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Venturi Flume Experiment

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Contents

Introduction (3)

Theory (4)

Fig 1.0 plan view of the channel (4)

Fig 1.1 force+momentum graph (5)

Fig 1.2 Cv and b/B values table (6)

Method of experiment (7)

Results (8)

Fig 1.3 venturi program graphs (8)

Fig 1.4 table of results (9)

Fig 1.5 points of flow (10)

Conclusions (11)

Appendices pictures of channel (12-15)

References (16)

Introduction

In civil engineering it is sometimes necessary to understand the behaviour of fluids, in particular, water. A marina, a dam, sewage works and even a bridge built over a river all require knowledge of fluid behaviour. This knowledge prevents negative consequences occurring such as poor drainage of surface water, lowering of local water tables which could affect irrigation and agriculture, sedimentation build up and potential damage to submerged structures.

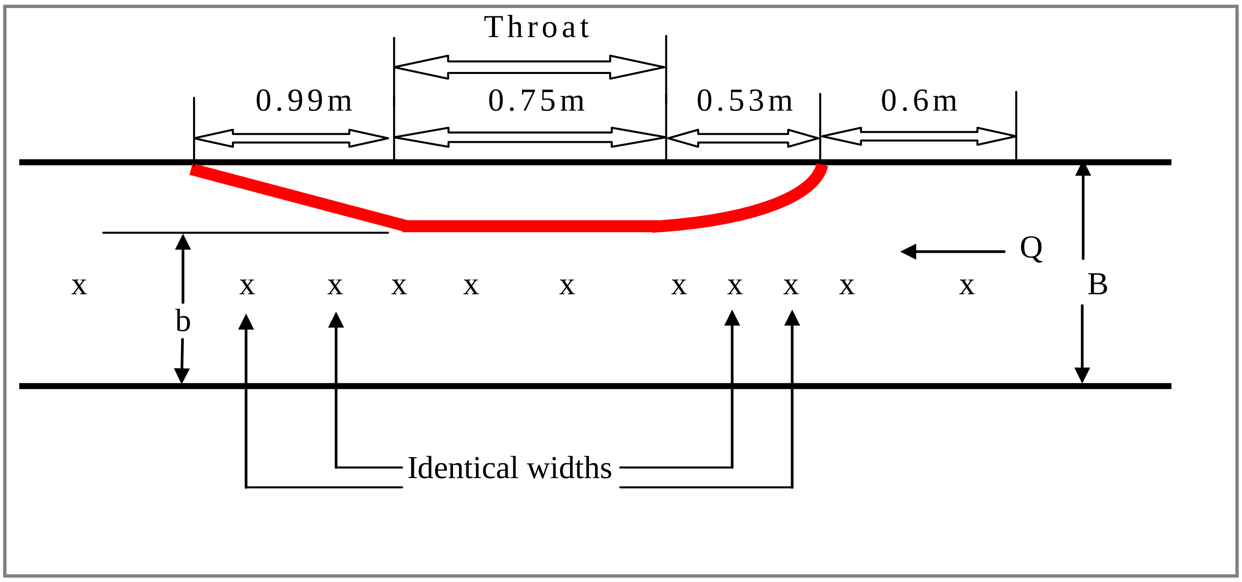
Hydraulic jump is a phenomenon that occurs in various forms around the world. It occurs when fast flowing water collides with slow moving water. The initial velocity of the fast flowing water decides how turbulent the hydraulic jump becomes. These can be natural or man made but can both cause damaging consequences if they are not taken into account. A great deal of energy can be dissipated by the hydraulic jump, which is useful when constructing a dam. Water from the fast flowing upstream at a spillway can cause erosion to the streambed downstream. By engineering the position of the jump it is possible to design an artificial streambed capable of handling the hydraulic forces exerted on it from the jump and then once the energy has been dissipated introduce the water back into the natural streambed thus reducing souring effects to the bed and avoiding leaks from the dam.

This report will investigate the hydraulic jump phenomenon and compare the widely used theoretical equations to actual data from the experiment and see how accurate the theory is in practice. The limitations and applications of this theory will be assessed along with potential uses for flumes as flow measuring devices.

Theory

Whenever a channel changes shape, the flowing water experiences rapidly varied flow. The channel used in the experiment was a venturi flume, which induces this rapidly varied flow by changing its geometry with the addition of a throat as shown in Fig1.0.

[Fig 1.0 shows a plan view of the channel with venturi flume used in the experiment]



The venturi flume used in the experiment also had the required geometry to create a hydraulic jump just after the throat with a given discharge. This happens when supercritical flow collides with sub critical flow. This happens in the experiment because the velocity increases as the channel area decreases and then when the channel area increases again the velocity reduces, but at the same time creates the sub critical flow required to collide with the supercritical flow thus inducing a hydraulic jump.

At the point of the hydraulic jump a great deal of turbulence can be created which results in a loss of energy.

The specific energy of a given point in the channel can be calculated from:

$$Es = y + \frac{v^2}{2g} \qquad \text{(Eq1)}$$

Or

$$Es = y + \frac{\alpha Q^2}{2gb^2y^2}$$

With a steady discharge.

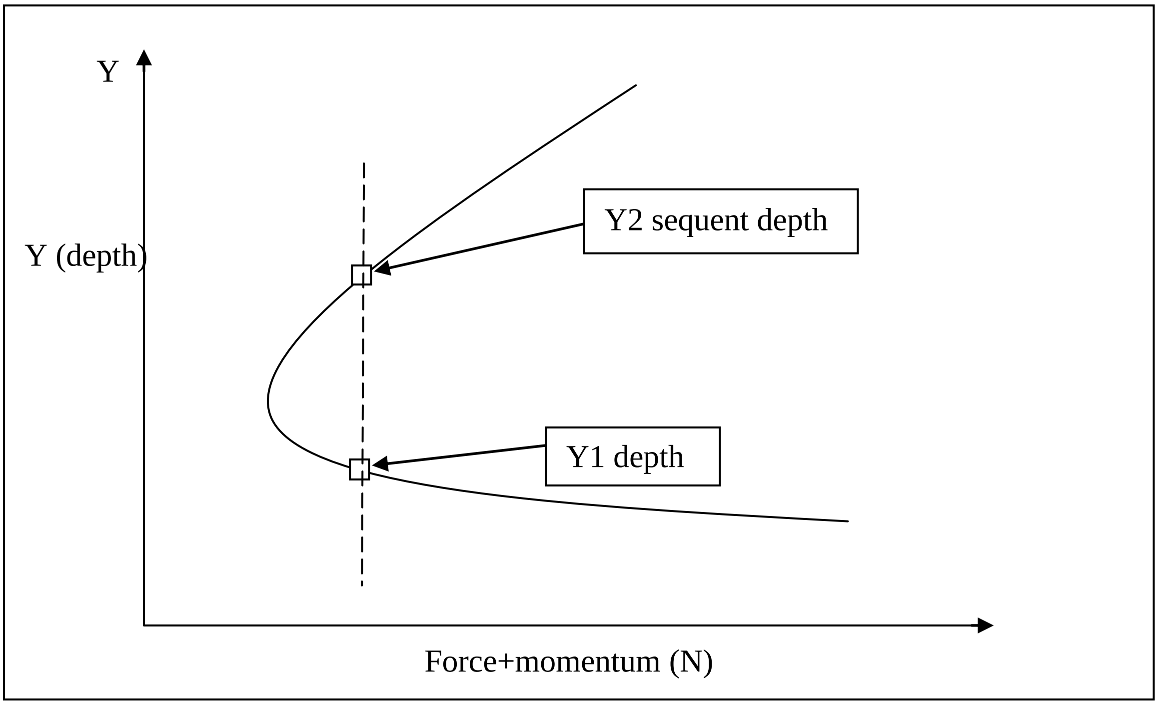
This equation can also be used to derive the discharge from a steady specific energy (Chadwick A J and Morfett J C, 1993):

$$Q = \sqrt{\frac{2g}{\alpha}(by)(Es - y)^{\frac{1}{2}}} \qquad \text{(Eq2)}$$

From these equations it can be proven that at the critical depth then the specific energy is at a minimum and the discharge is at a maximum. This is significant when using a hydraulic jump to dissipate energy in a spillway and can help with the design.

The force+momentum equation is used to visualise the depths of y1 and y2, y1 being the initially depth and y2 being the resulting depth. We can see from this graph how stable our hydraulic jump will be.

[Fig 1.1 shows a force+momentum graph and the points of y1, y2 in a stable hydraulic jump]



If y2 were to be located out of line to this at a higher depth then the jump would move upstream and if it were located lower it would move downstream.

This example can be likened to the comparison in froude numbers. By calculating the upstream froude number we can estimate the height of the jump. The higher the froude number upstream then the higher the jump will be, this also means that a high froude number indicates a high loss of energy.

For this experiment the discharge will be calculated using a manometer and a software program will be used to produce the specific energy curve and the force momentum curve. Then this information will be compared to results from theoretical equations. This will highlight differences which could arise from human error, variances of flow, unexpected losses etc.

To work out the discharge using the manometer we use the equation:

$Q = 0.01738\sqrt{R}$ Where R is the difference in meters from the manometer. (Eq3)

To work out the discharge using theoretical equations we will use:

$Q = 1.7046bCdCvH^{\frac{3}{2}}$ Where Cv and Cd are discharge coefficients, these values are found from the following table:

[Fig 1.2 shows the Cv values]

b/B	0.2	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70
Cv	1.0091	1.0143	1.0209	1.0290	1.0386	1.0500	1.0635	1.0793	1.0980	1.1203	1.1465

We then need to find Cd, which can be found using:

$Cd = \left(1 - \frac{0.006L}{b}\right)\sqrt{1 - \frac{0.003L}{h}}$ Where h is height and b is width of channel (eq4)

By looking at the equation for discharge we can see the usefulness of knowing the discharge in the system as it can be rearranged to tells us the upstream height.

$$H^{\frac{3}{2}} = \frac{Q}{1.7046bCdCv}$$

Or

$$H = \sqrt[\frac{3}{2}]{\frac{Q}{1.7046bCdCv}} \qquad \text{(Eq5)}$$

The froude number, as mentioned earlier, can indicate the type of flow that will occur i.e. supercritical, critical or sub critical. To find this we use:

$Fr = \frac{V}{\sqrt{gDm}}$ Where g is gravity and Dm is the channel mean depth (eq6)

If Fr is more than 1 we have supercritical flow
Fr is equal to 1 we have stable conditions
Fr is less than 1 we have sub critical flow.

Method of experiment

To begin the experiment the following items were needed:

- Laboratory channel with a point gauge and downstream sluice gate
- A supply of water from a low-level header tank.
- An orifice plate measured the discharge.
- A half-venturi flume was mounted.

The procedures were as follows to conduct the experiment:

- The point gauge was set to zero along with the downstream level gauge
- The control valves were opened and manometer readings were taken when it reached a difference of between 1m-1.2m
- Then the sluice was adjusted until an hydraulic jump was formed in the flow
- We then measured widths and downstream distance along with the water depth at certain points along the channel.

Potential risks included the risk of flooding which could lead to property damage or danger if any electrical equipment were to be submerged. By using a laboratory channel in a specifically designed hydraulics lab the risks were minimised by the design of the equipment.

Many students carried out the experiment so the risk of human error was high. Each student took readings at different points along the channel.

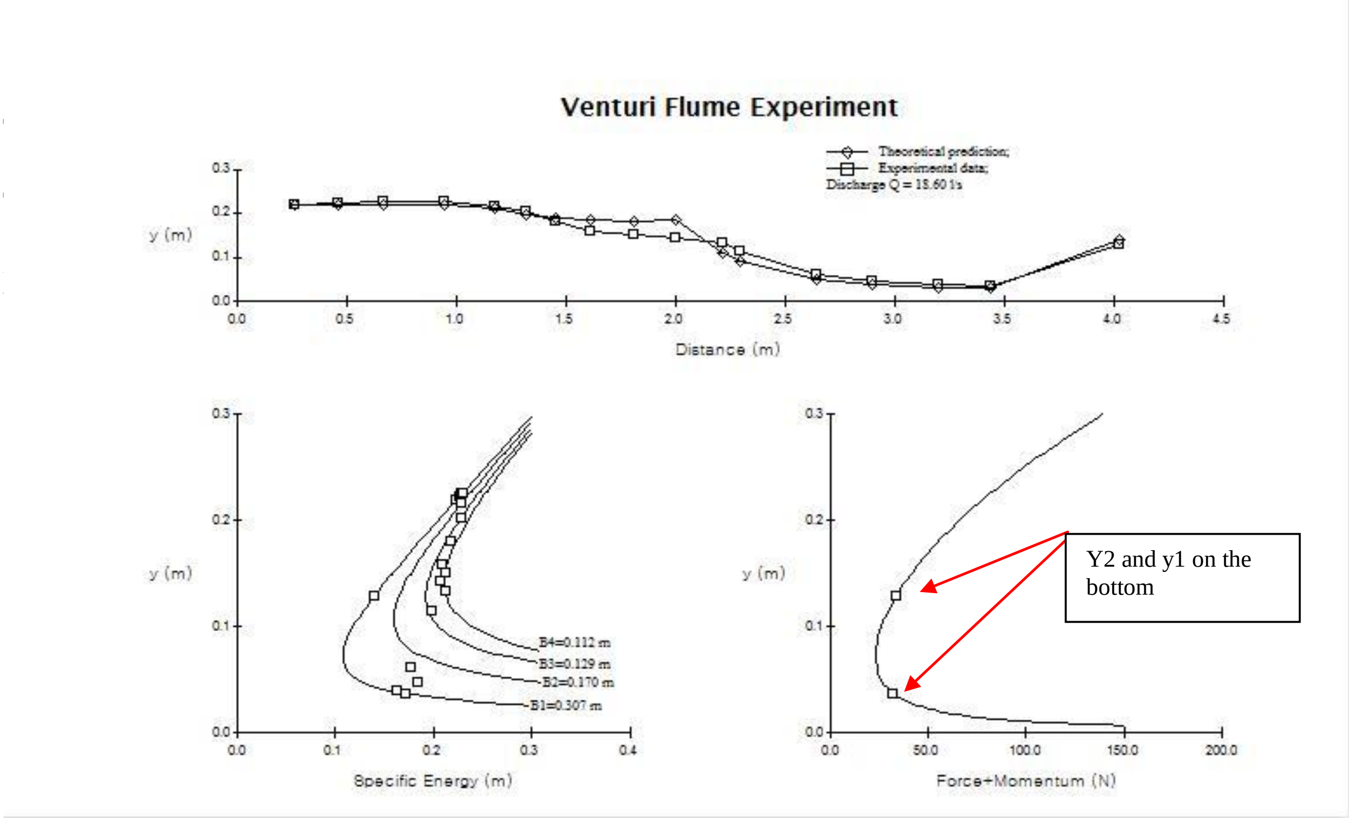
Results

Once we had the measurements we inputted the values along with the discharge. The discharge was calculated from the manometer and eq into Dr. She’s venturi flume program to produce three graphs.

- Y vs. Force+momentum
- Y vs. specific energy
- Y vs. distance along channel.

These can be seen in fig 1.3 below

[Fig 1.3 shows the venturi program graphs]



Y2 and y1 on the bottom

Below is a spreadsheet that shows the results of our experiment along with the values calculated using eq1 and eq7 for specific energy and force+momentum.

[Fig1.4 shows table of results for the experiment]

	Downsteam Distance (m)	**Width b (m)**	**Depth y (m)**	**Q (m/s)**	**Area (m2)**	**Velocity (m/s)**	**Fr**	**E specific**
1	0.264	0.307	0.220	0.0186	0.068	0.276	0.19	0.224
2	0.463	0.315	0.223	0.0186	0.070	0.265	0.18	0.227
3	0.670	0.312	0.226	0.0186	0.071	0.264	0.18	0.230
4	0.951	0.301	0.226	0.0186	0.068	0.274	0.18	0.230
5	1.180	0.170	0.217	0.0186	0.037	0.505	0.35	0.230
6	1.320	0.129	0.203	0.0186	0.026	0.712	0.50	0.229
7	1.460	0.119	0.181	0.0186	0.021	0.868	0.65	0.219
8	1.615	0.117	0.159	0.0186	0.019	0.999	0.80	0.210
9	1.810	0.112	0.151	0.0186	0.017	1.104	0.91	0.213
10	2.020	0.115	0.143	0.0186	0.016	1.133	0.96	0.208
11	2.220	0.112	0.133	0.0186	0.015	1.253	1.10	0.213
12	2.300	0.126	0.115	0.0186	0.014	1.292	1.22	0.200
13	2.650	0.199	0.062	0.0186	0.012	1.511	1.94	0.178
14	2.900	0.240	0.047	0.0186	0.011	1.638	2.40	0.184
15	3.200	0.299	0.040	0.0186	0.012	1.558	2.49	0.164
16	3.437	0.308	0.037	0.0186	0.011	1.653	2.76	0.176
17	4.030	0.306	0.129	0.0186	0.039	0.472	0.42	0.140

We can see from these results that our Froude number indicates that our critical flow occurs around 2.020m downstream and has a depth of 0.143m.
This where the throat narrows which is what is needed to create supercritical flow.
We can see also from the results that the water is supercritical at about the 5th point judging by the velocity. Here it speeds up as it goes through the throat and then slows again once it hits the sub critical flow.

From the equation:

$$Yc = \left(\frac{q^2}{g} \right)^{\frac{1}{3}}$$

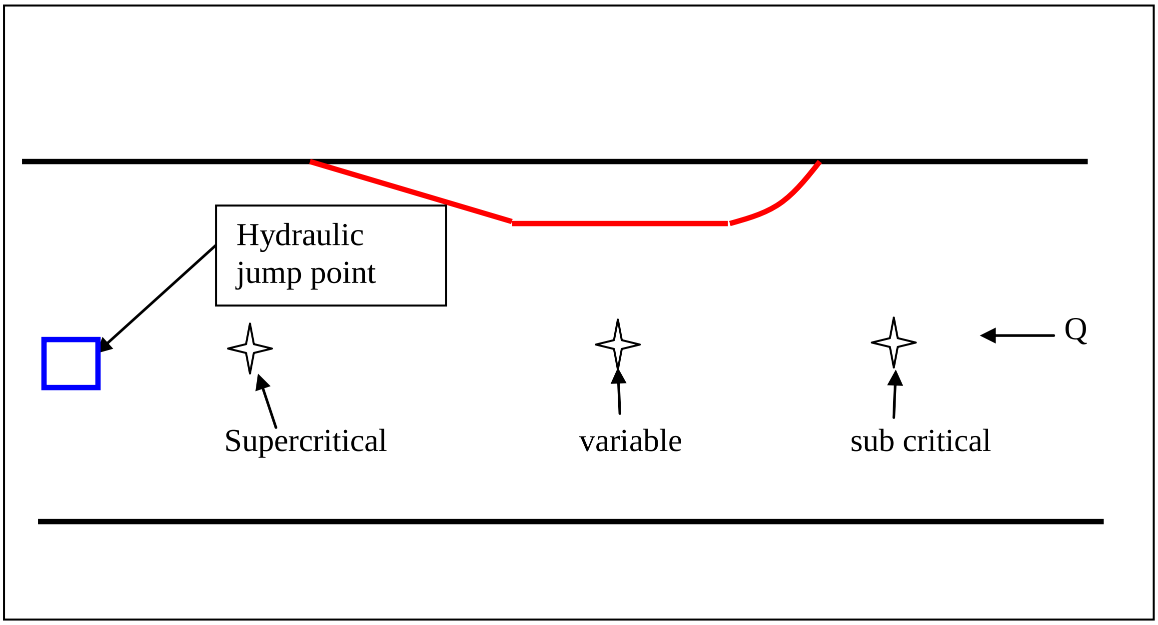
We can obtain our critical depth level, which is the required level for the flow to drop below to enable the hydraulic jump to occur. From our values we can calculate our critical depth:

$$Yc = \left(\frac{0.0186^2}{9.81} \right)^{\frac{1}{3}}$$

Yc=0.0327m

This depth is achieved at point 16 which is interesting as this point occurs after the jump point so this is clearly an mathematical error as the jump did occur!

[Fig 1.5 shows the points of flow through the channel]



It is clear there are some errors with our results as the theory and actual happenings don't completely match up. This is expected when different people take different measurements.

Conclusions

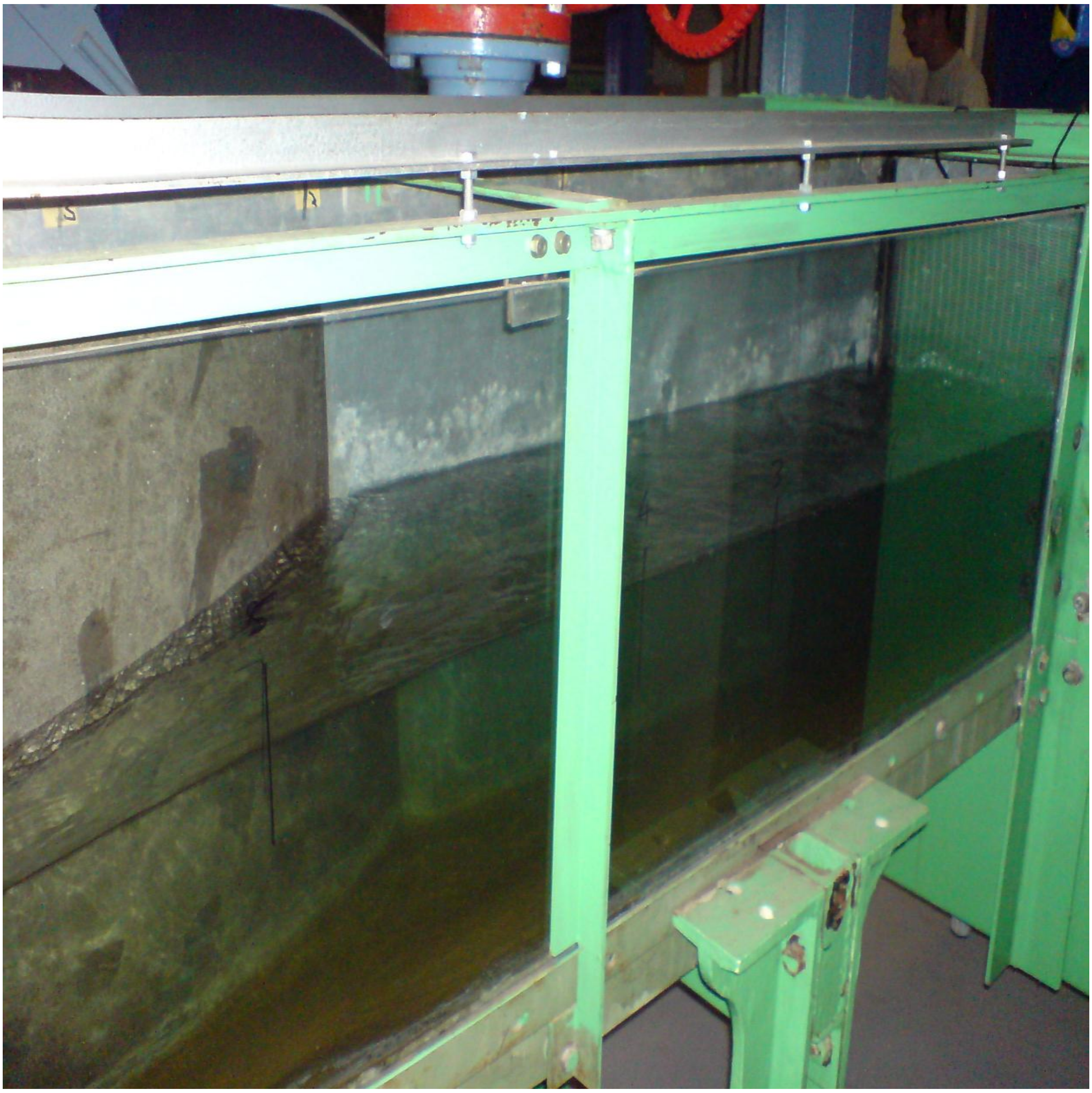
This principle is useful as civil engineers and can aid in the design of many industrial applications using water. In spillways it can tell us the water depth by knowing the discharge, we can predict the behaviour of the dissipation of energy and where it will occur and we can predict the turbulence of the hydraulic jump. All these things all come from the principles of momentum, which are widely used through hydraulics.

We can clearly see from the graphs that when the water goes through the throat it has the least specific energy, which approximately agrees with the theoretical predictions and means this is where the highest discharge is located.

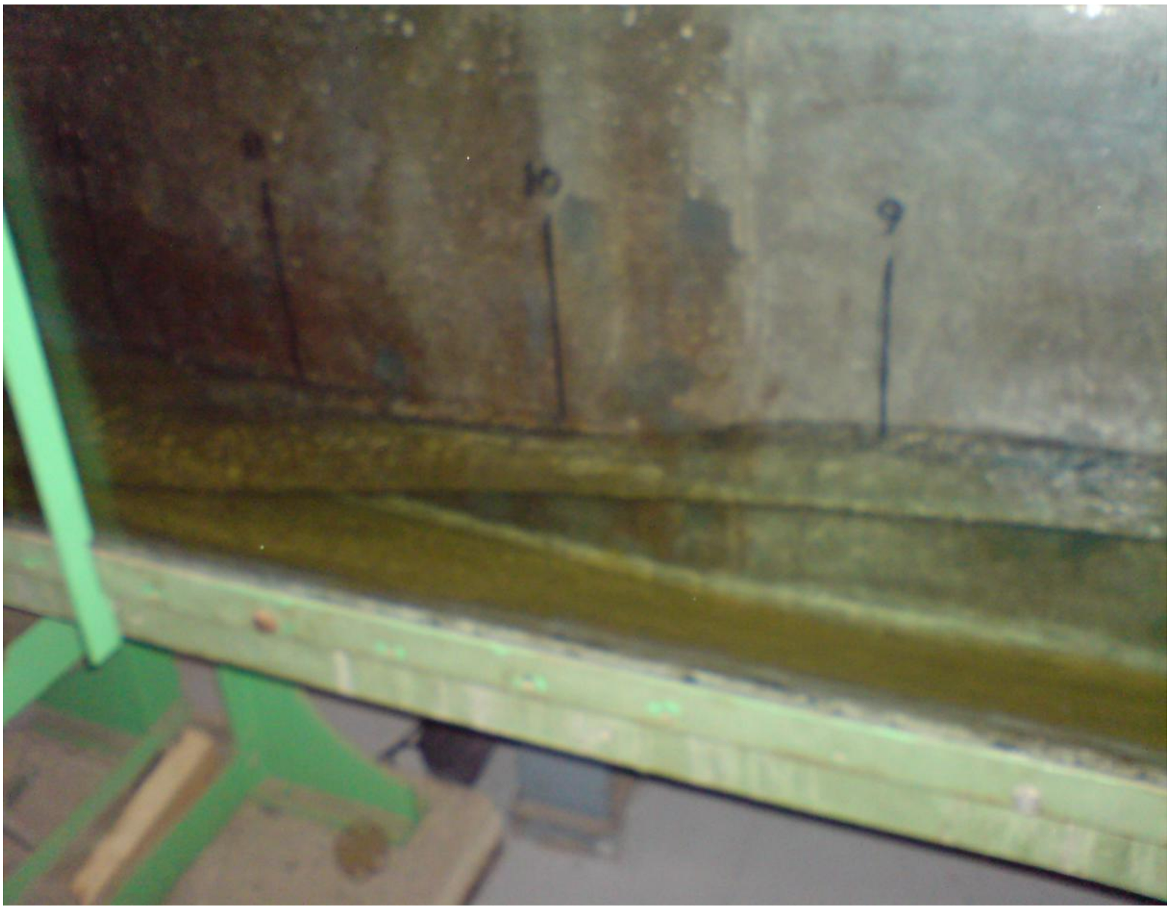
The equations used for this experiment have been derived from experiments so it's not surprising to see that they are fairly accurate with the results but with hydraulics it is difficult to include every loss. In the experiment for example turbulence and air entrainment where not considered but both were clearly happening towards the end of the channel. This increases the density of the water, which can induce errors. The friction of the surface was also no taken into account, which too would induce errors.

The flume could be used as a flow-measuring device by knowing the depths and geometry it would be possible to measure the discharge at given points along a channel. This could be useful for canals where it is important to have the correct flow conditions. Another application would be at the spillway of a dam to ensure that the energy dissipation hydraulic jump doesn't move from the designed spillway or scouring could occur on the streambed.

A view of the beginning of the throat

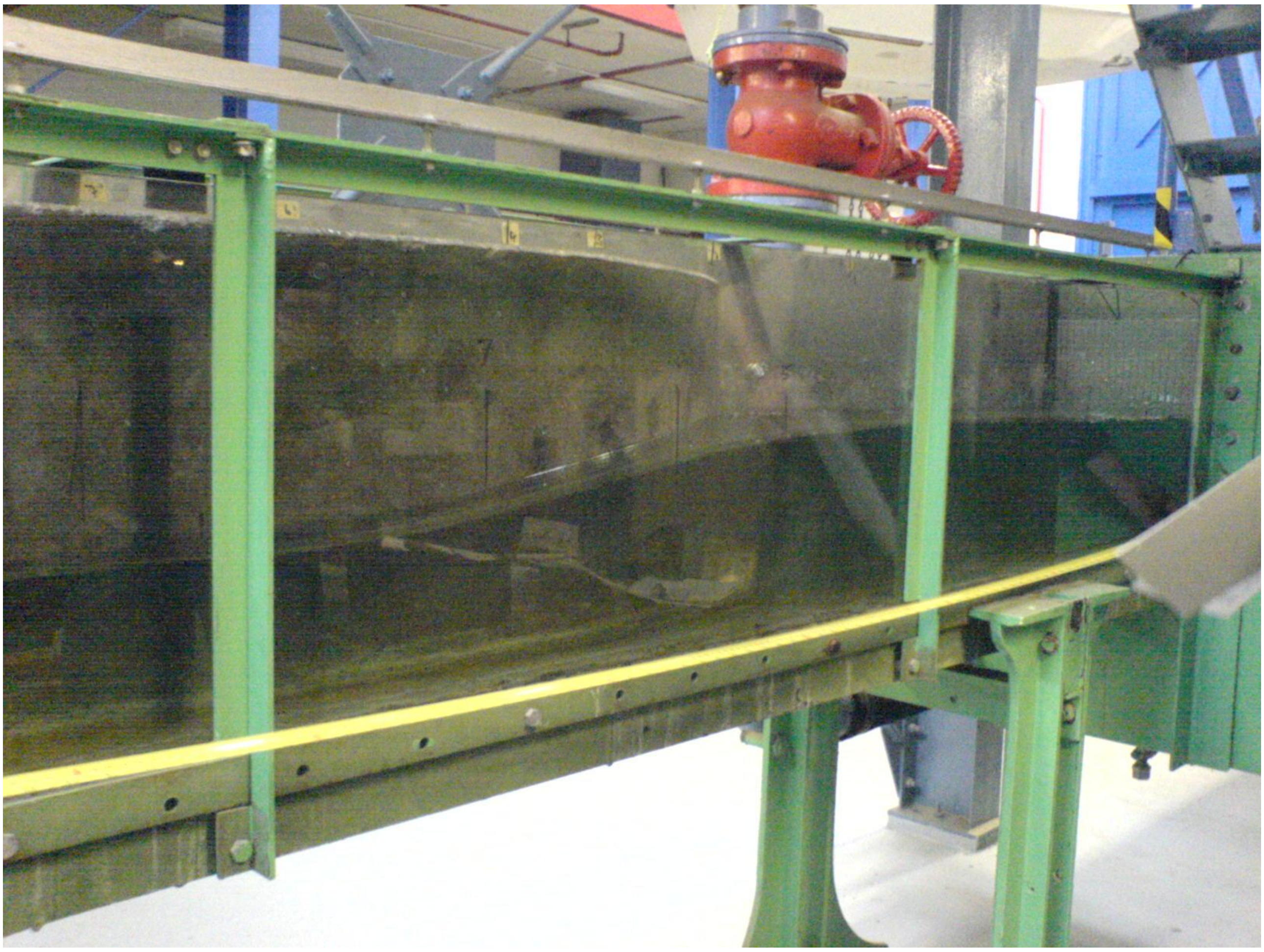


This shows the depth change before the hydraulic jump occurred



This shows the hydraulic jump

This shows a side view of the depth change



References

- Andrew Chadwick and John Morfett. Hydraulics in civil and environmental engineering. Second edition (1993) pg138. Published by E&FN Spon. ISBN 0 419 18160 1
- Dr.K.She handout for class CN225