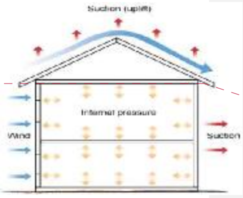
ENG1001 Engineering Design 1

Structure & Loads

Determine forces that act on structures causing it to deform, bend, and stretch
Forces push/pull on objects

Structures are loaded by:
> Dead loads – permanent fixed loads (all fixed attachments i.e partitions, tiles etc)
> Live loads – Temporary or transient loads (Removable loads i.e people, furniture)
Dead and live loads are vertical forces due to gravity (gravity gives weight to objects). Objects experience force of gravity directed to centre of earth
> Wind loads – Act in any direction, act inside and out, are a function of:
Building size and shape, height off ground, geographical location, surrounding obstructions



Commented [tr1]: Earthquake loads
Earth pressure loads (basement walls)
Liquid loads (bridge piers)
Thermal loads

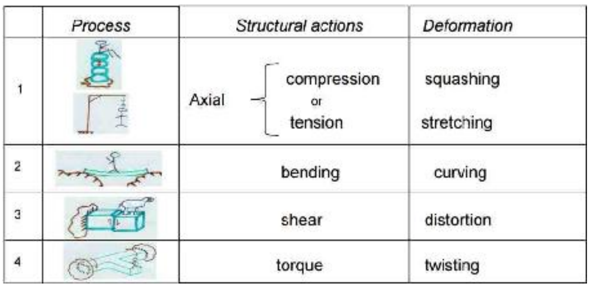
Commented [tr2]:
Force (or weight) = mass*gravity
Units: N (newtons) = $kg*m/s^2$

Commented [tr3]: More streamlined the shape, the less the force

- Load Path
  Route along which applied loads are transferred to support (ground)
  Vary as function of structure (bird on roof, weight on roof sheet to purlins to truss to ground)

- Load transfer
  Process of load transfer involves structural actions

Commented [tr4]: Moments cause bending, curving
Torque causes twisting



	Process	Structural actions	Deformation
1		Axial – compression or tension	squashing / stretching
2		bending	curving
3		shear	distortion
4		torque	twisting

One face squashes, other stretches

Structural Forms	Structural Actions	Load transfer
Arches (domes)	Compression	Axial compression – Vertical loads are turned into radial compression forces which are then reacted by the abutments
Beams (slabs)	Bending & shear	Horizontal member supporting vertical loads; materials that transfer both tensile and compressive stresses (timber, steel) Beams transfer load by bending
Cables (membranes)	Tension	Axial tensions
Trusses (space frame)	Tension or compression	Axial tension & compression Truss transfer load by members being in either tension or compression Triangulated structures (efficient for large spans; top/bottom chords, diagonals and verticles)

- Calculating loads dead (self weight) and live loads

  Water = 1000kg/m^3 (10kN/m^3)

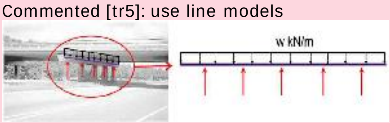
  Concrete = 2400 kg/m^3 (24kN/m^3)

  Steel = 7850 kg/m^3 (78.5kN/m^3)

Self-Weight (kN) = W_{total}(kN) = Volume * density

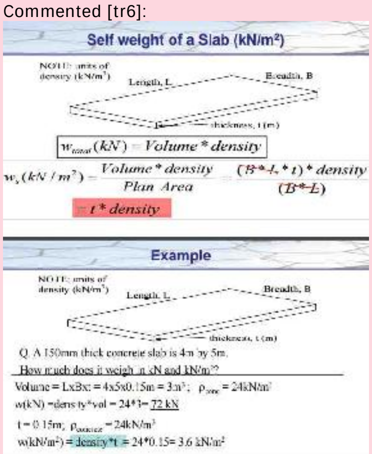
Self-Weight (kN/m) = W(kN/m) = A_x * density

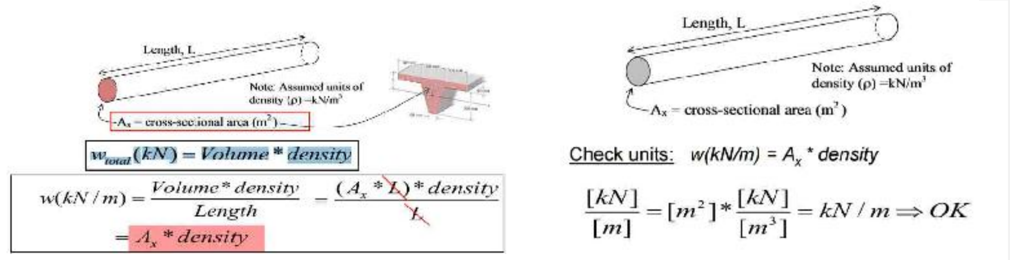
Commented [tr5]: use line models

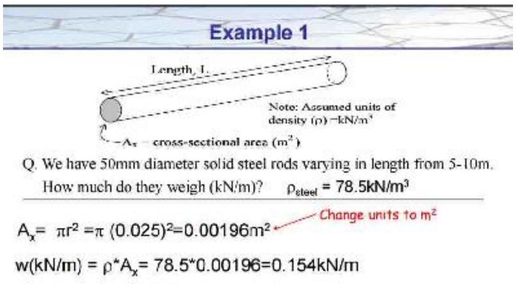


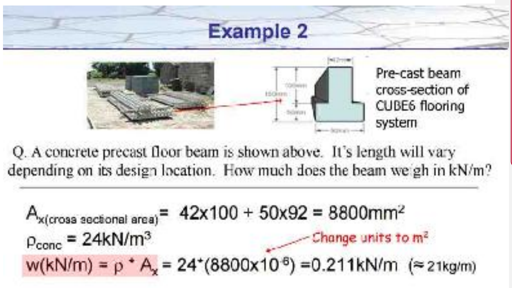
- Self weight of a member

Commented [tr6]:



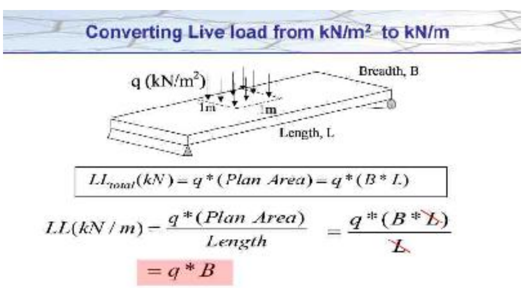


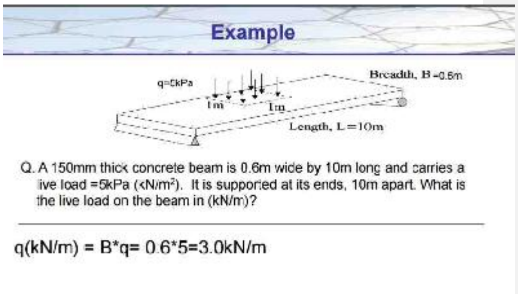




- Calculating Live loads

kPa = kN/m^2 e.g. 3kPa = 3x100kg people standing In every m^2





- Converting units

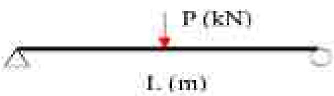
E.g. Water = 1000kg/m^3 (10kN/m^3)

Show in g/cm^3

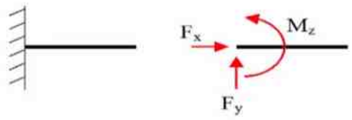
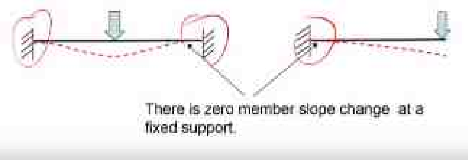
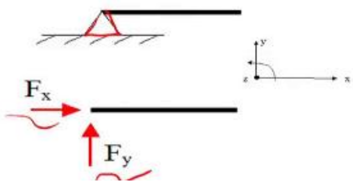
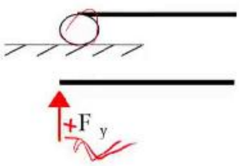
1000g = 1kg 100cm = 1m

$\Rightarrow 1000 \frac{kg}{m^3} = 1000 \frac{(1000g)}{(100cm)^3} = \frac{10^6}{10^6} \frac{g}{cm^3} = 1 g/cm^3$

Calculating Reactions

Idealised Loads		
Type of load	Simple Structural Model	
Point Loads		Single arrow at concentrated force
Uniformly Distributed (line) Loads		Load per m length of beam (kN/m) In 3D: area load (kN/m^2) kPa acting on plan area (
Applied Loads/moment		Result of two applied forces not being in line Moment=Force*d (Nm)

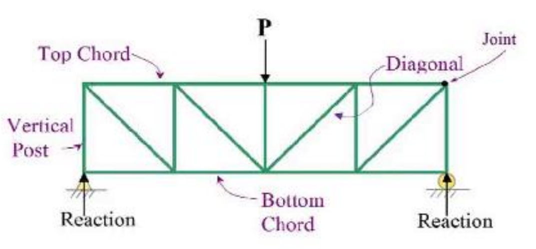
Commented [tr9]: Common units of Load
kN – concentrated/point load
kN/m – line load
kN/m² – area load (stress)
kNm – applied moment load

Idealised Supports		
Type of support	Simple Support Model	Deflected shape
Fixed support	 Fixed support provides reactions to prevent translation (forces) & rotation. Force and moment reactions occur	A member cannot translate or rotate at a fixed support 
Simple/Pin support	 Member cannot translate at support, but can rotate. Only force reactions occur	As long as <u>some</u> rotation is possible, the support is considered a pin/simple support 
Roller support	 Structure is free to move in one direction & rotate. Support provides one force reaction only to prevent translation in one direction.	Single force reaction is ± restraint. Weight of the structure prevents upwards movement. Lateral movement and rotation allowed i.e through rubberised bearing pads which shear laterally allowing lateral movements while supporting vertical loads w/ minimal compression (need to freely allow for thermal expansion)

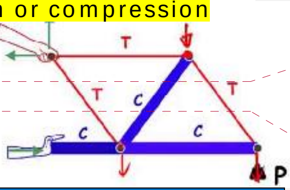
Trusses

- **How does a Truss work?**

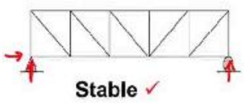
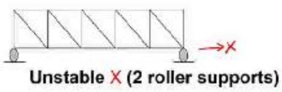
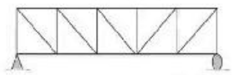
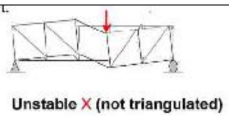
Remember structures carry loads in four ways via structural actions
> Axial compression or tension (stretching/shortening)
> Bending (curving)
> Shear (distortion)
> Torque (twisting)

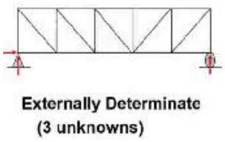
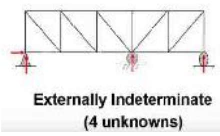
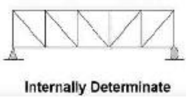
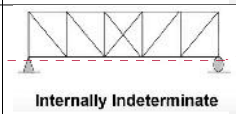


Individual members in a truss experience either axial tension or compression
Here, two mathematical assumptions are being made:
1) Trusses are loaded and supported only at joints
2) All joints in a truss are pin joints



- **Stability & Determinacy of Trusses**

External & Internal Stability of Trusses		
Convention	Stable Model	Unstable Model
Externally Stable Supports provide adequate rotational & translational restraint	 3 restraints ensure no translation in x and y direction and rotation	 No horizontal restraint
Internally Stable Arrangement of members can carry the applied loads through to support	 Fully triangulated ∴ stable	 Not fully triangulated, assume pin joints if one applied vertical load we see that movement

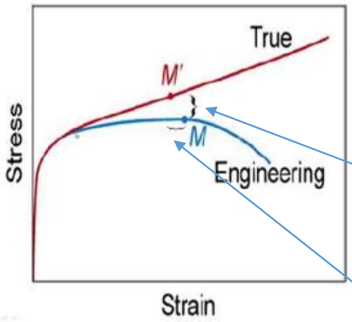
External & Internal Determinacy of Trusses			
Externally Determinate Supports provide just enough restraint i.e. reactions calculator using equilib.		Externally Indeterminate Supports provide extra restraint	
Internally Determinate Member forces can be determined using equilib.		Internally Indeterminate Truss has extra members, so equilib doesn't provide enough eq^{ns}	

Commented [tr12]: Applied loads at stringers, load transfers through stringer to secondary beam member and then appears on truss at joint location

Commented [tr13]: In practice truss joints are usually semi-rigid, if loaded at joints; moments & shear forces are small compared to internal axial forces ∴ simplifying assumption of pin joints is acceptable

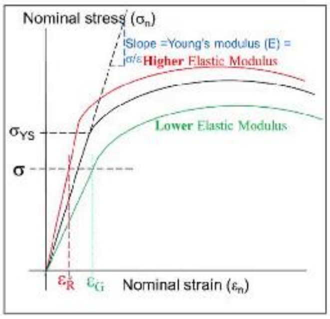
Commented [tr14]: Indeterminate trusses have more than one load path

- Measuring mechanical properties of materials



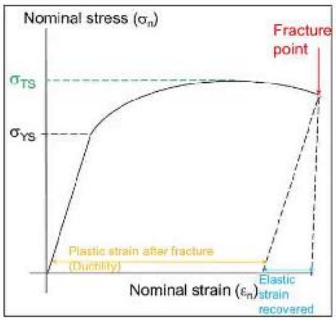
Blue = Nominal (engineering stress)
Red = true stress
Volume is constant, $L_0A_0 = LA$
>> $A = (L_0A_0/L)$
∴ True stress, $\sigma_t = F/A = F/(L_0A_0 / L)$
$= (FL / L_0A_0) = (F/A_0)*(L/L_0)$
$= \sigma_n ((L0 + \Delta L / L_0)$
$\sigma_t = \sigma_n(1+\varepsilon_n) > \sigma_n$
Earlier we found that:
$\varepsilon_t = \ln(1+\varepsilon_n) < \varepsilon_n$
Actual (true) stress keeps ↑ until final failure

- What properties are we interested in



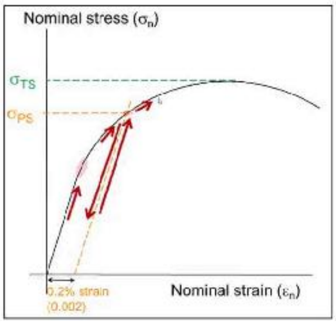
σYS = Yield stress (Yield strength)
Once plastically deformed, dimensions changed permanently
± = E£ (Hookes Law; valid for the linear Elastic region)
E (= σ/ε) – Young's Modulus (Elastic modulus)

If we stress two materials to same point, higher modulus material will elongate a certain amount, lower modulus material at the same stress will elongate more



σTS = Tensile strength (Ultimate Tensile Strength – UTS); Occurs at peak

Measuring a specimen after its broken, it doesn't have same strain, it has a smaller strain. Elastic strain has been recovered (as its fully recoverable) which we get back after fracture, where then left w/ plastic strain after fracture (ductility)
∴ Elongation at point of fracture = Ductility + Elastic strain



σPS = Proof Stress (offset yield strength) (σ0.2% strain)

E.g.
If we took sample to 0.2% strain then release and re-apply the load, we go past initial yield strength and it stays linear (↑ elastic portion of material; yield strength ↑, and once we get past this new yield strength we will plastically deform).

Commented [tr23]: Criteria for failure

Commented [tr24]: We can determine Young's modulus (E) by initial slope; E = σ/ε

This impacts stiffness of material; important in deflection limit design, want material to withstand certain force and only deflect certain amount

Commented [tr25]: Ductility only looks at plastic strain, we recover some strain from elastic component

Commented [tr26]: This is called work hardening; we strengthen material by plastically deforming it

- <u>Buckling</u>
  Members under axial compression are usually weaker than that under axial tensions because of buckling (which equates to a member failing)

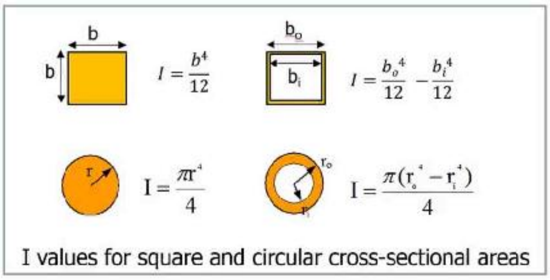
  Load at which member buckles or fails is defined by Euler buckling formula

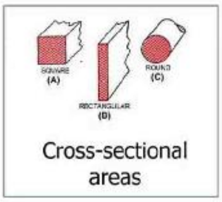
Euler Buckling Load $\boxed{P_e = \frac{\pi^2 EI}{(L_e)^2}}$

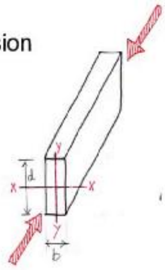
E=Young's modulus
I = weakest 2nd moment of area or moment of inertia
L_e = Effective length

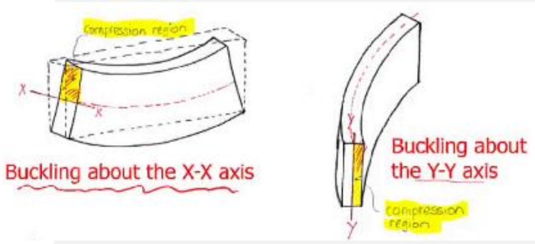
<u>Second moment of area, I</u>
Describes bending/buckling stiffness of a cross-section

sion









A section has 2 possible axes which it might buckle (x and y axis, 90º apart)
Buckle axes divides region in compression from region in tension
>>A section will always buckle about its least stiff (weaker) axis

- <u>Eulers Buckling</u>

$$\boxed{P_e = \frac{\pi^2 EI}{(L_e)^2}}$$

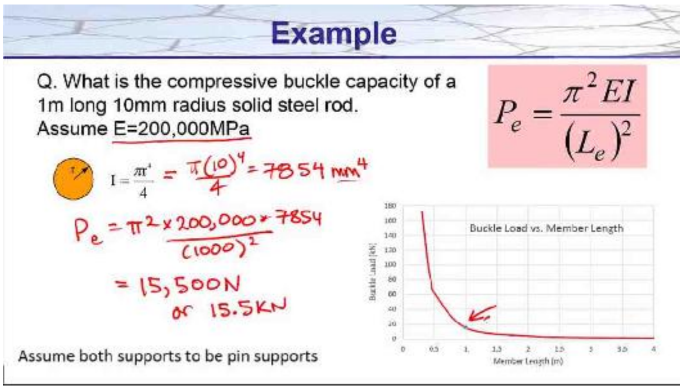
E, I and pi are constant ∴

$$P_e \propto \frac{1}{(L_e)^2}$$

Commented [tr32]: UNITS:
Use N, mm and MPa (N/mm²)

$$[N] = \frac{[N/mm^2][mm^4]}{[mm^2]}$$

E.g.



Kinetics

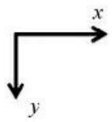
How forces influence acceleration

- ## Newtons Laws of Motion
  1. A particle at rest or moving in a straight line w/ constant velocity, will remain in this state provided the particle is not subjected to an unbalanced force
  2. A particle acted upon by an unbalanced force (F) experiences an acceleration (a) that has the same direction as the force and a magnitude that is directly proportional to the force
     $\sum F = m * a$
  3. Mutual forces of actions and reaction between two particles are =, opposite and collinear

- ## FBDs and Dynamics

  FBD shows all forces acting on body

  1. Define coordinate system
  2. Draw in forces you want to include



- ## Forces to Consider

  Common forces you'd expect to encounter

  It's vital we include all relevant forces acting on all masses in our system

  Gravity [mg]

  $F = m*g$ at sea level

  $g = 10$ m/s^2

  Normal Force [F_n]

  Force between two objects contacting

  Normal force between surface of mass and surface its resting on

  Always outward from surface

  Friction

  Acts in opposite direction to movement

  $F = u * F_n$

  u = coefficient of friction (material dependant)

  F_n = normal force

  Elastic forces

  $F = k*x$

  k = spring coefficient

  x = displacement (direction of displacement is important)

  Damping

  When you move through a fluid it provides damping

  Damping acts against direction of motion; linear damping is modelled by:

  $F = c*v$

  c = damping coefficient

  v = velocity (damping is dependent on velocity)

Particle Rotation

When a body rotates about a fixed axis it experiences two accelerations:

Radial acceleration – proportional to angular velocity

accelerating towards centre

Tangential acceleration – proportional to the angular acceleration

accelerating in direction of motion

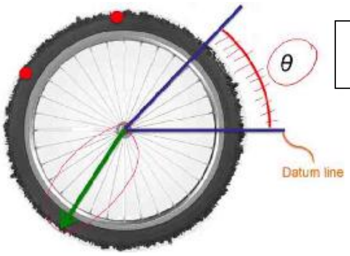
- Fundamental definitions

Set up rotation coordinate system: CCW = positive

Angular Position:

SI units: radians

$$\theta = \frac{\text{Arc Length}}{\text{Radius}}$$



Red = arc length
Green = Radius

Angular Displacement:

*Can be vectors

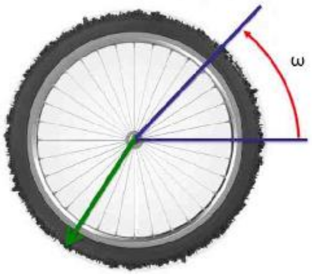
$$\Delta\theta = \theta_2 - \theta_1$$

Angular Velocity:

SI units: radians/second

$$\omega_{ave} = \frac{\Delta\theta}{\Delta t} = \frac{(\theta_2 - \theta_1)}{(t_2 - t_1)}$$

$$\omega = \frac{d\theta}{dt}$$



Angular Acceleration:

SI units: radians/second^2

$$\alpha_{ave} = \frac{\Delta\omega}{\Delta t} = \frac{(\omega_2 - \omega_1)}{(t_2 - t_1)}$$

$$\alpha = \frac{d\omega}{dt}$$