Solid Mechanics Sessional (MES 451)

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References

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6. https://www.youtube.com/watch?v=aAmHTiaX5dU

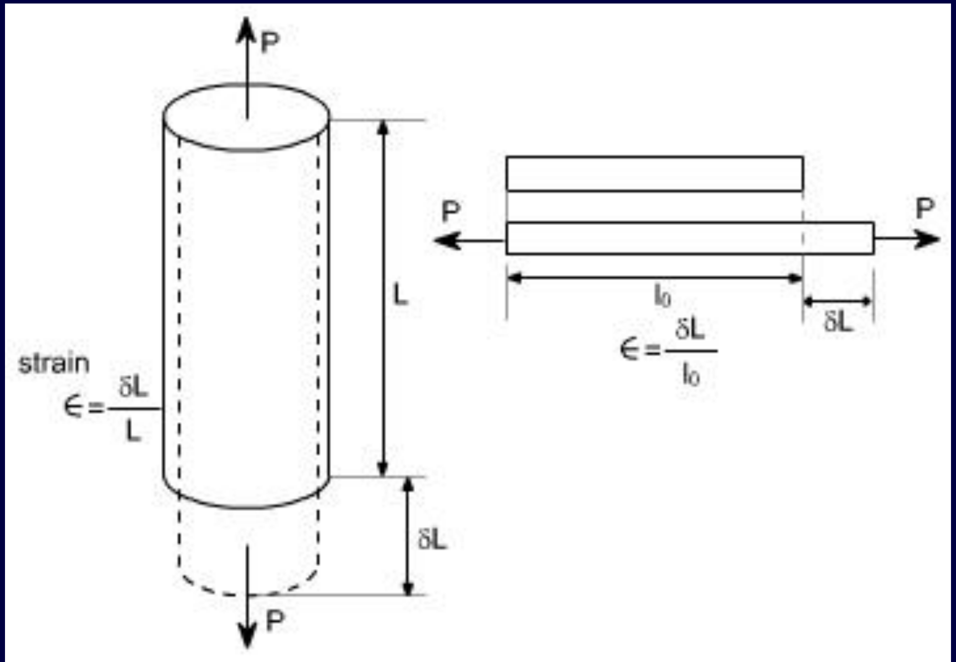
Syllabus

- Mohr’s Circle on strain Rosette- Graphical Solution.
- Mohr’s Circle on Moment of Inertia - Graphical Solution.
- Mechanical testing of Engineering Materials.
- Experiments on the principles of strength of materials.
- Instrumentation for measurement of deflection under loading.

Concept of Strains

Linear strain or normal strain or the longitudinal strain:

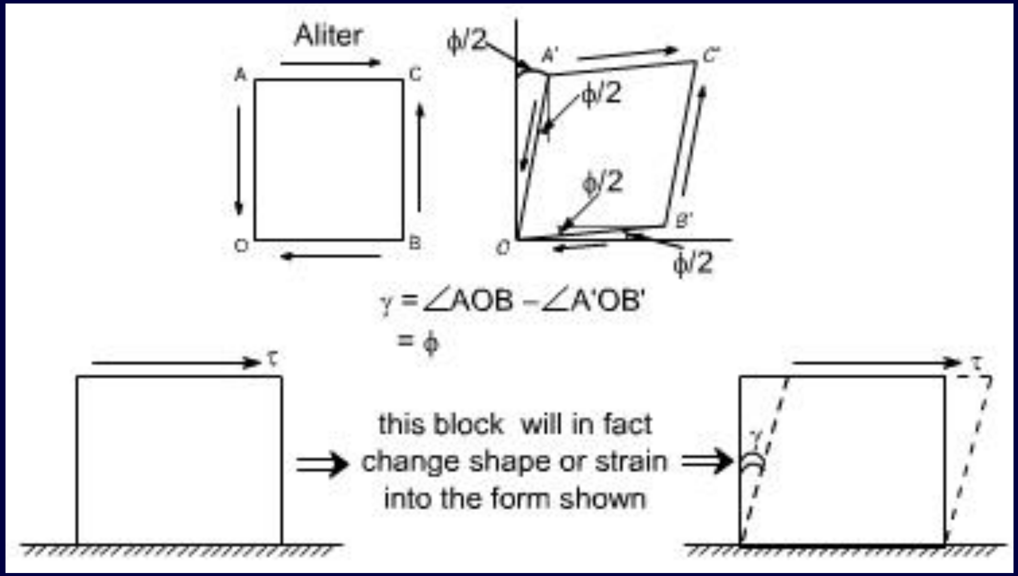
$$\text{strain}(\varepsilon) = \frac{\text{change in length}}{\text{orginal length}} = \frac{\delta L}{L}$$



Sign convention for strain: Tensile strains are positive whereas compressive strains are negative.

- The tangent of the angle through which two adjacent sides rotate relative to their initial position is termed shear strain. In many cases the angle is very small and the angle it self is used, (in radians), instead of tangent, so that

$$\gamma = \angle AOB - \angle A'OB' = \phi$$



Hook's Law: A material is said to be elastic if it returns to its original, unloaded dimensions when load is removed.

$$\boxed{\frac{\text{stress}}{\text{strain}} = \text{constant}}$$

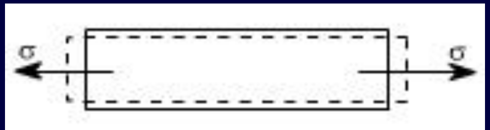
This constant is given by the symbol E and is termed as the modulus of elasticity or Young's modulus of elasticity

$$E = \frac{\text{strain}}{\text{stress}} = \frac{\sigma}{\epsilon}$$
$$= \frac{P/A}{\delta L/L}$$
$$\boxed{E = \frac{PL}{A\delta L}}$$

Poisson's ratio: If a bar is subjected to a longitudinal stress there will be a strain in this direction equal to σ/E . There will also be a strain in all directions at right angles to σ. The final shape being shown by the dotted lines.

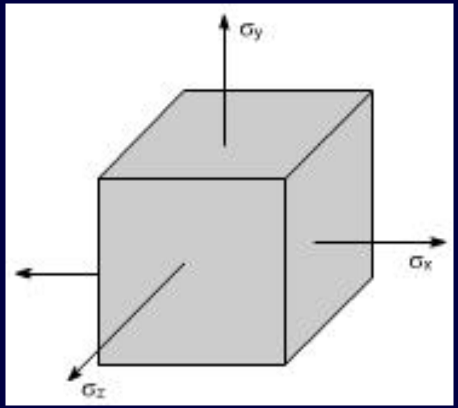
It has been observed that for an elastic materials, the lateral strain is proportional to the longitudinal strain. The ratio of the lateral strain to longitudinal strain is known as the poison's ratio .

Poison's ratio (μ) = -lateral strain /longitudinal strain



For most engineering materials the value of m his between 0.25 and 0.33.

Three dimensional state of strain: Consider an element subjected to three mutually perpendicular tensile stresses σ_x , σ_y and σ_z as shown in the figure below.



$$\varepsilon_x = \frac{\sigma_x}{E} - \mu\frac{\sigma_y}{E} - \mu\frac{\sigma_z}{E}$$

$$\varepsilon_y = \frac{\sigma_y}{E} - \mu\frac{\sigma_x}{E} - \mu\frac{\sigma_z}{E}$$

$$\varepsilon_z = \frac{\sigma_z}{E} - \mu\frac{\sigma_x}{E} - \mu\frac{\sigma_y}{E}$$

The negative sign indicating that if σ_y and σ_z are positive i.e. tensile, these they tend to reduce the strain in x direction.

Principal strains in terms of stress: In the absence of shear stresses on the faces of the elements let us say that σ_x, σ_y and σ_z are in fact the principal stress. The resulting strain in the three directions would be the principal strains.

i.e. We will have the following

$$\varepsilon_1 = \frac{1}{E}\left[\sigma_1 - \mu\sigma_2 - \mu\sigma_3\right]$$

$$\varepsilon_2 = \frac{1}{E}\left[\sigma_2 - \mu\sigma_1 - \mu\sigma_3\right]$$

$$\varepsilon_3 = \frac{1}{E}\left[\sigma_3 - \mu\sigma_1 - \mu\sigma_2\right]$$

Two dimensional state of strain: stress in third direction is zero (σ_z =0 or σ_3 = 0). Although the strains will be there in this direction due to the stresses σ_1 , σ_2

$$\varepsilon_1 = \frac{1}{E}\left[\sigma_1 - \mu\sigma_2\right]$$

$$\varepsilon_2 = \frac{1}{E}\left[\sigma_2 - \mu\sigma_1\right]$$

$$\varepsilon_3 = \frac{1}{E}\left[-\mu\sigma_1 - \mu\sigma_2\right]$$

Hence a strain can exist without a stress in that direction

i.e if $\sigma_3 = 0$; $\epsilon_3 = \frac{1}{E}\left[-\mu\sigma_1 - \mu\sigma_2\right]$

Also

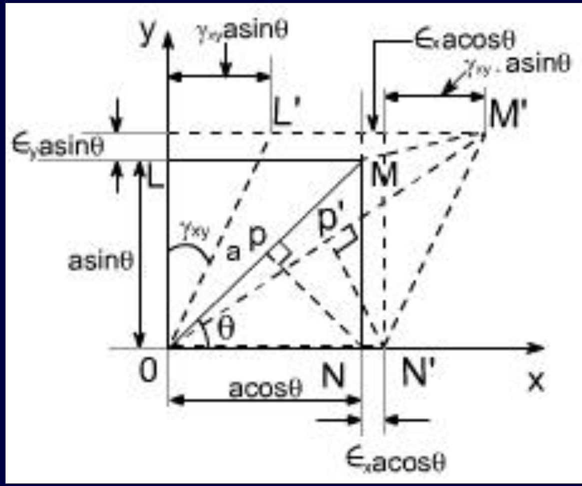
$\epsilon_1 . E = \sigma_1 - \mu\sigma_2$

$\epsilon_2 . E = \sigma_2 - \mu\sigma_1$

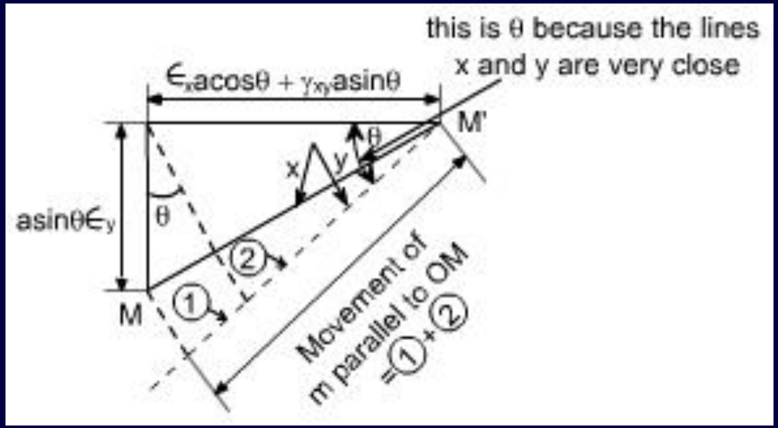
so the solution of above two equations yields

$$\boxed{\begin{aligned}\sigma_1 &= \frac{E}{(1-\mu^2)}\left[\epsilon_1 + \mu\epsilon_2\right] \\ \sigma_2 &= \frac{E}{(1-\mu^2)}\left[\epsilon_2 + \mu\epsilon_1\right]\end{aligned}}$$

Strains on an oblique plane ---- (a) Linear strain



If M moves to M', then the movement of M parallel to x axis is $\epsilon_x a\cos\theta + \gamma_{xy}\sin\theta$ and the movement parallel to the y axis is $\epsilon_y a\sin\theta$



Thus the movement of M parallel to OM , which since the strains are small is practically coincident with MM'. and this would be the summation of portions (1) and (2) respectively and is equal to

$$= (\epsilon_y\ a\sin\theta)\sin\theta + (\epsilon_x\ a\cos\theta + \gamma_{xy}a\sin\theta)\cos\theta$$

$$= a\left[\epsilon_y\ \sin\theta.\sin\theta + \epsilon_x\ \cos\theta.\cos\theta + \gamma_{xy}\ \sin\theta.\cos\theta\right]$$

hence the strain along OM

$$= \frac{\text{extension}}{\text{original length}}$$

$$\epsilon_\theta = \epsilon_x\ \cos^2\theta + \gamma_{xy}\ \sin\theta.\cos\theta + \epsilon_y\ \sin^2\theta$$

$$\epsilon_\theta = \epsilon_x\ \cos^2\theta + \epsilon_y\ \sin^2\theta + \gamma_{xy}\ \sin\theta.\cos\theta$$

Recalling $\cos^2\theta - \sin^2\theta = \cos 2\theta$

or $2\cos^2\theta - 1 = \cos 2\theta$

$$\cos^2\theta = \left[\frac{1+\cos 2\theta}{2}\right]$$

$$\sin^2\theta = \left[\frac{1-\sin 2\theta}{2}\right]$$

hence

$$\epsilon_\theta = \epsilon_x\left[\frac{1+\cos 2\theta}{2}\right] + \epsilon_y\left[\frac{1-\sin 2\theta}{2}\right] + \gamma_{xy}a\sin\theta.\cos\theta$$

$$= \frac{\epsilon_x + \epsilon_y}{2} + \frac{\epsilon_x - \epsilon_y}{2}\cos 2\theta + \frac{1}{2}\gamma_{xy}\ \sin 2\theta$$

$$\epsilon_\theta = \left\{\frac{\epsilon_x + \epsilon_y}{2}\right\} + \left\{\frac{\epsilon_x - \epsilon_y}{2}\right\}\cos 2\theta + \frac{1}{2}\gamma_{xy}\ \sin 2\theta$$

Shear strain: shear stain in the direction OM = displacement of point P at the foot of the perpendicular from N to OM; and the following expression can be derived as

$$\frac{1}{2}\gamma_\theta = -\left[\frac{1}{2}(\epsilon_x - \epsilon_y)\sin 2\theta - \frac{1}{2}\gamma_{xy}\cos 2\theta\right]$$

In the above expression ½ is there so as to keep the consistency with the stress relations. Further -ve sign in the expression occurs so as to keep the consistency of sign convention, because OM' moves clockwise with respect to OM it is considered to be negative strain.

The other relevant expressions are the following :

Principal planes :

$$\tan 2\theta_p = \frac{\gamma_{xy}}{\epsilon_x - \epsilon_y}$$

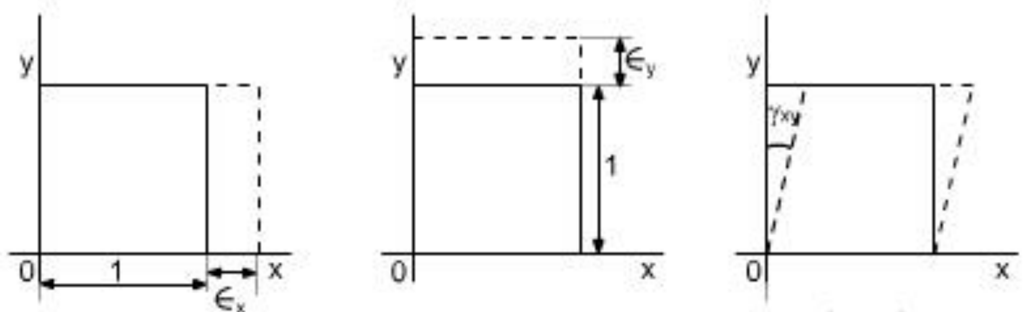
Principal strains :

$$\epsilon_{1,2} = \frac{\epsilon_x + \epsilon_y}{2} \pm \sqrt{\left(\frac{\epsilon_x - \epsilon_y}{2}\right)^2 + \left(\frac{\gamma_{xy}}{2}\right)^2}$$

Maximum shear strains :

$$\frac{\gamma_{max}}{2} = \pm\sqrt{\left(\frac{\epsilon_x - \epsilon_y}{2}\right)^2 + \left(\frac{\gamma_{xy}}{2}\right)^2}$$

<u>Plane Strain</u>: In xy plane three strain components may exist as can be seen from the following figures:



(Fig.1) (Fig.2) (Fig.3)

Plane strain condition is defined only by the components , ϵ_y , γ_{xy}: $\epsilon_z = 0$; $\gamma_{xz} = 0$; $\gamma_{yz} = 0$

Plane stress is not the stress system associated with plane strain. The plane strain condition is associated with 3-D stress system and plane stress is associated with 3-D strain system.

Principal Strain and Mohr's Circle for Strain

$$\epsilon_\theta = \left\{\frac{\epsilon_x + \epsilon_y}{2}\right\} + \left\{\frac{\epsilon_x - \epsilon_y}{2}\right\}\cos 2\theta + \frac{1}{2}\gamma_{xy}\sin 2\theta \qquad (1)$$

$$\frac{1}{2}\gamma_\theta = -\left[\frac{1}{2}(\epsilon_x - \epsilon_y)\sin 2\theta - \frac{1}{2}\gamma_{xy}\cos 2\theta\right] \qquad (2)$$

Re writing the equation (1) as below :

$$\left[\epsilon_\theta - \left(\frac{\epsilon_x + \epsilon_y}{2}\right)\right] = \left\{\frac{\epsilon_x - \epsilon_y}{2}\right\}\cos 2\theta + \frac{1}{2}\gamma_{xy}\sin 2\theta \qquad (3)$$

squaring and adding equations (2) and (3)

$$\left[\epsilon_\theta - \left(\frac{\epsilon_x + \epsilon_y}{2}\right)\right]^2 + \left\{\frac{1}{2}\gamma_\theta\right\}^2 = \left[\left\{\frac{\epsilon_x - \epsilon_y}{2}\right\}\cos 2\theta + \frac{1}{2}\gamma_{xy}\sin 2\theta\right]^2 + \left[\frac{1}{2}(\epsilon_x - \epsilon_y)\sin 2\theta - \frac{1}{2}\gamma_{xy}\cos 2\theta\right]^2$$

$$\left[\epsilon_\theta - \left(\frac{\epsilon_x + \epsilon_y}{2}\right)\right]^2 + \left\{\frac{1}{2}\gamma_\theta\right\}^2 = \left(\frac{\epsilon_x + \epsilon_y}{2}\right)^2 + \frac{\gamma^2_{xy}}{4}$$

Now as we know that

$$\epsilon_{1,2} = \frac{\epsilon_x + \epsilon_y}{2} \pm \sqrt{\left(\frac{\epsilon_x - \epsilon_y}{2}\right)^2 + \left(\frac{\gamma_{xy}}{2}\right)^2}$$

$$\epsilon_1 + \epsilon_2 = \epsilon_x + \epsilon_y$$

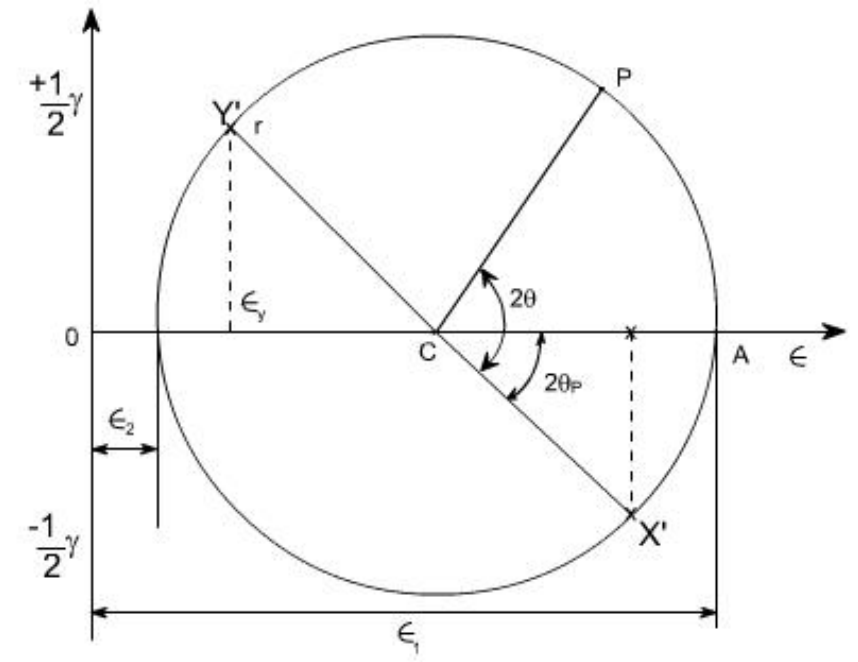
$$\left(\frac{\epsilon_1 - \epsilon_2}{2}\right)^2 = \left(\frac{\epsilon_x - \epsilon_y}{2}\right)^2 + \frac{\gamma^2_{xy}}{4}$$

Therefore the equation gets transformed to

$$\left[\epsilon_\theta - \left(\frac{\epsilon_1 + \epsilon_2}{2}\right)\right]^2 + \left[\frac{\gamma_\theta}{2}\right]^2 = \left(\frac{\epsilon_1 - \epsilon_2}{2}\right)^2 \qquad (4)$$

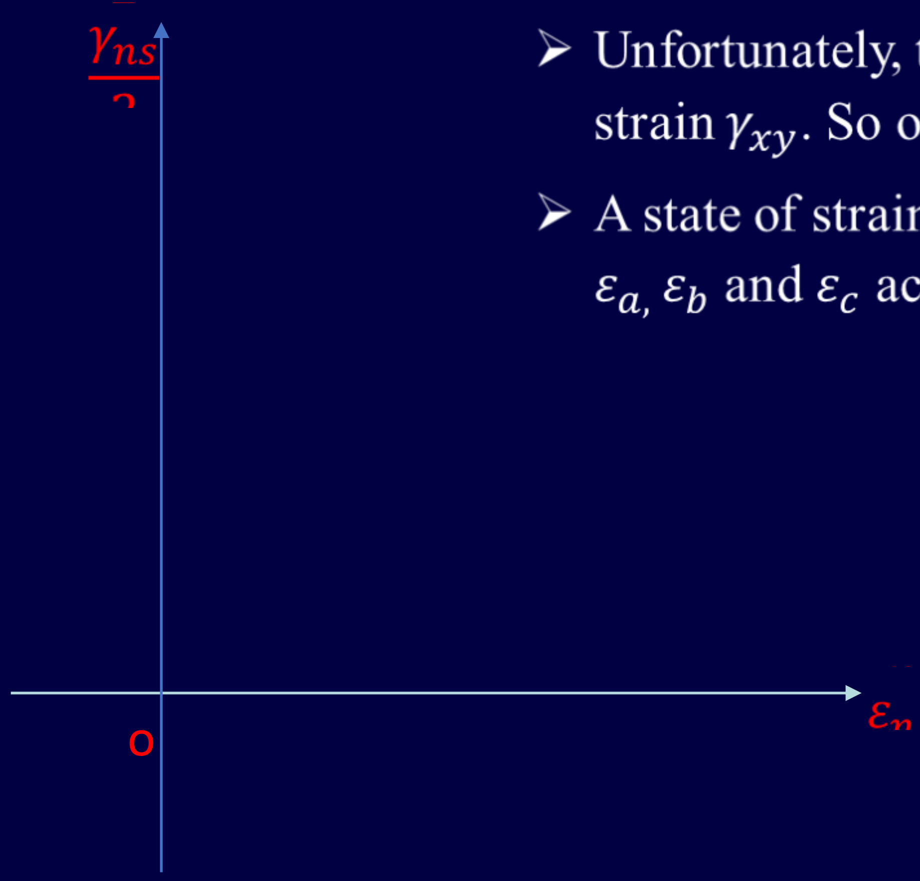
If we plot equation (4) we obtain a circle of radius $\left(\frac{\epsilon_1 - \epsilon_2}{2}\right)$ with center at $\left(\frac{\epsilon_1 + \epsilon_2}{2}, 0\right)$

For the strains on an oblique plane we have two equations which are identical in form with the equation defining the direct stress on any inclined plane θ .

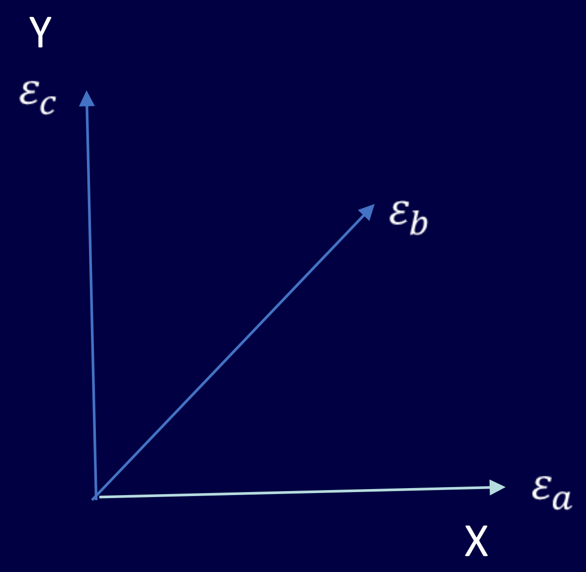


MOHR'S CIRCLE ON STRAIN ROSETTE- GRAPHICAL SOLUTION.

- A single strain gage oriented in the direction of a uniaxial stress is sufficient for computing the stress.
- For biaxial stress, we are in need of three strains, ε_x , ε_y and γ_{xy}.
- Unfortunately, there is no equipment that gives a direct measurement of the shearing strain γ_{xy}. So other methods are needed.
- A state of strain is uniquely determined by the measurement of three linear strains $\varepsilon_{a,}$ ε_b and ε_c acting in three arbitrary direction θ_a, θ_b and θ_c at the same point.



- As a matter of practical convenience, the linear strains are obtained by using either of two combinations of three resistance strain gages
   1. Three gages set with their axes at 45° with each other,
   2. Three gages set with their axes at 60° with each other
- These combinations are known as <u>strain rosettes.</u>
- The three gages are electrically insulated from each other and are used to determine the strain at the surface of the structure to which they are attached.

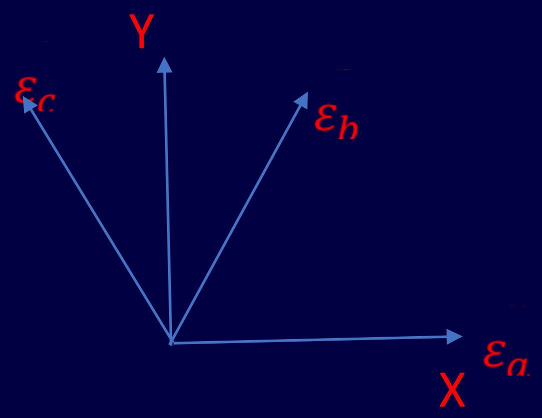


<u>The 45° or Rectangular Strain Rosette</u>

$\theta_a = 0°,\ \theta_b = 45°,\ \theta_c = 90°,\ \ \varepsilon_x = \varepsilon_a,\ \varepsilon_y = \varepsilon_c,\ \gamma_{xy}/2 = (\varepsilon_a + \varepsilon_c)/2 - \varepsilon_b$

This defines a state of strain from which the strain circle and the stress circle may be drawn.

The 60° or Equiangular Strain Rosette



$\theta_a = 0°, \theta_b = 60°, \theta_c = 120°,$

$\varepsilon_x = \varepsilon_a, \ \varepsilon_y = \frac{1}{3}(2\varepsilon_b + 2\varepsilon_c - \varepsilon_a), \ \frac{\gamma_{xy}}{2} = \frac{(\varepsilon_c - \varepsilon_b)}{\sqrt{3}}$

A strain circle is readily transformed into a stress circle by means of

$R_\sigma = R_\varepsilon \frac{E}{1+\mu}; \ OC_\sigma = OC_\varepsilon \frac{E}{1-\mu}$

PROBLEM 1: Determine principal stresses, maximum and minimum shear stresses and stress components on plane whose normal makes an angle 30° with x- direction.

$\varepsilon_x = -400 * 10^{-6}$, $\varepsilon_y = +200 * 10^{-6}$, $\gamma_{xy} = +800 * 10^{-6}$, E = 200 G Pa , $\mu = 0.30$

State of strain of x-plane is denoted by point A. A $(\varepsilon_x, \frac{\gamma_{xy}}{2})$, A $(-400 * 10^6 , 400 * 10^6)$,

State of strain of x-plane is denoted by point B. B $(\varepsilon_y, -\frac{\gamma_{xy}}{2})$, B $(200 * 10^6 , -400 * 10^6)$,

Mohr's Circle for Strain:

Scale 1 cm = $100 * 10^{-6}$

Measure OC of strain circle, OC =

Measure R of strain circle, R =

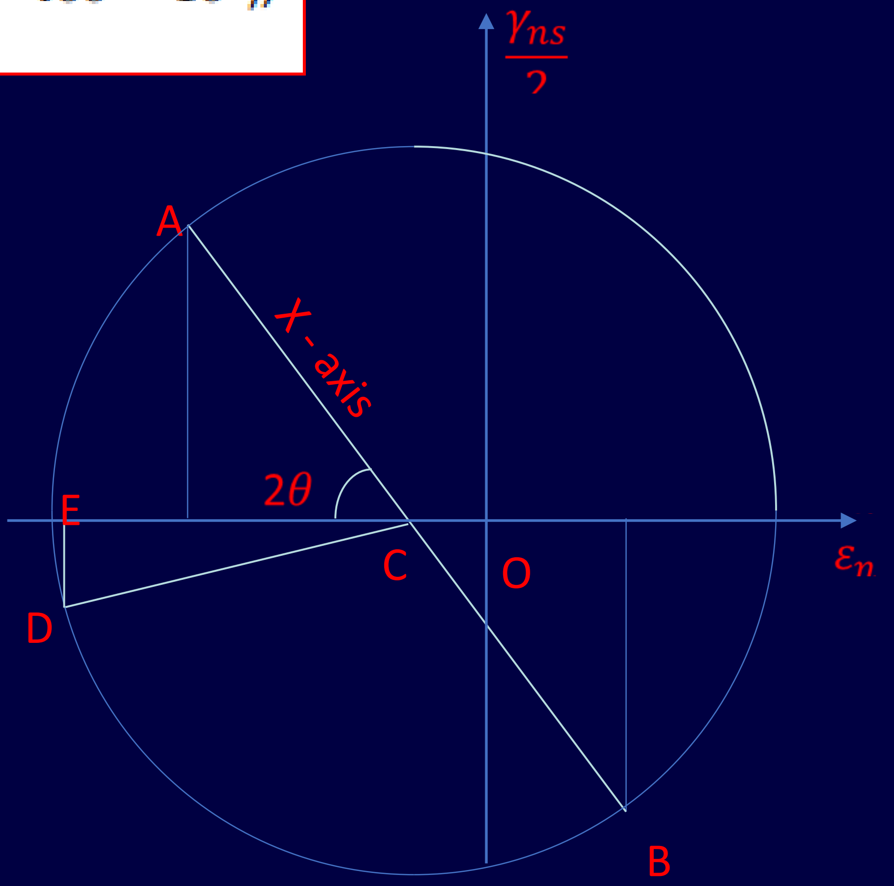
Maximum Principal Strain, ε_{max} = OC + R

Minimum Principal Strain, ε_{min} = OC - R

Maximum Shearing Strain, $\frac{\gamma_{max}}{2}$ = R

Minimum Shearing Strain, $\frac{\gamma_{min}}{2}$ = - R

Measure angle 2θ, 2θ = 53°



Strain components on plane whose normal makes an angle 30°

In the Mohr's Circle at an angle 60° anticlockwise we are getting point D on the Mohr's Circle.

Drop a perpendicular from D on ε_n axis DE

Co-ordinate of point D (OC + CE, ED)

Measure these lengths and multiply by scale to get normal and shearing strain components.

	Magnitude	**Direction with x-axis (anticlockwise)**
OC_ε		
R_ε		
ε_{max}		$\theta + 90°$
ε_{min}		θ
$\frac{\gamma_{max}}{2}$		$\theta + 135°$
$\frac{\gamma_{min}}{2}$		$\theta + 45°$
ε_n		30°
$\frac{\gamma_{ns}}{2}$		30°

Transformation of strain circle to a stress circle

$$R_\sigma = R_\varepsilon \frac{E}{1+\mu};\ OC_\sigma = OC_\varepsilon \frac{E}{1-\mu}$$

Calculate OC of stress circle, OC =

Calculate R of stress circle, R =

Maximum Principal Stress, σ_{max} = OC + R

Minimum Principal Stress, σ_{min} = OC - R

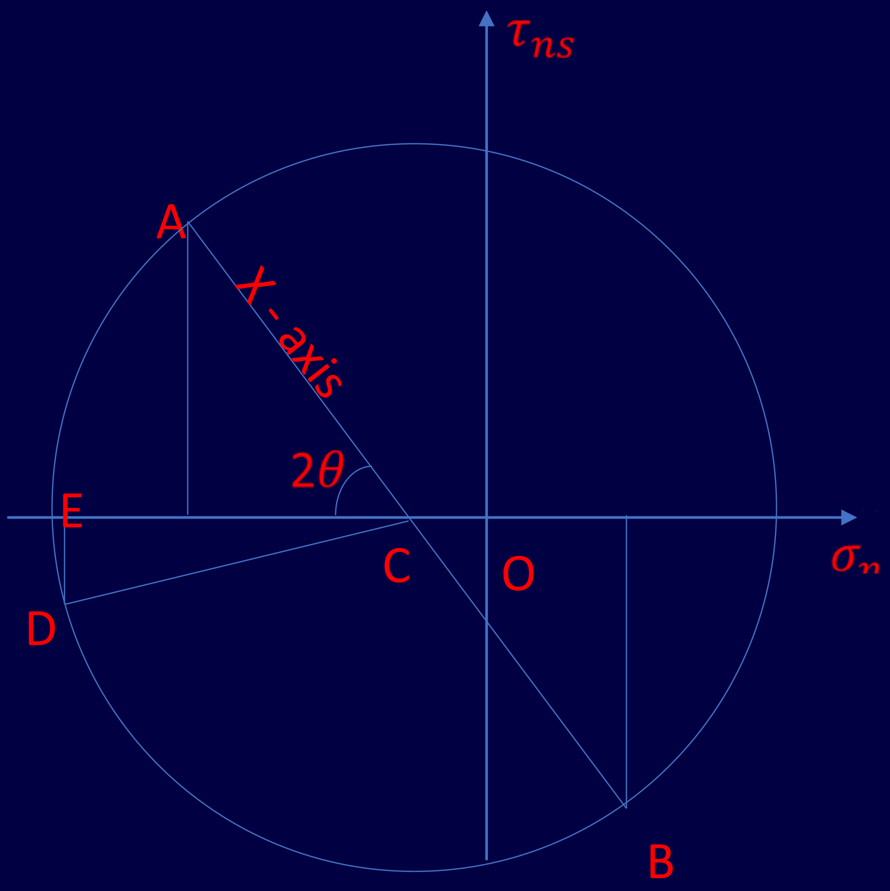
Maximum Shearing Stress, τ_{max}= R

Minimum Shearing Stress,τ_{min} = - R

Measure angle 2θ, 2θ = 53°

Mohr's Circle for Stress

Scale 1 cm =

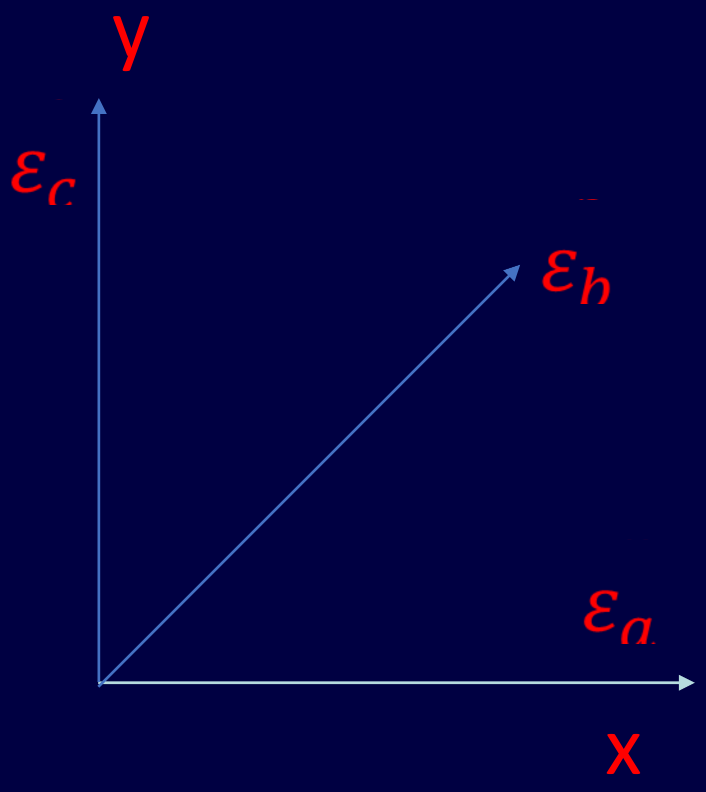


Write answers in tabular form as shown

	Magnitude	Direction with x-axis (anticlockwise)
OC_σ		
R_σ		
σ_{max}		θ + 90°
σ_{min}		θ
τ_{max}		θ + 135°
τ_{min}		$\theta + 45°$
σ_n		30°
τ_{ns}		30°

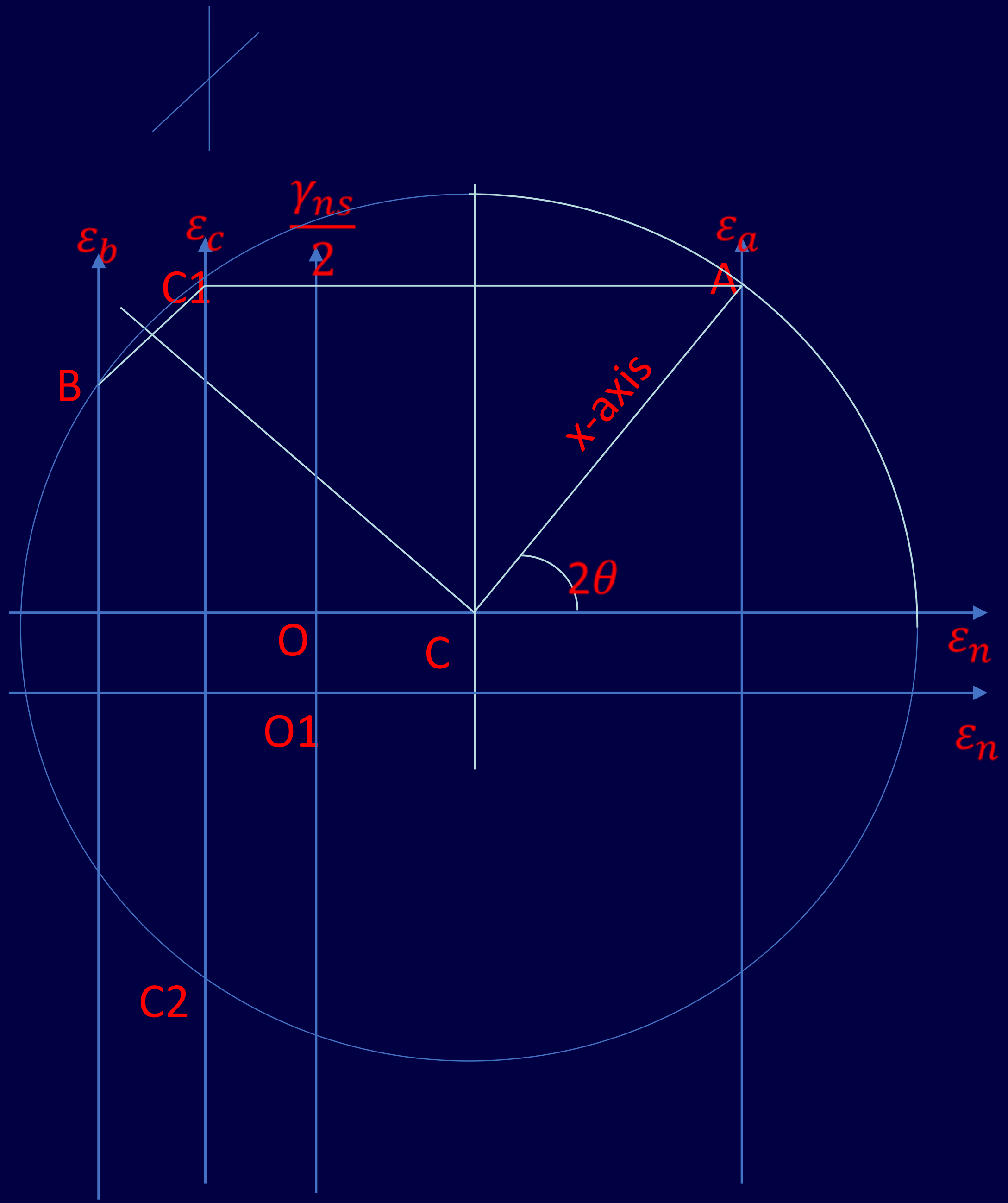
Determine principal stresses and their directions for the following strain rosettes:

a) 45° STRAIN ROSETTE: $\varepsilon_a = 400 * 10^{-6}$, $\varepsilon_b = -200 * 10^{-6}$, $\varepsilon_c = -100 * 10^{-6}$,
$E = 200$ G Pa , $\mu = 0.30$



We will draw Strain Circle by Graphical Method.

- Draw ε_n axis and $\frac{\gamma_{ns}}{2}$ axis as shown, o1 is the origin.
- Draw vertical lines for linear strains $\varepsilon_a = 400 * 10^{-6}$, $\varepsilon_b = -200 * 10^{-6}$ and $\varepsilon_c = -100 * 10^{-6}$
- Consider the middle strain within ε_a, ε_b, and ε_c.
- In this problem ε_c is the middle strain.
- Take a line element on this vertical line.
- In the strain rosette if you rotate ε_c 45° clockwise you will meet ε_b
- Rotate the line element 45° clockwise to meet ε_b line, you will get C1B line between ε_c and ε_b
- Rotate the line element 90° clockwise to meet ε_c line, you will get C1A line between ε_c and ε_a



Draw perpendicular bisector of C1B and C1A, meeting at point C, the centre of Mohr's circle.

Pass ε_n axis through C point as shown in the figure and rub the previous ε_n axis.

O is the new origin

BC = C1C = AC = R = Radius of Mohr's Circle.

With this radius draw a circle with C as centre passing through points A, B and C1.

Add A and C points. Radius AC represents x-axis.

Measure OC of strain circle, OC =

Measure R of strain circle, R =

Maximum Principal Strain, ε_{max} = OC + R

Minimum Principal Strain, ε_{min} = OC - R

Maximum Shearing Strain, $\frac{\gamma_{max}}{2}$ = R

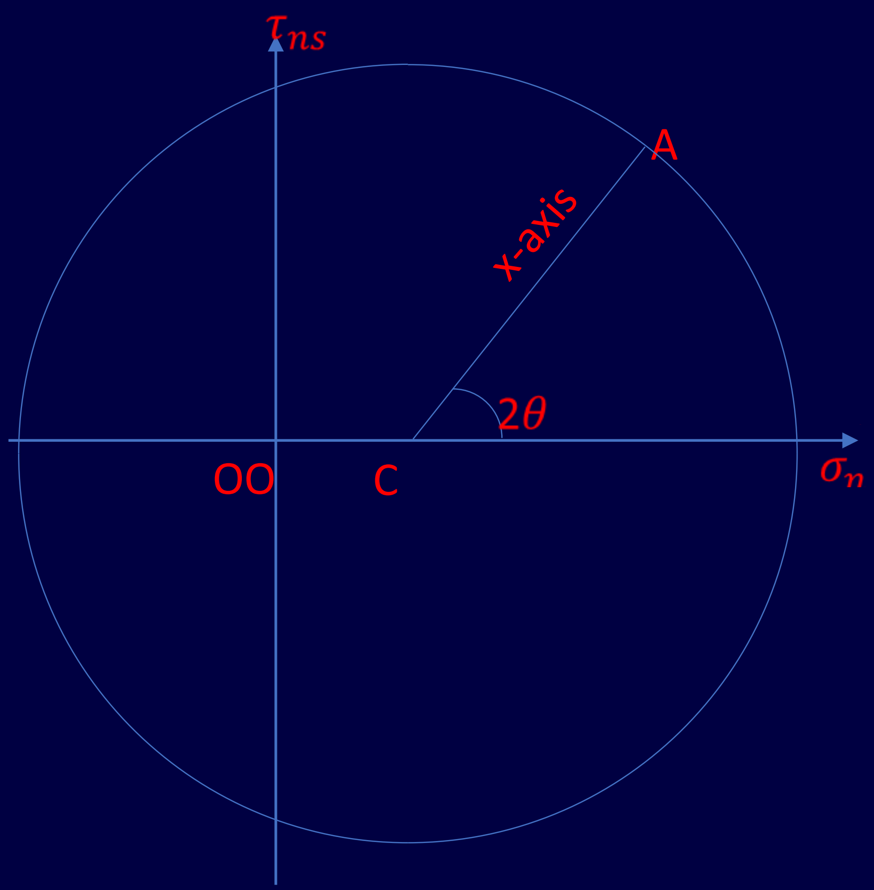
Minimum Shearing Strain, $\frac{\gamma_{min}}{2}$ = - R

Measure angle 2θ, 2θ =

	Magnitude	Direction with x-axis (anticlockwise)
OC_{ε}		
R_{ε}		
ε_{max}		$180°- \theta$
ε_{min}		$90° - \theta$
$\frac{\gamma_{max}}{2}$		$45° - \theta$
$\frac{\gamma_{min}}{2}$		$135° - \theta$

Transformation of strain circle to a stress circle

$$R_\sigma = R_\varepsilon \frac{E}{1+\mu};\ OC_\sigma = OC_\varepsilon \frac{E}{1-\mu}$$



Calculate OC of stress circle, OC =

Calculate R of stress circle, R =

Maximum Principal Stress, σ_{max} = OC + R

Minimum Principal Stress, σ_{min} = OC - R

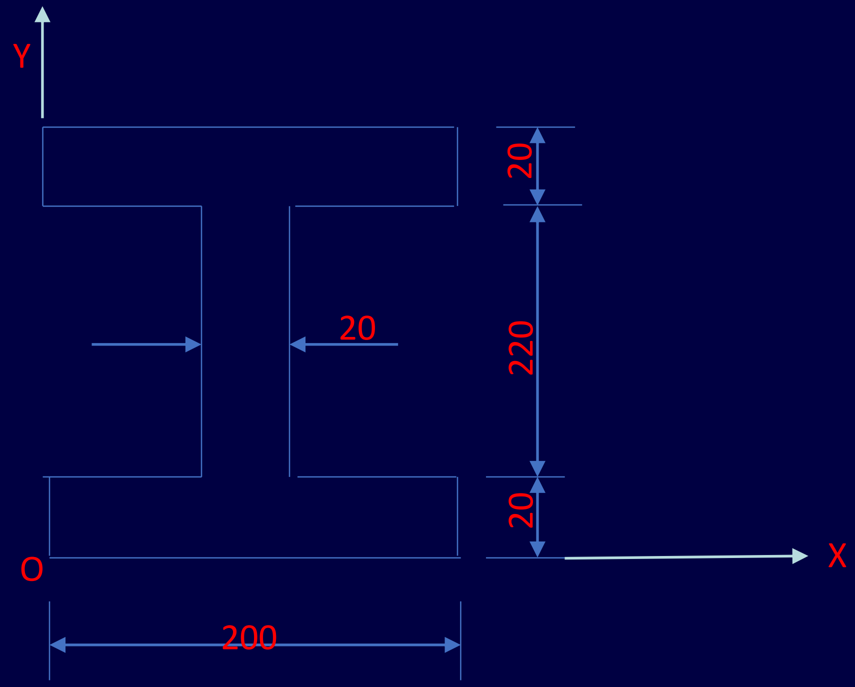
Maximum Shearing Stress, τ_{max}= R

Minimum Shearing Stress, τ_{min} = - R

Measure angle 2θ, 2θ =

	Magnitude	Direction with x-axis (anticlockwise)
OC_σ		
R_σ		
σ_{max}		180°- θ
σ_{min}		$90° - \theta$
τ_{max}		$45° - \theta$
τ_{min}		$135° - \theta$

Find out the principal moment of inertia about centroid and their orientation from centroidal axis for the following sections.



Take X and Y axes as shown in the figure. O is the origin

To get centre of gravity use formula

$$\bar{x} = \frac{\sum_{i=1}^{n} A_i x_i}{\sum_{i=1}^{n} A_i};\ \bar{y} = \frac{\sum_{i=1}^{n} A_i y_i}{\sum_{i=1}^{n} A_i}$$

$$\bar{x} = \frac{A_1x_1 + A_2x_2 + A_3x_3}{A_1 + A_2 + A_3}\quad \bar{y} = \frac{A_1y_1 + A_2y_2 + A_3y_3}{A_1 + A_2 + A_3}$$

TOP FLANGE

A_1 = 4000 mm^2 = 40 cm^2; x_1 = 100 mm = 10 cm; y_1 = 250 mm = 25 cm;

BOTTOM FLANGE

A_2 = 4000 mm^2 = 40 cm^2; x_2 = 100 mm = 10 cm; y_2 = 10 mm = 1 cm;

WEB

A_3 = 4400 mm^2 = 44 cm^2; x_3 = 100 mm = 10 cm; y_3 = 130 mm = 13 cm;

$$\bar{x} = \frac{A_1x_1 + A_2x_2 + A_3x_3}{A_1 + A_2 + A_3} = \frac{40*10+40*10+44*10}{40+40+44} = \frac{1240}{124} = 10 \text{ cm}$$

$$\bar{y} = \frac{A_1y_1 + A_2y_2 + A_3y_3}{A_1 + A_2 + A_3} = \frac{40*25+40*1+44*13}{40+40+44} = \frac{1612}{124} = 13 \text{ cm}$$

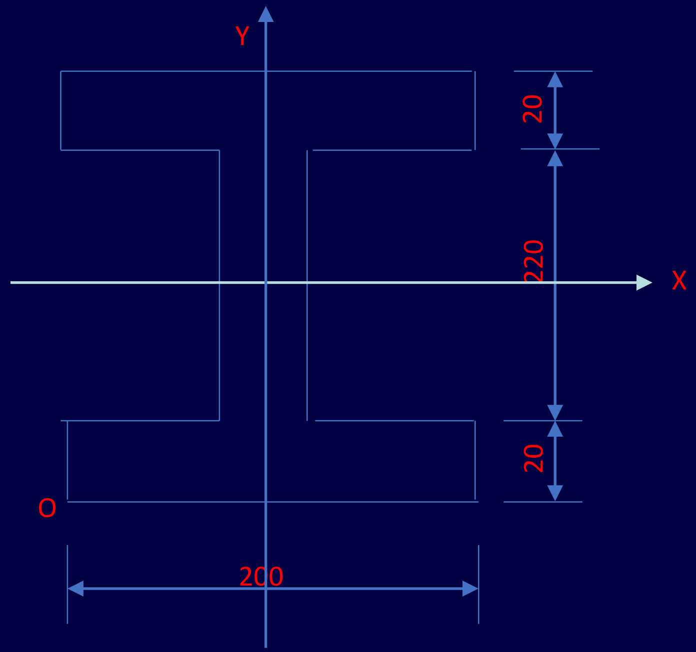
Calculate moment of inertia about x-axis, I_x, about y-axis, I_y and product of inertia P_{xy} .

$$I_x = \frac{1}{12}[\mathrm{b}\, h^3 \;-\; b_1 h_1^3] = \frac{1}{12}[20 * 26^3 \;-\; 18 \,*\, 22^3] = 13321\ cm^4$$

$$I_y = 2 * \frac{1}{12} b_3\, h_3{}^3 \;+\; \frac{1}{12} b_4 h_4^3 = 2 * \frac{1}{12}\; 2 * 20^3 \;+ \frac{1}{12}\; 22 \,*\, 2^3 = 2681\ cm^4$$

$$P_{xy} = 0$$

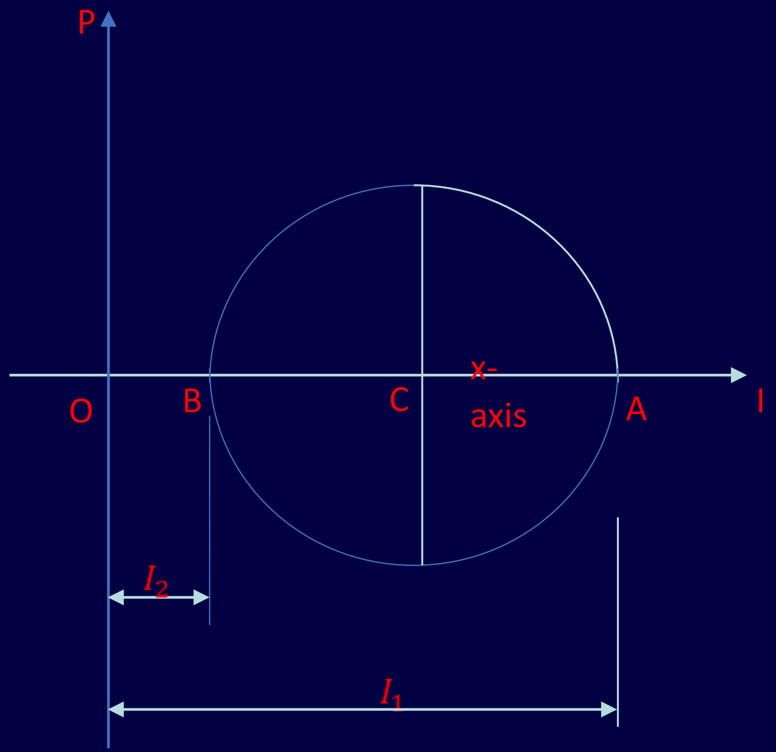
If an area has an axis of symmetry, this axis together with any axis perpendicular to it will form a set of axes for which the product of inertia is zero.



Mohr's Circle for moment of inertia

https://www.youtube.com/watch?v=XjKWXqCwX00

A (I_x, P_{xy}), B ($I_y, -P_{xy}$),



Scale : 1 cm =

Measure OC and radius of Mohr's Circle R

Maximum moment of inertia, $I_1 = \mathrm{OC} + \mathrm{R}$, $\theta = 0°$

Minimum moment of inertia, $I_2 = \mathrm{OC} - \mathrm{R}$, $\theta = 90°$

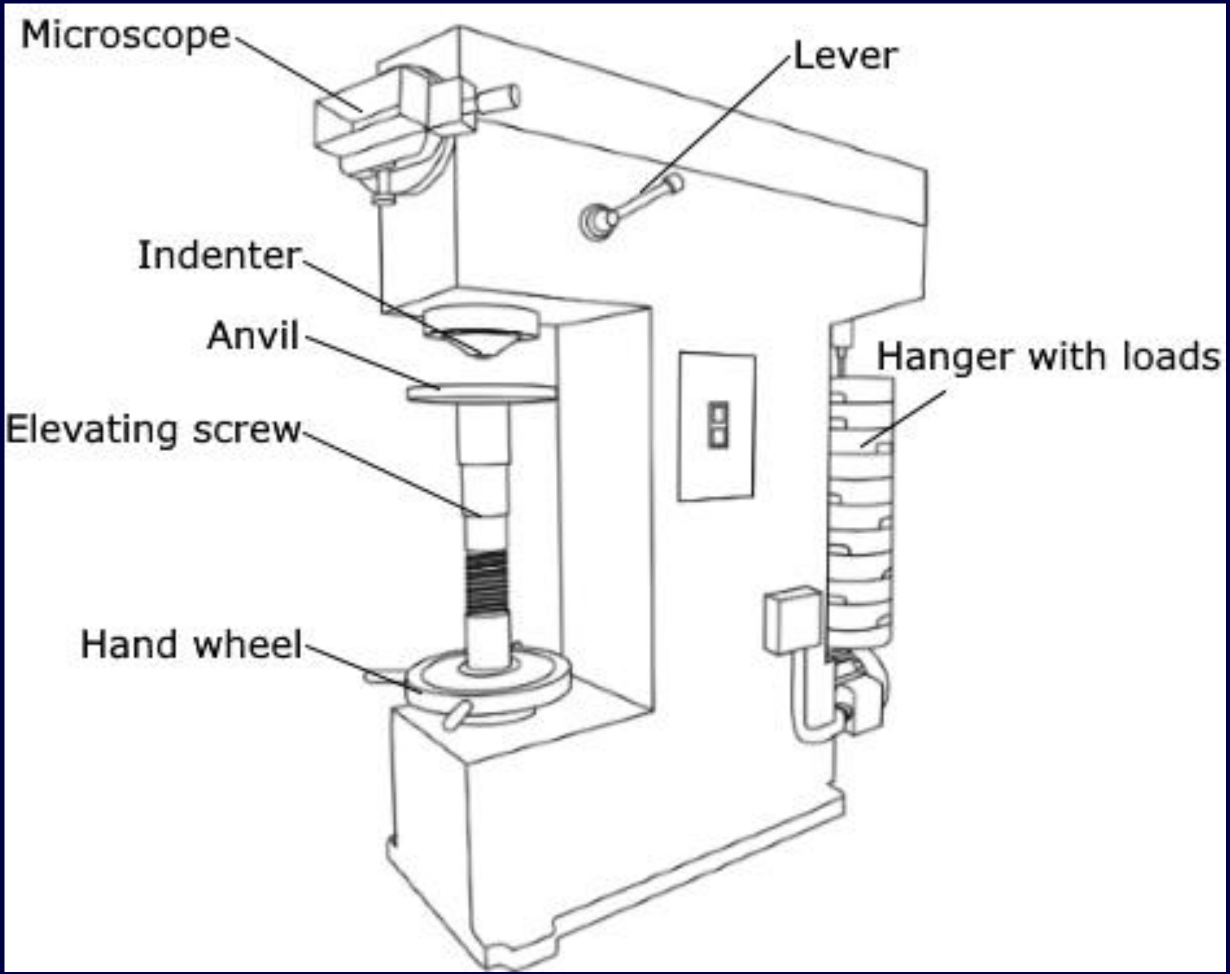
Maximum product of inertia, $P_1 = \mathrm{R}$, $\theta = 45°$

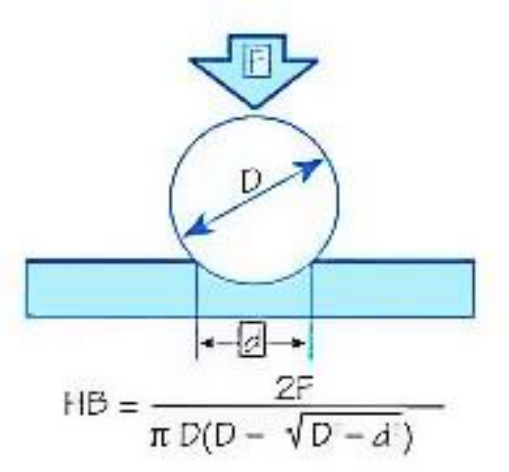
Minimum product of inertia, $P_2 = -\mathrm{R}$, $\theta = 135°$

Write the results in a tabular form

	cm^4	Direction from x-axis in the anticlockwise sense.
OC		
R		
I_1		
I_2		
P_1		
P_2		

Brinell Hardness Test





$$HBW = \frac{2P}{\pi D[D - \sqrt{(D^2 - d^2)}]}$$

$$HBW = 0.102 \times \frac{2F}{\pi D[D - \sqrt{(D^2 - d^2)}]}$$

Test Method Illustration

P = Load in Kg

D = Ball diameter (mm)

d = impression diameter (mm)

HBW = Brinell result (Kg/mm2)

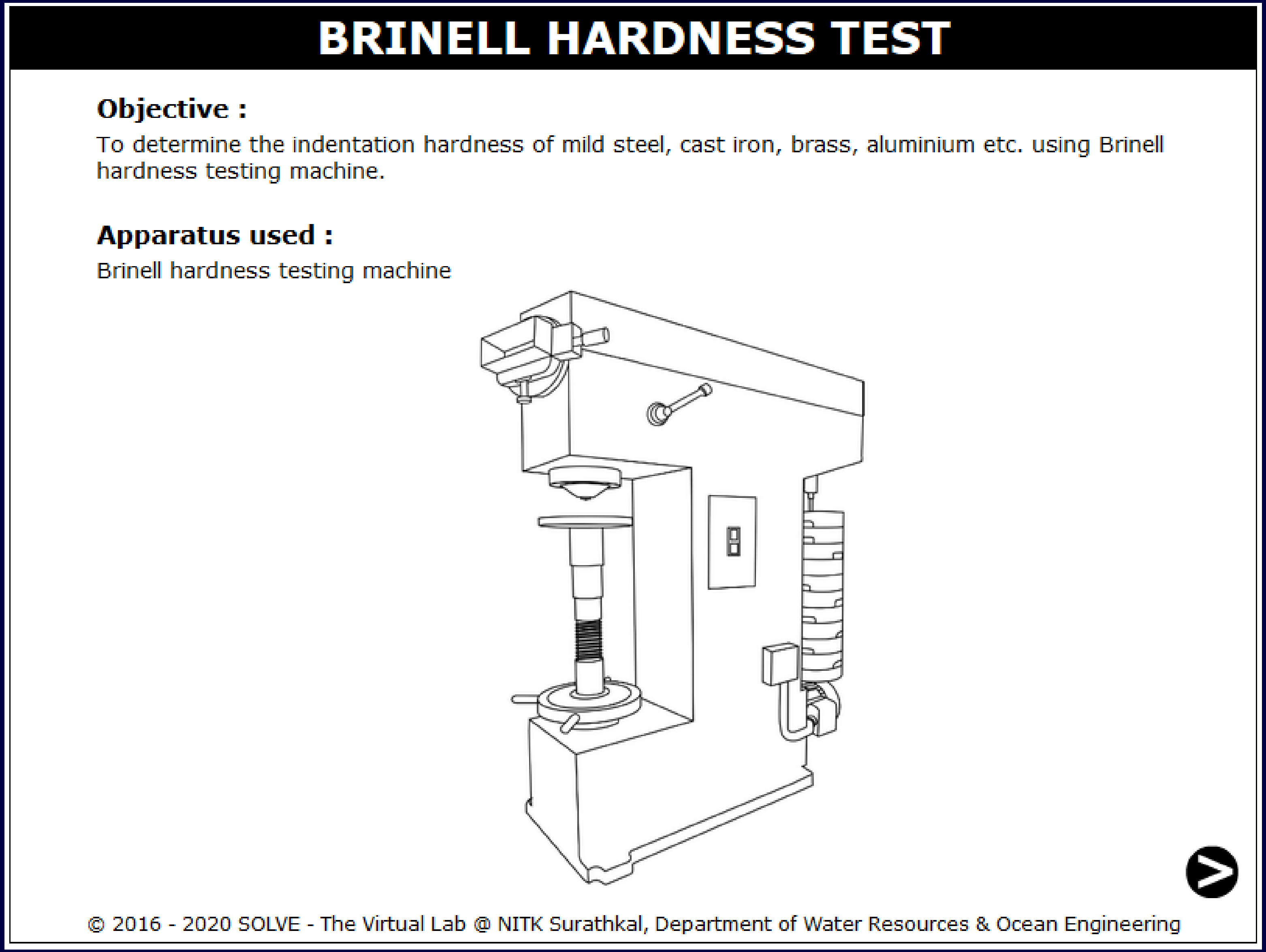
F = load in Newton

https://www.youtube.com/watch?v=Mz-o0pqtWoM https://sm-nitk.vlabs.ac.in/exp10/index.html

Brinell Hardness Test - Procedure

STEPS:

1.When you click on a Brinell test file, a new window will open as shown below.



Click on the NEXT button at the bottom right corner to move to the next step.

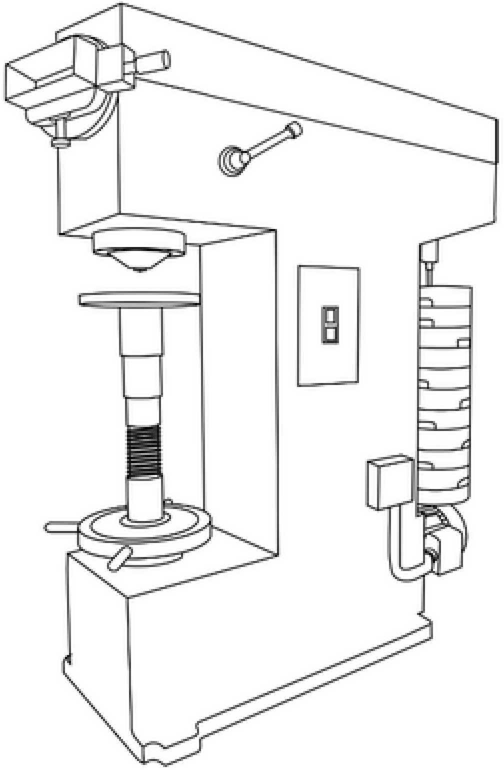
BRINELL HARDNESS TEST

Objective :

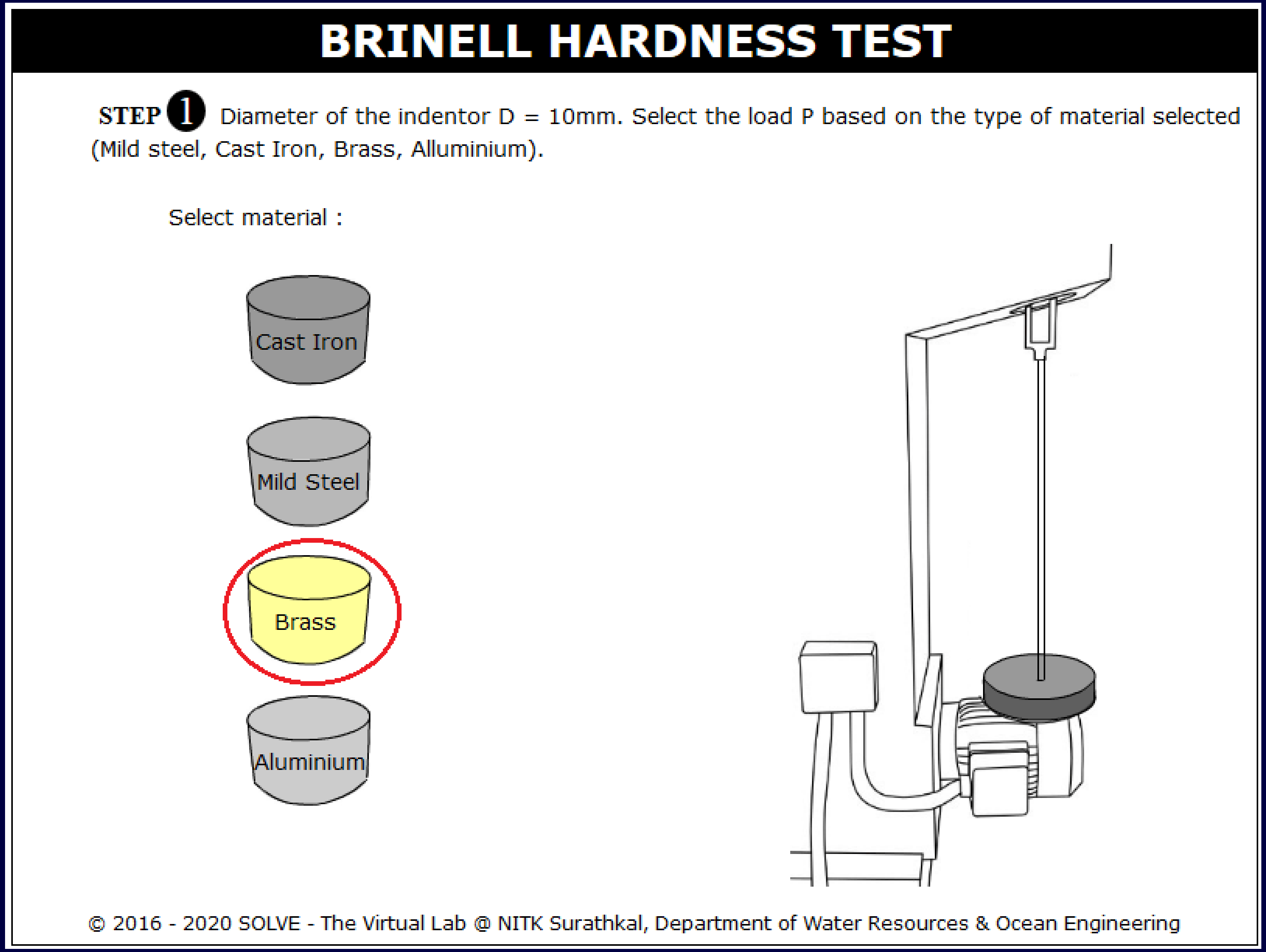
To determine the indentation hardness of mild steel, cast iron, brass, aluminium etc. using Brinell hardness testing machine.

Apparatus used :

Brinell hardness testing machine



Click on the material to select the required specimens and the load to be applied on that is shown, and then click on NEXT button.

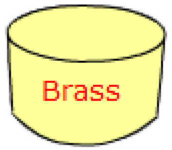


The load to be applied on the selected specimen is displayed here, click NEXT button to mount the specimen on setup.

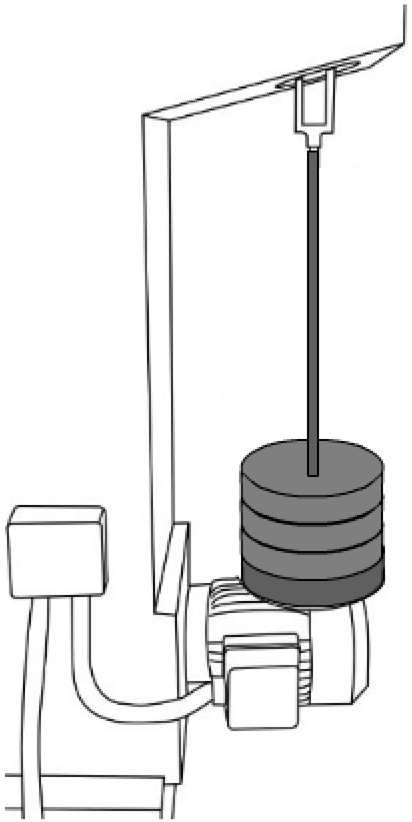
BRINELL HARDNESS TEST

STEP 1 Diameter of the indentor D = 10mm. Select the load P based on the type of material selected (Mild steel, Cast Iron, Brass, Alluminium).

Selected material : Brass Load : 1000Kg

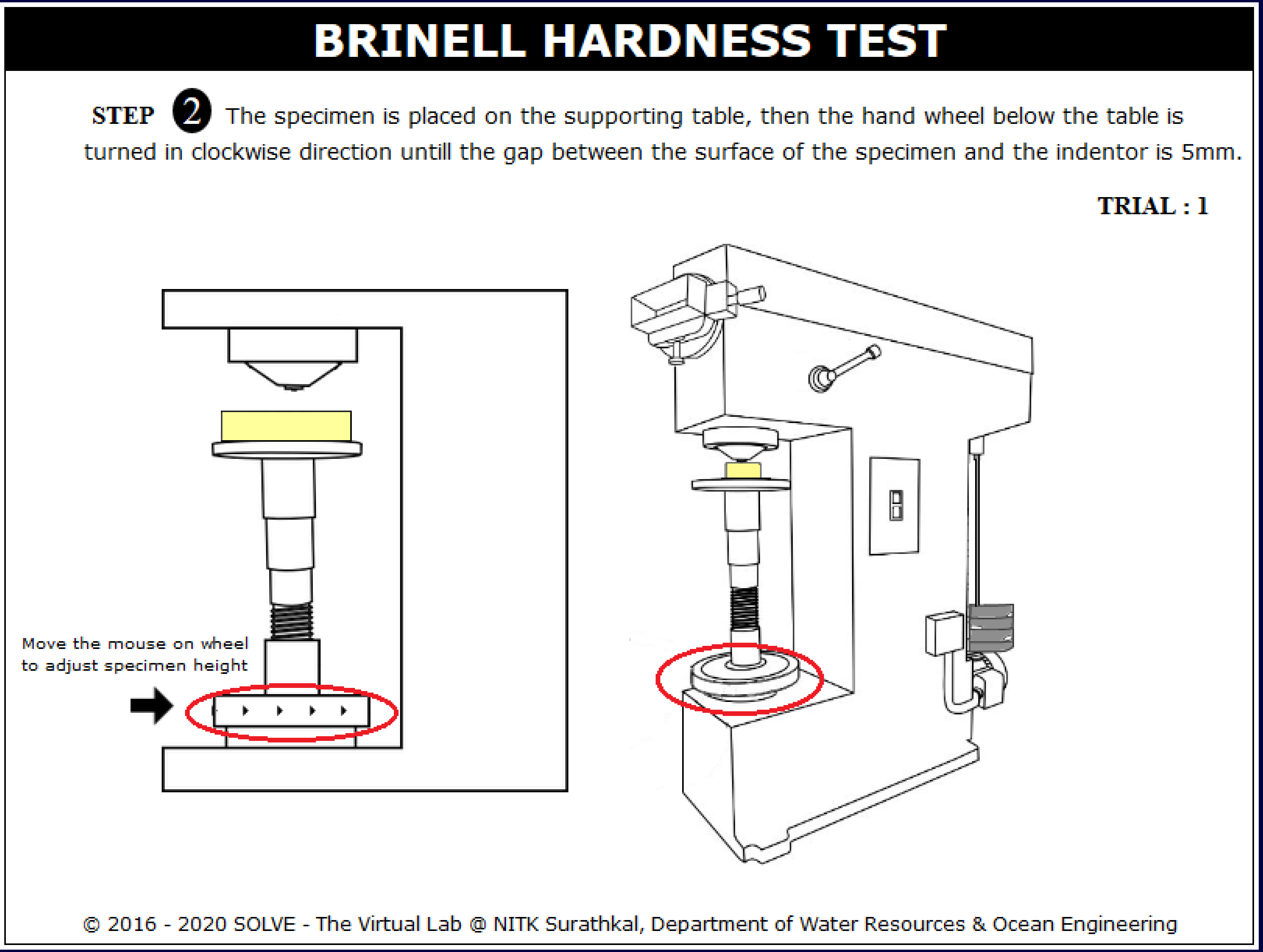


Material	Load 'P' (Kg), diameter 'D' (mm) (Diameter of the indentor D=10mm)
Cast Iron & Mild Steel	P=30, D^2 = 3000Kg
Brass, copper & bronze	P=10, D^2 = 1000Kg
Aluminum, Magnesium & Zinc	P=5, D^2 = 500Kg

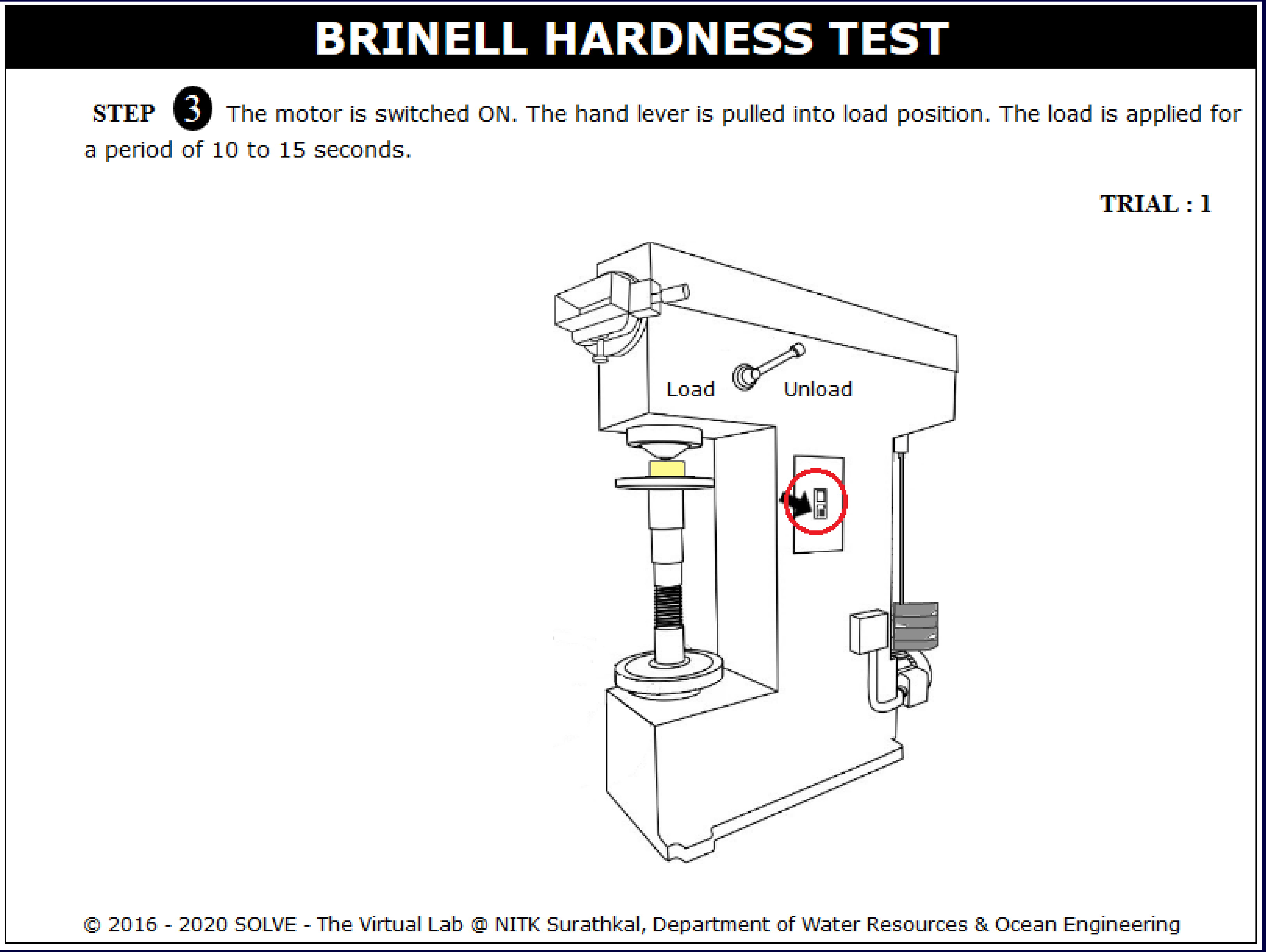


(Each weight is equivalent to 250Kg, supporting hanging rod and base plate is 250Kg)

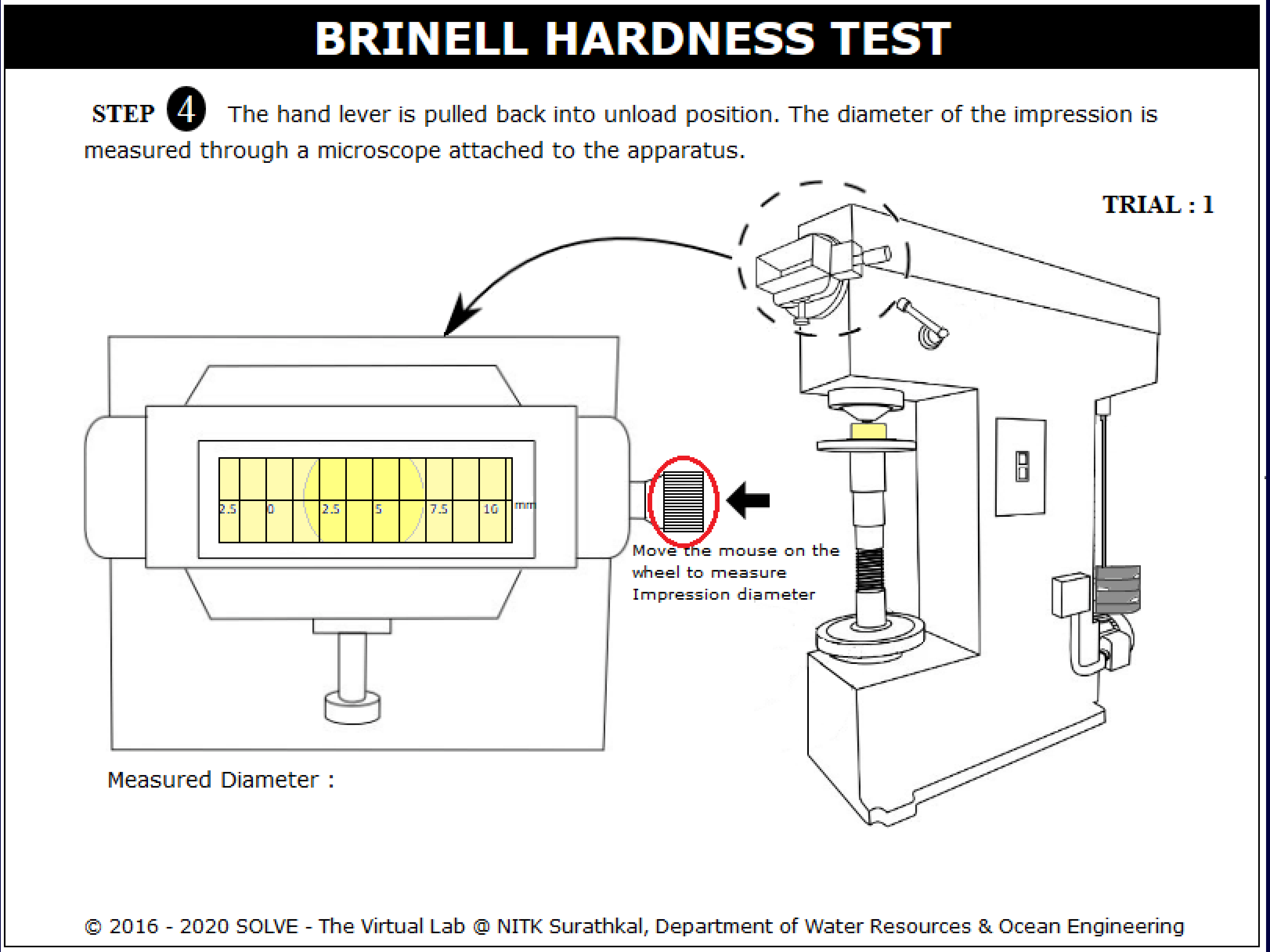
Click on hand wheel then move mouse pointer over the hand wheel to rotate it in clockwise direction till the specimen is in position, after adjusting the specimen in specified position then move to the next step by clicking on NEXT button.



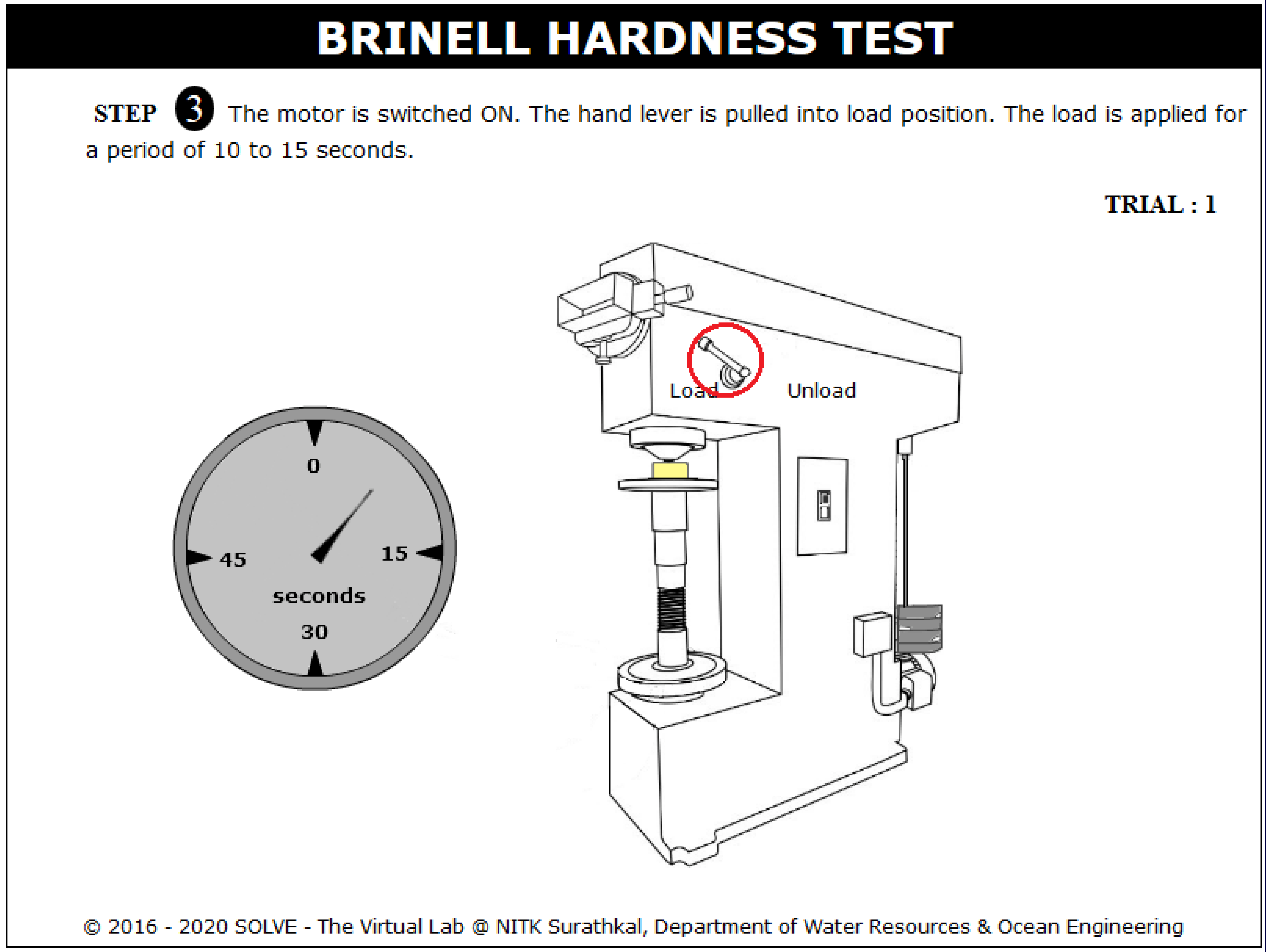
Switch on the machine and click on hand lever to apply load, again click on unload after applying load of 10 to 15 sec for ferrous material and up to 30sec for nonferrous material.



Scroll mouse over the microscope adjusting screw to view the indentation, adjust the indentation corner to zero.



Click on hand lever again to stop the loading process.



The observation of trial 1 is given; repeat the same steps for other trials.

BRINELL HARDNESS TEST

Observations:

Calculate the Brinell Hardness Number (HBW)

TRIAL : 1

[HBW (H from hardness, B from brinell and W from the material of the indenter, tungsten (wolfram) carbide)]

Material	Diameter of indenter D (mm)	Load P (Kg)	P/D^2	Diameter of indentation (mm)		Average diameter d_i (mm)	d/D	HBW (Kg/mm^2)
				d_{ix} (mm)	d_{iy} (mm)			
Brass	10	1000	10	3.79	3.79	3.79	0.379	85.38

$$HBW = \frac{2\,P}{\pi\, D\,[D-\sqrt{(D^2-d^2)}]}$$

Average diameter, $d_1 = \dfrac{d_{1x}+d_{1y}}{2}$

The final average hardness value from different trials is given here.

BRINELL HARDNESS TEST

Observations:

Trial	Material	Diameter of indenter D (mm)	Load P (Kg)	Average diameter d_i (mm)	HBW (Kg/mm^2)	Average HBW (Kg/mm^2)
1	Brass	10	1000	3.79	85.38	93.64
2				3.48	101.9	

Charpy Impact Test