0 kNm

MC = 1/2 (100)(5) = 250 kNm

MB= 250 - 1/2 100 (5) = 0 kNm

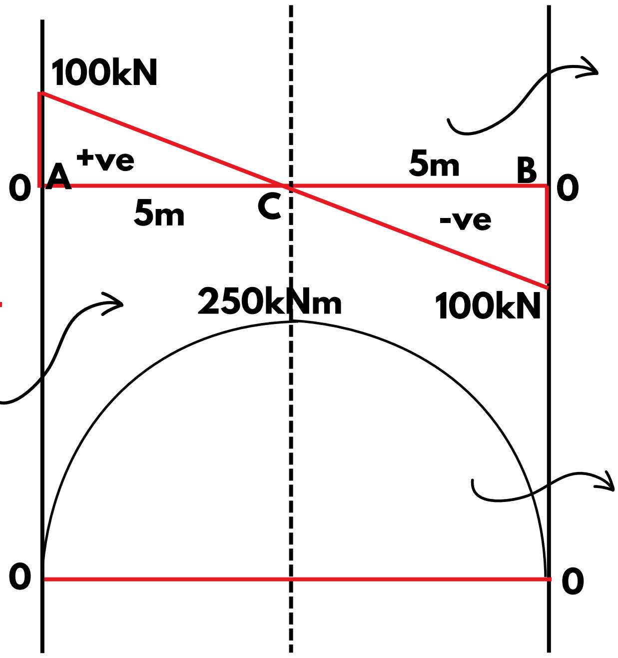
Bending at point C, consideraton of total area of triangle shape : (1/2 (SF * distance)

Forces acting downward. (-ve) value of total area of triangle shape.

Step 5 :

Drawing/Sketching the BMD

Maximum bending moment accurs at x-axis section



Shear Force Value:
FA = 100 kN
FC = 100 - 20(5) = 0 kN
FB = 0 - 20 (10) = -100 kN
FB'= -100 + 100 = 0 kN

Bending Moment Value:
MA = 0 kNm
MC = 1/2 (100)(5) = 250 kNm
MB= 250 - 1/2 100 (5)= 0kNm

The shape of SFD and BMD are depends on the type of load;
UDL Load;
SFD = Linear
BMD = Parabolic/Curved

Watch & Learn how to draw SFD & BMD @ youtube:

2.4: SHEAR FORCE AND BENDING MOMENT DIAGRAM

EXAMPLES 2.13 : Simply Supported Beam (UDL Load).

Determine the reaction at figure 2.19 below. Sketch the Shear Force and Bending Moment diagram.

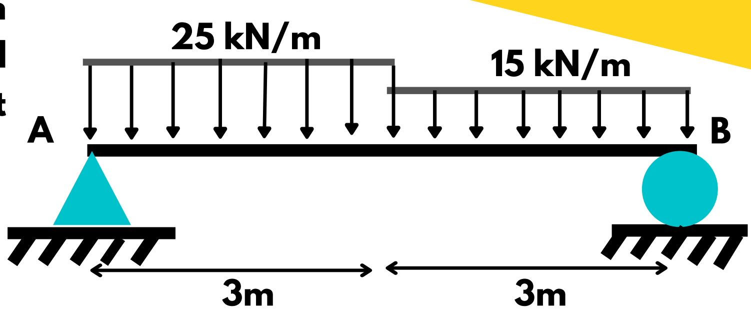
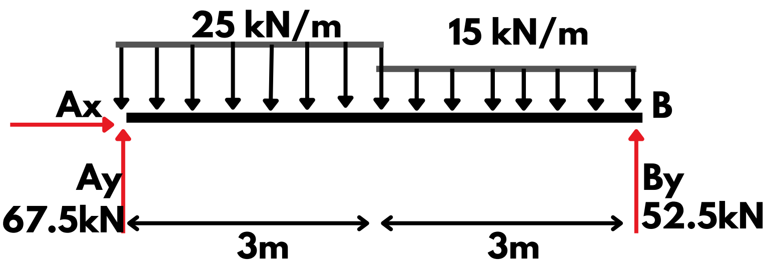


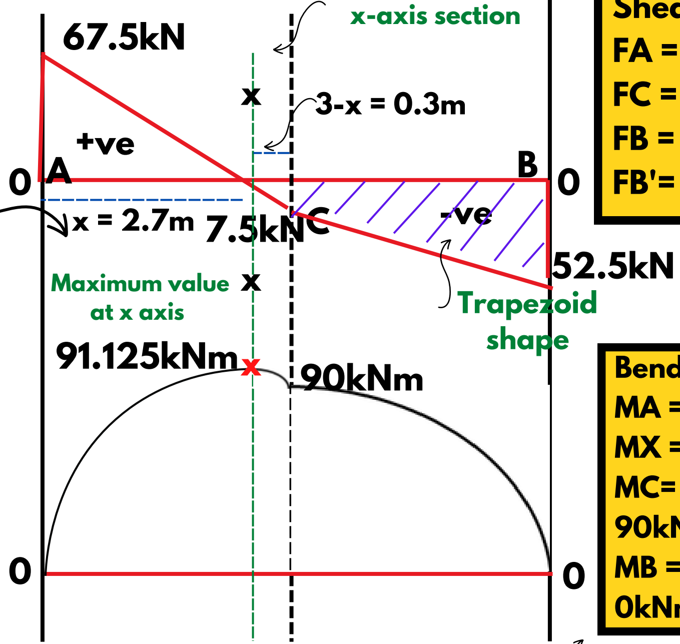
Figure 2.19 : Simply Supported Beam With UDL

Solution:



Lets say the value of reaction are as below:
Ax = 0kN
Ay = 67.5kN
By = 52.5kN

Maximum bending moment accurs at x-axis section



Shear Force Value:
FA = 67.5 kN
FC = 67.5 - 25(3) = -7.5kN
FB = -7.5 - 15(3) = -52.5 kN
FB'= -52.5 + 52.5 = 0 kN

Use similiar triangle method to find the value of the distance.

Similiar triangle method:

$$\frac{67.5}{x} = \frac{7.5}{3-x}$$

7.5 x = 3-x (67.5)
7.5x +67.5x = 202.5
75x = 202.5
x = 2.7m

Bending Moment Value:
MA = 0 kNm
MX = 1/2 (67.5)(2.7) = 91.125 kNm
MC= 91.125 - 1/2 (7.5) (0.3)= 90kNm
MB = 90 - (1/2)(52.5+7.5)(3) = 0kNm

MB value, use formula for total area of trapezoid : (1/2 * distance * (FC + FB)

2.4: SHEAR FORCE AND BENDING MOMENT DIAGRAM

EXAMPLES 2.14 : Simply Supported Beam (Point Load & Moment).

Determine the reaction at figure 2.20 below. Sketch the Shear Force and Bending Moment diagram.

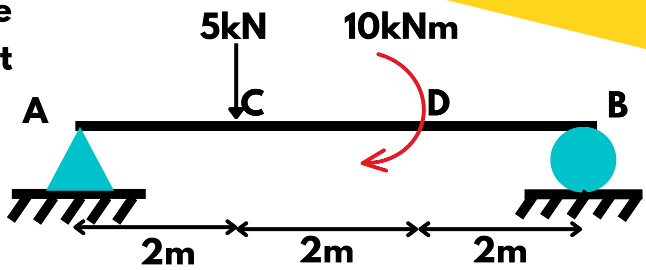
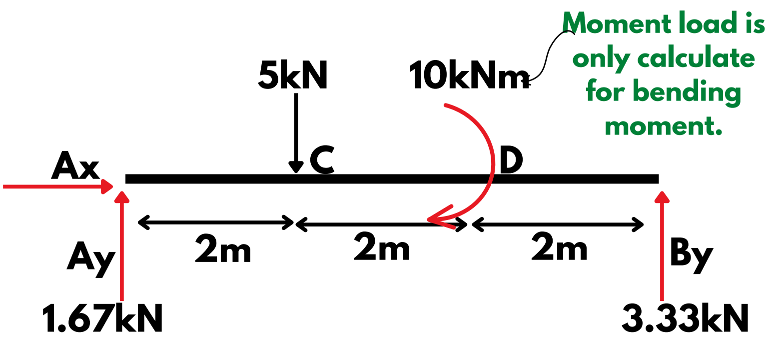


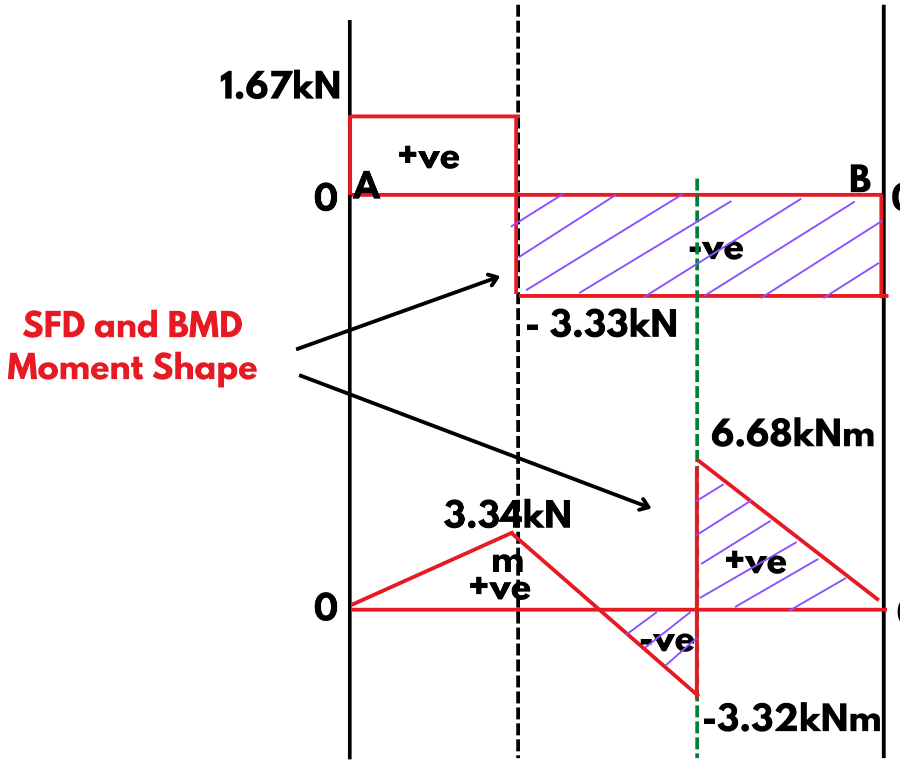
Figure 2.20: Simply Supported Beam With Point Load and Moment

Solution:



Solution:

Lets say the value of reaction are as below:
Ax = 0kN
Ay = 1.67kN
By = 3.33kN



Shear Force Value:
FA = 1.67 kN
FC = 1.67 - 5 = -3.33kN
FB =-3.33 +3.33 = 0 kN

Bending Moment Value:
MA = 0 kNm
MC= 1.67(2) = 3.34 kNm
MD= 3.34 +-3.33(2) = -3.32kNm
MD'= -3.32 + 10 = 6.68kNm
MB = 6.68 - 3.33 (2) = 0kNm

MD' is in clockwise direction (10kNm), so it is acting in positively.

2.4: SHEAR FORCE AND BENDING MOMENT DIAGRAM

EXAMPLES 2.15 : Simply Supported Beam (with several types of load).

Determine the reaction at figure 2.21 below. Sketch the Shear Force and Bending Moment diagram.

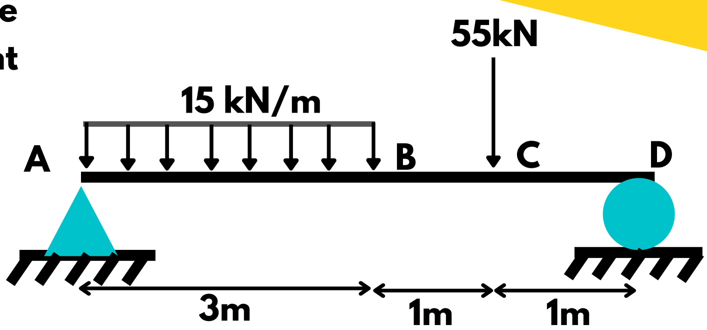
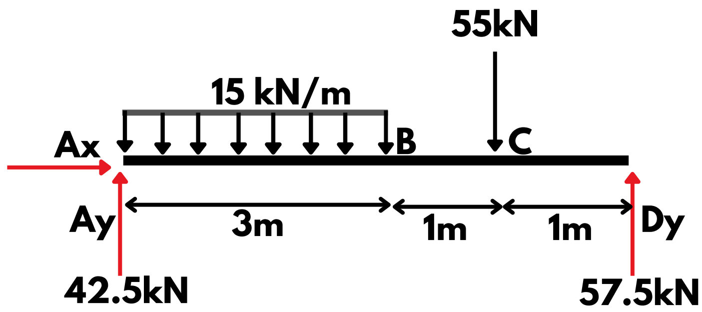


Figure 2.21 : Simply Supported Beam With Point Load and UDL

Solution:

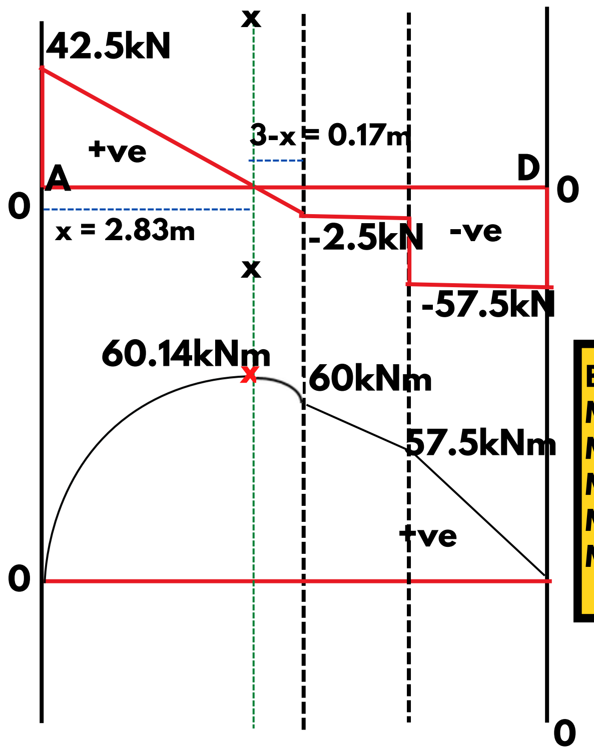


Lets say the value of reaction are as below:
Ax = 0kN
Ay = 42.5kN
By = 57.5kN

Similiar triangle method:

$$\frac{42.5}{x} = \frac{2.5}{3-x}$$

2.5 x = 3-x (42.5)
2.5x +42.5x = 127.5
45x = 127.5
x = 2.83m



Shear Force Value:
FA = 42.5 kN
FB = 42.5 - 15(3) = -2.5kN
FC =-2.5 - 55 = -57.5kN
FD = -57.5 + 57.5 = 0kN

Bending Moment Value:
MA = 0 kNm
MC= 1/2(42.5)(2.83)= 60.14 kNm
MD= 60.14 -1/2(2.5)(0.17)= 60kNm
MD'= 60 - 2.5(1) = 57.5kNm
MB = 57.5 - 57.5(1) = 0kNm

Watch & Learn how to draw SFD & BMD @ youtube:

2.4: SHEAR FORCE AND BENDING MOMENT DIAGRAM

Example 2.16:Simply Supported Beam (With all types of loading)

Determine the reaction at figure below. Sketch the Shear Force and Bending Moment diagram.

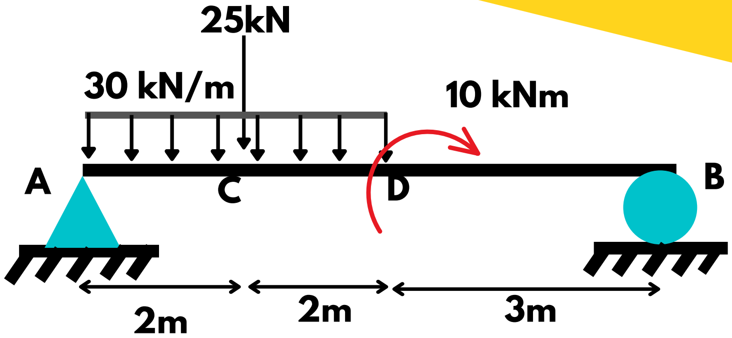
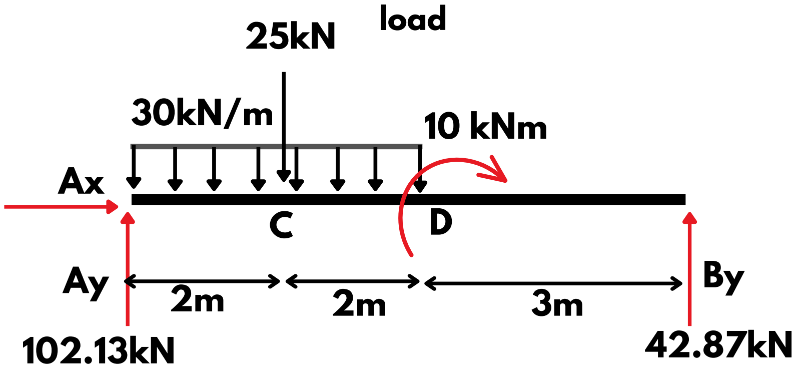


Figure 2.22: Simply Supported Beam With Compound load

Solution:



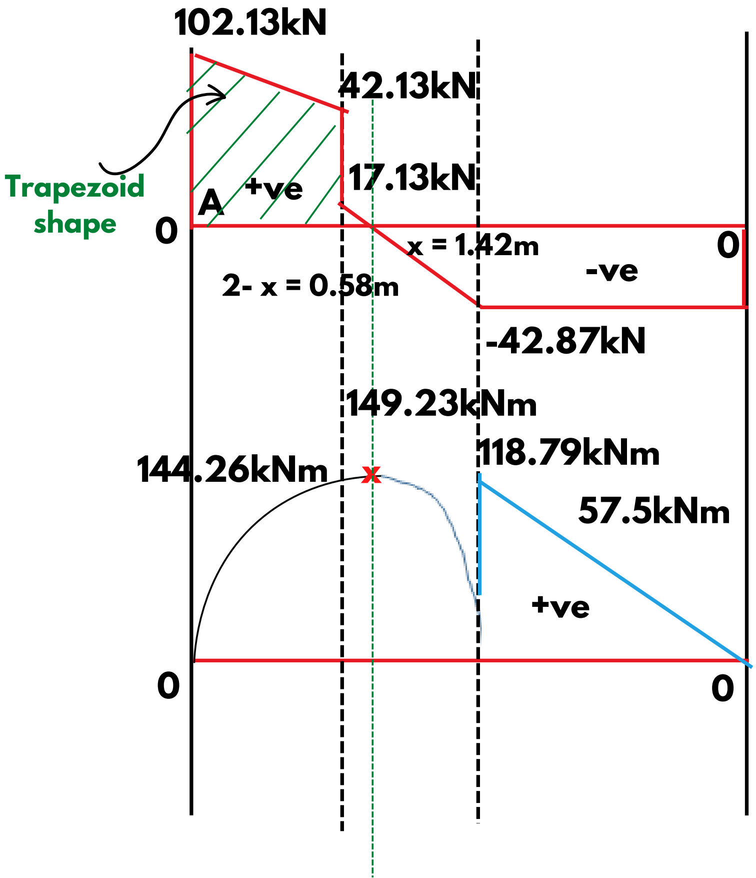
Lets say the value of reaction are as below:
Ax = 0kN
Ay = 102.13kN
By = 42.87kN

SFD for UDL load is in linear, so the distance need to calculate before sketch BMD

How to find distance at point x axis (triangle shape) ?

Use similar triangle method

17.13 / 2-x = 42.13 / x
17.13 x = 2-x (42.13)
17.13x +42.13x = 84.26
59.26x = 84.26
x = 1.42m



Shear Force Value:
FA = 102.13 kN
FC = 102.13 - 30(2) = 42.13kN
FC =42.13 -25 = 17.13kN
FD = 17.13 - 30(2) = -42.87kN
FB = -42.87 + 42.87 = 0

Bending Moment Value:
MA = 0 kNm
MC= 1/2(102.13+42.13)(2)= 144.26 kNm
MC'= 144.26 +1/2(17.13) 0.58)=149.23kNm
MD= 149.23- 1/2(42.87)(1.42) = 118.79kNm
MB= 118.79 + 10 - 42.87(3) = 0kNm

2.4: SHEAR FORCE AND BENDING MOMENT DIAGRAM

Example 2.17 : Cantilever Beam (Point Load and UDL)

Determine the reaction at figure below. Sketch the Shear Force and Bending Moment diagram.

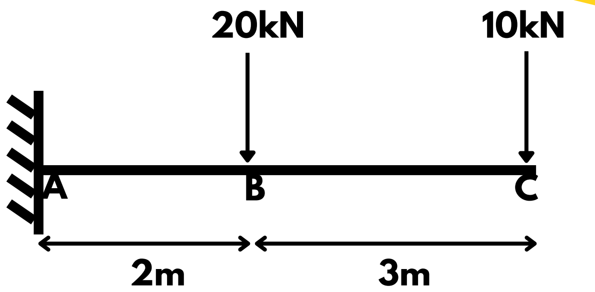
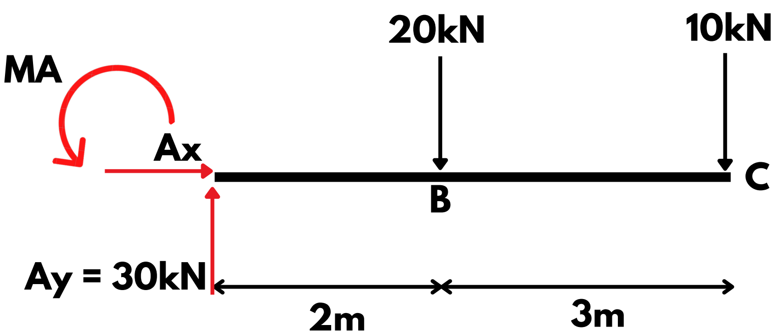
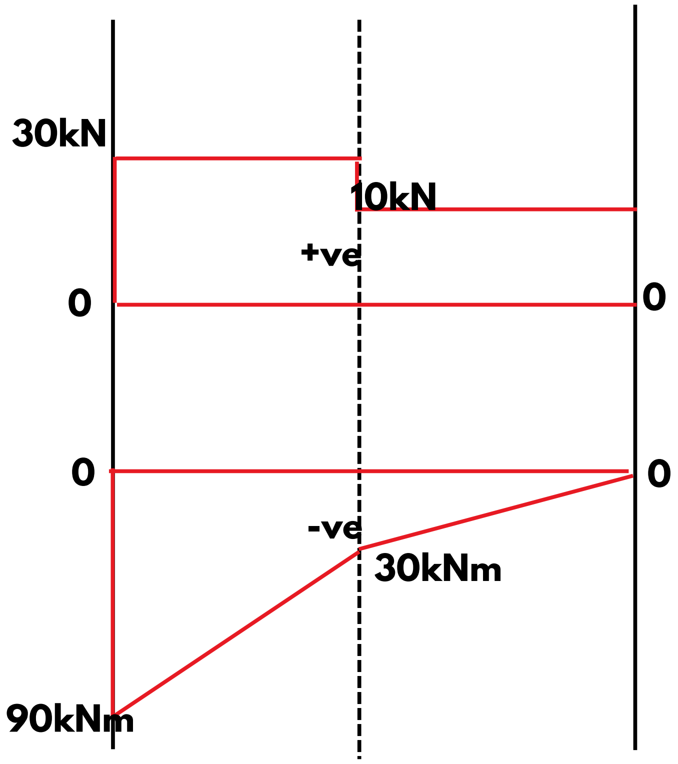


Figure 2.23 : Cantilever Beam With Point load

Solution:



Lets say the value of reaction are as below:
Ax = 0kN
Ay = 30kN
MA = 90kNm



Shear Force Value:
FA = 30 kN
FB= 30 - 20 = 10kN
FC =10 - 10 = 0kN

Bending Moment Value:
MA = -90 kNm (anticlockwise)
MB= - 90 + 30(2) = - 30kNm
MC = -30 + 10(3) = 0kNm

Watch & Learn how to draw SFD & BMD @ youtube:

https://bit.ly/3BVOO0W

2.4: SHEAR FORCE AND BENDING MOMENT DIAGRAM

Example 2.18 : Cantilever Beam (UDL and Moment)

Determine the reaction at figure below. Sketch the Shear Force and Bending Moment diagram.

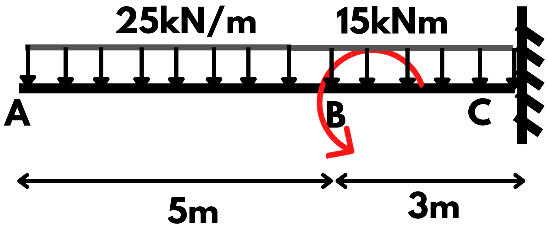
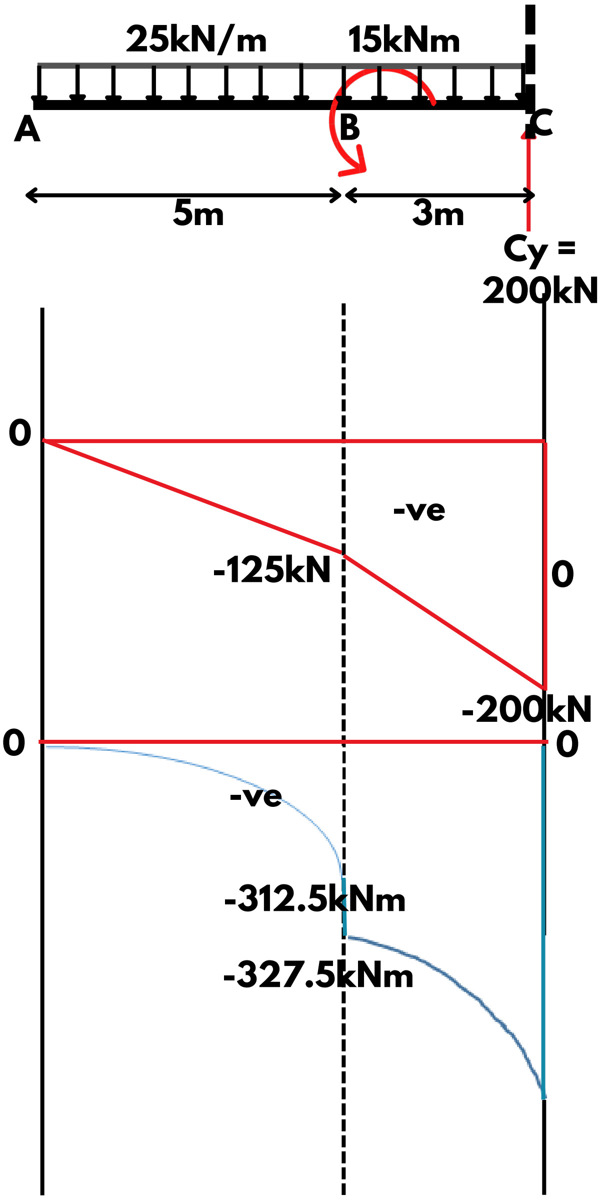


Figure 2.24 : Cantilever Beam With UDL and Moment

Solution:



Lets say the value of reaction are as below:
Cx = 0kN
Cy = 200kN
MC = 815kNm

Shear Force Value:
FA = 0
FB = - 25 (5) = -125kN
FC= -125 - 25(3) = -200kN
FC' =-200 + 200 = 0kN

Bending Moment Value:
MA = 0 kNm
MB= 0 -1/2 (5)(125) =-312.5kNm
MB'= -312.5 - 15 = -327.5kNm
MC= - 327.5 - 1/2(125+200)(3) = -815
MC'= -815 + 815 =0kNm

2.4: SHEAR FORCE AND BENDING MOMENT DIAGRAM

Example 2.19 : Overhanging Beam (Point Load and UDL)

Determine the reaction at figure below. Sketch the Shear Force and Bending Moment diagram.

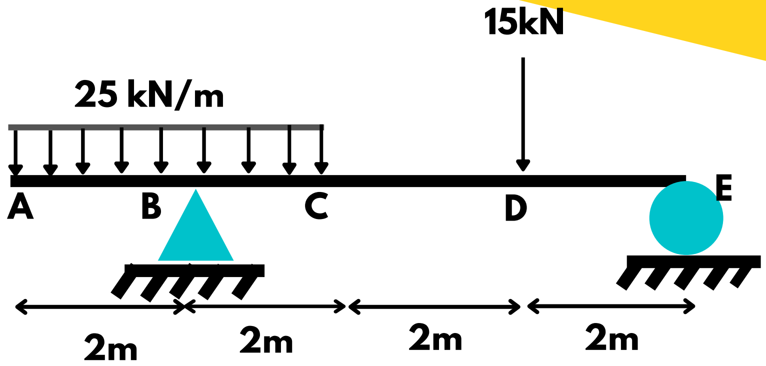
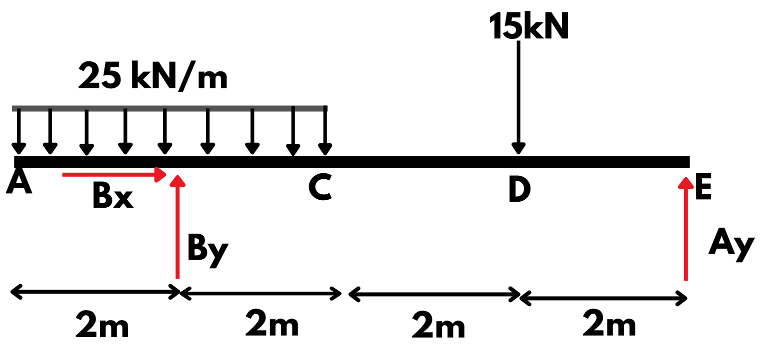
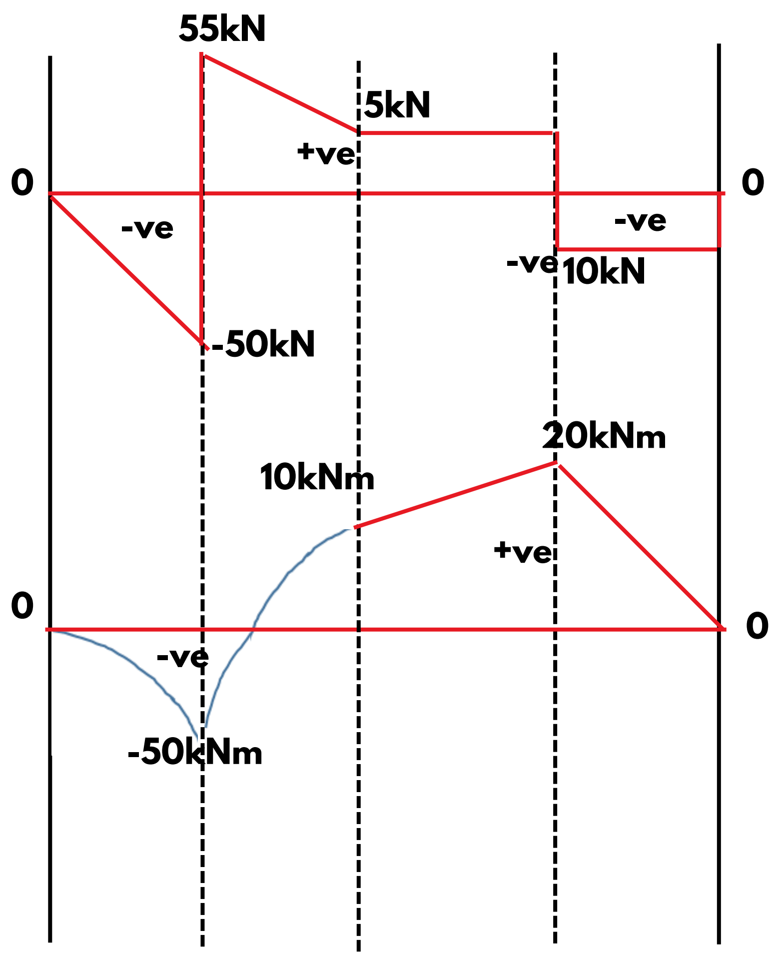


Figure 2.25 : Overhanging Beam With Point Load and UDL

Solution:





Lets say the value of reaction are as below:
Bx = 0
By = 105 kN
Ey = 10 kN

Shear Force Value:
FA = 0
FB = 0-25(2) = -50kN
FB'= -50 + 105 = 55kN
FC =55 - 25(2) = 5kN
FD = 5 -15 = -10kN
FE = -10 + 10 = 0kN

Bending Moment Value:
MA = 0
MB= -1/2 (50)(2) = -50kNm
MC= -50 + (1/2)(55+5)(2) = 10kNm
MD= 10 + (5)(2) = 20kNm
ME = 20 - 10 (2) = 0

Watch & Learn how to draw SFD & BMD @ youtube:

2.4: SHEAR FORCE AND BENDING MOMENT DIAGRAM

Example 2.19 : Overhanging Beam (Point Load and UDL)

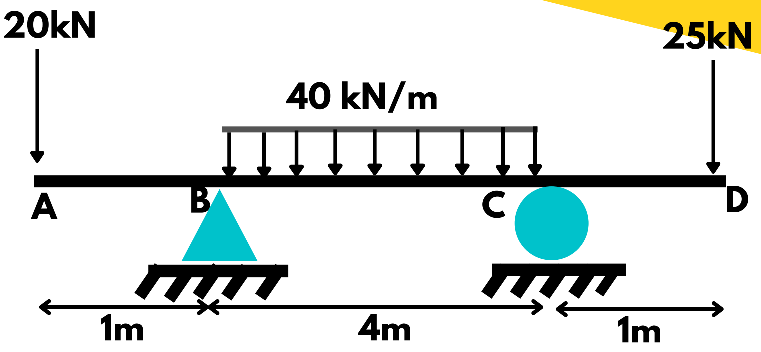
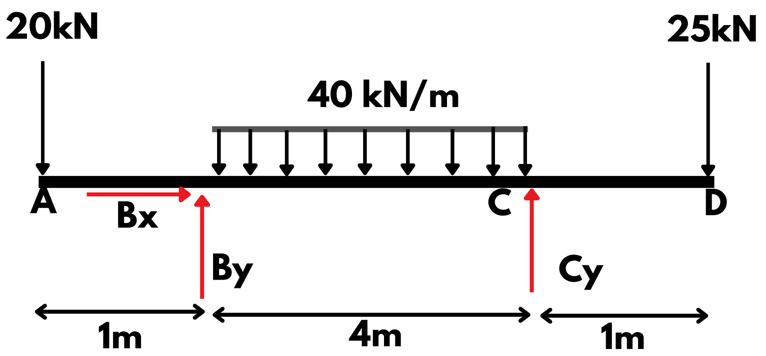


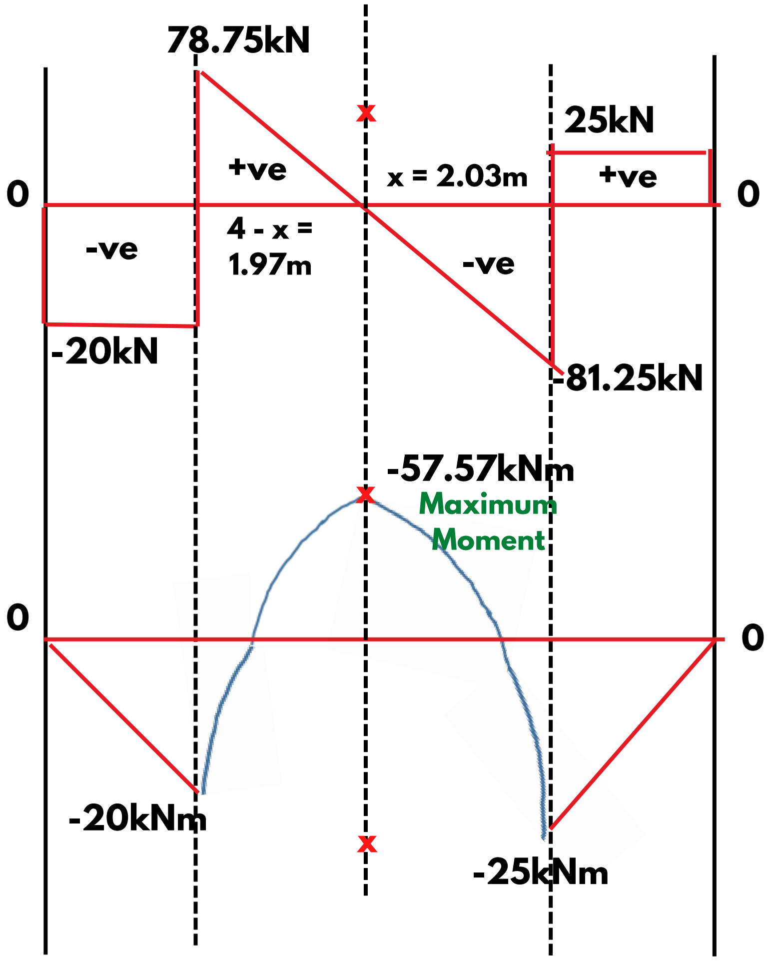
Figure 2.26 : Overhanging Beam With Both end Hanging

Determine the reaction at figure below. Sketch the Shear Force and Bending Moment diagram.

Solution:

Lets say the value of reaction are as below:
Bx = 0
By = 98.75 kN
Cy = 106.25 kN





Shear Force Value:
FA = -20kN
FB = -20 + 98.75 = 78.75kN
FC = 78.75 - 40(4)= -81.25kN
FC' =-81.25 + 106.25 = 25kN
FD = 25 - 25 = 0kN

Use similar triangle method

78.75 / 4-x =81.25/ x
78.75 x = 4-x (81.25)
78.75x +81.25x = 325
160x = 325
x = 2.03m

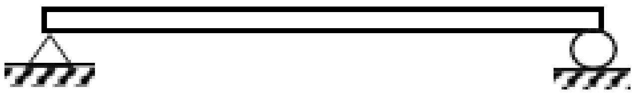
Bending Moment Value:
MA = -20(1) = -20kNm
MB= -20 + 1/2(78.75)(1.97) = 57.57kNm
MC= 57.57 - (1/2)(81.25)(2.03) = -25kN
MD= -25 + (25)(1) = 0kNm

TUTORIAL QUESTION

TRY TO SOLVE THIS QUESTION

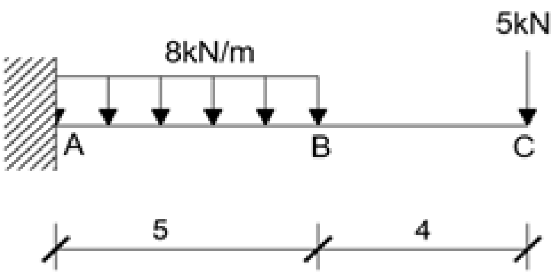
QUESTION 1

Based on Figure 1, state the number of unknown either determinate beam or indeterminate beam.



QUESTION 2

A cantilever beam is subjected to a point load and distributed load as shown in Figure 2. Calculate vertical reaction force at support A.



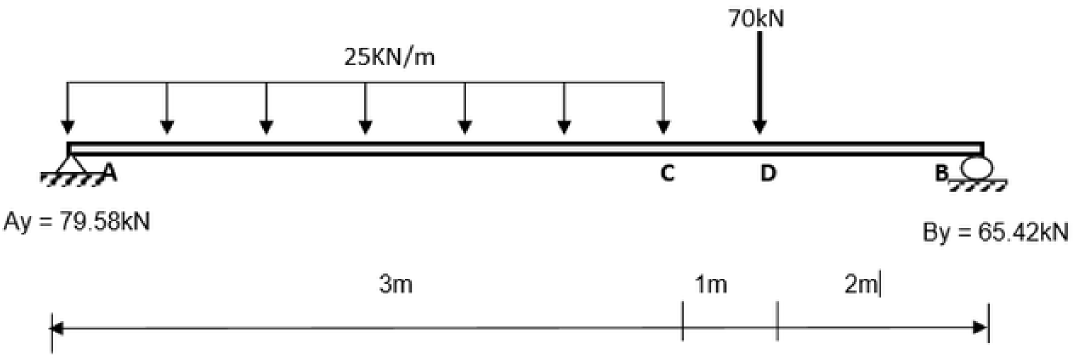
QUESTION 3

The Figure 3 shown a simply supported beam with reactions Ay=79.58kN and By=65.42kN. Using the equilibrium concept for shear force and bending moment:

a) Identify the value of shear force and bending moment at point A, B, C and D.

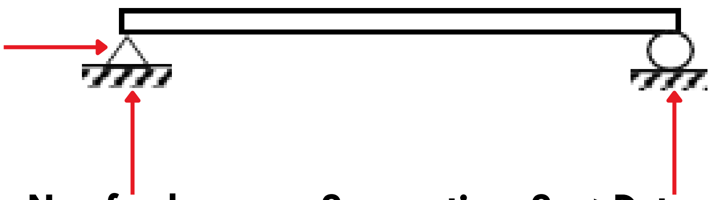
b) Draw both of shear forces diagram (SFD) and bending moment diagram (BMD) for the beam.

c) Calculate the maximum bending moment value and its position.



TUTORIAL ANSWER

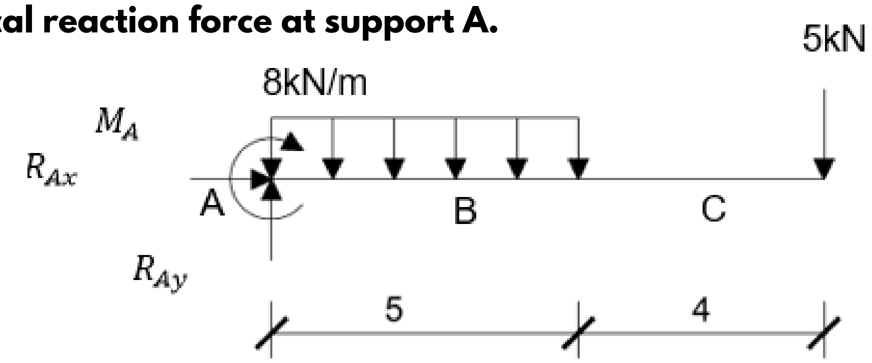
ANSWER QUESTION 1



No of unknown = 3, equation=3; =>Determinate beam

ANSWER QUESTION 2

A cantilever beam is subjected to a point load and distributed load as shown in Figure 2. Calculate vertical reaction force at support A.



Horizontal force :

ΣFx=0,(Assuming direction to the right is positive)
ΣFx=RAx
RAx=0

Moment at A :

ΣMA=0,(Assuming clockwise is positive)
ΣMA=MA+(8)(5)(5/2)+(5)(9)
0=MA+(8)(5)(5/2)+(5)(9)
0=MA+145kNm
MA=-145kNm or MA=+145kNm (anti-clockwise)

Vertical force :

ΣFy=0,(Assuming upwards is positive)
ΣFy=RAy-(8)(5)-5kN
0=RAy-45kN
RAy=45kN

TUTORIAL ANSWER

ANSWER QUESTION 3

The Figure 3 shown a simply supported beam with reactions Ay=79.58kN and By=65.42kN. Using the equilibrium concept for shear force and bending moment:

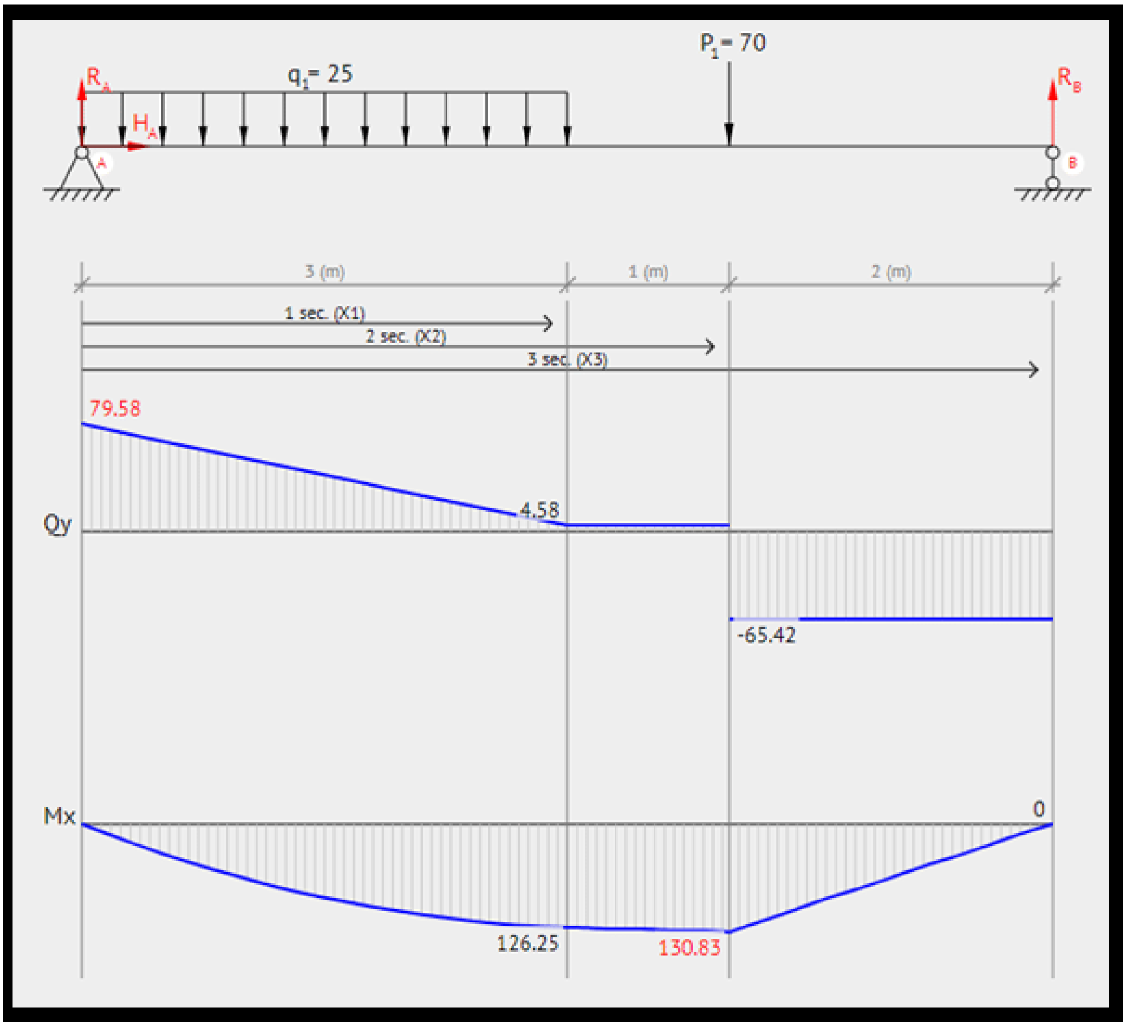
a) Identify the value of shear force and bending moment at point A, B, C and D.

Solution:

Shear Force value;
VA = 79.58 kN
VC = 79.58 - 75kN = 4.58 kN
VD = 4.58 - 70kN = -65.42kN
VE = 65.42kN + 65.42kN = 0kN

Bending Moment value;
MA = 0
MC = (1/2x(79.58+4.58x3) = 126.25kN.m
MD = 126.25+ (4.58x1) = 130.83kN.m
ME = 130.83 - (65.42x2) = 0

b) Draw both of shear forces diagram (SFD) and bending moment diagram (BMD) for the beam.

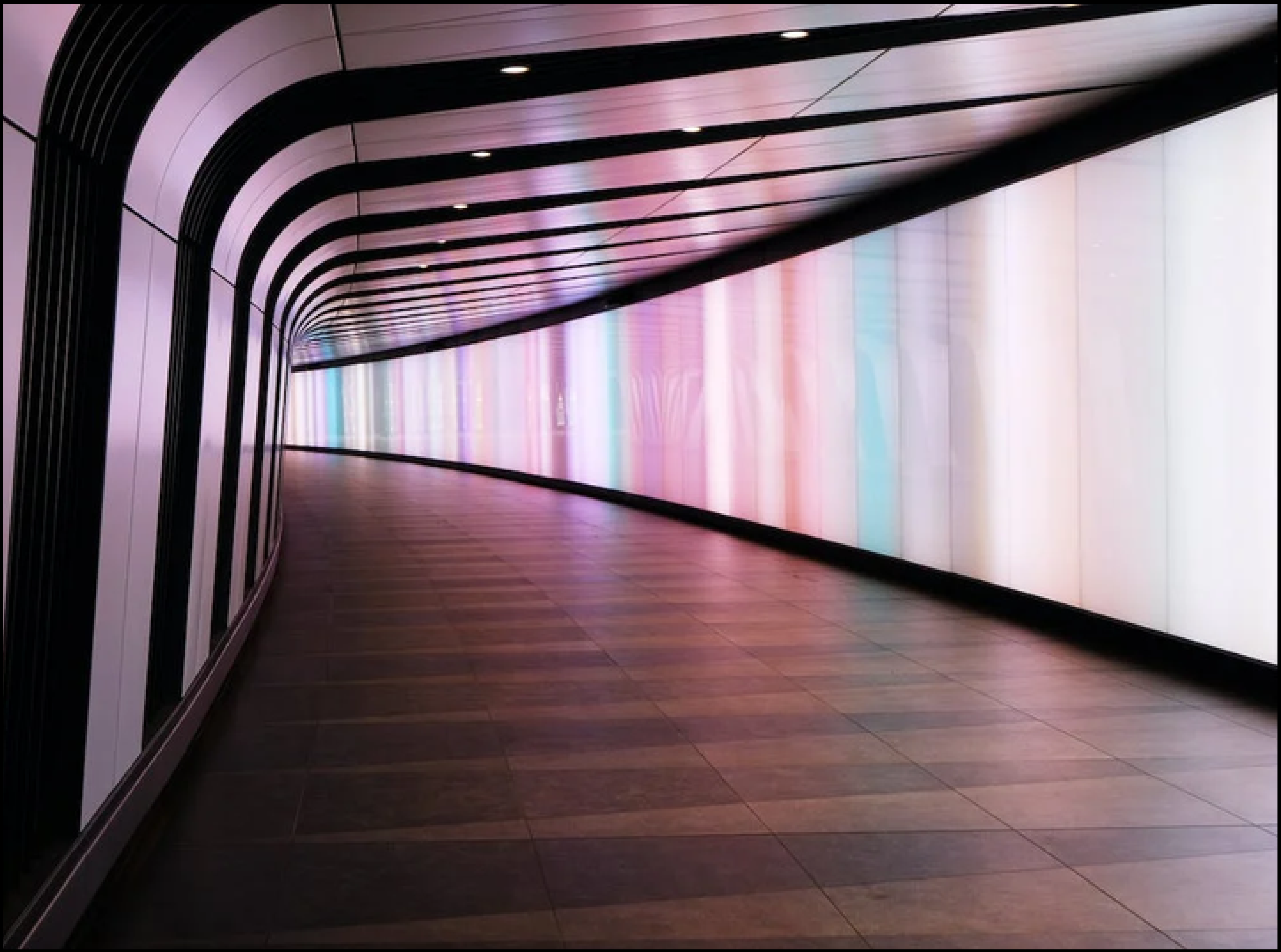


c) Calculate the maximum bending moment value and its position.

Answer:

Maximum bending moment is 130.83 kNm at distance of 4 m from point A

CHAPTER 3
DIRECT STRESS



3.0 INTRODUCTION

BACKGROUND

A lot of buildings in the whole world are made of reinforced concrete. Reinforced concrete is a material made of a combination of concrete and steel. Now, have you ever wondered how we measure the strength of concrete and the strength of steel? The strength of concrete usually refers to the concrete's ability to resist compressive force, while the strength of steel usually refers to the steel's ability to resist tensile force.

Consider a compressive strength test conducted on a cylinder sample made of concrete, as illustrated in Figure 3.1. A few observations can be made during the test.

Figure 3.1: Compressive strength test conducted on a concrete cylinder sample

First - The sample of concrete is applied with a pair of loads perpendicular to the sample's cross-sectional area.

Second - One load is applied on the top surface while the other load is applied on the bottom surface.

Third - The orientation of the force is perpendicular to the surface of the sample

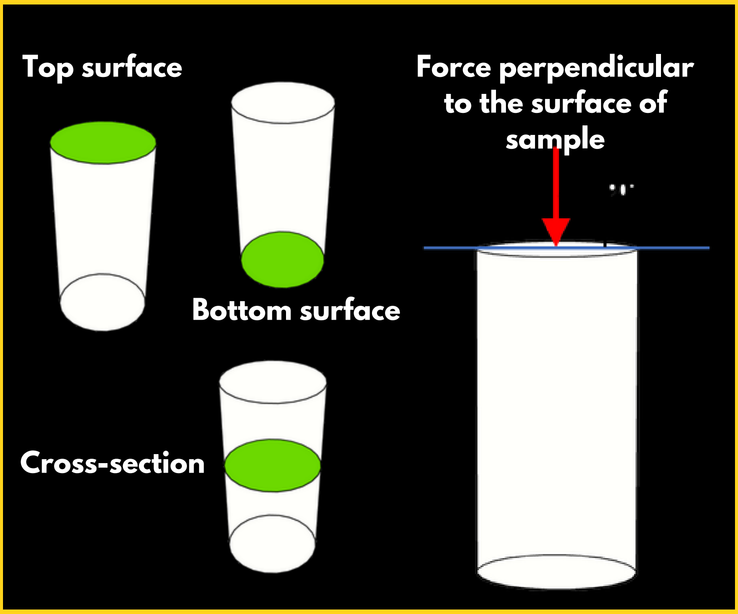
These are the indicators that the cylinder concrete sample is experiencing DIRECT STRESS

Also can be observed:

Fourth - The sample becomes shorter and shorter as the compression force applied to it increases

This situation shows that the sample is experiencing

Terminologies



3.1 DIRECT STRESS

WHAT IT IS DIRECT STRESS?

When a body is subjected to an external load, it tends to experience a change in shape which include size or dimension. During the change of shape, there exist internal resistance within the body to withstand the change. In brief, direct stress is an internal force in the form of a reaction of the material to an applied force or load.

This internal force is against and in opposite direction to the applied force of the body. If the applied force is inwards, then the body is said to experience compressive force. On the other hand, if the applied force is outwards, then the body is said to experience tensile force.

DEFINITION

Intensity of internal load per unit area

EQUATION

$$Stress, \sigma = \frac{Force}{Area} = \frac{P}{A}$$

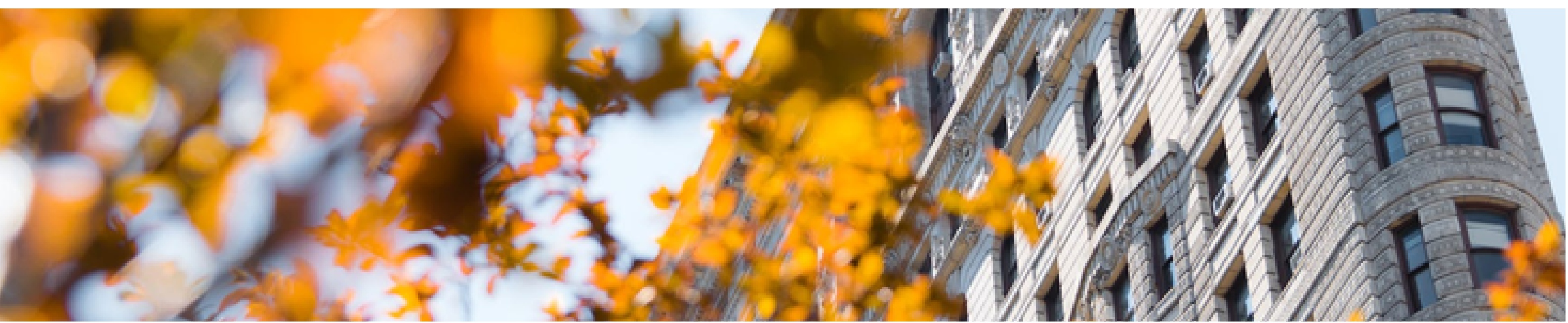
UNIT

Unit load per unit area that includes

N/mm^2, kN/mm^2, N/m^2, kN/m^2

Compressive force

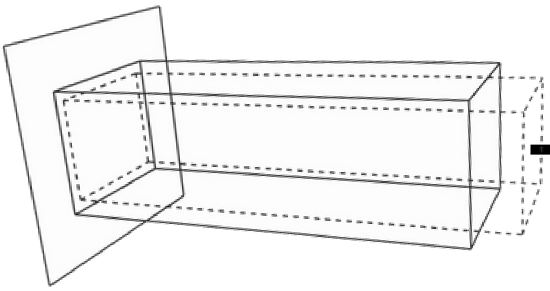
Tensile force



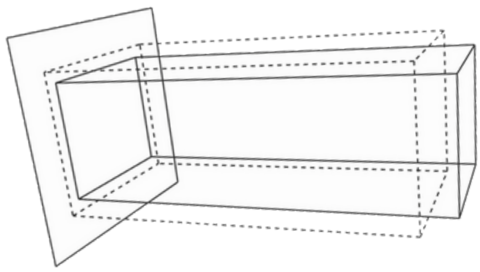
3.2 DIRECT STRAIN

WHAT IT IS DIRECT STRAIN?

A structural member that is subjected to an external load will experience a change of shape which also causes a change of dimension in the member. When a tensile force, P is applied, the member will extend longer in the direction of the force and followed by a reduction in sectional size.



On the other hand, when a compressive force P is applied, the member will become shorter in the direction of the force and followed with an expansion in section size of the member



DEFINITION

The change of shape or length of a body per unit length

EQUATION

$$Strain, \varepsilon = \frac{Change\ of\ length}{Original\ length} = \frac{\delta l}{l}$$

UNIT

No units

Why strain don't have a unit?

$$Strain, \varepsilon$$

$$= \frac{Change\ of\ length}{Original\ length}$$

$$= \frac{unit\ length}{unit\ length}$$

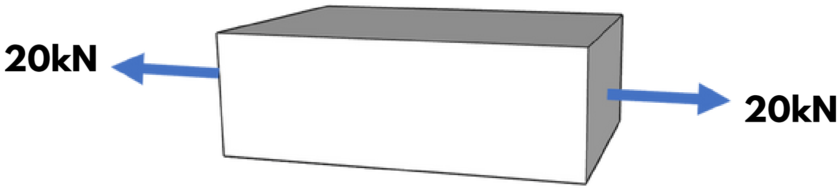
$$= no\ units$$

3.3 DIRECT STRESS & STRAIN

EXAMPLE OF CALCULATION

Example 3.1

A steel bar with a cross section of 20cm high and 40cm width is pulled with 20kN force at both ends. Determine the stress induced in the steel bar



1. What is the equation? $Stress, \sigma = \frac{Force}{Area} = \frac{P}{A}$

2. Relate between the information given and the equation

$Stress, \sigma = \frac{Force}{Area} = \frac{P}{A}$

Force = 20kN
Height = 20cm
Width = 40cm

3. Calculate $Cross - sectional\ area = 20cm \times 40cm = 800cm^2$

$$\therefore Stress, \sigma = \frac{20kN}{800cm^2} = 0.025\ {}^{kN}/_{cm^2}$$

Example 3.2

Let's say that the steel bar from example 3.1 elongate 0.5mm after being pulled by a pair of forces. The original length of the steel bar is 3m long. So how much strain is experienced by the bar?

1. Equation

$$Strain, \varepsilon = \frac{Change\ of\ length}{Original\ length} = \frac{\delta l}{l}$$

2. Calculate

$$Strain, \varepsilon = \frac{0.5mm}{3000mm} = 0.0002$$

3.4 MODULUS OF ELASTICITY

DEFINITION

It has already been established that when a body is applied with force, be it compressive or tensile force; the body will experience a change in shape. Afterwards, if the body can revert to its original shape after removing the force, it is said to show an elastic characteristic.

DEFINITION

The modulus of elasticity, also known as modulus young, uses the symbol E with a unit that is the same as stress.

EQUATION

$$Modulus\ of\ elasticity, E = \frac{Stress}{Strain} = \frac{\sigma}{\varepsilon}$$

UNIT

Same unit as stress

Material	Modulus of Elasticity $(\times 10^3\ {}^{N}/_{mm^2})$
Diamond	1000
Tungsten	407
Steel	200
Iron	170
Brass	120
Copper	117
Gold	79
Aluminum	69
Concrete	30
Bone	18
Wood	16
Plastic	2
Rubber	0.02

the material with the highest E value is DIAMOND!

Example 3.3

Calculate the value of E for the steel bar mentioned in Example 3.1 and 3.2

1. Equation

$$E = \frac{\sigma}{\varepsilon}$$

2. Information

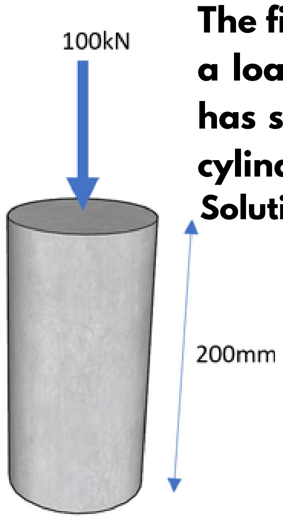
$\sigma = 0.025\ {}^{kN}/_{cm^2}$

$\varepsilon = 0.0002$

3. Calculate

$$E = \frac{\sigma}{\varepsilon} = \frac{0.025\ {}^{kN}/_{cm^2}}{0.0002} = 125\ {}^{kN}/_{cm^2}$$

Example 3.4



The figure shows a concrete cylinder that is applied with a load of 100kN. The cylinder's diameter is 98mm and has shortened by 0.05mm. Calculate the E value of the cylinder.

Solution map:

$$E = \frac{\sigma}{\varepsilon}$$

$\sigma = \frac{P}{A}$, P → 100kN, $A = \frac{\pi D^2}{4}$, D → 98mm

$\varepsilon = \frac{\delta l}{l}$, δl → 0.05mm, l → 200mm

Based on this solution map, can you find the answer?

Answer =

$$E = 53{,}030\ {}^{N}/_{mm^2}$$

3.5 DIRECT STRESS & STRAIN

EXAMPLE OF CALCULATION

Example 3.5

A rod of 2.5m long with a cross-sectional area of 1290mm experiences an elongation of 1.5mm when subjected to a tensile force of 142 kN. Calculate:-

a. Tensile stress of rod
b. Strain
c. Modulus of Elasticity

Make sure that every parameter has the same unit.
For example, if one parameter is using m, and another is using mm, then change either m to mm to make both parameters in mm, or change mm to m to make both parameters in m.

Solution

Given:

Length, l	= 2500mm
Area, A	= 1290mm^2
Elongation, δl	= 1.5mm
Tensile force, P	= 142kN

a. Tensile stress, σ

$$\sigma = \frac{P}{A} = \frac{142{,}000N}{1290mm^2} = 110.08\ {}^{N}/_{mm^2}$$

b. Strain, ε

$$\varepsilon = \frac{\delta l}{l} = \frac{1.5mm}{2500mm} = 6 \times 10^{-4}$$

c. Modulus of Elasticity, E

$$E = \frac{\sigma}{\varepsilon} = \frac{110.08\ {}^{N}/_{mm^2}}{6 \times 10^{-4}} = 1.83 \times 10^{5}\ {}^{N}/_{mm^2}$$

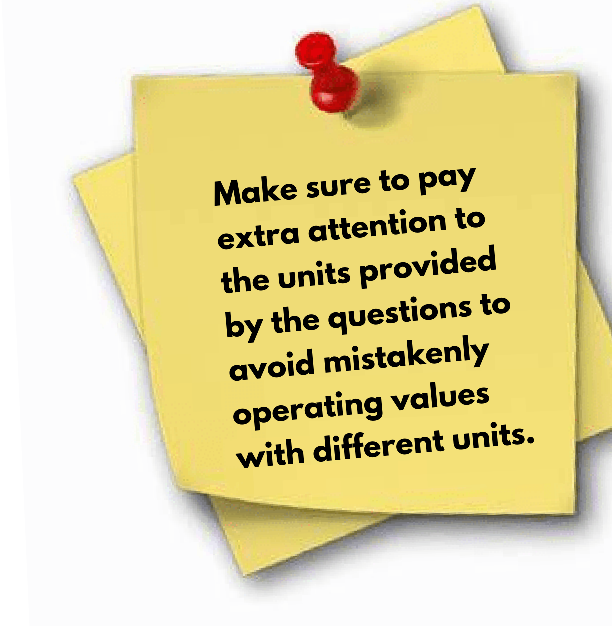
3.6 DIRECT STRESS & STRAIN

EXAMPLE OF CALCULATION

Example 3.6

A steel rod 3m long carries a load of 20kN. If the elongation is not permitted to exceed greater than 0.2mm, calculate;

a. Minimum cross-sectional area of rod
b. Tensile stress of rod
c. Strain of rod. Given E = 206 kN/m²



Solution

Given:

Length, l = 3000mm

Maximum elongation, δl = 0.2mm

Load, P = 20kN

Mod. of Elasticity, E = 206 kN/m²

$$= 206\frac{kN}{m^2} \times \frac{1^2 m^2}{1000^2 mm^2} \times \frac{1000N}{1kN} = 0.206\frac{N}{mm^2}$$

a. $E = \frac{Pl}{A\delta l}$

Rearrange,

$$A = \frac{Pl}{E\delta l} = \frac{20{,}000N(3000mm)}{0.206\frac{N}{mm^2}(1.5mm)} = 1.46 \times 10^9 mm^2$$

b. $\sigma = \frac{P}{A}$

$$\sigma = \frac{P}{A} = \frac{20{,}000N}{1.46 \times 10^9 mm^2} = 1.375 \times 10^5\ {}^{N}/_{mm^2}$$

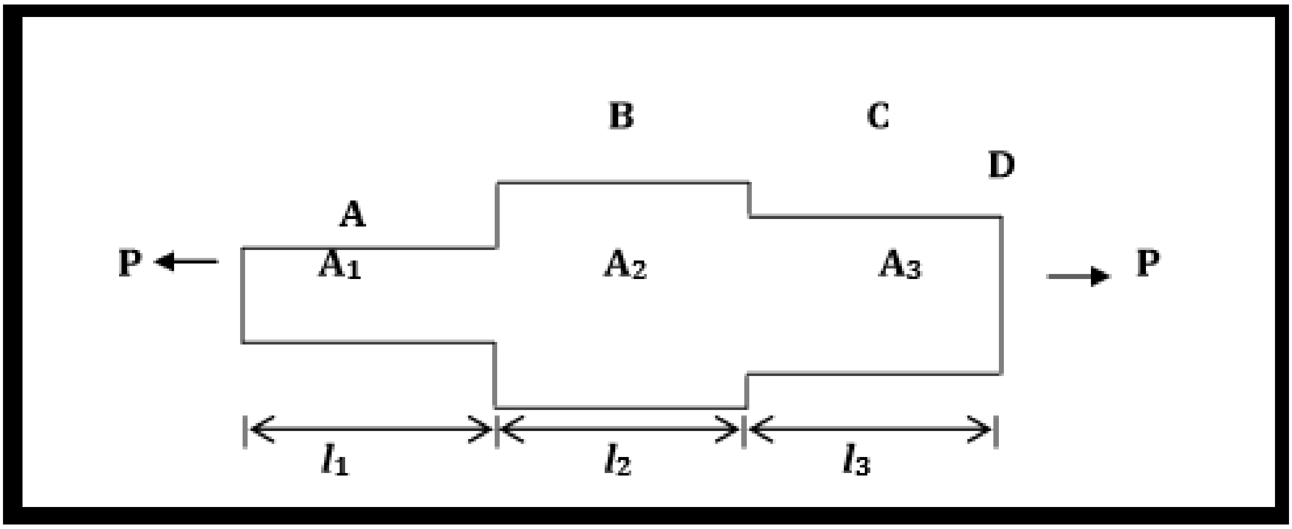
c. $\varepsilon = \frac{\delta l}{l}$

$$\varepsilon = \frac{\delta l}{l} = \frac{0.2mm}{3000mm} = 6.67 \times 10^{-5}$$

3.6 DIRECT STRESS & STRAIN

STRESS AND STRAIN IN PRISMATIC BAR

It is a bar to have difference cross sectional area at the length. So, stress, strain and change in length to each bar component act separated. The total of change in length is added for change in length at each component bar section.



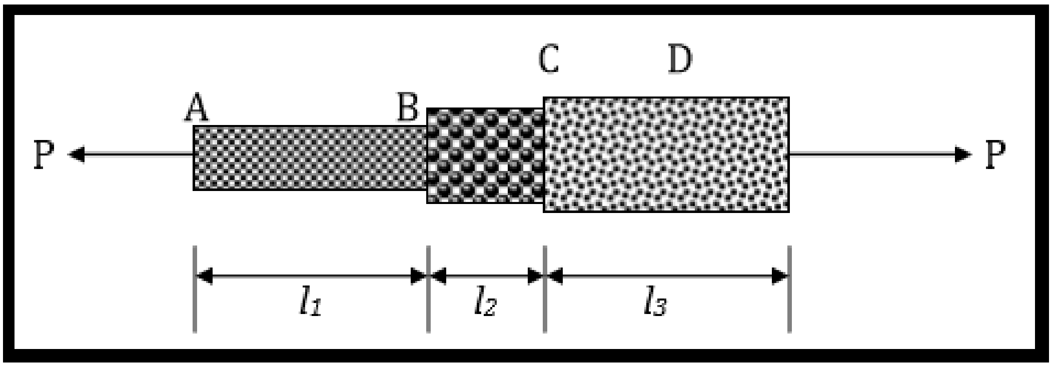
So, the formula for prismatic bar is:

$$\Sigma \delta l = \frac{P}{E}\left[\frac{l_1}{A_1} + \frac{l_2}{A_2} + \frac{l_3}{A_3}\right]$$

A = area of the section bar;
l = length of the section bar;
E = Modulus Elasticity

3.7 DIRECT STRESS & STRAIN

STRESS AND STRAIN COMPLEX SECTION BAR



Complex section bar is about two or more material which is both materials set up in rigid position to share a load and experience the same elongation, δl.

This Complex section bar were imposed with the same axial force, P

Writing Intensity of stress,

$\sigma = P/A$

So;

$\sigma 1 = P/A1$
$\sigma 2 = P/A2$
$\sigma 3 = P/A3$

P is the same value for section 1, 2 and 3
Rewriting;

$A_1\sigma_1 = P \qquad A_2\sigma_2 = P \qquad A_3\sigma_3 = P$

Meaning;

$A_1\sigma_1 = A_2\sigma_2 = A_3\sigma_3$

Writing ***Total elongation***, $\Sigma\delta l = \delta l_1 + \delta l_2 + \delta l_3$

$\delta l_1 = \dfrac{Pl_1}{A_1E_1} \qquad \delta l_2 = \dfrac{Pl_2}{A_2E_2} \qquad \delta l_3 = \dfrac{Pl_3}{A_3E_3}$

So;

$$\Sigma\delta l = \frac{Pl_1}{A_1E_1} + \frac{Pl_2}{A_2E_2} + \frac{Pl_3}{A_3E_3}$$

P is the same value for section 1, 2 and 3
Rewriting;

$$\Sigma\delta l = P\left[\frac{l_1}{A_1E_1} + \frac{l_2}{A_2E_2} + \frac{l_3}{A_3E_3}\right]$$

3.8 HOOKE'S LAW

INTRODUCTION

Hooke's Law

In the 19th-century, while studying springs and elasticity, English scientist Robert Hooke noticed that many materials exhibited a similar property when the stress-strain relationship was studied. There was a linear region where the force required to stretch the material was proportional to the extension of the material, known as Hooke's Law.

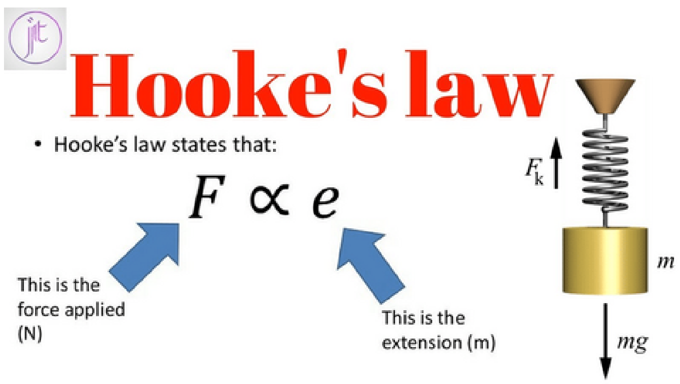
Hooke's Law states that the strain of the material is proportional to the applied stress within the elastic limit of that material.

- **Hooke's law says that a body be returned to the original length after applied load transferred from it as long as it is in the elasticity limit.**
- **also said that; if the materials are not exceed with the elastic limit, so the deformation changes continuously with the load.**
- **as the load changes continuously with the stress; and elongation changes continuously with strain, SO the stress changes continuously with the strain**

HOOKE'S LAW

Hooke's Law conditions

- **axial loading (pembebanan paksi)**
- **cross-section of the body is uniform / constant (keratan rentas jasad adalah seragam)**
- **the material of the body is homogenous (sifat bahan yang sekata pada keseluruhan jasad)**



3.8 HOOKE'S LAW

MECHANICAL CHARACTERISTIC OF MATERIALS

a) Flexible (Mulur)
- refers to a substance that has a high elongation (suatu bahan yg mempunyai pemanjangan yang tinggi)

b) Elastic (Anjal)
- refers to the material back to the original length when the load is left of it. (keadaan bahan yang kembali kepada panjang asal apabila beban ditanggalkan darinya).

c) Plastic (Plastic)
- the ability of a material having excessive elongation when stressed. (kebolehan sesuatu bahan mengalami pemanjangan yang berlebihan apabila ditegangkan.)

d) Brittle (Rapuh)
- brittle material is material having a low elongation before fracture without any warning. (bahan rapuh iaitu bahan mengalami pemanjangan yang rendah sebelum patah tanpa sebarang amaran)

HOOKE'S LAW

MODULUS OF ELASTICITY

are constants in the equation of Hooke's law and also known as Modulus Young or Modulus Elasticity

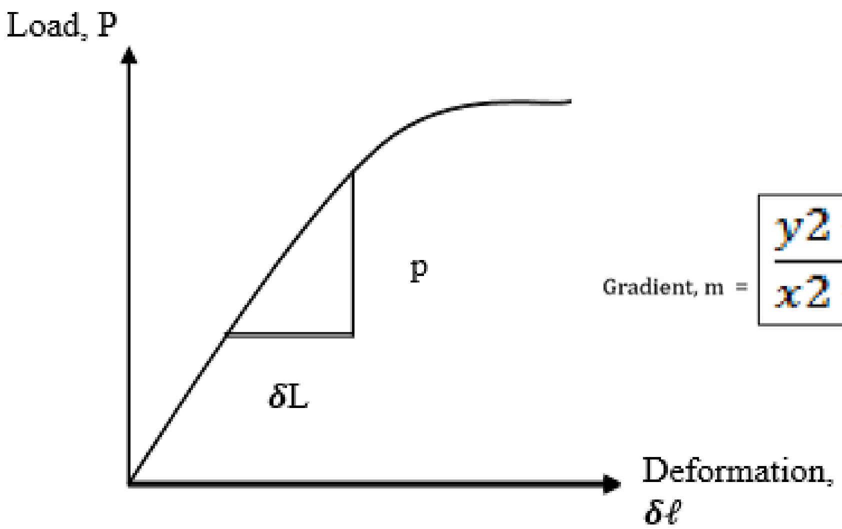
3.8 HOOKE'S LAW

MECHANICAL CHARACTERISTIC OF MATERIALS

HOOKE'S LAW

VALUE OF MODULUS ELASTICITY FROM THE GRAPH

Tensile Test ;



Gradient, m = $\frac{y2 - y1}{x2 - x1}$ @ $p / \delta\ell$

Modulus Young,

$$E = \frac{PL}{A\delta\ell}\ ; \quad E = \frac{p}{\delta\ell} \times \frac{L}{A}\ ;$$

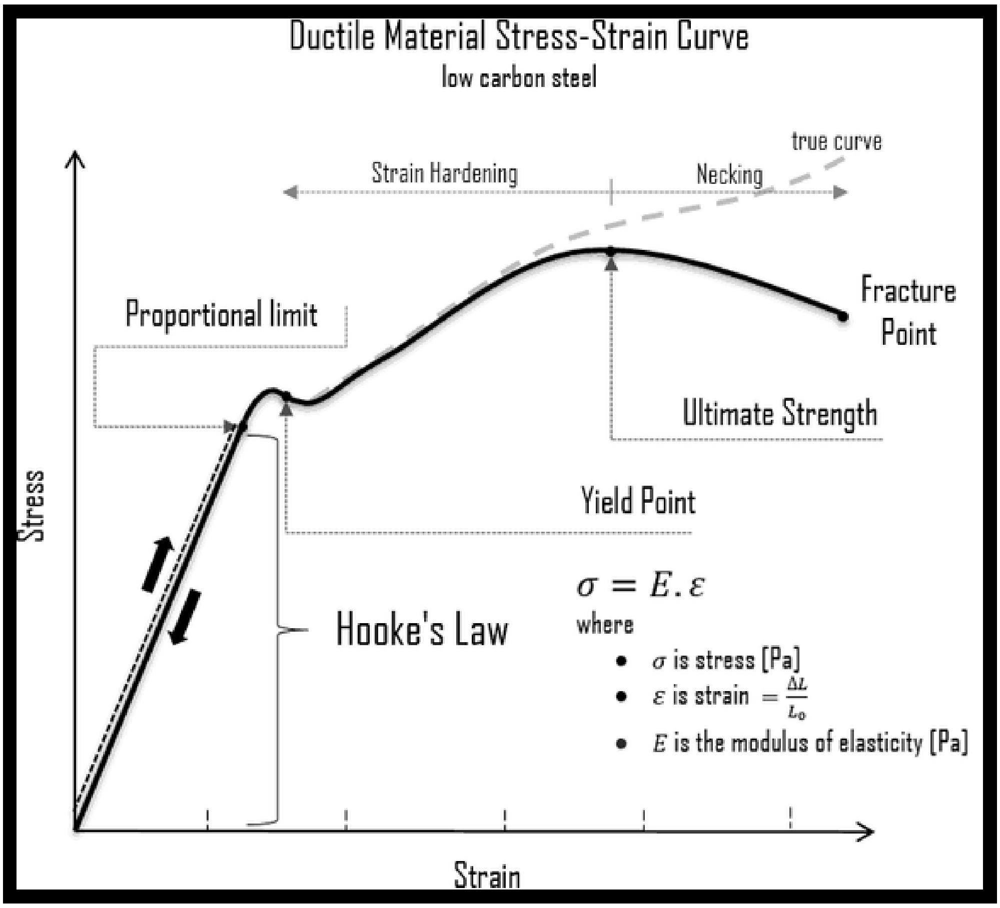
SO THE EQUATION WILL BE;

$$E = m \times \frac{L}{A}$$

A = sectional area of the sample
L = Length of the sample
$p/\delta\ell$ = Gradient from the graph, m

3.8 HOOKE'S LAW

CHARACTERISTIC STATE OF MATERIAL FROM GRAPH



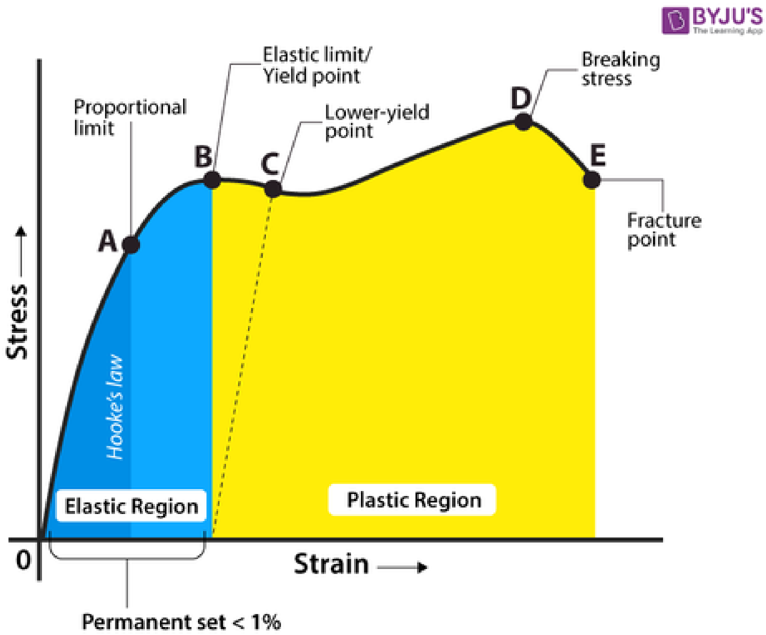
Stress-Strain Curve: When we stretch a spring by applying load to its ends, the length of the spring increases slightly. When you remove the load at the ends, it regains its original size and shape.

Similarly, rubber can be pulled to several times its original length and still return to its original shape. But after crossing a certain limit of the load, we will observe that cracks are generated, and then the rubber breaks.

The same thing will happen with spring or any other material. This phenomenon also occurs in compression. After a certain limit of compressive force, the material fails.

3.8 HOOKE'S LAW

CHARACTERISTIC STATE OF MATERIAL FROM GRAPH



The different regions in the stress-strain diagram are:

(i) Proportional Limit
It is the region in the stress-strain curve that obeys Hooke's Law. In this limit, the stress-strain ratio gives us a proportionality constant known as Young's modulus. The point OA in the graph represents the proportional limit.

(ii) Elastic Limit
It is the point in the graph up to which the material returns to its original position when the load acting on it is completely removed. Beyond this limit, the material doesn't return to its original position, and a plastic deformation starts to appear in it.

(iii) Yield Point
The yield point is defined as the point at which the material starts to deform plastically. After the yield point is passed, permanent plastic deformation occurs. There are two yield points (i) upper yield point (ii) lower yield point.

(iv) Ultimate Stress Point
It is a point that represents the maximum stress that a material can endure before failure. Beyond this point, failure occurs.

(v) Fracture or Breaking Point
It is the point in the stress-strain curve at which the failure of the material takes place.

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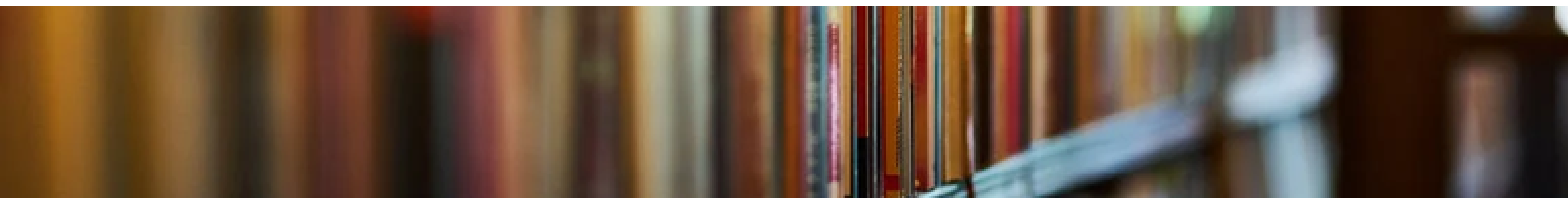

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