Broad-crested weir flow

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INTRODUCTION

The intent of this photographic experiment was to image an interesting fluid phenomenon that was worth photographing. The submitted photograph was the third image assignment called “Team Assignment 1” for a class called Flow Visualization. Specifically, the objective of this particular image was to capture the movement of water flowing over a weir. The particular weir used in the image is a broad crested weir. The main driving force of this phenomenon is the pressure build up as the water runs towards the weir. As water flows from the beginning of the flume towards the weir it flows up and over the object. This causes changes in potential energy and water height before and after the weir. Many different phenomena could have been photographed for this first team image; it was the task of the photographer to create a flow worth submitting. The idea for this image came from seeing the flume in operation in the Integrated Teaching and Learning Laboratory (ITLL). After being tasked with creating a team image this apparatus immediately came to mind.

FLOW APPARATUS

Controlling water has been important to civilizations for centuries. It allows many different types of dams and water collection methods to exist. The most common way that water flow rates are controlled is through different types of weirs. This photograph displays a functioning broad crested weir. This flow control device has been used in important engineering applications ranging from dams and flood prevention to mining [4]. The flow is governed by Bernoulli’s equation, which will be discussed later. Through experimental data the discharge coefficient can be found using this equation, which is useful in controlling the fluid at different scales. Friction caused by the interaction between the working fluid and the weir interface causes this coefficient of discharge, which in turn causes a change in mass flow rate when a weir is inserted [1, 2].

The flume apparatus in the ITLL is available for any body to use. Essentially it simulates water running through a channel that can be blocked by various weirs. There is a hook in the flume that allows the weirs to be secured down, as can be seen in the diagram below.

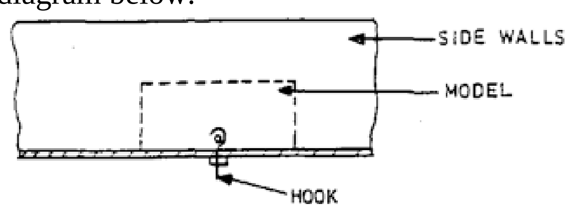

Figure 1: Flume Hook Set-up

Once the weir has been secured to the flume floor the water can be turned on. The flow rate of water is adjusted using a valve on the side of the flume. It is also possible to change the angle of the weir with respect to the floor of the ITLL. This is done using a valve at the back of the flume. For this particular picture the flow rate was at approximately 85 liters per minute and the angle between the floor and the flume floor was 0 degrees. An apparatus exists on the flume that makes measuring flow rate easy. By timing the rate at which a cavity (with marked volume measurements) fills, the flow rate was estimated. The maximum flow that this flume can produce is 125 liters per minute. Other specifications of the flume can be found in the table below.

Table 1: Flume Specifications

Specification	Value
Length of Flume Working Section	2500 millimeters
Width of Working Section	76 millimeters
Depth of Working Section	250 millimeters
Flow rate	50-125 liters/minute

The weir inserted was one of many provided by the ITLL for a flume experiment. The dimensions of the broad crested weir are shown in the table below.

Table 2: Weir Specifications

Specification	Value
Width	76 millimeters
Height	100 millimeters
Length	355 millimeters

FLOW ANALYSIS

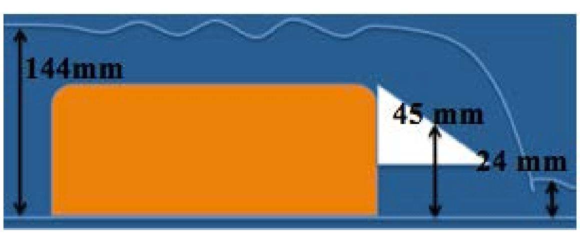

Figure 2: Flow Diagram

Typically weirs are used to disrupt the water movement by introducing a shape that will slow down and deform the natural flow of water. When systems are viewed on large scales many inconsistent values affect the flow rate and head before and after the weir [1]. To account for this variability a dimensionless number was created that can be measured on small-scale experiments and applied to real life scenarios. This value is called the discharge coefficient.

The coefficient of discharge is a ratio of the ideal flow of the system without a weir, and the ideal flow of the system with the weir in place [3]. It can be experimentally measured in a flume setup by repeatedly recording the flow rate during a time the flume is running with the weir in place. Bernoulli's equation for ideal flow through an open channel can be reduced to the following relation for coefficient of discharge.

$$\boldsymbol{C_d = \frac{3Q}{2bh^{3/2}\sqrt{2g}} = \frac{3*0.0021}{2*0.076*0.044^{3/2}\sqrt{2*9.81}}}$$

Equation 1: Bernoulli's

An experimentally derived equation is also available for the discharge coefficient. This equation is called the Rehbock equation and appears as below. In these equations there are several variables, which can be easily explained. Q is the flow rate in cubic meters per second, b is the width of the weir in meters, h is the head upstream of the flume in meters, P is the height of the weir, and g is gravity in meters per second squared. To find head upstream the height of the weir was subtracted from the upstream water height.

$$C_d = 0.602 + 0.083\frac{h}{P} = 0.602 + 0.083\frac{0.044}{0.10}$$

Equation 2: Rehbock

Using these two equations leads us to two slightly different discharge coefficients. For Bernoulli's equation (Eq. 1) we find a C_d of 0.68. For the Rehbock equation (Eq. 2) we find a C_d of 0.64. Normally these values would be experimentally calculated over multiple trials but this is an expected value for a broad crested weir [1].

As can be seen from the photograph nearly all of the flow that is captured is laminar. It is slow moving and does not represent any turbulent trends at all. After the water has collapsed post-weir the flow becomes more complicated but that is out of the scope of this image. The photograph is also spatially resolved; the most defined attribute of the photograph is the falling water above the air nappe. There are several pixels defining the boundaries of this air pocket leading the belief that this is spatially resolved.

IMAGING TECHNIQUE

To create this image the water flowing through the flume was mixed with a Pearl-Ex dye that helped show the pathway of the liquid. The Pearl-Ex was a gold powder that easily diffused into the water and was not very helpful in visualizing the flow after it had mixed in. It did however give the water a gold tint, leading to the final choice of a sepia tone for the image. The Pearl-Ex was purchased at an arts store in Boulder called Guiry's.

The lighting used in this photograph is a mixture of fluorescent lighting from the ceiling and a strong pair of 500W work lights. A strong issue encountered here was a glare on the clear sidewall of the flume due to the lighting. If the lighting was not focused on the subject however, it was not bright enough to get a sharp image. It took a long time to balance the lights at the correct spot to avoid glare and still have enough light for a good shot.

PHOTOGRAPHIC TECHNIQUE

This photo was taken with a digital Nikon D3000 with approximately one meter to the subject. It provided a (3872x2592) pixel resolution that, after editing, resulted in a (3366×967) pixel resolution. The D3000 is a digital single lens reflex camera (DSLR). When the image was taken the ISO was set to 1800, the lens focal length to 34mm, shutter speed to 1s/320 for a sharp image, and aperture set at f/5.

After importing the original raw image it was clear what the center of the picture should have been. By cropping out almost 70% (by area) of the photo the weir became the center of the image. To accurately image these a wide angle lens would have been necessary, or a panoramic shot. Besides the large cropping job the image was also converted to a sepia tone. This really brought out the definition of the weir and gave the image the feel of an old time photograph.

CONCLUSION

This image shows a sexy side to a lab experiment that is underappreciated. The application of weirs is extremely important and it is very easy to oversee that as a mechanical engineer. The photo shows a side to the weir that is not typically seen; an artistic side. The physics of this photograph nearly cover the entire area of the image. The effects of the weir in the flume are clearly seen and the air pocket sparks an interest in anybody viewing the photo.

One question that lingers post assignment is what other factors play a role in forming this water movement, and primarily what exactly causes the air nappe. I am curious if the air pocket could change shape if you inserted more air into it during operation, or if you could move air out. I am also curious what the photo would look like with much more Pearl-Ex inserted into the flume.

My intent for this project was not only to capture an interesting flow that showed physics at work, but also to make it look stunning. This photograph encompasses both of those goals well and I am very proud of the picture.

To improve on this image I would like to have a panoramic view of this, with more definition on the flow. This would be to really focus in on the part of the image I am interested in, allowing for a much higher quality image. If I had more time to spend on this photo I would like to get the flume back out and only take pictures of the broad crested weir, and lots of them. Then I would like to create a panoramic image, or maybe even a video of the weir in action with increasing flow rate. I think that would show more interesting physics and help show what is causing the fluid formation. Overall I feel accomplished with this photograph.

REFERENCES

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3. Hollingshead, Colter L. *Discharge Coefficient Performance of Venturi, Standard Concentric Orifice Plate, V-cone, and Wedge Flow Meters at Small Reynolds Numbers*. Diss. Utah State University, 2011. Salt Lake City, Utah: Digital Commons at USU, 2011.
4. “Planning and Design of Navigation Dam”. *Engineering Manual.* Web. 21 Mar. 2012. <http://140.194.76.129/publications/eng-manuals/em1110-2-2607/entire.pdf>.

APPENDIX

Figure A 1: Unedited Image (3872 × 2592) Pixels

Figure A 2: Edited Image (3366 × 967) Pixels