TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING
(DEPARTMENT OF MECHANICAL ENGINEERING)

LABORATORY MANUAL

ON

MECHANICS OF SOLIDS
(EG 624 ME)

FOR

B.E. in Mechanical Engineering Program
(Third Year, Mechanical Engineering Students)

Prepared By

Prashant Kr. Ghimire
(Lecturer)

Deparpament of Mechanical Engineering Pulchowk Campus
Institute Of Engineering (IOE)

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About the Lab Manual

The main objective of this laboratory manual is to help the students learn various practical aspects of Mechanics of Solids subject and prove various theoretical concepts with the help of apparatus supplied in the Lab.

The manual thus prepared will help the students learn and observe the concepts that they have developed in the theoretical portion of the subject. The manual is prepared in such a way that the students will be able to perform the experiments without much assistance from the teachers.

Detail theoretical explanations, as and when required, are given as appendix at the end of the concerning experiment. For the experiments on the topic 'Deflection of Frames' various options are included, but the student have to perform any one type and study about all. Remaining theories have been abridged since they will be covered in the theoretical portion as well.

With an expectation that this manual will be of great assistance to the students trying to seek practical knowledge in the field of Mechanics of Solids,

Prashant Kr Ghimire

CONTENTS

ACKNOWLEDGMENTS

EXPERIMENT NO :   1

TITLE :   THE SHEAR CENTER OF A CHANNEL SECTION

OBJECTIVE

To find the shear center of a channel section and compare with the theoretical value.

APPARATUS REQUIRED:

The following   part list and accessories are required (as shown in Fig 1)

- SM103 Unsymmetrical Cantilever Apparatus
- Aluminium Channel   (25.4 x 25.4 x 3.175 mm - length 500 mm.)
- Two similar Indicating Dial Gauges

- The Shear Center Crosspiece
- Weight 1.0 kgf
- Weight Hanger (0.5 kgf)
- Allen Key -1

In Fig 1 the channel section cantilever has flanged ends to enable it to be secured to a right top plate, and can be rotated through 360^0. The bending moment is applied via a weight through a string attached to the free end of the cantilever via a pulley. For meaningful results the direction of pull must always be the same, and this is achieved by moving the pulley along its shaft so that the string is always parallel to grid on the upper surface of the pulley support bracket.

A shear center crosspiece must be fitted to the free end of the cantilever if the shear center is to be found. This has grooves machined at 5mm intervals, to which the string is attached. The different groove positions enable the section to be twisted through varying angles. The angle of twist is measured using the two dial gauges, which are turned so that they rest against the end of the crosspiece.

(Note:- The measurement point of the dial gauge on the cantilever specimen is at a length of 500mm. However, the actual length at which the cantilever is pulled is at approx 509mm. This will induce a small error in the results.)

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FIG 1

SM103 UNSYMMETRICAL
CANTILEVER APPARATUS

The applied force
induces shearing stress
in the section

Shearing stresses give rise to
shearing forces. For equilibrium,
the vertical shear force is equal to
F; the two horizontal shearing
forces are equal

Coupling due to
vertical forces

Coupling due to
horizontal forces

The Coupling due to the vertical
and horizontal forces are in the
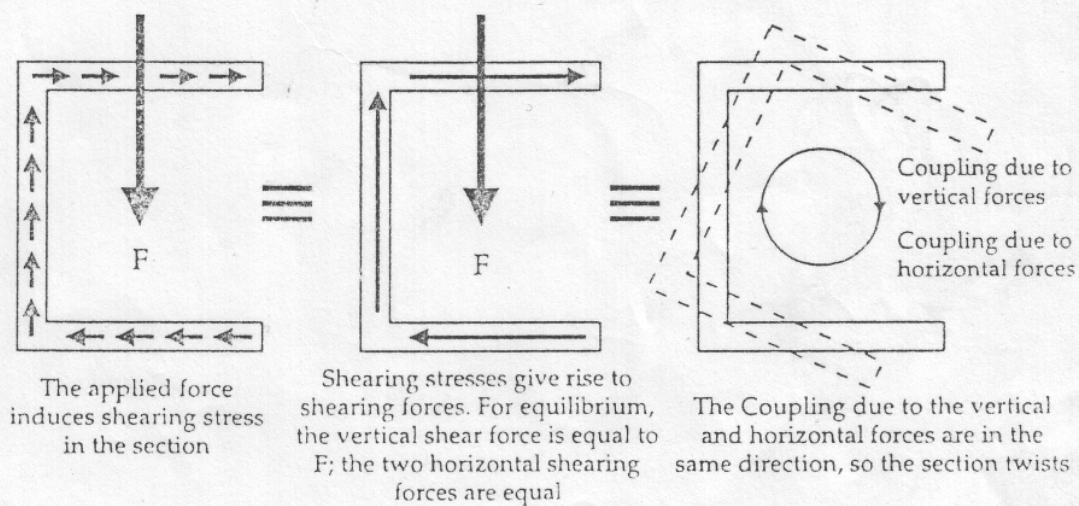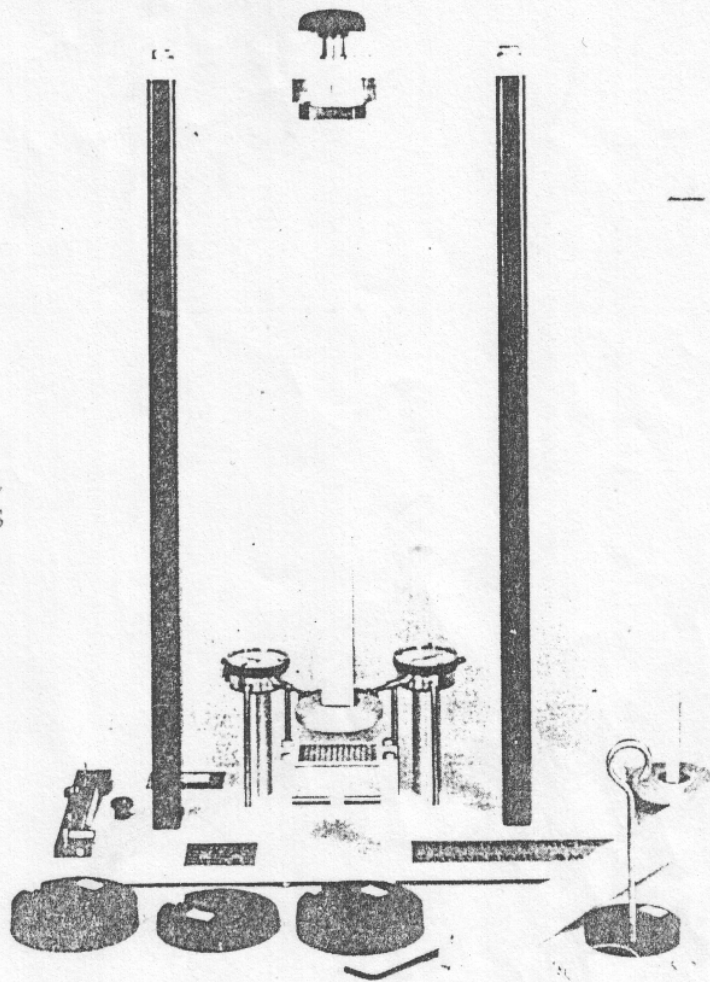same direction, so the section twists

Fig 2 Twisting of a Channel Section Under Load

THEORY

A beam always bends when it is loaded but unless the load is applied through the Shear Center, bending is accompanied by twisting of the section. Fig 2 shows a channel section loaded by a force F. The applied load sets up a shearing stress in the section caused by the shearing force. For equilibrium the vertical force must balance the applied load, and the two horizontal shearing forces must be equal and opposite. The two vertical forces and the two horizontal forces form two couples, which combine to twist the section.

However, if the beam is somehow loaded through a point S outside the section, as shown in Fig 3 the two couples cancel out. The beam bends but it does not twist . The point $\underline{S}$ is called the **Shear Center**.

Shear Center of a Channel Section (See fig 4)

The following analysis <u>assumes</u> that the section is thin. Using the symbols shown in Fig 4, no twisting take place if:

$$F.h = 2H.B$$

$$or, \qquad h = \frac{2H.B}{F} \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(1)$$

Form Standard theory, the shearing stress (τ) in the flange at a distance 'a' from the end is given by:

$$\tau = \frac{F.a.t.B}{t I_A}$$

$$\tau = \frac{F.a.B}{I_A} \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots(2)$$

The total shearing force H in each horizontal flange is:

$$H = \int_0^A t.\tau.da = \int_0^A \frac{F.a.B.t.da}{I_A}$$

$$H = \frac{F.B.A^2.t}{2 I_A} \qquad \dots\dots\dots\dots\dots\dots\dots\dots(3)$$

Coupling due to
vertical forces

Coupling due to
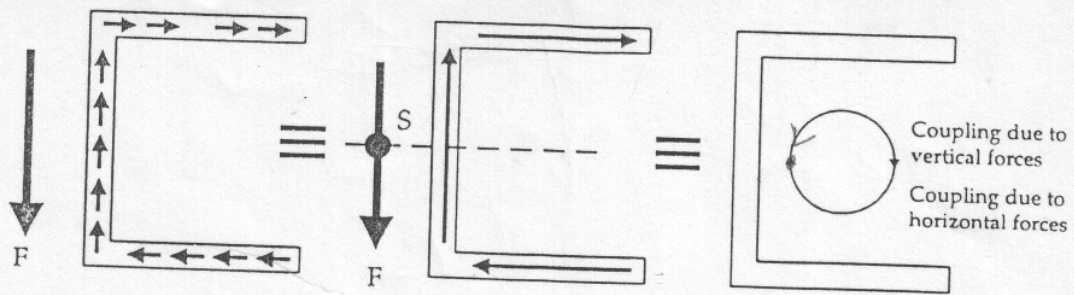horizontal forces

Fig 3 Shear Center for Channel Section

Fig 4

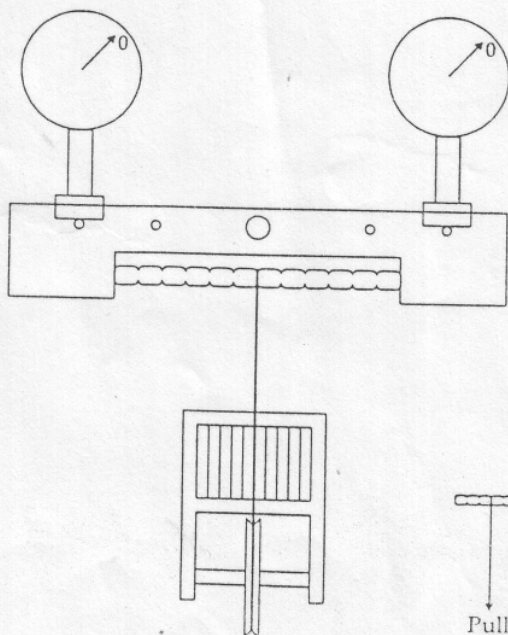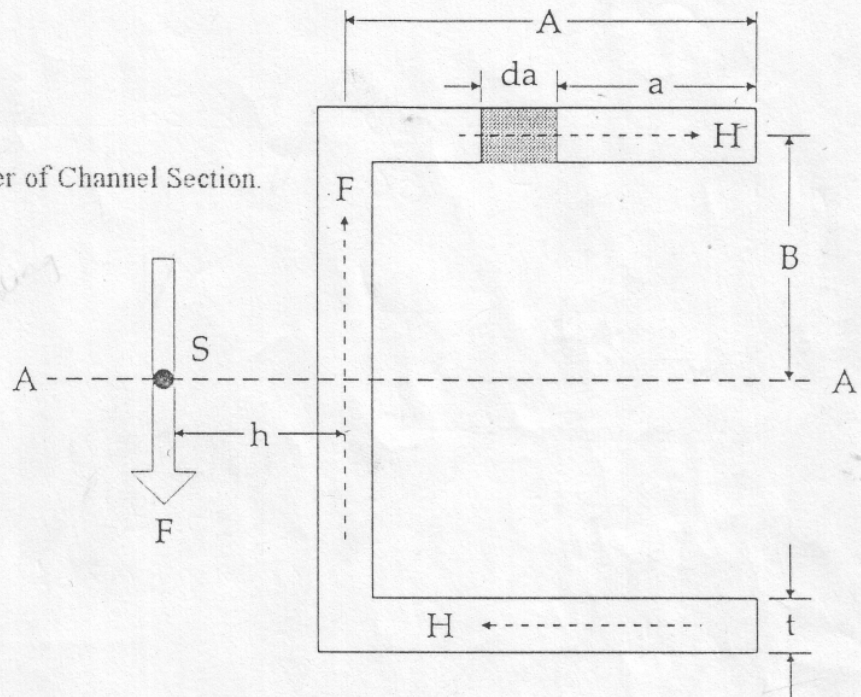Notation for Shear Center of Channel Section.

Fig 5 Cantilever Positioning

Pull

4

The position of the Shear Center is found by substituting equation (3) in equation (1) giving:

$$h = \frac{B^2 A^2 t}{I_A} \qquad \dots\dots \dots\dots \dots\dots \dots(4)$$

PROCEDURE

1. Turn the cantilever section so that it is positioned relative to pulley as shown in Fig 5.

2. Fit the shear center accessory to the free of the cantilever and turn the dial gauge so that they rest against the attachment, as shown in Fig 5. The grooves in the notched bar have a spacing of 5mm.

3. Turn the scales of the dial gauges until they read zero.

4. Move the string to the left hand notch. Move the pulley to the left, and hang the weight hanger on the end of the string. Put a weight of 1.0 kgf on the hanger so that the total weight is 1.5 kgf.

5. Adjust the position of the pulley until the string is parallel to the lines on the pulley bracket. Record the readings of both dial gauges.

6. Repeat for each position of the notch.

OBSERVATION, CALCULATIONS, PLOTS AND RESULTS

Note down the dial readings in the following Table,

SN	Total wt (kgf)	Notch No.	Dial Reading		Gauge reading converted into mm		Remarks
			LHS	RHS	LHS	RHS	

1) Plot the reading of each gauge against notch position on the same set of axes.

2) Draw the best straight line through each set of points.

3) The intersection of the two lines correspond to the shear center position. .

4) Compare the experimental result with the theoretical one.

(Please refer appendix for typical results in the next page.)

CONCLUSION, SUGGESTIONS AND DISCUSSION

For most practical applications, combine bending and twisting is very undesirable. It is therefore important to load beams, somehow, through the Shear Center. Discuss how this loading point in case of channel section. Also discuss about location of Shear Center in angle section and rectangular section.

Appendix, Typical Results (An illustration)

Fig 6 shown a typical set of results obtained, by experimental measurement, for the Channel Section. The experimental position of the Shear Center is 9.5mm from the outside of the web.

From equation (4) the theoretical position of the channel shear center is given by:

$$h = \frac{B^2.A^2.t}{I_A}$$

For the section used;

$$h = \frac{(11.11)^2.(23.81)^2(3.175)}{21894}$$

$$h = 10.1 \quad mm \quad from \quad the \quad web.$$

It is recommended that the specimen supplied should be carefully measured and that theoretical calculations are based on the actual measurements not the nominal ones.
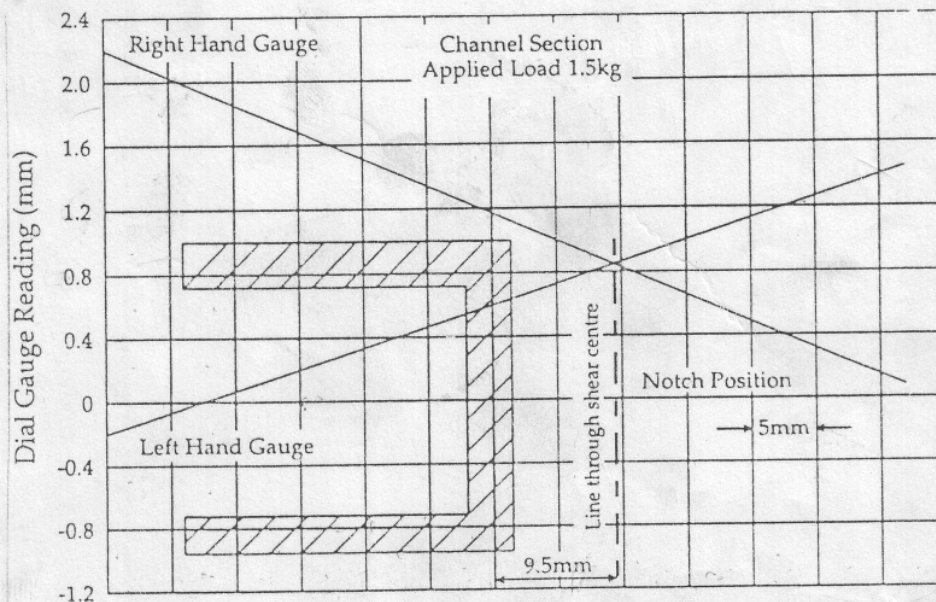

Fig 6 Typical Results

EXPERIMENT NO: 2

TITLE: **TORSION TEST OF A SOLID CIRCULAR SHAFTS AND THIN WALLED CIRCULAR TUBES**

OBJECTIVE:

a) To investigate the relationship between torque and angle of twist for solid circular shafts of various metals.

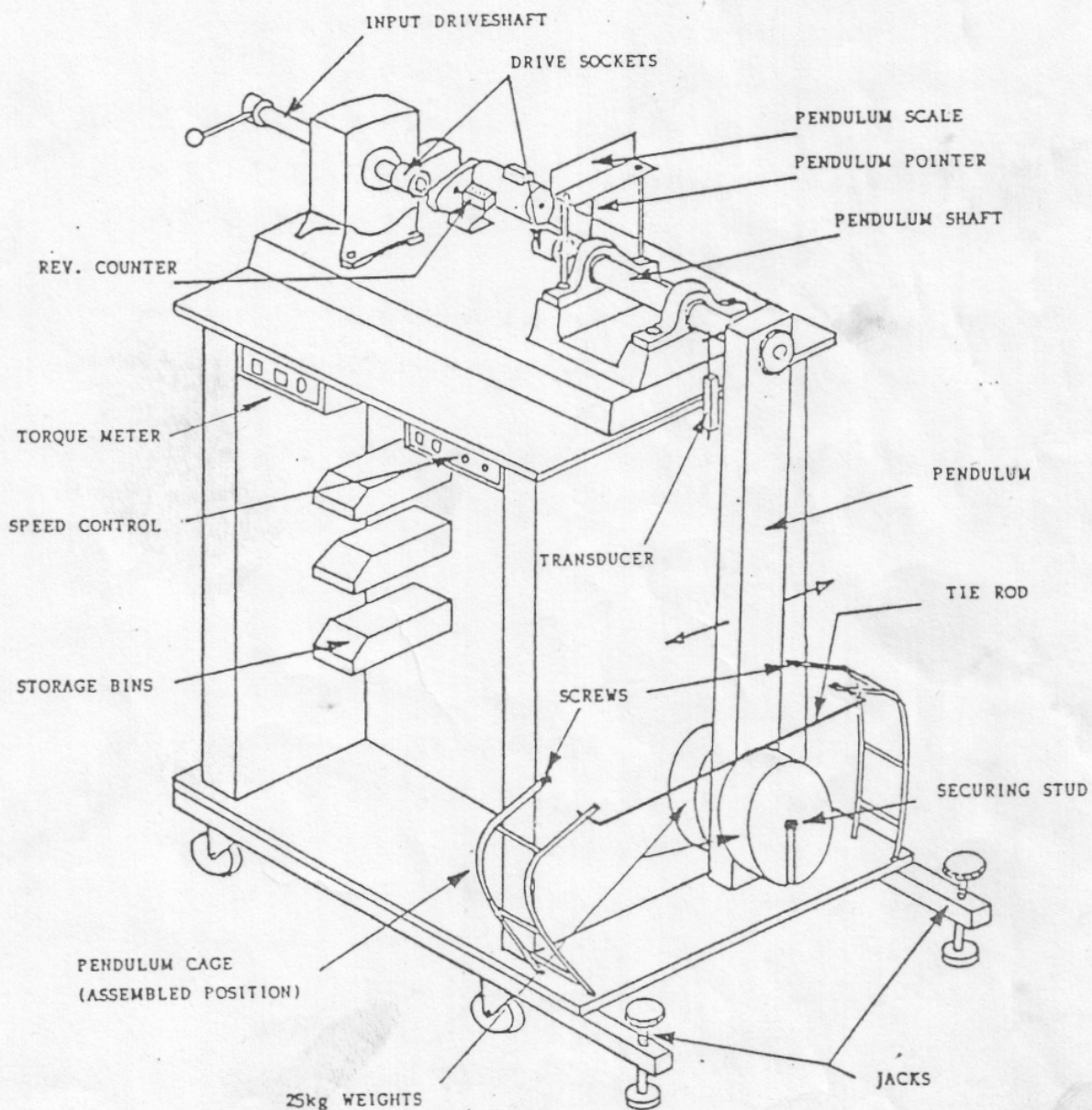b) To determine the shear modulus of various metals from the torque - angle of twist data.

Fig. 1

APPARATUS REQUIRED :

(see Appendix, Torsionmeter, for details about the torsionmeter)

(a) Jack up the pendulum end (see Fig 1) of the rig using the two jacking screws in order to prevent movement of the rig due to any swinging if the pendulum during tests. (This should occur only when a specimen fractures.)

(b) Connect the speed control and torque meter modules to a single phase mains supply and switch on.

(c) Fit the appropriate sized sockets (and adaptors if required) to the input and pendulum shafts.

(d) With the pendulum steady, set the torque meter to zero using the "set zero" control at the rear of the meter unit and set the pointer to zero on the pendulum angle scale.

(e) Withdraw the input shaft through the gearbox and insert the specimen in one of the sockets. Run the motor using the speed control until the second socket will slide onto the other end of the specimen. Ensure that the input shaft is pushed inwards as far as it will go before applying any load. (Note: Select "forward" when first starting the motor.)

(f) Slowly inch the motor until the torque meter reading just begins to change, then set the input revolution counter to zero by pressing the trip lever on the left.

NOTE: NO ATTEMPT SHOULD BE MADE TO REMOVE A SPECIMEN WHEN UNDER LOAD.

THEORY:

The SI 21 Advanced Torsion Testing Machine (as shown in Fig. 1) enables forward and reverse torsion tests on a range of sizes and lengths of specimens requiring test torques of up to 200 Nm. Load is applied by a variable speed electric motor driving through a 5:1 belt drive and a 1200:1 reduction gearbox. The torque reaction is provided by a pendulum whose movement is measured by a linear potentiometer connected to a digital meter giving a readout calibrated in torque units (N-m or lbf-in). Input rotation is measured by a digital counter, one unit being equal to 0.3^0 units of the input shaft rotation. The pendulum angle is measured by a scale and pointer. The twist of the specimen can be regarded as the difference between the angle of rotation of the input shaft and the pendulum angle. Accurate measurements of twist angle, and

hence of strain can be obtained using the SM21a Torsionmeter for specimen having hexagonal ends up to 24 mm A/ F.)

When a shaft is subjected to torque it undergoes torsional deformation characterized by the angle of twist. The relation between the angle of twist and the torque is a measure of the torsional stiffness , and the shear modulus of material can be found from this relation. Relations for the engineering strain (for small strains)

$$\gamma = \frac{d\theta}{2L}$$

angle of twist ,

$$\theta = \frac{2\gamma L}{d}$$

Shear stress is related to shear strain by

$$\tau = G\gamma \quad ; \qquad \tau_{max} = \frac{Td}{2J}$$

For solid circular shafts of diameter 'd',

$$J = \frac{\pi d^4}{64} \qquad (J = Polar \quad moment \quad of \quad inertia)$$

another useful relation for angle of twist 'θ' is,

$$\theta = \frac{TL}{GJ}$$

From the table calculated, Plot a graph of the applied torque T against the angle of twist θ for each specimen, and using the above relation, determine the modulus of rigidity G, from the slope of the graph.

The test specimens are held at each end by sockets mounted on the input and pendulum shafts. The true shear-stress vs shear-strain curve for a material can be produced by testing a thin-walled tubular specimen also. The main assumption is that the wall is thin enough to produce a uniform shear-stress distribution across it given by:

$$\tau = \frac{16.d_0 \text{T}}{\pi\left(d_0^4 - d_i^4\right)}$$

where   t = wall thickness, = d_0 -d_i

d_0 = outer diameter

d_i = inner diameter

The bore must be smooth otherwise stress raisers (stress concentration) will be present and give erroneous results and premature failure.

Care must be taken not to distort the specimen when fitting the torsionmeter.

EXPERIMENTAL PROCEDURE

Before proceeding with experimental work two point must be carefully noted:

i)   Since it is not sufficient to measure deflection between the grips of a testing machine; a torsiometer is required to demonstrate general behavior accurately. It must be remembered that in destructive testing there is no opportunity to go back and check readings

ii)   In torsion testing the observed readings are those of torque and twist. The results of interest are of shear-stress and shear-strain, in particular, the shear-stress vs shear-strain characteristics of the material. This is due to our interest in stress analysis for design purposes. If we merely require the torsional strength of a shaft we can apply torque to that shaft and measure the deflection over its length. In carrying out a tension test the assumption that the stress is uniform over the cross-section is usually accurate and, therefore , it is a simple matter to convert from force to stress. In the case of the torsion of a solid circular shaft the stress varies directly as the radius; it is not a simple matter to convert from torque to shear-stress.   One way of finding this true shear stress is to use thin walled tubular specimens where radial stress variation along thickness of the tube is neglected.

For purposes- of comparison what is usually done is to plot the NOMINAL SHEAR-STRESS V SHEAR-STRAIN curve (which was studied in torsion test of solid bar under the subject strength of material in B.E I I yr)

Step wise procedure:

(a) Use the motor to rotate the input shaft in increments of say 1.5^0 (i.e 5 revs to the counter). At each value record the counter reading, the torque value and the pendulum angle. This can be carried out incrementally or continuously (constant strain rate).

(b) Continue until the specimen has yielded, then increase the interval between reading to, say 6^0 (20 revs) and later to 15^0 (50revs) or more if testing relatively ductile specimens.

(c) If it is required to remove a strained specimen before fracture (for example for heat treatment), reverse the motor and run it until the pendulum angle falls to zero, and sockets become loose on the specimen. Then withdraw the sliding input shaft and remove the specimen.

NOTE: ALWAYS USE PROTECTION GLASS BEFORE ROTATING THE INPUT SHAFT.

OBSERVATION, CALCULATION, PLOTS AND RESULTS

In the case of the torsion of a thin walled hollow circular shaft the radial stress variation is assumed to be negligible; therefore it is assumed that the shear stress (τ) is true. Use the following table and calculations for plotting true Shear stress (τ) vs true Shear strain (γ) curve (τ - γ curve).

Observation table   (when torsion meter Not used)

speed counter reading (I)	Input shaft rotation = (I) x 0.3° (II)	Pendulum angle (III)	Total twist (θ) = [(II)-(III)] x π/180 rad	Applied torque T (N.m)	τ = (N/m²)	γ = (d x θ)/ (2 L)

Observation table   (when Torsionmeter Is Used)

speed counter reading (I)	Rotation Reading mainsacle (II)	Rotation Reading vernier scale (III)	Total twist (θ) = [(II)-(III) x LC] x π/180 rad	Applied torque T (N.m)	τ = (N/m²)	γ = (d x θ)/ (2 L)

Note:

$$\tau = \frac{16.d_0 T}{\pi\left(d_0^4 - d_i^4\right)}$$

where, t = wall thickness(d_0 -d_i)   ; d_0 = outer diameter; d_i = inner diameter

  T = torque (Nm);   θ = twist of the specimen (rad);

  L = gauge length of the specimen (m);   τ = True shear stress (N/m²)

  γ = True shear strain;   LC= least count of the vernier scale.

CONCLUSION, DISCUSSIONS AND SUGGESTIONS

a) Compare the experimentally determined values of G with published values and comment on it.

b) What may be the possible sources of errors in the experiment?

c) Discuss the importance of conducting the torsion test in a thin walled hollow tube?

Appendix, Torsionmeter,

The Tecquipment Torsiometer SM 21a

INTRODUCTION

The Tecquipment Torsiometer Model SM 21a is specially designed to fit onto the standard. This torsiometer can accomodate total strains of any magnitude due to the facility of being able to adjust the dial indicator drive. It can be used therefore to measure strains accurately in both the elastic and plastic regions.

CONSTRUCTION: A sectional arrangement of the TecQuipment Torsiometer Model SM 21a is shown in Figure 2 to which reference should be made. The torsiometer consists basically of two cylindrical components A and B which are capable of relative rotation but are constrained against relative axial movement by two shoulder screws C. Each part, A and B, contains two diametrically opposite screws D which have 90° cone points. The screws in part A are short socket drive screws whilst those in B are much longer for ease of manipulation. These sets of screws are used to clamp the torsiometer to the specimen and set the gauge length to 50 mm. Integral with component B is a disc E carrying a scale F marked out in degrees. A dial gauge G is also attached to the disc E in such a position that its axis is 25 mm from the axis of the specimen. The dial gauge plunger should rest on the flat portion of the rod H which is attached to ring J. Also attached to J is a cursor K which moves over the scale F. This assembly is held in position on component A by the locating ring L. (Note: In figure 2 ring J is shown 90° out of position.) The locking screw M in ring J is used to set the zero position of the dial gauge (and the initial position of the cursor). It is also used to adjust the position of J during testing so as to accommodate large strain readings.

ATTACHMENT : The Torsiometer is attached to specimen by threading the specimen through the center of the torsiometer after unscrewing, the four gripping screws D (2 at each end). Place the two segments corresponding to the specimen diameter in position as shown in Fig 3 then, holding the torsiometer in the required position relative to the length of the specimen, tighten the two gripping screws so that the clearance between the segment and the specimen is the same for each segment.

After these two screws have been tightened tipping the whole assembly upside down will allow the segments to fall out of position. The segments should now be placed in the corresponding position at the other end of the torsiometer. Rotate this end so that the two sets of gripping screws are at 90° to each other and tighten up as before.

Remove the segments and insert the assembly in the torsion machine as described below.

OPERATION: The dial gauge is easier to read if the specimen is inserted in the machine with the end B of the torsiometer adjacent to the pendulum scale. Withdraw the drive shaft to its full extent. Slide the end of the specimen into the drive socket attached to the pendulum shaft then push the drive shaft toward the specimen. At this stage it may be necessary to drive / inch the motor to line up the drive socket with the specimen. Slide the drive shaft so that the specimen is fully engaged by the drive socket.

The torsiometer is now ready for use. Should the full-scale deflection of the dial gauge be insufficient at the first clamp position of ring J, it may be adjusted to enable further readings to be taken by slackening the screw M and setting the ring J. This does not disturb the clamping of the torsiometer in any way and allows continual adjustment throughout the test.
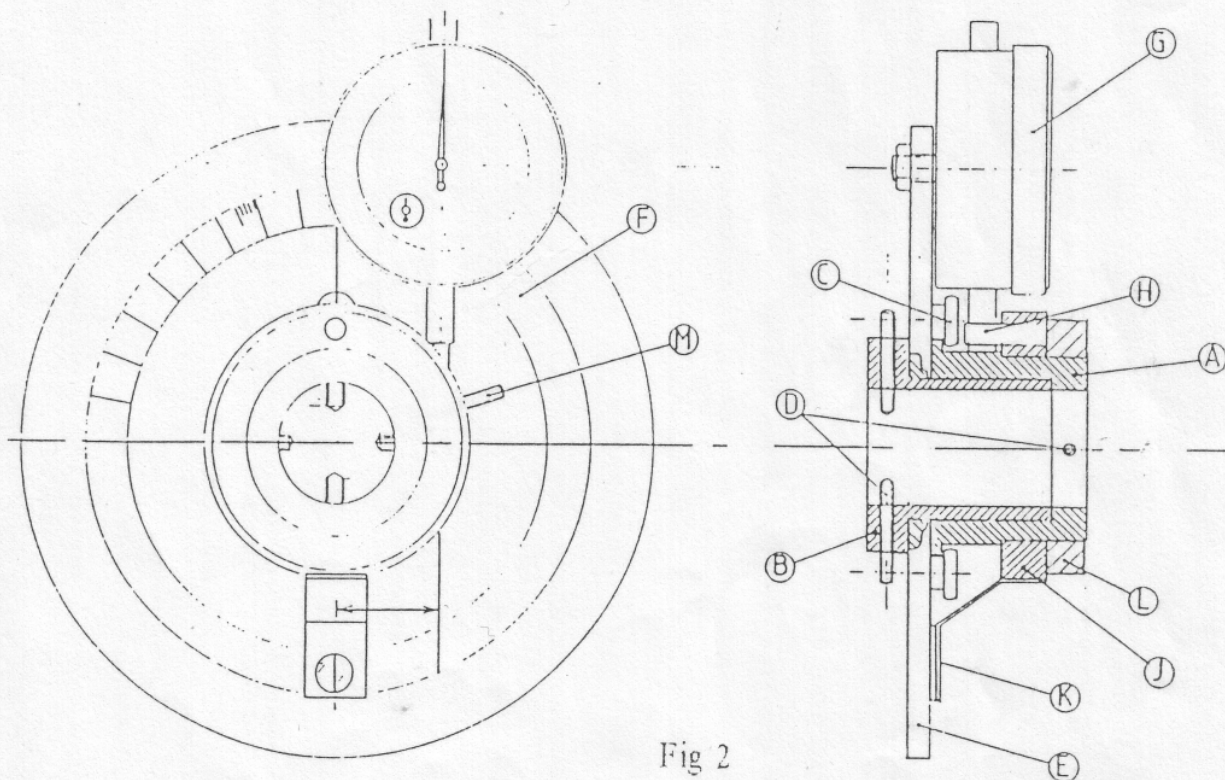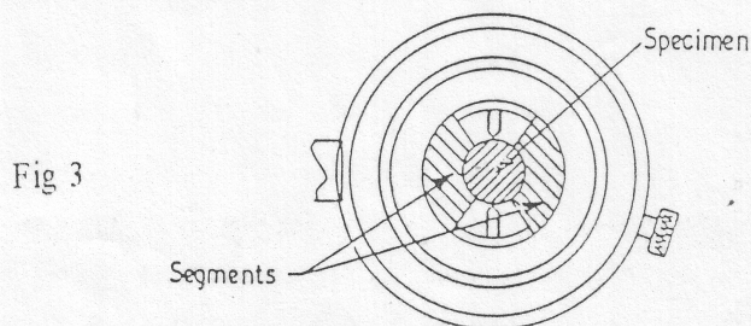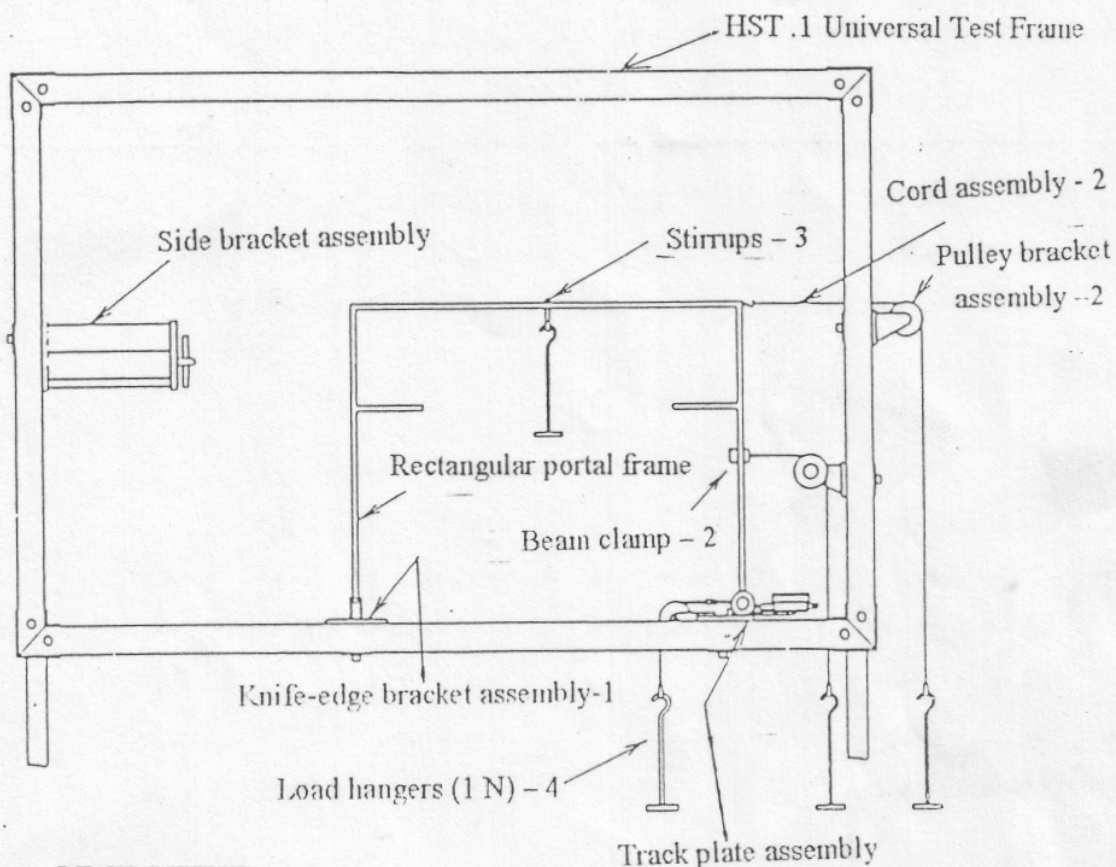
Fig 2

Fig 3

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EXPERIMENT NO : 3

TITLE :   DEFLECTION OF FRAMES

HST .1 Universal Test Frame

Side bracket assembly

Stirrups – 3

Cord assembly - 2

Pulley bracket assembly –2

Rectangular portal frame

Beam clamp – 2

Knife-edge bracket assembly-1

Load hangers (1 N) – 4

Track plate assembly

OBJECTIVE:

To compare experimental and theoretical values of the deflection of frames.

APPARATUS REQUIRED :

The standard set of items (HST .303)) supplied consists of:

- HST .1 Universal Test Frame – 1 Set
- Pulley bracket assembly –2 Nos
- Stirrups – 3
- Beam clamp – 2
- Track plate assembly – 1
- Knife-edge bracket assembly-1
- Side bracket assembly - 1

- Rectangular portal frame -1
- Dial gauge assembly- 1 No.
- Open square frame – 1
- 'S' frame with rollers –1
- Cord assembly - 2
- Load hangers (1 N) – 4
- Allen key (1- 6mm) – 1 set

- The weight set required is 50N -1, 20N -2, 10N -4, 5N -1, 2N -2, 1N -1, 0.5N – 1, 0.2N - 2, 0.1N -1.

Three standard test frames made from 25 x 8 mm mild steel bar are provided with end supports as required. The open square frame is cantilevered from a side bracket. The 'S' frame is simply supported between a knife edge at one end and a clamp-on roller.   The

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rectangular portal frame has internal brackets to simulate an overhead travelling crane fixing. One foot terminates in a knife edge while the other has a roller which is set up on a track plate to provide zero or a variable horizontal restraint. The track plate is fitted with a horizontal deflection dial gauge. A knife edge bearing plate completes the support accessories . A collection of fastenings, cables, pulley brackets and load hangers affords the opportunity to load the frames vertically or horizontally when erected in the HST.1 Universal test frame . A side bracket enables fixing of the Open Square and 'S' Frames.

(*Optional Extra frames can be : Unsymmetrical Portal Frame, Redundant Square Frame, Square Portal Frame, Rectangular Portal Frame.*)

THEORY

Calculation of the deflection of frames is an important part of structural analysis. Many industrial buildings are single story enclosed spaces with the roof and walls supported on portal frames. For economy these frames are normally redundant, either two pinned or fixed base portals. The classical solution of the former is to find what horizontal ground restraint is required to cancel the outward deflection the applied load would cause to the unrestrained portal. Fixed base portals are analyzed by a different method introduced later (see experiments 3/10 and 3/11) under the headings Slope Deflection and Moment Distribution.

This experiment takes one through the process of determining deflections by the unit load method, and then using the deflections of a portal frame to analyze a two pinned portal. There is an obvious similarity to the solution already used for a propped cantilever. (*Refer "Detail Theory for Calculation " later in this manual*).

PROCEDURE

Part 1, OPEN SQUARE FRAME

The open square frame is set up by clamping it to the side bracket on the left side of the HST.1 frame. Detailed instructions are given in the construction. Appendix, clauses 1- 4. Check that the center line dimensions of the frame are 450 x 450 mm.

1. The side bracket is to be permanently fixed with the top edge 315 mm above the base of the HST.1 frame(see also 8.)

2. The open square test specimen is to be clamped to the side bracket to give a free length of 450 mm to the center line of the top member.
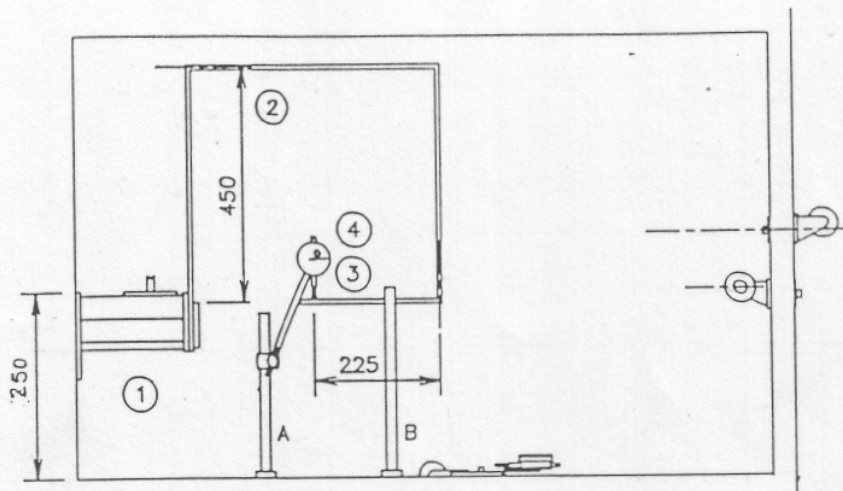
3. Place a stirrup and load hanger 225 mm along the bottom member from the center line of the vertical side member.

4. Set up the dial gauge with a flat anvil on the top of the stirrup taking care that the anvil lays level on the stirrup . There must be enough clearance between the load hanger and the dial gauge stand to use a 20N weight. The dial gauge spindle must be up nearly at its top position (reading around 1200).

Record the dial gauge reading with only the load hanger in position as the "no load " value. Apply 40 N load in increments of 10 N entering the dial gauge readings at each increase in Table 1.

Table 1
Open Square Frame

End Load (W) (N)	Dial Gauge Reading (.01mm)	Deflection (mm)	Theoretical Deflection (mm)

5. At the end of part 1 move the dial gauge out of the way before changing the test specimen.

(*Note: See "Result Appendix" for Part 1, later in this manual*)

Part 2, 'S' FRAME

(*Note: If the previous users of the apparatus finished work with the rectangular portal in position it would save time to do part 2).*

The 'S' frame is set up between the raised knife edge bracket and with the roller bearing on the track plate. Detailed instructions are given in the Construction Appendix clauses 6 to 13.

CONSTRUCTION (APPENDIX) (For Part 2)
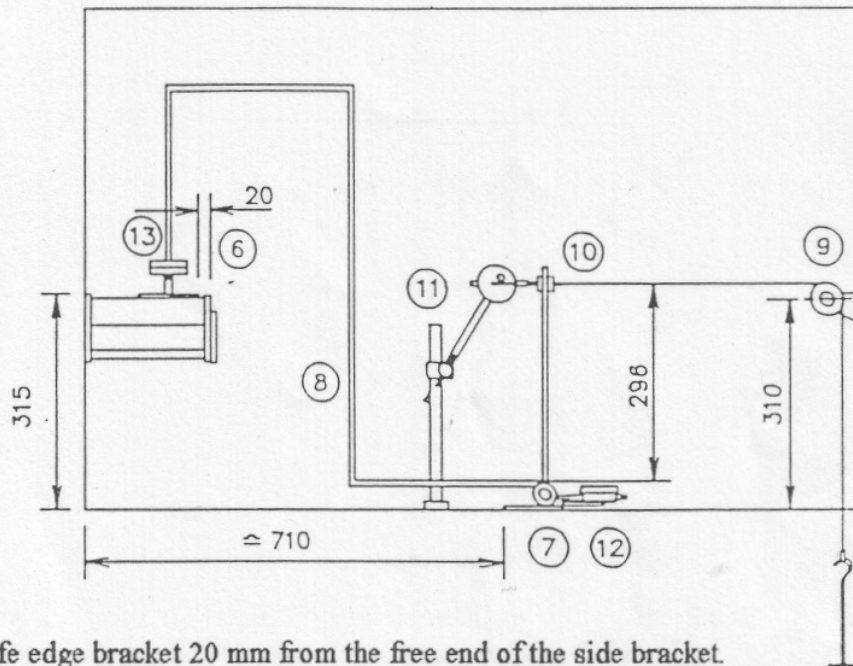
6. Position the knife edge bracket 20 mm from the free end of the side bracket.

7. Position the track plate about 710 mm from the left side of the HST.1 frame

8. Place the 'S' frame on the knife edges and its rollers on the track plate. Check that the two rollers bear evenly on the track plate. This can be achieved by twisting the side bracket within its clearance in the HST.1 frame, but once done the bracket should not be moved.

9. Fix a pulley bracket with the center of the pulley 310 mm above the base of theHST.1.

10. Using a beam clamp or stirrup, a load cord and a load hanger, arrange for a horizontal force to be applied 300 mm above the center line of the base member of the 'S' frame .

11. Set up a dial gauge to read the horizontal movement of the loaded point. For a beam clamp use a ball anvil: for a stirrup use a flat anvil carefully laid levelly on the stirrup. The dial gauge spindle must be fully to the left with a reading around 1200.

12. If necessary, adjust the position of the track plate so that its dial gauge has nearly zero reading (spindle fully to left).

13. Finally place two 10 N on the knife edge end of the 'S' frame to hold it down when the load is applied.

Check that the center line dimensions of the frame are based on a 300mm module within an overall size of 600 x 600 mm. Make sure that the 20 ballast weight is holding down the knife edge support.

Record the "no load" dial gauge readings with only the load hanger in place. Apply 30 N load in 5N increments entering the dial gauge reading at each loading in Table 2.

Table 2
'S' Frame

	Loaded Point			Roller Bearing		
Horiz.	Dlg.		Theoret.	Dlg.	Deflec.	Theoret.
Load	Reading	Deflec.	Deflec.	reading		Deflec.
(mm)	(.01mm)	(mm).	(mm)	(.01mm)	(mm).	(mm)

14. After part 2 remove the load, then the free end dial gauge, next the two 10N ballast weights and then the 'S' frame. (*See "Result Appendix" for Part 2, later in this manual*)

Part 3, RECTANGULAR PORTAL FRAME

To set up the rectangular portal frame follow the detailed instructions in the Construction Appendix stage by stage. Clauses 15 to 19 describe the positioning of the portal for all stages. Measure the center line dimensions.

CONSTRUCTION (APPENDIX) (For Part 3)
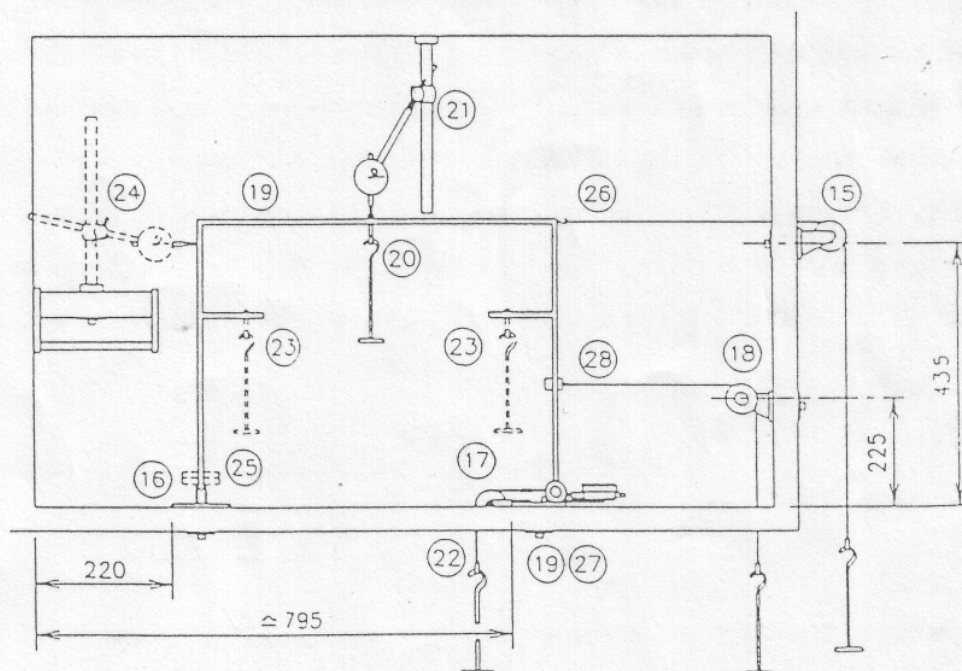
15. One pulley bracket is permanently fixed with the center of the anchor screw 435 mm above the base of the HST.1 frame.

16. Move the knife edge bracket from the side bracket to the base of the HST.1 frame 220 mm from the left side.

17. Move the track plate to 795 mm from the left side.

18. Move the lower pulley bracket so that the center of the pulley is 225 mm above the base of the frame.

19. place the portal frame in position. Check that the rollers bear evenly on the track plate. If not, insert folded paper packing under the lose side of the track plate to even the bearing of the roller.

For stage (i) position load hangers and dial gauges according to clauses 20 to 22.

20. Place a stirrup and load hanger at the mid-span of the portal .

21. Set up the dial gauge with a flat anvil on the top of the stirrup and the anchorage on the top of the HST.1 frame.

22. Run the horizontal load cord of the portal right hand bearing over the track plate pulley and apply a load hanger. If necessary, adjust the position of the track plate so that the dial gauge is at mid-travel (about 600).

Record the "no load" dial gauge readings. Place a 50N load at mid-span of the top member of the portal and note the new dial gauge readings. Repeat these zero and 50N load readings twice more to obtain an average of the three sets and as a check of the repeatability. It is necessary to bang the base of the HST.1 frame to ease the friction in the roller bearing. Remove the 50N load and record the "no load" datum reading of the dial gauges. Apply loading of 5N by increments of 1N to the horizontal thrust hanger of the roller bearing. At each load note both dial gauge readings. Use Table 3.

Table 3
RECTANGULAR PORTAL FRAME

Horiz. Load. (N)	Loaded point			Roller Bearing		
	Dlg. Reading (.01mm)	Deflec. (mm)	Theoret. Deflec. (mm)	Dlg. Reading. (.01mm)	Deflec. (.1mm).	Theoret. Deflec. (.1mm)

Finally with no load on both hangers take the datum reading of the track plate dial gauge. Place the 50N at mid- span and add weights to the horizontal through hanger until the dial gauge reading returns to its datum value. Record the horizontal the horizontal force is zero displacement condition.

Prepare for stage (ii) as described in clause 23 having first removed the mid-span load hanger and stirrup.

(ii)

23. After the first stage of Part 3 is done, apply stirrups with load hangers on the bracket arms 75 mm from the center line of the vertical sides of the portal frame.

Record the reading of the track plate dial gauge with no load on the bracket arms of the portal legs. Note the new reading when 20N (2 x 10N) is placed on each of the brackets simultaneously. Repeat these readings twice more for averaging. Finally with both 20N loads in place add weights to the horizontal thrust hanger until the track plate dial gauge returns to its no load reading. Note the value of these weights.

Move the dial gauge to measure the horizontal sideways at the top of the portal for stage (iii) as in clauses 24 to 27 of the Construction Appendix.

(iii)

24. For the third stage move the dial gauge to the side bracket and use the ball anvil against the top corner of the portal. Arrange for the maximum travel to the right.

25. Put two 10N ballast weights on the knife edge bearing of the portal to prevent it lifting.

26. Using a load cord and a hanger, arrange to apply a horizontal load as close as possible to the top of the right hand leg of the portal. Remove all other stirrups and hangers.

27. Adjust the position of the track plate so that the dial gauge reading is nearly zero to allow maximum travel to the right.

Make sure a ballast of 20N is placed on the knife edge support of the portal. There should now be no load hangers on the portal frame and just one being used to produce a sway force at the top of the portal. Record the "no load" reading of both dial gauges, and also the readings when 10N horizontal force acts on the portal. Repeat the readings for averaging.

For Parts 1 and 2 tabulate the sets of dial gauge readings and use the derived deflections to plot graphs of deflection against load. Draw the best fit straight lines and compare the gradients with theoretical values using $E = 205$ kN/mm^2.

For the final stage (iv) a second horizontal force is applied at mid-height of the leg of the portal (see clause 28). Again obtain a set of no load readings (hangers only) and readings with a pair of 10N forces acting sideways on the portal.

(iv)

28. Using a second beam clamp or stirrup, a load cord and a hanger, arrange to apply a horizontal load halfway up the right hand leg of the portal.

   (See "Result Appendix" for Part 3, later in this manual).

OBSRVATIONS, CALCULATION, PLOTS and RESULTS

For Part 1 and 2 tabulate the sets of dial gauge readings and use the derived deflections to plot graphs of deflection against load. Draw the best fit straight lines and compare the gradients with theoretical values using $E = 205$ kN./ mm^2.

In Part 3 compare the averaged results with theoretical values. The 'detail theory for calculation' shows how to calculate the deflections. Draw the bending moment diagram for the portal in the special case of stage (I) where the horizontal thrust imposes the condition of zero deflection at the roller bearing.

CONCLUSIONS/ DISCUSSIONS / SUGGESTIONS

How well did the experimental and theoretical deflections agree?

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DETAIL THEORY FOR CALCULATION (APPENDIX)

This is a further use of the unit load method and Simpson's rule. The formula is

$$\Delta = \int \frac{M_P m\, ds}{EI}$$

in which ds is taken along the central axis of each part in bending. Because the frames have vertical and horizontal parts a system for defining +ve and -ve when drawing the BMD' is needed. The safest system is to draw the BMD on the tension side of the bending member. The product $M_P \cdot m$ is then +ve when the BMD's are on the same side of the member. For example see the 'S' frame and the BMD's for the deflection at the bottom corner.

Open Square Frame

M_P & m_V (P=1)
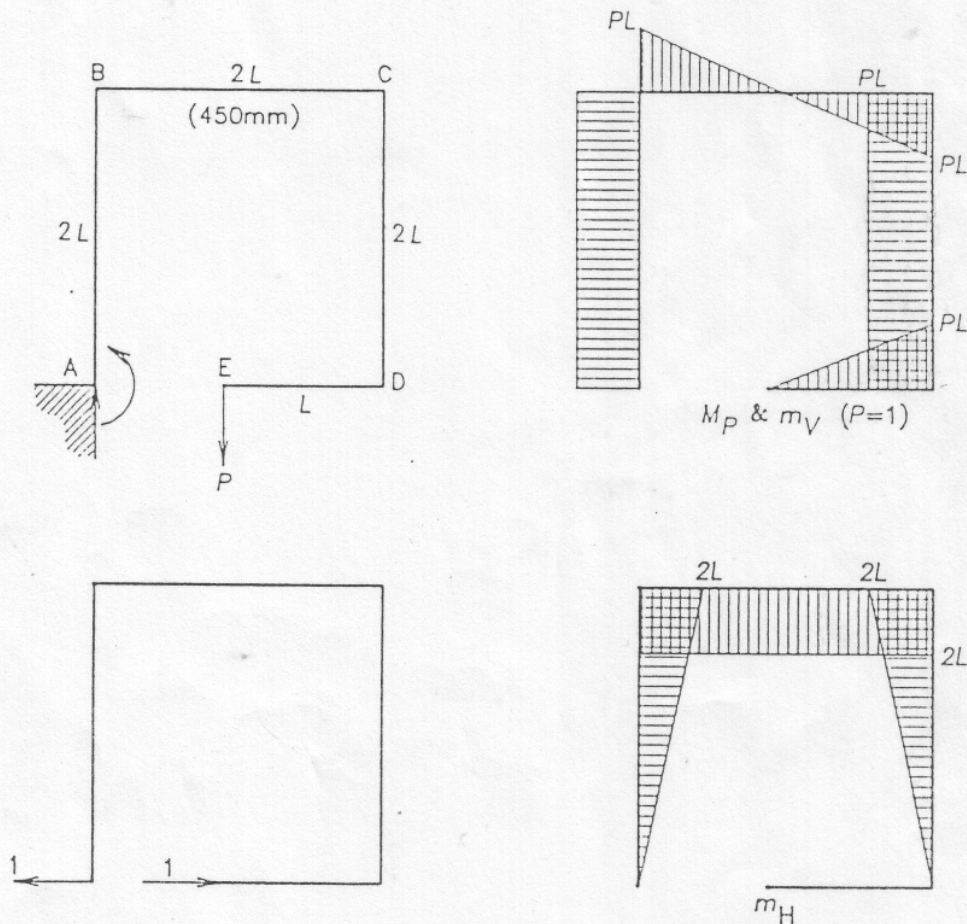
At E

$$\delta_v = \oint \frac{M_p m_v ds}{EI}$$

ED $\quad \int \quad = \quad \dfrac{L}{6EI}\left[0 \quad + \quad \dfrac{4PL.L}{2}\dfrac{L}{2} \quad + \quad PL.L\right] \quad = \quad \dfrac{PL^3}{3EI}$

DC,AB $\quad \int \quad = \quad 2 \quad x \quad \dfrac{2L}{6EI}\left[PL.L + 4PL.L + PL.L\right] \quad = \quad \dfrac{4PL^3}{EI}$

BC $\quad \int \quad = \quad 2\int ED \quad = \quad \dfrac{2PL^3}{3EI}$

$\qquad \delta_v \quad = \quad \dfrac{5PL^3}{EI}$

$\qquad \delta_H \quad = \quad 0$ (negative and positive equal)

P=40 N $\quad \delta_v \quad = \quad \dfrac{5 \times 40 \times 225^3}{219 \times 10^6} \qquad = \quad 10.4$ mm

$\qquad EI \quad = \quad \dfrac{205 \times 10^3 \times 25 \times 8^3}{12} \quad = \quad 219 \times 10^6$ N.mm^2

'S' Frame

M_P & m_F (P=1)

m_E
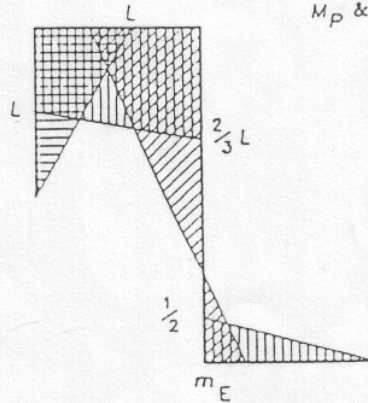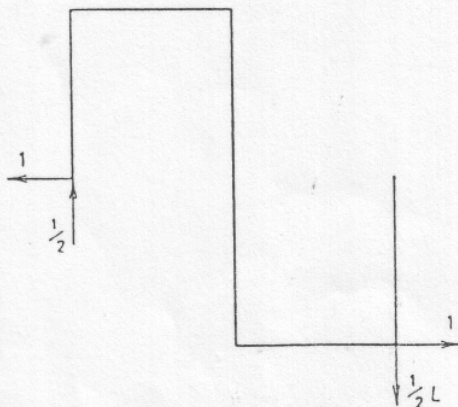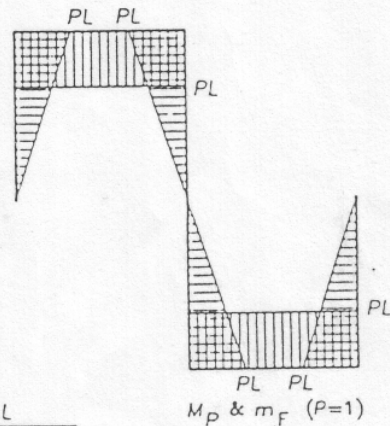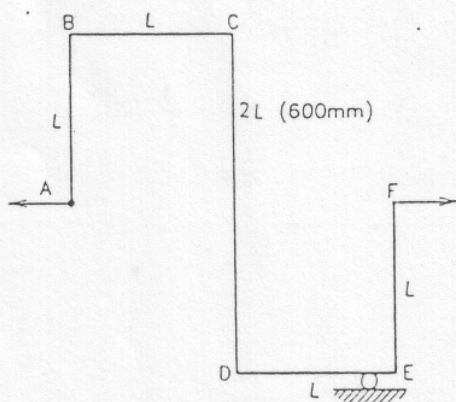
At F

$$\delta_F = \oint \frac{M_p m_F ds}{EI}$$

EF,AB CD $\quad \int \quad = \quad 2 \quad x \quad \dfrac{PL^3}{3EI} \quad + \quad 2 \quad x \quad \dfrac{PL^3}{3EI} \qquad = \quad \dfrac{4PL^3}{3EI}$

BC,DE $\quad \int \quad = \quad 2 \quad x \quad \dfrac{PL^3}{EI} \quad = \quad \dfrac{2PL^3}{EI}$

$\qquad \delta_F \quad = \quad \dfrac{10PL^3}{3EI}$

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At E

$$\delta_E = \oint \frac{M_P m_E ds}{EI}$$

ED $\quad \int = \dfrac{L}{6EI}\left(0 \quad + \quad 4 \quad \times \quad \dfrac{L.PL}{4} \quad + \quad \dfrac{L.PL}{2}\right) \quad = \quad \dfrac{PL^3}{4EI}$

DC $\quad \int = \dfrac{2L}{6EI}\left(\dfrac{L.}{2}\ \dfrac{PL}{2} \quad + \quad 0 \quad + \quad \dfrac{3L.PL}{2}\right) \quad = \quad \dfrac{7PL^3}{12EI}$

CB $\quad \int = \dfrac{L}{6EI}\left(\dfrac{3L.PL}{2} \quad + \quad 4 \quad \times \quad \dfrac{5L.PL}{4} \quad + \quad L.PL\right)= \quad \dfrac{5PL^3}{4EI}$

BA $\quad \int = \dfrac{PL^3}{3EI}$

$$\delta_E = \frac{29PL^3}{12EI}$$

$P = 30\ N \quad \delta_F = \dfrac{10 \times 30 \times 300^3}{3 \times 219 \times 10^6} \quad = \quad 12.3\ \text{mm (to right)}$

$\delta_E = \dfrac{29 \times 12.3}{40} \quad = \quad 8.9\ \text{mm (to right)}$

Rectangular Portal

M_P & $m_1(P=1)$ $\qquad\qquad m_2 \qquad\qquad M_W$

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