

Principal Stress & Maximal Shear Stress

2-Dimensional

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

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

$$\sigma_{x'} = \frac{\sigma_x + \sigma_y}{2} + \left(\frac{\sigma_x - \sigma_y}{2}\right) \cos 2\theta + \tau_{xy} \sin 2\theta$$

$$\sigma_{y'} = \frac{\sigma_x + \sigma_y}{2} - \left(\frac{\sigma_x - \sigma_y}{2}\right) \cos 2\theta + \tau_{xy} \sin 2\theta$$

$$\tau_{x'y'} = \frac{\sigma_x - \sigma_y}{2} \sin 2\theta + \tau_{xy} \cos 2\theta$$

$$\theta = \frac{1}{2} \arctan \left(\frac{2\tau_{xy}}{\sigma_x - \sigma_y} \right)$$

$$I_{xx} = \int y^2 dA, I_{yy} = \int x^2 dA, I_{xy} = \int xy dA, I_{xx'} = I_{xx} \cos^2 2\theta - I_{yy} \sin^2 2\theta + 2I_{xy} \sin 2\theta$$

3-Dimensional

Determinants Equations (Stress Invariants)

$$I_1 = \sigma_x + \sigma_y + \sigma_z$$

$$I_2 = \sigma_x \sigma_y + \sigma_x \sigma_z + \sigma_y \sigma_z$$

$$I_3 = \sigma_x \sigma_y \sigma_z - \tau_{xy} \tau_{yz} - \tau_{yz} \tau_{zx} - \tau_{zx} \tau_{xy}$$

$$I_4 = \sigma_x \tau_{xy} \tau_{yz} + \sigma_y \tau_{yz} \tau_{zx} + \sigma_z \tau_{zx} \tau_{xy} - \tau_{xy}^2 \sigma_z - \tau_{yz}^2 \sigma_x - \tau_{zx}^2 \sigma_y$$

$\sigma_{1,2,3}$ = roots of $\lambda^3 - I_1 \lambda^2 + I_2 \lambda - I_3 = 0$

$$\sigma_{1,2,3} = \frac{I_1}{3} \pm \sqrt{\frac{2}{3} \left(\frac{I_2}{3} - \frac{I_1^2}{9} \right) + \frac{2}{27} \left(\frac{I_3}{3} - \frac{I_1 I_2}{3} \right)}$$

See text for principal direction

$$\tau_{1,2,3} = \frac{I_4}{\sigma_{1,2,3}}$$

$$\tau_{1,2,3} = \frac{I_4}{\sigma_{1,2,3}}$$

Centroidal Bending

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

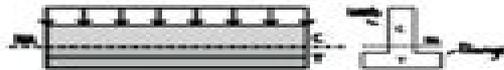
C is distance from NB to point of interest; y is taken for counter-clockwise

I is NB with the MCT neutral axis

bending stress will be MCT (negative) side

MCA is neutral (deformed) stress distribution

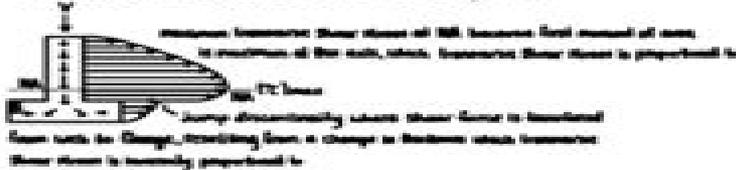
tensile bending → positive, compression bending → negative



Transverse Shear

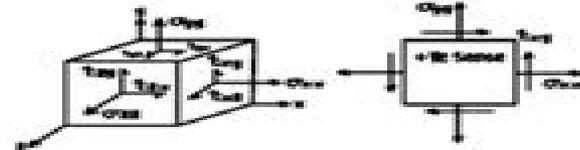
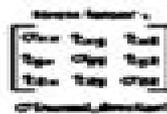
$$\tau = \frac{VQ}{It}$$

Q is area above/below the point of interest along axis that I/Q are with respect to. I/Q will be MCT axis opposite to V (other axis longitudinal)



Torsion

$$\tau = \frac{T \rho}{J}$$



Plane Sectional Properties

$$C = \frac{1}{A} \int y dA$$

Second Moment of Area

$$I = \int y^2 dA = \int x^2 dA$$

$$I_y = \int x^2 dA$$

if I_{xy} = 0, then I_{xy} is the line perpendicular to y-z axis

if I_{xy} = 0, then I_{xy} = 0

Area Moment of Inertia

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

I_x = I_{xy} = 0 if bar is used as a beam

First Moment of Area

moment of area above or below point of interest

$$Q = A y_c$$

where A is the remaining cross-sectional area above or below that point

and y_c is the distance between the centroid of that area to the centroid of the entire cross-section

2-Dimensional Plane Stress & Strain

Stress

(1) — one dimension compared to other two dimensions is very small

(2) — plate or a shell, stress with large constant

(3) — shell has to be in the plane of the plate, etc., same way it does not

Strain

(1) — one dimension compared to other two dimensions is very large

(2) — symmetric loading condition

Stress-Strain

A: point of interest

$$\begin{bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} \begin{bmatrix} \epsilon_x \\ \epsilon_y \\ \gamma_{xy} \end{bmatrix} \rightarrow \begin{bmatrix} E_{11} & E_{12} & E_{13} \\ E_{21} & E_{22} & E_{23} \\ E_{31} & E_{32} & E_{33} \end{bmatrix} \begin{bmatrix} \epsilon_x \\ \epsilon_y \\ \gamma_{xy} \end{bmatrix} \rightarrow \begin{bmatrix} E_{11} & E_{12} & E_{13} \\ E_{21} & E_{22} & E_{23} \\ E_{31} & E_{32} & E_{33} \end{bmatrix}$$

Stress-Strain Relationship

$$E_{11} = E(\nu^2 + 1) / (1 - \nu^2)$$

$$E_{22} = E(\nu^2 + 1) / (1 - \nu^2)$$

$$E_{33} = E(\nu^2 + 1) / (1 - \nu^2)$$

$$E_{12} = E\nu / (1 - \nu^2), E_{13} = E\nu / (1 - \nu^2), E_{23} = E\nu / (1 - \nu^2)$$

$$G = E / (2(1 + \nu))$$

Plane Stress Condition

$$E_{11} = E(\nu^2 + 1) / (1 - \nu^2)$$

$$E_{22} = E(\nu^2 + 1) / (1 - \nu^2)$$

$$E_{33} = -\nu E(\nu^2 + 1) / (1 - \nu^2)$$

$$E_{12} = E\nu / (1 - \nu^2)$$

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