EVALUATION OF UNSTEADY OPEN CHANNEL FLOW CHARACTERISTICS OVER A CRUMP WEIR

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ABSTRACT: Nowadays, application and development of hydraulic and hydrology field has become among important thing in our life. Structures such as crump weir are placed in a channel to estimate or measure the flow rate. By using Bernoulli's equation, a weir equation can be derived and apply it to determine the flow rate, Q. The objectives of this study are to determine the relationship between upstream head and flow rate of water flow over crump weir and also to obtain an approximation free surface profile in unsteady open channel flow. Varied flow rate are used from $0.002 m^3/s$, $0.004 m^3/s$, $0.006 m^3/s$, $0.008 m^3/s$, $0.010 m^3/s$, $0.012 m^3/s$, $0.014\ m^3/s$, $0.016 m^3/s$, $0.018 m^3/s$ and $0.02 m^3/s$. This study comprises a laboratory works of physical model of crump weir based on unsteady open channel flow.

KEYWORDS: Unsteady open channel flow, crump weir, characteristics flow of open channel

1. INTRODUCTION

A crump weir is commonly used to measure discharge in open flow channels. The cross-section can be rectangular, trapezoidal and triangular and the slopes are made to specific angles. This type of weir is easy to construct and is used as an alternative to a rectangular weir when water head is limited. Figure 1.1 is shown a modeling of a crump weir.

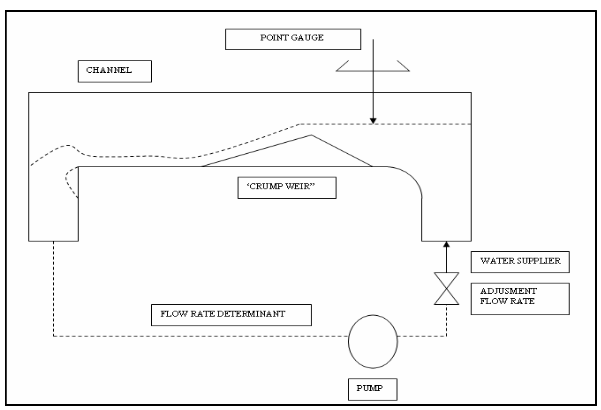

Figure 1.1: Sketch Of Crump Weir Model

1.1 Problem Statement

Engineer simply applies formula such as Manning equation to obtain water depth with known discharge rates. However, determining the depth of flow is complicated by side inflows and boundary features with existing of transition structure like a weir. This structure can cause the flow to choke or to produce a series of standing waves and all these will complicate channel design. Besides water depth, consideration should be given to flow velocity when design the channel section.

In many cases, structures placed in a channel for other purposes to estimate the flow rate. Among the structures whose primary function is the estimation of the flow rate are weirs and critical depth flumes.

The equation for the discharge over a weir cannot be derived exactly because the flow pattern of one weir differs from another of a different shape and the flow pattern varies with the discharges (Richard H. French, 1985).

Thus, this research includes the laboratory test by using Bernoulli's equation aspects that the open channel model with crump weir will be applied as a hydraulic structural control which an alternative solution in the management of water resources problem.

1.2 Objectives

The objectives of this research are to determine the relationship between upstream head and flow rate of water flow over crump weir and also to obtain an approximation free surface profile in unsteady open channel flow

1.3 Scope Of Study

This study will focus on identifying the characteristics of flow and to obtain the profile of water flow over a crump weir. Test in laboratory will be carried out to find the required data such as upstream head, downstream head, specific energy and flow rate. This laboratory test will be done at Water Resources Laboratory, Department of Water Resources and Environmental Engineering, University of Tun Hussein Onn Malaysia. Crump weir in the rectangular open channel model will be used to identify the characteristics of unsteady flow.

2. LITERATURE RIVIEW

Crump weir is an alternative structure to measure the flow rate in open channel. From Bernoulli's equation, a weir equation can be derived and apply it to determine the flow rate, Q of flow over a crump weir.

a. Hydraulic Equation

This research including the equations that use to identifying the characteristics of flow over a crump weir and to determine the free surface profile in open channel.

2.1.1 Bernoulli's Equation

The Bernoulli's Equation was obtained for a frictionless steady flow of incompressible fluid. The gravity constant of Bernoulli's Equation is expressed in meters. Along any streamline, the total head is defined as;

$$H = \frac{y^2}{2g} + z + \frac{P}{\rho g} \tag{2.1}$$

Where z is altitude and P is pressure. The term (P/ (ρg) + z) is often called the piezometric head. From this equation, the total head from the flow can be predicted.

2.1.2 Flow rate per width unit

The laboratory works was used a straight and prismatic rectangular open channel. For easier calculation, flow rate per breadth unit always used as;

$$\mathrm{q(m^2/s/m)} = \frac{\mathrm{Flowrate, Q}}{\mathrm{Width, B}} \tag{2.2}$$

Where, B is the width of the channel.

2.1.3 Specific energy

Specific energy is the energy per weight of water at a cross section from the bottom of the channel as a datum shown in equation 2.3. E unit is in distance, meters (m). It is the energy of flow in Joule per

Newton at any cross section of the channel as vertical distance from the bottom of channel and energy line.

$$\mathrm{E} = y + \left(\frac{q^2}{2gy^2} \right) \tag{2.3}$$

2.1.4 Froude Number

The ratio of inertia force and gravity force is called as Froude Number, Fr and is written as;

$$\mathrm{Fr} = \frac{q}{\sqrt{9.81 y^3}} \tag{2.4}$$

Froude Number was used to get the flow pattern in open channel. If the Froude Number is less than 1, (Fr < 1) the flow is called as sub critical, while the Froude Number is more than 1, (Fr > 1) the flow is called as super critical and the Froude Number is equal to 1, (Fr = 1) the flow is called as critical.

2.1.5 Critical Depth

The critical depth is the most important criteria for critical flow of a rectangular open channel. It is shown that the specific energy is minimum value if q value is determined. The critical depth and minimum specific energy are shown below;

$$y_c = \sqrt[3]{\frac{q^2}{g}} \tag{2.5}$$

$$\mathrm{E}_{\min} = 1.5\, y_c \tag{2.6}$$

2.1.6 Dissipated Energy

In the hydraulic jumps, velocity of flow would change from rapid flow to slow, and then an increasing of water is immediately. The decreasing of velocity will cause the decreasing of head velocity. The increasing of water level is not enough to become equal to the origin of head gravity. The total of decreasing of this energy is called as dissipated energy;

$$\mathrm{dE} = \mathrm{E}_2 - \mathrm{E}_1 \tag{2.7}$$

2.1.7 Dissipated Power

Dissipated power is caused by dissipated of energy. It is depends on flow rate, dissipated energy and others liquid behavior. In this study, the dissipated power is useful for determine how much the power is dissipating over a crump weir at differences flow rate. From that, the best flow rate can be choosing to design the structure hydraulic for the purpose flood control or irrigation. If the dissipated power is in International System unit (meter), flow rate is in m^3/s, density is in kg/m^3 and gravity acceleration is in m/s^2. So, dissipated power is in watt unit as shown below;

$$\Delta P(W) = \rho g Q . dE \tag{2.8}$$

ρ = 1000 N/m^3

g = 9.81 N/m^3

2.1.8 Hydraulic Jump

From the specific energy curve, shown that if specific force is determined, the curve will give two depths of flow are known as conjugate depth;

$$\frac{y_2}{y_1} = \frac{1}{2}\left\{-1 + \sqrt{1 + 8Fr^2}\right\} \tag{2.9}$$

At the critical point, specific force is minimum value and depth of flow is critical. When the Froude Number and flow depth,y_1 are known, the another flow depth,y_2 can be predicted. y_1 is the depth of flow before the flow is over a crump weir. While, y_2 is depth of flow at hydraulic jump is occurred.

3. RESULTS AND DISCUSSION

By using the equations which has been discussed in the literature, the raw data was calculated and processed using Microsoft excel to easier analysis. There are two types of graph were illustrated for the result of experiment as follows:

1) Flow Depth,y (m) against Specific Energy, E (m).

This graph shows the relation between specific energy and flow depth (ideal) with flow rate per unit width, q. From the specific energy curve, it has proof the critical depth, y_c and minimum specific energy can be predicted at different flow rates.

2) Surface profile of flow and total specific energy line.

This graph showns the surface profile of flow over a crump weir. From that, the pattern of flow and hydraulic characteristics of flow can be determined.

3.1 Data Analysis and Discussion

This experiment has been conducted on eight (8) times for different flow rates from 0.002m^3/s, 0.004m^3/s, 0.006m^3/s, 0.008m^3/s, 0.010 m^3/s, 0.012m^3/s, 0.014m^3/s, 0.016m^3/s, 0.018m^3/s and 0.02m^3/s to get the flow pattern and ideal flow rate.

3.1.1 Relationship between specific energy and flow depth over a crump weir.

From the study, it shows that in different flow rates, the shape of graph is curve into left. Figure 3.1 shows the example of Specific Energy for Flow rate 0.02 m^3/s. Except for flow rate at 0.010m^3/s and 0.012m^3/s, the shape of graph is straight line. Figure 3.2 shows the example of specific energy for flow rate 0.0010m^3/s. The results show that specific energy value decrease when the flow over a crump weir at downstream of channel. But, specific energy value will be increased when the flow passing the weir. From the plotted graph, it can be explained as when the flow rate is increased, depth of flow, y(m) at specific energy is increased at sub critical flow and decrease at super critical flow.

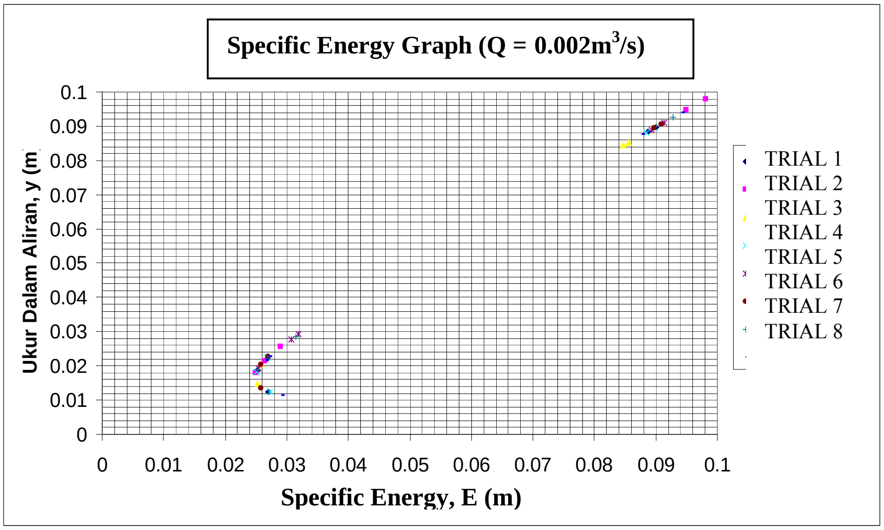

Figure 3.1 : Specific Energy for Q = $0.002m^3/s$

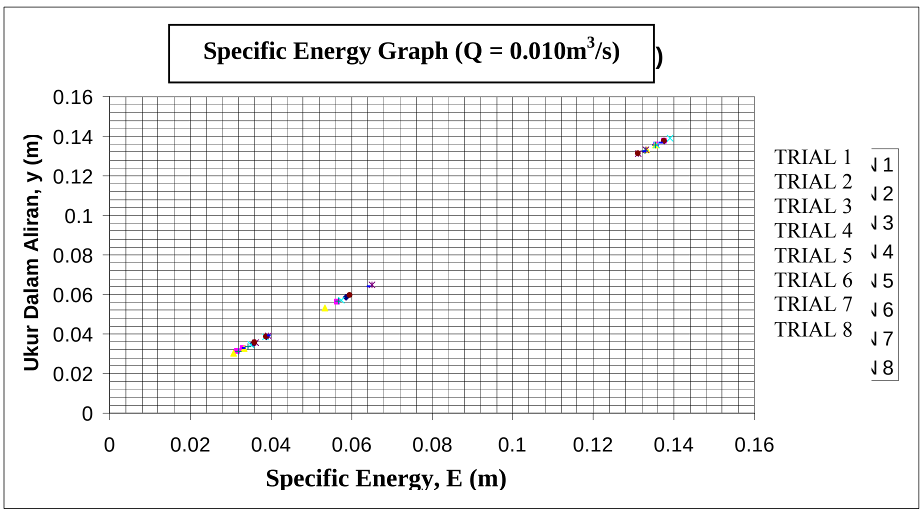

Figure 3.2 : Specific Energy for Q = $0.0010m^3/s$

Besides, the graph has shown that the minimum specific energy, E_{min} (m) and critical depth, y_c (m) can be determined. So, the calculation formula to get these values by theory can be compared. Table 3.1 shows the summary of comparation between minimum specific energy, E_{min} (m) and critical depth,y_c(m) by theory and experiment. Generally, the value from experiment closely to the theory means that the experiment is accepted.

FLOW RATE, Q (m^3/s)	THEORY		EXPERIMENT	
	MINIMUM SPECIFIC ENERGY HEAD, E_{min} (m)	CRITICAL DEPTH, Y_C (m)	MINIMUM SPECIFIC ENERGY HEAD, E_{min} (m)	CRITICAL DEPTH, Y_C (m)
0.002	0.0248	0.01655	0.0245	0.0165
0.004	0.0394	0.0263	0.039	0.0275
0.006	0.0516	0.0344	0.051	0.033
0.008	0.0625	0.0417	0.062	0.0425
0.010	0.0721	0.0481		
0.012	0.082	0.0546		
0.014	0.091	0.061	0.092	0.0615
0.016	0.099	0.066	0.098	0.065
0.018	0.107	0.072	0.105	0.073
0.020	0.115	0.0768	0.115	0.078

Table 3.1 : The summary of comparation between minimum specific energy, E_{min} (m) and critical depth, Y_c(m) by theory and experiment.

Figure 3.3 shows the distance of station at crump weir. Generally, the maximum specific energy occurred at station 1 and minimum specific energy occurred at station 3 just for flow rate 0f 0,016m^3/s, 0.018m^3/s and 0.02m^3/s. While others flow rate are shown the variable of point station at maximum and minimum specific energy.

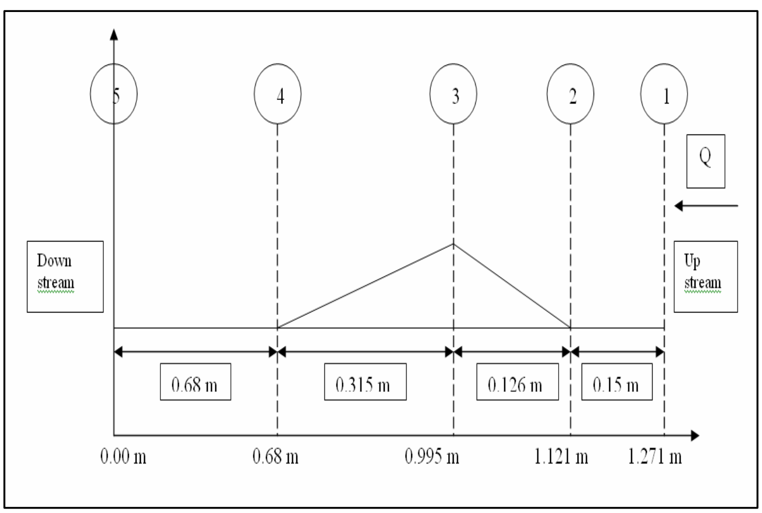

Figure 3.3: The distance of station at crump weir

3.1.2 Surface profile and total specific energy of flow over crump weir

Figure 3.4 shows the example of surface profile and total specific energy of flow over crump weir for flow rate 0.002 m^3/s. The flow at upstream is sub critical and super critical at downstream. Specific energy also decrease when the flow over a crump weir.

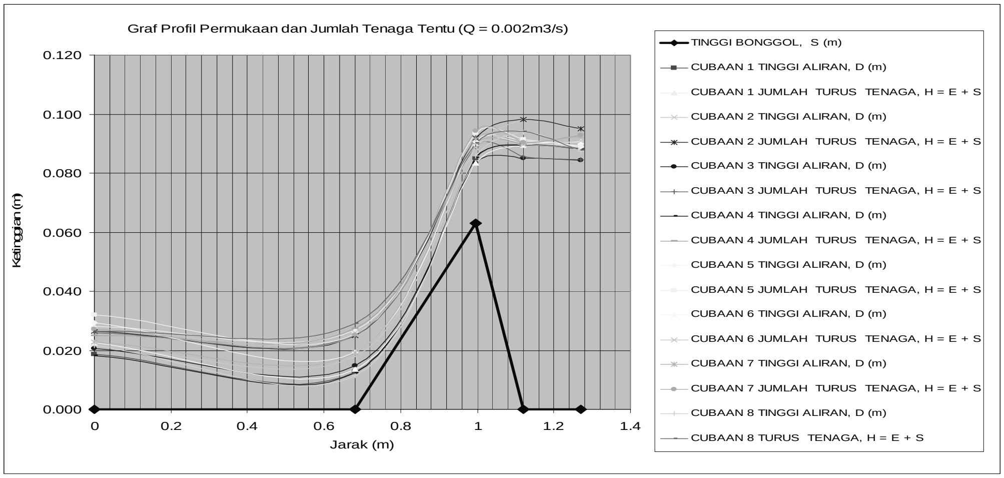

Figure 3.4: Graph of surface profile and total spesific energy (Q =0.002m^3/s)

3.1.3 Types of hydraulic jumps

By using Froude number, types of hydraulic jump can be determined for every depth of flow at different flow rates.

From the experiment, it is found that at flow rate of 0.002m^3/s, hydraulic jump will not been occurred because the value are less then 0.00. In other words, the flow is sub critical along the flow over a crump weir. While, at flow rate of 0.004 m^3/s, 0.006 m^3/s, 0.008 m^3/s, 0.010 m^3/s, 0.012 m^3/s, 0.014 m^3/s, 0.016 m^3/s, 0.018 m^3/s and 0.02 m^3/s, show that the flow is sub critical at upstream flow which are in station 1,2 and 3.

But it will be changed to super critical at station 4 and 5. Oscillating flow occurs at station 4 at every flow rate because the value of Froude number is between $1.0 < Fr < 1.7$. At flow rate 0.008 m^3/s, 0.012 m^3/s, 0.014 m^3/s, 0.016 m^3/s and 0.018 m^3/s, the hydraulic jumps has changed to weak flow ($1.7 < Fr < 2.5$) at station 5. Figure 3.5 to Figure 3.7 shows the different jump for the result of the study.

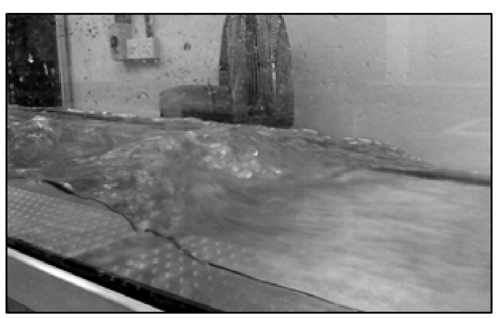

Figure 3.5 : Oscillating Jump

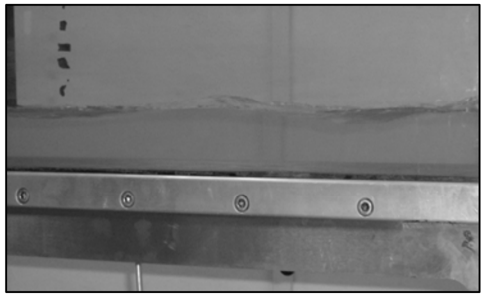

Figure 3.6 : Weak Jump

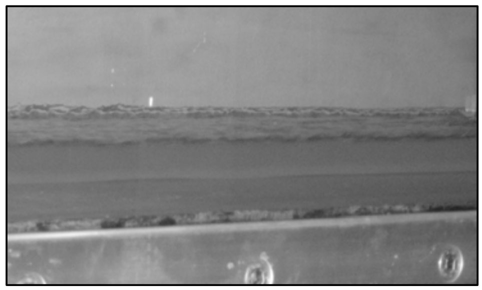

Figure 3.7 : No Jump

Generally, Critical phenomenon occurs for this flow because it has changing from sub critical to super critical. This is the most important characteristics of the hydraulic structure because from that we knew the depth of flow and flow rate that must been to control of the stream.

4. CONCLUSION

The study is focus on the laboratory experiment that uses open channel flow model with a crump weir. The hydraulic characteristics of unsteady open channel can be predicted and to determine the relationship between the specific energy and flow depth of water flow over a crump weir.

From the experiment and the relationship graph between flow rate and flow depth, the characteristics of hydraulic for variable flow rate is shown. The increasing of flow depth will cause the increasing of specific energy. The flow is become sub critical. The specific energy is decreasing at super critical flow. It has shown that when the increasing of flow, flow depth is increasing at sub critical flow and decreasing at super critical flow.

From the graph of surface profile and total specific energy line, shows that upstream flow is sub critical and downstream flow is super critical. Head energy is decreased when flow is over a crump weir. So, flow surface profile for unsteady open channel is influenced by the existing of weir.

Specific energy curves show that the value of ideal flow depth and specific energy (from 8 times lab experiment conducted) for variable flow rate.

Another finding in this study is;

1. At flow rate of 0.010m^3/s and 0.020m^3/s, the specific energy, E (m) and depth of flow, Y (m) can't be determined by plotting the graph because the graph is straight line not a curve into left. So, point of curve can't be predicted to get the minimum specific energy, E_{min} (m).

2. Comparation between critical depth, Y_c (m) and minimum specific energy, E_{min} (m) by theory and experiment shown that flow rate of 0.010m^3/s and 0.020m^3/s cannot be determined.

3. At flow rate of $Q = 0.016m^3/s$, $Q = 0.018m^3/s$ and $Q = 0.020m^3/s$, value of E_{max} at station 1. While E_{min} at station 3. But, at flow rate $0.002m^3/s$, $0.004m^3/s$, $0.006m^3/s$, $0.008m^3/s$, $0.010m^3/s$, $0.012m^3/s$ and $0.014m^3/s$, E_{max} and E_{min} value at variable point of station.

4. At flow rate of $0.002m^3/s$, the flow is sub critical along the flow is over a crump weir. While, at flow rate of 0.004 m^3/s, 0.006 m^3/s, 0.008 m^3/s, 0.010 m^3/s, 0.012 m^3/s, 0.014 m^3/s, 0.016 m^3/s, 0.018 m^3/s and 0.02 m^3/s show that the flow is sub critical at station 1, 2 and 3. But, it changes into super critical flow at station 4 and 5.

5. Increasing of flow depth will cause the specific energy value will raise up as the reason is to determine the sub critical flow occurred. Besides, the increasing of flow depth will cause the decreasing of specific energy for super critical flow.

6. At low rate of $0.002m^3/s$, hydraulic jump will not occur. While, at flow rate of 0.004 m^3/s, 0.006 m^3/s, 0.008 m^3/s, 0.010 m^3/s, 0.012 m^3/s, 0.014 m^3/s, 0.016 m^3/s, 0.018 m^3/s and 0.02 m^3/s shown that hydraulic jump occurred as oscillating jump to weak jump at station 4 and 5.

7. Generally, the pattern of flow over a crump weir shows that it has changed from sub critical to supercritical flow for different flow rates value except at flow rate of $0.002m^3/s$.

8. Energy dissipated during hydraulic jump will cause power dissipated. Power dissipated depends on the flow rate, energy dissipated and other hydraulics criteria.

9. Power dissipated at flow rate of $0.002m^3/s$ shows that the specific energy at upstream flow is low than the downstream flow. But, at the rest of flow rate, the specific energy at the downstream flow is high than the upstream flow. It is because of the difference of flow depth at these sections.

10. This study has achieved the objectives to determine the relationship between upstream head and flow rate of water flow over crump weir and also to obtain an approximation free surface profile in unsteady open channel flow.

5. RECOMMENDATIONS

From experiment conducted in lab, still found lacking of perfect result. The recommendations below are some of the improvements that can be carried out for further study.

1) Variety study scope such as variable position of station at crump weir to see the effects against changing of flow found.
2) The data which are conducted should be more and sufficient to find the best flow profile especially to get curve shape as required.
3) The suitable of depth of crump weir for this design hydraulic structure is 0.063m with 0.3m width. Flow rate that suggested are $0.016m^3/s$, $0.018m^3/s$ or $0.02m^3/s$. This value is suitable for determine the profile of flow over a crump weir to control the flow in applied of flood control or irrigation. As for continuous study, suggest that, to get the flow profile by using the bigger amount of flow rate.
4) Depth of weir and width of channel in variable value are suggested to get the best flow rate for hydraulic structure of crump weir design.
5) Recommendation for continuous study is find out the reason why at the flow rate 0.010 m^3/s and $0.012m^3/s$, the specific energy graph get the straight line not a curve into left. Besides, how to know the minimum specific energy and critical depth by the experiment before compare it with theory value.
6) Calibration device for better data collection suggested using a volume meter to get the flow rate over a crump weir. Flow rate determinant is a sensitive electrical device and sometimes give the uncertain data.

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