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A Civil Engineering Senior Design Research Effort to Ascertain Discharge Coefficients of Different Orifice Geometries

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Abstract: The present researched topic was conceived from a senior design course for Civil Engineering students at CSUN (California State University), Northridge. In this work, experimental trials were performed and compared to establish theoretical values of the discharge coefficient. The discharge coefficient is a dimensionless number used to characterize the flow and pressure loss behavior of nozzles and orifices in fluid systems. A group of low-income undergraduate students with diverse backgrounds designed multiple 3D printed orifices where each 3D printed orifice had a specific shape. Utilizing the methods of technical problem solving, the undergraduates found experimental discharge coefficient values for the following orifices: borda, short-tubed, and sharp-edged. Implementing ethics of engineering practice and utilizing university resources, this study is a representation of the collaborative work of minorities and females that want to expand their knowledge within their respective discipline of Civil Engineering.

Key words: Education, orifice, 3D-printing, theory, test.

1. Introduction

To determine the discharge coefficient of the different 3D printed orifices, multiple trials for each orifice were conducted. The design and calibration are very satisfactory for use as primary standards [1]. Knowing the vessel's diameter, the height of the water from the designated datum, and orifice dimensions, the discharge coefficient C_d was calculated. The three orifices that were used during tests are borda, short-tubed, and sharp-edge with theoretical discharge coefficients of 0.61, 0.62, and 0.51 respectively. Calculated experimental data were compared and analyzed to theoretical data.

Orifices are defined as openings, which are placed well below the upstream water level, and are commonly used for water flow [2]. Time of drainage is one of the major factors when calculating the discharge coefficient. The time of drainage is dependent on the geometry of the orifice opening. Based on the tank dimensions, and correct C_d, the drainage time can be calculated. Ref. [3] demonstrated that a 0.61 C_d should be used for an actual, sharp edged orifice.

In this research, comparison is made between experimental results and theoretical predictions. One of the purposes in this effort was to educate students with diverse backgrounds about how mechanisms such as this are built and can yield nearly similar results to theoretical published values. There were slight discrepancies between experimental and theoretical data which were due to the principle fabrication errors of the orifice, experimental setup of the orifice which led to minor leaking issues. The orifices used in experimentation were 3D printed.

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2. Orifice Geometry

3 PLA (Polylactic acid) 3D printed circular orifices of ½ in. diameter were used in the experiment (Figs. 1-3). The circular orifices were 3D printed to replicate the theoretical orifice shapes borda, short-tubed and sharp-edged to investigate whether the calculated experimental discharge coefficient was similar to the theoretical constant. In this experiment, the discharge coefficient C_d was calculated by recording the drainage time of water from a specific height to the specific datum. The three orifices were designed to have equal areas to limit the number of variables and experimental errors. The purpose of this experiment was to calculate the discharge coefficient, the coefficient responsible for mass flow rate ratio in respect to nozzle discharge. To compare the theoretical value, the research students replicated illustrations shown in the senior design course based on a figure "Discharge from a Tank" [4].

For Figs. 1-3, each was hand calculated to have the same cross sectional areas. Figs. 1-3, demonstrate all orifices to have an exterior diameter of 2 inches. The orifices were then modeled on AutoCAD Inventor, a 3D modeling software used for parametric modeling.

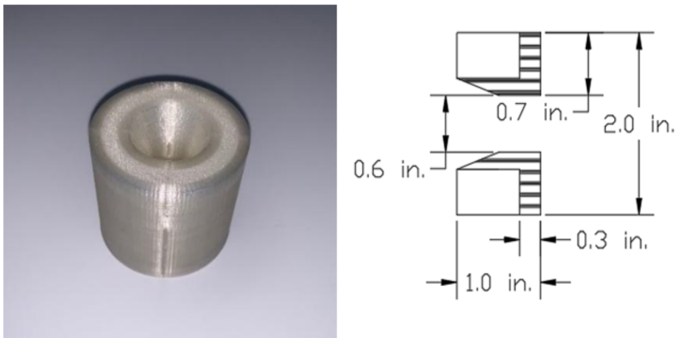

Fig. 1 Borda.

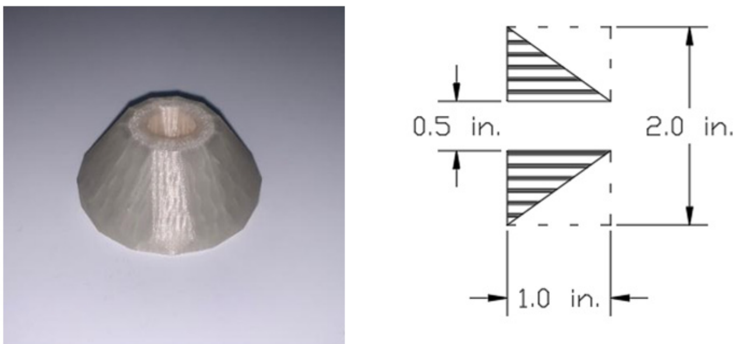

Fig. 2 Short-tubed.

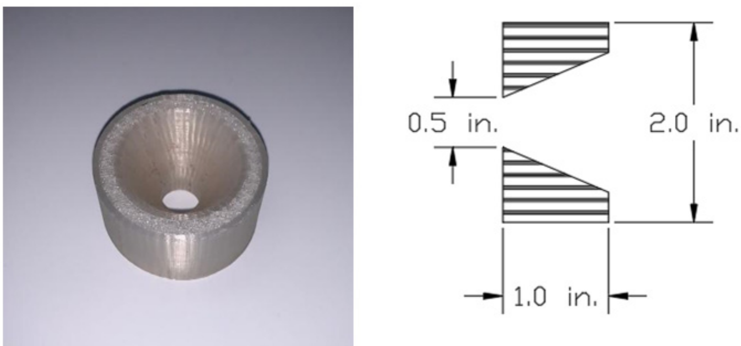

Fig. 3 Sharp-edged.

3. Testing Details

Two containers were positioned with a significant elevation to allow uninterrupted water flow between the water container with the orifice and the collecting container. The orifice was placed within a male adapter surrounded by a washer to prevent any leakage. The adapter was placed in the container to be tested (Fig. 4). The experiment was performed five times per orifice. Student researchers were assigned specific roles consisting of a spotter and three timekeepers. The spotter was in charge of releasing the water cork to allow the water to flow, therefore announcing the start and end of the experiment. The three timekeepers were assigned to time the experiment starting with the release of the cork and stopping when the spotter announces that the water has reached the orifice. The reason behind having multiple time keepers was to reduce human error by taking the average of the three recorded times to represent a single time value.

4. Discussion of Results

The equation used to perform the calculations was utilized using resources found in Ref. [4]. The discharge coefficient of the orifice is calculated by the following equation

$$C_d = \frac{2A_t\left(\sqrt{z_1 - z_2}\right)}{tA_0\sqrt{2g}} \qquad (1)$$

In Eq. (1) the area of the tank A_t was kept constant for each trial, using the same apparatus to conduct the experiment. The value for the A_t, was 103.81 (in^2). The distance between the height of the water, Z_1 to the center of the orifice, Z_2, was 9 (in). The datum was set to be the center of the orifice, Z_2. The areas of each orifice, A_0, were designed to be of equal value of 0.283 (in^2). The results had an error of 29.78% for borda, 0.23% for short-tubed, and 9.93% for sharp-edged as shown in Table 1.

The varying degrees of discrepancies in this study can be attributed to two major components: fabrication

Fig. 4 Experimental setup.

Table 1 Comparison of test and theoretical discharge coefficient.

	Theoretical	Experimental	Error (%)
Borda	0.51	0.726	29.78
Short-tubed	0.61	0.611	0.23
Sharp-edged	0.62	0.688	9.93

and modeling. The student researchers designed the orifices with similar dimensions to attempt to replicate theoretical values. However, after the orifices were fabricated using 3D printers, there were slight dimensional discrepancies, borda in particular with a length dimension of 2 inches as opposed to 1 inch, which would account for the largest experimental error. It was found that the different printing temperatures of the white PLA yielded different ultimate tensile strength and percent crystallinity results as well [5]. The modeling of the experimental apparatus also contributed to theoretical discharge coefficient discrepancies.

5. Educational Objectives

An important aspect of this experiment was to understand the basic fundamental concepts of hydraulic design pertaining to Civil Engineering using research techniques. Knowledge about the orifice coefficients and discharges through circular and rectangular orifice is very important when determining its usage based on the low or high discharges as well as high or low orifice coefficients [6]. As students with different learning capabilities, this experiment integrates engineering and research as a tool to engage students in the active learning process. Another important facet of this experiment was the knowledge gained through the application of theoretical information to real world practice, paramount to developing skills that may be applied to students' respective discipline of engineering. Through these research techniques the development of mathematic principles, as well as discerning experimental, theoretical and numerical based information are reinforced. These educational pedagogies set a precedent for future success in engineering courses and educational practice.

6. Conclusion

The student researchers were required to learn a brief introduction into fluids mechanics in order to progress throughout the experiment. Results varied on error percentage when comparing experimental and theoretical values. Head loss due to friction was ignored due to length not being a considerable factor for any pressure loss calculations. Variables such as areas, height and time were crucial when calculating the discharge coefficient. The student team of researches benefited greatly by visualizing and analyzing the behavior of liquids in motion. All the knowledge gained from the water resources module, a section from the senior design course, guided the students to understand the concept and purpose of the experiment performed. Throughout the course of this experiment, the team of researches faced many obstacles such as: leakage, scheduling, and lack of materials and tools. The success of the experiment was established on team performance, assembling of ideas, and inspiration.

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