COURSE INFORMATION

COURSE TITLE: ENGINEERING LABORATORY V (BDA 37001)

TOPIC 1: DEFLECTION OF CANTILEVER BEAM

1. INTRODUCTION

The Beam Apparatus allows an extensive range of experiments to cover virtually all course requirements relating to bending of beams. The basic unit provides facilities for supporting beams on simple, built-in and sinking supports, applying point loads, and measuring support reactions and beam deflections. The Beam Apparatus can be used for an almost limitless number of experiments ranging from determination of the elastic modulus for beams of different materials, through to studies of continuous beams with any loading.

2. OBJECTIVE

The main objective of this experiment is to study the variation of deflection of a simply supported beam with load and different beam’s material.

3. LEARNING OUTCOME

At the end of this experiment, students should be able to:

3.1 Conduct experiment, record, tabulate and analyze the raw data.
3.2 Plot the graph of load against deflection for every specimen tested.
3.3 Determine the modulus of elasticity for each specimen.
3.4 Compare the value of modulus of elasticity from experiment with the theory.
3.5 Produce good conclusion from the experiment conducted.

4. THEORY

When a beam is loaded in such a way that it bends only in the plane of the applied moment (Figure 1), the stress distribution and curvature of the beam are related by:-

\[ \frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R} \]  \[\text{Figure 1}\]

\[ \sigma = \frac{My}{I_y} \]

Where,

M is the bending moment
I, is the second moment of area of the beam section (moment of inertia)
E is the modulus of elasticity
R is the radius of curvature
\( \sigma \) is the bending stress at the distance y from the neutral axis
y is the distance from the neutral axis.

It can also be shown that the curvature of a beam \( 1/R \) is given to a close approximation, by the second derivative of the deflection. If z is the deflection of the beam at distance x from a chosen origin then:

\[
\frac{d^2z}{dx^2} = \frac{1}{R} = \frac{M}{EI} \quad \text{(2)}
\]

Using equation (2) it can be shown that the deflection of a beam subjected to direct loading can always be expressed in the form:

\[
z = a \frac{WL^3}{EI} \quad \text{(3)}
\]

Where,

- \( a =1/48 \) for the central axial loading of a simply supported beam.
- \( z \) is the deflection
- \( W \) is the load acting on the beam
- \( L \) is the span
- \( E \) & \( I \) are defined above.

Figure 1
5. **APPARATUS.**

**Figure 2** shows TQ SM104 Beam apparatus, set of weights and three beams (Steel, Brass, Al).

![Figure 2](image)

6. **PROCEDURE** (Refer to **Figure 3**)

6.1 Measure and record the dimension of each beam (length, height and width). Fill up **Table 1**
6.2 Set up one of the beam on the knife edge (choose a suitable length, L).
6.3 Place a hanger at mid span so that the loading point is on the centerline of the beam, (L/2).
6.4 Set up a dial gauge L/4 -span to the right of mid-span reading (dial gauge F).
6.5 Check that the beam is parallel to the cross member by adjusting the height of the knife edge using the knife edge supporting screw so that the dial gauge reads zero.
6.6 Set the dial gauge to zero.
6.7 Apply a load to the hanger and record the beam deflection on the dial gauge F and \( W_2 \).
6.8 Set dial gauge D to zero.

6.9 Increase the load to the hanger and record the new dial gauge reading (deflection).
6.10 Record the value of \( W_2 \) and deflection F for every additional load.
6.11 Decrease the load by the same steps as 6.9 and record the beam deflection at each step.
6.12 Make sure dial gauge D is set to zero after each removal of load.
6.13 Repeat the experiment for the three beams. Fill up Table 2, 3 and 4.
6.14 Using Macaulay Method,

\[
EI \frac{d^2 y}{dx^2} = W_2 x - W \left( x - \frac{L}{2} \right) \quad \ldots (1)
\]

\[
EI \frac{dy}{dx} = \frac{W_2 x^2}{2} - \frac{W}{2} \left( x - \frac{L}{2} \right)^2 + C \quad \ldots (2)
\]

\[
EI Y = \frac{W_2 x^3}{2} - \frac{W}{6} \left( x - \frac{L}{2} \right)^3 + Cx + D \quad \ldots (3)
\]

\[ x = L, \quad Y = 0 \quad \Rightarrow C = \frac{1}{4L^2} \left( W L^2 - 3 W_2 L^2 \right) \]

\[ x = L, \quad \frac{dy}{dx} = 0 \quad \Rightarrow W_2 = \frac{5W}{16} \]

Deflection at point \( x = L/4 \)

\[
y = \frac{L^3}{EI} \left( \frac{W_2}{384} + \frac{W - 3 W_2}{192} \right) \quad \ldots (4)
\]

Where,

\( L \) = Length of beam (choose suitable length from experiment)

\( E \) = Young’s Modulus = 205GPa

\( I \) = Second moment area of beam

\( W \) = Load

\( Y \) = Deflection at point \( x = L/4 \)
7. **OBSERVATIONS**

Table 1

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<th>Specimen</th>
<th>Length (mm)</th>
<th>Thickness (mm)</th>
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<th>$I$ value($m^4$)</th>
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Table 2: Mild Steel

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<th>F (x0.1mm)</th>
<th>$W_2$ (x0.2Nmm)</th>
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Table 3: Brass

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Table 4: Aluminium

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<th>Load decreased(N)</th>
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*Note: The tables above show the material testing results for Brass, Mild Steel, and Aluminium.*
8. ADDITIONAL THEORY

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9. OBSERVATION

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10. DISCUSSION

10.1 For each beam plot a graph of deflection against load. Determine the gradient of each graph to calculate the modulus of elasticity.

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11. CONCLUSION

Write your observations and comments whenever possible in your discussion in term of achievement, problems facing throughout the experiment and recommendation for improvement.

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TOPIC 2: BUCKLING OF STRUT

1. INTRODUCTION

A strut is a thin compression member. It may collapse under a compressive load by buckling and bowing out as shown in Figure 1. The diagram shows the member with its length horizontal but it is just as likely to be vertical. It is drawn this way so that the x-y coordinates are in the normal position at the left end. \( x \) measures the distance along the length and \( y \) is the deflection.

![Figure 1](image)

2. OBJECTIVE

The main objective of this experiment is to study the buckling of slender columns and relationships between length, end fixing conditions and buckling load.

3. LEARNING OUTCOME

At the end of this experiment, students should be able to:

3.1 Conduct experiment, record, tabulate and analyze the raw data.
3.2 Understand relationship between strut length and collapse load.
3.4 Understand relationship between various end-fixing conditions and collapse load.
3.4 Understand the nature of deflection and deflected shapes with various end-fixing conditions.
3.5 Produce good conclusion from the experiment conducted.
4. THEORY

Euler Theory For Collapse

Assumptions:

1. The strut is initially straight.
2. Axial load is applied.
3. Strut is made of homogeneous material.

For an ideal case, strut will remain straight when load is increased slowly until it reaches the critical load, if when disturbed, the strut will buckle suddenly. If the load is increased, the strut will fail, if load is reduced, the strut will be straight again.

If the above conditions are not fulfilled, the strut will bend immediately when an axial load is applied to it.

Equation solution (1) is
\[ y = A \cos \mu x + B \sin \mu x \] . . . . . . . . . . . (3)

Boundary conditions

When \( x = 0 \), \( y = 0 \), \( A \cos 0 = 0 \), hence \( A = 0 \)
When \( x = L \), \( y = 0 \), \( 0 + B \sin \mu L = 0 \)

Hence either \( B = 0 \) or \( \sin \mu L = 0 \)

If \( B = 0 \) hence becomes indeterminate hence buckling is indeterminate
If \( \sin \mu L = 0 \) hence \( B \) is determinate and strut buckling is determinate.

When \( \sin \mu L = 0 \)

\[ \mu L = \pi, 2\pi, 3\pi, \ldots \ldots \]

or \( \mu L = n\mu \) with \( n = 1, 2, 3, \ldots \ldots \)

From the above equation:

\[ \mu = \frac{n\pi}{L} \]

From equation (2):

\[ \mu^2 = \frac{n^2\pi^2}{L^2} = \frac{P}{EI} \]

Which gives:

\[ P = \frac{n^2\pi EI}{L^2} \ldots \ldots (4) \]

Hence from equation (4) for buckling to occur the smallest value is \( n = 1 \) i.e.

\[ \ldots \ldots \text{which is known as the Euler Load} \]

5. **APPARATUS.**

**Figure 2** shows the Buckling of Struts experiment. There are five aluminium alloy struts included in this experiment. Printed on the equipment are a number of equations and pieces of information that you will find useful while using the equipment.
6. PROCEDURE

Part1: Buckling Load of a Pinned-End Strut

Compressive members can be seen in many structures. They can form part of a framework for instance in a roof truss, or they can stand-alone; a water tower support is an example of this. Unlike a tension member which will generally fail if the ultimate tensile stress is exceeded, a compressive member can fail in two ways. The first is via rupture due to the direct stress, and the second is by an elastic mode of failure called Buckling. Generally, short wide compressive members that tend to fail by the material crushing are called columns. Long thin compressive members that tend to fail by buckling are called struts. When buckling occurs the strut will no longer carry any more load, it will simply continue to displace i.e. its stiffness becomes zero and it is useless as a structural member.

In this experiment we will load struts until they buckle to investigate the effect of the length of the strut. To predict the buckling load we will use the Euler buckling
formula. Critical to the use of the Euler formulae is the slenderness ratio, which is the ratio of the length of the strut to its radius of gyration \((l/k)\). The Euler formulae become inaccurate for struts with a \(l/k\) ratio of less than 125 and this should be taken into account in any design work. The struts provided have an \(l/k\) ratio of between 520 and 870 to show clearly the buckling load and the deflected shape of the struts. In practice struts with an \(l/k\) ratio of more than 200 are of little use in real structures.

We will use the Euler buckling formula for a pinned strut:

\[
P_c = \frac{\pi^2 EI}{L^2}
\]

Where:

- \(P_c\) = Euler buckling load (N)
- \(E\) = Young’s modulus (Nm\(^{-2}\))
- \(I\) = Second moment of area (m\(^4\))
- \(L\) = Length of strut (m)

Referring to Figure 3, fit the bottom chuck to the machine and remove the top chuck (to give 2 pinned ends). Select the shortest strut, number 1, and measure the cross section using the vernier caliper provided and calculate the second moment of area, \(I\), for the strut.

**Figure 3: Experimental layout (pinned ends)**

Adjust the position of the sliding crosshead to accept the strut using the thumbnuts to lock the slider. Ensure that there is maximum amount of travel available on the handwheel thread to compress the strut. Finally tighten the locking screws. Carefully back off the handwheel so that the strut is resting in the notch but not transmitting any load; rezero the force meter using the front panel control. Cautiously start to load the strut. If the strut begins to buckle to the left, “flick” the strut to the right and vice versa (this reduces any errors associated with the straightness of the strut). Turn the hand wheel until there is no further increase in
Load (the load may peak and then drop as it settles into the notches). Record the final load in Table 1 under ‘buckling load’.

Repeat with strut numbers 2, 3, 4 and 5 by adjusting the crosshead as required to fit the strut. More care should be taken with the shorter struts, as the loads are quite low. Try loading each strut several times a consistent result for each strut is achieved.

**Table 1: Results for Experiment 1 (pinned end)**

<table>
<thead>
<tr>
<th>Strut No.</th>
<th>Length (mm)</th>
<th>Buckling Load (N) Experiment</th>
<th>Buckling Load (N) Theory</th>
<th>1/L² (m⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>315</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>365</td>
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<tr>
<td>3</td>
<td>415</td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td>465</td>
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<td>5</td>
<td>515</td>
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</tbody>
</table>

Examine the Euler buckling equation and select an appropriate parameter to establish a linear relationship between the buckling load and the length of the strut (Hint: remembers π, E and I are all constants). Calculate the values and enter them into Table 1 with an appropriate title. Plot a graph to prove the relationship is linear. Compare your experimental value to those calculated from the Euler formula by entering a theoretical line onto the graph. Does the Euler formula predict the buckling load?

**Part 2: The Effect of End Conditions on the Buckling Load**

Follow the same procedure as in Part 1, but this time remove the bottom chuck and clamp the specimen using the cap head screw and plate to make a pinned-fixed end condition. Record your results in Table 2 and calculate the values of 1/L² for the struts. Note that the test length of the struts is shorter than in Experiment 1 due to the allowance made for clamping the specimen.

**Table 2: Results for Experiment 2 (pinned-fixed)**

<table>
<thead>
<tr>
<th>Strut No.</th>
<th>Length (mm)</th>
<th>Buckling Load (N) Experiment</th>
<th>Buckling Load (N) Theory</th>
<th>1/L² (m⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>315</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>365</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>415</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td>465</td>
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<td></td>
<td></td>
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<tr>
<td>5</td>
<td>515</td>
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</tbody>
</table>
Now fit the top chuck with the two cap head screws and clamp both ends of the specimen, again this will reduce the experimental length of the specimen and you will have to calculate new values for $1/L^2$. Take care when loading the shorter struts near to the buckling load.

**CAUTION:** Do not continue to load the struts after the buckling load has been reached otherwise the struts will become permanently deformed!

Enter the results into **Table 3**.

**Table 3:** Results for Experiment 3(fixed end)

<table>
<thead>
<tr>
<th>Strut No.</th>
<th>Length (mm)</th>
<th>Buckling Load (N) Experiment</th>
<th>Buckling Load (N) Theory</th>
<th>$1/L^2$ (m$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>315</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>365</td>
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<tr>
<td>3</td>
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<tr>
<td>4</td>
<td>465</td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td>515</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Plot separate graphs of buckling load versus $1/L^2$ and calculate the gradient of each line. Establish ratios between each end condition (taking the pinned-pinned condition as 1). Finally examine the Euler buckling formulae for each end condition and confirm that the experimental and theoretical ratios are similar.

**Table 4:** Comparison of experimental and theoretical ratios by end condition

<table>
<thead>
<tr>
<th></th>
<th>Pinned-pinned</th>
<th>Pinned-fixed</th>
<th>Fixed-fixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental gradient</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Experimental ratios</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theoretical ratios</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Write your observations and comments whenever possible in your discussion in term of achievement, problems facing throughout the experiment and recommendation for improvement.
7. ADDITIONAL THEORY

8. OBSERVATION

9. DISCUSSION
10. CONCLUSION

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11. REFERENCES

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1. INTRODUCTION

A beam is a structural element that is capable of withstanding load primarily by resisting bending. The bending force induced into the material of the beam as a result of the external loads, own weight and external reactions to these loads is called a bending moment. Beams generally carry vertical gravitational forces but can also be used to carry horizontal loads (i.e., loads due to an earthquake or wind). The loads carried by a beam are transferred to columns, walls, or girders, which then transfer the force to adjacent structural compression members.

2. OBJECTIVE

The main objective of this experiment is to investigate the relationship between load, span, height and deflection of a beam placed on two bearers affected by a concentrated load.

3. LEARNING OUTCOME

At the end of this experiment, students should be able to:

3.1 Conduct experiment, record, tabulate and analyze the raw data.
3.2 Determine the relationship between the deflections and the applied load.
3.3 Determine the modulus of elasticity for each specimen
3.5 Understand the effect of variations in length and cross section i.e. deflection per unit load

4. THEORY

When a beam is loaded and bends (Figure 1). The upper portion of the beam is compressed due to the bending while the lower portion is stretched. Between the upper and lower portions there lies a layer where neither contraction nor stretching is experienced. This layer is called the neutral surface. The load creates a bending moment in the beam, which causes bending stress in the beam as it bends.
Simply supported beam with central point load

For this arrangement, it can be shown that the deflection under the load i.e. maximum deflection

\[ \Delta = \frac{PL^3}{48EI} \quad \text{where} \quad I = \frac{bd^3}{12} \]

Simply supported beam subjected to uniform bending moment
For this arrangement, it can be shown that the central deflection relative to the supports, i.e., maximum deflection between the supports:

\[ \Delta = \frac{Wl^3}{8EI} \quad \text{where} \quad I = \frac{bd^3}{12} \]

\[ \therefore \text{beam compliance} \quad \frac{\Delta}{W} = \frac{3al^2}{2Ebd^3} \]

5. **APPARATUS.**

*Figure 2* shows the bending apparatus that is used in this experiment.

![Figure 2](image)

6. **PROCEDURE**

**Task:** To investigate the relationship between load, span, height and deflection of a beam, placed on two bearing affected by a concentrated load at the center.

![Diagram]

\[ F \]
6.1: Investigate the relationship between load and deflection

1. Set the bearers so that a span of 600 mm. is obtained.
2. Place a test specimen with dimensions of 6 x 25 mm. on the bearers and mount the load device in the center of test specimen.
3. Set the testing device so that the top of the gauge is centered on the upper plane of the load device. Lower the gauge so that its small hand is at about 10 and set the gauge to zero by twisting its outer ring. Load with weights as shown in the table below and read off the deflection. One revolution of the lame hand of the gauge corresponds to 1 mm. of deflection.

<table>
<thead>
<tr>
<th>Load (N)</th>
<th>Deflection (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
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<tr>
<td>15</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

4. Draw a graph of deflection vs. loading.

6.2: Investigate relationship between span and deflection

1. Employ a test specimen with dimensions of 6x25 mm and load with weight 10 N. Vary the span as indicated in the table and read off the deflection.

<table>
<thead>
<tr>
<th>Span Length (mm)</th>
<th>Deflection (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td></td>
</tr>
<tr>
<td>600</td>
<td></td>
</tr>
</tbody>
</table>

2. Draw a graph of deflection vs. span.
6.3: Investigate the relationship between the height and deflection of the test specimen.

1. Set the bearers for a span of 500 mm. Employ the test specimens indicated in the table below, load with weight 5 N and read off the deflection.

<table>
<thead>
<tr>
<th>Test Speciment Dimensions (mm$^3$)</th>
<th>Deflection (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 x 25</td>
<td></td>
</tr>
<tr>
<td>4 x 25</td>
<td></td>
</tr>
<tr>
<td>5 x 25</td>
<td></td>
</tr>
<tr>
<td>6 x 25</td>
<td></td>
</tr>
</tbody>
</table>

2. Draw a graph of deflection vs. height of test specimen.

7. ADDITIONAL THEORY

8. OBSERVATION
9. DISCUSSION

Discuss the relationship observed for experiment 6.1, 6.2 and 6.3. Possible sources of error include errors in cross-sectional dimensions and gauge measurements. How much error do these factors contribute to the obtained results?
10. CONCLUSION

Write your observations and comments whenever possible in your discussion in term of achievement, problems facing throughout the experiment and recommendation for improvement.

11. REFERENCES
COURSE INFORMATION

COURSE TITLE: ENGINEERING LABORATORY V (BDA 37001)

TOPIC 4: DEFLECTION OF CURVED BARS AND DAVITS

1. INTRODUCTION

Davits and curved bars are simple and common structures. Examples of where you can see them include the structures used on ships to suspend lifeboats and along railway tracks to suspend electricity cable. A limiting factor in the design of these structures is the deflection caused by the load they will suspend.

2. OBJECTIVE

The main objective of this experiment is to perform experiments with curved bars and davits, and monitor the horizontal and vertical deflection and compare with theoretical values.

3. LEARNING OUTCOME

At the end of this experiment, students should be able to:

   3.1 Conduct experiment, record, tabulate and analyze the raw data.
   3.2 Plot the graph of load against deflection for every specimen tested.
   3.3 Determine the structure behavior after being applied with load and observe the horizontal and vertical deflections.
   3.5 Produce good conclusion from the experiment conducted.

4. APPARATUS

Figure 1 shows the TecQuipment's Curved Bars and Davits experiment apparatus. It consists of a back plate, a pair of dial indicators arranged at 90°, and one of four test structures. The two indicators are on a magnetic base. The base can moved to any position on the back plate. One of the indicators measures horizontal deflection, the other vertical deflection. The four structures are a quarter circles, a semicircle, a curved davit and an angled davit. Each structure has a boss fitted to the free end. This allows you to apply loads and measure deflections in both the horizontal and vertical directions. Some useful information is printed on the back plate of the equipment. Make a note of this – you will need it to analyze your results after you have completed the experiment.
5. **PROCEDURE**

Davits and curved bars are simple and common structures. Examples of where you can see them include the structures used on ships to suspend lifeboats and along railway tracks to suspend electricity cable. A limiting factor in the design of these structures is the deflection caused by the load they will suspend. In this experiment we will load each of the four structures and measure the horizontal and vertical deflection and compare this to theory.

You will need the following information as well as that printed on the back plate: For a rectangular section: $I = \frac{bd^3}{12}$

Where:

$I = \text{Second Moment of area (m}^4)$

$b = \text{Breadth of the section (m)}$

$d = \text{Depth of the section (m)}$

Also the Young modulus ‘$E$’ for aluminum alloy = 69 GNm$^2$

1. Referring to **Figure 1**, set up the equipment to test the semicircle first. Ensure you have mounted the semicircle with a plate each side of the end, and you have clamped in securely.

![Figure 1](image-url)
2. Measure and record the breadth and depth of the section on several places of the structure and take an average.
3. Clip the weight hanger onto the two lugs on the loading boss. Gently pull down on the weight hanger and note the direction the loading boss on structure moves. Set the indicator positions so they contact horizontally and vertically and have the maximum amount of travel in each direction. Carefully zero the indicators.
4. Apply a mass of 100g to the hanger, tap the test frame to reduce the effects of friction then take readings of both indicators. Repeat with masses up to 500g in 100g increments by tapping the test frame each time.
5. From the measurements of the section calculate the second moment of area ‘I’. Enter all of your results and values into Table 1.
6. Remove the semicircle and attach it to the side of the frame rather than the bottom member, replace it with the quarter circle. Ensure there are clamp plates each side of the structure and the indicator positions give the amount of travel needed for the maximum loading.
7. Repeat the experiment. Similarly repeat the experiment for the curved davit and the angle davit.
8. Enter all of your results into Table 1. You must calculate the ‘I’ value for each structure as the manufacturing process may change the thickness and width of the material.

### 6. OBSERVATIONS

<table>
<thead>
<tr>
<th>Mass(g)</th>
<th>Load(N)</th>
<th>( \Delta V )</th>
<th>( \Delta H )</th>
<th>( \Delta V )</th>
<th>( \Delta H )</th>
<th>( \Delta V )</th>
<th>( \Delta H )</th>
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<tbody>
<tr>
<td>0</td>
<td>0</td>
<td></td>
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<tr>
<td>100</td>
<td>0.98</td>
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<td></td>
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<tr>
<td>200</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300</td>
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<td></td>
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<tr>
<td>400</td>
<td>3.92</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>500</td>
<td>4.92</td>
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</table>

I Value (m^4)
7. ADDITIONAL THEORY

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8. OBSERVATION

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9. DISCUSSION

a) Plot graphs for each section, with load versus the horizontal and vertical deflection. Calculate the gradient of each line in mm/N.

b) Compare this to values calculated from the standard formulae for each section or those calculated from first principles.

c) Did your results agree with the theoretical values? Name any sources of error in the experiment.

..........................................................................................................................................................................................
10. CONCLUSION

Write your observations and comments whenever possible in your discussion in term of achievement, problems facing throughout the experiment and recommendation for improvement.

11. REFERENCES
1. INTRODUCTION

The analysis of the stress distribution in a thick cylinder is of considerable practical importance in pressure vessels. With the SM1011 Computerized Thick Cylinder Apparatus, the student is able to verify the various analytical formulae with actual measured results. Strain gauges, mounted on various radii and at different alignments throughout the cylinder wall, provide the opportunity for students to measure the strains, and hence stress distribution throughout the wall, of a cylinder subjected to an internal pressure.

2. OBJECTIVE

The main objective of this experiment is to demonstrate and analyze the stress systems in a thick cylinder.

3. LEARNING OUTCOME

At the end of this experiment, students should be able to:

3.1 Determine the magnitude of stress with varies internal pressure in thin cylinder.
3.2 Analyze the stress distribution across the thick cylinder cross section.

4. THEORY

Figure 1 show a hollow cylinder, which is subjected to a uniformly distributed internal pressure P. The figure details an element of material at some radius r, contained within an elemental cylinder. Due to the design of the SM1011 Thick Cylinder the longitudinal stress $\delta_L$ may be ignored and only a bi-axial system be considered. Hence the stress formulas are shown below and Figure 2 shows the stress variation throughout the wall cylinder.
Maximum $\delta_R$ occurs at the inner radius ($R_1$) i.e. $\sigma_R = -P$
Minimum $\delta_R$ occurs at the outer radius ($R_2$) i.e. $\sigma_R = 0$

Maximum $\delta_H$ occurs at the inner radius ($R_1$) i.e. $\sigma_H = \frac{P(K^2 + 1)}{(K^2 - 1)}$  \hspace{1cm} (1)
Minimum $\delta_H$ occurs at the outer radius ($R_2$) i.e. $\sigma_H = \frac{2P}{(K^2 - 1)}$  \hspace{1cm} (2)

Where $K = \frac{R_2}{R_1}$

Now for a cylinder under internal pressure and free from axial loading, the maximum shear stress will occur at the inner radius.

i.e. Max. Shear stress ($\dot{\tau}$) = $\frac{1}{2} \times$ (difference of the principal stresses).

$$\dot{\tau} = \frac{\sigma_R - \sigma_H}{2}$$  \hspace{1cm} (3)

Substituting we get:

$$\dot{\tau} = \frac{P R_1^2}{R_2^2 - R_1^2}$$  \hspace{1cm} (4)

Therefore:

$$\dot{\tau} = \frac{P K^2}{(K^2 - 1)}$$  \hspace{1cm} (5)

In the case of the TQ cylinder:

Figure 1: Cylinder under Internal Pressure

Figure 2: Stress Variation Throughout a Cylinder Wall
5. APPARATUS.

Figure 3 shows the thick cylinder and PC. As you can see, there are two halve of cylinder firmly cemented together at the interface. One face of the joint has a shallow circular groove turned eccentrically to the bore. This groove contains ten active strain gauges fixed in the position depicted by Figure 4 and Table 1. As can be seen from this, the hoop and radial strains can be measured at five different radii. Additional active gauges in the hoop and the longitudinal directions, on both the bore and outside diameter of the cylinder, allow measurement of principal strains on these surfaces.

![Figure 3: SM1011 Computerized Thick Cylinder](image)

**Figure 3**: SM1011 Computerized Thick Cylinder

**Table 1**: The Location of Strain Gauges

<table>
<thead>
<tr>
<th>Gauge Number</th>
<th>Radius (mm)</th>
<th>Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28</td>
<td>Hoop</td>
</tr>
<tr>
<td>2</td>
<td>28</td>
<td>Radial</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>Hoop</td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td>Radial</td>
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<tr>
<td>5</td>
<td>45</td>
<td>Hoop</td>
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<tr>
<td>8</td>
<td>56</td>
<td>Radial</td>
</tr>
<tr>
<td>9</td>
<td>63</td>
<td>Hoop</td>
</tr>
<tr>
<td>10</td>
<td>63</td>
<td>Radial</td>
</tr>
<tr>
<td>11</td>
<td>18.5</td>
<td>Circumferential</td>
</tr>
<tr>
<td>12</td>
<td>75</td>
<td>Longitudinal</td>
</tr>
<tr>
<td>13</td>
<td>75</td>
<td>Circumferential</td>
</tr>
</tbody>
</table>

**Figure 4**: Disposition of Strain Gauges

**Technical Information**
### Material and Specifications

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>203 mm</td>
</tr>
<tr>
<td>Outside diameter, D₁</td>
<td>150 mm</td>
</tr>
<tr>
<td>Inside diameter (bore), D₂</td>
<td>37 mm</td>
</tr>
<tr>
<td>K, Ratio of R₂ to R₁</td>
<td>4.054</td>
</tr>
<tr>
<td>Cylinder material</td>
<td>Aluminium alloy</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>73.1 GN/m²</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.33</td>
</tr>
<tr>
<td>Maximum allowable test pressure</td>
<td>6.89 MN/m²</td>
</tr>
<tr>
<td>Strain gauges</td>
<td>Electrical Resistance Type</td>
</tr>
</tbody>
</table>

### Procedure

#### 6. PROCEDURE

**6.1 Strain Distribution**

1. Ensure the cylinder is at zero pressure by checking that the hand wheel turns freely and the pressure gauge reads zero.
2. Select ZERO READINGS to zero the pressure and strain signals.
3. Increase the pressure to the desired pressure allowing about 5 seconds for the pressure and strain readings to stabilize and then take the readings to the data table.

#### Calculation of Strains:

1. **Hoop Strain**:
   
   \[ \varepsilon_H = \frac{P}{1128.2 \times 10^3} \left[ 1 + \frac{5625}{r^2} \right] - 0.33 \left[ 1 - \frac{5625}{r^2} \right] \]

2. **Radial Strain**:
   
   \[ \varepsilon_R = \frac{P}{1128.2 \times 10^3} \left[ 1 - \frac{5625}{r^2} \right] - 0.33 \left[ 1 + \frac{5625}{r^2} \right] \]

3. **Longitudinal Strain**:
   
   \[ \varepsilon_L = -2.925 \times 10^{-7} P \left[ 1 + \frac{5625}{r^2} \right] + \left[ 1 - \frac{5625}{r^2} \right] \]

*Calculations must be shown in Table 4.1 for respective internal cylinder pressure.*
Internal cylinder pressure = \ldots \text{MN/m}^2

### Table 4.1: Strains

<table>
<thead>
<tr>
<th>Radius (mm)</th>
<th>28</th>
<th>36</th>
<th>45</th>
<th>56</th>
<th>63</th>
<th>18.5</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gauge Number</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Nature of Strain</td>
<td>\varepsilon_H</td>
<td>\varepsilon_R</td>
<td>\varepsilon_H</td>
<td>\varepsilon_R</td>
<td>\varepsilon_H</td>
<td>\varepsilon_R</td>
<td>\varepsilon_H</td>
</tr>
<tr>
<td>Measured Strain (x \text{10}^6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculated Strain (x \text{10}^6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error Difference</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 6.2 Stress Distribution

From Equations:-

\[ \sigma_H = E\varepsilon_H + \nu\sigma_R \]  
\[ \sigma_R = E\varepsilon_R + \nu\sigma_H \]

Therefore (measured stress):

\[ \sigma_H = \frac{E}{1-\nu^2} \left(\nu\varepsilon_R + \varepsilon_H\right) \text{ (N/m}^2) \]  
\[ \sigma_R = \frac{E}{1-\nu^2} \left(\nu\varepsilon_H + \varepsilon_R\right) \text{ (N/m}^2) \]

By substituting into these equations the measured strain values from Table 4.1, the individual stresses in the Cylinder wall can be calculated. These values can then be compared with the calculated theoretical values.

Calculated theoretical stress

\[ \sigma_H = \frac{P}{(K^2-1)} \left(1 + \frac{R^2}{r^2}\right) \text{ (N/m}^2) \]  
\[ \sigma_R = \frac{P}{(K^2-1)} \left(1 - \frac{R^2}{r^2}\right) \text{ (N/m}^2) \]
### Table 4.2: Stress

<table>
<thead>
<tr>
<th>Radius (r mm)</th>
<th>Calculated</th>
<th>Derived</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\sigma_H$ N/m$^2$</td>
<td>$\sigma_R$ N/m$^2$</td>
</tr>
<tr>
<td>18.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td></td>
<td></td>
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<tr>
<td>45</td>
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<td></td>
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<tr>
<td>56</td>
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<td>75</td>
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</table>

7. **ADDITIONAL THEORY**

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8. **OBSERVATION**

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9. DISCUSSION

a. Construct a graph of Lame line which is graph of hoop and radial stress vs cylinder radius.

b. Compare and comment the experimental value with the theoretical value

c. Give some example for the application of thick cylinder in industry
10. CONCLUSION

Write your observations and comments whenever possible in your discussion in term of achievement, problems facing throughout the experiment and recommendation for improvement.

11. REFERENCES
CHAPTER III

FLUID MECHANICS II LABORATORY

3.1 AIM

The aim of the chapter is to provide knowledge to students in order to relate the theories that have been studied in the subject of Fluid Mechanics with the applied field.

3.2 OBJECTIVES

The objectives of this part are to enable the students to:

i. To increase the understanding of Fluid Mechanics principles and its concept.
ii. To relate the principles that have been studied in theory with the applied field

3.3 LIST OF TOPICS

Fluid Mechanics II Laboratory cover;

i. Pelton Wheel
ii. Friction Loss Along a Pipe
iii. Centrifugal Pump
iv. Boundary Layer
v. Cavitation

COURSE INFORMATION
COURSE TITLE: ENGINEERING LABORATORY V (BDA 37001)

TOPIC 1: PELTON WHEEL

1. INTRODUCTION

The Pelton Wheel is a hydraulic turbine, in which one or more water jets impinge tangentially onto buckets mounted around a wheel. The force produced by the jet impact generates a torque that causes the wheel to rotate, thus producing power. The name ‘Pelton’ derives from L.A Pelton, an American engineer who performed notable research in order to determine the best shape of the buckets.

Although the concept is very simple, some very large machines of high efficiency have been developed. Power outputs of more than 100 MW, with efficiencies of around 95% are not uncommon. On a small laboratory model, however, the output may be just a few watts. The efficiency will therefore be very much smaller, because losses in bearings and by wind age are proportionally much higher than in a large, powerful turbine.

2. OBJECTIVE

The objective of this experiment is to determine the characteristics of performance and torque of Pelton Wheel.

3. LEARNING OUTCOME

At the end of this experiment, students should be able to understand the relationship between torque, power, wheel speed and efficiency of the Pelton Wheel.

4. THEORY

The Pelton Wheel requires a source of water in order to run. If the head of water is known along with the flow rate then it is possible to deduce the best size of wheel to use, how fast it should rotate to obtain the maximum efficiency, and power it is likely to develop. The velocity of the jet can be estimated by using the known flow rate. A suitable jet diameter can be chosen in relation to the jet size; typically the wheel would have a diameter of 10 times than of the jet. The best speed of rotation may then be selected, such that the speed of the buckets is approximately half of the jet speed.
The power developed in the jet can be calculated from the speed and cross-sectional area. The power developed by the Pelton Wheel will be less than this, in the ratio of the wheel’s efficiency, which may be estimated by reference to the known performance of existing machines of comparable size and output. Depending on the head and flow rate available the size and speed of the Pelton Wheel obtained in this way may prove to be impracticable or uneconomic. Fortunately, other types of water turbine are available to suit a wide variety of circumstances. The Pelton Wheel is usually chosen when the available head is high, but the flow rate is comparatively low.

\[ T = |F_1 - F_2| \cdot r \quad \text{..........................(1)} \]

Where:
- \( r \) = Brake wheel radius (0.025m)
- \( F_1 \) = Force on spring balance (0-25N)
- \( F_2 \) = Force on spring balance (0-15N)
Turbine power :

\[ P = \frac{2\pi NT}{60} \]  
\[ \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \q
Figure 3: Pelton Wheel Arrangement with Hydraulic Bench

7. DATA FOR CALCULATION

Travel of spear : 6 – 7mm (approx.)
Diameter of the nozzle outlet : 10 mm

Listed below are positions of the spear with its corresponding nozzle area.

Table 1: Nozzle area details

<table>
<thead>
<tr>
<th>Position of spear (Number of turns or mm)</th>
<th>Area at nozzle (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed</td>
<td>0</td>
</tr>
<tr>
<td>½ turn or 0.75mm</td>
<td>9.4</td>
</tr>
<tr>
<td>1 turn or 1.50mm</td>
<td>18.3</td>
</tr>
<tr>
<td>1 ½ turn or 2.25mm</td>
<td>26.5</td>
</tr>
<tr>
<td>1st data: 2 turn or 3.00 mm</td>
<td>34.4</td>
</tr>
<tr>
<td>2 ½ turn or 3.75mm</td>
<td>41.1</td>
</tr>
<tr>
<td>3 turn or 4.50mm</td>
<td>47.7</td>
</tr>
<tr>
<td>3 ½ turn or 5.25mm</td>
<td>53.5</td>
</tr>
<tr>
<td>2nd data: 4 turn or 6.00mm</td>
<td>58.7</td>
</tr>
<tr>
<td>4 ½ turn or 6.75mm</td>
<td>63.3</td>
</tr>
</tbody>
</table>
8. RESULTS

a. Calculate and fill up Table 2 and 3.

Table 2: Results of 1st position

<table>
<thead>
<tr>
<th>VALVE POSITION:</th>
<th>NOZZLE AREA:</th>
<th>PRESSURE:</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO.</td>
<td>Wheel Speed, N (rpm)</td>
<td>Force, F₁ (N)</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
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<td>7</td>
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<tr>
<td>8</td>
<td></td>
<td></td>
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<tr>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3: Results of 2\textsuperscript{nd} position

<table>
<thead>
<tr>
<th>VALVE POSITION</th>
<th>NOZZLE AREA</th>
<th>PRESSURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO.</td>
<td>Wheel Speed, N (rpm)</td>
<td>Force, F\textsubscript{1} (N)</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b. Plot two graphs:

Graph 1: Calculated Torque, T against Measured Speed, N
Graph 2: Power, P against Measured Speed, N
(Both graphs can be plotted in one graph with its own separate axis.)

9. DISCUSSION

a. Discuss the results from the graphs.

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b. What suggestions do you have to improve the experiment?

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c. Give suggestions to reduce the frictions in the experiment.

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d. State four sources of error in the experiment.

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e. Conclusion.

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COURSE INFORMATION

COURSE TITLE: ENGINEERING LABORATORY V (BDA 37001)

TOPIC 2: FRICTION LOSS ALONG A PIPE

1. INTRODUCTION

In hydraulic engineering practice, it is frequently necessary to estimate the head loss incurred by a fluid as it flows along a pipeline. For example, it may be necessary to calculate what additional head would be required to double the rate of flow along an existing pipeline.

Loss of head is incurred by fluid mixing which occurs at fittings such as bends or valves, and by frictional resistance at the pipe wall. Where there are numerous fittings and the pipe is short, the major part of the head loss will be due to the local mixing near the fittings. For a long pipeline, on the other hand, skin friction at the pipe wall will predominate.

2. OBJECTIVE

The objective of this experiment is to measure the loss of energy due to fluid friction along a straight pipe with smooth walls.

3. LEARNING OUTCOMES

At the end of this experiment, students should be able to:

3.1 Understand the concept of fluid flow and the head loss along a pipe.
3.2 Relate the factors of head loss, determine the Reynolds No. and friction factors based on the region of flow.

4. THEORY

Figure 1 illustrates flow along a length of straight uniform pipe of diameter D. All fittings such as valves or bends are sufficiently remote as to ensure that any disturbances due to them have died away, so that the distribution of velocity across the pipe cross section does not change along the length of pipe under consideration. Such a flow is said to be “fully developed.” The shear stress at the wall, which is uniform around the perimeter and along the length, produces resistance to the flow. The piezometric head h therefore falls at a uniform rate along the length, as shown by the piezometers in Figure 1. Since the velocity head is constant along the length of the pipe, the total head H also falls at the same rate.
The slope of the piezometric head line is frequently called the “hydraulic gradient”, and is denoted by the symbol \( i \):

\[
\frac{dl}{dh} = \frac{-dH}{dl} \quad ...........(1)
\]

(the minus signs are due to the fact that head decreases in the direction of increasing \( L \), which is measured positive in the same sense as the velocity \( V \). The resulting value of \( i \) is then positive).

\[ \text{Figure 1: Illustration of fully developed flow along a pipe} \]

Over the length \( L \) between section 1 and 2, the fall in piezometric head is:

\[
h_1 - h_2 = iL \quad ...........(2)
\]

Expressed in term of piezometric pressures \( p_1 \) and \( p_2 \) at section 1 and 2:

\[
p_1 - p_2 = wL = \rho giL \quad ...........(3)
\]

in which \( w \) is the specific weight and \( \rho \) is the density of water.

There is a simple relationship between wall shear stress \( \tau \) and hydraulic gradient \( i \). The pressures \( p_1 \) and \( p_2 \) acting on the two ends of the length \( L \) of pipe produce a net force. This force, in the direction of flow, is

\[
(p_1 - p_2)A
\]
in which \( A \) is the cross-sectional area of the pipe. This is opposed by an equal and opposite force, generated by the shear stress \( \tau \) acting uniformly over the surface of the pipe wall.

The area of pipe wall is \( PL \), where \( P \) is the perimeter of the cross section, so the force due to shear stress is \( \tau .PL \)

Equating these forces:
\[
(p_t - p_z)A = \tau .PL
\]

this reduces, by use of Equation (3), to
\[
\tau = \left( \frac{A}{P} \right) \rho g i
\]

\[\text{…………. (4)}\]

Now, expressing \( A \) and \( P \) in terms of pipe diameter \( D \), namely \( A = \pi D^2/4 \) and \( P = \pi D \) so that \( (A/P) = D/4 \), we obtain the result:
\[
\tau = \left( \frac{D}{4} \right) \rho g i
\]

\[\text{…………. (5)}\]

In the case of laminar flow, the velocity profile is parabolic. The ratio \( U/V \) of centre line velocity to mean velocity is
\[
\frac{U}{V} = 2
\]

\[\text{…………. (6)}\]

and the velocity gradient of the wall is given by
\[
\left( \frac{du}{dr} \right)_w = -\frac{4U}{D} = -\frac{8V}{D}
\]

\[\text{…………. (7)}\]

So that the wall shear stress \( \tau \) due to fluid viscosity is
\[
\tau = \frac{8\mu V}{D}
\]

\[\text{…………. (8)}\]

Substituting for \( \tau \) in Equation (5) from this equation leads to the result of Poiseuille’s equation
\[
i = \frac{32\nu V}{gD^2}
\]

\[\text{…………. (9)}\]

In the case of turbulent flow the nature of flow has made it impossible to find a simple expression for the wall shear stress, so the value has to be found experimentally. So a dimensionless friction factor \( f \) could be defined by
\[
\tau = f \cdot \frac{1}{2} \rho V^2
\]

\[\text{…………. (10)}\]
The hydraulic gradient \( i \) may now be expressed in term of \( f \) by use of equation (5), and the following result is readily obtained:

\[
i = \frac{4f V^2}{D \cdot 2g} \quad \text{(11)}
\]

Therefore, the head loss \( (h_1 - h_2) \) between sections 1 and 2 of a pipe of diameter \( D \), along which the mean velocity is \( V \), is seen from the Equation (2) to be given by:

\[
h_1 - h_2 = 4f \frac{L V^2}{D \cdot 2g} \quad \text{(12)}
\]

Where, \( L \) is the length of pipe run between the sections. This is frequently referred to as Darcy’s equation.

There is no corresponding theoretical for turbulent flow. However, correlation of many experimental results on smooth walled pipes, due to Blasius, is:

\[
f = 0.079 \text{ Re}^{-\frac{1}{4}} \quad \text{(13)}
\]

This gives explicit values which are in agreement within 2% over the limited range of \( \text{Re} \) from \( 10^4 \) to \( 10^5 \). Above \( 10^5 \), it diverges substantially from experiment.

5. **EQUIPMENT**

Equipment used for this experiment are:

a. Friction Loss along a Pipe.

b. Hydraulic bench.

c. Measuring cylinder 1000 ml.

d. Thermometer.

e. Stop watch.

6. **PROCEDURE** (Refer to Figure 2)

Steps to run the experiment are:

a. Set the apparatus (1) on the bench and level so that the manometer stands vertically.

b. Fully open the bench supply valve (2) and adjust until there is a steady flow down the overflow pipe (3), so that it provides a constant head to the pipe under test.

c. Open partly the needle valve (4) to allow water through the system.

d. Remove the trapped air by manipulating the flexible connecting pipes (5).

e. Clear all the trapped air from the piezometer connection.

f. Close the needle valve (4) after the levels in the two limbs in manometer give the same value.
g. Adjust the height of water level by allowing air to escape through the air valve (6) at the top, or may be depressed by pumping air through the valve. (note: manual pump while m/c off).

h. Open the needle valve (4) fully to obtain a differential head at least 400 mm.

i. Collect the discharge rate by measuring the volume of 300 ml in the measuring cylinder (7). Record time, t in Table 1.

j. Let the reading stable for a while before recording \( h_1 \) and \( h_2 \) it in the Table 1. Take a few readings and record the mean value.

k. Close the needle valve so that the \( h_1 \) value reduced to about 20 mm. Repeat step i onwards. Readings will be at reducing flow rates.

l. Record the water temperature at a frequent interval. These readings cover the laminar and transition region only.

Figure 2: Arrangement of Friction Losses in Pipe
7. RESULTS

a. Calculate and fill up Table 1.

Length of pipe between piezometer tappings, \( L = 524 \) mm

Diameter of pipe, \( D = 3.00 \) mm

Cross sectional area of pipe \( \pi D^2/4, A = 7.069 \text{ mm}^2 = 7.069 \times 10^{-6} \text{ m}^2 \)

Table 1: Results with water manometer (for laminar and transition flow region)

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<tr>
<th>No.</th>
<th>Qty (ml)</th>
<th>t (s)</th>
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b. Plot three graphs:

Graph 1: Hydraulic gradient, i against velocity, V (m/s)
Graph 2: Log f, against log Re.
Graph 3: Log i, against log Re
(All the graphs can be plotted in one graph with its own separate axis).

c. Find the slope of a linear portion for the Graph 1. It gives the value of \( \frac{i}{V} \).

8. DISCUSSION

a. Discuss the result of the graphs:

i. Graph 1:

ii. Graph 2:
iii. Graph 3:

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b. Rewrite Equation (9) in the form of kinematic viscosity, $\nu$.

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c. Insert the slope value, $i/V$ to get the theoretical value of kinematic viscosity, $\nu$.

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d. Compare and discuss the result of theoretical and experimental values of kinematic viscosity, \( \nu \).

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g. Give the conclusion.

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9. QUESTIONS

a. What suggestions do you have to improve the apparatus?

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b. State at least 5 sources of error in this experiment.

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COURSE INFORMATION

COURSE TITLE: ENGINEERING LABORATORY V (BDA 37001)

TOPIC 3: CENTRIFUGAL PUMP

1. INTRODUCTION

Centrifugal pumps consist basically of an impeller rotating within a spiral casing. The fluid enters the pump axially through the suction pipe via the eye of the impeller; it is discharged from the impeller around the entire circumference either into a ring stationary diffuser vanes (and through them into the volute casing) or directly into the casing. The casing ‘collects’ the fluid, decelerates it – thus converting some of the kinetic energy into pressure energy – and finally discharges the fluid through the delivery flange.

![Figure 1: Centrifugal Pump Test Rig](image)

2. OBJECTIVE

The objective of this experiment is to obtain the characteristics performance of centrifugal pump.

3. LEARNING OUTCOME

At the end of this experiment, students should be able to understand the operating principles and application of centrifugal pump.
4. THEORY

Assuming steady flow, pump basically increases the Bernoulli head of the flow between point 1 (suction) and point 2 (delivery), neglecting viscous work and heat transfer, this denotes by head, H. The head of a pump is the mechanical work transferred by the pump to the medium pumped under local gravity conditions. The head, H tells us the increment of mechanical energy, E between inlet and outlet.

Head could be defined as :

\[ H = (Z_D - Z_S) + \frac{(P_D - P_S)}{\rho g} + \frac{(V_D^2 - V_S^2)}{2g} \] ...........(1)

Where

- \( Z_D - Z_S \) : difference in the height of the inlet and outlet cross section on the pump.
- \( \frac{P_D - P_S}{\rho g} \) : difference in the pressure head of the medium pumped between inlet and outlet.
- \( \frac{V_D^2 - V_S^2}{2g} \) : difference in the speed of the medium pumped between inlet and outlet.

Usually \( V_D \) and \( V_S \) are about the same; \( Z_D - Z_S \) is no more than a meter or so.

Therefore, the net pump head, H equals to change in pressure head ;

\[ H \approx \frac{P_D - P_S}{\rho g} \] ................. (2)

The power required to drive the pump is brake power, \( P_{mech} \)

\[ P_{mech} = T \cdot \omega \]

\[ = T \cdot \frac{2\pi N}{60} \] .................(3)

Where T = torque (Nm)
Hydraulic power output, \( P_{\text{hydr}} \):

\[
P_{\text{hydr}} = \rho g Q H
\]  

(4)

The pump efficiency, \( \eta \) is given by the ratio between the power output by a pump and the power drawn from the shaft, i.e

\[
\eta = \frac{P_{\text{hydr}}}{P_{\text{mech}}}
\]  

(5)

**PUMP CHARACTERISTIC CURVE**

On a centrifugal pump driven at a constant speed, the head, \( H \); the power required, \( P \) (and thus the efficiency), as well as the parameter \( \text{NSPH}_{\text{req}} \) depend on the flow rate \( Q \). The relationship between these performance data is displayed in characteristic curves. The operating behaviour of each centrifugal pump is characterized by these characteristic curves.

**SYSTEM CHARACTERISTIC CURVE**

The system characteristic curve is given by the pressure losses in the pipes at a specific flow rate. The operating point of a pump is positioned, as in Figure 2, where the head of the pump and the system are the same, that is at the point where the system characteristic curve and pump characteristic curve converged.

**Figure 2**: Operating Point of a Pump
5. **EQUIPMENT**

Equipment used for this experiment is Basic Module Water Pump with:

a. A Self-Priming Centrifugal Pump.
b. Drive and Brake Unit.

6. **PROCEDURE** (Refer to Figure 3 and 4)

Series of measurements at various speeds must be performed on the pumps. The pump must be running at constant speed and the system must be more or less in a steady state condition. Steps to run the experiment are:

a. Turn ON all main switches and check the apparatus is ready.
b. The belt guard (1) must be in place and the direction of the rotation indicator in “clockwise direction” is illuminated.
c. The pump can only start with back pressure. The ball valve (2) for flow rate regulation must be closed.
d. Move the potentiometer (3) to start the motor. Fully open the ball valve.
e. Set the speed to 1000 rpm and observe whether water is pumped back to the tank (4).

**EXPERIMENT AT CONSTANT SPEED, 2900 rpm**

a. Check to ensure the ball valve is fully opened.
b. Increase the speed to 2900 rpm by turning the potentiometer.
c. For this experiment, take the flow rate reading from magnetic-inductive only (5).
d. Record flow rate, \( P_1 \), \( P_2 \) and torque.
e. Close a little the ball valve to reduce the flow rate.
f. Repeat from j until the minimum flow rate.

**EXPERIMENT AT VARIOUS SPEED**

a. Set the speed to 1500 rpm with the ball **valve fully opened**.
b. Record flow rate, \( P_1 \), \( P_2 \) and torque.
c. Increase the speed into 1600 rpm (100 rpm increment).
d. Repeat from n until the maximum speed, i.e 2900 rpm.
**Figure 3**: Self – Suction and delivery pressures display

**Figure 4**: Self - Priming Centrifugal Pump
7. **RESULTS**

a. Calculate and fill up Table 1 and 2.

\[
\text{Speed} = \ldots \text{rpm}
\]

**Table 1:** Results at constant speed

<table>
<thead>
<tr>
<th>NO</th>
<th>Flow rate, (Q) (l/s)</th>
<th>Suction Pressure, (P_1) (bar)</th>
<th>Delivery Pressure, (P_2) (bar)</th>
<th>Torque, (T) (Nm)</th>
<th>Head, (H) (m)</th>
<th>Mechanical Power, (P_{\text{mech}}) (W)</th>
<th>Hydraulic Power, (P_{\text{hydr}}) (W)</th>
<th>Efficiency, (\eta)</th>
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### Table 2: Results at various speed

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<th>No</th>
<th>Motor Speed N (rpm)</th>
<th>Flow Rate Q (1/s)</th>
<th>Suction Pressure $P_1$ (bar)</th>
<th>Delivery Pressure, $P_2$ (bar)</th>
<th>Head H (m)</th>
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b. Show the calculation.

c. Plot the following graphs

**MEASUREMENTS AT CONSTANT SPEED, N=2900 RPM**

Graph 1: Head, $H$ (m) against Flow Rate, $Q$ (m$^3$/hr)

Graph 2: Mechanical Power, $P_{\text{mech}}$ (W) against Flow Rate, $Q$ (m$^3$/hr)

Graph 3: Efficiency, $\eta$ against Flow Rate, $Q$ (m$^3$/hr)
MEASUREMENTS AT VARIOUS SPEEDS

Graph 4: Head, H (m) against Flow Rate, Q (m$^3$/hr)

(All graphs can be plotted in one graph with its own separate axis. Graph 4 must be drawn using the template of Graph 1).

8. DISCUSSION

a. Discuss the results from the graphs.

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b. What suggestions do you have for improving the experiment?

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c. Find the operating point of the pump. Mark on the graph.

d. Describe the significance of the pump’s operating point.

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e. Conclusion

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COURSE INFORMATION

COURSE TITLE: ENGINEERING LABORATORY V (BDA 37001)

TOPIC 4: BOUNDARY LAYER

1. INTRODUCTION

When fluid flow over a solid object, the fluid adjacent to the object’s surface moves with the velocity of the object. The fluid’s relative velocity increases from zero at the surface to the velocity of the free-stream through a region called a boundary layer.

A boundary layer is defined as a region of fluid flow past or through an object where the vorticity and shear stress are nonzero. In the case of internal flows, where the boundary layers over the wetted surface meet and mix, the flow is called fully developed. Our concern will be with external flows, where the flow is partitioned into rotational (boundary layer) and irrotational (free-stream) flows.

Consider a steady flow over a smooth plate as shown in Figure 1, where the streaming velocity $U$ is constant over the length of the plate. It is found that the thickness of the boundary layer, $\delta$, grows along the length of the plate as indicated in the diagram. The motion in the boundary layer is laminar at the beginning, but if the plate is sufficiently long, a transition to turbulence is observed. This transition is produced by small disturbances which, beyond a certain distance, grow rapidly and merge to produce the apparently random fluctuations of velocity which are the characteristics of turbulent motion. The parameter which characterizes the position of the transition is the Reynolds number, $Re_x$ based on distance $x$ from the leading edge:

$$Re_x = \frac{U_x}{v}$$

(1)
The nature of the process of transition renders it prone to factors such as turbulence in the free stream and surface roughness of the boundary. Therefore it is impossible to give a single value of \( \text{Re}_x \) at which transition will occur, but it is usually found in the range \( 1 \times 10^5 \) to \( 5 \times 10^5 \).

2. OBJECTIVES

The objectives of this experiment are:

i. To measure the velocity distribution, displacement thickness and momentum thickness in a boundary layer of a flat plate.

ii. To compare the values measured for both smooth and rough plate installed with a pressure gradient.

3. LEARNING OUTCOMES

At the end of this experiment, students should be able to:

i. Understand the concept of fluid flow pass a flat plate through a region called the boundary layer.

ii. Relate the effect of smooth and rough surface of the plate to the formation of the boundary layer.

4. THEORY

![Diagram of Velocity Distribution and Displacement Thickness of Boundary Layer](image)

**Figure 2**: Velocity Distribution and Displacement Thickness of Boundary Layer

A useful concept of thickness by which fluid outside the layer is displaced away from the boundary by the existence of the layer, as indicated schematically in **Figure 2**, by the approaching streamline. The curve OA shows the distribution of velocity \( u \) within the layer as a function of distance \( y \) from the boundary. If there were no boundary layer, the free stream velocity \( U \) would persist right down to the boundary as shown.
by the line CA. The reduction in volume flow rate (per unit normal to the diagram) due to the reduction of velocity in the layer is therefore

$$\Delta Q = \int_{y_0}^{y_h} (U - u) \, dy \quad \text{.........(2)}$$

which corresponds to the shaded area OAC in the diagram, the dimension h being chosen so that $u = U$ for any value of y greater than h. If the volume flow rate is now considered to be restored by displacement of the streamline at A’ A away from the position to a position B’ B through a distance $\delta^*$, the volume flow rate between A’ A and B’ B is also $\Delta Q$, and this is seen to be

$$\Delta Q = U \delta^* \quad \text{.........(3)}$$

Equating the results of Equation (2) and (3) gives

$$\delta^* = \frac{1}{U} \int_{y_0}^{y_h} (U - u) \, dy \quad \text{.........(4)}$$

or

$$\delta^* = \frac{1}{U} \int_{y_0}^{y_h} (1 - \frac{u}{U}) \, dy \quad \text{.........(5)}$$

Now $h$ is any arbitrary value which satisfy the condition

$$u = U \quad \text{or} \quad 1 - \frac{u}{U} = 0$$

For all values of y greater than h. The value of h may therefore be increased indefinitely without affecting the value of integral, so we allow h to increase towards infinity:

$$h \to \infty$$

and obtain the result for the displacement thickness

$$\delta^* = \int_{y_0}^{\infty} (1 - \frac{u}{U}) \, dy \quad \text{.........(6)}$$

The displacement thickness, $\delta^*$ is the thickness by which fluid outside the layer is displaced away from the boundary due to the boundary layer.
Considering mass and momentum flux in boundary layer, momentum thickness $\theta$ is a measure of the loss of momentum that the fluid experience as it passes through the boundary layer.

$$\theta = \int_{0}^{\infty} \frac{u}{U} (1 - \frac{u}{U}) dy \quad \ldots \ldots (7)$$

Therefore, skin friction drag coefficient $C_f$ is

$$C_f = 2 \frac{d\theta}{dx} \quad \ldots \ldots (8)$$

Overall skin friction coefficient $C_f$

$$C_f = \frac{D_f}{\frac{1}{2} \rho U^2 L} \quad \ldots \ldots (9)$$

This equation gives the overall skin friction coefficient on a flat plate in terms of the momentum thickness at the trailing edge and the length of the plate:

$$C_f = 2 \frac{\theta_L}{L} \quad \ldots \ldots (10)$$

It is frequently useful to refer to the ratio of displacement thickness $\delta^*$ to momentum thickness $\theta$, and this is called shape factor $H$.

$$H = \frac{\delta^*}{\theta} \quad \ldots \ldots (11)$$
The effect of pressure gradient

The preceding discussion relates to a boundary layer development along a smooth plate with uniform flow in the free-stream in conditions of zero pressure gradient along the plate. If the stream is accelerating or decelerating, substantial changes take place in the boundary layer development. For this experiment, liners which is fitted to the test section has produced decelerating free stream. The boundary layer grows more rapidly and the shape factor increases in the downstream direction. The pressure rises in the direction of flow, and this pressure rise tends to retard the fluid in the boundary layer more severely than that in the main stream since it is moving slower. Energy diffuses from free stream through the outer part of the boundary layer towards the surface to maintain the forward movement against the rising pressure. However, if the pressure gradient is sufficiently steep, this diffusion will be insufficient to sustain the forward movement, and the flow along the surface will reverse, forcing the main stream to separate. It is this separation, or stall as it is sometimes called, which leads to the main component of drag on bluff bodies and to the collapse of the lift force of an aerofoil when the angle of incidence is excessive.

5. EQUIPMENT

a. The AF10 Air Flow Bench (TQ)
b. The AF10A Multitube Manometer.
c. The AF14 Boundary Layer Apparatus, fitted with liners.
d. Accessories i.e. a flat plate (smooth and rough surface) and a Pitot tube.

6. PROCEDURE (Refer to Figure 3 and 4)

a. Check the air valve (1) for the airbox of Air Flow Bench to ensure it is fully opened.
b. Take the ambient temperature (2) and record in Table 1.
c. Placed a flat plate (3) at mid height in the section, with a sharpened edge (4) facing the oncoming flow.
d. Liners (5) to be fitted on the wall of working section with the position of decelerating free stream.

e. Set a Pitot tube (6) exactly on contact on the surface of the plate. Do not over press the Pitot tube on the plate surface.

f. Take the current reading of micrometer (7) and it becomes a zero.

g. Select only one tube of the Manometer (8) and take the water level reading. Use this as an initial reading at atmospheric pressure.

h. Press the ‘ON’ button – green button (9) to start the Air Flow Bench. Let a few minutes to stabilize the manometer reading.

i. Take the first reading of Manometer. Record it in the Table 1. The traverse distance, y should start from 0.20 mm.

j. Increase the value of micrometer (7) by 0.20 mm. Take the second reading and repeat the steps until y exceeding 1.00 mm.

k. Then increase each reading by 0.50 mm. Continue with the same procedure.

l. Repeat step 6.10 until the readings becoming constant as the velocity equals to free stream velocity.

m. Press the ‘OFF’ button (10). Unlock the screw of the plate (11) and change the side of the plate into rough side (3).

n. Repeat from step h until completed.
Figure 3: Arrangement of Test Section
Figure 4: Air Flow Bench with Test Section
7. **RESULT**

a. Calculate and fill up Table 1 and 2.

    Ambient temperature, T (°C): ......................

**Table 1**: Velocity Distribution on a Smooth Flat Plate

<table>
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<tr>
<th>No.</th>
<th>Micrometer Reading (mm)</th>
<th>Axis Distance, y (mm)</th>
<th>Manometer Reading, h (mm)</th>
<th>Pressure, $P$ (N/m$^2$)</th>
<th>Air velocity, $u$ (m/s)</th>
<th>Velocity Ratio, $u/U$</th>
<th>$1-(u/U)$</th>
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Table 2: Velocity Distribution on a Rough Flat Plate

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<th>Axis Distance, y (mm)</th>
<th>Manometer Reading, h (mm)</th>
<th>Pressure, P (N/m²)</th>
<th>Air velocity, u (m/s)</th>
<th>Velocity Ratio, u/U</th>
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b. Fluid Properties for Calculation (Table 1 and 2)

**PARAMETER**

Atmospheric pressure, \( P_{atm} = 1010 \text{ mb} = 1.010 \times 10^5 \text{ N/m}^2 \)

Air density, \( \rho_{air} = \frac{P_{atm}}{RT_{ambient}} \)

Gas constant, \( R = 287.2 \text{ J/kg.K} \)

Water density, \( \rho_{water} = 1000 \text{ kg/m}^3 \)

Dynamic viscosity (air), \( \mu \text{ kg/ms (based on } T_{ambient} \text{)} \)

Kinematic viscosity (air), \( \nu = \frac{\mu}{\rho_{air}} \text{ kg/m}^2 \text{s}^2 \)

Temperature, \( T = 273 + T_{ambient} \text{ K} \)

Length of plate, \( L = 0.265 \text{ m} \)

Thickness of Pitot tube, \( 2t = 0.40 \text{ mm} \); \( t = 0.20 \text{ mm} \)

Values of \( u/U \), \( \frac{u}{U} = \sqrt{\frac{P}{P_o}} \); \( P_o \) = Pitot tube reading in the free stream

c. Plot the graph, traverse distance \( y \) against the velocity ratio \( (u/U) \) for both smooth and rough plate.

d. Plot on the same graph, traverse distance \( y \) against \( u/U(1 - u/U) \) for both smooth and rough plate.

e. Calculate displacement thickness \( \delta^* \) and momentum thickness \( \Theta \) based on the area of the above graph. Then, calculate the shape factor \( H \). This will be an experimental value.

f. Calculate theoretical value of displacement thickness \( \delta^* \), momentum thickness \( \Theta \) and shape factor \( H \).
8. DISCUSSION

a. Compare and discuss the result of theoretical and experimental values.

b. Explain the effect of surface condition on the formation of boundary layer.

c. For the rough plate, the velocity distribution does not fall towards zero at y = 0. State the reason and the method to solve this problem.
d. Predict the result if the liners on the test section is reversed, i.e. becoming accelerating flow. What would happen?

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e. State at least 5 sources of error in this experiment.

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f. Give the conclusion.

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COURSE INFORMATION

COURSE TITLE: ENGINEERING LABORATORY V (BDA 37001)

TOPIC 5: CAVITATION

1. OBJECTIVE

The objective of this experiment is to demonstrate the cavitation phenomenon in a throat.

2. LEARNING OUTCOMES

At the end of this experiment, students should be able to understand the parameters which contribute to the formation of cavitation.

3. INTRODUCTION

Since the molecules of a liquid are in constant agitation, some of the molecules in the surface layer will have sufficient energy to escape from the attraction of the surrounding molecules into the space above the free surface. Some of these molecules will return and condense, but others will take their place. If the space above the liquid is confined, an equilibrium will be reached so that the number of molecules of liquid in the space above the free surface is constant. These molecules produce a partial pressure known as the vapour pressure in the space.

Under certain conditions, areas of low pressure can occur locally in a flowing fluid. If the pressure in such areas falls below the vapour pressure, there will be local boiling and a cloud of vapour bubbles will form. This phenomenon is known as cavitation and can cause serious problems, since the flow of liquid can sweep the flow of bubbles on into an area of higher pressure where the bubbles will collapse suddenly. If this should occur in contact with a solid surface, very serious damage can result due the very large force with which the liquid hits the surface. Cavitation can affect the performance of hydraulic machinery such as pumps, turbines and propellers, and the impact of collapsing bubbles can cause local erosion of metal surfaces.

Cavitation can also occur if a liquid contains dissolved air or other gases, since the solubility of gases in a liquid decreases as the pressure is reduced. Gas or air bubbles will be released in the same way as vapour bubbles, with the same damaging effects. Usually, this release occurs at higher pressures and, therefore, before vapour cavitation commences.
4. THEORY

When water flows through the venturi meter (Figure 1), where the cross section area at section (1) is large, the velocity of Water at the section is low and the accompanying pressure at section (1) is high. On the other hand, the pressure at section (2) is low.

![Figure 1: Water flows through the Venturi Meter](image)

Applying energy equation between section (1) and (2), neglecting the energy loss between (1) and (2) gives:

\[ \frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2 \]  
……………….. (1)

In the case of horizontal venturi meter, \( Z_1 = Z_2 \), then equation (1) becomes:

\[ \frac{p_1}{\gamma} + \frac{V_1^2}{2g} = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} \]  
………………………………. (2)

Cavitation will occur when pressure \( p_2 \) at the throat reduced to saturated vapour pressure, \( p_v \), then from equation (2) gives:

\[ \frac{p_1}{\gamma} + \frac{V_1^2}{2g} = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} \]

\[ p_v = p_1 + \frac{\gamma}{2g} (V_1^2 - V_2^2) \]

…………………………………………………………… (3)

\[ p_{v, abs} - p_{atm} = p_1 + \frac{\gamma}{2g} (V_1^2 - V_2^2) \]

\[ p_{v, abs} = p_{atm} + p_1 + \frac{\gamma}{2g} (V_1^2 - V_2^2) \]  
……….. (4)
Where,

\[ p_1 = \text{pressure at section (1), N/m}^2 \]
\[ p_2 = \text{pressure at section (2), N/m}^2 \]
\[ p_{\text{atm}} = \text{atmospheric pressure} \]
\[ p_{v,\text{abs}} = \text{(saturated) vapor pressure, N/m}^2, \text{ abs} \]
\[ p_v = \text{(saturated) vapor pressure, N/m}^2 \]
\[ V_1 = \text{average velocity at section (1), m/s} \]
\[ V_2 = \text{average velocity at section (2), m/s} \]
\[ Z_1 = \text{elevation of section (1), m} \]
\[ Z_2 = \text{elevation of section (2), m} \]
\[ g = \text{acceleration due to gravity, m/s}^2 \]
\[ \gamma = \text{specific gravity (N/m}^3) \]

5. **EQUIPMENT**

The Cavitation Apparatus is a self-contained unit for demonstration of cavitation when water flows through a throat with water flow rate and pressure is lower than vapor pressure. The apparatus consists of:

a. Cavitation Panel
   i. Venturi meter with 6x35mm inlet, 6x6mm throat and 6x35mm outlet.
   ii. Pressure gauge (0-3.5 kg/cm\(^2\)) at the inlet and vacuum gauge for the throat.
   iii. Inlet and outlet port with flow control valve at inlet side.

b. Flow meter, range 10-75 litre/m.

c. Storage tank.

d. Water pump
   i. operational power, 0.55kW
   ii. maximum delivery pressure is over 2kg/cm\(^2\)
   iii. maximum flow rate of over 60 litre/min
6. **PROCEDURE** (Refer to Figure 2)

Steps to run the experiment are:

a. Check the water storage tank level (1) as it must be nearly full.
b. Record the atmospheric pressure.
c. Start water pump (2).
d. Adjust flow rate to 10litre/min using a flow control valve (3).
e. Record $P_1$, $P_2$ and flow rate.
f. Observe and record the formation of cavitation at the throat (4).
g. Increase the flow rate by 5litre/min.
h. Repeat steps e and f until 50litre/min
7. **CALCULATION**

a. Calculate and fill up Table 1.

**TABLE 1**

<table>
<thead>
<tr>
<th>NO.</th>
<th>FLOW RATE, Q (litre/min)</th>
<th>PRESSURE $p_1$ (N/m$^2$)</th>
<th>PRESSURE $p_2$ (N/m$^2$)</th>
<th>VELOCITY $V_1$ (m/s)</th>
<th>VELOCITY $V_2$ (m/s)</th>
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Water Temperature : ………………($^0$C)
Atmospheric Pressure : ………………(N/m$^2$)
8. RESULTS

a. Compare $p_c$ calculated from equation (3) to $p_2$, obtained from the experiment when the bubble begins to appear at the throat.

b. Compare $p_{vabs}$ calculated from equation (4) to saturated vapour pressure in the text.
c. Conclusion.

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REFERENCES

SOLID MECHANICS


FLUID MECHANICS II

5. Emeritus Prof. E. Markland (2000), A First Course in Airflow, TQ Education & Training Ltd.
7. Manual of Pelton Wheel, TQ Education & Training Ltd.
8. Emeritus Prof. E. Markland (1996), A First Course in Hydraulics, TQ Education & Training Ltd.
# LAPORAN MAKMAL/LABORATORY REPORT

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