MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

L - 01

LECTURE HANDOUTS

CIVIL **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : I – STRESS AND STRAIN

Date of Lecture:

Topic of Lecture: Stress & strain at a point

Introduction:

Stress is a measure of the force put on the object over the area. Strain is the change in length divided by the original length of the object. Experiments have shown that the change in length (ΔL) depends on only a few variables.

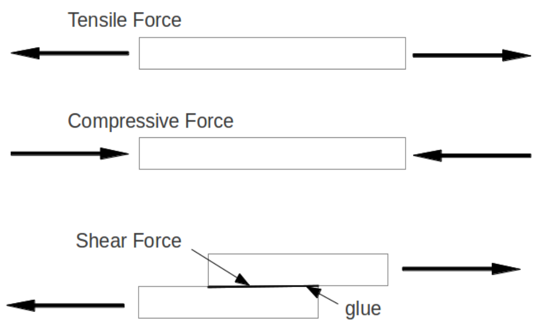
Prerequisite knowledge for Complete understanding and learning of Topic:

- No prerequisite knowledge required

Detailed content of the Lecture:

Stress:

Stress is the ratio of applied force F to a cross section area - defined as "force per unit area".



tensile stress - stress that tends to stretch or lengthen the material - acts normal to the stressed area.

compressive stress - stress that tends to compress or shorten the material - acts normal to the stressed area.

shearing stress - stress that tends to shear the material - acts in plane to the stressed area at right-angles to compressive or tensile stress.

Tensile (or) Compressive Stress - Normal Stress:

Tensile or compressive stress normal to the plane is usually denoted "normal stress" or "**direct stress**" and can be expressed as

$$\sigma = F_n / A \qquad (1)$$

where

σ = normal stress (Pa (N/m2), psi (lbf/in2))

Fn = normal force acting perpendicular to the area (N, lbf)

A = area (m2, in2)

A normal force acts perpendicular to area and is developed whenever external loads tends to push or pull the two segments of a body.

Shear Stress:

Stress parallel to a plane is usually denoted as "shear stress" and can be expressed as

$$\tau = F_p / A \qquad (2)$$

where

τ = shear stress (Pa (N/m2), psi (lbf/in2))

Fp = shear force in the plane of the area (N, lbf)

A = area (m2, in2)

A shear force lies in the plane of an area and is developed when external loads tend to cause the two segments of a body to slide over one another.

Strain (Deformation):

Strain is defined as "deformation of a solid due to stress".

Normal strain - elongation or contraction of a line segment

Young's Modulus:

$$E = \text{stress} / \text{strain}$$

$$= \sigma / \varepsilon$$

$$= (Fn / A) / (dl / lo) \qquad (4)$$

where

E = Young's Modulus (N/m2) (lb/in2, psi)

Modulus of Elasticity, or Young's Modulus, is commonly used for metals and metal alloys and expressed in terms 106 lbf/in2, N/m2 or Pa. Tensile modulus is often used for plastics and is expressed in terms 105 lbf/in2 or GPa.

Shear Modulus of Elasticity - or Modulus of Rigidity:

$$G = \text{stress} / \text{strain}$$

$$= \tau / \gamma$$

$$= (Fp / A) / (s / d) \qquad (5)$$

where

G = Shear Modulus of Elasticity - or Modulus of Rigidity (N/m2) (lb/in2, psi)

τ = shear stress ((Pa) N/m2, psi)

γ = unit less measure of shear strain

Fp = force parallel to the faces which they act

A = area (m2, in2)

s = displacement of the faces (m, in)

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=7Eiv7Qr4HQ8

https://www.youtube.com/watch?v=EC2dNWGSHCc

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(1-2)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(1.1-1.15)

Course Teacher

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L - 02

LECTURE HANDOUTS

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : I – STRESS AND STRAIN

Date of Lecture:

Topic of Lecture: Hooke's law – Relationship among Elastic constants

Introduction:

According to Hooke's law, when a body is subjected to tensile stress or compressive stress, the stress applied is directly proportional to the strain within the elastic limits of that body. The ratio of applied stress to the strain is constant and is known as Young's modulus or modulus of elasticity.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Simple stress
- ✓ Simple strain
- ✓ Elastic limit

Detailed content of the Lecture:

Hooke's Law:

Hooke's law states thatthe strain of the material is proportional to the applied stress within the elastic limit of that material.When the elastic materials are stretched, the atoms and molecules deform until stress is been applied and when the stress is removed they return to their initial state.

Elastic constant formula

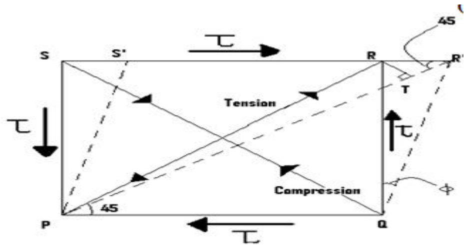
$$E = \frac{9KG}{G + 3K}$$

Where,

K is the Bulk modulus

G is shear modulus or modulus of rigidity.

E is Young's modulus or modulus of Elasticity.



Consider a solid cube, subjected to a Shear Stress on the faces PQ and RS and complimentary Shear Stress on faces QR and PS. The distortion of the cube, is represented by the dotted lines. The diagonal PR distorts to PR'.

(a) Relationship between E and G

Modulus of Rigidity, G = shear stress/shear strain

Shear Strain = Shearstress/G

From the diagram, Shear Strain φ = PR'/QR

Since Shear Stress = τ,

RR′/QR=τG.......(i)

From R, drop a perpendicular onto distorted diagonal PR'

The strain experienced by the diagonal = TR′/PR(Considering that PT ≈ PR)

=RR′cos45/(QR/cos45)=RR′/2QR

Strain of the Diagonal PR = RR′/2QR=τ/2G(FromI)........(ii)

Let f be the Direct Stress induced in the diagonal PR due to the Shear Stress τ

Strain of the diagonal = τ/2G=f/2G..........(iii)

The diagonal PR is subjected to Direct Tensile Stress while the diagonal RS is subjected to Direct Compressive Stress.

The total strain on Diagonal PR would be = f/E+1/m(f/E)

=f/E(1+1/m)...........(iv)

Comparing Equations (III) and (IV), we have

f/2G=f/E(1+1/m)

Re – arranging the terms, we have,

E=2G(1+1/m)...........(A)

(b) Relationship between E and K

Instead of Shear Stress, let the cube be subjected to direct stress f on all faces of the cube.

We know,

$$e_v=fx+fy+fz/E[1-2/m]$$

Since f=fx=fy=fz

$$e_v=3f/E[1-2/m]\text{............}(v)$$

Also, by the definition of Bulk Modulus,

$$e_v=f/K\text{..........}(vi)$$

Equating (V) and (VI), we have:

$$f/K=3fE[1-2m]$$

$$E=3K[1-2/m]\text{.............}(B)$$

(c) Relationship between E, G and K

From the equation **(A)**,

$$1/m=E-2G/2G$$

From the equation **(B)**

$$1/m=3K-E/6K$$

Equating both, we get,

$$E-2G/2G=3K-E/6K$$

Simplifying the equation, we get,

$$E=\frac{9KG}{G+3K}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=xQivKrSGbNM
https://www.youtube.com/watch?v=576rhe40C6g
https://www.youtube.com/watch?v=PWQm4ynYVSE

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(59-84)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(1.3-1.5)

Course Teacher

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L - 03

LECTURE HANDOUTS

CIVIL **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : I – STRESS AND STRAIN

Date of Lecture:

Topic of Lecture: Stress – strain diagram for mild steel

Introduction:

Stress strain curve is a behavior of material when it is subjected to load. In this diagram stresses are plotted along the vertical axis and as a result of these stresses, corresponding strains are plotted along the horizontal axis.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Proportional Limit
- ✓ Elastic Limit
- ✓ Yield Point
- ✓ Ultimate Stress Point
- ➢ Breaking Point

Detailed content of the Lecture:

Stress:

If aapplied force causes change in the dimension of the material then the material is in the state of stress. If we divide the applied force, F by the cross-sectionalarea, A then we will get the stress.

The symbol of stress is σ (Greek letter sigma).

The **unit of stress** is the pascal (Pa), Where, 1 Pa = 1 N/ m.**stress, (σ) = F/A**

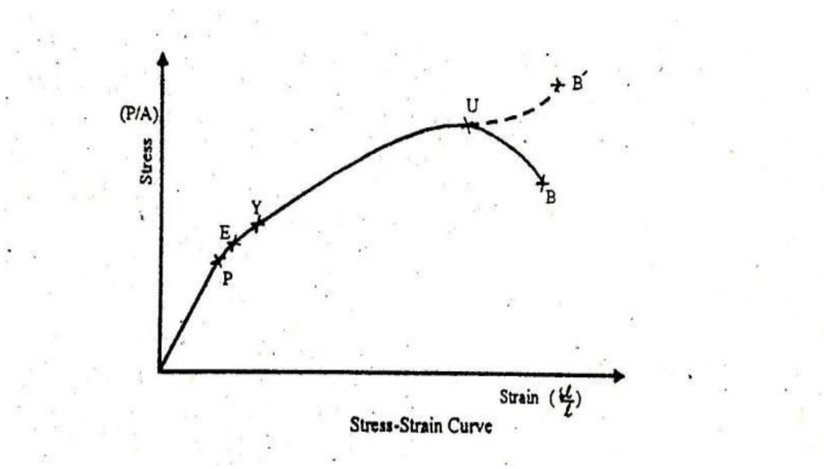
Strain:

Change in the dimension with respect to the original dimension due to stress is known as strain. It is denoted by the symbol epsilon(ε).

Strain,(ε) = x/ L

Stress Strain Curve Explanation:

Stress strain curve is a behavior of material when it is subjected to load. In this diagram stresses are plotted along the vertical axis and as a result of these stresses, corresponding strains are plotted along the horizontal axis.



Stress-Strain Curve

These stages are:

- ❖ Proportional Limit
- ❖ Elastic Limit
- ❖ Yield Point
- ❖ Ultimate Stress Point
- ❖ Breaking Point

PROPORTIONAL LIMIT:

Proportional limit is point on the curve up to which the value of stress and strain remains proportional. From the diagram point P is the called the proportional limit point or it can also be known as limit of proportionality. The stress up to this point can be also be known as proportional limit stress.

ELASTIC LIMIT:

Elastic limit is the limiting value of stress up to which the material is perfectly elastic. From the curve, point **E** is the elastic limit point. Material will return back to its original position, If it is unloaded before the crossing of point **E**. This is so, because material is perfectly elastic up to point **E**.

YIELD STRESS POINT:

Yield stress is defined as the stress after which material extension takes place more quickly with no or little increase in load. Point **Y** is the yield point on the graph and stress associated with this point is known as yield stress.

ULTIMATE STRESS POINT:

Ultimate stress point is the maximum strength that material have to bear stress before breaking. It can also be defined as the ultimate stress corresponding to the peak point on the stress strain graph. On the graph point **U** is the ultimate stress point. After point **U** material have very minute or zero strength to face further stress.

BREAKING STRESS (POINT OF RUPTURE):

Breaking point or breaking stress is point where strength of material breaks. The stress associates with this point known as breaking strength or rupture strength. On the stress strain curve, point **B** is the breaking stress point

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=WLDyp2Ds1XQ
https://www.youtube.com/watch?v=fMslltk1nt4

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(2-15)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(1.6-1.22)

Course Teacher

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Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : I – STRESS AND STRAIN

Date of Lecture:

Topic of Lecture: Thermal stresses

Introduction:

Thermal stress is stress causedbydifferences in temperature or by differences in thermal expansion. A crack formed as a result of thermal stress produced by rapid cooling from a high temperature. Because the section of rail was fixed at both ends it experienced a thermal stress when the ambient temperature increased.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Stress and Strain
- Modulus of Elasticity

Detailed content of the Lecture:

Thermal stresses:

Stress which is induced in a body due to change in the temperature is known as thermal stress and the corresponding strain is called thermal strain. Let,

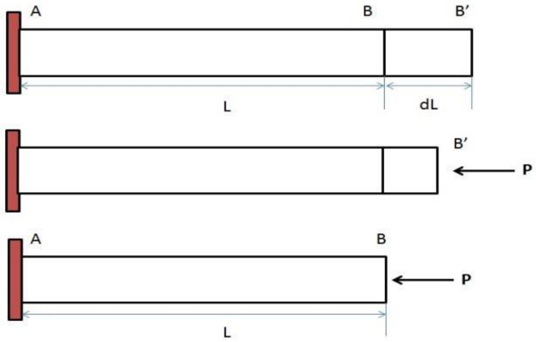
$$Extension\ produced = \alpha TL$$

$$dL = \alpha TL$$

L = Original length of the rod,

T = Rise in temperature,

Due to the increase in the temperature, there is an extension produced in the rod. When the rod is allowed to expand freely, the extension produced in the rod is given by



Here, AB is the original length of the rod, and BB′ is the extension produced in the rod. Suppose a compressive load P is applied at the end BB′.Compressive stress and strain is produced in the rod and is given by

$$Compressive\ strain = \frac{Decrease\ in\ length}{Original\ length} = \frac{\alpha TL}{L + \alpha TL} = \frac{\alpha TL}{L} = \alpha T$$

$$Stress = strain \times E = \alpha TE$$

Formula of the Thermal Stress and Strain:

Stress and strain is setup in the rod. The stresses and strain setup in the rod is known as thermal stresses and strains.

Thermal stress induced is given by

$$Stress = Strain \times E = \alpha TE$$

$$\sigma = \alpha TE$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=JCEIQqcmYGY
https://www.youtube.com/watch?v=FwOsoeOvZzo

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(42-44)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(1.23-1.25)

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LECTURE HANDOUTS

L - 05

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : I –STRESS AND STRAIN

Date of Lecture:

Topic of Lecture: Strain energy due to axial force

Introduction : (Maximum 5 sentences)

In a molecule, strain energy is released when the constituent atoms are allowed to rearrange themselves in a chemical reaction. The external work done on an elastic member in causing it to distort from its unstressed state is transformed into strain energy which is a form of potential energy.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ Strain energy
- ✓ Analysis force

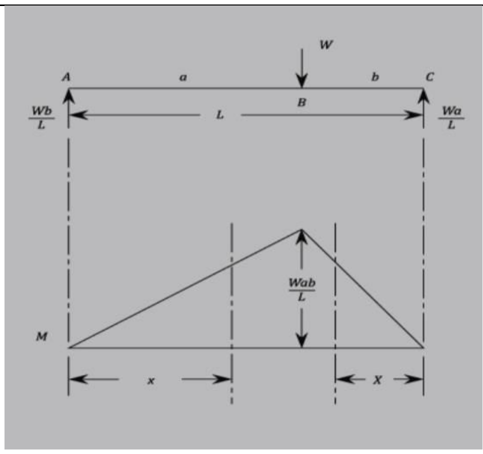
Detailed content of the Lecture:

Problem

A simply supported beam of length l carries a concentrated load W at distances of a and b from the two ends. Find expressions for the total strain energy of the beam and the deflection under load.

Solution,

The integration for strain energy can only be applied over a length of beam for which a continuous expression for M can be obtained. This usually implies a separate integration for each section between two concentrated loads or reactions.



For the section AB,

$$M = \left(\frac{Wb}{l}\right) x$$

$$U_a = \int_0^a \frac{W^2\, b^2\, x^2}{2\, l^2\, EI}\, dx$$

$$\therefore \quad U_a = \frac{W^2\, b^2}{2\, l^2\, EI}\left[\frac{x^3}{3}\right]_0^a$$

$$\therefore \quad U_a = \frac{W^2\, a^3\, b^2}{6\, E\, I\, l^2}$$

Similarly, by taking a variable X measured from C

$$\therefore \quad U_b = \int_0^b \frac{W^2\, a^2\, X^2}{2\, l^2\, E\, I} dX = \frac{W^2\, a^2\, b^3}{6\, E\, I\, l^2}$$

Total

$$U = U_a + U_b = \left(\frac{W^2\, a^2\, b^2}{6\, E\, I\, l^2}\right)(a + b)$$

$$\therefore \quad U = \frac{W^2\, a^2\, b^2}{6\, E\, I\, l}$$

But if δ is the deflection under the load, the strain energy must be equal to the work done by the load if it is gradually applied.

$$\frac{1}{2} W\, \delta = \frac{W^2\, a^2\, b^2}{6\, E\, I\, l}$$

$$\therefore \quad \delta = \frac{W\, a^2\, b^2}{3\, E\, I\, l}$$

For a Central Load

$$\therefore \quad \delta = \left(\frac{W}{3\, E\, I\, l}\right)\left(\frac{l^2}{4}\right)\left(\frac{l^2}{4}\right)$$

Hence

$$\delta = \frac{\mathbf{W\ l^3}}{\mathbf{48\ E\ I}}$$

Strain Energy

$$U = \frac{W^2 a^2 b^2}{6EIl}$$

Deflection

$$\delta = \frac{Wl^3}{48EI}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=yNASIxckvzg
https://www.youtube.com/watch?v=m14sqLGg4BQ

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(15-20)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(1.24-1.30)

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Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : I – STRESS AND STRAIN

Date of Lecture:

Topic of Lecture: Resilience

Introduction : (Maximum 5 sentences)

The resilience is defined as the capacity of a strained body for doing work on the removal of the straining force. The total strain energy stored in a body is commonly known as resilience.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ Thermal Stress
- ✓ Stress and Strain

Detailed content of the Lecture:

Resilience:

When a body subjected to external load within the elastic limit, the body gets deformed. On the removal of the external load, the body will get its original shape (Under load within elastic limit). Why because the body can store some internal energy.

From the **Hooke's law**"Stress is directly proportional to the Strain".

Stress is the load applied per area whereas the strain is the deformation (Change in length/ Original length).

This Energy stored by the body to regain its original shape is called Strain Energy. The strain Energy stored in a body due to the external loading is known as the Resilience.

Proof Resilience:

The maximum amount of the strain energy can be stored in the body up to the elastic limit is defined as the Proof resilience.

Modulus of Resilience:

Mathematically Modulus of Resilience can be defined as the ratio of the proof resilience to the volume of the body.

$$\text{Strain Energy (U)} = \frac{\sigma^2 \text{x} \, V}{2E}$$

Resilience is nothing but the Strain energy. from the above equation, we can calculate the resilience.

Units for Resilience = joule per cubic meter (J ·m−3)

$$\text{Modulus of Resilience} = \frac{\sigma^2}{2E}$$

σ = Tensile stress or Compressive Stress.

E = Youngs modulus of the material of the body.

Important Observation

$$\text{Modulus of Resilience (Shear loading)} = \frac{\tau^2}{2C}$$

$$\text{Modulus of Resilience (Torsional loading)} = \frac{\tau^2}{4C}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=Gro_7hgst_w

https://www.youtube.com/watch?v=JyZmIO1EzMU

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(143-145)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(1.29-1.32)

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L - 07

LECTURE HANDOUTS

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : I –STRESS AND STRAIN

Date of Lecture:

Topic of Lecture: Stresses due to impact & sudden loads

Introduction : (Maximum 5 sentences)

Impact load is moving load.The moving body striking another body creates impact load. It causes many times stress when if the same load is applied gradually.When the total force is applied in one installment i.e. force of 100 N is applied in one installment.

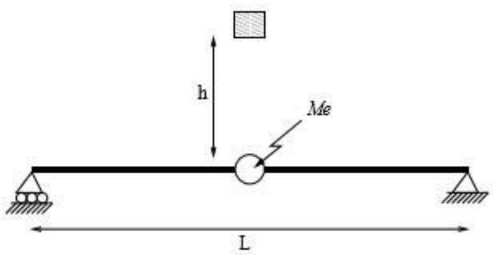
Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ Analysis of load
- ✓ Stress
- ✓ Strain

Detailed content of the Lecture:

Example:

If we do not ignore the mass of the beam, we need to determine an equivalent mass of the beam at the point of impact in order to simplify the problem to a level we can solve relatively easily.



The beam is replaced with a massless beam with equivalent mass, Me lumped at point of impact. Note that deflection is still given by 5.1, as expected — the lumped mass only helps determine the kinetic + potential energy of the mass and beam.

$$\frac{V(L/2)}{V(x)} = \frac{y(L/2)}{y(x)}$$

The Kinetic energy of the beam is then

$$\begin{aligned} K.E. &= 2 \times \frac{1}{2}\int_0^{\frac{L}{2}} V(x)^2 dm \\ &= \rho A \int_0^{\frac{L}{2}} V(L/2)^2 \left[\frac{3L^2x - 4x^3}{L^3}\right]^2 dx \\ &= \frac{1}{2} m_b \frac{22}{35} V(L/2)^2 \end{aligned}$$

Thus an equivalent mass can be thought of as Me = 22/35mb. This is not quite the end as we need to know V (L/2). Recall that at impact, the velocity of a falling mass is √2gh, thus, a momentum balance determining the transfer of momentum at impact is:

$$\begin{aligned} m\sqrt{2gh} &= \left(m + \frac{22}{35}m_b\right) V(L/2) \\ V(L/2) &= \frac{m\sqrt{2gh}}{m + \frac{22}{35}m_b} \end{aligned}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=RwiJ2jZi9Xk
https://www.youtube.com/watch?v=iKklM2D2cIA

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(5-15)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(1.12-1.27)

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L - 08

LECTURE HANDOUTS

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : I – STRESS AND STRAIN

Date of Lecture:

Topic of Lecture: Compound bars

Introduction: (Maximum 5 sentences)

The compound bar consists of strips of dissimilar metals bonded together, and can be used to demonstrate unequal expansion in different metals on heating. The bar bends when it is heated on one side by a Bunsen burner.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

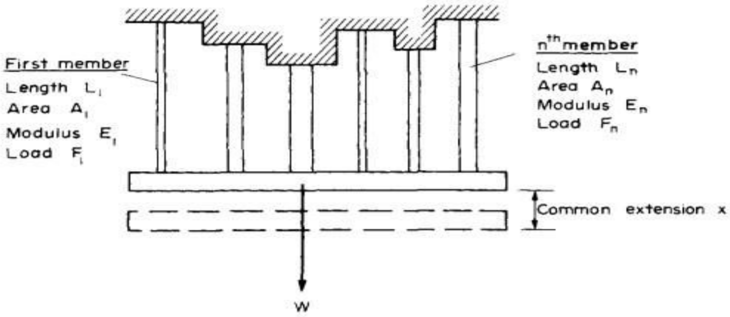
- ✓ No prerequisite knowledge requested

Detailed content of the Lecture:

Compound bars

In certain applications it is necessary to use a combination of elements or bars made from different materials, each material performing a different function. In overhead electric cables, for example, it is often convenient to carry the current in a set of copper wires surrounding steel wires, the latter being designed to support the weight of the cable over large spans. Such combinations of materials are generally termed compound burs.

Consider, therefore, a compound bar consisting of n members, each having a different length and cross-sectional area and each being of a different material. Let all members have a common extension x, i.e. the load is positioned to produce the same extension in each member.



$$\frac{\text{stress}}{\text{strain}} = E_n = \frac{F_n L_n}{A_n x_n}$$

$$F_n = \frac{E_n A_n x}{L_n}$$

$$F_1 = \frac{E_1 A_1 x}{L_1}$$

$$x = \frac{W}{\Sigma \frac{E_n A_n}{L_n}}$$

$$F_1 = \frac{\frac{E_1 A_1}{L_1}}{\Sigma \frac{EA}{L}} W$$

The stress in member 1 is then given by

$$\sigma_1 = \frac{F_1}{A_1}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=Y8Yhu5lXoBo
https://www.youtube.com/watch?v=JeOLHcRGMcA

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(15-20)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(1.29-1.35)

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L - 09

LECTURE HANDOUTS

CIVIL **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : I – STRESS AND STRAIN

Date of Lecture:

Topic of Lecture: Thin cylinders & shells

Introduction:(Maximum 5 sentences)

Thin cylinder is cylinder whose wall thickness is lesser than 1/20 times of its internal diameter. If the thickness of the wall of the shell is less than 1/10 to 1/15 of its diameter, then shell is called thin shells.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ Analysis shell
- ✓ Analysis of cylinders

Detailed content of the Lecture:

Thin Cylindrical Shell

Thin Shell

A vessel is a thin if its thickness is less as compared to its diameter. Mathematically it is expressed as a thin shell if D/t. A vessel is a thin shell where stresses are assumed to be uniform. Uniform stresses mean stress at the inner to outer radius is of same magnitude.

VARIOUS STRESSES IN A THIN SHELL

(i) Hoop stress or Tangential stress or Circumferential stress(σh)

It acts in the tangential direction at the point of consideration

(ii) Longitudinal stress (σl)

It acts in the longitudinal direction at the point of consideration

(iii) Radial stress(σr)

SHAPES OF THIN SHELLS

a) Cylindrical
b) Spherical
c) Modified

DERIVATION OF FORMULA OF VARIOUS STRESSES

(i) σh = hoop stress

It will break the cylinder length wise

Therefore, equating the resisting force to bursting force,

we get

$$2\ \sigma h\ L\ t = p\ DL$$

$$\sigma h = pD/2t$$

If the efficiency of the longitudinal joint is considered then $\sigma h = pD/2t\ \eta long$

(ii) σl = Longitudinal stress

If the cylinder fails at the circumference joint due to fluid pressure

Equating the resistance of the material to the breaking force.

Therefore,

$$\sigma l\ \pi\ Di\ t = p(\pi/4)Di2)$$

$$\sigma l = pDi/4t$$

If the efficiency of the circumferential joint is considered then $\sigma l = pD/4t\ \eta circum$

(iii) Radial stress = σr = inside fluid pressure

$$\Sigma r = pi$$

From the equations it can be easily concluded that the radial stress is negligible as compared to hoop and longitudinal stresses because of d/t ratio minimum value is 20.

CHANGE IN DIMENSIONS OF A THIN SHELL

(a) Change in length δL

$$\delta L/L = \sigma l/E - \mu\ \sigma h/E = pDi/4tE - \mu\ pD/2tE$$

$$\delta L/L = (pDi/4tE)\ (1-2\mu)$$

$$\delta L = (pDi\ L/4tE)\ (1-2\mu)$$

(b) Change in diameter of the shell, δD

δD/D = Change in circumference / Original circumference= π δD/πD

Therefore,

$$\delta D/D = \sigma h/E - \mu\, \sigma L/E = pDi/2tE - \mu\, pD/4tE$$

$$\delta D/D = (pDi/4tE)\,(2-\mu)$$

$$\delta D = (pDiDi\ /4tE)\,(2-\mu)$$

$$\delta D = (pDi2\ /4tE)\,(2-\mu)$$

(c) Change in volume, δV

$$\delta V/V = \text{Volumetric strain} = 2\,\delta D/D + \delta L/L$$

$$\delta V/V = 2\,(pDi/4tE)\,(2-\mu) + (pDi/4tE)\,(1-2\mu)$$

$$\delta V/V = (pDi/4tE)\,(5-4\mu)$$

$$V = (\pi/4)\, D2L$$

$$\delta V = (pDi/4tE)\,(5-4\mu)\,(\pi/4)D2L$$

$$\delta V = (\pi pD3L/16tE)\,(5-4\mu)$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=6gRbYSEWx-

ghttps://www.youtube.com/watch?v=tXPks3VXUPY

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(747-760)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(1.37-1.46)

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LECTURE HANDOUTS

CIVIL | **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : II SHEAR AND BENDING IN BEAMS

Date of Lecture:

Topic of Lecture: Beams & Bending - Introduction

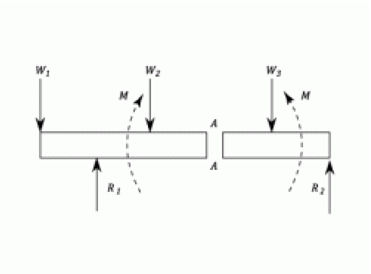
Introduction: (Maximum 5 sentences)

Bending Moments are rotational forces within the beam that cause bending. At any point within a beam, the Bending Moment is the sum of each external force multiplied by the distance that is perpendicular to the direction of the force.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ Bending moments
- ✓ Types of load
- ✓ Types of support

Detailed content of the Lecture:



Bending Moments

In a similar manner it can be seen that if the Bending moments (BM) of the forces to the left of AA are clockwise, then the bending moment of the forces to the right of AA must be anticlockwise.

Types of load:

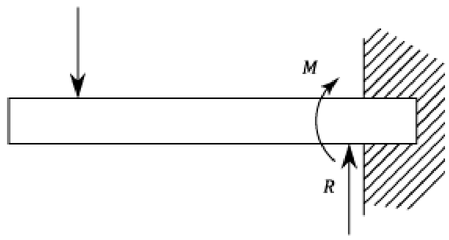
A beam is normally horizontal and the loads vertical. Other cases which occur are considered to be exceptions.

A Concentrated load is one which can be considered to act at a point, although in practice it must be distributed over a small area.

A Distributed load is one which is spread in some manner over the length, or a significant length, of the beam. It is usually quoted at a weight per unit length of beam. It may either be uniform or vary from point to point.

Types of support:

A Simple or free support is one on which the beam is rested and which exerts a reaction on the beam. It is normal to assume that the reaction acts at a point, although it may in fact act act over a



A Built-in or encastre' support is frequently met. The effect is to fix the direction of the beam at the support. In order to do this the support must exert a "fixing" moment M and a reaction R on the beam.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=5K27dJqGpf8

https://nptel.ac.in/courses/105105166/

https://www.youtube.com/watch?v=UahfUvcS24o

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(291-295)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(2.1-2.5)

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LECTURE HANDOUTS

CIVIL **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : II SHEAR AND BENDING IN BEAMS

Date of Lecture:

Topic of Lecture: Types of Loads - supports

Introduction : (Maximum 5 sentences)

The loads on a beam can be point loads, distributed loads, or varying loads. There can also be point moments on the beam. The beam itself is supported at one or more points.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

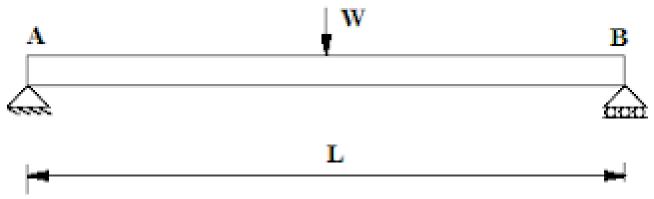
- ✓ Concentrated or Point Load
- ✓ Uniformly Distributed Load
- ✓ Uniformly Varying Load

Detailed content of the Lecture:

Point load or concentrated load

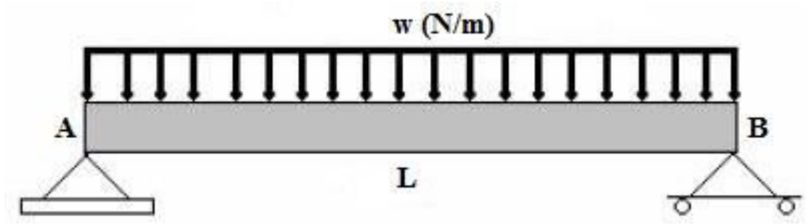
Point load or concentrated load, as name suggest, acts at a point on the beam. If we will see practically, point load or concentrated load also distributed over a small area but we can consider such type of loading as point loading and hence such type of load could be considered as point load or concentrated load.

Following figure displayed here indicates the beam AB of length L which will be loaded with point load W at the midpoint of the beam. Load W will be considered here as the point load.



Uniformly distributed load

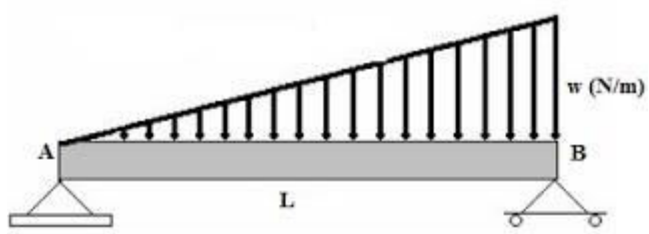
Uniformly distributed load is the load which will be distributed over the length of the beam in such a way that rate of loading will be uniform throughout the distribution length of the beam. Let us consider the following figure, a beam AB of length L is loaded with uniformly distributed load and rate of loading is w (N/m)



Total uniformly distributed load, P = w*L

Uniformly varying load

Uniformly varying load is the load which will be distributed over the length of the beam in such a way that rate of loading will not be uniform but also vary from point to point throughout the distribution length of the beam.



Total load, P = w*L/2

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=1Cry0ehP0XY

https://www.youtube.com/watch?v=1Cry0ehP0XY

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(237-240)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(2.1-2.10)

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LECTURE HANDOUTS

CIVIL **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : II SHEAR AND BENDING IN BEAMS

Date of Lecture:

Topic of Lecture: Shear force & Bending Moment diagram for statically determinate beam

Introduction: (Maximum 5 sentences)

In the shear forces and bending moments are the resultants of stresses distributed over the cross section, they are known as stress resultants and in statically determinate beams can be calculated from the equations of static equilibrium.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ Cantilever beams
- ✓ Simply supported beams
- ✓ Overhanging beams
- ✓ Fixed beams

Detailed content of the Lecture:

Shear Force and Bending Moment:

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

Shear and Bending Moment Diagrams:

The loading on most beams is such that the stress resultant on planes perpendicular to the axis of the beam consists of a shear force, V, and a bending moment, M. In determining beam responses, it is very convenient, if not essential, to first determine the shear and bending moment diagrams.

The basic procedure for determining the shear and moment diagrams is to determine the values of V and M at various locations along the beam and plotting the results.

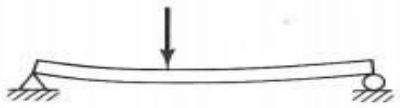
In doing so, we will determine critical sections within the beam. A critical section is one where a critical or maximum stress occurs.

Section of Maximum Shear – Since the shear, V, at any transverse section of the beam is the algebraic sum of the transverse forces to the left of the section, the shear, in most cases, can be evaluated at a glance.

Section of Maximum Moment – It can be shown mathematically, that when the shear force is zero or changes sign; the bending moment will be either a maximum or relative maximum.

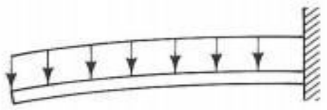
Simply supported beam:

A simply supported beam is a type of beam that has pinned support at one end and roller support at the other end. Depending on the load applied, it undergoes shearing and bending. It is the one of the simplest structural elements in existence.



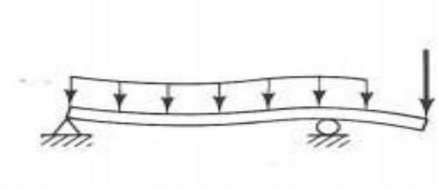
Cantilever Beams:

Cantilever beam means a rigid beam or bar that is fixed to a support usually a vertical structure or wall and the beam's other end is free. It is y a horizontal beam that is firm at only one end while the other end is left free to carry some vertical loads. The beam's fixed end has a reaction force and moment created by the load acting at the free end. The intention of cantilever beam is to create a bending effect to certain limit. Diving board at swimming pool is a perfect example for cantilever beam. Aircraft wing that carries wind force is another good example for cantilever beam.



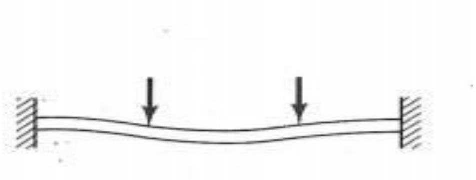
Overhanging beam:

A overhanging beam is a beam that has one or both end portions extending beyond its supports. It may have any number of supports. If viewed in a different perspective, it appears as if it is has the features of simply supported beam and cantilever beam.



Fixed beams:

A fixed beam is one with ends restrained from rotation. In reality a beams ends are never completely fixed, as they are often modeled for simplicity. However, they can easily be restrained enough relative to the stiffness of the beam and column to be considered fixed.



Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=SgpUcuJc4ao
https://www.youtube.com/watch?v=pN8zj44_DoY
https://www.youtube.com/watch?v=2Cb2IseM9EE

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(241-260)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(2.5-2.25)

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LECTURE HANDOUTS

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : II SHEAR AND BENDING IN BEAMS

Date of Lecture:

Topic of Lecture: Shear force & Bending moment for different types of loading conditions

Introduction: (Maximum 5 sentences)

A bending moment is the reaction induced in a structural element when an external force or moment is applied to the element causingthe element to bend.Simply supported means that each end of the beam can rotate.therefore, each end support has no bending moment. The ends can only react to the shear loads.

Prerequisite knowledge for Complete understanding and learning of Topic:

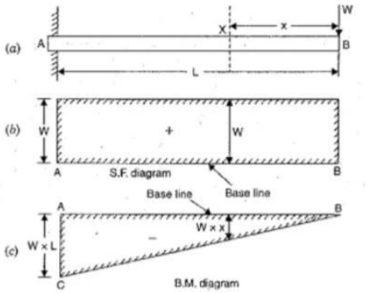
(Max. Four important topics)

- ✓ Analysis of loading condition
- ✓ Shear force
- ✓ Bending moment

Detailed content of the Lecture:

Problem for SF and BM different types of loading conditions:

Draw SFD and BMD for a cantilever beam carrying point load (W) At the free end.



Let,

F_x = Shear force at X,

M_x = Bending moment at X.

The shear force at this section is equal to the resultant force acting on the right portion at the section X is W and acting in the downward direction. But a force on the right portion acting downwards is considered positive. Hence shear force at X is positive.

$$F_A=+W$$

The shear force will be constant at all sections of the cantilever between A and Bas there is no other load between A and B.

Bending Moment Diagram:

The bending moment at the section X is given by

$M_X=-W*X$

(Bending moment will be negative as for right portion of the section, the moment of W at X is clockwise. Also, the bending of cantilever will take place in such a manner that convexity will be at the top of the beam).

Hence B.M follows the straight-line law.

At point A,

take AC = W × L in the downward direction.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=DhWPVEStMug
https://www.youtube.com/watch?v=iPPEYi2Jocc

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(241-270)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(2.5-2.25)

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LECTURE HANDOUTS

CIVIL **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : II SHEAR AND BENDING IN BEAMS

Date of Lecture:

Topic of Lecture: Theory of simple bending

Introduction : (Maximum 5 sentences)

When a beam is subjected to a loading system or by a force couple acting on a plane passing through the axis, then the beam deforms. In simple terms, this axial deformation is called as bending of a beam. Due to the shear force and bending moment, the beam undergoes deformation. These normal stress due to bending are called flexure stresses.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

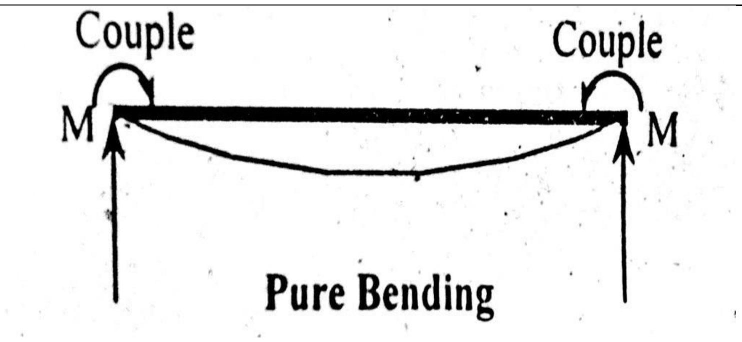
- ✓ Pure Bending Stress
- ✓ Simple Bending Stress
- ✓ Normal Strains
- ✓ Transverse Strain

Detailed content of the Lecture:

Types of Bending Stress

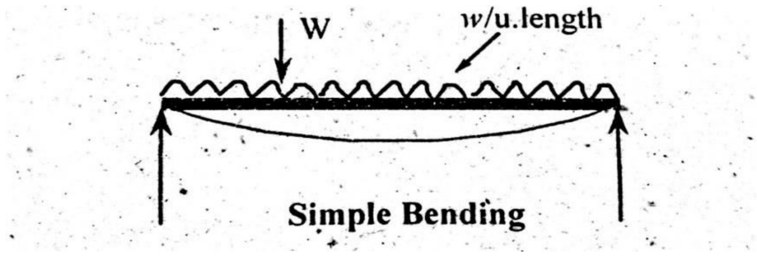
1.Pure Bending Stress:

Bending will be called as pure bending when it occurs solely because of coupling on its end. In that case there is no chance of shear stress in the beam. But, the stress that will propagate in the beam as a result will be known as normal stress. Normal stress because it not causing any damages to beam. As shown below in the picture.



2.Simple Bending Stress:

Bending will be called as simple bending when it occurs because of beam self-load and external load. This type of bending is also known as ordinary bending and in this type of bending results both shear stress and normal stress in the beam. As shown below in the figure.



Formula for Flexural Stress:

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}$$

$$\frac{M}{I} = \frac{\sigma_{max}}{c}$$

$$\sigma_{max} = \frac{Mc}{I} = \frac{M}{Z}$$

Where, Z= section modulus and is given by,

Z = I/c

Types of Bending Strain

1. Normal Strains:

As a result of bending, somewhere between the top and bottom of the beam is a surface in which the longitudinal fibres do not change in length. This surface is called the neutral surface of the beam and its intersection with any cross-sectional plane is called the neutral axis of the cross-section.

All the longitudinal fibres other than those in the neutral surface either lengthen or shorten, thereby creating longitudinal strains ε_x.

$\varepsilon_x = \pm ky$

Where k = curvature = 1/R

This equation shows longitudinal strains are proportional to the curvature and that they vary linearly with the distance y from the neutral surface. This equation is derived from the geometry of the deformed beam and is independent of the properties of the material. The equation is valid irrespective of the stress-strain diagram of the material.

2. Transverse Strain:

The axial strains ε_x are accompanied by lateral or transverse strains due to the effect of Poisson's ratio. Positive strains are accompanied by negative transverse strains ε_z.

$\varepsilon_z = \gamma \varepsilon_x$

Where γ is the Poisson's Ratio.

As a result of these strains, the shape of the cross-section change. For example, let us study the case of a beam of rectangular cross-section subjected to pure bending so as to induce tension at the top and compression at the bottom.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=H96aaks551k

https://nptel.ac.in/courses/105105108/

https://www.youtube.com/watch?v=0H__cNY4TvM

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(295-310)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(2.57-2.70)

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LECTURE HANDOUTS

CIVIL **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : II SHEAR AND BENDING IN BEAMS

Date of Lecture:

Topic of Lecture: Analysis of beams for stresses

Introduction : (Maximum 5 sentences)

Compressive and tensile forces develop in the direction of the beam axis under bending loads. These forces induce stresses on the beam. The maximum compressive stress is found at the uppermost edge of the beam while the maximum tensile stress is located at the lower edge of the beam.

Prerequisite knowledge for Complete understanding and learning of Topic: (Max. Four important topics)

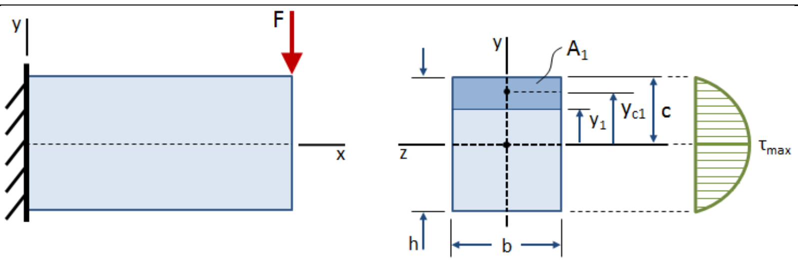
- ✓ Analysis of beam
- ✓ Stress Concentration

Detailed content of the Lecture:

Shear Stresses in Beams:The shear force, V, along the length of the beam can be determined from the shear diagram. The shear force at any location along the beam can then be used to calculate the shear stress over the beam's cross section at that location. The average shear stress over the cross section is given by:

$$\tau_{avg} = \frac{V}{A}$$

The shear stress varies over the height of the cross section, as shown in the figure below:



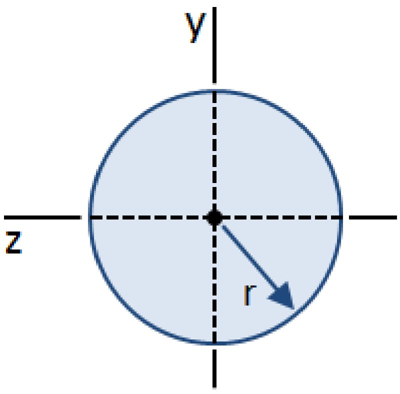
The shear stress is zero at the free surfaces (the top and bottom of the beam), and it is maximum at the centroid. The equation for shear stress at any point located a distance y1 from the centroid of the cross section is given by:

$$\tau = \frac{VQ}{I_c b}$$

where V is the shear force acting at the location of the cross section, Ic is the centroidal moment of inertia of the cross section, and b is the width of the cross section. These terms are all constants. The Q term is the first moment of the area bounded by the point of interest and the extreme fiber of the cross section:

$$Q = \int_{y1}^{c} y\, dA$$

Shear Stresses in Circular Sections:



The equations for shear stress in a beam were derived using the assumption that the shear stress along the width of the beam is constant. This assumption is valid at the centroid of a circular cross section, although it is not valid anywhere else. Therefore, while the distribution of shear stress along the height of the cross section cannot be readily determined, the maximum shear stress in the section (occurring at the centroid) can still be calculated. The maximum value of first moment, Q, occurring at the centroid, is given by:

$$Q_{max} = \frac{2r^3}{3}$$

The maximum shear stress is then calculated by:

$$\tau_{max} = \frac{VQ_{max}}{I_c b} = \frac{4V}{3A}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=FeZWbM_wT_o
https://www.youtube.com/watch?v=C5TsyNLoqzU

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(281-290)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(2.57-2.70)

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LECTURE HANDOUTS

CIVIL **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : II SHEAR AND BENDING IN BEAMS

Date of Lecture:

Topic of Lecture: Stress distribution due to shear force & bending moment for cantilever

Introduction : (Maximum 5 sentences)

Shear force on cantilever beam is the sum of vertical forces acting on a particular section of a beam. While bending moment is the algebraic sum of moments about the centroidal axis of any selected section of all the loads acting up to the section.

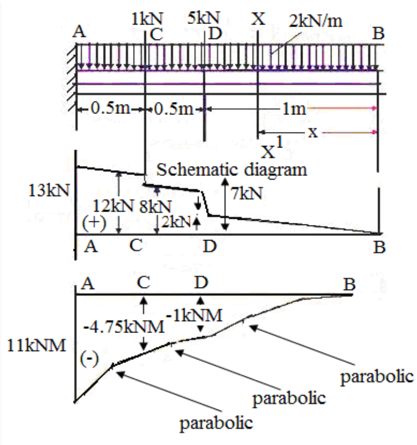
Prerequisite knowledge for Complete understanding and learning of Topic: (Max. Four important topics)

- ✓ No prerequisite knowledge required

Detailed content of the Lecture:

Problems:

A cantilever beam is subjected to various loads as shown in below. Draw the shear force diagram and bending moment diagram for the beam.



Solution:

Consider a section (X – X′) at a distance x from section B. shear force. between B and D;

Shear force Fx = + wx

At x = 0, Fb = 0

x = 1 m; Fd just right = 2 × 1 = 2 kN

S.F. between D and C; Fx = + wx + 5

At x = 1 m; FD just left = (2 × 1) + 5 = 7 kN

At x = 1.5 m; Fc just right = (2 × 1.5) + 5 = 8 kN

S.F. between C and A

Fx = + wx + 5 + 4

At x = 1.5 m; Fc just left = 2 × 1.5 + 5 + 4 = 12 kN

At x = 2 m; FA = 2 × 2 + 5 + 4 = 13 kN

Bending moment between C and A;

Mx = – (wx).x/2

Mx = wx2/2 – 5 (x – 1) – 4 (x – 1.5)

At x = 1.5 m; Mc = –2 × (1.5)2 / 2 –5 (1.5 – 1) – 4 (1.5 – 1.5)

Mc = –4.75 kN- m

x = 2.0 m; Ma = – 2 × (2)2 / 2 – 5 (2.0 – 1) – 4 (2.0 – 1.5)

Ma = - 11 kN-m

(The sign of bending moment is taken to be negative because the load creates hogging).

The shape of bending moment diagram is parabolic in shape from B to D, D to C, and, also C to A.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=R0rW7ziiuZM
https://www.youtube.com/watch?v=_dsHdnLO4kE

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(237-245)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(2.12-2.25)

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LECTURE HANDOUTS

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : II SHEAR AND BENDING IN BEAMS

Date of Lecture:

Topic of Lecture: Stress distribution due to shear force & bending moment for SSB

Introduction : (Maximum 5 sentences)

A beam is a member subjected to loads applied transverse to the long dimension, causing the member to bend. For example, a simply-supported beam loaded at its third-points will deform into the exaggerated bent shape. A beam supported by pins, rollers, or smooth surfaces at the ends is called a simple beam.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ Stress Concentration
- ✓ Types of beams

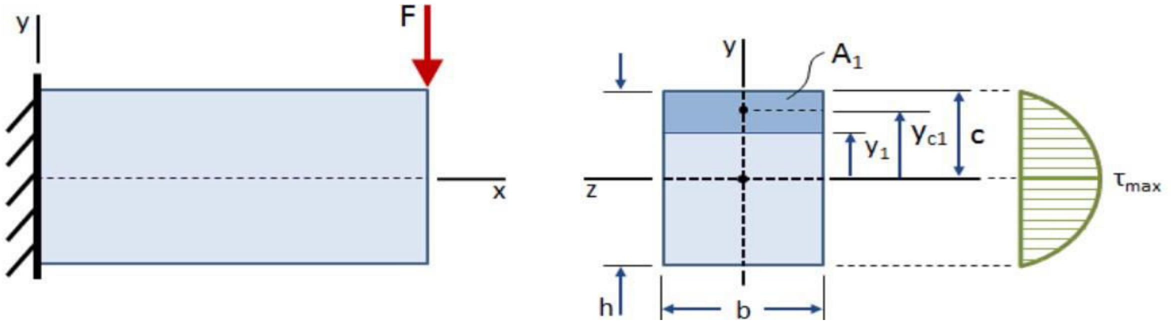
Detailed content of the Lecture:

Shear Stresses in Beams:

The shear force, V, along the length of the beam can be determined from the shear diagram. The shear force at any location along the beam can then be used to calculate the shear stress over the beam's cross section at that location. The average shear stress over the cross section is given by:

$$\tau_{avg} = \frac{V}{A}$$

The shear stress varies over the height of the cross section,



The shear stress is zero at the free surfaces (the top and bottom of the beam), and it is maximum at the centroid. The equation for shear stress at any point located a distance y1 from the centroid of the cross section is given by:

$$\tau = \frac{VQ}{I_c b} \qquad Q = \int_{y1}^{c} y\, dA$$

,

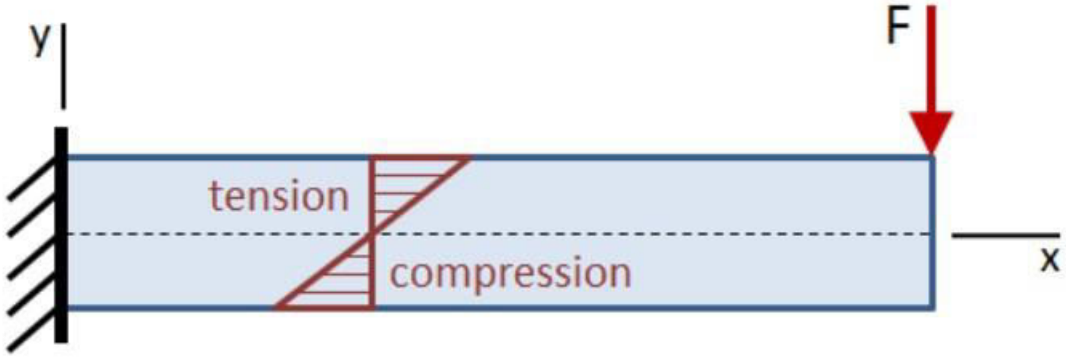
Bending Stresses in Beams:

The bending moment, M, along the length of the beam can be determined from the moment diagram. The bending moment at any location along the beam can then be used to calculate the bending stress over the beam's cross section at that location. The bending moment varies over the height of the cross section according to the flexure formula below:

$$\sigma_b = -\frac{My}{I_c}$$

where M is the bending moment at the location of interest along the beam's length, Ic is the centroidal moment of inertia of the beam's cross section, and y is the distance from the beam's neutral axis to the point of interest along the height of the cross section. The negative sign indicates that a positive moment will result in a compressive stress above the neutral axis.

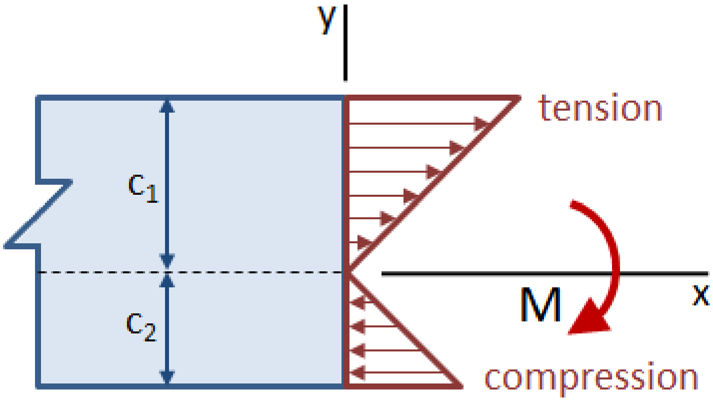
The bending stress is zero at the beam's neutral axis, which is coincident with the centroid of the beam's cross section. The bending stress increases linearly away from the neutral axis until the maximum values at the extreme fibers at the top and bottom of the beam.



The maximum bending stress is given by:

$$\sigma_{b.max} = \frac{Mc}{I_c}$$

If the beam is asymmetric about the neutral axis such that the distances from the neutral axis to the top and to the bottom of the beam are not equal, the maximum stress will occur at the farthest location from the neutral axis. In the figure below, the tensile stress at the top of the beam is larger than the compressive stress at the bottom.



The section modulus of a cross section combines the centroidal moment of inertia, Ic, and the centroidal distance, c:

$$S = \frac{I_c}{c}$$

$$\sigma_{b.max} = \frac{M}{S}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=7WD3fCnA2jY
https://www.youtube.com/watch?v=ouuRroDon0A

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(254-260)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(2.25-2.40)

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LECTURE HANDOUTS

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : II SHEAR AND BENDING IN BEAMS

Date of Lecture:

Topic of Lecture: Stress distribution due to shear force & bending moment for overhanging

Introduction : (Maximum 5 sentences)

Shear force is the internal force on a member when the force is not applied at the axis. Shearing force is the force divided by the cross-sectional area. Bending moment is the force trying to rotate the member. Moment is the perpendicular distance from the force to the axis multiplied by the force.

Prerequisite knowledge for Complete understanding and learning of Topic: (Max. Four important topics)

- ✓ Shear force
- ✓ Bending moment
- ✓ Point of contra-flexure

Detailed content of the Lecture:

Sample Problem:

A simply supported beam overhanging on one side is subjected to a uniform distributed load of 1 kN/m. Sketch the shear force and bending moment diagrams and find the position of point of contra-flexure.

Solution:

Consider a section (X – X′) at a distance x from end C of the beam.

To draw the shear force diagram and bending moment diagram we need RA and RB.

By taking moment of all the forces about point A.

$RB \times 3 - w/2 \times (4)2 = 0$

RB = 1 × (4)2 / 2 × 3 = 8/3 kN

For static equilibrium;

RA + RB – 1 × 4 = 0

RA = 4 – 8/3 = 4/3 kN

To draw shear force diagram we need shear force at all salient points:

Taking a section between C and B, SF at a distance x from end C. we have,

$Fx = +\omega .x$ kN

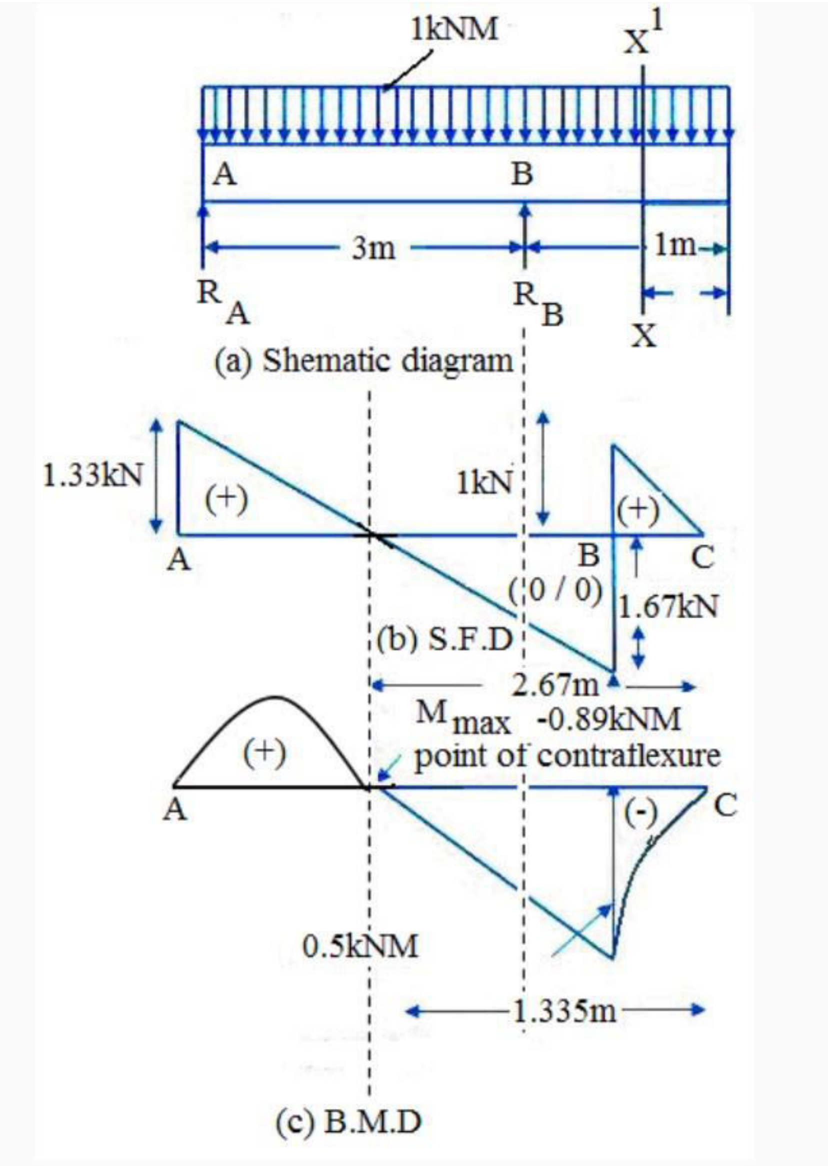
At x = 0; FC = 0

x = 1 m; FB just right = 1 × 1 = + 1 kN

Now, taking section between B and A, at a distance x from end C, the SF is:

$Fx = \omega .x - 8/3 = \omega.x\text{-}8/3$

When, x = 1 m; $F_B = 1 \cdot 1 - 8/3 = \omega.x\text{-}8/3 = -5/3$ kN $= -1.67$ kN



At x = 4 m; $F_A = 4 - 8/3 = +4/3$ kN = + 1.33 kN

The shear force becomes zero;

$$Fx = \omega\, x - 8/3 = 0$$

x = 2.67 m

Mx = – wx2 / 2 = –1.x2/2 kN m $= \omega x^2/2 = -1\, x^2/2$

When x = 0, MC = 0

At x = 1 m. MB = –1 × (1)2 / 2 = –0.5 kN m

The maximum bending moment occurs at a point where

dMx / dx = 0

= d/dx [–x2 / 2 + 8/3 x – 8/3] = 0

= –1/2 × 2x + 8/3 = 0

= x = 8/3 m from end C.

= Mmax = –1/2 (8/3)2 + 8/3 (8/3 – 1) = 0.89 kN m

The point of contraflexure occurs at a point, where

Mx = 0

= –x2/2 + 8/3 (x – 1) = 0

= x2 = 16/3 (x – 1)

= x2 – 16/3 x + 16/3 = 0

x = 1.335 m or 4 m

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=BHNf-uwW7wg

https://www.youtube.com/watch?v=VUCdW-pIC6o

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(237-250)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(2.40-2.57)

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Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : III DEFLECTION

Date of Lecture:

Topic of Lecture: Slope & Deflection

Introduction: (Maximum 5 sentences)

SLOPE- It is angular shift at any point of the beam between no load condition and loaded beam. Deflection- It is the vertical shift of a point on the beam between no load condition and loaded beam. Its value is different at different points on the length of the beam. It is represented by y or δ.

Prerequisite knowledge for Complete understanding and learning of Topic: (Max. Four important topics)

- ✓ Slope
- ✓ Deflection
- ✓ Mohr's theorem

Detailed content of the Lecture:

SLOPE:

It is angular shift at any point of the beam between no load condition and loaded beam. Its value is different at different points on the length of the beam. It is represented by dy/dx or θ. Its units are radians. There is a maximum limit for slope for any loaded beam.

Deflection:

It is the vertical shift of a point on the beam between no load condition and loaded beam. Its value is different at different points on the length of the beam. It is represented by y or δ. Its units are mm. There is a limit for maximum deflection for any loaded beam.

METHODS TO FIND SLOPE AND DEFLECTION

1. Double Integration Method: It is valid for finding slope and deflection for one load at a time.Thus, it is time consuming.
2. Macaulay's Method: Uses SQUARE BRACKETS. It is applicable for any number and any types of loads.
3. Superposition Method.
4. Moment Area Method or Graphical Method: Uses Two Mohr's Theorems
   1) **MOHR'S FIRST THEOREM:** It is for finding Slope: It states that the difference of slopes between any two points on the loaded beam is equal to the area of the BMD between those two points divided by Bending Stiffness EI. $\theta B - \theta A$=AREA OF BMD BETWEEN A AND B/EI
   2) **MOHR'S SECOND THEOREM** is for finding deflection. It states that the difference of deflections between any two points on the loaded beam is equal to Moment (about the first point) of the area of the BMD between those two points divided by Bending Stiffness EI.

      $\delta B - \delta A = YB - yA$ =(AREA OF BMD BETWEEN A AND B) x XB/EI
5. Strain Energy Method.

DEFLECTED BEAM:

Exact differential equation of the deflected beam

$$(EI\ d2y/dx2)/[1+(dy/dx)2] = \pm Mx$$

$$(EI\ d2y/dx2) = \pm Mx$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=pJlbSEcshg
https://www.youtube.com/watch?v=K8yvy3cB9aM&vl=en

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(515-518)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(3.1-3.15)

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CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : III DEFLECTION

Date of Lecture:

Topic of Lecture: Methods of Compilation for Slope & Deflections

Introduction : (Maximum 5 sentences)

The slope-deflection method is an alternate way to analyses indeterminate structures. In many ways, it can be thought of as the opposite of the force method

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

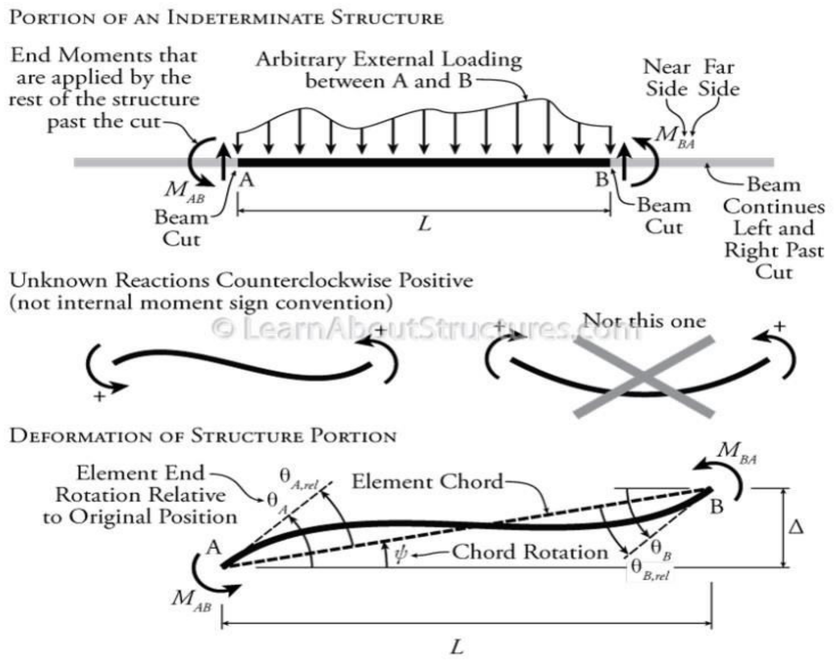
- ✓ Double integration method.
- ✓ Moment–area method.
- ✓ Macaulay's method.
- ✓ Conjugate beam method.

Detailed content of the Lecture:

Slope – deflection method:

The slope-deflection method relies on the use of the *slope-deflection equation*, which relate the rotation of an element (both rotation at the ends and rigid body rotation) to the total moments at either end. The ultimate goal is to find the end moments for each member in the structure as a function of all of the DOFs associated with both ends of the member. From there, we can apply equilibrium conditions at all of the joints to solve for the unknown rotations. This is the system of equations that we will have to solve, where the equations are the equilibrium equations for each node and the unknowns are the translations and rotations of the nodes.

Based on the positive moment sign convention (counter-clockwise), the general deformed shape of our individual portion of the structure will be as shown at the bottom of Each end of the element (at node A or B) has its own rotation relative to the element's initial position (θAθA and θBθB) as shown in the figure. In addition, node B can translate vertically by an amount ΔΔ relative to node A as also shown



Due to the chord rotation ψψ, not all of the rotation at each end (θAθA and θBθB) will cause internal moment in the member. If we would like to find the rotation at each end that is associated with the internal moment in the element, then we must remove the component of the total rotation that is caused by the chord rotation.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=9Uwx4XWZlNQ
https://www.youtube.com/watch?v=MBAA-JaPMmI

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(515-525)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(3.1-3.15)

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LECTURE HANDOUTS

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : III DEFLECTION

Date of Lecture:

Topic of Lecture: Double Integration Method

Introduction: (Maximum 5 sentences)

The double integration method is a powerful tool in solving deflection and slope of a beam at any point because we will be able to get the equation of the elastic curve. In calculus, the radius of curvature of a curve y = f(x).

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ No prerequisite knowledge required

Detailed content of the Lecture:

Double integration method:

The double integration method is a powerful tool in solving deflection and slope of a beam at any point because we will be able to get the equation of the elastic curve.

In calculus, the radius of curvature of a curve y = f(x) is given by

$$\rho = \frac{[1 + (dy/dx)^2\,]^{3/2}}{|\,d^2y/dx^2\,|}$$

In the derivation of flexure formula, the radius of curvature of a beam is given as

$$\rho = \frac{EI}{M}$$

Deflection of beams is so small, such that the slope of the elastic curve dy/dx is very small, and squaring this expression the value becomes practically negligible,

$$\rho = \frac{1}{d^2y/dx^2} = \frac{1}{y''}$$

If EI is constant, the equation may be written as:

$$EI\, y'' = M$$

where x and y are the coordinates shown in the figure of the elastic curve of the beam under load, y is the deflection of the beam at any distance x. E is the modulus of elasticity of the beam, I represent the moment of inertia about the neutral axis, and M represents the bending moment at a distance x from the end of the beam. The product EI is called the flexural rigidity of the beam.

The first integration y' yields the slope of the elastic curve and the second integration y gives the deflection of the beam at any distance x. The resulting solution must contain two constants of integration since EI y" = M is of second order.. For instance, in the case of a simply supported beam with rigid supports, at x = 0 and x = L, the deflection y = 0, and in locating the point of maximum deflection, we simply set the slope of the elastic curve y' to zero

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=ojrFXL06Uyo

https://www.youtube.com/watch?v=og9TxwcfKrc

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(523-527)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(3.4-3.10)

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LECTURE HANDOUTS

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : I – INTRODUCTION

Date of Lecture:

Topic of Lecture: Problem on double integration method

Introduction: (Maximum 5 sentences)
The double integration method is a powerful tool in solving deflection and slope of a beam at any point because we will be able to get the equation of the elastic curve. where x and y are the coordinates shown in the figure of the elastic curve of the beam under load, y is the deflection of the beam at any distance x.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ Analysis of loading condition
- ✓ Shear force
- ✓ Bending moment

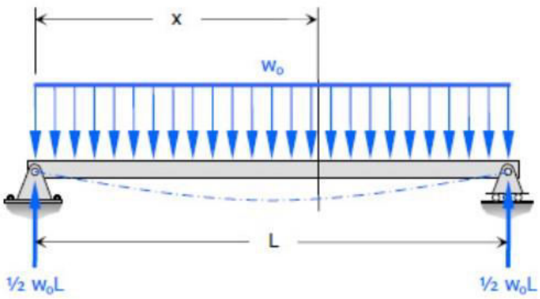
Detailed content of the Lecture:

Problem on double integration method:

Determine the maximum deflection δ in a simply supported beam of length L carrying a uniformly distributed load of intensity wo applied over its entire length.

Solution:

$$EI\,y'' = \frac{1}{2}w_oLx - w_ox(\frac{1}{2}x)$$
$$EI\,y'' = \frac{1}{2}w_oLx - \frac{1}{2}w_ox^2$$



$$EI\,y' = \tfrac{1}{4}w_o L x^2 - \tfrac{1}{6}w_o x^3 + C_1$$

$$EI\,y = \tfrac{1}{12}w_o L x^3 - \tfrac{1}{24}w_o x^4 + C_1 x + C_2$$

At x = 0, y = 0, therefore $C_2 = 0$

At x = L, y = 0

$$0 = \tfrac{1}{12}w_o L^4 - \tfrac{1}{24}w_o L^4 + C_1 L$$

$$C_1 = -\tfrac{1}{24}w_o L^3$$

Therefore,

$$EI\,y = \tfrac{1}{12}w_o L x^3 - \tfrac{1}{24}w_o x^4 - \tfrac{1}{24}w_o L^3 x$$

Maximum deflection will occur at x = ½ L (midspan)

$$EI\,y_{max} = \tfrac{1}{12}w_o L(\tfrac{1}{2}L)^3 - \tfrac{1}{24}w_o(\tfrac{1}{2}L)^4 - \tfrac{1}{24}w_o L^3(\tfrac{1}{2}L)$$

$$EI\,y_{max} = \tfrac{1}{96}w_o L^4 - \tfrac{1}{384}w_o L^4 - \tfrac{1}{48}w_o L^4$$

$$EI\,y_{max} = -\tfrac{5}{384}w_o L^4$$

$$\delta_{max} = \frac{5w_o L^4}{384EI}$$

Taking $W = w_o L$:

$$\delta_{max} = \frac{5(w_o L)(L^3)}{384EI}$$

$$\delta_{max} = \frac{5WL^3}{384EI}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=HSMsxihUd4M

https://www.youtube.com/watch?v=6uIADOSw6Os

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(525-530)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(3.4-3.20)

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LECTURE HANDOUTS

CIVIL **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : III - DEFLECTION

Date of Lecture:

Topic of Lecture: Macaulay's Methods

Introduction : (Maximum 5 sentences)

Macaulay's method (the double integration method) is a technique used in structural analysis to determine the deflection of Euler-Bernoulli beams. Use of Macaulay's technique is very convenient for cases of discontinuous and/or discrete loading.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ No prerequisite knowledge required

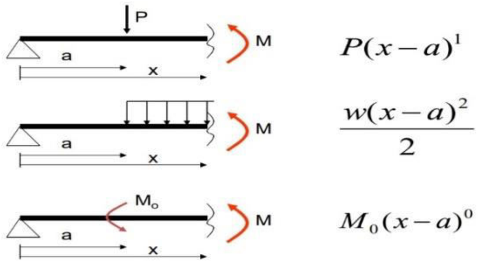
Detailed content of the Lecture:

GENERAL:

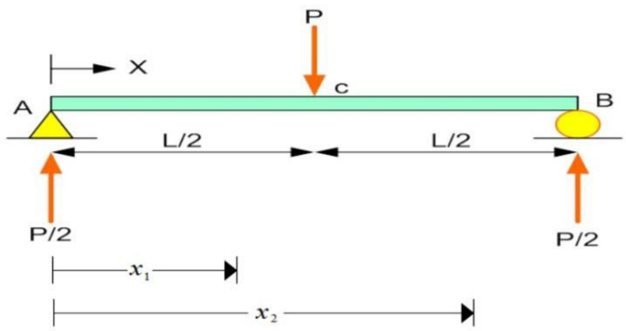
1. Macaulay's method is a means to find the equation that describes the deflected shape of a beam. From this equation, any deflection of interest can be found.
2. Macaulay's method enables us to write a single equation for bending moment for the full length of the beam.
3. When coupled with the Euler-Bernoulli theory, we can then integrate the expression for bending moment to find the equation for deflection using the double integration method.
4. Macauly's Method allow us to 'turn off' partial of moment function when the value inside a bracket in that function is zero or negative.

Macaulay's Methods:

In this method, the moment function only will be considered at end of the section.



1. Let us again consider a simply supported beam AB of length L and carrying concentrated load P at mid spanC. EI is constant. This example are going to show how to find the equation of elastic curve for the beam by 'turn off' part of a function using Macauly's Method.



2. Again, we must write a function for the beam moment that can describe the moment for the beam wholly from the left side.
3. This beam have 2 span. Macauly's Method will use the moment function to the very right with only x function as distance. Where here for example:
4. Span L/2<x<L

$$M = \frac{P}{2}x - P\left\langle x - \frac{L}{2}\right\rangle$$

5. Take note here Macauly's Method use a different bracket that have a special function that have an advanced understanding and application.
6. Span L/2<x

$$M = \frac{P}{2}x - P\left\langle x - \frac{L}{2}\right\rangle$$

7. The bracket above allow the function of 'turn off' when inside value is negative or zero.
8. Means if we have x< L/2 the {x – L/2} will be zero.
9. Applying Euler-Bernoulli Theory replace M into slope and displacement integration.

From the displacement integration :

$$vEI = \int \int \frac{P}{2}x - P\left\langle x - \frac{L}{2}\right\rangle dx$$

$$vEI = \int \frac{P}{4}x^2 - \frac{P}{2}\left\langle x - \frac{L}{2}\right\rangle^2 + C_1\, dx$$

$$vEI = \frac{P}{12}x^3 - \frac{P}{6}\left\langle x - \frac{L}{2}\right\rangle^3 + C_1 x + C_2$$

10. Again Ttke note here that {x – L/2} is integrate as a function of x.
11. From slope and displacement integration procedure, 2 unknown were obtained and solved using the boundary condition:

– At $x = \frac{L}{2}$

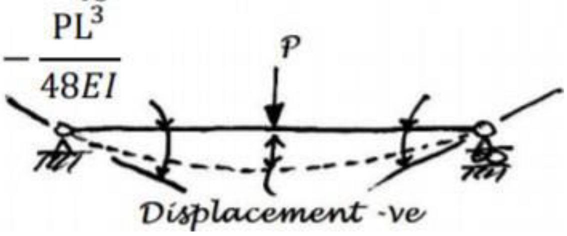
$$vEI = \frac{P}{12}\left(\frac{L}{2}\right)^3 - \frac{P}{6}\left(\frac{L}{2} - \frac{L}{2}\right)^3 - \frac{3PL^2}{48}\left(\frac{L}{2}\right)$$

Inside the bracket $\left\langle x - \frac{L}{2}\right\rangle = 0$

$$vEI = -\frac{PL^3}{48}$$

$$v = -\frac{PL^3}{48EI}$$

Negative means downward



Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=Lg9ZfwUP2GE
https://www.youtube.com/watch?v=8pIh_w0K2o8
https://www.youtube.com/watch?v=QWctUcDr-l8

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(550-555)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(3.39-3.49)

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LECTURE HANDOUTS

CIVIL | **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : III - DEFLECTION

Date of Lecture:

Topic of Lecture: Area Moment Method

Introduction : (Maximum 5 sentences)

Area Moment Method is a semi graphical solution that relates slopes and deflections of elastic curve to the area under the M/EI diagram. And the moment of the area of M/EI Diagram. This method is useful when deflection at a specific point of the beam required.

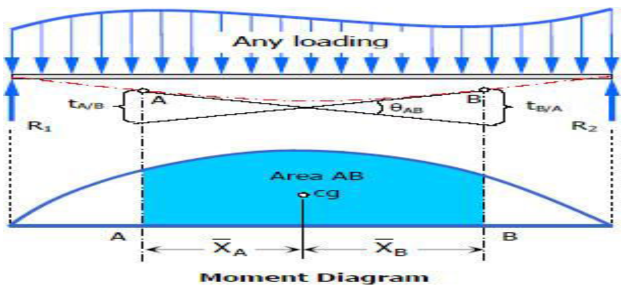
Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ Analysis of column
- ✓ Bucking load
- ✓ Euler's theorem

Detailed content of the Lecture:

Area moment method:

Another method of determining the slopes and deflections in beams is the area-moment method, which involves the area of the moment diagram.



Theorems of Area-Moment Method:

Theorem I:

The change in slope between the tangents drawn to the elastic curve at any two points A andB is equal to the product of 1/EI multiplied by the area of the moment diagram betweenthese two points.

$$\theta_{AB} = \frac{1}{EI}(Area_{AB})$$

Theorem II:

The deviation of any point B relative to the tangent drawn to the elastic curve at any otherpoint A, in a direction perpendicular to the original position of the beam, is equal to the product of 1/EI multiplied by the moment of an area about B of that part of the moment diagram between points A and B.

$$t_{B/A} = \frac{1}{EI}(Area_{AB}) \cdot \bar{X}_B$$

Rules of Sign:

1. The deviation at any point is positive if the point lies above the tangent, negative if the point is below the tangent.
2. Measured from left tangent, if is counter clockwise, the change of slope is positive, Negative if is clockwise

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=BJ9JiANtqwE

https://www.youtube.com/watch?v=4W47rgTE09M

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(552-560)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(3.57-3.60)

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LECTURE HANDOUTS

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : III - DEFLECTION

Date of Lecture:

Topic of Lecture: Problems on macaulay's & moment area method

Introduction : (Maximum 5 sentences)
Macaulay's method (the double integration method) is a technique used in structural analysis to determine the deflection of Euler-Bernoulli beams. Use of Macaulay's technique is very convenient for cases of discontinuous and/or discrete loading.

Prerequisite knowledge for Complete understanding and learning of Topic: (Max. Four important topics)

- ✓ No prerequisite knowledge required

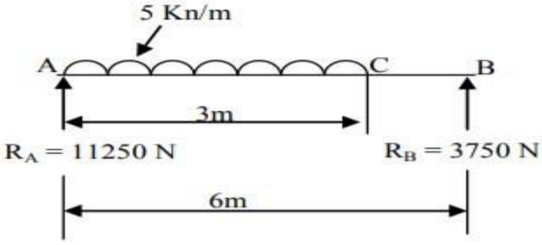
Detailed content of the Lecture:

Problems:

For macaulay's area method:

A SSB of spam 6m carries UDL 5kN/m over a length of 3m extending from left end. Calculate deflection at mid span E =2 × 105 N/ mm2. I = 6.2 × 106 mm4.

Given Data:



$L = 6m = 6000mm$

$W = 5kN/m = 5N/mm$

$E = 2 \times 10^5 \ N/mm^2$

$I = 6.2 \times 10^6 \ mm^4$

To find : Deflection at mid-span, Y_c =?

Solution: Taking moment about A,

$$R_B \times 6000 = 5 \times 3000 \times \frac{3000}{2}$$

$$R_B = 3750N$$

$$R_A + R_B = 5 \times 3000$$

$$R_A = 11250N$$

$$EI\frac{d^2y}{dx^2} = 3750x \qquad -\frac{5(x-3000)^2}{2}$$

Integrating the above equation twice,

$$EI\frac{dy}{dx} = \frac{3750x^2}{2} + C_1 \qquad -\frac{5(x-3000)^3}{6}$$

$$EI.y = \frac{3750x^2}{6} + C_1x + C_2 \qquad -\frac{5(x-3000)^4}{24}$$

Applying the following boundary conditions

(i) When x = 0, y =0

(ii) When x = 6000 m, y = 0

Applying first B.C

$$\theta = \frac{3750(0)^3}{6} + C_1(0) + C_2 - \frac{5(0-3000)^4}{24}$$

$$C_2 = 1.6875 \times 10^{13}$$

For the second B.C

$$0 = \left[\frac{3750(6000)^3}{6} + C_1(6000) + 1.6875 \times 10^{13} - \frac{5(6000-3000)^4}{24}\right]$$

$$C_1 = -2.25 \times 10^{10}$$

Deflection at mid-span x = 3000mm

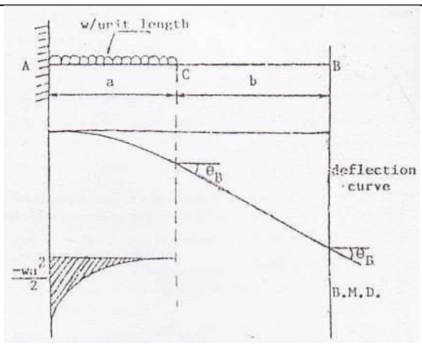
$$y_{max} = \frac{1}{2 \times 10^5 \times 6.2 \times 10^6}\left[\frac{3750(3000)^3}{6} - 2.25 \times 10^{10} \times 3000 + 1.6875 \times 10^{13} - \frac{5(3000-3000)^4}{24}\right]$$

= -27.22mm (Take only its magnitude)

Result: Maximum deflection, Y_{max} = 27.22mm

for the moment area method

Solution:



for the moment area method

$$\theta_B = \theta_C = \left(\frac{1}{EI}\right)\text{(Area of Bending Moment diagram between A and C)}$$

$$= \frac{wa^2}{2} \times a \times \frac{1}{3} \times \frac{1}{EI}$$

$$= \frac{wa^3}{6EI}$$

$$\delta_C = \frac{1}{EI}\text{(moment of area of the BMD between A and C about C)}$$

$$= \frac{wa^3}{6} \times \frac{3a}{4} \times \frac{1}{EI}$$

$$= \frac{wa^4}{24EI}$$

$$= \frac{wa^3}{6} \times \frac{3a}{4} \times \frac{1}{EI}$$

$$= \frac{3wa^4}{24EI}$$

$$\delta_B = \delta_C + (l-a)\theta_B$$

$$= \frac{3wa^4}{24EI} + (l-a) \times \frac{wa^3}{6EI}$$

$$= \frac{wa^3}{24EI}(4l-a)$$

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=cSzzTbA267I
https://www.youtube.com/watch?v=4R1SakL5LmY

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(553-556)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(3.57-3.64)

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LECTURE HANDOUTS

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : III - DEFLECTION

Date of Lecture:

Topic of Lecture: Conjugate beam method

Introduction : (Maximum 5 sentences)

Conjugate beam is defined as the imaginary beam with the same dimensions (length) as that of the original beam but load at any point on the conjugate beam is equal to the bending moment at that point divided by EI. The conjugate-beam method is an engineering method to derive the slope and displacement of a beam.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ Analysis of beam
- ✓ Analysis of support

Detailed content of the Lecture:

Conjugate Beam Method and Beam Deflection:

Slope on real beam = shear on conjugate beam

Deflection on real beam = moment on conjugate beam

Properties of Conjugate Beam:

1. The length of a conjugate beam is always equal to the length of the actual beam.
2. The load on the conjugate beam is the M/EI diagram of the loads on the actual beam.
3. A simple support for the real beam remains simple support for the conjugate beam.

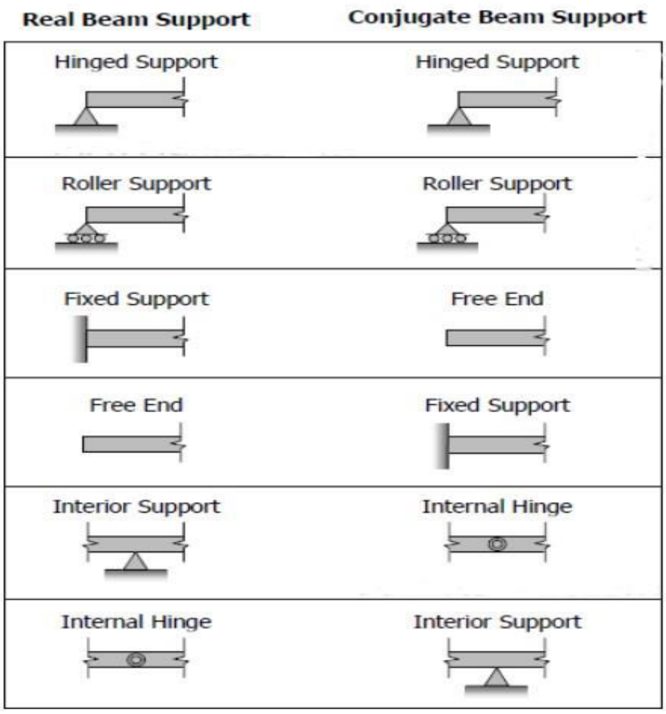
4. A fixed end for the real beam becomes free end for the conjugate beam.

5. The point of zero shear for the conjugate beam corresponds to a point of zero slope for the real beam.

6. The point of maximum moment for the conjugate beam corresponds to a point of maximum deflection for the real beam.

Supports of Conjugate Beam:

Knowing that the slope on the real beam is equal to the shear on conjugate beam and the deflection on real beam is equal to the moment on conjugate beam, the shear and bending moment at any point on the conjugate beam must be consistent with the slope and deflection at that point of the real beam.



Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=whZ2y-qXzkIhttps://www.youtube.com/watch?v=xOIz8NY7puY

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(583-597)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(3.69-3.70)

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LECTURE HANDOUTS

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CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : III - DEFLECTION

Date of Lecture:

Topic of Lecture: Problems on conjugate beam method

Introduction : (Maximum 5 sentences)
Shear force is the internal force on a member when the force is not applied at the axis. Shearing force is the force divided by the cross-sectional area. Bending moment is the force trying to rotate the member. Moment is the perpendicular distance from the force to the axis multiplied by the force.

Prerequisite knowledge for Complete understanding and learning of Topic: (Max. Four important topics)

- ✓ Analysis of beam
- ✓ Analysis of support

Detailed content of the Lecture:

Problem:

For the beam diagram given below, find the value of EIδ at 2 ft from R_2.

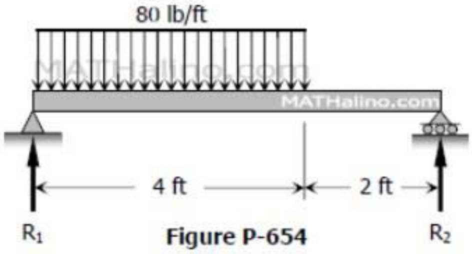


Figure P-654

Solution:

Solving for reactions

$\Sigma M_{R2} = 0$

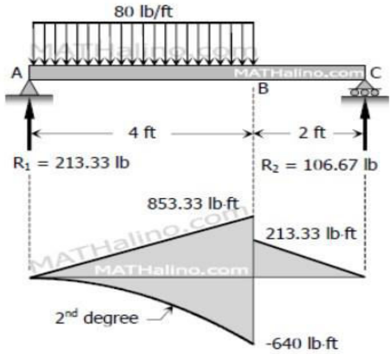
$6R_1 = 80(4)(4)$

$R_1 = 213.33$ lb

$\Sigma M_{R1} = 0$

$6R_2 = 80(4)(2)$

$R_2 = 106.67$ lb



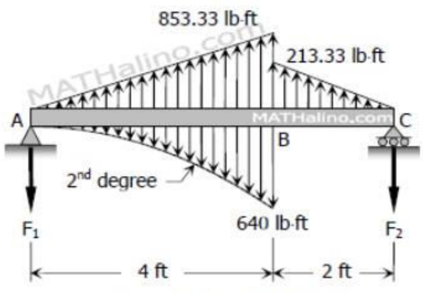
Moment Diagram by Parts

From the conjugate beam

$\Sigma M_A = 0$

$6F_2 + \frac{1}{3}(4)(640)[\frac{3}{4}(4)] = \frac{1}{2}(4)(853.33)[\frac{2}{3}(4)] + \frac{1}{2}(2)(213.33)[4 + \frac{1}{3}(2)]$

$F_2 = 497.77\ \text{lb} \cdot \text{ft}^2$



Conjugate Beam Loaded with M/EI Diagram

$M_B = \frac{1}{2}(2)(213.33[\frac{1}{3}(2)] - 2F_2$

$M_B = \frac{1}{2}(2)(213.33[\frac{1}{3}(2)] - 2(497.77)$

$M_B = -853.32\ \text{lb} \cdot \text{ft}^3$

Thus, the deflection at B is

$EI\,\delta_B = M_B$

$EI\,\delta_B = -853.32\ \text{lb} \cdot \text{ft}^3$

$EI\,\delta_B = 853.32\ \text{lb} \cdot \text{ft}^3$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=uXHoeehmZXE

https://www.youtube.com/watch?v=z7tZUvSJtQk

https://www.youtube.com/watch?v=xOIz8NY7puY

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(583-597)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(3.69-3.70)

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LECTURE HANDOUTS

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : IV PRINCIPAL STRESS AND STRAIN & ANALYSIS OF PLANE TRUSS

Date of Lecture:

Topic of Lecture: Plane stress – Principals& max – shear stress

Introduction : (Maximum 5 sentences)

Principal stress is the maximum normal stress a body can have at its some point. It represents purely normal stress. The extreme values of normal stresses are called the Principal Stresses and the planes on which the principal stresses act is called the principal planes.

Prerequisite knowledge for Complete understanding and learning of Topic:

(Max. Four important topics)

- ✓ Stress tensor
- ✓ Volumetric strain
- ✓ Strain energy
- ✓ Residual stresses

Detailed content of the Lecture:

The basic steps to be followed for finding the displacement or slope of a beams and frames are summarized as

- Load carrying capacity and design of members
- Applications and analysis of stress
- Dilation and distortion will be studied
- Principle stresses and principle strain

Principal Directions, Principal Stress

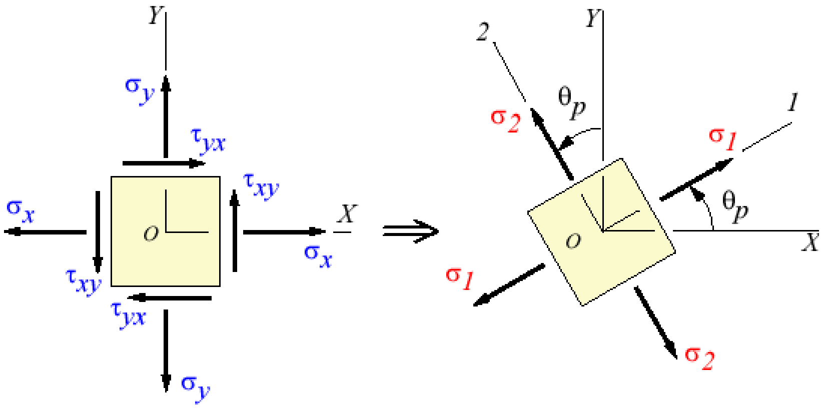
The normal stresses ($s_{x'}$ and $s_{y'}$) and the shear stress ($t_{x'y'}$) vary smoothly with respect to the rotation angle q, in accordance with the coordinate transformation equations. There exist a couple of particular angles where the stresses take on special values.

$$\tan 2\theta_p = \frac{2\tau_{xy}}{\sigma_x - \sigma_y}$$

The angle q_p defines the *principal directions* where the only stresses are normal stresses. These stresses are called *principal stresses* and are found from the original stresses

$$\sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}{}^2}$$

The transformation to the principal directions can be illustrated as,



Stresses in given coordinate system

Principal stresses

Maximum Shear Stress Direction

The maximum shear stress is equal to one-half the difference between the two principal stresses,

$$\tau_{max} = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}{}^2} = \frac{\sigma_1 - \sigma_2}{2}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=C207JS-HM4Q
https://www.youtube.com/watch?v=M45QEukPNkc

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(85-100)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(5.1-5.12)

Course Teacher

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LECTURE HANDOUTS

CIVIL **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : IV PRINCIPAL STRESS AND STRAIN & ANALYSIS OF PLANE TRUSS

Date of Lecture:

Topic of Lecture: Mohr's circle for plane stress

Introduction : (Maximum 5 sentences)

Mohr's circle is the locus of points representing the magnitude of normal and shear stress at the various plane in a given stress element. Graphically, a variation of normal stress and shear stress are studied with the help of Mohr's circle.

Prerequisite knowledge for Complete understanding and learning of Topic: (Max. Four important topics)

- ✓ Analysis of stress
- ✓ Analysis of strain

Detailed content of the Lecture:

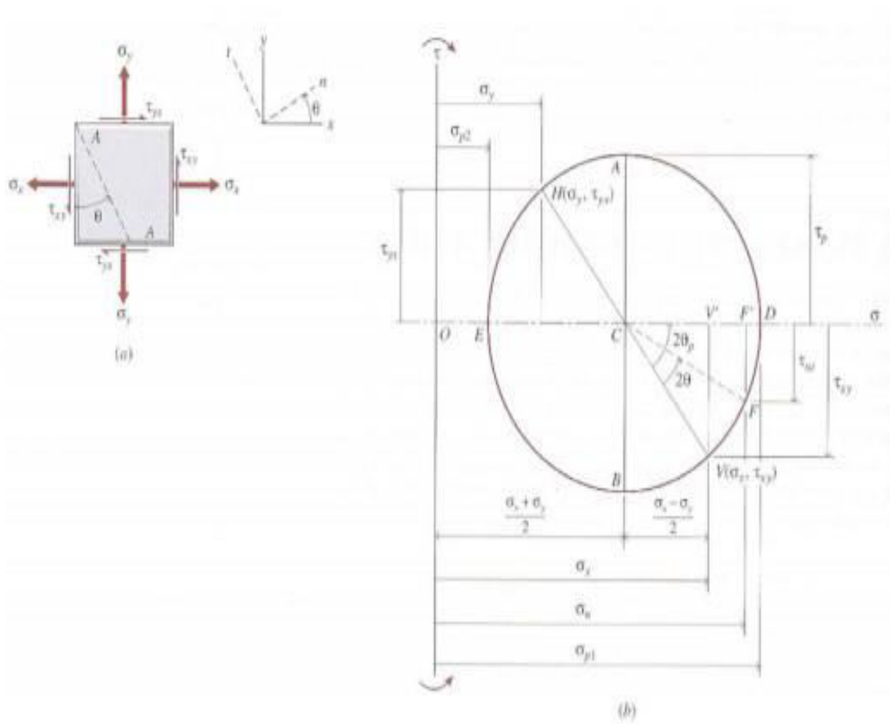
Mohr's circle for plane stress:

The transformation equations for plane stress can be represented in a graphical format known as Mohr's circle. This representation is useful in visualizing the relationships between normal and shear stresses acting on various inclined planes at a point in a stressed body.

Construct Mohr's circle as follows:

1. Determine the point on the body in which the principal stresses are to be determined.
2. Treating the load cases independently and calculated the stresses for the point chosen.
3. Choose a set of x-y reference axes and draw a square element centered on the axes.
4. Identify the stresses σx, σy, and $\tau xy = \tau yx$ and list them with the proper sign.
5. Draw a set of σ - τ coordinate axes with σ being positive to the right and τ being positive in the

upward direction. Choose an appropriate scale for each axis.



6. Using the rules on the previous page, plot the stresses on the x face of the element in this coordinate system (point V). Repeat the process for the y face (point H).

7. Draw a line between the two-point V and H. The point where this line crosses the σ axis establishes the center of the circle.

8. Draw the complete circle.

9. The line from the center of the circle to point V identifies the x axis or reference axis for angle measurements (i.e. θ = 0).

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=lFN6MPWsNU8

https://www.youtube.com/watch?v=TQXrGi2blfE

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(123-137)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(5.12-5.26)

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LECTURE HANDOUTS

CIVIL | **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : IV PRINCIPAL STRESS AND STRAIN & ANALYSIS OF PLANE TRUSS

Date of Lecture:

Topic of Lecture: Determination of principal stresses & planes

Introduction : (Maximum 5 sentences)

In every object, there are three planes which are mutually perpendicular to each other. ... The maximum stress is called the Principal stress and the plane at which the maximum stress induced is called the Principal plane and the shear stress will be zero on the principal planes

Prerequisite knowledge for Complete understanding and learning of Topic: (Max. Four important topics)

- ✓ Analysis of stress and strain

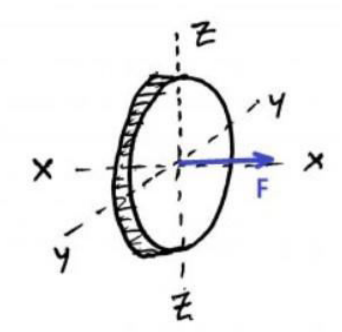
Detailed content of the Lecture:

Principal Stresses and Principal Planes

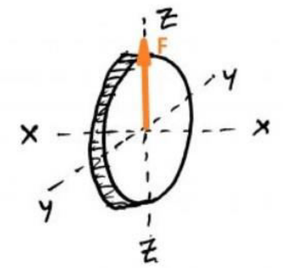
A stress is a perpendicular force acting on an object per unit area. In every object, there are three planes which are mutually perpendicular to each other. These will carry the direct stress only no shear stress. Out of these three direct stresses, there will be one maximum stress and one minimum stress among these planes.

Case i:

When a force is applied normal(Along X-axis) to the surface area of the disc as shown then there will be normal stress on the YZ plane. There will be no shear stresses.

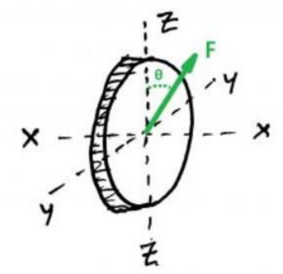


Case ii:



When a force is applied tangentially to the disc surface (along Z-axis) then there will be shear stress induced in the layers of the disc. there is no normal stress will be induced.

Case iii:



Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=C207JS-HM4Qhttps://www.youtube.com/watch?v=mehubAM0fFA
https://www.youtube.com/watch?v=MkbHigsw52o

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(85-110)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(5.1-5.25)

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LECTURE HANDOUTS

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : IV PRINCIPAL STRESS AND STRAIN & ANALYSIS OF PLANE TRUSS

Date of Lecture:

Topic of Lecture: Plane strain

Introduction : (Maximum 5 sentences)

Plane strain is a two-dimensional state of strain in which all the shape changes of a material happen on a single plane. Plane strain is applicable to forging, where deformation in a particular direction is constrained by the die wall.

Prerequisite knowledge for Complete understanding and learning of Topic: (Max. Four important topics)

- ✓ Volumetric strain
- ✓ Strain energy
- ✓ Residual stresses

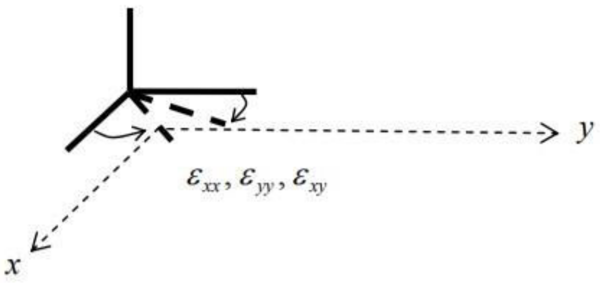
Detailed content of the Lecture:

Plane Strain:

If the strain state at a material particle is such that the only non-zero strain components act in one plane only, the particle is said to be in plane strain.

The axes are usually chosen such that the x – y plane is the plane in which the strains are non-zero,

Then $\varepsilon_{xz} = \varepsilon_{yz} = \varepsilon_{zz} = 0$. The fully three dimensional strain matrix reduces to a two dimensional one:



$$\begin{bmatrix} \varepsilon_{xx} & \varepsilon_{xy} & \varepsilon_{xz} \\ \varepsilon_{yx} & \varepsilon_{yy} & \varepsilon_{yz} \\ \varepsilon_{zx} & \varepsilon_{zy} & \varepsilon_{zz} \end{bmatrix} \rightarrow \begin{bmatrix} \varepsilon_{xx} & \varepsilon_{xy} \\ \varepsilon_{yx} & \varepsilon_{yy} \end{bmatrix}$$

Maximum Shear Strain:

Analogous to Eqn. 3.5.9, the maximum shear strain occurring at a point is

$$\varepsilon_{xy}\Big|_{\max} = \frac{1}{2}\left(\varepsilon_1 - \varepsilon_2\right)$$

and the perpendicular line elements undergoing this maximum angle change are oriented at 45^0 to the principal directions.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=QHyUv49jRBI
https://www.youtube.com/watch?v=LemCyiy9bh8

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(85-100)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(5.1-5.15)

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LECTURE HANDOUTS

CIVIL | **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : IV PRINCIPAL STRESS AND STRAIN & ANALYSIS OF PLANE TRUSS

Date of Lecture:

Topic of Lecture: Applications of plane stress

Introduction : (Maximum 5 sentences)

If you are trying to analyses a spanner or a plate with riveted joints, the thickness of such kind applications are small when compared to the length of the object and mostly the loading conditions are in plane only. The stress variation in the thickness direction is very negligible.

Prerequisite knowledge for Complete understanding and learning of Topic:

(Max. Four important topics)

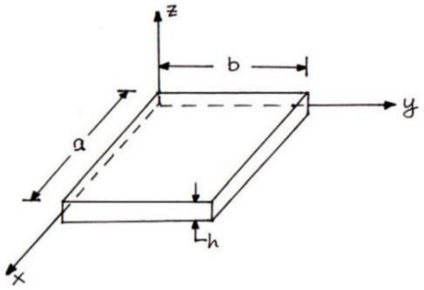
- ✓ Stress tensor
- ✓ pressure vessels
- ✓ stress in beams

Detailed content of the Lecture:

Plane Stress:

This deals with stretching and shearing of thin slabs.

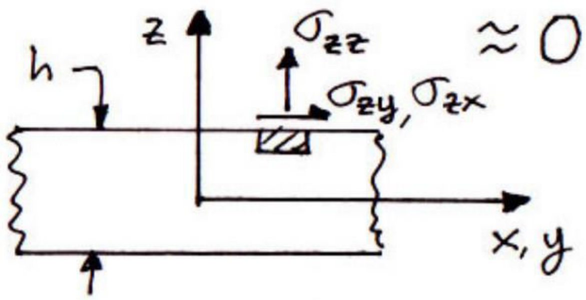
Representation of Generic Thin Slab:



The body has dimensions such that h << a, b

Thus, the plate is thin enough such that there is no variation of displacement (and temperature) with respect to y_3 (z). Furthermore, stresses in the z-direction are zero (small order of magnitude).

Representation of Cross-Section of Thin Slab:



Thus, we assume:

$$\sigma_{zz} = 0$$
$$\sigma_{yz} = 0$$
$$\sigma_{xz} = 0$$
$$\frac{\partial}{\partial z} = 0$$

So the equations of elasticity reduce to:

Equilibrium

$$\frac{\partial \sigma_{11}}{\partial y_1} + \frac{\partial \sigma_{21}}{\partial y_2} + f_1 = 0 \qquad (1)$$

$$\frac{\partial \sigma_{12}}{\partial y_1} + \frac{\partial \sigma_{22}}{\partial y_2} + f_2 = 0 \qquad (2)$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=xdxVpC856ms
https://www.youtube.com/watch?v=ydcgLPbz_zQ

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(85-100)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(5.1-5.15)

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LECTURE HANDOUTS

CIVIL | **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : IV PRINCIPAL STRESS AND STRAIN & ANALYSIS OF PLANE TRUSS

Date of Lecture:

Topic of Lecture: Maximum stresses in beam

Introduction : (Maximum 5 sentences)

The Distortion Energy Theory states that when the distortion energy in a material equals or. exceeds the distortion energy present at the onset of yielding in uniaxial loading tensile test for. that material, the part will experience plastic deformation

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ Stress tensor
- ✓ Volumetric strain
- ✓ Strain energy
- ✓ Residual stresses

Detailed content of the Lecture:

Stresses & Deflections in Beams:

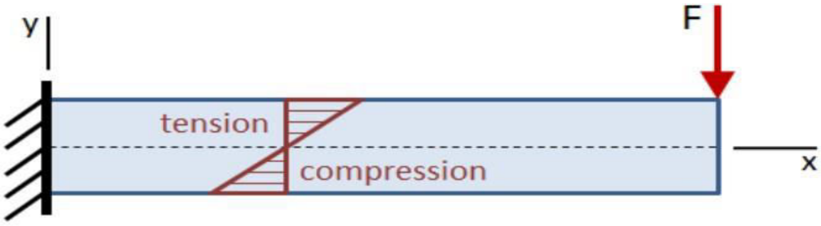
Many structures can be approximated as a straight beam or as a collection of straight beams. For this reason, the analysis of stresses and deflections in a beam is an important and useful topic. This section covers shear force and bending moment in beams, shear and moment diagrams, stresses in beams, and a table of common beam deflection formulas.

Bending Stresses in Beams:

The bending moment, M, along the length of the beam can be determined from the moment diagram. The bending moment at any location along the beam can then be used to calculate the bending stress over the beam's cross section at that location. The bending moment varies over the height of the cross section according to the flexure formula below:

$$\sigma_b = -\frac{My}{I_c}$$

where M is the bending moment at the location of interest along the beam's length, Ic is the centroidal moment of inertia of the beam's cross section, and y is the distance from the beam's neutral axis to the point of interest along the height of the cross section.



The maximum bending stress is given by:

$$\sigma_{b.max} = \frac{Mc}{I_c}$$

The section modulus of a cross section combines the centroidal moment of inertia, Ic, and the centroidal distance, c:

$$S = \frac{I_c}{c}$$

The benefit of the section modulus is that it characterizes the bending resistance of a cross section in a single term.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=fDbL6gIoAz0
https://www.youtube.com/watch?v=4S9ydNeQNHY

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(85-100)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(5.1-5.25)

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LECTURE HANDOUTS

L - 34

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : IV PRINCIPAL STRESS AND STRAIN & ANALYSIS OF PLANE TRUSS

Date of Lecture:

Topic of Lecture: Determination of principal stresses

Introduction : (Maximum 5 sentences)

The tensor relates a unit-length direction vector n to the traction vector T across an imaginary surface perpendicular to n: where, The SI units of both stress tensor and stress vector are N/m2, corresponding to the stress scalar. The unit vector is dimensionless.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

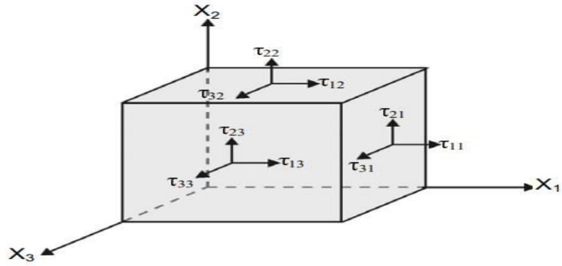
- ✓ Stress tensor
- ✓ Volumetric strain
- ✓ Strain energy
- ✓ Residual stresses

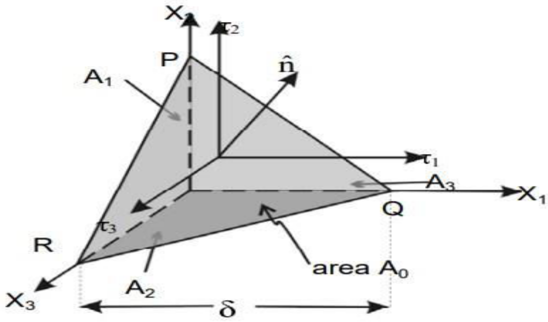
Detailed content of the Lecture:

Stress tensor:

The stress (force per unit area) at a point in a fluid needs nine components to be completely specified, since each component of the stress must be defined not only by the direction in which it acts but also the orientation of the surface upon which it is acting.

The first index i specifies the direction in which the stress component acts, and the second index j identifies the orientation of the surface upon which it is acting. Therefore, the i th component of the force acting on a surface whose outward normal points in the jth direction is τ_{ij} .





Consider an infinitesimal body at rest with a surface PQR that is not perpendicular to any of the Cartesian axis. The unit normal vector to the surface PQR is n^ = n1x^1+n2x^2+n3x^3. The area of the surface = A0, and the area of each surface perpendicular to Xi is Ai = A0ni, for i = 1, 2, 3.

$$\text{Newton's law:} \quad \sum_{\text{on all 4 faces}} F_i = (\text{volume force})_i \text{ for } i = 1, 2, 3$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=qrROIlBCZPE
https://www.youtube.com/watch?v=uO_bW2zzrNU

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(87-120)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(5.5-5.25)

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LECTURE HANDOUTS

CIVIL | **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : IV PRINCIPAL STRESS AND STRAIN & ANALYSIS OF PLANE TRUSS

Date of Lecture:

Topic of Lecture: Methods of sections

Introduction : (Maximum 5 sentences)

The method of sections is a process used to solve for the unknown forces acting on members of a truss. The method involves breaking the truss down into individual sections and analyzing each section as a separate rigid body.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ No prerequisite knowledge required

Detailed content of the Lecture:

Method of Sections:

In this method, we will cut the truss into two sections by passing a cutting plane through the members whose internal forces we wish to determine. This method permits us to solve directly any member by analyzing the left or the right section of the cutting plane.

The method of Sections is used to solve larger truss structures in a fast, simple manner. It involves taking a 'cut' through a number of members to evaluate their axial forces, and use this as our basis to solve the rest of the truss structure.

Types of Truss Structures:

Pratt Truss:

A Pratt Truss has been used over the past two centuries as an effective truss method. The vertical members are in compression, whilst the diagonal members are in tension. This simplifies and produces a more efficient design since the steel in the diagonal members (in tension) can be reduced. This has a few effects – it reduces the cost of the structure due to more efficient members, reduces the self-weight and eases the constructability of the structure. This type of truss is most appropriate for horizontal spans, where the force is predominantly in the vertical direction.

Warren Truss:

The Warren Truss is another very popular truss structure system and is easily identified by its construction from equilateral triangles. One of the main advantages of a Warren Truss is its ability to spread the load evenly across a number of different members; this is however generally for cases when the structure is undergoing a spanned load (a distributed load). Its main advantage is also the cause of its disadvantage – the truss structure will undergo concentrated force under a point load. Under these concentrated load scenarios, the structure is not as good at distributing the load evenly across its members.

K Truss:

The K Truss is a slightly more complicated version of the Pratt Truss. Its main difference is that the vertical members have become shortened – improving its resistance against buckling. It does, however, have similar pros and cons to the Pratt Truss and although it is not widely used, it is a strong design. One of its main disadvantages is that the members don't always behave as expected.

Howe Truss:

Howe trusses are essentially the opposite of Pratt trusses in terms of geometry. In fact, looking at a Pratt truss upside-down will visualize a Howe truss of sorts. The entire structure is still relatively the same, but the diagonal braces are now occupying the opposite or the unoccupied joints. This switch in position of the diagonal members has a very important effect structurally.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=Bj2SORGmywo

https://www.youtube.com/watch?v=PiPXvSwCoKY

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(475-500)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(5.69-5.75)

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LECTURE HANDOUTS

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : IV PRINCIPAL STRESS AND STRAIN & ANALYSIS OF PLANE TRUSS

Date of Lecture:

Topic of Lecture: Methods of joints

Introduction : (Maximum 5 sentences)

The method of joints is a process used to solve for the unknown forces acting on members of a truss. The method centers on the joints or connection points between the members, and it is usually the fastest and easiest way to solve for all the unknown forces in a truss structure

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ Hinge Joints.
- ✓ Condyloid Joints.
- ✓ Saddle Joints.

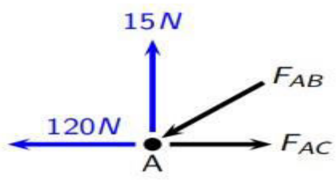
Detailed content of the Lecture:

Method of joint:

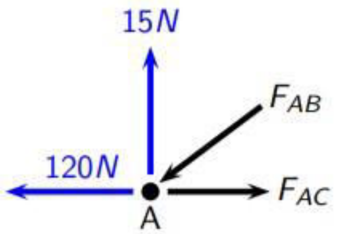
- ➢ The method of joints is one of the simplest methods for determining the force acting on the individual members of a truss because it only involves two force equilibrium equations.
- ➢ The method of joints is one of the simplest methods for determining the force acting on the individual members of a truss because it only involves two force equilibrium equations.
- ➢ Since only two equations are involved, only two unknowns can be solved for at a time. Therefore, you need to solve the joints in a certain order. That is, you need to work from

the sides towards the center of the truss.

- The method of joints is one of the simplest methods for determining the force acting on the individual members of a truss because it only involves two force equilibrium equations.
- Since only two equations are involved, only two unknowns can be solved for at a time. Therefore, you need to solve the joints in a certain order. That is, you need to work from the sides towards the center of the truss.



- Let's start with joint A. We begin by drawing all the forces that act on the bolt at joint A.



- Note that FAB points towards the joint. This is because FAB and the 15 N force are the only vertical forces. Therefore, FAB must point downwards to balance the 15 N force pointing up..
- This helps us determine the direction of FAC . FAC must point away from the joint since that is the only way to balance the forces in the horizontal direction

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=f_XPy4W7IPM

https://www.youtube.com/watch?v=EXNZ6_dVhPw

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(469-475)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(5.30-5.35)

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LECTURE HANDOUTS

CIVIL **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : V TORSION OF SHAFTS AND SPRING

Date of Lecture:

Topic of Lecture: Torsional deformations of a circular bars

Introduction: (Maximum 5 sentences)

Torsion refers to the twisting of a structural member that is loaded by couples (torque) that produce rotation about the member's longitudinal axis. In other words, the member is loaded in such a way that the stress resultant is a couple about the longitudinal axis and the response is a twisting motion about that axis.

Prerequisite knowledge for Complete understanding and learning of Topic: (Max. Four important topics)

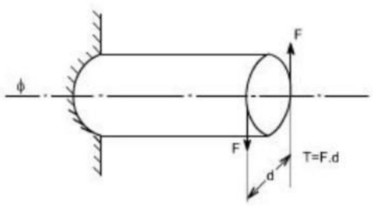
- ✓ Torsion load
- ✓ Shear stress

Detailed content of the Lecture:

Torsion of circular shafts:

Definition of Torsion:

Consider a shaft rigidly clamped at one end and twisted at the other end by a torque T = F.d applied in a plane perpendicular to the axis of the bar such a shaft is said to be in torsion.



Effects of Torsion:

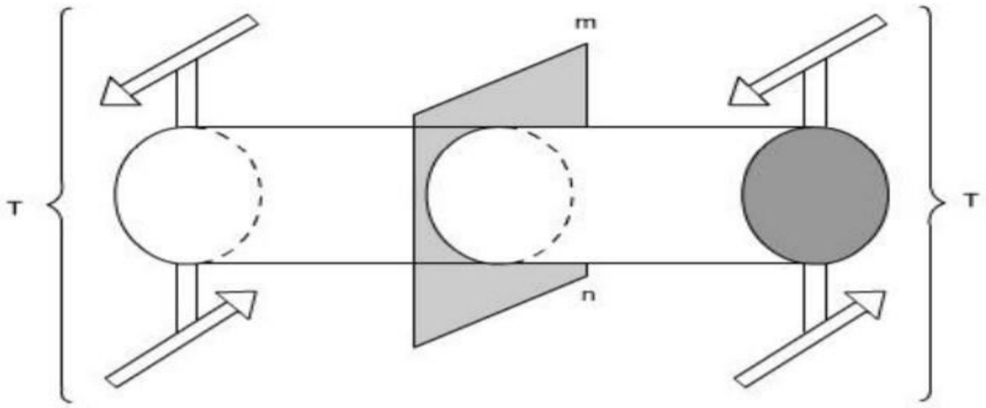
The effects of a torsional load applied to a bar are

(i) To impart an angular displacement of one end crosssection with respect to the other end.

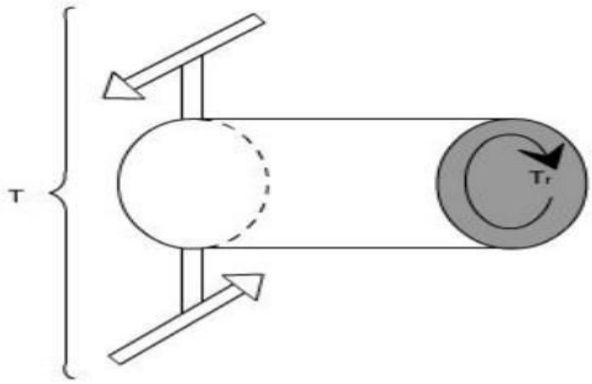
(ii) To setup shear stresses on any cross section of the bar perpendicular to its axis.

Generation of shear stresses:

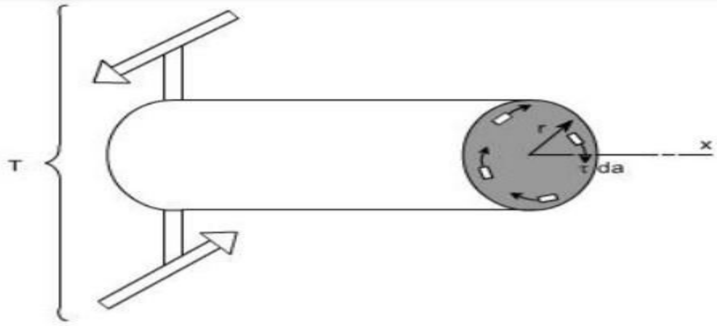
The physical understanding of the phenomena of setting up of shear stresses in a shaft subjected to a torsion.



Here the cylindrical member or a shaft is in static equilibrium where T is the resultant external torque acting on the member. Let the member be imagined to be cut by some imaginary planemn'.



When the plane mn' cuts remove the portion on R.H.S. Now since the entire member is in equilibrium, therefore, each portion must be in equilibrium. Thus, the member is in equilibrium under the action of resultant external torque T and developed resisting Torque T_r.



the resisting torque T_r is developed. The resisting torque T_r is produced by virtue of an infinites mal shear forces acting on the plane perpendicular to the axis of the shaft. Obviously, such shear forces would be developed by virtue of sheer stresses.

Therefore, we can say that when a particular member (say shaft in this case) is subjected to a torque, the result would be that on any element there will be shear stresses acting. While on other faces the complementary sheer forces come into picture. Thus, we can say that when a member is subjected to torque, an element of this member will be subjected to a state of pure shear.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=1nPhUk3FDTU

https://www.youtube.com/watch?v=ICDZ5uLGrI4

https://www.youtube.com/watch?v=C2yp7YWAqwg

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(679-685)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(4.1-4.15)

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LECTURE HANDOUTS

CIVIL **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : V TORSION OF SHAFTS AND SPRING

Date of Lecture:

Topic of Lecture: Uniform torsion

Introduction : (Maximum 5 sentences)

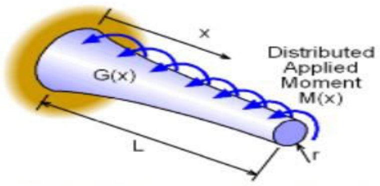
However, in a constrained prismatic bar under torsion (non-uniform torsion), the axial displacement is not uniform in the longitudinal direction. Both shearing and normal stresses are present in the cross section of a bar under non-uniform torsion.

Prerequisite knowledge for Complete understanding and learning of Topic: (Max. Four important topics)

- ✓ Circular Bars and Shafts
- ✓ Nonuniform and Indeterminate Torsion
- ✓ Thin-walled Tubes
- ✓ Non-Circular Bars and Shafts

Detailed content of the Lecture:

Nonuniform Torsion:



Shaft with Changing Moment Load, Stiffness, and Radius

In the previous section on circular bars and shafts, the bar cross section, internal moment, and stiffness was assumed to be constant. This simplified the process of finding the angle of twist. The total angle of twist for a shaft could be found by summing smaller segments of the shaft, giving

$$\theta = \sum_{i=1}^{n} \theta_i = \sum_{i=1}^{n} \frac{T_i L_i}{G_i J_i}$$

$$\theta = \int_0^L \frac{T(X)\, dX}{G(X)\, J(X)}$$

Where,

- T(x) is the internal moment function,
- G(x) is a function describing the changing stiffness,
- J(x) is a function based on the cross section (changing radius). The bar or shaft is still assumed to be circular.

It is important to note the applied moment,

- M(x) is not the same as the internal moment,
- T(x) can be determined from applied moment and boundary conditions.

If T, G, and J are all simultaneously functions of x, the integral can be extremely complex and a closed form solution may not be possible. In those cases, numerical solution techniques are required.

In general, the internal moment is the most common parameter that will vary. A good example is a drill where the moment builds up as the shaft goes deeper into the material (oil drilling, screw, etc.).

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=eY6IV2iH1zQ

https://www.youtube.com/watch?v=UWGfW7vv-mA

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(679-681)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(4.1-4.5)

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LECTURE HANDOUTS

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CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : V TORSION OF SHAFTS AND SPRING

Date of Lecture:

Topic of Lecture: Stresses & Strains in pure shear

Introduction: (maximum 5 sentences)

Stress and strain in pure shear. Increased, deformation also increases. Causing deformation, it is said to be elastic. Removal of load, not all the induced strain is removed.

Prerequisite knowledge for Complete understanding and learning of Topic: (Max. Four important topics)

- ✓ Pure shear
- ✓ Stresses
- ✓ Strain
- ✓ Work done

Detailed content of the Lecture:

Stresses and Strains in pure shear:

Considering a thin sheet under tensile load, as described by Jones and Treloar [5], it is possible to calculate the work done by the external applied force taking into account the unstrained block, which gives.

$$dW = P_{11} d\lambda_1, \quad \text{with} \quad P_{11} = \frac{F_{ps}}{A_{ps}}$$

The principal Cauchy stresses

$$\sigma_i = \lambda_i \frac{\partial W}{\partial \lambda_i} - p$$

$$\sigma_1 = \lambda_1 \frac{\partial \widehat{W}}{\partial \lambda_1}$$

In order to compare simple and pure shear, the simple shear stress is also analyzed. In the present work, the statement assumed by Jones and Treloar was considered. They have assumed that "Simple shear differs from pure shear only by a rotation; the strain energy W is, thus, the same as for the equivalent pure shear". Taking this assumption into account,

$$\sigma_{12} = \frac{dW}{dk} = \frac{dW}{\partial \lambda_1}\frac{\partial \lambda_1}{dk} = P_{11}\frac{\lambda_1^2}{\lambda_1^2+1}$$

with $k = \lambda_1 - \lambda_1^{-1}$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=v-yeWwEmuis

https://www.youtube.com/watch?v=0-S4rR9vwHMhttps://www.youtube.com/watch?v=srgMoMoHU1A

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(680-685)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(4.3-4.5)

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LECTURE HANDOUTS

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : V TORSION OF SHAFTS AND SPRING

Date of Lecture:

Topic of Lecture: Stepped shafts

Introduction: (Maximum 5 sentences)

Shafts are stepped in order to increase the torsional rigidity so that load bearing capacity increases and to ensure that shaft does not fail under higher torsional loads.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ Stepped shaft
- ✓ Twisting moment
- ✓ torsion stiffness

Detailed content of the Lecture:

Stepped shaft,Twist and torsion stiffness:

Stepped Shafts:

The shafts are the machine elements which are used to transmit power in machines.

With our vast experience and expertise, we are engaged in offering an exquisite range of Stepped Shafts to fulfill the demands of our customers. These products are sturdily constructed and ensure longer operational life. Our products are well known for their optimum strength, durability and reliable performance. All these products are available at standard specification and can be customized as per the need.

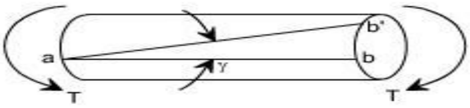
Twisting Moment:

The twisting moment for any section along the bar / shaft is defined to be the algebraic sum of the moments of the applied couples that lie to one side of the section under consideration. The choice of the side in any case is of course arbitrary.

Shearing Strain:

If a generator ab is marked on the surface of the unloaded bar, then after the twisting moment 'T' has been applied this line moves to ab.

measured in radians, between the final and original positions of the generators is defined as the shearing strain at the surface of the bar or shaft. The same definition will hold at any interior point of the bar.



Modulus of Elasticity in shear:

The ratio of the shear stress to the shear strain is called the modulus of elasticity in shear OR Modulus of Rigidity and in represented by the symbol

$$G = \frac{\tau}{r}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=eoX99KPXwY8
https://www.youtube.com/watch?v=NqD2Ow78i00

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(694-698)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(4.5-4.9)

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Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : V TORSION OF SHAFTS AND SPRING

Date of Lecture:

Topic of Lecture: Shafts fixed at both ends

Introduction : (Maximum 5 sentences)

If you have a shaft fixed at both ends and somehow produce a central axis torque in the shaft, both ends must remain fixed. So, use your right-hand rule to follow the direction of the torque through the direction of the whole shaft. You'll have a reaction at one end and a discontinuity at the other end.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ No prerequisite knowledge required

Detailed content of the Lecture:

Power Transmitted by a shaft:

In practical application, the diameter of the shaft must sometimes be calculated from the power which it is required to transmit. Given the power required to be transmitted, speed in rpm N' Torque T, the formula connecting.

These quantities can be derived as follows

$$P = T.\omega$$
$$= \frac{T.2\pi N}{60} \text{watts}$$
$$= \frac{2\pi NT}{60\times10^3} (\text{kw})$$

Torsional stiffness:

The torsional stiffness k is defined as the torque per radian twist.

$$k = \frac{T}{\theta}$$

$$\text{i.e} = \frac{GJ}{L}$$

$$\text{or } k = \frac{G.J}{L}$$

For a ductile material, the plastic flow begins first in the outer surface.

For a material which is weaker in shear longitudinally than transversely for instance a wooden shaft, with the fibres parallel to axis the first cracks will be produced by the shearing stresses acting in the axial section and they will upper on the surface of the shaft in the longitudinal direction.

In the case of a material which is weaker in tension than in shear. For instance, a, circular shaft of cast iron or a cylindrical piece of chalk a crack along a helix inclined at 450 to the axis of shaft often occurs.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=FHHeNId-D0shttps://www.youtube.com/watch?v=e5c3aFbWdUU

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(695-699)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(4.6-4.9)

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LECTURE HANDOUTS

CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : V TORSION OF SHAFTS AND SPRING

Date of Lecture:

Topic of Lecture: Strain energy in torsion & pure shear

Introduction : (Maximum 5 sentences)

Total shear strain energy stored in the shaft will be determined by integrating the above equation from 0 to R. ... use the above value of polar moment of inertia in equation of strain energy stored in the shaft due to torsion and we will have following expression for strain energy stored in the shaft due to torsion.

Prerequisite knowledge for Complete understanding and learning of Topic:

(Max. Four important topics)

- ✓ Torsion in strain energy
- ✓ Pure shear

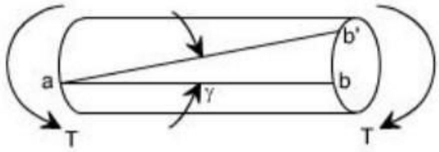
Detailed content of the Lecture:

Shaft:

The shafts are the machine elements which are used to transmit power in machines.

Twisting Moment:

The twisting moment for any section along the bar / shaft is defined to be the algebraic sum of the moments of the applied couples that lie to one side of the section under consideration. The choice of the side in any case is of course arbitrary. Shearing Strain: If a generator ab is marked on the surface of the unloaded bar, then after the twisting moment 'T' has been applied this line moves to ab'. The angleγ' measured in radians, between the final and original positions of the generators is defined as the shearing strain at the surface of the bar or shaft. The same definition will hold at any interior point of the bar.

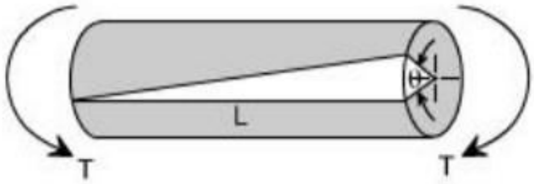


Modulus of Elasticity in shear:

The ratio of the shear stress to the shear strain is called the modulus of elasticity in shear OR Modulus of Rigidity and in represented by the symbol.

Angle of Twist:

If a shaft of length L is subjected to a constant twisting moment T along its length, then the angle γ



- despite the differences in the forms of loading, we see that there are number of similarities between bending and torsion, including for example, a linear variation of stresses and strain with position.
- Not all torsion problems, involve rotating machinery, however, for example some types of vehicle suspension system employ torsional springs. Indeed, even coil springs are really curved members in torsion.
- Many torque carrying engineering members are cylindrical in shape. Examples are drive shafts, bolts and screw drivers.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=tDbhSRbiKY8
https://www.youtube.com/watch?v=G0f_Mi59uVQ
https://www.youtube.com/watch?v=q3tReW-yLow

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(695-702)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(4.6-4.11)

Course Teacher

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LECTURE HANDOUTS

CIVIL | **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : V TORSION OF SHAFTS AND SPRING

Date of Lecture:

Topic of Lecture: Springs types

Introduction : (Maximum 5 sentences)

Springs are mechanical devices that pull, push, wind, support, lift, or protect. They are used mainly in mechanical assemblies to provide force—compressive, tensile, or torsion—where they can be used to lift engine valves, open die sets, or hold batteries in place, to name just a few examples. Springs are commonly wound from wire, but can be machined from solid steel, built as cylinders, formed as bags, stamped from steel, or assembled from other springs.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ Types of springs

Detailed content of the Lecture:

Different Types of Springs and their Characteristics:

- ✓ Compression Springs
- ✓ Extension Springs
- ✓ Torsion Springs
- ✓ Constant Force Springs
- ✓ Belleville Springs
- ✓ Drawbar Springs
- ✓ Volute Springs
- ✓ Garter Springs

- ✓ Flat Springs
- ✓ Gas Springs
- ✓ Air Springs

Compression Springs

Compression springs are helically coiled wires designed to provide an opposing force when compressed. Under increasing load, the space between coils closes until the spring's compressed length is reached, when the coils touch.

Extension Springs:

Extension springs are helically coiled wires designed to provide an opposing force when stretched. Key specifications include the spring rate, helix type, spring ends type, wire diameter, material, and free and maximum extended lengths. Extension springs are used primarily in manufacturing applications where a variable, opposing force is required between two components.

Torsion Springs:

Torsion springs are helical or flat spiral coils or strips used to apply or resist torque loads. Key specifications include the spring rate, spring ends type, wire diameter, material, and the torque rating at a known position. Torsion springs are used primarily in manufacturing applications as components for various motion controls.

Constant Force Springs:

Clocks feature clock springs, or constant force springs. Constant force springs are tightly wound bands of steel that resemble a roll of tape. A load forces the spring to contract, and when it is removed, the spring rebounds with a constant force. Constant force springs are also found in wind-up toys and similar devices.

Belleville Springs:

Belleville springs, or washers, resemble a slightly tapered disc, and for this reason, are also known as disc springs. They are used in conjunction with fasteners like bolts for pre-tensioning purposes. Typically, a bolt is inserted in a Belleville spring, and then attached to a substrate. Belleville springs are available in a variety of material options, including 17-7 PH stainless steel, 301 stainless steel, beryllium copper, H13, Inconel®, phosphor bronze, ZC plated, and ZY plated.

Drawbar Springs:

Drawbar springs are coil compression springs incorporating U-shaped wire forms inserted for use in extension applications. The drawbar spring combines the tension application of the extension spring with the positive stop feature of the compression spring.

Air Springs:

Air springs are air pressurized bellow or bladder type devices of a variety of shapes and sizes and used for providing actuation, shock absorption, and vibration isolation. Key specifications include the intended application, type, style, physical dimensions, mounting type, as well as the features. Air springs are used primarily in machine applications such as vehicle suspensions for shock absorption and as machine mounts for vibration isolation.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=QkfSXD4jo08
https://www.youtube.com/watch?v=XMO2jdqFECc&vl=en

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(741-745)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(4.20-4.25)

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CIVIL

III/II

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : V TORSION OF SHAFTS AND SPRING

Date of Lecture:

Topic of Lecture: Helical & leaf springs

Introduction : (Maximum 5 sentences)

Helical spring. A spring is defined as an elastic body, whose function is to distort when loaded and to recover its original shape when the load is removed. Leaf spring is a suspension system for vehicles that has been used as far back as medieval times. They were originally called carriage or laminated springs.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- ✓ Fitted Leafs.
- ✓ Leaf Springs.
- ✓ Compression
- ✓ extension

Detailed content of the Lecture:

Helical spring:

A spring is defined as an elastic body, whose function is to distort when loaded and to recover its original shape when the load is removed.

The helical springs are made up of a wire coiled in the form of a helix and are primarily intended for compressive or tensile loads. The cross-section of the wire from which the spring is made may be circular, square or rectangular. Helical compression springs have applications to resist applied compression forces or in the push mode, store energy to provide the "push". Different forms of compression springs are produced.

leaf springs:

Leaf springs are a basic form of suspension made up of layers of steel of varying sizes sandwiched one upon the other. Most leaf spring setups are formed into an elliptical shape through the use of spring steel which has properties that allow it to flex as pressure is added at either end, but then returning to its original position through a damping process. The steel is generally cut into rectangular sections and then once held together by metal clips at either end and a large bolt through the centre of the leafs. It is then mounted to the axle of the vehicle using large U-bolts, securing the suspension in place.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=YXo3RwScdMg
https://www.youtube.com/watch?v=_gbSQuQlwhY

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(741-745)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(4.20-4.35)

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MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

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LECTURE HANDOUTS

CIVIL | **III/II**

Course Name with Code :19CED02/ MECHANICS OF SOLIDS

Course Teacher :Mrs.M.SANCHAYA

Unit : V TORSION OF SHAFTS AND SPRING

Date of Lecture:

Topic of Lecture: Stresses & deflection of springs

Introduction: (Maximum 5 sentences)

Helical springs are wire springs made of helically coiled wire. This is the most common type of wire spring. Extensive analysis has been performed on this type of spring. The basic stress analysis is presented in overview first and refined for wire curvature afterwards.

Prerequisite knowledge for Complete understanding and learning of Topic: (Max. Four important topics)

- ✓ Stresses and deflections
- ✓ wire springs
- ✓ flat springs
- ✓ special-shaped springs.

Detailed content of the Lecture:

Stresses and deflection of springs:

Helical springs are wire springs made of helically coiled wire. This is the most common type of wire spring. Extensive analysis has been performed on this type of spring. The basic stress analysis is presented in overview first and refined for wire curvature afterwards.

the direct shear force on a given cross-section of the spring is V = F and the torsional moment T = FD/2 where D is the mean diameter. Then the torsional shear stress is maximum at the inner diameter of the spring.

If springs are more expensive and have been studied less, so their properties are not well-understood. Occasionally an application with limited space will require one, but other means should be attempted, first.

The Curvature Effect:

The curvature of the spring's coil has not been taken into account in the preceding. We will use the Bergstrasser factor KB to replace the shear stress-correction factor.

Deflection of Helical Springs:

It can be shown that the displacement y across a helical spring is linear to the applied force F with proportionality constant called the spring constant/rate k.

Commonly used spring materials:

One of the important considerations in spring design is the choice of the spring material. Some of the common spring materials are given below.

Hard-drawn wire:

This is cold drawn, cheapest spring steel. Normally used for low stress and static load. The material is not suitable at subzero temperatures or at temperatures above120^0c.

Oil-tempered wire:

It is a cold drawn, quenched, tempered, and general-purpose spring steel. However, it is not suitable for fatigue or sudden loads, at subzero temperatures and at temperatures above180^0c. When we go for highly stressed conditions then alloy steels are useful.

Spring manufacturing processes:

If springs are of very small diameter and the wire diameter is also small then the springs are normally manufactured by a cold drawn process through a mangle. However, for very large springs having also large coil diameter and wire diameter one has to go for manufacture by hot processes. First one has to heat the wire and then use a proper mangle to wind the coils.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=RfiXsft3bO8
https://www.youtube.com/watch?v=SWpINMKNl9s

Important Books/Journals for further learning including the page nos.:

1. Strength of Materials(Mechanics of Solids) by Dr.R.K.Bansal in the pg No(743-745)
2. Mechanics of solids, Sri Krishna Publication,2013 by Dr.V. Rajendran Pg no –(4.21-4.25)

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