Université d'Ottawa · University of Ottawa

Faculty of Engineering

CVG 2116 : FLUID MECHANICES

LAB 1: FORCE ON A SLUICE GATE

Peter Alexander Mott
Justin Armstrong
Khalil Barakzai
Nathan Rodriguez
Mohamed Abuhajar

Lab Date: Jan 28, 2015
Report Date: Feb 7, 2014
T.A: Steven Douglas
Lab Group: Group 17

1.0 Abstract/Summary

This report will encompass all the essential information and experimental findings of the laboratory experiment conducted in the University of Ottawa's fluids lab located in the Colonel By building on February 28^{th}, 2015. The primary purpose of this experiment is to determine the fluid force acting on a sluice gate using two separate methods. Firstly, the piezometric head is measured at distributed points on the sluice gate and from this information the force distribution can be found. Once the distribution is found, the force and its resultant force application can be determined through the integration method. The second method uses the momentum flux equation and can be used given the steady flow conditions of the apparatus. The experimental results and the subsequent calculations provided useful information that was consistent with the expected results. Using the integration method, the hydrostatic force is approximately 73.10N while the stagnation force is 71.54N. The force found using the momentum flux equation is 69.53N, which is a reasonable finding given the values close proximity to that of the stagnation force. The experiment conducted is useful in determining fluid behavior and the fluid forces that act on the gate.

Table of Contents

List of Tables, Figures and Graphs:

2.0 Objective

The purpose of this particular experiment is to measure the piezometric head at varying points on a sluice gate. From these measurements and other given conditions, calculations will be performed in order to findthe fluid force acting on the sluice gate. Two methods will be used to determine the resultant force; the integration method and the momentum flux method will be implemented and compared.

3.0 Introduction

The determination of fluid force, whether it be hydrostatic or hydrodynamic, is an integral in many civil engineering applications. Fluid force acting on a structure or mechanical component is particularly important to establish because it will ultimately determine the overall design and function of a project. By determining the distribution of the fluid force and the application of the resultant force on a sluice gate within laboratory conditions, key observations can be made and translated into large-scale applications such as dams.

When dealing with steady flow under a sluice gate it can be determined that the fluid force distribution varies as the gate is raised or lowered. In this experiment the gate will be raised one centimeter from the bottom and by measuring the piezometric head on the manometers attached to the gate, the distribution can be calculated and plotted. Once the distribution is known the method of integration is useful in determining the fluid force and its point of application. Furthermore, given the conditions of the apparatus a second method can be used. Due to the steady flow, the momentum flux equation can be used to find aforementioned components. The experimental results for both methods will be compared and analyzed throughout the report.

4.0 Theory

When measuring the fluid force acting on a gate, the concept is relatively simple when the gate is completely closed. As descent below the water surface occurs, the water pressure increases and at a certain point (the center of pressure) a hydrostatic force can be obtained. This can be accomplished by integrating the fluid pressure exerted on the gate.

$$F_n = \int_A p\,dA \qquad \textbf{(eq. 1)}$$

p = pressure,

F_n= hydrostatic force.

However, in this experiment the gate was slightly open (1cm) allowing a constant flow and as a result creating a different pressure distribution. When this occurs the pressure at the bottom of the gate is equal to zero. This complicates things and makes the theoretical aspect of calculating the force on the gate marginally more complex. In cases such as this, the integration method will still offer a very respectable estimate and can be calculated by breaking up the force distribution into similar shapes.

The following equation, the momentum flux equation, can be used to calculate the vector sum of external forces on a given control volume.

$$\Sigma F = \rho Q(v_2 - v_1) \quad \text{(eq.2)}$$

ΣF = vector sum of external forces
ρ= density of water
Q = constant flow rate
v_1 and **v_2**= inflow and outflow velocity vectors within in the control volume respectively.

In order to find the constant flow rate of the system the following equation can be used.

$$Q = 1.365 \Delta H^{2.5} \quad \text{(eq.3)}$$

ΔH= head above the V-notch weir.

The momentum flux equation is used to help simplify the problem with the use of a control volume, however, it doesn`t give any point of application.
For the completion of this lab and to be used as the pressures for first equation, solving for the normal force, the stagnation pressure and hydrostatic pressures were found using the following equations.

Stagnation pressure head: $(p/\gamma)_{stag} = h - z$ **(eq.4)**

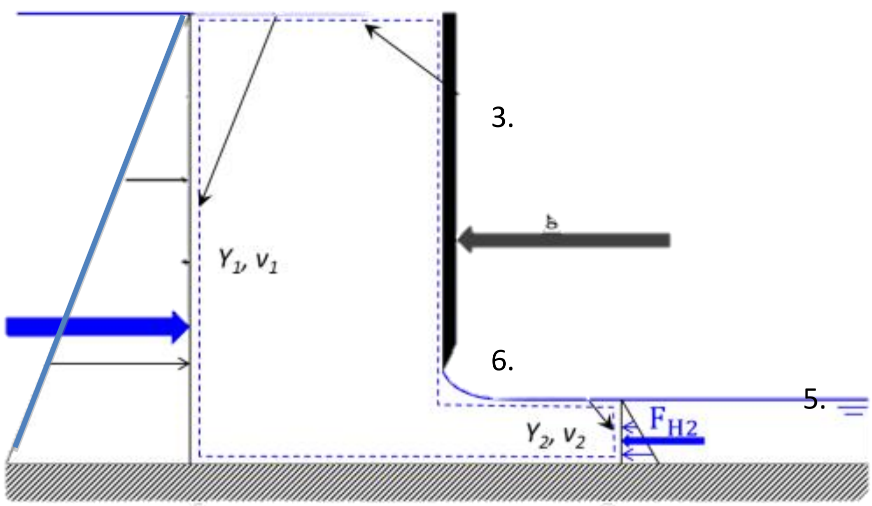
Hydrostatic pressure head: $(p/\gamma)_{hydr} = Y_1 - z$ **(eq.5)**

h= measured piezometric head for any manometer
z=elevation of the tapping point above channel bottom,

Y_1= depth of the upstream flow.

5.0 List of Equipment Apparatus and Materials

1. V-notch Reservoir
2. Manometer
3. Piezometric Taps
4. Ruler
5. Channel
6. Sluice Gate



<u>Figure 1:</u> Control volume used to derive momentum equation.

6.0 Procedure

Please refer to CVG2116 Fluid Mechanics Laboratory Manual for Complete Experimental Procedure

7.0 Calculations

<u>Step 1 – Find both the stagnation and hydrostatic pressure heads at each tapping point on the gate:</u>

<u>Sample calculation of *Manometer reading (h_i) for point 24*</u>:

$h_i = h - h_0$ where, - h_i is the adjusted piezometric head
- h is the measured piezometric head for any manometer
- h_0 is the zero reading of channel bed manometer

h_i = .481 m - .100m

h_i = .381 m

Sample calculation of *Stagnation pressure head for point 24:*

P_{stag} = (h_i – z_i)(9810 N/m^3) where, - h_i is the adjusted piezometric head
- 9810 N/m^3 is the specific weight of water
- z_i is the height of the taps above gate bottom

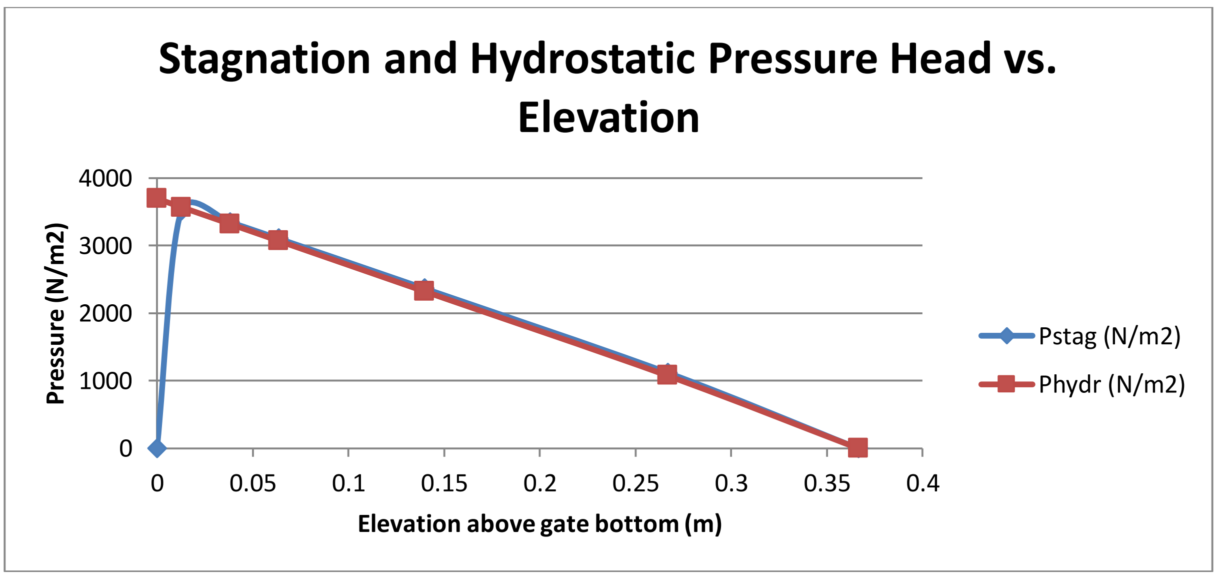
P_{stag} = (0.381 m – 0.2667 m)(9810 N/m3)
P_{stag} = 1121.28 N/m^{2dis}

Sample calculation *of Hydrostatic pressure head for point 24*:

P_{hydr} = (Y_1 – Z_i)(9810 N/m^3) where, - $Y_1$is the depth of upstream flow
- 9810 N/m^3 is the specific weight of water
- z_i is the height of the taps above gate bottom

P_{hydr} = (0.3665 m – 0.2667 m)(9810 N/m^3)
P_{hydr} = 979.038 N/m^2

Step 2 – Graph of Pressure vs. Elevation



Graph 1: Stagnation and Hydrostatic pressure head vs. Elevation

Step 3 – Find the resultant forces on the gate:

First we need to find the area under the curve for both stagnation pressure head and hydrostatic pressure head. Hydrostatic pressure acts linearly leading to a fairly simple area calculation:

$\mathbf{A_{hydr} = 0.5\ (0.3665\ m \times 3595.37\ N/m^2) = 676.83\ N/m}$

The stagnation pressure head vs. elevation curve is not linear, and therefore must be broken down into simpler shapes to find the area:

$\mathbf{A_{stag} = [0.5\ (0.3665\ m - 0.2667\ m)\ (1121.283\ N/m^2)] + [0.5\ (0.2667\ m - 0.0381\ m)\ (3344.23\ N/m^2 - 1121.28\ N/m^2)] + [(0.2667\ m - 0.0381\ m)\ (1121.283\ N/m^2)] + [(0.0381\ m - 0.0127\ m)\ (3344.23\ N/m^2)] + [\ 0.5(0.0127\ m)\ (3514.92\ N/m^2)] = 662.44\ N/m}$

Now we can multiply our area by channel width to find the resultant force :

$\mathbf{F_{hydr} = (676.83\ N/m)\ (0.108\ m)}$
$\mathbf{F_{hydr} = 73.10\ N}$

$\mathbf{F_{stag} = (662.44\ N/m)\ (0.108\ m)}$
$\mathbf{F_{stag} = 71.54\ N}$

<u>Step 4 – Use the standard V-notch weir formula to find the flow rate, Q:</u>

$\mathbf{Q = 1.365dH^{2.5}}$ **(SI units)** where,
- Q is the flow rate
- dH is the head above the V-notch weir

$\mathbf{Q = 1.365\ (0.312\ m - 0.242\ m)^{2.5}}$
$\mathbf{Q = 0.00177\ m^3/s}$

<u>Step 5 – Find the force on the gate using the momentum equation :</u>

First we must find v_1 and v_2, the inflow and outflow velocity vectors within the control volume:

V = Q/A where,
- V is velocity
- Q is flow rate
- A is area

$\mathbf{V_1 = (0.00177\ m^3/s)\ /\ (0.3765\ m \times 0.108\ m)}$
$\mathbf{V_1 = 0.0435\ m/s}$

$\mathbf{V_2 = (0.00177\ m^3/s)\ /\ (0.1086\ m \times 0.108\ m)}$
$\mathbf{V_2 = 0.1509\ m/s}$

Now we must find F_{H1} and F_{H2}, the hydrostatic force of the inflow and outflow respectively:

$\mathbf{F_{H1}} = 0.5\ (3693.465\ N/m^2)\ (0.3765\ m)\ (0.108\ m)$
$\mathbf{F_{H1} = 75.09\ N}$

$\mathbf{F_{H2}} = 0.5\ (981\ N/m^2)\ (0.1086\ m)\ (0.108\ m)$

F_{H2} = 5.75 N

Now we can use the momentum equation to solve for the force on the gate:

$\sum F = \rho Q (v_2 - v_1) + F_{H1} - F_{H2}$ where,
- $\sum F$ is the vector sum of the external forces acting on the control volume
- V_1 and v_2 are the inflow and outflow velocity vectors within the control volume, respectively
- ρ is the density of water
- Q is the flow rate
- F_{H1} is the hydrostatic force of the inflow
- F_{H2} is the hydrostatic force of the outflow

$\sum F$ = (1000 kg/m^3) (0.00177 m^3/s) (0.1509 m/s – 0.0435 m/s) + 75.0918 N – 5.7529 N

$\sum F$ = 69.53 N

8.0 Results

Tabular results of Step 1:

Manometer #	Elevation above gate bottom (m)	P_{stag} (N/m^2)	P_{hydr}(N/m^2)
-	0.3665	0	0
24	0.2667	1121.28	1077.14
23	0.1397	2367.15	2323.01
22	0.0635	3104.87	3070.53
21	0.0381	3344.23	3319.70
20	0.0127	3514.92	3568.88
-	0	0	3693.47

Table 1: Final results

9.0 Discussion

The pressure distribution plot, once analyzed, gives us useful information between the hydrostatic and stagnation pressure heads. The hydrostatic pressure head goes to zero at the water surface and is maximum at the bottom of the gate whereas the stagnation pressure head is zero at the water surface as well as the bottom of the gate. This is expected as the stagnation pressure head is inversely related to the velocity of the fluids, and it makes sense that the fluid is moving fastest near the opening (bottom of the gate) and the water surface. Of course, the hydrostatic pressure is highest at the bottom of the gate because it increase linearly with depth.

The pressure distribution plot differs depending on whether the gate is open or closed. This is because when the gate is closed, the hydrostatic pressure varies linearly with depth with the lowest point being the water surface and the highest point being the bottom of the gate. But once the gate is opened, the pressure at the bottom of the gate is equal to the pressure at the water surface which is the atmospheric pressure (or 0 gage), therefore resulting in a non-linear hydrostatic pressure plot.

The forces acting on the gate were calculated using two different methods, namely by integration and by using the momentum flux equation described above. For moving fluids, we expect the stagnation pressure to be higher than the static pressure, which is the case here as the hydrostatic pressure is 979.04 N/m^2 and the stagnation pressure is 1121.8 N/m^2. The resultant force, calculated using the integration method was 71.54 N compared to 69.53 N that was calculated using the momentum flux equation. These two values only have a relative error of 2.88% which is acceptable.

However, both methods have their disadvantages. The momentum flux equation is a good measure because it simplifies the problem using a control volume, therefore leading to more accurate results, but doesn't give you a point of application. The direct integration method is good because it calculate the force and its point of application, but has the downside of not being as accurate as it is next to impossible to derive an equation for the pressure curve and so we must instead approximate the area under the curve using shapes which may lead to inaccurate results.

This experiment has practical applications in that can be used to calculate forces on dam flood gates, and the resultant forces of winds on buildings and other structures.

One source of error is that the integration method can't be solved for the exact area leading to inaccurate resultant force calculations. Random errors include errors in measurement due to the students' unfamiliarity with the apparatus and equipment involved and the fact that air could have gotten into the manometers which would have affected the pressure readings.

10.0 Conclusion

This experiment was carried out to determine the resultant forces acting on a gate caused by a pressure distribution. The piezometric head at different points were examined for a deeper understanding of the pressure distribution and resulting flow rates. This was to be found using two different methods (eq. 1 and eq. 2) so that they could be examined and so that the efficiency of each may be compared to that of the other. The resultant force acting on the gate from a pressure distribution was found to be 71.54 N and 69.5 N by method of integration and by the momentum flux equation respectively. The relative error was found to be 2.88% showing that both methods are acceptable and prove to be useful in their own ways.

It should be noted that the main source of error for the experiment is caused by the inability to accurately determine the exact area of the pressure distribution on the sluice gate using the integration method. Multiple trials of this experiment with varying heights of the gate opening would give a better understanding of the pressure distributions. In conclusion, the experiment gives a pretty good representation of how water moves and reacts in a channel using a sluice gate.

11.0 References

(2014). CVG 2116 Introduction to Fluid Mechanics Laboratory Manual Winter 2015. University of Ottawa.