ENGG *2230

Fluid Mechanics: Lab 5

Laboratory #5 – Discharge over Weirs

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Section #3 - Group A1

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Intro

The purpose of this experiment is to establish a relationship between head upstream water level and discharge for different shapes of sharp edged notched weirs (Joy 2018). Weirs are used to regulate fluid flow without obstructing it completely. The different shapes of the weirs allow the fluid flow to be manipulated in different manners. Weirs are commonly used in many water resource and environmental systems to regulate flow in rivers and other open channels (Joy 2018). There were three different geometries for the weirs examined in this experiment; a rectangular weir and 2 V-notch weirs with internal angles of 30° and 90°.

The different geometries have different equations for calculating the discharge over weirs (Joy 2018). The difference of geometries affect the flow and rate of flow. Understanding how to regulate the flow of fluid is a vital skill and has many real world application. This includes the use of weirs in swimming pools, as a barrier to keep waste out of the water body while still maintaining sufficient flow into the pool.

Description of Apparatus

Water from the bench supply traverses from the hose to pipes that distribute the water into the tank. The tank contracts as seen in figure 1, and the weir is attached in this section of the apparatus. An adjustable ruler is suspended above the water level. Additional equipment provided for the experiment includes; 4kg weights to counter the flow and a stop watch to time to flow rate.

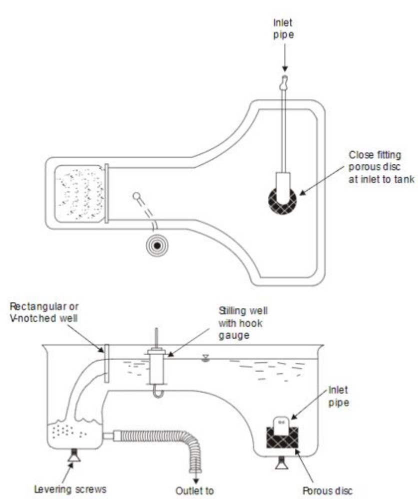

Figure 1 – Weir apparatus (Joy 2018)

Experimental Procedure

This experiment measures the flow through three different types of weirs. These are rectangular, a 30 degree weir notch and 90 degree V-notch weir (all 100 mm in height). The apparatus is set up as shown in figure 1 and the hydraulic bench is in the off position.

Before the pump is turned on, the first weir is placed where the notches are on the elevated channels. Once fastened in place, it is checked that it is flush with the channel so that no water can leak through the sides. The pump is turned on by opening the supply valve slowly, so that the water flows through the perforated pipes and begins to fill the tank. Keep the water flowing until the level is just seeping below the bottom of the weirs and there is no outflow of water onto the other side of the weir, the shut the water flow off. The water level may be adjusted with a container provided to ensure that the level is correct. For V-notch weirs, the reflection of the V in the surface indicated the correct level (Joy 2018). When the desired level is obtained, the hook gauge can be used on the water surface to get a zero reading (Joy 2018).

The control valve can be opened to let the water flow through the tank. Control the flow of water by adjusting the control valve, by observing on the hook gauge that the level stays steady to be able to take the flow readings. Release the weigh tank by sliding the bar holding the counter weight. Close it once the tank drops. When the counter weight touches the bar, instantly out a weight on the weigh bar and start timing until the bar rises again. Stop the watch and record the results. Record the amount of weight used and the amount of time it took to counter the flow. Repeat the flow measurement once to get more accurate results. Increase the flow of water using the control valve to finally take five different reading for each weir, leading to ten different flow readings. Change weirs and follow the same procedure after resetting the hook gauge.

Results, Calculations and Discussion

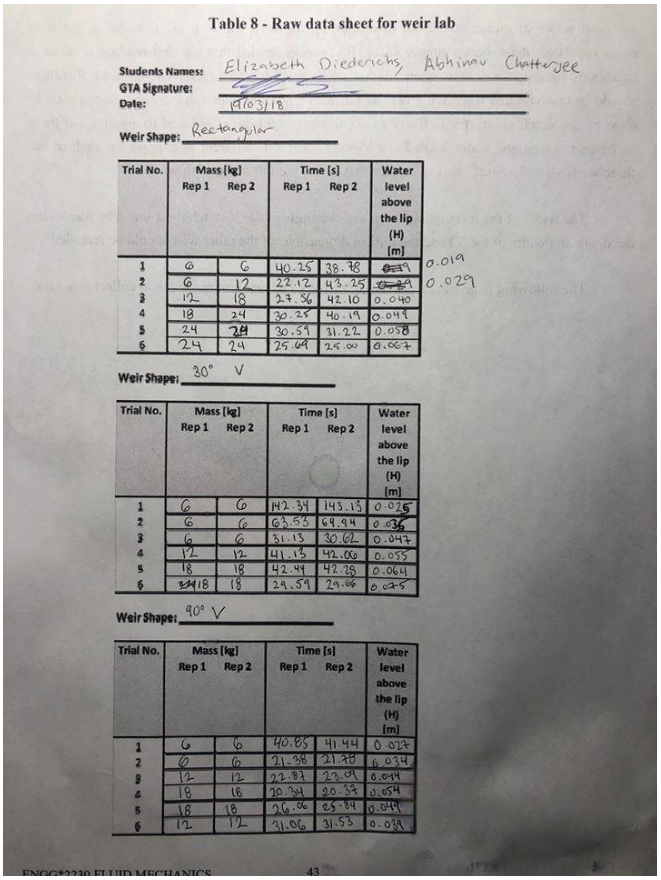

Table 8 - Raw data sheet for weir lab

Students Names: Elizabeth Diederichs, Abhinav Chatterjee
GTA Signature:
Date: 19/03/18

Weir Shape: Rectangular

Trial No.	Mass [kg] Rep 1	Mass [kg] Rep 2	Time [s] Rep 1	Time [s] Rep 2	Water level above the lip (H) [m]
1	6	6	40.25	38.78	~~[illegible]~~ 0.019
2	6	12	22.12	43.25	~~[illegible]~~ 0.029
3	12	18	27.56	42.10	0.040
4	18	24	30.25	40.19	0.049
5	24	24	30.59	31.22	0.058
6	24	24	25.69	25.00	0.067

Weir Shape: 30° V

Trial No.	Mass [kg] Rep 1	Mass [kg] Rep 2	Time [s] Rep 1	Time [s] Rep 2	Water level above the lip (H) [m]
1	6	6	142.34	143.13	0.025
2	6	6	63.53	64.94	0.036
3	6	6	31.13	30.62	0.047
4	12	12	41.13	42.06	0.055
5	18	18	42.44	42.28	0.064
6	~~[illegible]~~ 18	18	29.59	29.66	0.075

Weir Shape: 90° V

Trial No.	Mass [kg] Rep 1	Mass [kg] Rep 2	Time [s] Rep 1	Time [s] Rep 2	Water level above the lip (H) [m]
1	6	6	40.85	41.44	0.027
2	6	6	21.38	21.78	0.034
3	12	12	22.87	23.09	0.044
4	18	18	20.34	20.37	0.054
5	18	18	26.06	25.84	0.049
6	12	12	31.06	31.53	0.039

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There were three weir used; rectangular, a 30° V-notch and a 90° V-notch. The critical dimensions of each weir can be seen in Figure 2.

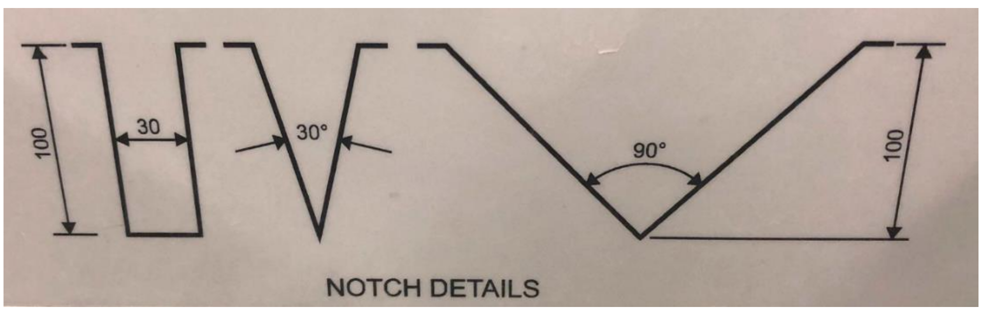

Figure 2 – Weir critical dimensions (in mm) (lab apparatus)

A graph of the log of the upstream water level and log of discharge can be seen in Figure 3. The slope and y-intercept of each weir data set can be used to determine experimental discharge coefficients and the exponent of H.

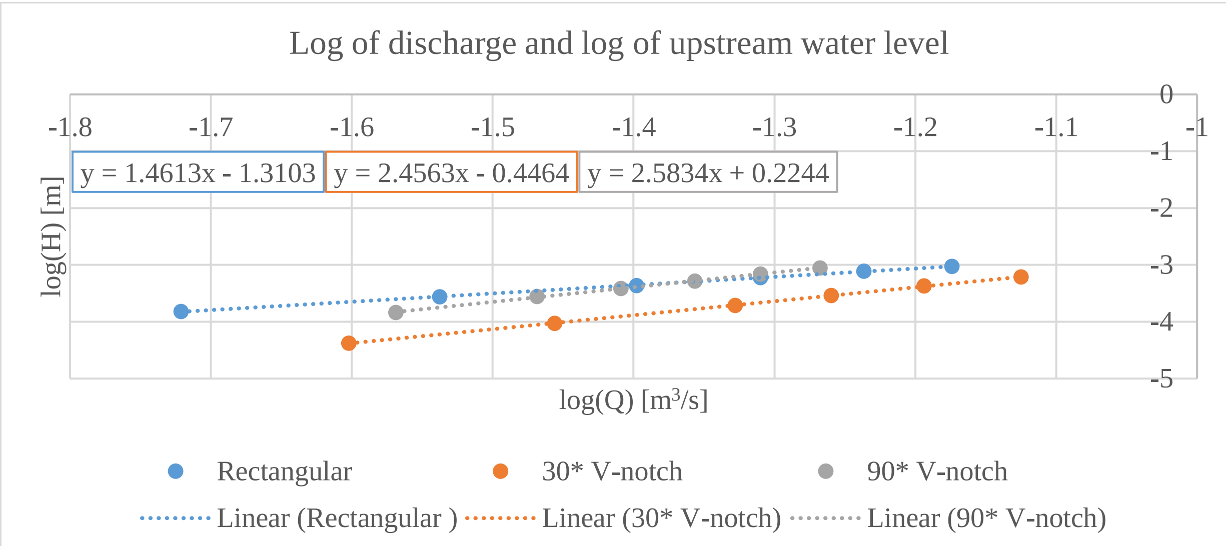

Figure 3 – Graph of log of discharge and log of upstream water level

The experimental and theoretical values of discharge coefficient and n are included in Table 1.

Table 1 – Determined and Published Discharge Values, C_{de}, and Exponent of H, n, for All Weirs

Weir Type	Experimental C_{de}	Experimental n	Theoretical C_{de}	Theoretical n
Rectangular	0.552	1.461	0.60 (1)	1.5 (3)
30° V-notch	0.565	2.456	0.44 (2)	2.5 (3)
90° V-notch	0.710	2.583	0.44 (2)	2.5 (3)

*(1) (Prycel et al. 2018), (2) (White 2016), (3) (Joy 2018)

This experiment looks at four ways to calculate discharge over a weir. These values for all three weirs can be seen in Table 2.

Table 2 – Discharge Calculations for Weirs

Trial No.	Weigh Tank Discharge (Q) [m^3/s]	Theoretical Discharge (Q_t) [m^3/s]	Discharge using Experimental K and n values (Q_e) [m^3/s]	Discharge using Published C_{de} and n Values (Q_p) [m^3/s]
Rectangular Weir				
1	1.52E-04	2.32E-04	1.49E-04	1.39E-04
2	2.74E-04	4.37E-04	2.77E-04	2.63E-04
3	4.31E-04	7.09E-04	4.43E-04	4.25E-04
4	5.96E-04	9.61E-04	5.97E-04	5.76E-04
5	7.77E-04	1.24E-03	7.63E-04	7.42E-04
6	9.47E-04	1.54E-03	9.42E-04	9.22E-04
30° V-Notch Weir				
Trial No.	Weigh Tank Discharge (Q) [m^3/s]	Theoretical Discharge (Q_t) [m^3/s]	Discharge using Experimental K and n values (Q_e) [m^3/s]	Discharge using Published C_{de} and n Values (Q_p) [m^3/s]
1	4.20E-05	6.26E-05	4.15E-05	2.75E-05
2	9.34E-05	1.45E-04	9.49E-05	6.38E-05
3	1.94E-04	3.03E-04	1.96E-04	1.33E-04
4	2.89E-04	4.49E-04	2.88E-04	1.98E-04
5	4.25E-04	6.56E-04	4.18E-04	2.89E-04
6	6.14E-04	9.75E-04	6.17E-04	4.29E-04
90° V-Notch Weir				
Trial No.	Weigh Tank Discharge (Q) [m^3/s]	Theoretical Discharge (Q_t) [m^3/s]	Discharge using Experimental K and n values (Q_e) [m^3/s]	Discharge using Published C_{de} and n Values (Q_p) [m^3/s]
1	1.46E-04	2.83E-04	1.49E-04	1.25E-04
2	2.78E-04	5.04E-04	2.70E-04	2.22E-04
3	5.22E-04	9.59E-04	5.25E-04	4.22E-04
4	8.84E-04	1.60E-03	8.91E-04	7.04E-04
5	6.94E-04	1.26E-03	6.93E-04	5.52E-04
6	3.83E-04	7.10E-04	3.84E-04	3.12E-04

Sample Calculations

Weigh Tank Discharge

$$Q = M_W\left(\frac{1\,L}{1\,kg}\right)\left(\frac{1\,m^3}{1000\,L}\right)\left(\frac{1}{\frac{t_1+t_2}{2}}\right)$$

$$Q = 6\,kg\left(\frac{1\,L}{1\,kg}\right)\left(\frac{1\,m^3}{1000\,L}\right)\left(\frac{1}{\frac{40.25\,s+38.78\,s}{2}}\right)$$

$$Q = 0.000152\ m^3/s$$

Experimental Discharge Coefficients, C_{de}

$$*\,refer\ to\ Figure\ 3$$

$$y - intercept = \log(K)$$

$$K = 10^{-1.3103}$$

$$K = 0.0489$$

a) Rectangular Weir

$$K = \frac{2}{3} C_{de} \sqrt{2g} L$$

$$C_{de} = \frac{\frac{3}{2} K}{\sqrt{2g} L}$$

$$C_{de} = \frac{\frac{3}{2}(0.0489)}{\sqrt{\left(2(9.81\ m^2/s)\right)}(0.03\ m)}$$

$$C_{de} = 0.552$$

b) V-notch Weirs

$$K = \frac{8}{15} C_{de} \sqrt{2g} \tan\left(\frac{\theta}{2}\right)$$

$$C_{de} = \frac{\frac{15}{8} K}{\sqrt{2g} \tan\left(\frac{\theta}{2}\right)}$$

$$\theta = 30°\ for\ 30°\ V - notch\ weir$$

$$\theta = 90°\ for\ 90°\ V - notch\ weir$$

Experimental Exponent of H, n

$$*\,refer\ to\ Figure\ 4$$

$$n = slope$$

$$n = 1.4613$$

Theoretical Discharge, Q_t

a) Rectangular Weir

$$Q_t = \frac{2}{3}\sqrt{2g}\ LH^{\frac{3}{2}}$$

$$Q_t = \frac{2}{3}\sqrt{2(9.81\ m^2/s)}\ (0.03\ m)(0.019\ m)^{3/2}$$

$$Q_t = 0.000232\ m^3/s$$

b) V-notch Weirs

$$Q_t = \frac{8}{15}\sqrt{2g}\ \tan(\theta/2)\ H^{\frac{5}{2}}$$

$$Q_t = \frac{8}{15}\sqrt{2(9.81\ m^2/s)}\ \left(\tan(\frac{30°}{2})\right)(0.025\ m)^{5/2}$$

$$Q_t = 6.26\ x\ 10^{-5}\ m^3/s$$

$$*\ for\ 90°\ V - notch\ weir, \theta = 90°$$

Discharge using Experimental K and n Values, Q_e

$$Q_e = KH^n$$

$$Q_e = 0.0489(0.019\ m)^{1.461}$$

$$Q_e = 0.000149\ m^3/s$$

Discharge using Published C_{de} and n Values, Q_p

$$Q_p = KH^n$$

a) Rectangular Weirs

$$Q_p = \frac{2}{3} C_{de}\sqrt{2g}\ L\ H^n$$

$$Q_p = \frac{2}{3}(0.60)\sqrt{2\left(9.81\frac{m^2}{s}\right)}\ (0.03\ m)(0.019\ m)^{1.5}$$

$$Q_p = 0.000139\ m^3/s$$

b) V-notch Weirs

$$Q_p = \frac{8}{15} C_{de} \sqrt{2g} \tan(\frac{\theta}{2})\ H^n$$

$$Q_p = \frac{8}{15} (0.44) \sqrt{2\left(9.81\frac{m^2}{s}\right)} \left(\tan(\frac{\theta}{2})\right) (0.025\ m)^{2.5}$$

$$Q_p = 2.752\ x\ 10^{-5}\ m^3/s$$

$$*\ for\ 90°\ V - notch\ weir, \theta = 90°$$

The calculated discharges shown in Table 2 were plotted on a graph of upstream water level and discharge (Figure 4).

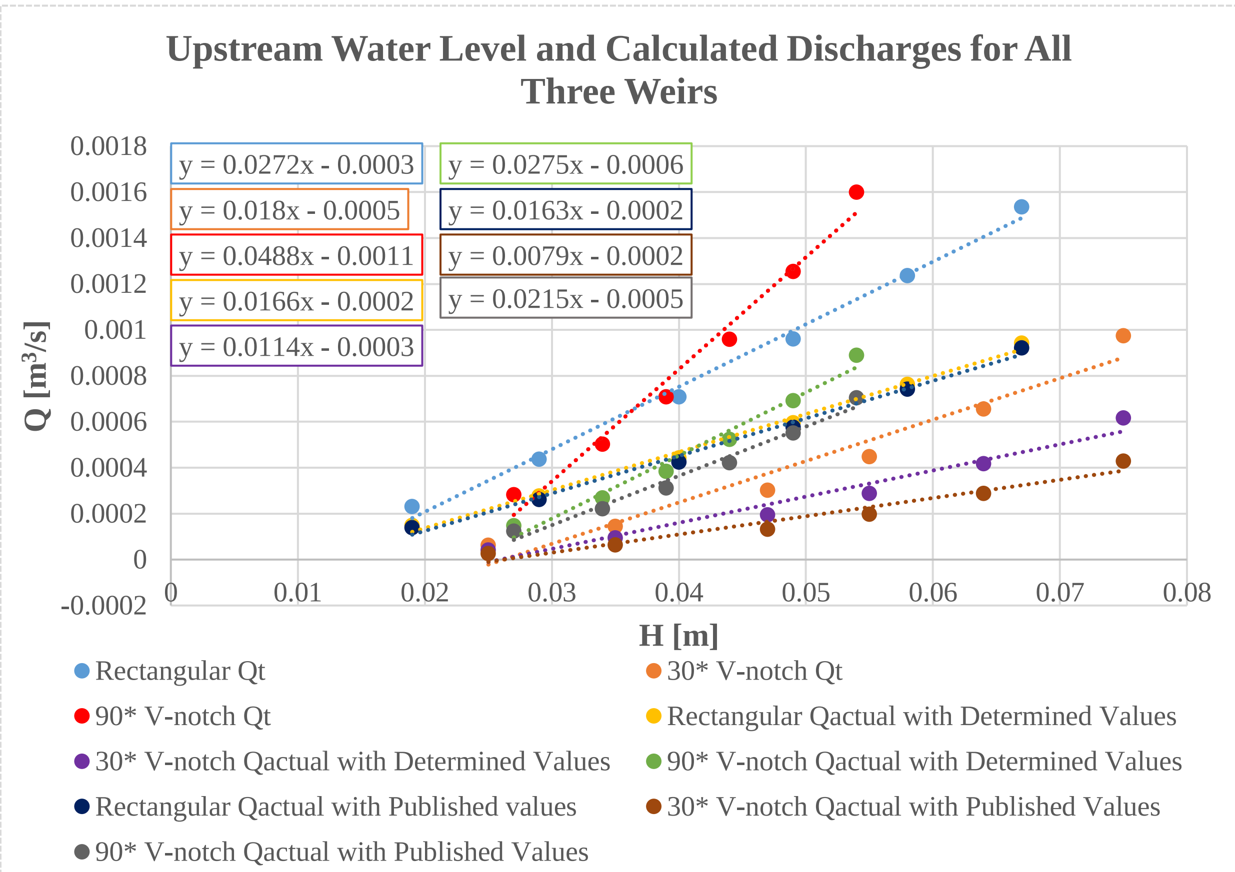

Figure 4 – Graph of upstream water level and calculated discharges for all three weirs

The first method of calculating discharge, Q_t, employs calculations that do not include the effect of contraction losses (Joy 2018). These losses occur in two dimensions. The vertical direction losses are a result of the top fluid level sloping downwards and the lower fluid level leaving the crest of the notch upwards as the fluid passes over the weir's notch (Joy 2018). The horizontal dimensions also experiences contraction losses due to the reduction in width as it passes through the notch (Joy 2018). This can be seen in figure 4, as in each weir case, the discharge calculated with the first method are much higher than the other calculate discharges. This is a result of neglecting the losses due to contraction. In the majority of the data series, the calculated discharge reduced by approximately ½ when the contraction loss was taken into consideration.

Figure 4 displays 3 calculated discharges for each of the three weirs. The 30° V-notch weir has the least change in discharge as the height increases. The lowest slope value was with the discharge calculated with published values with a value of 0.0079 m^2/s. This weir also displayed the lowest flow rate of the weirs. The other two weirs were fairly similar in the magnitude of discharge, especially at higher upstream water levels, however the 90° V-notch had a higher slope indicating upstream water level has a greater effect on the discharge in this weir. The discharge calculated with published values had a slope of 0.0215 m^2/s.

The calculated Qe and Qp values are much lower than the Qt values, evidently seen on figure 4 with the calculated values having a lower slope than the theoretical values. This is due to neglecting the effect of contraction losses on the discharge. From figure 4, it is evident that increase in height impacts discharge the strongest in the 90° v-notch with a value on the slope of the theoretical discharge of 0.0488, whereas the rectangular notch has a lower slope of 0.0272. The 30° v-notch discharge had the slowest reaction to increasing water height, with a slope of 0.018.

Conclusion

It is evident from the experimental results that the geometry of a weir has an effect on its discharge, as well as its reaction to increasing water levels. The discharge was calculated in three ways for each weir. The calculated discharge that matched the recorded weigh tank discharge the closest was the discharge calculated with experimentally determined variables. Therefore it is important to calibrate weirs before use. The slope between discharge and upstream water level is the strongest with a maximum value of 0.0488 for the 90° v-notch. This is followed by the rectangular with a maximum slope 0.0272 and the 30° v-notch with a maximum slope of 0.018. The discharge is calculated to the least accuracy with the theoretical discharge, as the effect of contraction losses are not accounted for. It is important to account for all losses in a system to accurately represent the fluid's behavior. Weirs have important applications in water control, especially in regards to water height and velocity.

Works Cited

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White, Frank M. (2016). Fluid Mechanics. University of Rhode Island. Eighth edition pg. 718-721, Eq. 10.58, 10.60.

Prycel, M., Ritter, E., and Roberts, C. (Accessed 03-26-18). Broad-Crested and Sharp-Crested Weirs. Colorado State University.