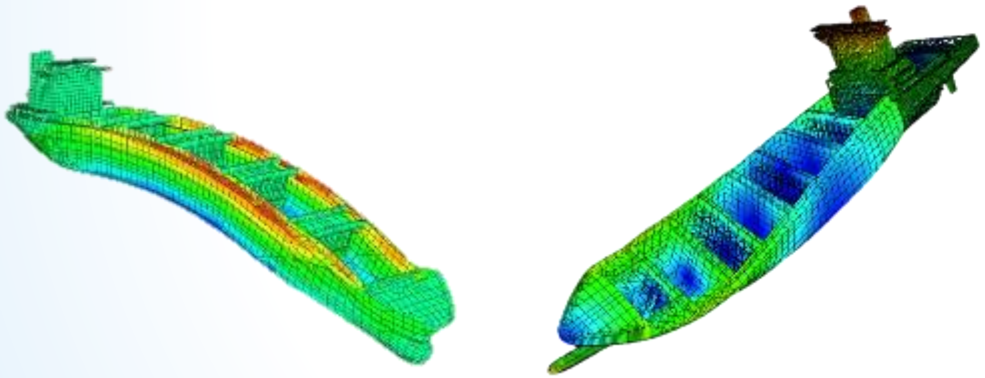
Topics in Ship Structures

(Advanced Local Structural Design & Analysis of Marine Structures)



* Elastic Plate Theory - Basic (Topic 4)

Do Kyun Kim

Seoul National University

https://sites.google.com/snu.ac.kr/ost

[Theory of Plates and Grillages]

[Part I] Plastic Design of Structures

- Plastic theory of bending (Topic 1)
- Ultimate loads on beams (Topic 2)
- Collapse of frames and grillage structures (Topic 3)

[Part II] Elastic Plate Theory under Pressure

- Basic (Topic 4)
- Simply supported plates under Sinusoidal Loading (Topic 5)
- Long clamped plates (Topic 6)
- Short clamped plates (Topic 7)
- Low aspect ratio plates, strength & permanent set (Topic 7A)

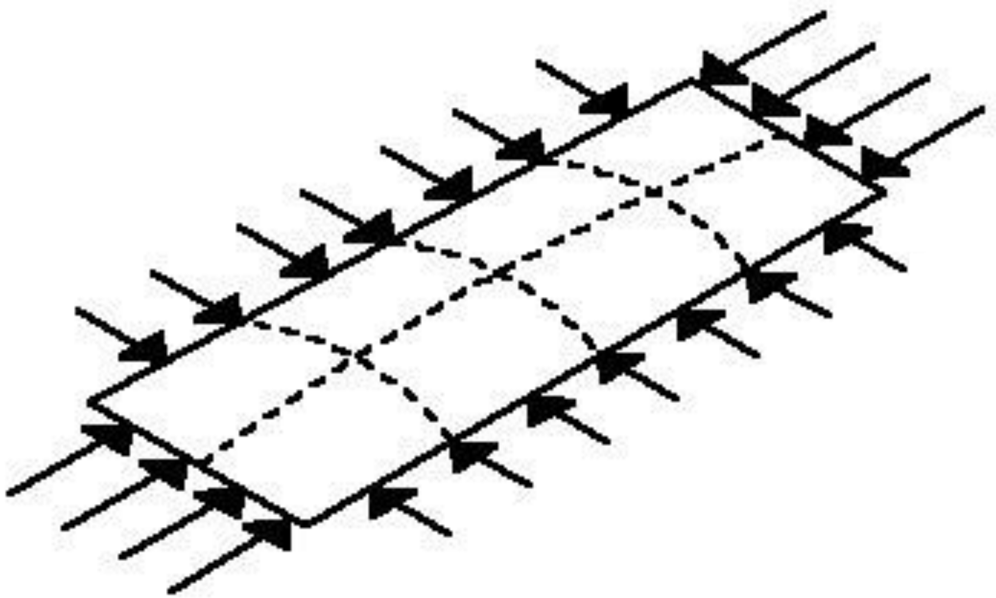
[Part III] Buckling of Stiffened Panels

- Failure modes (Topic 8)
- Tripping (Topic 9) + Post-buckling strength of plate (Topic 9A)
- Post-buckling behaviour (Topic 10)

Objectives

The aim of this lecture is:

- To equip you with the knowledge and understanding of elastic plate theory.



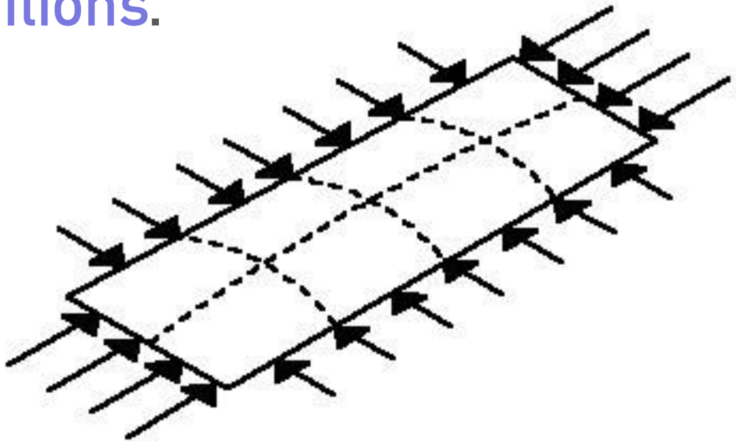
Picture from:
http://fgg-web.fgg.uni-lj.si/~/pmoze/esdep/master/wg08/l0100.htm

http://homepages.engineering.auckland.ac.nz/~pkel015/SolidMechanicsBooks/Part_I/
http://homepages.engineering.auckland.ac.nz/~pkel015/SolidMechanicsBooks/Part_II/

Learning Outcome

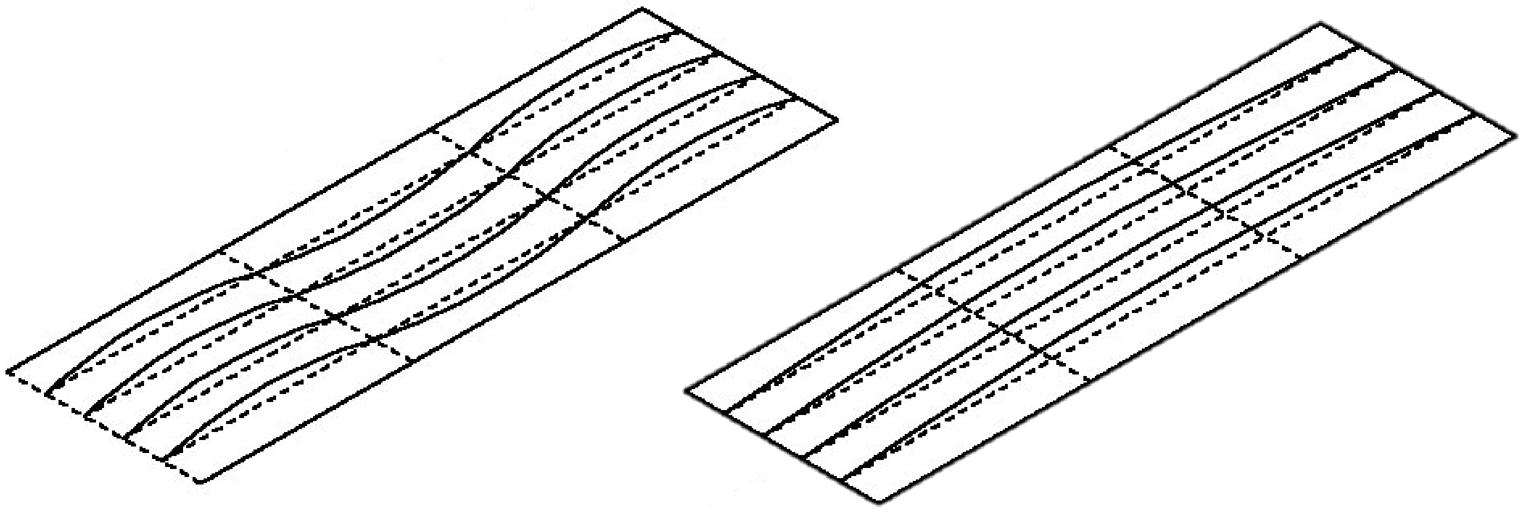
At the end of this lecture, you should be able to:

- Appreciate the assumptions of elastic plate theory
- Be familiar with the bending moment curvature relationship of plate and relationship between twisting moment and twist in a plate.
- Establish plate governing equilibrium equation.
- Be aware of plate edge conditions.

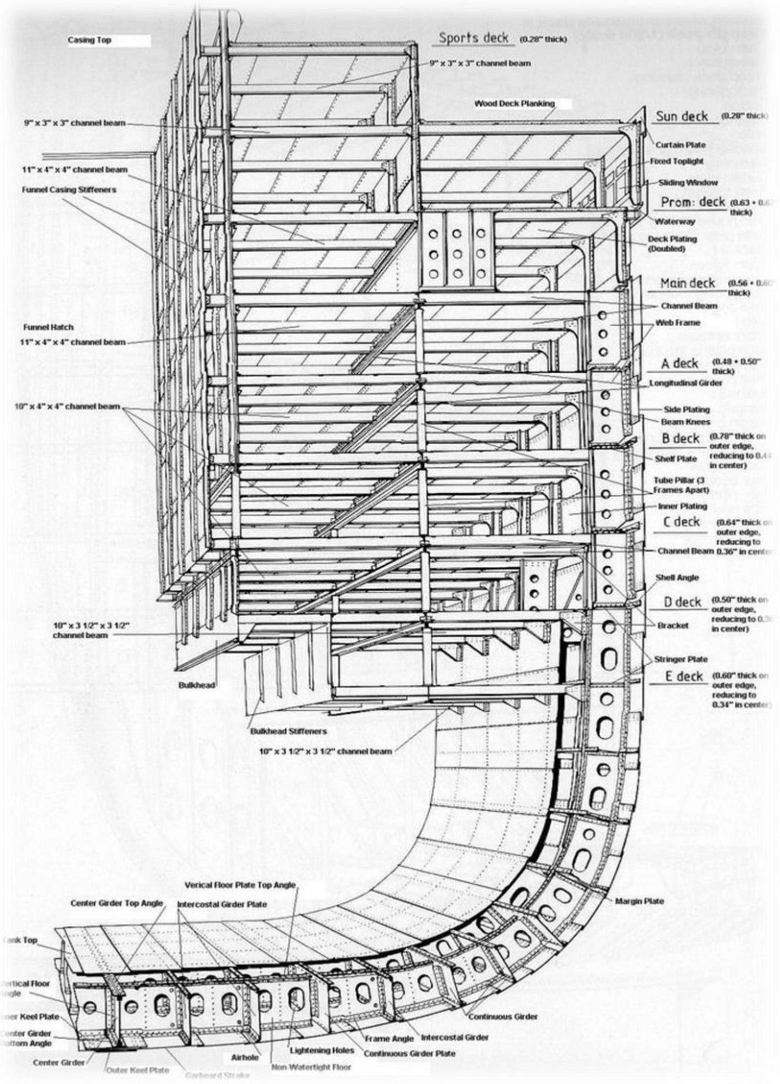


Introduction

- Ships are cut, almost entirely, from steel plate. Only a few structural elements are NOT made from plate (e.g. a few castings and some rolled sections).
- An understanding of plate behaviour is therefore Crucial.



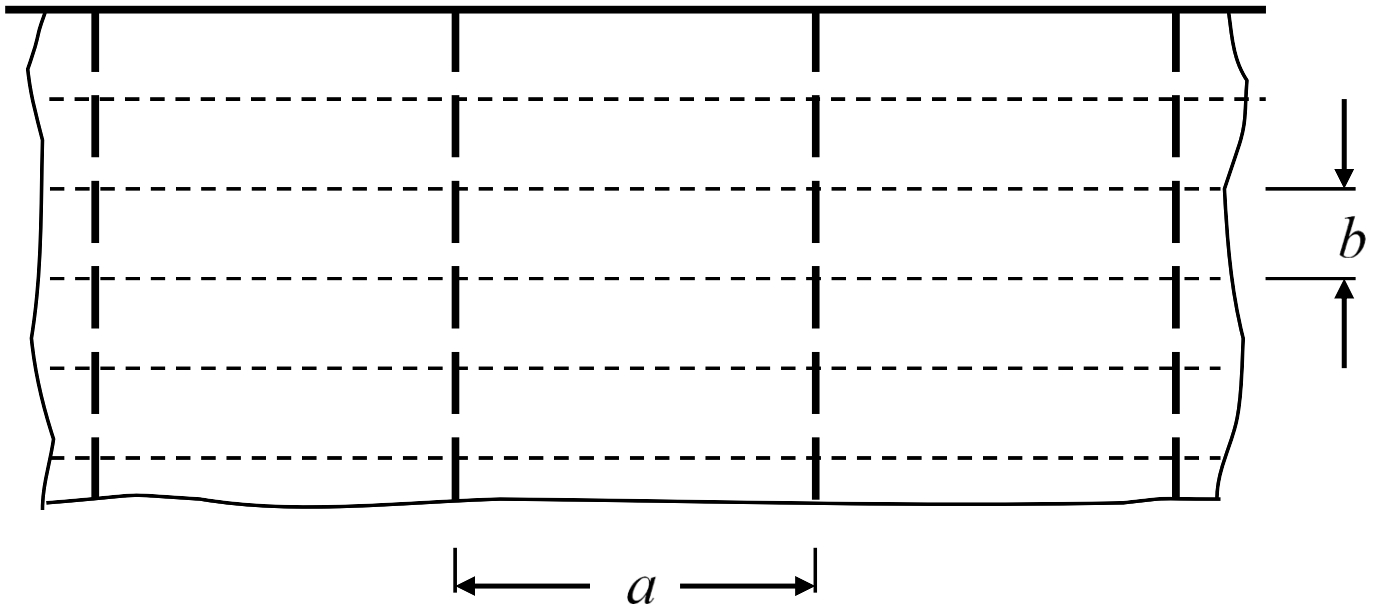
Introduction



- Some components such as deck plate between supports, behave as ideal plates under simple boundary conditions and loads.
- Other components, such as the webs of large frames are subject to more complex loading.
- Still, other components such as deck/stiffener combinations behave somewhat like simple plates, but with special aspects.

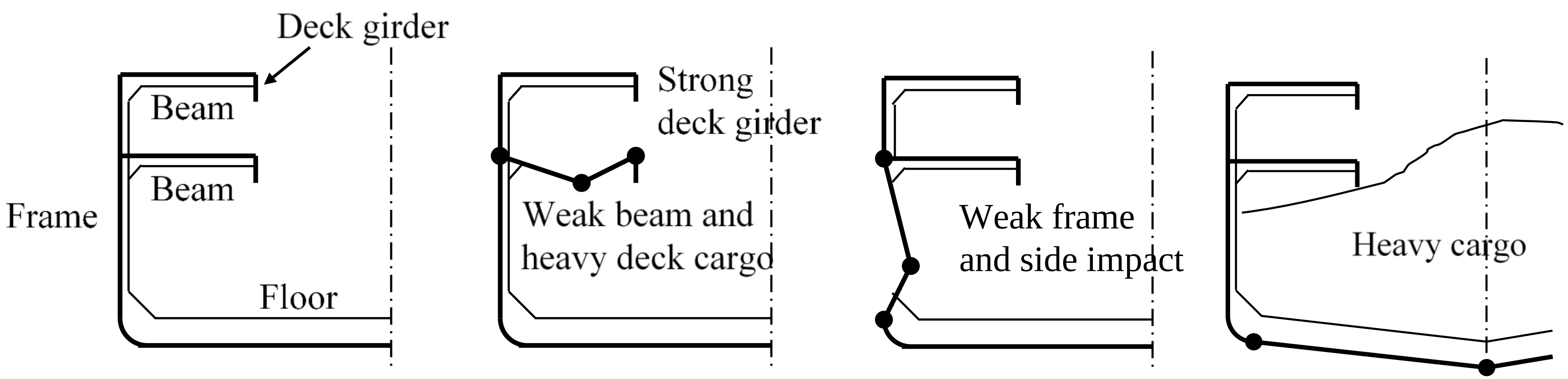
Introduction

- Main hull structures are made up with plating supported by stiffeners.
- For example, deck plates are supported by beams/longitudinals and girders/transverses, bottom plates supported by longitudinals, floors and bottom girders, etc.



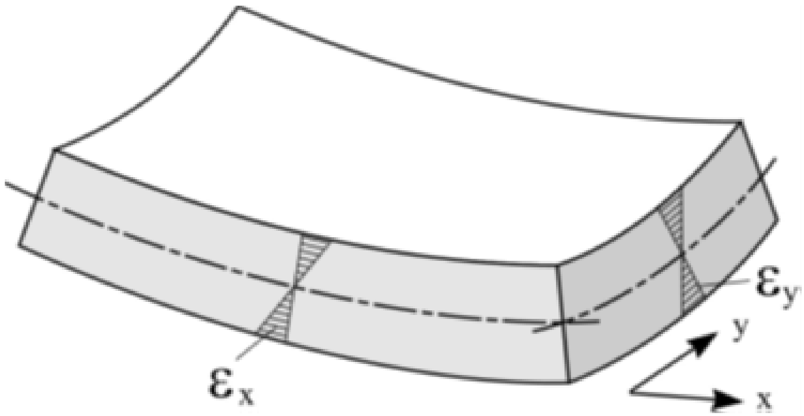
- These plates must have sufficient strengths to withstand lateral loads due to water pressures and/or cargoes, and stiffness to resist deformations.

- Now you should think how to relate the bending/twisting moment, curvature and plate flexural rigidity together in order to calculate stresses and strains arisen in the plates.



Ship Frame Structure — Deck failure mode — Frame failure mode — Floor failure mode

- We start by sketching a small portion of plate bending in two directions, but with no in-plane stress.



- In other words, the stress at the mid-plane will be ZERO, and (equivalently) the average stress in the x or y direction will be ZERO.

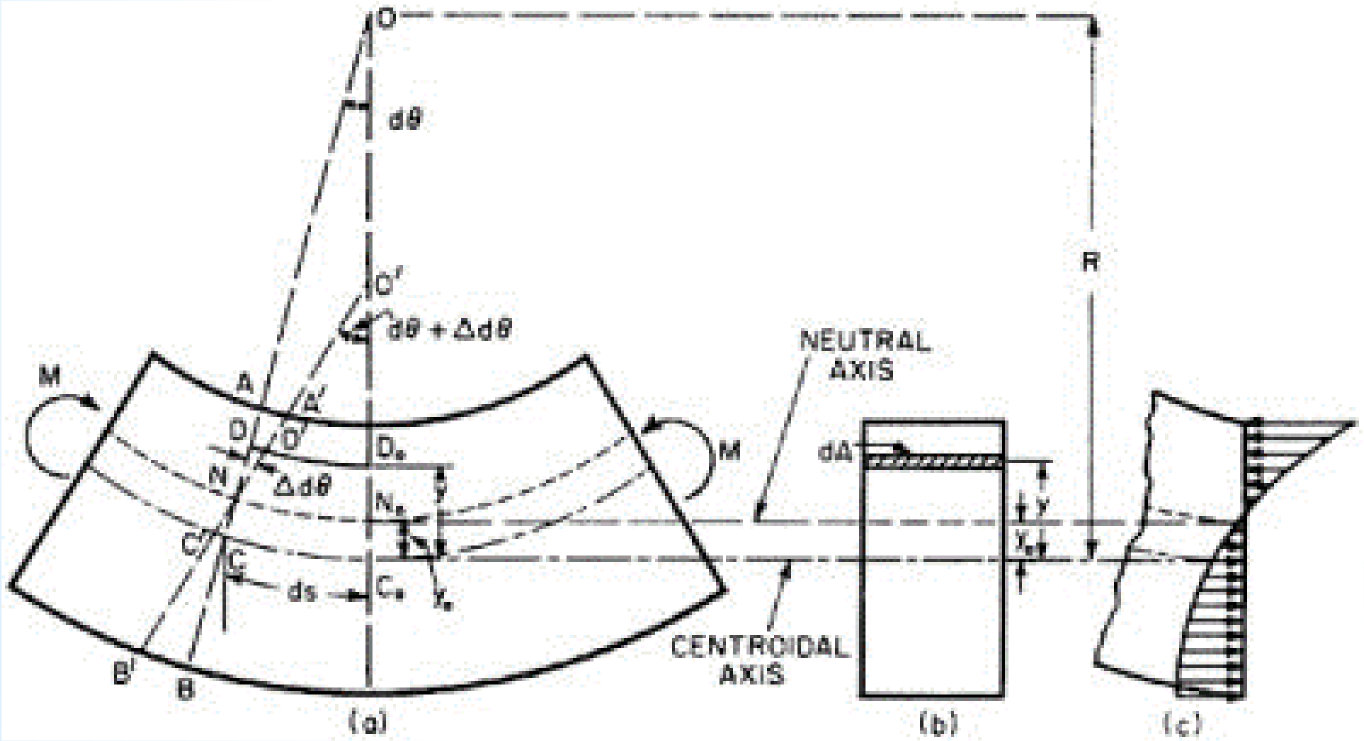
- There is bending stress and strain in both x and y directions. We assume that $\sigma_z \simeq 0$.

Assumptions

It's usually assumed that in the bending of rectangular plate elements under normal lateral load that:

1. The boundary supports (provided by the stiffeners) Do Not Deflect normal to the plate.
2. Stress and strain in a direction perpendicular to the plate may be Neglected.
3. Plane sections remain plane, with the middle surface as the neutral surface of the plate in the special case of pure bending.
4. Deflection w is Small (less than $t/2$).
5. Material remains Elastic.

- The resulting theory based on the above assumptions is known as "small deflection" or "linear theory"
- The results for a variety of loads are superposable always providing of course that the limit of proportionality of the material is not exceeded.



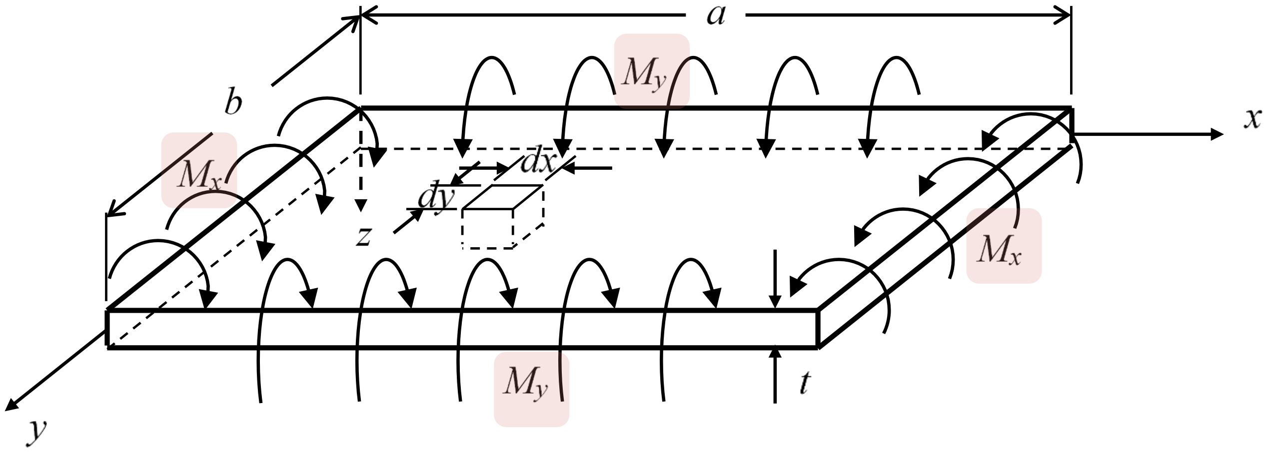
*Topic 4.1:

Bending Moment-Curvature Relationships

Picture from:
https://physics.stackexchange.com/questions/160497/is-the-moment-curvature-relation-for-an-elastic-beam-general

Moment-Curvature Relationships

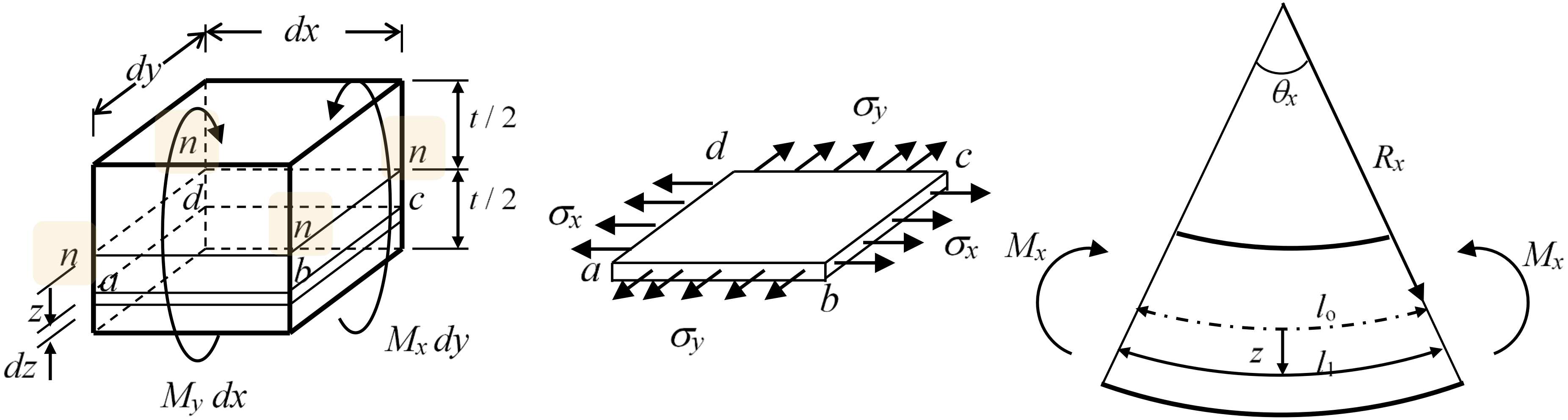
- A plate of thickness t, length a and breadth b is subjected to bending moments on its edges as shown below.



- M_x and M_y are the bending moments per unit length on the edges.
- The subscript indicates the direction of normal of the edge surface on which the bending moment acts.

Moment-Curvature Relationships

- Consider a small element $dx \times dy \times t$ in the plate.



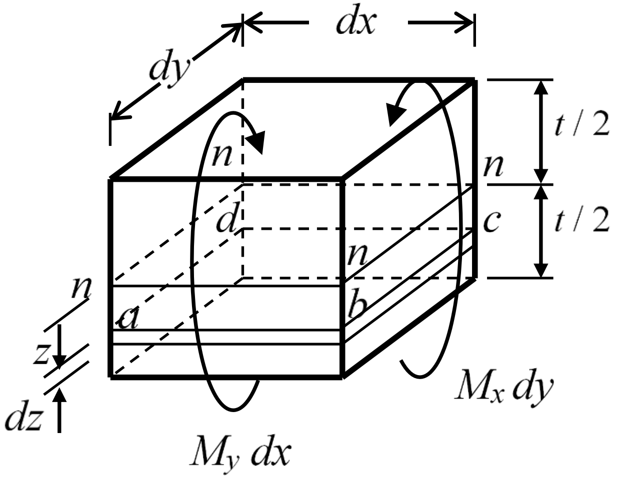
- nn is the neutral plane.

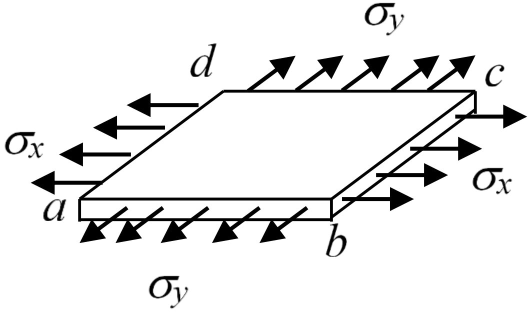
- Due to M_x and M_y, bending stresses σ_x and σ_y act on lamina $abcd$ of distance z from the neutral plane.

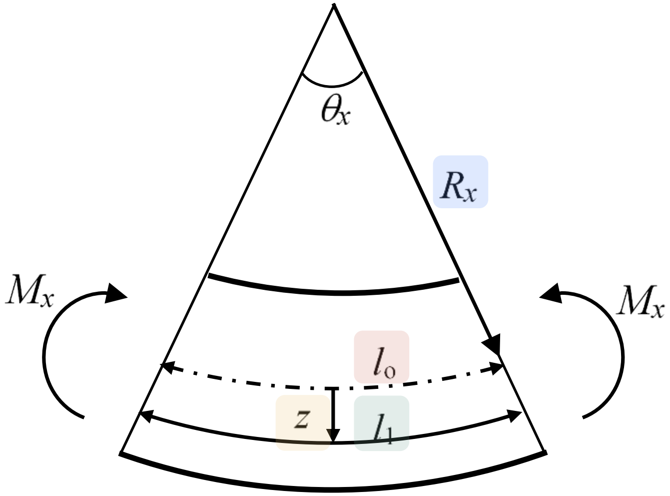
Moment-Curvature Relationships

[Assumption 3] Plane sections remain plane, with the middle surface as the neutral surface of the plate in the special case of pure bending.

- Using assumption 3, we have







- bending strain in x direction:

$$\varepsilon_x = (l_1 - l_o)/l_o = [(R_x + z)\theta_x - R_x\theta_x]/(R_x\theta_x) = \boxed{z / R_x}$$

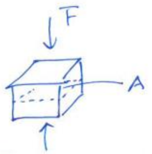
- bending strain in y direction: $\boxed{\varepsilon_y = z / R_y}$

where R_x and R_y are radii of curvature of neutral plane in xz and yz plane.

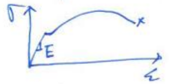
Moment-Curvature Relationships

Required Basics

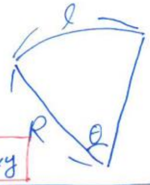
- $\boxed{\sigma = \dfrac{F}{A}}$



- $\boxed{\sigma = E\varepsilon}$
  (Hooke's Law)



- $\boxed{l = R\theta}$



- $\boxed{M = F \times y = \sigma A \times y}$

- $\varepsilon\ (\text{strain}) = \dfrac{\Delta\ (\text{elongation})}{l_0\ (\text{original length})}$

  where, $\Delta = l_1 - l_0$

$$\therefore \boxed{\varepsilon} = \frac{\Delta}{l_0} = \frac{l_1 - l_0}{l_0} = \frac{\cancel{(R+y)\theta - R\theta}}{\cancel{R\theta}} = \boxed{\frac{y}{R}}$$

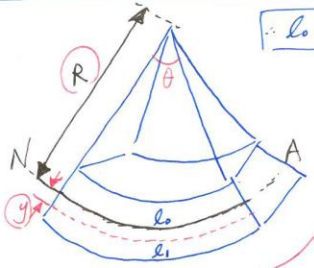
where, $l_1 = (R+y)\theta$
$l_0 = R\theta$

$$\therefore \boxed{\sigma} = E\varepsilon = E\left(\frac{y}{R}\right) = \boxed{\frac{Ey}{R}} \Rightarrow \boxed{\frac{E}{R} = \frac{\sigma}{y}}$$

$$\therefore \boxed{M} = Fy = \sigma A y = \boxed{\frac{EAy^2}{R}}$$

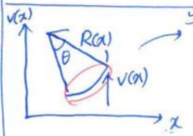
if we consider whole sectional area

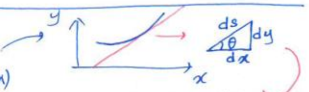
$$\boxed{M} = \frac{E}{R}\underbrace{\int y^2\, dA}_{I\ (\text{moment of inertia})} = \boxed{\frac{EI}{R}} \Rightarrow \boxed{\frac{1}{R} = \frac{M}{EI}}$$



$\boxed{\therefore l_0 = R\theta}$

$$\boxed{\theta} = \frac{l_0}{R} = \left(\frac{1}{R}\right) \times l_0 = \frac{M}{EI} l_0 = \boxed{\frac{Ml_0}{EI}}$$





$\therefore \tan\theta = \dfrac{dy}{dx}$

$\boxed{\theta = \tan^{-1}\left(\dfrac{dy}{dx}\right)}$

$\boxed{ds = \sqrt{(dx)^2 + (dy)^2}} \Rightarrow$ Pythagorean theorem

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curvature (c) ⇒ relationship with "Arc" (ds) according to the change of (dθ)

$$\therefore \boxed{C = \frac{d\theta}{ds} = \frac{d\theta}{dx} \times \frac{dx}{ds}}$$

$$\frac{dx}{ds} = \frac{dx}{\sqrt{dx^2 + dy^2}} = \boxed{\frac{1}{\sqrt{1 + \left(\frac{dy}{dx}\right)^2}}}$$

$$\left(= \frac{1}{R}\right) = \frac{d}{dx}\left[\tan^{-1}\left(\frac{dy}{dx}\right)\right] \times \frac{1}{\sqrt{1 + \left(\frac{dy}{dx}\right)^2}}$$

$$= \boxed{\frac{1}{1 + \left(\frac{dy}{dx}\right)^2} \times \frac{d^2y}{dx^2}} \times \frac{1}{\sqrt{1 + \left(\frac{dy}{dx}\right)^2}}$$

$$\therefore \boxed{C = \frac{d^2y/dx^2}{\left[1 + \left(\frac{dy}{dx}\right)^2\right]^{\frac{3}{2}}}}$$

if $\dfrac{dy}{dx} \ll 1$ (very small)

$$\boxed{C = \frac{d\theta}{ds} = \frac{1}{R} = \frac{d^2y}{dx^2}}$$

$$\therefore \boxed{\frac{1}{R} = \frac{M}{EI} = \frac{d^2y}{dx^2} \text{ or } \frac{d^2w}{dx^2}}$$

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

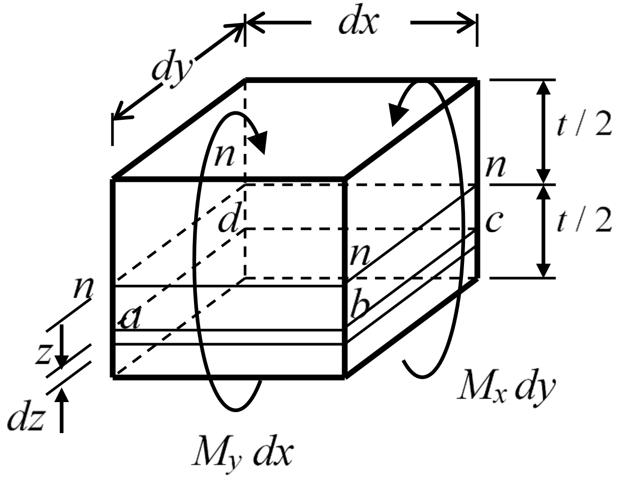
Additional tip!

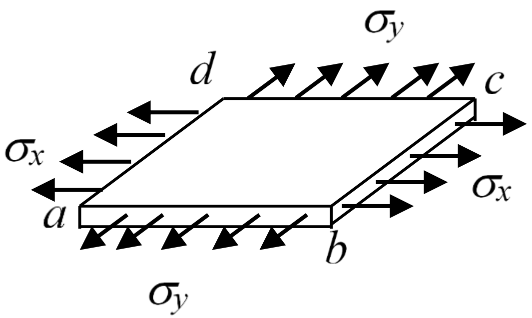
if) $y = \tan^{-1}(x)$ | $y' = \dfrac{dy}{dx} = \dfrac{1}{x^2+1}(x')$

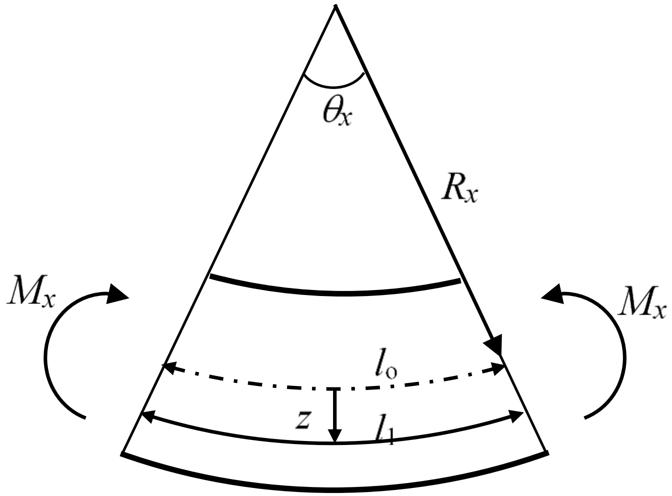
Moment-Curvature Relationships

[Assumption 4] Deflection w is Small (less than $t/2$).

- Using assumption 4, we have







Curvature (in x direction)

$$\frac{1}{R_x} = -\frac{\partial^2 w}{\partial x^2}$$

and

Curvature (in y direction)

$$\frac{1}{R_y} = -\frac{\partial^2 w}{\partial y^2}$$

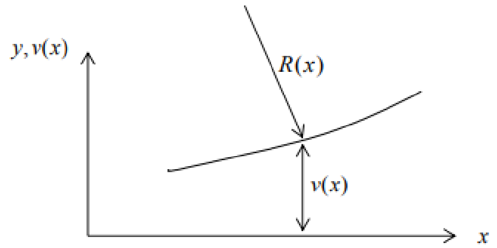
http://homepages.engineering.auckland.ac.nz/~pkel015/SolidMechanicsBooks/Part_I/

Moment-Curvature Relationships

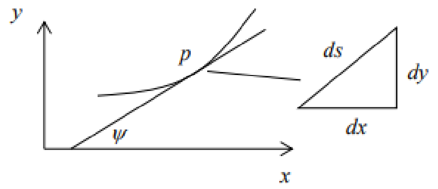
7.4.11 Appendix to §7.4

Curvature of the deflection curve

Consider a deflection curve with deflection $v(x)$ and radius of curvature $R(x)$, as shown in the figure below. Here, *deflection* is the transverse displacement (in the y direction) of the points that lie along the axis of the beam. A relationship between $v(x)$ and $R(x)$ is derived in what follows.



First, consider a curve (arc) s. The tangent to some point p makes an angle ψ with the x – axis, as shown below. As one move along the arc, ψ changes.



Define the **curvature** κ of the curve to be the rate at which ψ increases relative to s,

$$\kappa = \frac{d\psi}{ds}$$

Thus if the curve is very "curved", ψ is changing rapidly as one moves along the curve (as one increase s) and the curvature will be large.

From the above figure,

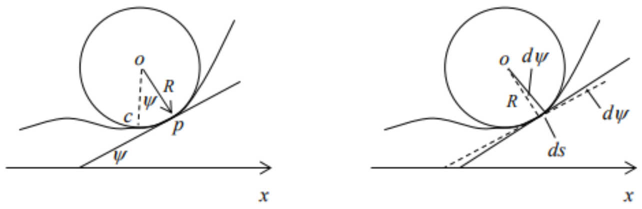
$$\tan\psi = \frac{dy}{dx}, \quad \frac{ds}{dx} = \frac{\sqrt{(dx)^2 + (dy)^2}}{dx} = \sqrt{1 + (dy/dx)^2},$$

so that

$$\kappa = \frac{d\psi}{ds} = \frac{d\psi}{dx}\frac{dx}{ds} = \frac{d(\arctan(dy/dx))}{dx}\frac{dx}{ds} = \frac{1}{1+(dy/dx)^2}\frac{d^2y}{dx^2}\frac{dx}{ds}$$
$$= \frac{d^2y/dx^2}{\left[1+(dy/dx)^2\right]^{3/2}}$$

Finally, it will be shown that the curvature is simply the reciprocal of the radius of curvature. Draw a circle to the point p with radius R. Arbitrarily measure the arc length s from the point c, which is a point on the circle such that $\angle cop = \psi$. Then arc length $s = R\psi$, so that

$$\kappa = \frac{d\psi}{ds} = \frac{1}{R}$$



Thus

$$\frac{1}{R} = \frac{\dfrac{d^2v}{dx^2}}{\left[1+\left(\dfrac{dv}{dx}\right)^2\right]^{\frac{3}{2}}}$$

If one assumes now that the slopes of the deflection curve are small, then $dv/dx << 1$ and

$$\frac{1}{R} \approx \frac{d^2v}{dx^2}$$

[Source] http://homepages.engineering.auckland.ac.nz/~pkel015/SolidMechanicsBooks/Part_I/BookSM_Part_I/07_ElasticityApplications/07_Elasticity_Applications_04_Beam_Theory.pdf

Moment-Curvature Relationships

[Assumption 5] Material remains <u>Elastic</u>.

$$\varepsilon_x = \frac{z}{R_x} = z\left(-\frac{\partial^2 w}{\partial x^2}\right) \quad \& \quad \varepsilon_y = \frac{z}{R_y} = z\left(-\frac{\partial^2 w}{\partial y^2}\right)$$

- Using assumption 5, we have the stress-strain relations for in-plane stresses (i.e. $\sigma_z = 0$) are:

$$\begin{Bmatrix}\varepsilon_x \\ \varepsilon_y\end{Bmatrix} = \frac{1}{E}\begin{bmatrix}1 & -\nu \\ -\nu & 1\end{bmatrix}\begin{Bmatrix}\sigma_x \\ \sigma_y\end{Bmatrix}$$

where ν is Poisson's ratio.

https://en.wikipedia.org/wiki/Sim%C3%A9on_Denis_Poisson
https://en.wikipedia.org/wiki/Poisson%27s_ratio

$$\begin{Bmatrix}\varepsilon_{xx} \\ \varepsilon_{yy} \\ \cancel{\varepsilon_{zz}}\end{Bmatrix} = \begin{Bmatrix}\frac{1}{E}\left[\sigma_{xx} - \nu\left(\sigma_{yy} + \cancel{\sigma_{zz}}\right)\right] \\ \frac{1}{E}\left[\sigma_{yy} - \nu\left(\sigma_{xx} + \cancel{\sigma_{zz}}\right)\right] \\ \frac{1}{E}\left[\cancel{\sigma_{zz}} - \nu\left(\sigma_{xx} + \sigma_{yy}\right)\right]\end{Bmatrix}$$

$$= \frac{1}{E}\begin{bmatrix}\sigma_{xx} & -\nu\sigma_{yy} \\ -\nu\sigma_{xx} & \sigma_{yy}\end{bmatrix} = \boxed{\frac{1}{E}\begin{bmatrix}1 & -\nu \\ -\nu & 1\end{bmatrix}\begin{bmatrix}\sigma_{xx} \\ \sigma_{yy}\end{bmatrix}}$$

- Re-arranging the above equations yields

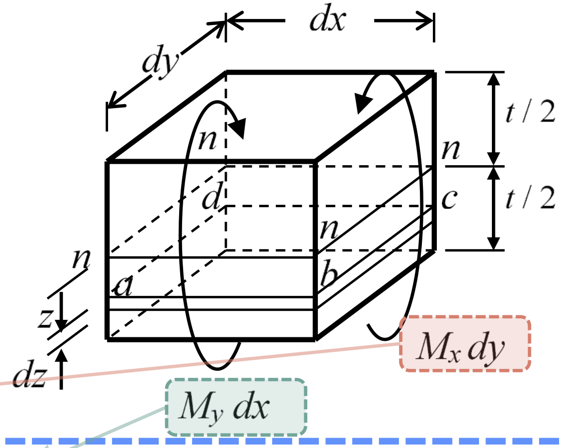
$$\begin{Bmatrix}\sigma_x \\ \sigma_y\end{Bmatrix} = \frac{E}{1-\nu^2}\begin{bmatrix}1 & \nu \\ \nu & 1\end{bmatrix}\begin{Bmatrix}\varepsilon_x \\ \varepsilon_y\end{Bmatrix}$$

Hence,

$$\begin{Bmatrix}\sigma_x \\ \sigma_y\end{Bmatrix} = -\frac{Ez}{1-\nu^2}\begin{bmatrix}1 & \nu \\ \nu & 1\end{bmatrix}\begin{Bmatrix}\partial^2 w/\partial x^2 \\ \partial^2 w/\partial y^2\end{Bmatrix} \qquad \text{(i)}$$

Moment-Curvature Relationships

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \end{Bmatrix} = -\frac{Ez}{1-\nu^2}\begin{bmatrix} 1 & \nu \\ \nu & 1 \end{bmatrix}\begin{Bmatrix} \partial^2 w/\partial x^2 \\ \partial^2 w/\partial y^2 \end{Bmatrix}$$ Eqn (i)



- The bending moments resulting from the stresses are

$$M_x dy = \int_{-t/2}^{t/2} z\sigma_x dydz$$ and $$M_y dx = \int_{-t/2}^{t/2} z\sigma_y dxdz$$

or

$$M_x = \int_{-t/2}^{t/2} z\sigma_x dz$$ and $$M_y = \int_{-t/2}^{t/2} z\sigma_y dz$$

- Substituting equations (i) into the above equations and integrating give

$$M_x = -D\left(\frac{\partial^2 w}{\partial x^2} + \nu\frac{\partial^2 w}{\partial y^2}\right)$$

$$M_y = -D\left(\frac{\partial^2 w}{\partial y^2} + \nu\frac{\partial^2 w}{\partial x^2}\right)$$

in which $D = \frac{Et^3}{12(1-\nu^2)}$ = plate flexural rigidity

Moment-Curvature Relationships

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \end{Bmatrix} = -\frac{Ez}{1-\nu^2}\begin{bmatrix} 1 & \nu \\ \nu & 1 \end{bmatrix}\begin{Bmatrix} \partial^2 w/\partial x^2 \\ \partial^2 w/\partial y^2 \end{Bmatrix}$$

$$M_x = -D\left(\frac{\partial^2 w}{\partial x^2} + \nu\frac{\partial^2 w}{\partial y^2}\right)$$

$$M_y = -D\left(\frac{\partial^2 w}{\partial y^2} + \nu\frac{\partial^2 w}{\partial x^2}\right)$$

$$D = \frac{Et^3}{12(1-\nu^2)}$$

<u>Notes:</u>

- D is sometimes expressed: $D = E'I'$

where, $E' = \dfrac{E}{1-\nu^2}$ is effective elastic modulus for plates

$I' = t^3/12$ is the second moment of area per unit length

- The moment-curvature relation for a beam is given by

$$M_x = -EI\frac{d^2 w}{dx^2}$$ in which EI is beam flexural rigidity.

- Substituting the bending moment-curvature equations into (i) gets

$$\boxed{\sigma_x = \frac{M_x z}{t^3/12}} \quad \text{and} \quad \boxed{\sigma_y = \frac{M_y z}{t^3/12}}$$

- These are analogous to $\boxed{\dfrac{\sigma}{z} = \dfrac{M}{I'}}$

Moment-Curvature Relationships

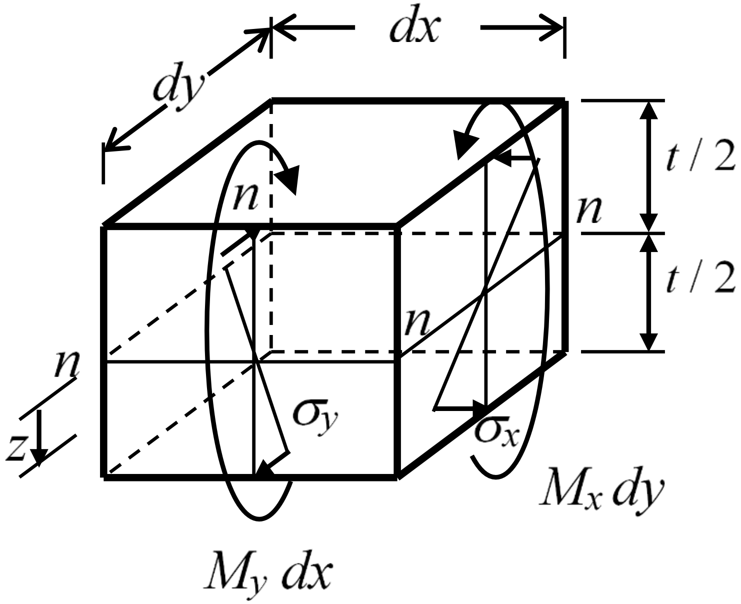
$$\sigma_x = \frac{M_x z}{t^3/12}$$

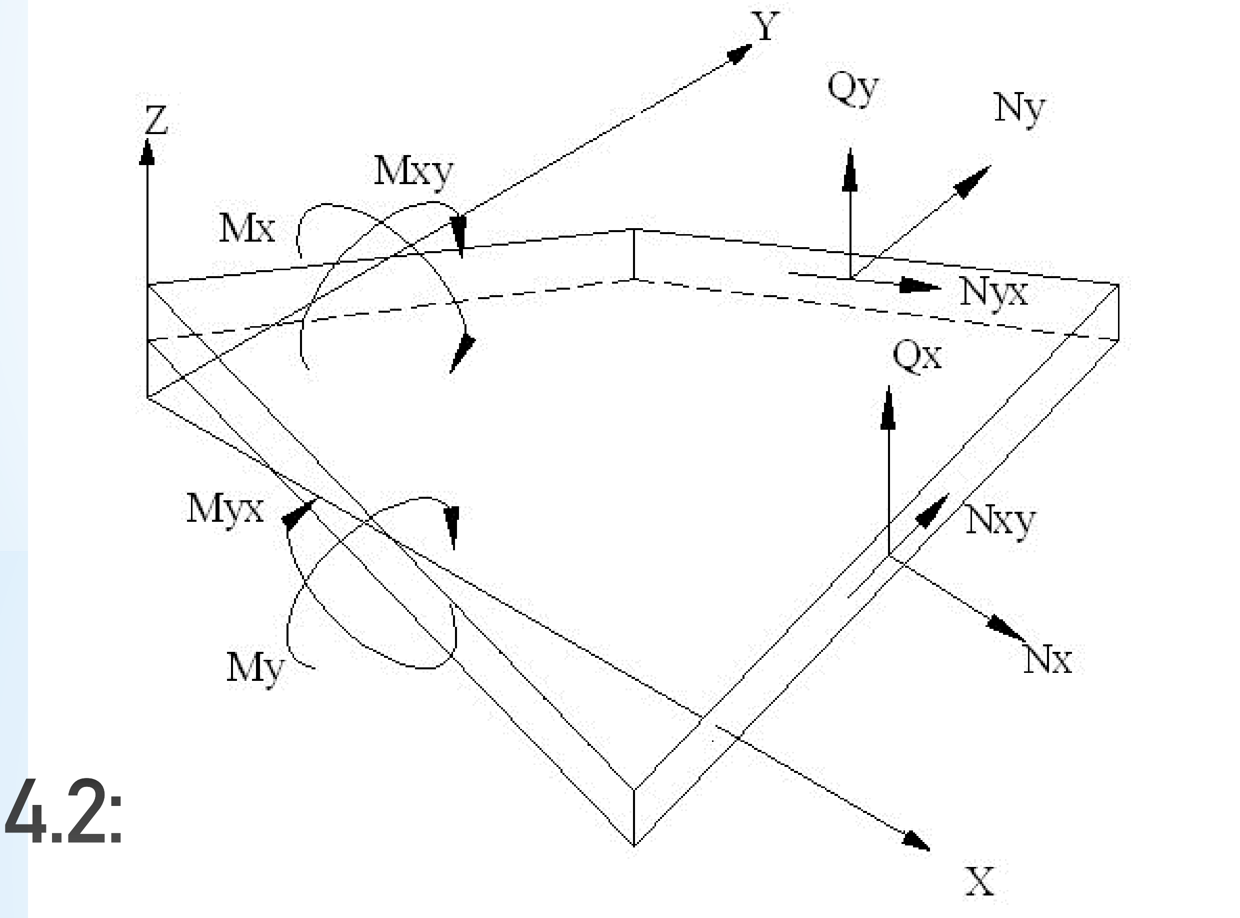
$$\sigma_y = \frac{M_y z}{t^3/12}$$

- Maximum stresses occur on plate surface:

$$(\sigma_x)_{\max} = \pm\frac{6M_x}{t^2}$$

$$(\sigma_y)_{\max} = \pm\frac{6M_y}{t^2}$$





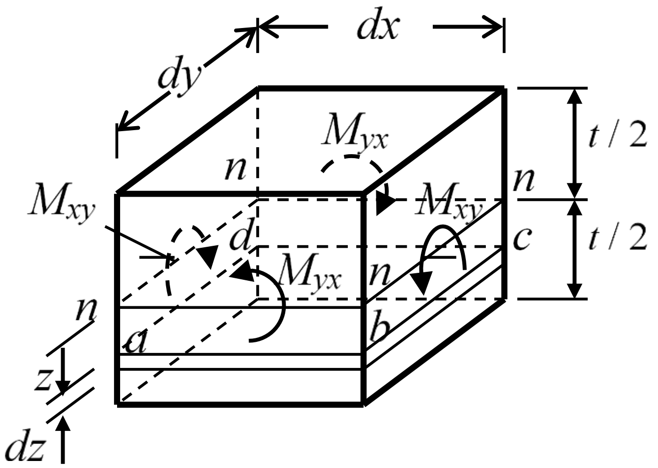
*Topic 4.2:

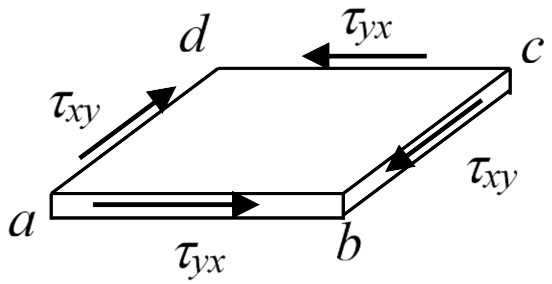
Twisting Moment-Twist of Plates Relationships

Twisting Moment and Twist of Plates

Relations between twisting moment and twist in a plane

- At a point in a plate subjected to lateral load there will in general act both bending and twisting moments.
- Bending moments are related to deflection w through curvature. A similar relation is required relating twisting moments to deflection.





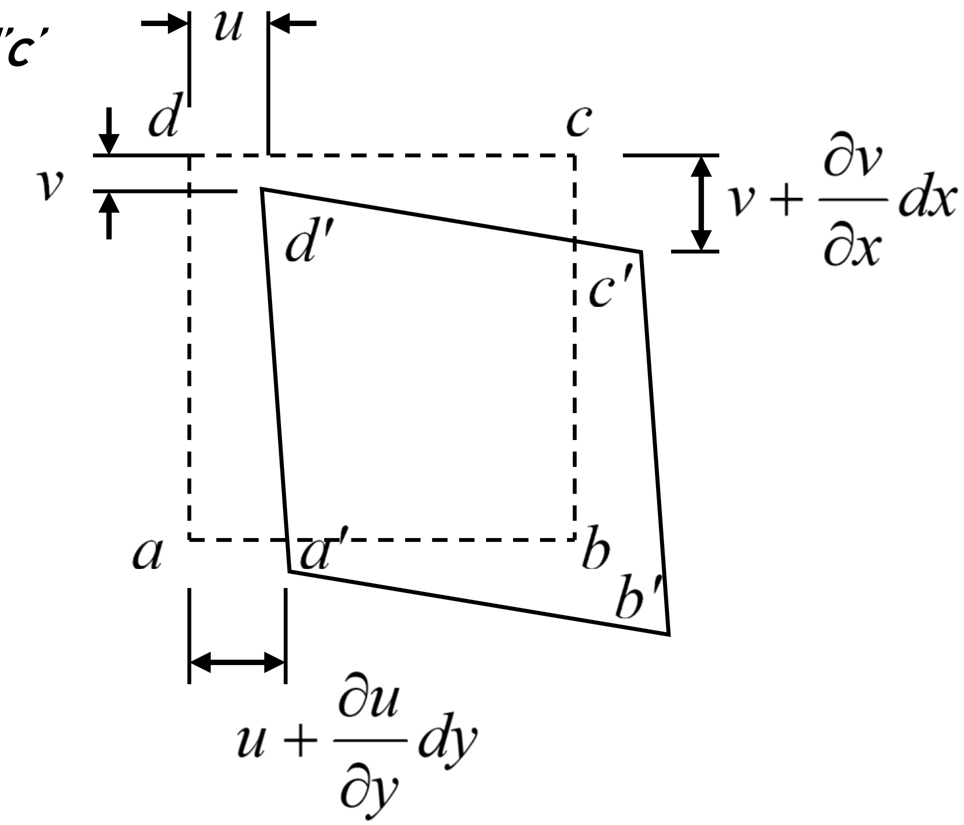
- M_{xy} and M_{yx} are twisting moments per unit length.
- The directions for twisting moments and shear stresses shown above are Positive.

Twisting Moment and Twist of Plates

- Shear strain γ_{xy} = angle *adc* – angle *a′d′c′*

$$\gamma_{xy} = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}$$

u and v are displacements in x and y direction.



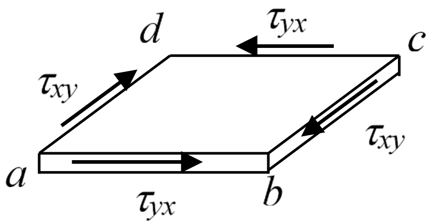
- Hence,

$$\gamma_{xy} = \gamma_{yx} = -2z \frac{\partial^2 w}{\partial x \partial y}$$

Twisting Moment and Twist of Plates

$$\gamma_{xy} = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}$$

$$\gamma_{xy} = \gamma_{yx} = -2z\frac{\partial^2 w}{\partial x \partial y}$$

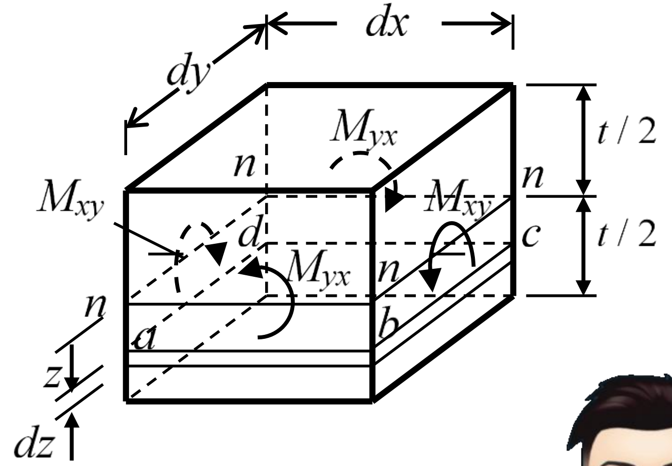


- From stress-strain relations for elastic material:

$$\tau_{xy} = G\gamma_{xy}$$

Thus,

$$\boxed{\tau_{xy} = \tau_{yx} = -2zG\frac{\partial^2 w}{\partial x \partial y}} \quad \text{(ii)}$$



- The applied twisting moments must equal the moments set up by shear stress:

$$M_{xy}dy = -\int_{-t/2}^{t/2} z\tau_{xy}dydz \quad \text{and} \quad M_{yx}dx = \int_{-t/2}^{t/2} z\tau_{yx}dxdz$$

or

$$\boxed{M_{xy} = -\int_{-t/2}^{t/2} z\tau_{xy}dz} \quad \text{and} \quad \boxed{M_{yx} = \int_{-t/2}^{t/2} z\tau_{yx}dz}$$

Twisting Moment and Twist of Plates

$$\tau_{xy} = \tau_{yx} = -2zG\frac{\partial^2 w}{\partial x \partial y} \qquad \text{(ii)}$$

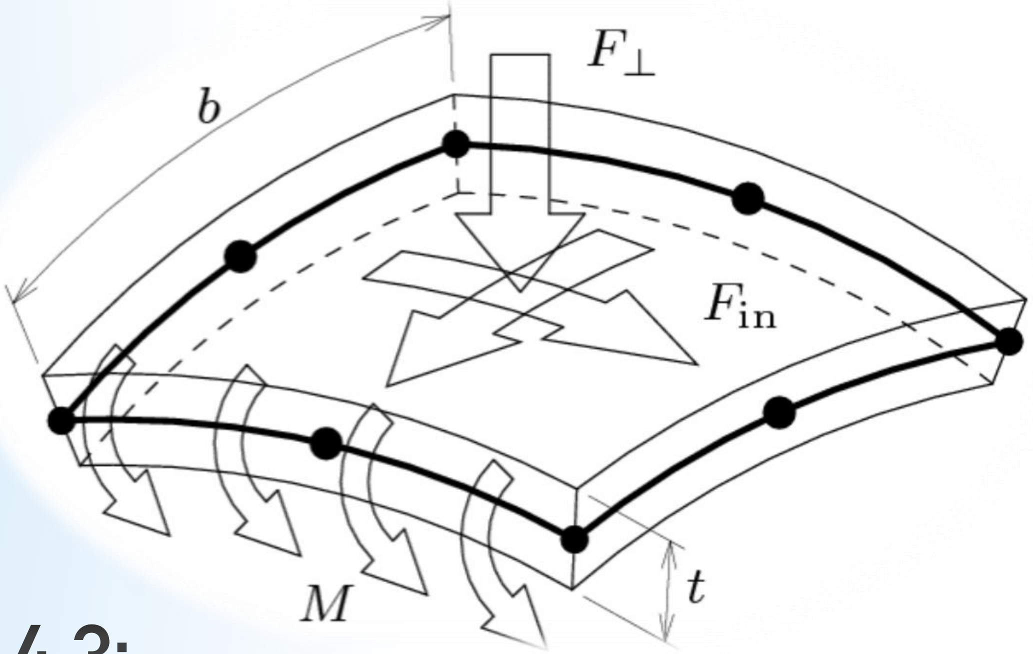
$$M_{xy} = -\int_{-t/2}^{t/2} z\gamma_{xy}\,dz \qquad M_{yx} = \int_{-t/2}^{t/2} z\gamma_{yx}\,dz$$

- Substituting equation (ii) into the foregoing equations and integrating give

$$M_{xy} = -M_{yx} = \frac{Gt^3}{6}\frac{\partial^2 w}{\partial x \partial y} \qquad \text{(iii)}$$

- Putting $G = \dfrac{E}{2(1+\nu)}$ and $D = \dfrac{Et^3}{12(1-\nu^2)}$ into (iii)

$$M_{xy} = -M_{yx} = D(1-\nu)\frac{\partial^2 w}{\partial x \partial y}$$



*Topic 4.3:

Plate Governing Equilibrium Equation

Plate Equilibrium Governing Equation

- In beams the lateral load q per unit length is related to the resulting deflection w through

$$EI\frac{\partial^4 w}{\partial x^4} = q$$

- A similar relation between pressure p on a plate and the resulting deflection $w(x,y)$ can be established.

Expected outcome (Important‼)

$v(x)$ or $w(x) = deflection(m)$

$\theta(x) = \frac{dv(x)}{dx} = v'(x) = slope(rad)$

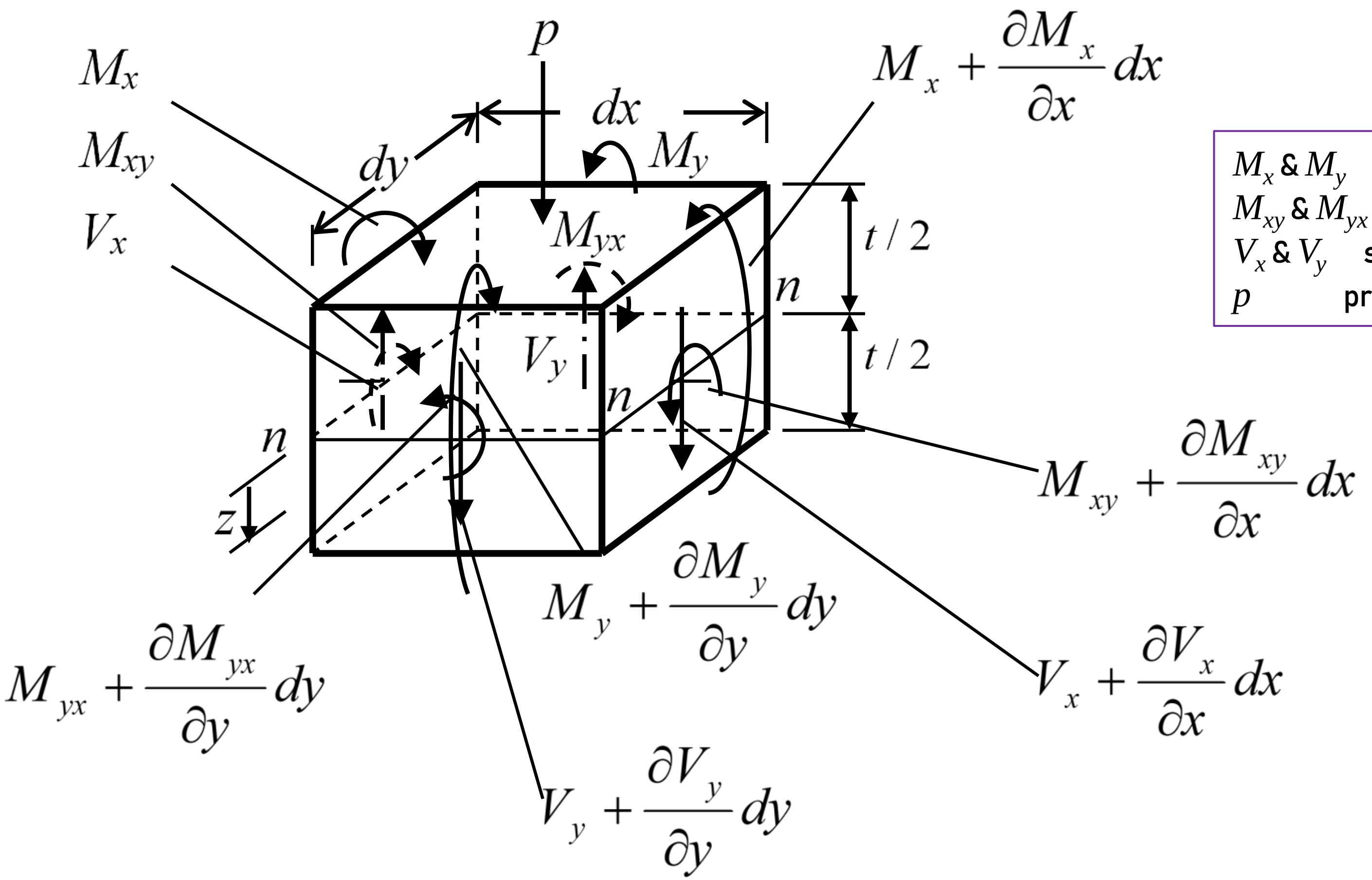
$M(x) = EI\frac{d^2v(x)}{dx^2} = EIv''(x) = moment(Nm)$

$V(x) = EI\frac{d^3v(x)}{dx^3} = EIv'''(x) = shear(N)$

$q(x) = EI\frac{d^4v(x)}{dx^4} = EIv''''(x) = Load(N/m)$

Plate Equilibrium Governing Equation

- A small element cut from the plate is subjected to the actions shown below. These actions (moments, twists, shear forces, etc) vary from point to point, i.e. they are functions of both x and y.



M_x & M_y bending moments
M_{xy} & M_{yx} twisting moments
V_x & V_y shear forces
} per unit length
p pressure

Plate Equilibrium Governing Equation

- For equilibrium

Net force in z direction must be zero

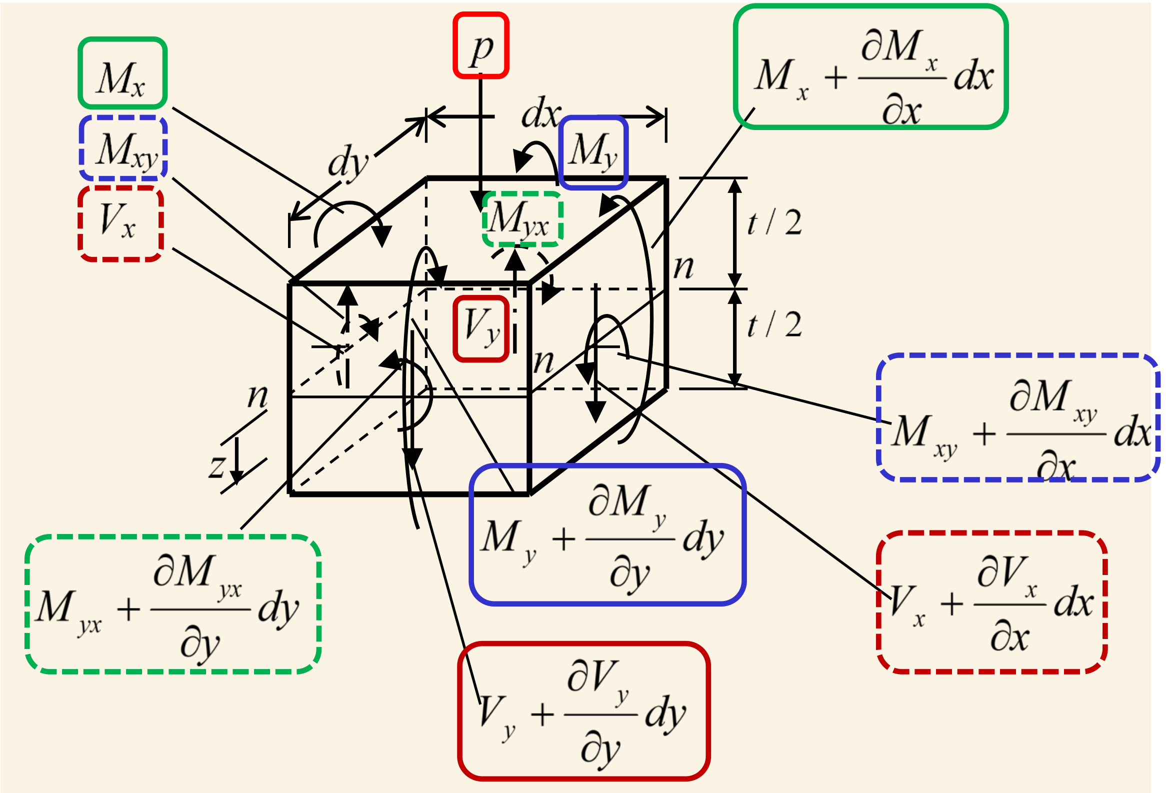
$$\frac{\partial V_x}{\partial x} + \frac{\partial V_y}{\partial y} + p = 0$$

Net moment about x axis must be zero

$$\frac{\partial M_{xy}}{\partial x} - \frac{\partial M_y}{\partial y} + V_y = 0$$

Net moment about y axis must be zero

$$\frac{\partial M_{yx}}{\partial y} + \frac{\partial M_x}{\partial x} - V_x = 0$$



M_x & M_y bending moments
M_{xy} & M_{yx} twisting moments per unit length
V_x & V_y shear forces
p pressure

Plate Equilibrium Governing Equation

$$\frac{\partial V_x}{\partial x}+\frac{\partial V_y}{\partial y}+p=0 \qquad \frac{\partial M_{xy}}{\partial x}-\frac{\partial M_y}{\partial y}+V_y=0 \qquad \frac{\partial M_{yx}}{\partial y}+\frac{\partial M_x}{\partial x}-V_x=0$$

Eliminating V_x and V_y gives

$$\frac{\partial^2 M_x}{\partial x^2}+\frac{\partial^2 M_y}{\partial y^2}+\frac{\partial^2 M_{yx}}{\partial x \partial y}-\frac{\partial^2 M_{xy}}{\partial x \partial y}+p=0$$

Substituting the moment-curvature relations into this equation gets

$$\frac{\partial^4 w}{\partial x^4}+2\frac{\partial^4 w}{\partial x^2 \partial y^2}+\frac{\partial^4 w}{\partial y^4}=\frac{p}{D} \qquad \frac{\partial^2 M}{\partial x^2}=\frac{\partial^4 w}{\partial x^4}$$

or

$$\boxed{D\nabla^4 w=p}$$

in which

$$\nabla^4=\frac{\partial^4}{\partial x^4}+2\frac{\partial^4}{\partial x^2 \partial y^2}+\frac{\partial^4}{\partial y^4}$$

Plate Equilibrium Governing Equation

Edge conditions

- Simple support: $w = 0$ and $M = 0$.
- Edge clamped: $w = 0$ and slope $= 0$.
- Elastic rotational restraint: $w = 0$.

Plate Equilibrium Governing Equation

- The major problems in applying plate theory to design of ship plates, or to predicting their performance under load, is the uncertainty about the boundary conditions particularly the in-plane ones.

- With large areas of plate under pressure load it is reasonable by symmetry to assume the edges of plate elements are clamped against rotation at the stiffeners, and with single loaded plates the rotational conditions are probably nearer those of simple support.

Learning Outcomes (Final Review)

- We have investigated the Elastic Plate Theory.

- Now we are able to:

  - Appreciate the assumptions of elastic plate theory
  - Be familiar with the bending moment curvature relationship of plate and relationship between twisting moment and twist in a plate.
  - Establish plate governing equilibrium equation.
  - Be aware of plate edge conditions.

- Details can be referred to topics 4 in the lecture notes.

[Theory of Plates and Grillages]

[Part I] Plastic Design of Structures

- Plastic theory of bending (Topic 1)
- Ultimate loads on beams (Topic 2)
- Collapse of frames and grillage structures (Topic 3)

[Part II] Elastic Plate Theory

- Basic (Topic 4)
- Simply supported plates under Sinusoidal Loading (Topic 5)
- Long clamped plates (Topic 6)
- Short Clamped plates (Topic 7)
- Additional (Low aspect ratio plates, strength & permanent set)

[Part III] Buckling of Stiffened Panels

- Failure modes (Topic 8)
- Tripping (Topic 9)
- Post-buckling behaviour (Topic 10)

Kam Sa Hab Ni Da

감사합니다

Thank you!

Questions?

Aerial View of Korean Presidential Archives in Sejong city
(Construction Completed in 2014)