$Fr = \frac{V}{\sqrt{gD_h}}$

Culvert Design Project

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Kellogg Honors College Capstone Project

Introduction:

Culvert design is an important design tool of hydraulic engineering. It is used to transport runoff from one side of the road to the other side. The structure itself can be a round pipe, rectangular box, arch, ellipse, bottomless, or any other shape. It can be made out of materials such as concrete, steel, types of metal, polyethylene, plastic, fiberglass, and many more. There are two types of flow control: inlet control and outlet control. Headwater, area, shape, inlet configuration, and barrel slope are the only factors that influence inlet control. The headwater is measured from the inlet control to the surface. Inlet area is cross-sectional area. It is usually the same as barrel area. Inlet configuration is the type of entrance that's being used. The inlet shape can also range from circular, elliptical, square edges, etc. The barrel slope is what influences how well the inlet control would perform, but it doesn't impact the inlet control that much. In outlet control, headwater, area, shape, inlet configuration, barrel roughness, length, slope, and tailwater heavily impact how the outcome of flowrate would be. This particular study would relate the expected outcome versus the actual outcome when tested in the lab. Through various trials, it had showed the accuracy of the typical submerged and unsubmerged equations used.

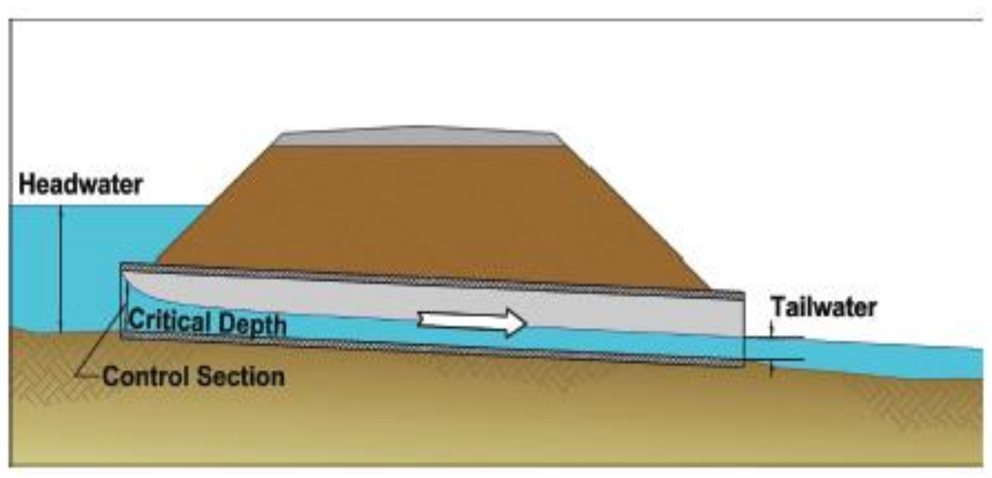


Figure 1 Concepts of Culvert Design (Hydraulic Design of Highway Culverts)

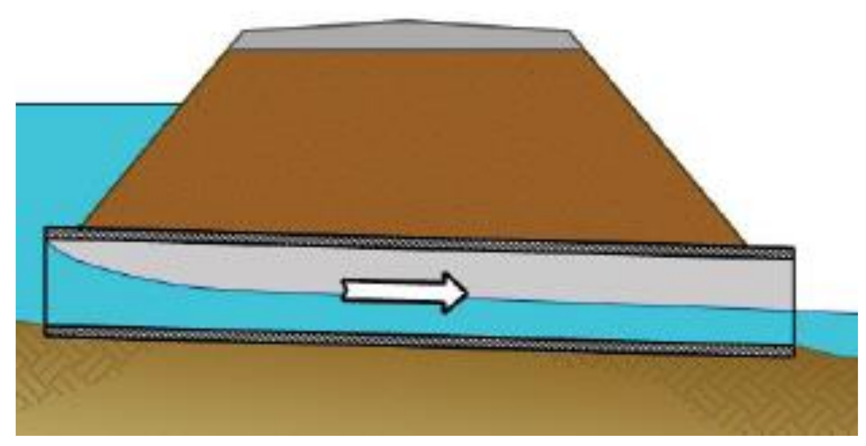


Figure 2A Unsubmerged inlet (Hydraulic Design of Highway Culverts)

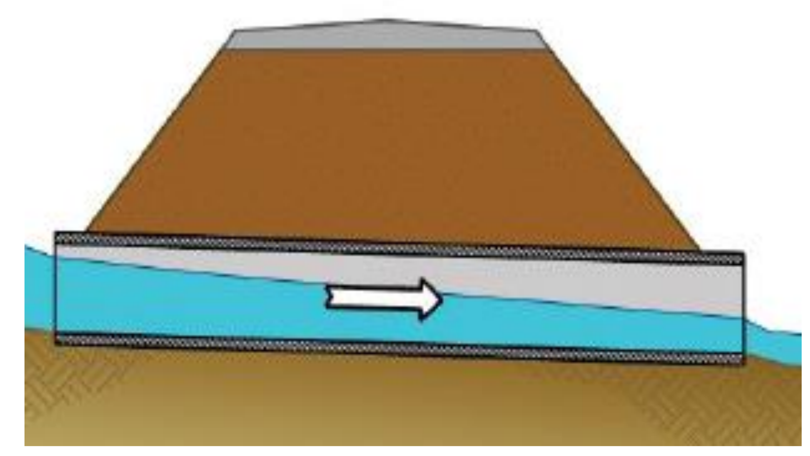


Figure 3 Submerged inlet (Hydraulic Design of Highway Culverts)

Objective:

The purpose was to create a laboratory experiment for CE332L in order to foster the importance of designing for a culvert. In addition, students will be able to fully grasp the understanding of how a culvert works. Students will later be able to see the comparison between the actual flowrate of the water in comparison with the headwater and the calculations from the equations.

Equations:

$$Fr = \frac{V}{\sqrt{gD_h}}$$

Equation 1. V is the average velocity, g is gravitational acceleration, D_h is the hydraulic depth, which is the representative depth for circular shapes :($\sqrt{A/2}$), for other shapes it would be flow area divide by the width. If Fr>1.0, flow would be considered supercritical, Fr<1.0 would be considered subcritical and Fr=1.0 would be considered critical.

By using Froude number, it can be interpreted the appropriate flow categorization. The partly full flow can be subcritical, critical, or supercritical.

$$Q = C_d \frac{\pi}{4} D^2 \sqrt{2g\left(HW + \frac{v^2}{2g} - d_c - h_L\right)}$$

Equation 6. C_d is the discharge coefficient. D is the diameter, g is gravity, HW is the headwater, v is velocity calculated using Q=VA, d_c is the critical depth, and h_L is the headloss calculated from the earlier equation.

The submerged inlet control, orifice flow equation is used. Orifice is submerged on the upstream and

$$Q = C_d \frac{\pi}{4} D^2 \sqrt{2g(HW - D/2)}$$

Equation 6. C_d is the orifice discharge coefficient, b is the culvert design, HW-b/2 is the average head over the culvert

Process:

Calculations were used based on varying depths of headwater and analyzed using excel. In addition, the flow rate of the water was also measured. The data collected was then graphed accordingly with the expected results from the equations used.

Submerged

Assuming Cd=.6	HW (in)	HW (ft)	HW (m)		Q	Q(GPM)
0.6	6	0.5	0.1524	6.000003	0.472709	212.1519
	6.5	0.541667	0.1651	6.500004	0.510584	229.1502
	7	0.583333	0.1778	7.000004	0.545838	244.9719
	7.5	0.625	0.1905	7.500004	0.578948	259.832
	8	0.666667	0.2032	8.000004	0.610265	273.8869
	8.5	0.708333	0.2159	8.500005	0.640051	287.255
	9	0.75	0.2286	9.000005	0.668512	300.0281
	9.5	0.791667	0.2413	9.500005	0.695809	312.2791
	10	0.833333	0.254	10.00001	0.722075	324.0674
	10.5	0.875	0.2667	10.50001	0.747419	335.4416
	11	0.916667	0.2794	11.00001	0.771931	346.4426
	11.5	0.958333	0.2921	11.50001	0.795688	357.1049
	12	1	0.3048	12.00001	0.818756	367.4579
	12.5	1.041667	0.3175	12.50001	0.841192	377.5271
	13	1.083333	0.3302	13.00001	0.863045	387.3346
	13.5	1.125	0.3429	13.50001	0.884358	396.8999
	14	1.166667	0.3556	14.00001	0.905169	406.24
	14.5	1.208333	0.3683	14.50001	0.925513	415.3701
	15	1.25	0.381	15.00001	0.945418	424.3038
	15.5	1.291667	0.3937	15.50001	0.964914	433.0533
	16	1.333333	0.4064	16.00001	0.984023	441.6294
	16.5	1.375	0.4191	16.50001	1.002768	450.0421
	17	1.416667	0.4318	17.00001	1.021169	458.3005
	17.5	1.458333	0.4445	17.50001	1.039244	466.4126

Figure 4 Submerged Data Calculations

Unsubmerged

Avg Discharge Coefficient for Circular Sharp-crested Weirs

h/d	Ce	ω	Φ	h (m)		Q (cms)	Q (gpm)
1	0.606	2	-	1		-	-
0.95	0.604	1.8678	2.2063	0.14478	5.700003	0.01208	191.515
0.9	0.602	1.7276	2.0407	0.13716	5.400003	0.01114	176.553
0.85	0.6	1.583	1.8699	0.12954	5.100003	0.01017	161.239
0.8	0.599	1.438	1.6986	0.12192	4.800003	0.00923	146.224
0.75	0.597	1.2939	1.5284	0.1143	4.500002	0.00827	131.133
0.7	0.596	1.1524	1.3612	0.10668	4.200002	0.00736	116.592
0.65	0.595	1.0147	1.1986	0.09906	3.900002	0.00647	102.492
0.6	0.594	0.8818	1.0416	0.09144	3.600002	0.00561	88.918
0.55	0.593	0.7551	0.892	0.08382	3.300002	0.00480	76.019
0.5	0.593	0.6354	0.7506	0.0762	3.000002	0.00404	63.968
0.45	0.594	0.5233	0.6182	0.06858	2.700001	0.00333	52.774
0.4	0.595	0.4203	0.4965	0.06096	2.400001	0.00268	42.456
0.35	0.597	0.3273	0.3866	0.05334	2.100001	0.00209	33.169
0.3	0.6	0.2443	0.2886	0.04572	1.800001	0.00157	24.886
0.25	0.604	0.1719	0.203	0.0381	1.500001	0.00111	17.621
0.2	0.61	0.1119	0.1322	0.03048	1.200001	0.00073	11.589
0.15	0.623	0.0642	0.0758	0.02286	0.9	0.00043	6.787
0.1	0.65	0.0286	0.0338	0.01524	0.6	0.00020	3.157
0.05	0.75	0.0071	0.00839	0.00762	0.3	0.00006	0.904

Figure 5 Unsubmerged Data Calculations

Data Collected

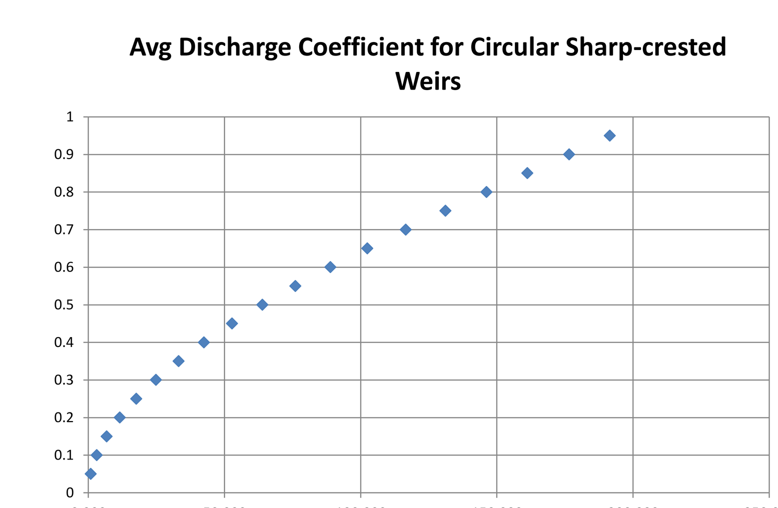
Q	HW
25	2.7
50	3.45
75	4.2
100	4.8
125	5.2
150	5.9
175	6.3
200	6.8
225	7.3

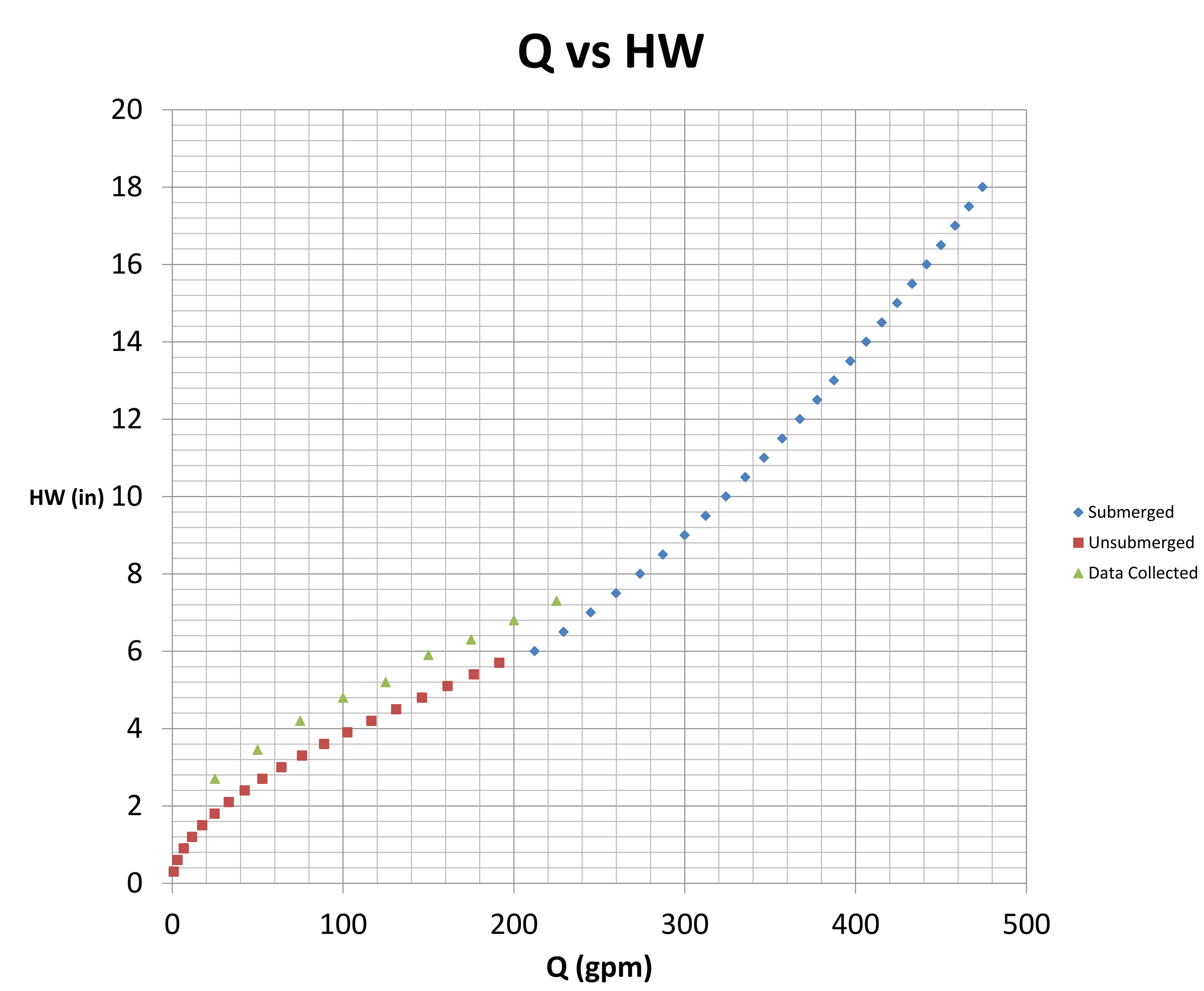
Figure 6 Lab Data Collection

Results:

The below figure shows the end result that compared and contracted between the submerged, unsubmerged, and the dat athat was collected. This graph clearly shows that there is a linear relationship between the unsubmerged data and the data that was collected in the labs.


Figure 7 Unsubmerged simulation





Future Work:

In the near future, it would be beneficial for the flowrate of the pump to go over the capacity of 300 gpm. In addition, other types of materials should also be analyzed in the discussion of the culvert. By analyzing the material, it could change the headloss and speed

References:

Schall, J. D., Thompson, P. L., Zerges, S. M., Kilgore, R. T., & Morris, J. L. (2012). Hydraulic Design of Highway Culverts Third Editions. *Department of Transportation*, 1-326.