Data Processing in Fluid Mechanics Laboratory

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Abstract

In the criteria for Accrediting Engineering Program, it is emphasized that engineering programs should demonstrate that their graduates have an ability to apply knowledge of mathematics, science, and engineering in their curriculum. They should also have the ability to design and conduct experiments, as well as analyze and interpret data. In the undergraduate Fluid Mechanics Laboratory the students conduct ten basic experiments, which proves to be a very fruitful experience for them. They can actually verify the existing theory, which they have learned in their lecture assignments. Sometimes the students face problems processing data on the computer. The results they get may not be what they expect. This can be frustrating. Too much dependence on the computer output and improper interpretation of the data lead to such problems. A simple error in the data can cause the result to deviate far from what is expected. The following laboratory assignments are selected in this paper as examples for discussion:

a) Flow through a Venturi
b) Calibration of a Triangular Weir

The results are initially found to be inconsistent. But, with a little modification and adjustment, the results are found to be very convincing. The students are required to investigate the reasons for the inconsistency. They have to study if any important factor is overlooked during the data processing.

Introduction

A Fluid Mechanics Laboratory course is required for all civil and mechanical engineering students in their junior year at Manhattan College. The civil engineering students take the Fluid Mechanics laboratory course along with the Fluid Mechanics lecture in the same semester. The mechanical engineering students take the laboratory class in the following semester. A total number of ten experiments are conducted by the students. The faculty provides guidance and technical assistance to each student. A laboratory report is required to be submitted by each individual student. For some lengthy experiments a group report is sufficient. Each student is asked to make a presentation on an assigned experiment at the end of the semester. Computational and plotting techniques are to be used in the presentations. The presentations are videotaped for departmental records. The course is designed to fulfill the objectives required by the department.

The course objectives are:

1. Observe and verify concepts learned in Fluid Mechanics.
2. Verify the concepts of potential, kinetic, total energy and head loss in a fluid flow.
3. Calibrate the meters in pressure flow pipes as well as in open channels.
4. Calibrate weirs in an open channel.
5. Determine the Manning's and Chezy's friction coefficients in an open channel.
6. Determine the specific energy, energy slope and critical depth in an open channel.
7. Work individually, in a group and communicate (written and verbal).

Students obtain the data during their experiments and process the data to obtain the expected result. If the result is far from expected, they have to conduct research to find the reason, correct it, and resubmit the report. With the knowledge of the theory and the study of empirical relationships between the variables obtained previously by researchers, the students should be able to process the data more realistically. Otherwise, they might think that the equipment is non-functional or, for some reason, their observed data is wrong. Two typical examples are cited in this paper.

Flow in a Venturi Tube

A typical laboratory venturi tube is shown in figure 1. Eleven Piezometers are connected at different tapping points having varying diameters, to measure the pressure heads. In each case, the velocities are calculated from the known flow corresponding to the diameters of the tube.

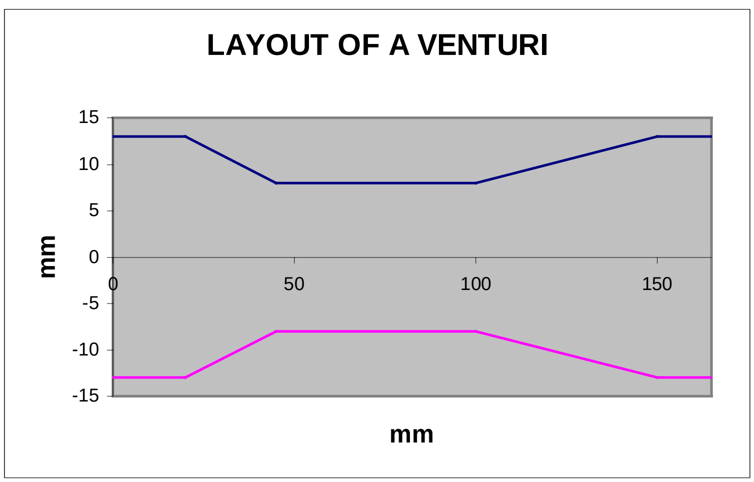

Figure 1

The energy of a flowing fluid at a particular point may be calculated as follows:

$E = Z + P/\gamma + V^2/2g$ …………..(1)

Where, E= total energy head in cm; P/γ = pressure head in cm ; V = velocity in cm/s ; $V^2/2g$ = velocity head in cm ; Z = elevation of the constant datum, which is considered as zero; g = acceleration due to gravity. Therefore, equation 1 can be written as:

$E = P/\gamma + V^2/2g$ ……………..(2)

Piezometric (pressure) heads are recorded at every tapping point. Corresponding velocity heads are also calculated. The data and the calculated results are shown in table 1. The line joining the pressure heads (hydraulic grade line) and line joining the energy heads (energy line) are shown in figure 2. Examining the energy line it is found that energy at points 5 & 6 are unusual. Energy cannot increase from point 5 to point 6 or from point 6 to point 7 as listed in table 1 or in figure 2. Some data adjustments are necessary. These adjustments are not arbitrary. There must be some scientific reason. A permanent frictional resistance is possible in a venturi tube. The major loss occurs at the diverging portion of the venturi tube and produces an undesirably low pressure at the throat, sufficient in some cases to cause liberation of dissolved air or even vaporization of the liquid due to cavitation. When there is an expansion of the liquid after the throat of the venturi, the effective area is reduced, because of stagnation along the side of the tube. The students are asked to find the appropriate coefficient of contraction at the selected location at the tapping points 5 & 6 of Table 1 and figure 1. After processing all the data, the results are tabulated as shown in table 2, and the energy line is adjusted as shown in figure 2.

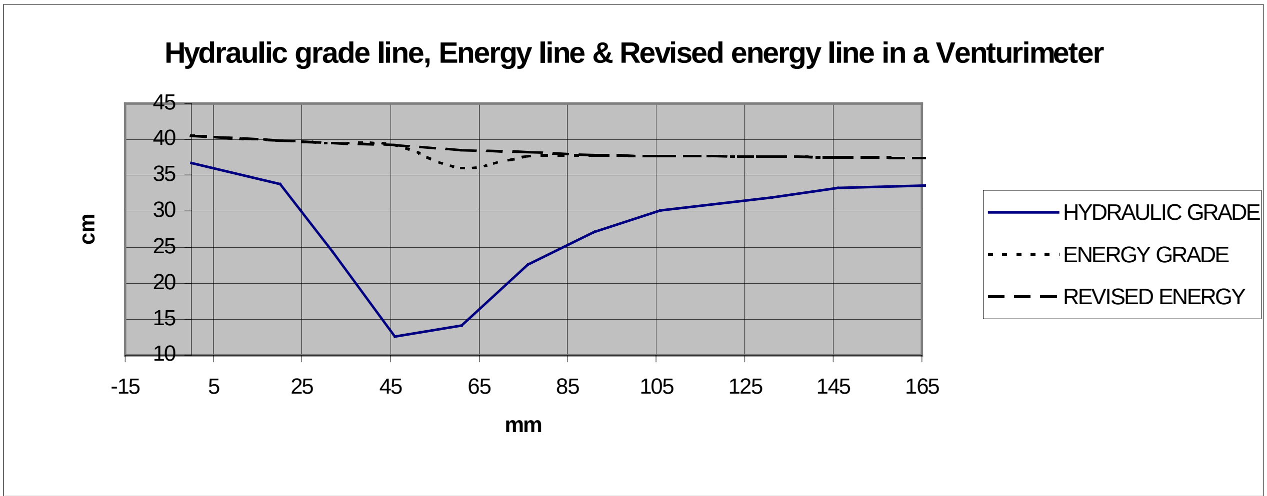

Figure 2

Calibration of a Triangular Weir

Triangular weirs are widely used as calibrating devices for certain flow rates in an open channel. Triangular weirs have the advantage that they can measure a very small flow as well as measure reasonably large flows. The students are required to calibrate a triangular weir in the laboratory. The actual relation between flow and head for the triangular weir can be expressed as:

$Q = K H^n$ …………….(3)

where, Q = flow in cm^3/s; H = head in cm above the weir crest; n= 2.5 ; K= Constant
In a triangular weir $K= 8/15\ C_D \tan(\theta/2)(2g)^{0.5}$; C_D= Coefficient of discharge. Using $\theta = 90^0$ and $g = 981\ cm/s^2$, $K = 23.62\ C_D$.

The flow Q is measured from the calibration curve of the open channel and the head is measured with a hook gage. Students are required to determine C_D for each run as well as a calibrated value from regression analysis. Table 3 lists the observed data and calculated values
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TABLE 1: VELOCITY HEAD, PRESSURE HEAD AND ENERGY
Flow = 459.1 cm^3/sec; g = 981 cm/sec^2

Piezometer Number	Distance X in mm	Area A in cm^2	Velocity V in cm/sec	Pressure head in cm	Velocity head in cm	Total head in cm
1	0	5.309	86.5	36.7	3.8	40.5
2	20	4.227	109.0	33.8	6.0	39.8
3	32	2.659	173.0	24.3	15.2	39.5
4	46	2.011	228.0	12.6	26.6	39.2
5	61	2.217	207.0	14.1	21.9	36.0*
6	76	2.680	171.0	22.6	15.0	37.6*
7	91	3.188	144	27.2	10.6	37.8
8	106	3.750	122	30.1	7.6	37.7
9	131	4.350	106	31.9	5.7	37.6
10	146	5.008	91.7	33.2	4.3	37.5
11	166	5.309	86.5	33.6	3.8	37.4

*Adjustments required

TABLE 2: ADJUSTED VELOCITY HEAD, PRESSURE HEAD AND TOTAL HEAD
Flow = 459.1 cm^3/sec; g = 981 cm/sec^2

Piezo-meter Number	Distance X in mm	Area A in cm^2	Coef. of contraction	Effective area A' cm^2	Velocity V in cm/sec	Pressure Head in cm	Vel. Head in cm	Total Head in cm
1	0	5.309	~1	5.309	86.5	36.7	3.8	40.5
2	20	4.227	~1	4.227	109.0	33.8	6.0	39.8
3	32	2.659	~1	2.659	173.0	24.3	15.2	39.5
4	46	2.011	~1	2.011	228.0	12.6	26.6	39.2
5	61	2.217	~0.946	2.098	218.8	14.1	24.4	38.5*
6	76	2.680	~0.979	2.625	174.9	22.6	15.6	38.2*
7	91	3.188	~1	3.188	144.0	27.2	10.6	37.8
8	106	3.750	~1	3.750	122.0	30.1	7.6	37.7
9	131	4.350	~1	4.350	106.0	31.9	5.7	37.6
10	146	5.008	~1	5.008	91.7	33.2	4.3	37.5
11	166	5.309	~1	5.309	86.5	33.6	3.8	37.4

* Adjusted values

TABLE 3: DATA FOR THE TRIANGULAR WEIR.

Readings	Head H in cm	Flow Q in cm^3/ sec	C_D (Individual)	LOG H	LOG Q
1	11.87	6060	0.530	1.074	3.782
2	10.75	4820	0.539	1.031	3.683
3	10.67	4690	0.534	1.028	3.671
4	10.04	4060	0.538	1.001	3.609
5	9.61	3560	0.527	0.983	3.551
6	9.29	2938	0.469	0.968	3.468 *

* Rejected value in the final analysis.

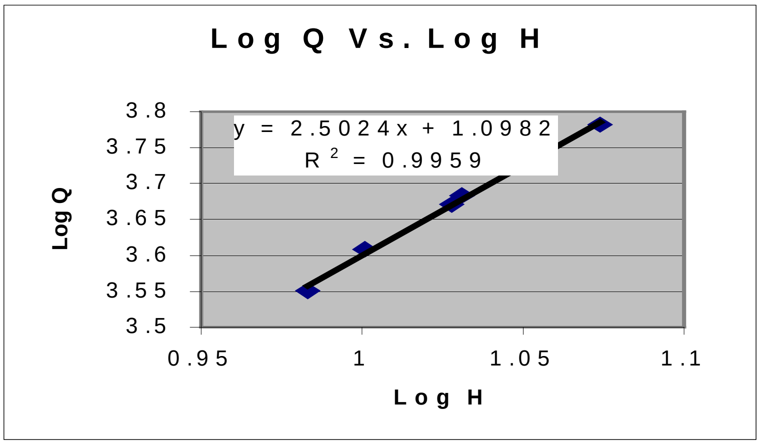

Fig 3a: Adjusted Calibration Curve

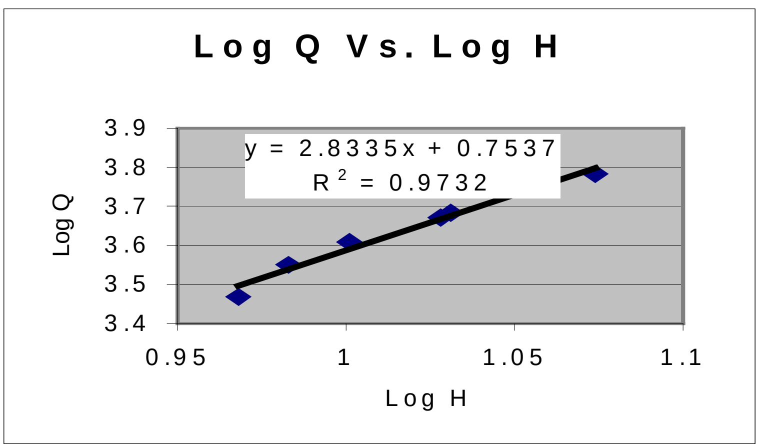

Fig 3b: Non adjusted Calibration Curve

Performing the regression analysis it is observed that the equation of the triangular weir is: LOG Q = 2.8335 LOG H + 0.7537, or, $Q = 5.67\ H^{2.8}$ For K = 5.67, C_D is calculated to be 0.24. Some adjustment of the data is essential because the exponent is too high and the C_D value is too low. From the study by Lenz, the expected value of C_D is 0.58 and the exponent is 2.5. At a very low head, when the nappe clings to the weir plate, the phenomenon can no longer be classified as weir flow and the weir flow equation is inapplicable. If the sixth reading from table 3 is rejected, and the regression analysis is performed again, the results are found to be very close to what is expected. The modified equation for the triangular weir is: LOG Q = 2.50 LOG H + 1.0982, or $Q = 12.537\ H^{2.5}$. The corresponding C_D is 0.53 and it is very close to the expected value. The exponential value of 2.5 is exact. The adjusted calibration curve and the calibration curve before adjustment of the data is shown in figures 3a and 3b.

Conclusion

In Fluids Mechanics Laboratory courses the students obtain data and analyze it according to the theory. Sometimes the results are far from those expected. Students often believe that the apparatus is nonfunctional or the obtained data are erroneous. But with the proper knowledge of the subject and the limitations of the range of data, the students can process the obtained data effectively. Guidance from the faculty and review of pertinent literature are required. At the end of the semester, the instructor hands out the sheet, shown in Table 4, for students' comment to identify to what extent the course objectives are met. It is observed that there are no weak areas in outcomes. The strongest areas are outcomes 1 and 7. Table 4 lists the course objectives for students' comment.

TABLE 4: Evaluation of Course Objectives

SEMESTER: Fall 2000 INSTRUCTOR : Dr. S. Bagchi

Please identify to what extent the course objectives (outcomes) are met.

	Course Objectives (Outcomes)	**Excellent**	**Good**	**Adequate**	**Poor**	**Comments (as necessary)**
1	Observe and verify concepts learned in Fluid Mechanics class.					
2	Verify the concepts of pressure head and head loss in a fluid flow.					
3	Calibrate the meters in pressure flow pipes as well as in open channel.					
4	Calibrate weirs in open channel.					
5	Determine the Manning's and Chezy's friction coefficients in an open channel.					
6	Determine the specific energy, energy slope and critical depth in an open channel.					
7	Ability to work in a group, communicate (written and verbal)					

Bibliography

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2. Arno T. Lenz, Viscosity and Surface Tension Effects on V-notch Weir coefficient, Trans. ASCE, Vol. 108, 1943.
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