

# Summary | Statics

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## Introduction

### Centroid / Centre of area

The point where the area of a figure is assumed to be concentrated.

Located on the axes of symmetry.

### First moment of area

$$\text{About x-axis} = \int_A y dA$$

$$\text{About y-axis} = \int_A x dA$$

### Second moment of area

$$\text{About x-axis} = I_{xx} = I_x = \int_A y^2 dA$$

$$\text{About y-axis} = I_{yy} = I_y = \int_A x^2 dA$$

### The product of moment of area about x,y axes

$$I_{xy} = \int_A xy dA$$

The polar moment of area about z axis

$$I_{zz} = J_0 = \int_A r^2 dA = I_{xx} + I_{yy}$$

Radius of gyration

About x-axis  $= r_x^2 = \frac{I_{xx}}{A}$

About y-axis  $= r_y^2 = \frac{I_{yy}}{A}$

About z-axis  $= r_z^2 = \frac{I_{zz}}{A}$

Derived Formulas for Common Shapes

Shape	Description	$I_{xx}$
Rectangle	Base $b$ . Height $h$ . About centroidal axis parallel to base.	$\frac{bh^3}{12}$
Triangle	Base $b$ . Height $h$ . About base.	$\frac{bh^3}{12}$
Triangle	Base $b$ . Height $h$ . About centroidal axis parallel to base.	$\frac{bh^3}{36}$
Circle	Diameter $d$ . About centroidal axis.	$\frac{\pi d^4}{64}$
Parallelogram	Base $b$ . Height $h$ . About centroidal axis parallel to base.	$\frac{bh^3}{12}$

## Parallel Axis Theorem

$$I_x = I_{x_1} + A\bar{y}^2$$

$$I_y = I_{y_1} + A\bar{x}^2$$

$$I_{xy} = I_{x_1y_1} + A\bar{x}\bar{y}$$

Here

- On LHS, the moments of area are about some  $x$ ,  $y$  axes.
- On RHS, the moments of area are about centroidal axes  $x_1$ ,  $y_1$  parallel to  $x$ ,  $y$ .
- $\bar{x}$  is the distance between  $x$  and  $x_1$  axes.
- $\bar{y}$  is the distance between  $y$  and  $y_1$  axes.

### Note

$I_x$  is at a minimum when the axis is through the centroid. Same for  $I_y$ .

## Perpendicular Axis Theorem

$$I_{zz} = I_{xx} + I_{yy} = I_{mm} + I_{nn}$$

$x$ ,  $y$ ,  $z$  are a set of axes.  $m$ ,  $n$ ,  $z$  are another set of axes.

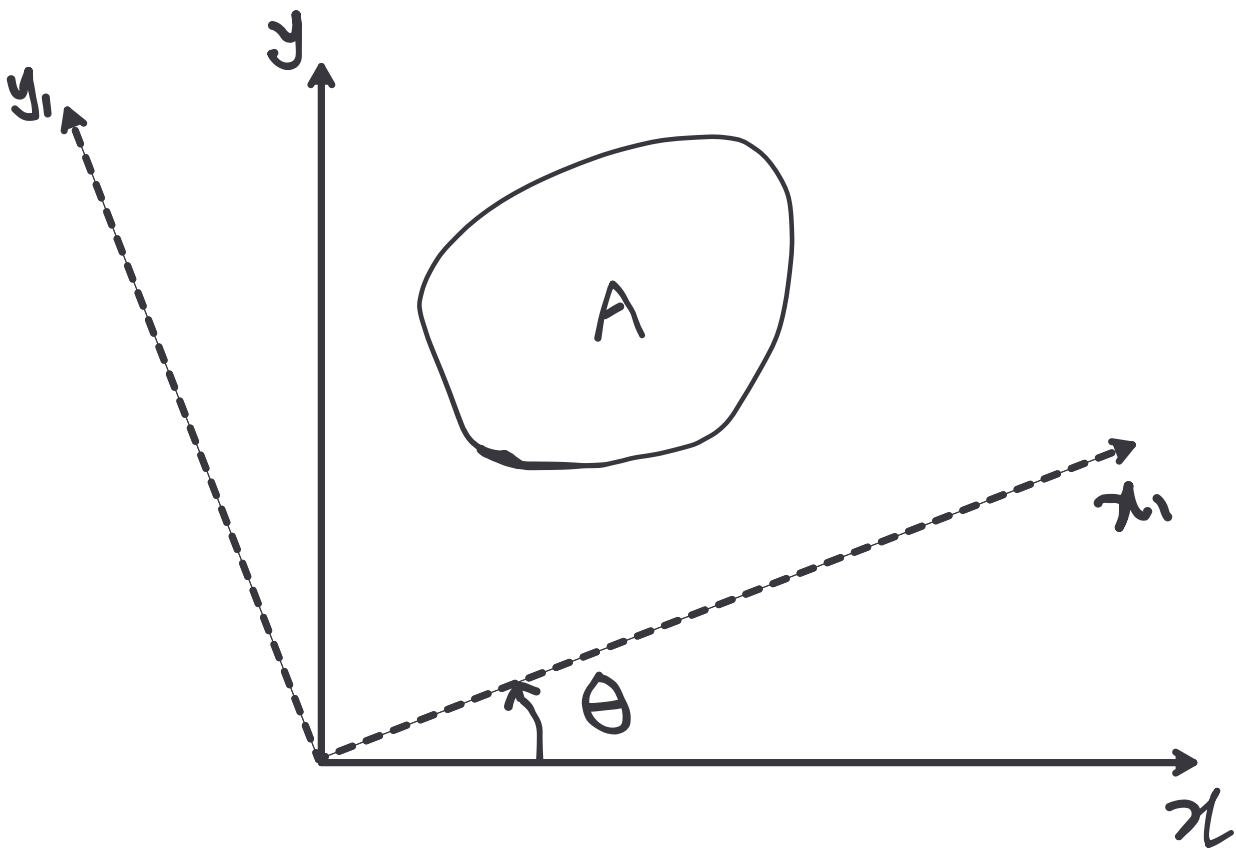
If  $I_{xx}$  is at maximum,  $I_{yy}$  will be at minimum.

## Transformation Law

The 2 sets of axes must share the origin.

### Note

Don't have to memorize this. Will be given on exams, if required.



$$I_{x_1x_1} = \frac{I_{xx} + I_{yy}}{2} + \left( \frac{I_{xx} - I_{yy}}{2} \right) \cos 2\theta - I_{xy} \sin 2\theta$$

$$I_{y_1y_1} = \frac{I_{xx} + I_{yy}}{2} - \left( \frac{I_{xx} - I_{yy}}{2} \right) \cos 2\theta + I_{xy} \sin 2\theta$$

$$I_{x_1y_1} = \left( \frac{I_{xx} - I_{yy}}{2} \right) \sin 2\theta + I_{xy} \cos 2\theta$$

## Principal Axes

The product of moment of area is zero about principal axes.

$$I_{xy} = 0$$

There will be 2 directions of principal axes which are perpendicular to each other.

Any axis of symmetry is a principal axis.

## Principal second moments of area

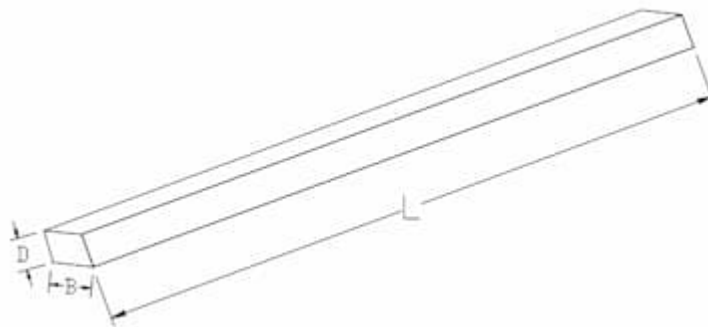
Second moments about the principal axes.

About principal axes second moments of area will be at minimum and maximum.

## Centroidal principal axes

Principal axes through the centroid.

## Beams

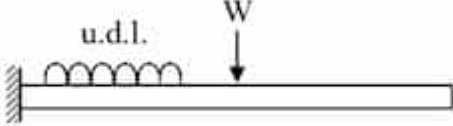
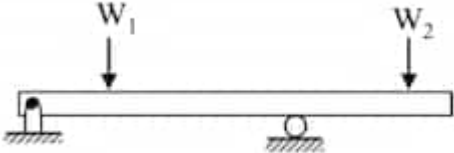
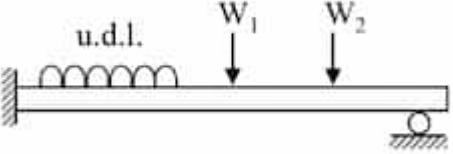
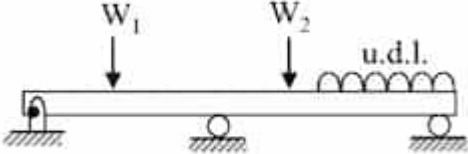
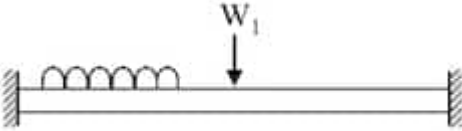


- long (  $L \gg B, D$  )
- axis of the beam is straight
- constant cross-section throughout its length

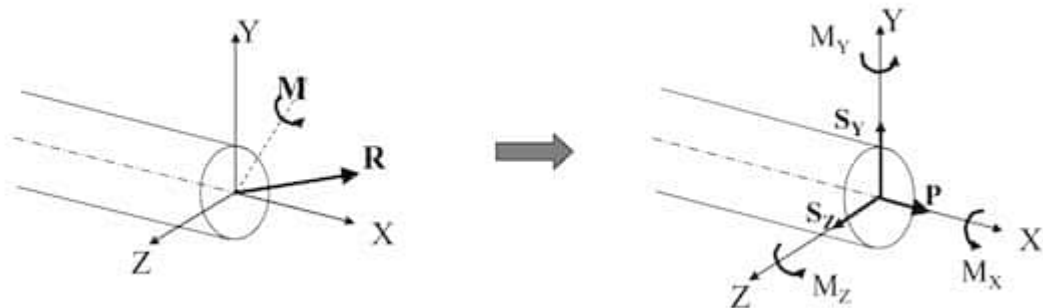
## Classified by supporting conditions

First 3 are the mandatory ones.

Type	Image
Simply supported beam	A 2D diagram of a horizontal beam. The left end is supported by a pin support, and the right end is supported by a roller support. Two downward-pointing arrows, labeled $W_1$ and $W_2$ , represent point loads applied to the beam.

Type	Image
Cantilevered beam	
Overhanging beam	
Propped cantilevered beam	
Continuous beam	
Fixed beam	

## At a section



- $P$  - Normal force / Axial force
- $S_y, S_z$  - Shear forces along  $y$  and  $z$  axis
- $M_x$  - Twisting moment / Torque
- $M_y, M_z$  - Bending moments about  $y$  and  $z$  axis

## Degress of freedom

A plane member have 3 degress of freedom. Any of the 3 can be restrained.

- Displacement in x-direction
- Displacement in y-direction
- Rotation about z-direction

## SFD & BMD

### Sign convention

- Bending moment
  - Hogging (curves upwards) is **(+)ve**
  - Sagging (curves downwards) is **(-)ve**
- Shear force
  - Clockwise shear is **(+)ve**.
  - Counterclockwise shear is **(-)ve**.

#### **Note**

A member is in pure bending when shear force is 0 and bending moment is a constant in a part of a beam.

## Distributed load, shear force & bending moment

When a beam is under a distributed load of  $w = f(x)$  per unit length.

$$\frac{dS}{dx} = -w$$

$$\frac{dM}{dx} = -S; \frac{d^2M}{dx^2} = w$$

## Principle of Superposition

A beam with multiple loads can be split into multiple systems each with a single load. Reason for doing so is the ease of calculations.

Values will be the sum of each system's corresponding value.

## Structural Elements

3 types

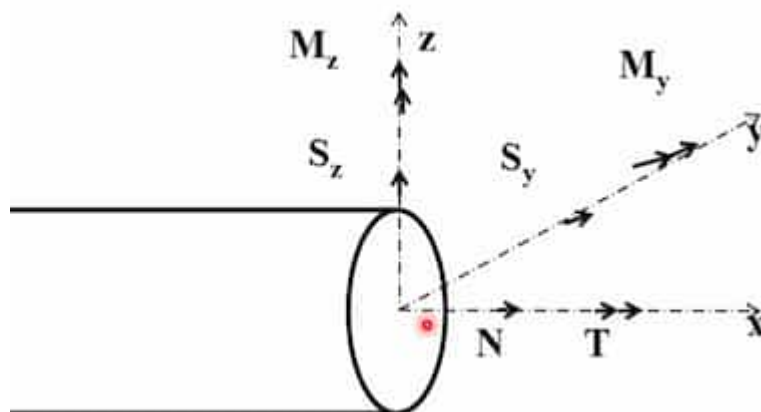
- Bars (1D)
- Plates and Shells (2D)
- Blocks (3D)

Bar elements are only focused for 1st semester.

## Pin Joint

Doesn't exert a moment. Free rotations are allowed. When only pin joints are used, bars will have only axial forces.

## Bars



Here



- $N$  - Axial force
- $S_x, S_y$  - Shear force
- $M_x$

## Types of bars

### Axially loaded

Generally in trusses, **pin joints** are considered.

- Predominant tension - Ties
- Predominant compression - Struts

### Flexural

- Predominant bending - beams

### Torsional

- Predominant torque - shafts

## Trusses

Also known as Ties-Struts model.

### Definition

An assembly of members used to span long distances. Idealized as

- Connected by **frictionless** [pin joints](#) at their ends
- Developing axial forces

### Types

2 types

- Plane truss (2D)
- Space truss (3D)

A truss requires 3 external reactions for equilibrium.

Predominant force is axial force.

## Advantages of truss

- High/length span
- Material efficiency

## Triangulation

- Start with a triangle (3 bars and 3 joints)
- Add 2 more bars and a joint repeatedly to create a truss

This type of truss is a **simple truss**.

## Simple (Closed) Truss

When a truss is only made of bars and joints.

## Open Truss

When a truss is pinned directly to a foundation. It has 1 member & 2 free joints less than a closed truss.

## Stability of trusses

When a truss is:

- unstable: it's called a mechanism
- stable: it's called a structure

## Stable truss

When the shape cannot be altered, the structure is **internally stable**.

## Stable & determinate (simply stiff)

**Determinate** means internal forces can be determined by laws of statics alone.

## Stable & indeterminate

**Indeterminate** means laws of statics alone are not sufficient to determine forces; relative stiffness of members will influence the solution (Indeterminate trusses are safer)

## Unstable truss

When the shape can be altered, the truss is called a mechanism.

## Necessary condition for a 2D simple (closed) truss

$m = 2j - 3$  is a necessary but not sufficient condition being simply stiff.

- $m < 2j - 3$  - truss is unstable
- $m = 2j - 3$  - truss is determinate if stable
- $m > 2j - 3$  - truss is indeterminate if stable

## Necessary condition for a 2D open truss

$m = 2j$  is a necessary but not sufficient condition being simply stiff.

- $m < 2j$  - truss is unstable
- $m = 2j$  - truss is determinate if stable
- $m > 2j$  - truss is indeterminate if stable

## Necessary condition for a 3D simple (closed) truss

$m = 3j - 6$  is a necessary but not sufficient condition for being simply stiff.

## Necessary condition for a 3D open truss

$m = 3j$  is a necessary but not sufficient condition for being simply stiff.

# Analysis of Trusses

Deviations from the ideal in real trusses.

- Loads are not applied only at joints; hence there is bending in members
- Joints are not perfectly pinned, so moments can be developed at joints

# Method of Joints

## Principle

Since the truss is in equilibrium, each pin joint must be in equilibrium.

### Note

2 equilibrium equations can be written at each joint – vertical & horizontal

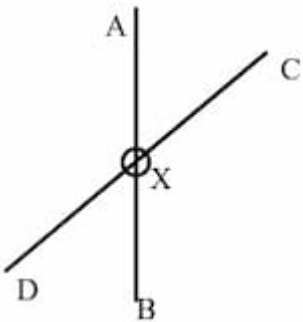
## Sign convention

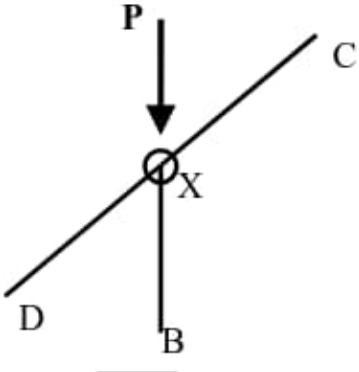
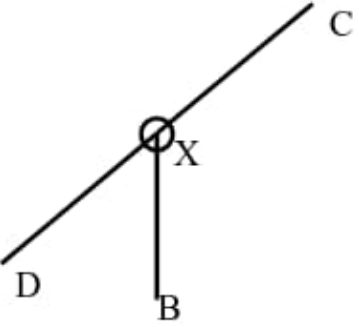
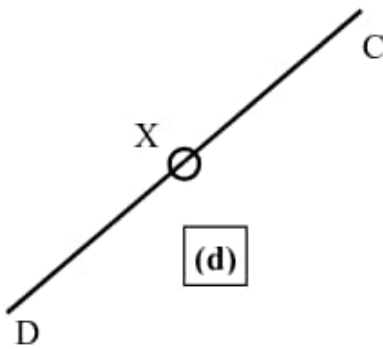
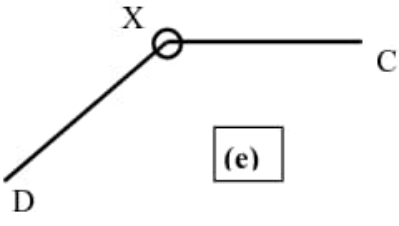
Forces acting on each joint is marked. Tensile forces are positive. Compressive forces are negative.

## Method

- Find external reactions using equilibrium using equilibrium equations for the entire truss.
- Start with a joint with only 2 unknown joint forces.
- Mark the tensile forces (consider all forces are tensile) acting on the join.
- Find the unknown forces at the selected joint, using 2 equilibrium equations for the joint.
- Go to all other joints in turn and find forces in all the members.

## Special cases

Case	Description
	$F_{AX} = F_{XB} \wedge F_{DX} = F_{XC}$

Case	Description
	$F_{AX} = F_{XB} \wedge F_{DX} = F_{XC}$
	$F_{XB} = 0 \wedge F_{DX} = F_{XC}$
	$F_{DX} = F_{XC}$
	$F_{DX} = F_{XC} = 0$

# Method of Sections

## Principle

Since the truss is in equilibrium, each part of it must be in equilibrium in stable equilibrium.

## Method

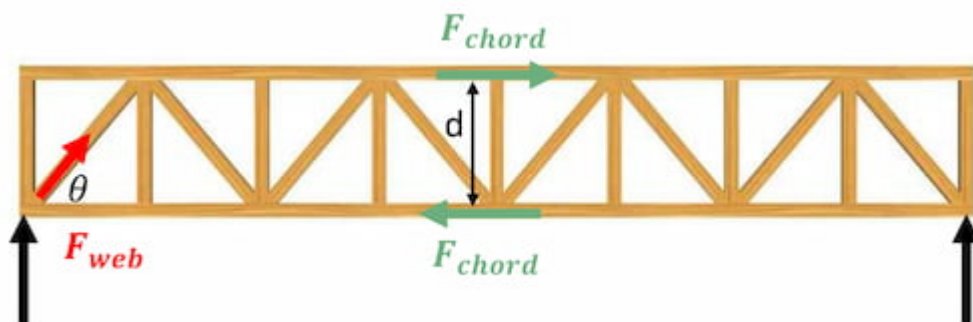
- Decide on which member's internal force must be calculated.
- Cut the truss through **3 or less** members including the target member.
- Internal forces in cut members become external forces. Can be represented as tensile forces.
- Use equilibrium equations for RHS or LHS section to find the internal forces.

## Beam Analogy (Approximate) method

We find the internal forces assuming the elongated truss is a beam.

### ① For a simply supported beam

- Maximum bending moment is at mid-span:  $M_{\max} = \frac{wL^2}{8}$
- Maximum shear force is at the supports:  $\frac{wL}{2}$



Here:

- Chord members - horizontal members
- Web members - diagonal members
- $d$  - truss depth

In the truss,

- Bending moment is carried by chord members.

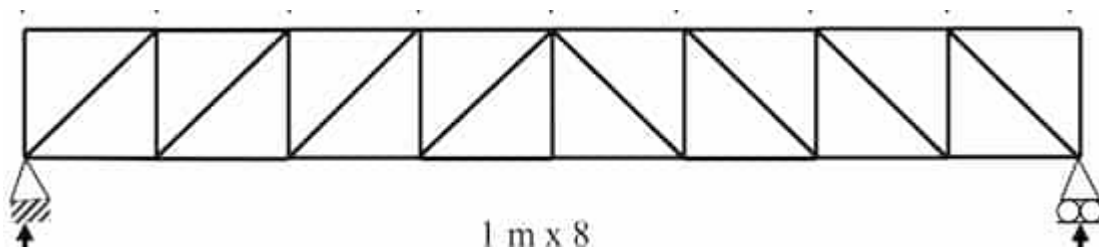
$$\text{Bending moment} = F_{\text{chord}} \times d$$

- Shear force is carried by vertical component of web member force

### ① Pratt & Howe type trusses

Above-mentioned truss is **Pratt type**. *(is that correct?)*

**Howe type truss** is a similar structure.



In pratt type truss, internal force in web members are tensile. In howe type trusses, internal force in web members are compressive. Usually **Pratt type** is cost-efficient. To make sure a howe type truss is strong enough like pratt type, web members must be shorter and thicker.

## Indeterminate Trusses

When a truss is indeterminate, one or more compatibility equations (related to truss deformation) must be used.