STRUCTURAL LABORATORY

(LPCCE-108)

BACHELOR OF TECHNOLOGY

(Civil Engineering)

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DEPARTMENT OF CIVIL ENGINEERING

GURU NANAK DEV ENGINEERING COLLEGE LUDHIANA

(An Autonomous College Under UGC ACT)

CONTENTS

R.H.S.

Experiment No. 1

Aim: To determine the deflection of a simply supported beam and verify Clark-Maxwell's reciprocal theorem.

Apparatus: Simply supported beam setup, weights, hanger, dial gauge, scale, and vernier calliper.

Theory: Clark-Maxwell's reciprocal theorem in its simplest form states that the deflection of any point Q of any elastic structure due to the load W at any point P is the same as the deflection of the beam at P due to the same load applied at Q.

Procedure:

1. The given beam is placed on the knife edge to form a simply supported beam.
2. Mark two points P and Q on a beam.
3. The dial gauge is placed at point P through the magnetic stand to measure deflection at point P.
4. The hanger is placed on point P, to add weight.
5. The dial gauge is adjusted to zero (or the initial reading is noted) before adding weight to the beam.
6. The different weights are then applied and the deflection at point Q is noted for every load applied.
7. The hanger and dial gauge are then interchanged to apply loads at point Q and measure the corresponding deflection at point P.

Result: As, $\Delta_1 \approx \Delta_2$, therefore Maxwell's reciprocal theorem is verified experimentally.

Precautions:

1. Apply the loads without any jerk.
2. Measure the reading of deflection from the dial gauge very accurately.
3. Ensure the supports are rigid.
4. Avoid external disturbances.

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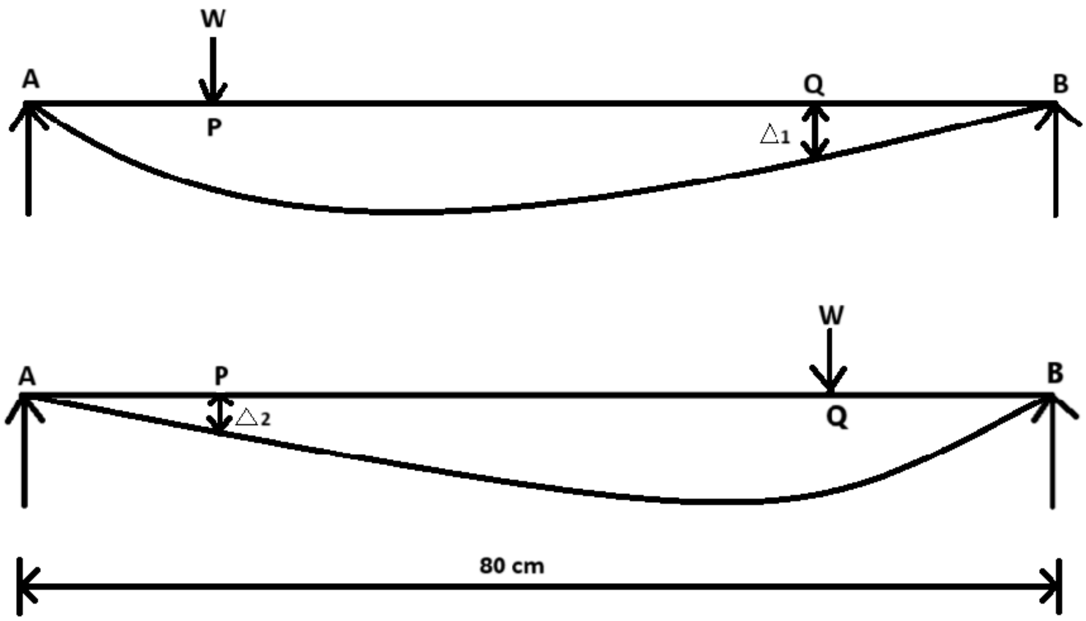
Experiment No. 1

Aim: **To determine the deflection of a simply supported beam and verify Clark-Maxwell's reciprocal theorem.**

Apparatus: Simply supported beam setup, weights, hanger, dial gauge, scale, and vernier calliper.

Diagram:



Observation Table:

S. No.	Load at P (g)	Deflection at Q (mm)	Load at Q (g)	Deflection at P (mm)
1.	200	0.12	200	0.12
2.	400	0.24	400	0.23
3.	600	0.36	600	0.35

Result: As, $\Delta_1 \approx \Delta_2$, therefore Maxwell's reciprocal theorem is verified experimentally.

R.H.S.

Experiment No. 2

Aim: To determine the flexural rigidity of a given beam.

Apparatus: Elastic properties of the deflected beam, weights, hanger, dial gauge, scale, and vernier calliper.

Theory: Flexural Rigidity is the measure of the resistance of a beam to bending. It is measured as the product of the modulus of elasticity (E) and moment of inertia (I).

For the beam with two equal overhangs and subjected to two concentrated loads W each at free ends, maximum deflection y at the centre is given by central upward deflection.

Central upward deflection, $\mathbf{y = waL^2/8EI}$

Where,

a = length of overhang on each side
w = load applied at the free ends
L = main span
E= modulus of elasticity of the material of the beam
I = moment of inertia of cross- section of the beam

$\mathbf{EI = waL^2/8y}$

It is known that, EI for beam with rectangular cross-section is given by, $\mathbf{E \times bd^3/12}$

Where, b = width of beam
d = depth of beam

Procedure:

1. Setup the apparatus for the beam with two equal overhangs.
2. Measure the main span and overhang span of the beam with a scale.
3. Find the b and d of the beam. Calculate the theoretical value of EI by equation I= $bd^3/12$
4. Now place the 200gm load at the both free end of the overhang beam and note down the deflection at the point E.
5. Repeat the above step for 400gm load and note down the deflection at some point E.

Result:

Flexural rigidity is found approximately the same theoretically and experimentally.

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Precautions:

1. Measure the centre deflection very accurately.

2. Apply loads without any jerk.
3. Loading should be within the elastic limit of the material.

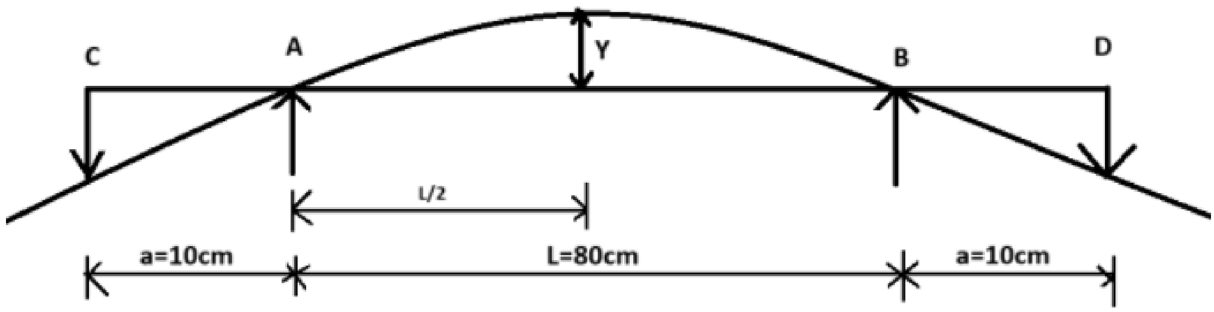
L.H.S.

Experiment No. 2

Aim: To determine the flexural rigidity of a given beam.

Apparatus: Elastic properties of deflected beam, weight 's, hanger, dial gauge,scale and vernier calliper.

Diagram:



$$y = wal^2/8EI \text{ — } 1$$

$$EI = wal^2/8y \text{ — } 2$$

Calculations:

Length,l = 80 cm
Width, b = 24 cm
Depth,d = 5.5 cm
Overhang both sides , a = 10 cm

EI (theoretical) = 2×10^6 kg/cm² × I

Where, $I = bd^3/12 = 2.4\times(0.55)^3/12 = 0.033275\ cm^4$

$EI = 2\times10^6\ kg/cm^2 \times 0.33275\ cm^4$

$EI = 6.65\ kg/cm^2$

EI (experimental) :

For (0.2 kg) = $0.2\times10\times(80)^2/8\times0.19 = 8.42\times10^4\ kg/cm^2$

For (0.4 kg) = $0.4\times10\times(80)^2/8\times0.38 = 8.42\times10^4\ kg/cm^2$

For (0.6 kg) = $0.6\times10\times(80)^2/8\times0.61 = 7.86\times10^4\ kg/cm^2$

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Observation table:

S.no	Load at C (kg)	Load at D (kg)	Deflection at E (y) (mm)	EI (Experimental) (kg/cm²)	EI (Theoretical) (kg/cm²)
1.	0.2	0.2	0.19	8.42×10^4	6.65
2.	0.4	0.4	0.38	8.42×10^4	6.65
3.	0.6	0.6	0.61	7.86×10^4	6.65

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Experiment No. 03

Aim: **Verification of Moment-Area Theorem for Slope and Deflection of a Beam.**

Objective: To verify the moment-area theorem by determining the slope and deflection of a simply supported beam subjected to point loads and comparing experimental results with theoretical values.

Apparatus: Simply supported beam setup with movable supports, Weights, Dial gauge, Measuring scale, Moment-area theorem formulae, Digital or manual protractor, Vernier calliper.

Theory: (Moment-Area Theorem): The moment-area theorem consists of two theorems:

1. First Theorem: The change in slope between two points on a beam is equal to the area under the bending moment diagram between those points divided by the flexural rigidity (EI) of the beam.

$$\theta_B - \theta_A = \frac{1}{EI}\int_A^B M\,dx$$

2. Second Theorem: The vertical deflection at any point relative to another point is equal to the moment of the area of the bending moment diagram about the first point divided by EI.

$$\Delta_B = \frac{1}{EI}\int_A^B M(x)\cdot x\,dx$$

Procedure:

1. Place the beam horizontally on two knife-edge supports at the ends (simply supported).
2. Measure and record the dimensions of the beam (length, width, and thickness).
3. Calculate the moment of inertia (I) of the beam''s cross section and determine the Young's modulus (E) for the material (provided or obtained from material data).
4. Apply a point load (W) at a specific position on the beam (typically at midspan).
5. Record the deflection at multiple points using the dial gauge,
6. Repeat the measurement for various load magnitudes or different load positions.

Theoretical Calculation:

- Draw the bending moment diagram for the given load configuration.
- Use the moment-area theorem to calculate the theoretical slope and deflection

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  at specific points.
- Use the formula for slope:-

$$\theta = \frac{1}{EI} \int M(x)\, dx$$

- Use the formula for deflection:-

$$\Delta = \frac{1}{EI} \int M(x) \cdot x\, dx$$

- Compare theoretical values with the experimentally measured deflections.

Conclusion:

- Conclude whether the experimental results agree with the theoretical results derived from the moment-area theorem.
- Discuss possible sources of errors such as dial gauge calibration, support movement, or beam material inconsistencies.

Precautions:

1. Ensure that the supports are rigid and do not move during the experiment.
2. Avoid overloading the beam beyond the elastic limit.
3. Ensure that the dial gauge is placed perpendicular to the beam for accurate deflection measurements.
4. Take multiple readings to reduce experimental error.

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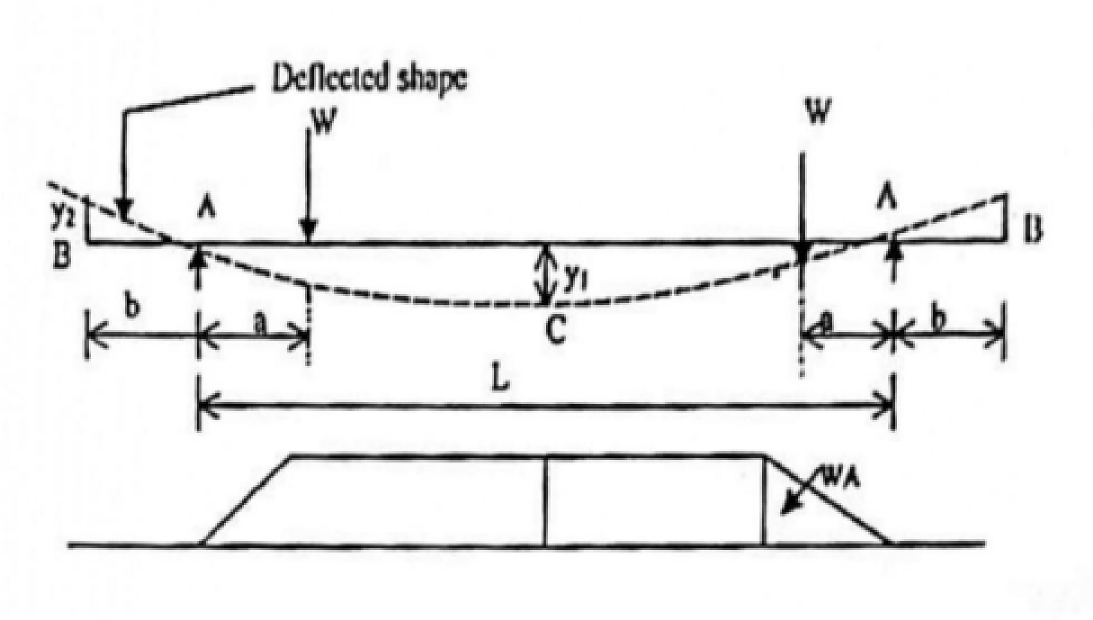
Experiment No.03

Aim: **Verification of Moment-Area Theorem for Slope and Deflection of a Beam.**

Objective: To verify the moment-area theorem by determining the slope and deflection of a simply supported beam subjected to point loads and comparing experimental results with theoretical values.

Apparatus: Simply supported beam setup with movable supports, Weights, Dial gauge, Measuring scale, Moment-area theorem formulae, Digital or manual protractor, Vernier calliper.

Diagram:



Observation:

Length = 80 cm
Width = 2.4 cm
Thickness = 5.5 cm
Overhang on both sides = 10 cm

Calculations:

$I = \frac{bd^3}{12} \quad =24\times\frac{(0.55)^3}{12}=0.33275$

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$EI=2.1\times 10^6\times 0.33275$

$=6.98\times 10^4 kg\ cm^2$

Theoretical Value:

For 0.2 kg$=\frac{wl^3}{48EI}$

$=\frac{0.2\times(80)^3}{48\times6.98\times10^4}$=0.030 cmZ

For 0.4 kg$=\frac{wl^3}{48EI}$

$=\frac{0.4\times(80)^3}{48\times6.98\times10^4}$=0.061 cm

For 0.6 kg$=\frac{wl^3}{48EI}$

$=\frac{0.6\times(80)^3}{48\times6.98\times10^4}$=0.092 cm

S. No	Load(kg)	Experimental Value		Theoretical Value	
		θA(radian)	yc_1(cm)	θA(radian)	yc_2(cm)
1.	0.2	1.59×10^{-3}	0.29	1.3×10^{-3}	0.30
2.	0.4	2.31×10^{-3}	0.61	2.3×10^{-3}	0.61
3.	0.6	3.47×10^{-3}	0.89	3.4×10^{-3}	0.92

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Experiment No. 04

Aim: **Study of behaviour of columns and struts with different end conditions.**

Apparatus: Model of Struts and Columns.

Theory: **Struts-** A bar or a member of a structure in any position other than vertical, subjected to an axial compressive load is called a strut.

Column- A bar or a member of a structure inclined at 90^0 to the horizontal and carrying an axial compressive load is called a column

Depending on support conditions four cases may arise. The effective length for each of which are given as -

1. Both ends are pinned Le = L
2. Both ends are fixed Le = L/2
3. One end is fixed and other is pinned Le = $\frac{l}{\sqrt{2}}$
4. One dls fixed and other is free Le = 2L

Procedure:

1. Pia a graph paper on the wooden bound beled the column
2. Apply the load at the top of columns increasing gradually. At sertale stage of Loading the columns shows abnormal deflections and gives the buckling hand
3. Not the buckling load for each of the four columns.
4. Trace the deflected shapes of the columns over the paper, Mark the points of change of curvature of the curves and measure the effective equivalent length for each case separately.
5. Calculate the theoretical effective lengths and thus buckling loads by the expressions given above and compare them with the observed value.

Result: The theoretical and experimental Euler's buckling load for each case is found nearly the same.

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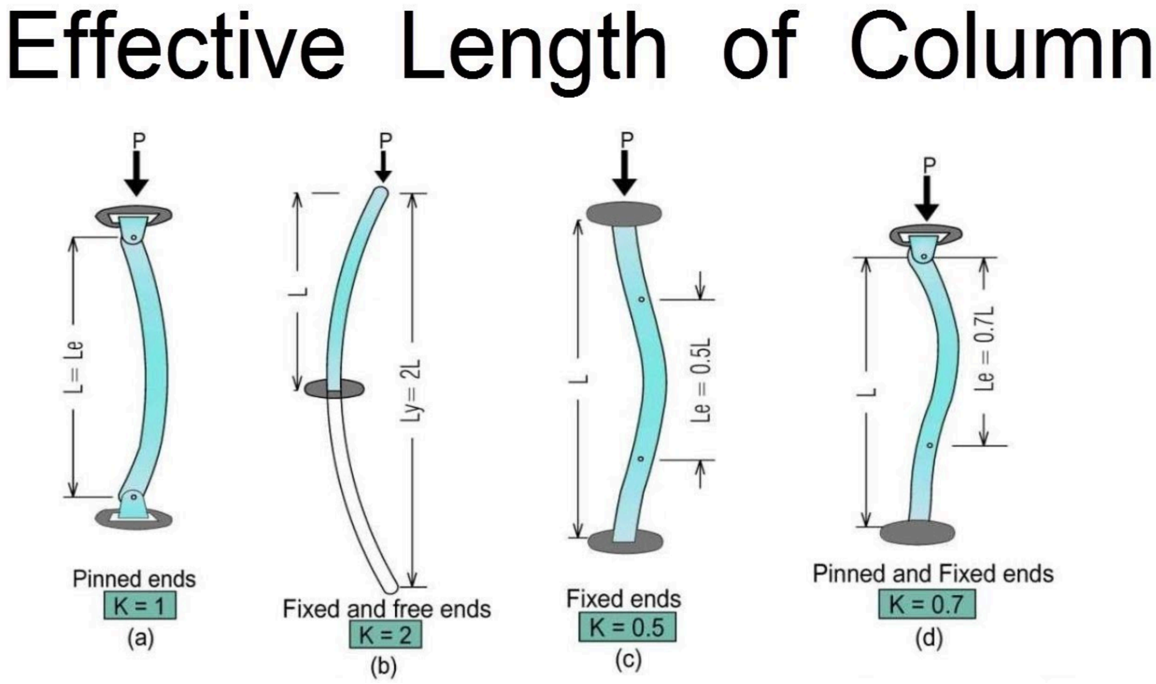
Experiment No. 04

Aim: **Study of behaviour of columns and struts with different end conditions**

Apparatus: Model of Struts and Columns.

Diagram:



Observation:

1. Width of strip (mm) b = 10 mm
2. Thickness of strip (mm) t = 0.5 mm
3. Length of strip (mm) L = 16.2 mm
4. Least moment of inertia $I = \frac{bt^3}{12}$

$$I = \frac{10\times(0.5)^3}{12} = 0.10\ mm^4$$

Sample calculation:

End condition : Both ends fixed

Euler's buckling load = $P = \pi^2\ \frac{EI}{le^2} = \frac{(3.14)^2\times2.1\times10^4\times0.10}{(16.8)^2}$ = 0.850 kg

b) $p = \frac{\pi^2 EI}{(l/2)^2} = \frac{(3.14)^2\times2.1\times10^4\times0.104}{8.5}$ = 2.98 kg

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c) $p = \frac{\pi^2 EI}{(0.7l)} = \frac{(3.14)^2\times2.1\times10^4\times0.504}{0.7\ l}$ = 1.67 kg

d) $p = \frac{\pi^2 EI}{(le)} = \frac{(3.14)^2 \times 2.1 \times 10^4 \times 0.104}{104.976} = 0.205$ kg

S. No	End Conditions	Euker's Buckling Load		Effective Length	
		Theoretical (kg)	Observed (kg)	Theoretical (mm)	Observed (mm)
1.	Both Ends Pinned	0.820	0.825	162	162
2.	Both Ends Fixed	2.98	3.0	170	170
3.	One End Fixed And One Pinned	1.67	1.7	162	162
4.	One End Fixed And Other Free	0.205	0.205	160	162

R.H.S.

Experiment No. 05

Aim: Experiment on a three-hinged arch.

Apparatus: Three hinged arch apparatus, weights etc.

Theory: A three hinged arch is a determinate structure with the axial thrust assisting in maintaining the stability.

Procedure:

1. Use lubricating oil at the roller end of the arch so as to have a free movement of the roller end. Balance the self weight of the arch by placing load on hanger for horizontal thrust until the best equilibrium conditions are obtained. Under this condition, the roller end of the arch has a tendency to move inside on tapping the table. Note down the load in kg.
2. Place a few loads on the arch in any chosen positions. Balance these by placing additional weights on the hanger for horizontal thrust. The additional weights on the thrust hanger give the experimental value of the horizontal thrust.
3. To obtain the influence line for H, place a load of 2 kg in turn on each hanger, one by one and find the balancing weight required on the thrust hanger.
4. Plot the ordinate representing ½ of the balancing weights on the load positions as base. This gives the influence line diagram for horizontal thrust.

Results:

1. Find the horizontal thrust for a given set of load experimentally and theoretically.
2. Plot the observed and calculated values of influence line ordinates on the same graph and comment on the accuracy obtained in the two cases.

Precautions:

1. 1. Put the weights in the thrust hanger very gently without a jerk.
2. 2. Measure the distance of loaded points from left hand support accurately.
3. 3. Perform the experiment away from vibration and other disturbances.

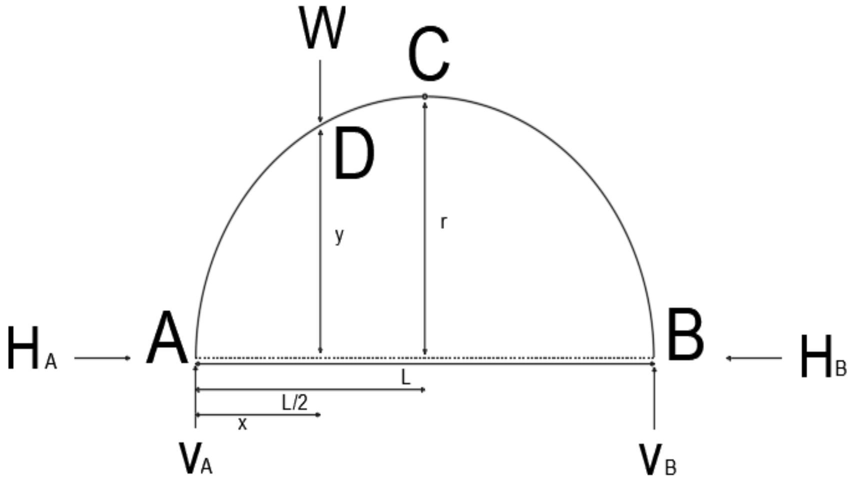
L.H.S.

Experiment No. 05

Aim: Experiment on a three-hinged arch.

Apparatus: Three hinged arch apparatus, weights etc.

Diagram:



Observation:

Span of the arch (L)=100cm
Central rise (r)= 25cm
Initial load on the thrust hanger for balancing, kg =1kg 500gm

Observation table:

Sr.No	Load(w) at D,(kg)	Experimental Horizontal Thrust(kg)	Theoretical Horizontal Thrust(kg)
1	0.2	.12	.12
2	0.4	.257	.25
3	0.6	.387	.38

Results:

1. Find the horizontal thrust for a given set of load experimentally and theoretically.

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2. Plot the observed and calculated values of influence line ordinates on the same graph and comment on the accuracy obtained in the two cases.

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Experiment No. 06

Aim: Experiment on a two-hinged arch.

Apparatus: Two I hinged Arch Apparatus, Weight's, I tanger, dial Gauge, Scale, Vernier Caliper.

Theory: The two hinged arch is a statically indeterminate structure of the first degree. The horizontal thrust is the redundant reaction and is obtained by the use of strain energy methods. Two hinged arch is made determinate by treating it as a simply supported curved beam and horizontal thrust as a redundant reaction. The arch spreads out under external load. Horizontal thrust is the redundant reaction obtained by the use of strain energy method.

$$\mathbf{H = 5WL\ (a - 2a' + a^4)/8r}$$

Where,

W—Weight applied at end support.

L= Span of two hinged arch.

r = rise of two hinged arch.

a = dial gauge reading.

Procedure:

1. Use lubricating oil at the roller end of the arch so as to have a free movement of the roller end. Balance the self weight of the arch by placing load on hanger for horizontal thrust until the best equilibrium conditions are obtained. Under this condition, the roller end of the arch has a tendency to move inside on tapping the table. Note down the load in kg.
2. Place a few loads on the arch in any chosen positions. Balance these by placing additional weights on the hanger for horizontal thrust. The additional weights on the thrust hanger give the experimental value of the horizontal thrust.
3. To obtain the influence line for H, place a load of 2 kg in turn on each hanger, one by one and find the balancing weight required on the thrust hanger.
4. Plot the ordinate representing ½ of the balancing weights on the load positions as base. This gives the influence line diagram for horizontal thrust.

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Result: The observed and horizontal displacement is nearly the same.

Precautions :

1. Apply the loads without a jerk.
2. Perform the experiment away from vibration and other disturbances.

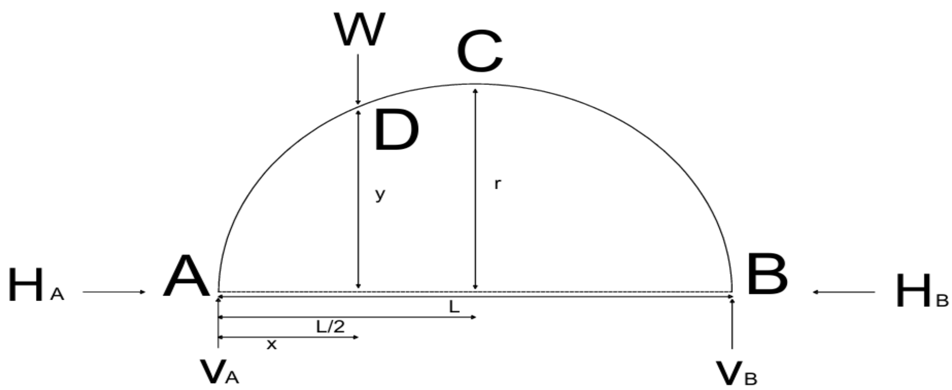
L.H.S.

Experiment No. 06

Aim: Experiment on a two-hinged arch.

Apparatus: Two I hinged Arch Apparatus, Weight's, I tanger, dial Gauge, Scale, Vernier Caliper.

Diagram:



Observation table:

Sr.No	Load(w) at D,(kg)	Experimental Horizontal Thrust(kg)	Theoretical Horizontal Thrust(kg)
1	0.2	.116	.163
2	0.4	.316	.332
3	0.6	.473	.501

Sample calculation:

Span of arch,(l)-100cm

Central rise,(r)-21.5cm

Initial load on the hanger for balancing - 1.2kg

Distance of D from A,(x) - 37.5cm

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Result :

The observed and horizontal displacement is nearly the same.

R.H.S.

Experiment No. 7

Aim: Experiment on curved beams.

Apparatus: Curved member apparatus, dial gauge, vernier calliper, micrometre, metre scale, weights etc.

Theory: Castigliano's first theorem is used to find the elastic displacements of the curved members. The theorem states "partial derivative of the total strain energy of a structure with respect to any force gives the displacement of the point of its application in the direction of the force."

The total strain energy of any structure is determined in terms of the entire load with its actual values and a fictitious load P applied at the point at which the deflection is required and it is acting in the same direction in which the deflection is required. In case no external load is acting at the joint in the direction desired, a fictitious load is applied in that direction and forces in all the members are worked ouL After partial differentiation with respect to P, zero is substituted for the fictitious load P (or if P is not fictitious its actual value is substituted). Thus the result is the required deflection.

A. Quadrant of a circle

Fixed at A free at B (radius R) and subjected to a concentrated load W at the free end.

Vertical displacement of load point $=\Delta_{BV} = \frac{\Pi WR^3}{4EI}$

Horizontal displacement of load point B $= \Delta_{BH} = \frac{WR^3}{2EI}$

B. Quadrant of a circle with a straight leg

From A to B, the quadrant of a circle of radius R, and B to C is straight of length of y

Vertical displacement of load point A$=\Delta_{AV} = \frac{\Pi WR^3}{4EI} + \frac{WR^2 y}{EI}$

Horizontal displacement of load point A $= \Delta_{AH} = \frac{WR}{2EI}(R + Y)^2$

C. Semicircle with straight arm

From A to C semicircle of radius R, A to B straight length of y

R.H.S.

Vertical displacement of loaded point B $= \Delta_{BV} =$

$$\frac{W}{6EI}\left[2y^3 + 3R\left(2\Pi y^2 + 8yR + \Pi R^2\right)\right]$$

Horizontal displacement of loaded point B $= \Delta_{BH} = \frac{WR^2}{EI}(\Pi y + 2R)$

D. **Circle of radius R**

Vertical displacement of loaded point B $= \Delta_{BV} = \frac{WR^3}{4\Pi EI}\left(\Pi^2 - 8\right)$

PROCEDURE:

1. Place a load on the hanger to activate the member and treat this as the initial position for measuring deflection.
2. Fix the dial gauges for measuring horizontal and vertical deflections.
3. Place the additional loads at the steps mentioned in the table below for each case and tabulate the values of the dial gauge reading against the applied loads.

Results:

The experimental values are found to be approximately equal to the theoretical values.

Precautions:

1. Apply the loads gently.
2. Measure the displacements very accurately.

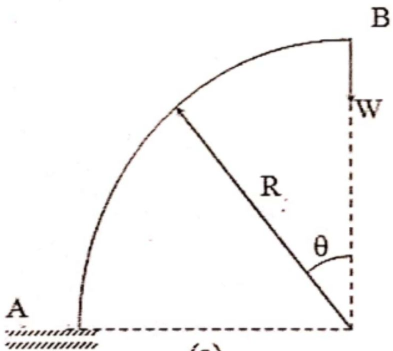
L.H.S.

Experiment No. 7

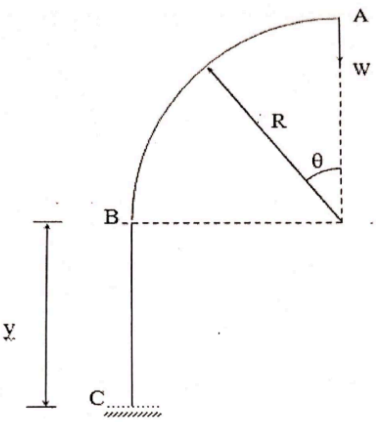
Aim: Experiment on curved beams.

Apparatus: Curved member apparatus, dial gauge, vernier calliper micrometre, metre scale, weights etc.

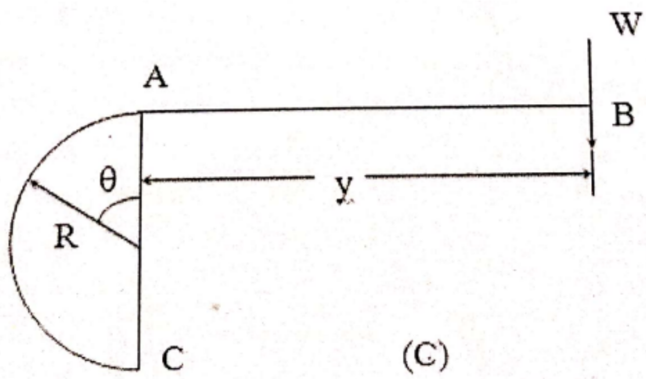
Diagram:



(a)

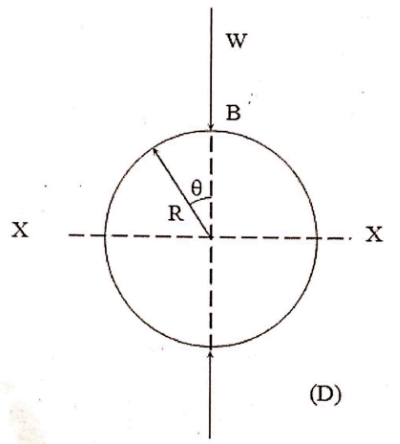


(b)



(C)

L.H.S.



Observation table:

Width of section (mm) b.=
Depth of section (mm) d =
Last moment of inertia I = $bd^3/12$
$E(kg/cm^2)= 2.1x10^6$

Quadrant of a circle

Sr. No.	Additional load (kg)	Experimental Value (mm)		Theoretical Value (mm)	
		Horizontal direction	**Vertical direction**	**Horizontal direction**	**Vertical direction**
1.	0.2	0.22	0.31	0.197	0.31
2.	0.4	0.42	0.6	0.394	0.62
3.	0.6	1.04	0.62	0.591	0.93

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Quadrant of a circle with a Straight leg

Sr. No.	Additional load (kg)	Experimental Value (mm)		Theoretical Value (mm)	
		Horizontal direction	Vertical direction	Horizontal direction	Vertical direction
1.	0.2	0.62	0.28	0.16	0.126
2.	0.4	1.24	0.56	0.32	0.252
3.	0.4	1.86	0.84	0.48	0.378

Semi-circle with a Straight leg

Sr. No.	Additional load (kg)	Experimental Value (mm)		Theoretical Value (mm)	
		Horizontal direction	Vertical direction	Horizontal direction	Vertical direction
1.	0.2	0.12	0.28	0.6	0.2
2.	0.4	030	0.55	1.2	0.4
3.	0.4	0.44	0.82	1.8	0.6

L.H.S.

Quadrant of a circle

Sr. No.	**Additional load (kg)**	**Experimental Value (mm)**		**Theoretical Value (mm)**	
		Horizontal direction	**Vertical direction**	**Horizontal direction**	**Vertical direction**
1.	0.2	-	0.03	-	0.011
2.	0.4	-	0.07	-	0.022
3.	0.4	-	0.11	-	0.033

RESULTS:-

1. Plot the graph load Vs deflection for each case to show that the structure remains within the elastic limit. ·
2. Measure the value of R and straight length in each case. Find width and depth of the steel section and calculate the value of I as bd3/12.

PRECAUTIONS:-

1. Apply the loads gently.
2. Measure the displacements very accurately.