ANALYSIS OF THE WATER FLOW IN RECTANGULAR OPEN CHANNEL FLUME WITH RECTANGULAR SHARP CRESTED WEIR

MUHAMMAD NORKHUZAIRI BIN SHAHARIN

A report submitted in partial fulfillment of the requirements for award of the degree
of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITY MALAYSIA PAHANG

JUNE 2013

ABSTRACT

The sharp-crested weir is the most commonly used device in channels for flow measurement and flow regulation due to its simplicity. Several attempts have been made to study in detail the flow over different shapes of normal conventional weirs including those with sharp crest, side weirs and oblique weirs, mainly based on experimental work. On the contrary, little efforts have been done to use numerical models in investigating flow characteristic and pressure distributing over these types of weirs. The concern of this paper is to study flow over a rectangular sharp crested weir and to provide a means to estimate the discharge coefficient. A CFD Software which is ANSYS CFx-14 has been used for evolving a relationship to estimate the discharge coefficient for rectangular sharp crested weirs. Several combinations of discharge and weir height have been used to develop a best fit curve for estimating the discharge coefficient. The discharge coefficient estimate by the develop model has been found to be in good agreement with those listed in the literature within $\pm 4\%$ error. The study showed that the important variable governing discharge over sharp crested weir was the water head over weir per weir divide by weir height, h/P. Furthermore, the advantages of an ANSYS CFX-14 as a tool for examining velocity vectors and pressure pattern over rectangular sharp crested weirs have been highlighted.

ABSTRAK

Empangan limpah berpuncak tajam adalah salah satu alatan yang biasa digunakan untuk mengukur pergerakan bendalir dan pengawalan sifat bendalir kerana ianya mudah untuk dikendalikan. Beberapa kajian telah dilakukan dalam usaha untuk menkaji dan mendapatkan maklumat penting yang berkaitan dengan alatan ini melalui kaedah eksperimen. Sebaliknya terdapat juga beberapa kajian yang menggunakan kaedah numerikal model untuk mengkaji sifat dan bentuk pengaliran bendalir serta tekanan yang terlibat terhadap empangan limpah tersebut. Perkara utama dalam tesis ini adalah untuk mengkaji pergerakan bendalir yang terjadi apabila melalui empangan berpuncak tajam yang berbentuk segi empat tepat. Selain itu, kajian ini juga adalah untuk mendapatkan nilai coefficient kadar air yang dilepaskan. Dalam kajian ini, satu software CFD digunakan pakai iaitu ANYSY CFx-14. Software ini digunakan untuk mengkaji perhubunghan antara nilai coefficient kadar air yang dilepaskan apabila melalui empangan limpah berpuncak tajam yang berbentuk segi empat tepat. Beberapa gabungan nilai coefficient kadar air yang dilepaskan dan ketinggian empang limpah telah digunakan dalam usaha untuk mendapatkan kadar terbaik lengkungan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

b	Width or length of weir (m)
h	Water head over weir (m)
P	Weir height (m)
C_d	Discharge coefficient
L	Length of the weir (m)
Q	Water discharge (m^3/s)

LIST OF ABBREVIATIONS

CAD	Computer Aided Design
CFD	Computational Fluid Dynamics

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The project title was Analyzed the Water Flow in the Rectangular Open Channel Flume with Rectangular Sharp Crested Weir. In order to conduct the hydro generator test, the open channel design was designed. The focus in the analysis was to determine accurate flow of the water in the open channel flume. Regulator was used in order to increase the performance in the open channel flume. In this analysis, the most important is to control and compute the water discharge in the open channel flume. The rectangular open channel flume was choosing as the shape of the open channel flume. The flow measurement in open channel is important in fluid engineering. There are a few of regulator that use in fluid measurement such as weirs, orifices, sluice gate etc. Among of these regulators, weirs are the most suitable structures to measure the discharge or the flow in the open channel flume. King and Barter study (Abd El-Hady Rady, 2011) has stated that weir is define as an obstruction in open channel that water must flow over and is used as an indirect method for obtaining the flow rate based on the weir geometry and head over the weir crest. The sharp crested weir was widely used to compute the flow discharge (M. Piratheepan et al., 2006). The sharp crested were divided into three types which are rectangular weir, V-notch weir and trapezoidal weir. In this analysis, the rectangular sharp crested weir was choosing as the regulator. This weir is the simplest forms of weirs and further classified into two types which are suppressed rectangular weir and contracted rectangular weir. The figure 1.1 shows example of the sharp crested rectangular weir.

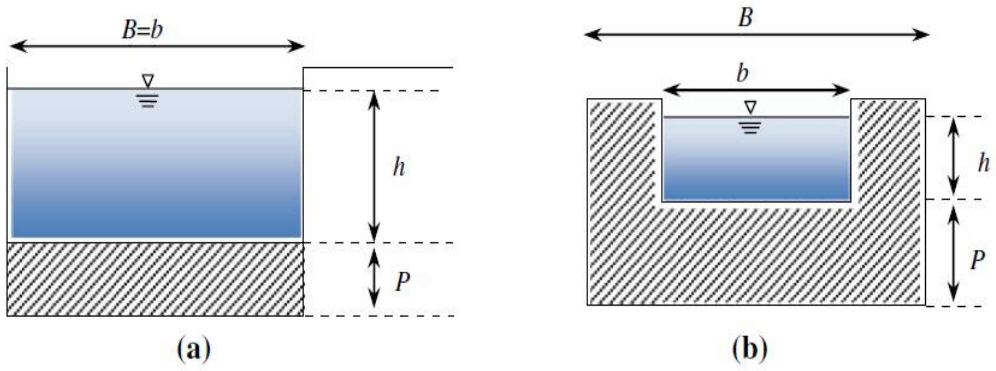

Figure 1.1: (a) Suppressed Rectangular Weir (b) Contracted Rectangular Weir

Source: Bagheri et al., 2009

In general, the sharp crested weir has used in the hydraulic laboratories, industries and irrigation pilot schemes where highly accurate discharge measurements are required (Bagheri et al., 2009). Volumetric flow rate over a sharp crested weir (*Q*) under free flow condition in a channel is expressed in terms of the following mathematical expression

$$Q = \frac{2}{3} C_d L \sqrt{2g} h^{1.5} \quad (1.1)$$

Where:

Q: Water discharge

C_d: Discharge coefficient

L: Width of the weir

h: Water head over the weir.

1.2 PROJECT BACKGROUND

This study is to analyze the flow patterns of the water in the rectangular open channel flume. The purpose of this study was to investigate the discharge coefficient of the water flow over the weir in the flume in order to get the accurate flow.

1.3 PROBLEM STATEMENTS

Since the time of the industrial revolution began, fuels are important requirements in order to advance each of the built industries. However, the amount of non-renewable fuels such as petroleum and natural gas are decreasing. In order to solve this problem, a number of alternative energy or renewable energy system was created. One of all alternative energies that have existed is hydro power. Hydro power energy is chosen because of the natural resource which is water is easy to get. As we know Malaysia is tropical country which means that it is rich in water resource. However Malaysia has few hydro power plants in order to supply energy.

PROJECT OBJECTIVES

There are a few objectives of this analysis. The objectives are:

1. To analyzed the water flow pattern in the rectangular open channel flume.
2. To analyzed the water surface profile of the water flow over the weir in the rectangular open channel flume.
3. To calculate the discharge coefficient, C_d of the water discharge in the rectangular open channel flume.

1.4 PROJECT SCOPE

The scope of this project is to guide the study in order to get the objective of this project. The design that has been choosing for this analysis is rectangular with the dimension 5 m long x 3m widths x 3m high. This project will be use for the student and researcher to get the accurate design of the regulator which is weir in order to compute the water discharge in the open channel. This open channel flume analysis will help the student and other researcher to do their experiment design accurately.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

For sharp crested rectangular weir, to measure the water discharge accurately is very important. However, the discharge is very difficult to define because it is dependent on many parameters such as viscosity, surface tension and geometry. In order to get the accurate discharge, many researchers have made an experiment or analysis to get accurate equation of discharge coefficient. In this chapter, details of some of the previous studies, in order to get the accurate discharge coefficient will be reviewed.

2.2 SHARP CRESTED WEIR

Sharp crested weirs are the simple device for open channel flow measurement. There are a few types of the sharp crested weir which is rectangular weir, trapezoidal weir and v-notch weir. Figure 2.1 show the examples of the sharp crested weirs.

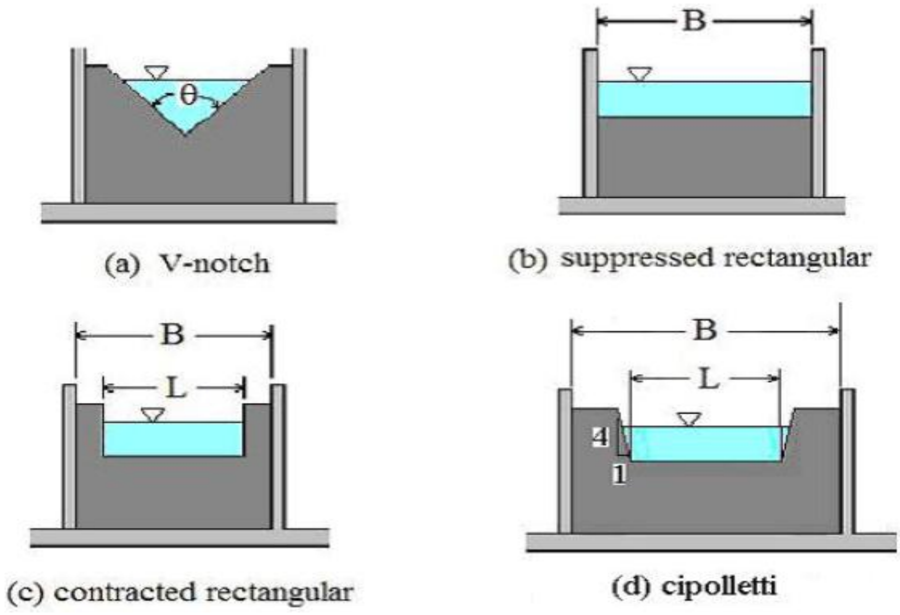

Figure 2.1: Type of Sharp Crested Weir

Source: Harlan, 2011

Sharp crested weirs consist of a vertical plate with a sharp edge at the top of the weir. The weirs are placed in an open channel flume in order to make the water flow over the weir (Harlan, 2011). The parameters that involve in the flow over the sharp crested weir have show in figure 2.2.

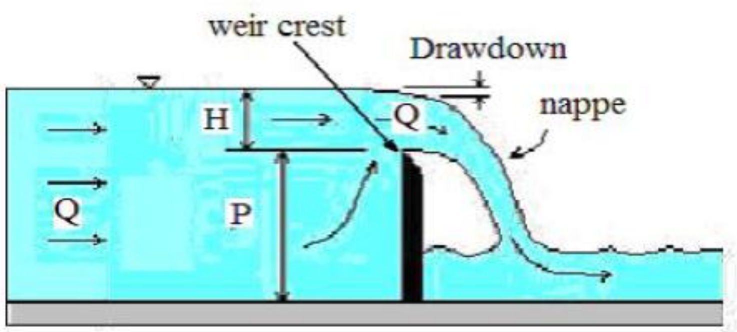

Figure 2.2: Flow over a Sharp Crested Weir

Source: Harlan, 2011

The sharp crested weir cannot be employed at higher submerged. Submerged will make the measurement of the water flow over the weir inaccurate.

2.3 RECTANGULAR SHARP CRESTED WEIR

Rectangular sharp crested weir is a rectangular notch made from metal plate that which is placed perpendicular to the water flow. The rectangular sharp crested weirs have three types which are fully contracted weir, full width weir and partially contracted weir (Abd El-Hady Rady, 2011). Fully contracted weir is the weir which has an approach channel whose bed and walls are sufficiently remote from the weir crest and sides for the channel boundaries to have no significant influence on the contraction of the napped. Full width weir is the weir that has the same width as the open channel flume. In the literature, the weir is called suppressed weir or Rehbock weir. Partially contracted weir is a weir that the contractions are not fully developed due to the proximity of the walls and the bottom of the approach channel.

Design of the rectangular sharp crested weir must incline angles 45^0 and 60^0 champers (cut-out) at the downstream edge as shown in figure 2.3.

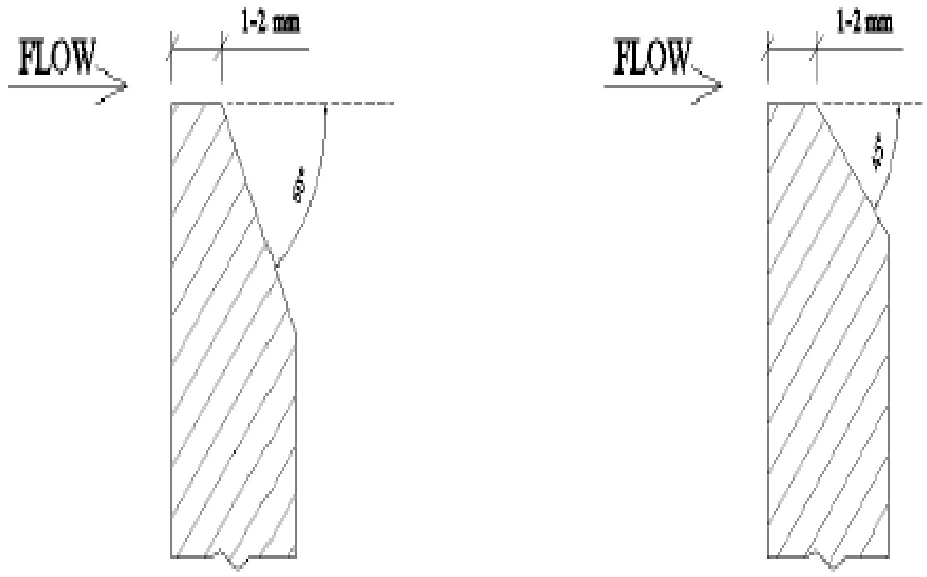

Figure 2.3: Cross Sectional of the Sharp Crested Weir

Source: Sisman, 2009.

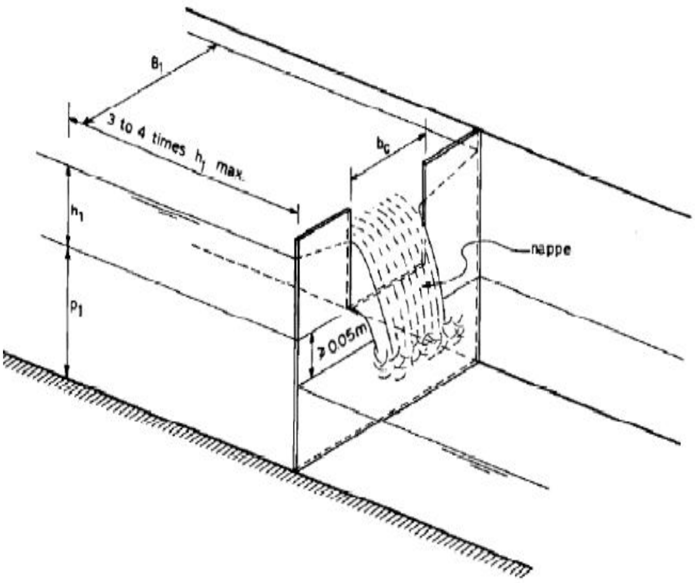

Figure 2.4: Parameters that Describe the Weir in the Analysis

Source: Abd El-Hady Rady, 2011

Figure 2.4 show the parameters that involve in the weir analysis. First parameter is h_1 is the water head over the weir and b_c is the weir width. P_1 is the weir height that use in the analysis. Head over weir, h_1 is the value that measured about $3h_{max}$ to $4h_{max}$ which is h_{max} is the maximum head over weir away from the upstream of the weir (Franzini et al., 1997). It is important to calculate the h_1 accurately by use the formula $3h_{max}$ to $4h_{max}$ because the value of h_1 must be accurate and drawdown effect can be neglected. Drawdown effect occurs when the water flow approaches the top of the weir and cross over it. Schematic diagram which shows the measuring point for $h_1$is shown in figure 2.5

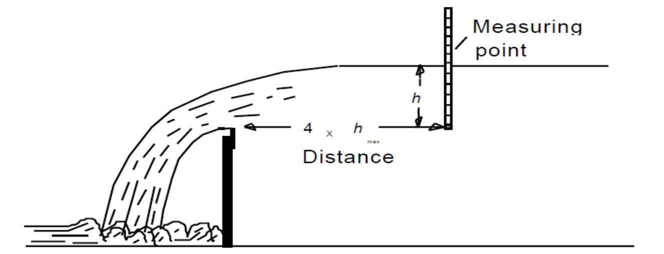

Figure 2.5: Measuring Point of *h*.

Source: Booklet of Flow Measurement Method in Open Channel, 2007

In order to get the accurate results, the discharge must be measured when the napped is aerated (Franzini et al., 1997). The example of aerated napped and non-aerated napped is shown in figure 2.6 below.

(a) (b)

Figure 2.6: (a) Aerated Napped (b) Non-Aerated Napped

2.4 EXPERIMENTAL AND COMPUTATIONAL ANALYSIS OF THE RECTANGULAR SHARP CRESTED WEIR.

2.4.1 SISMAN H. CIGDEM EXPERIMENTAL

In Sisman H. Cigdem, 2009, the measurement of the water flow can be calculated by using the sharp crested weir. This paper present that weir is commonly used as the tool to measured the water discharge. It is because the discharge coefficient is related to the water height over the weir, *h*) and the ratio of the water head to the weir height, *h/P*. (Rehbock, 1929). This paper also present from the Ramammurthy et al., 2007 experimental investigation which is the multi slit weir also can be used for measure water flow in the high discharge other than low discharge values. In order to prove the statement above, the experiment with the sharp crested rectangular weir is operate. The parameter of the weir is shown from the figure 2.7 below.

Figure 2.7: Parameter That Involve in the Experiment

Source: Sisman, 2009

From this paper, the accurate water height above the weir, *h* can be measured with this formula $3h_{max}$ to $4h_{max}$ away from the upstream of the weir. To get the accurate result, the discharge must be measured when the napped is aerated (Franzini et al., 1997). This paper also present that the water head over the weir which is below that 2cm is not taken into the consideration.

This experiment was conduct with 6.0m longs x 32cm width of fiberglass rectangular channel. The experiment was conduct with a few objectives. The first objective is to determine the water surface. To get the water surface, a few water discharges were used. At this experiment, the fully width of sharp crested weir was used. Second experiment was to determine the weir height, *h*. This experiment was conduct in order to get the discharge coefficient that independent to the water head to the weir height, *h/P*. This experiment also conducts in order to neglect the effect of bottom boundary. The third experiment was to study the water flow over the different weir opening.

The theoretical discharge, Q_{ideal} for a rectangular sharp crested weir is found by assuming frictionless, parallel and horizontal flow with no loss (Munson et al, 2002). Figure 2.8 show the schematic of flow over weir that describe in this study.

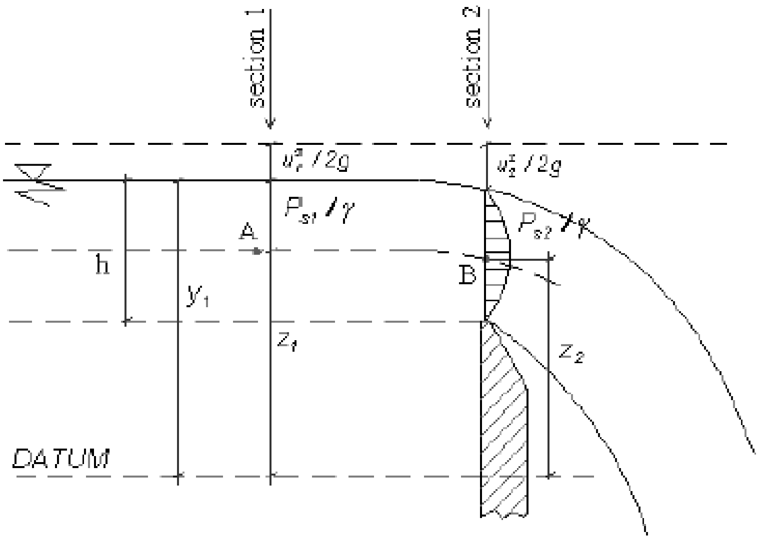

Figure 2.8: Schematic of Flow Over weir

Source: Sisman, 2009

In order to calculate the discharge coefficient, C_d the equation (2.1) below is used. It is important to determine the discharge coefficient in order to get the accuracy of discharge.

$$Q = C_d \frac{2}{3}\sqrt{2g}bh^{\frac{3}{2}} \tag{2.1}$$

Where: C_d = discharge coefficient, b = length of the weir, h = water head over the weir.

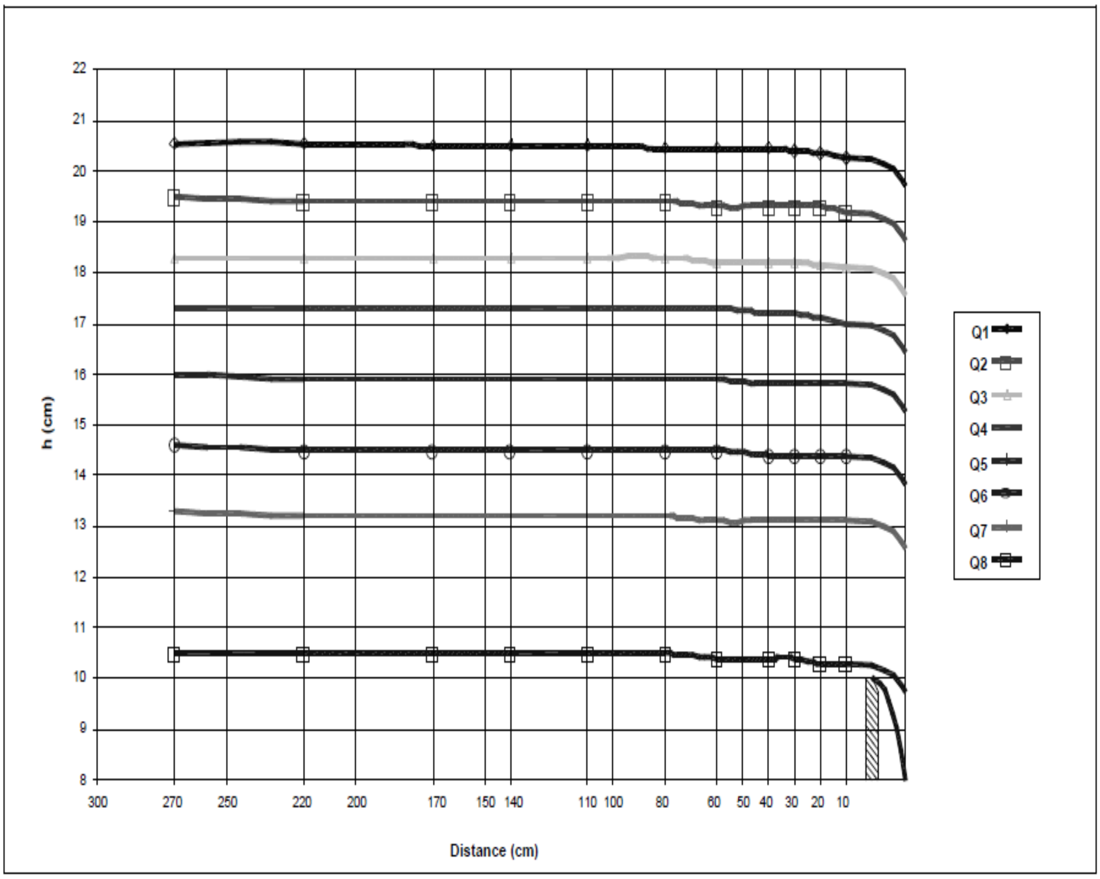

Figure 2.9: Surface Profile of the Flow over the Weir

Source: Sisman, 2009

Figure 2.9 above show the surface profile that obtains from the experiment. From the figure, the accurate point in order to determine the head over the weir can be located. The expression of $3h_{max}$ to $4h_{max}$ can use to get the point. From the figure 2.9, the stationary surface is almost after 1.00 m from the weir. So the expressions $3h_{max}$ to $4h_{max}$ has been prove that the equation can be used for this measurement.

Figure 2.10 show the relationship between the discharge and head over weir.

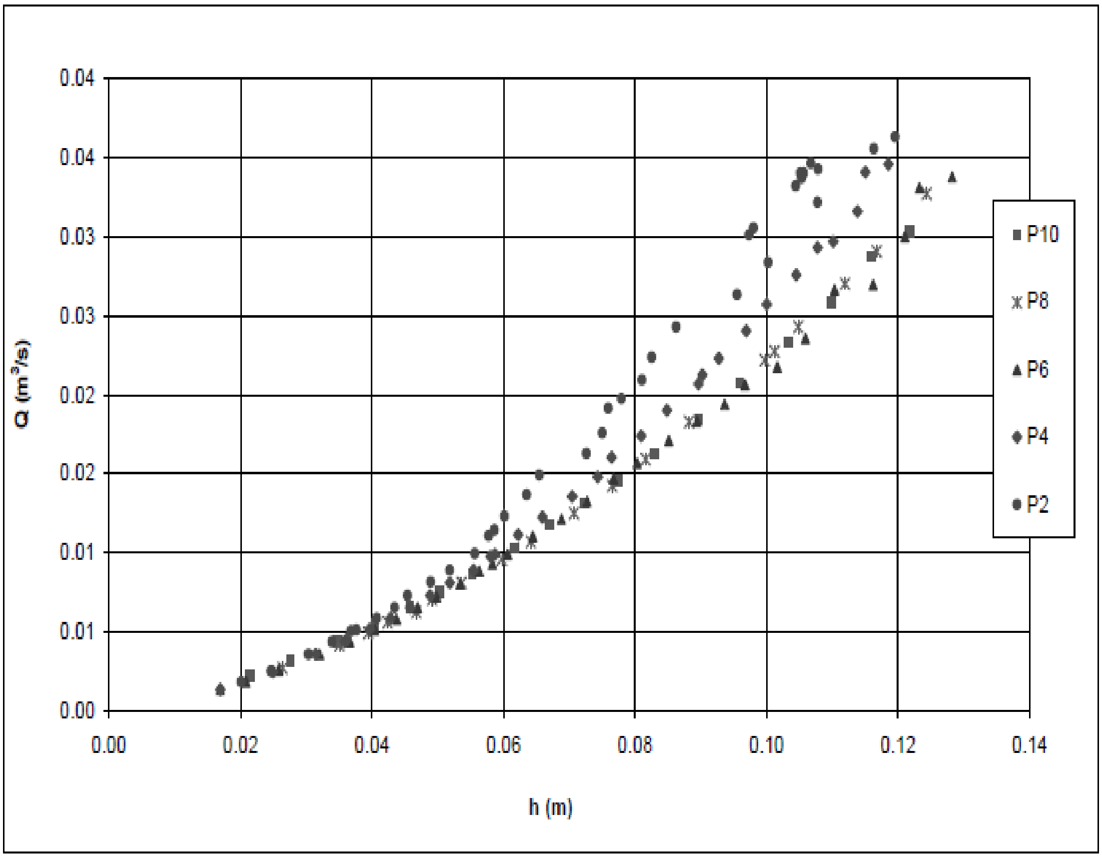

Figure 2.10: Water discharge, Q vs Head over weir, h

Source: Sisman, 2009

From the figure 2.10, the head over weir, h increase if the water discharge, Q is increase. From the figure above, there are no changes of the variation of Q over h after P = 6cm compared to P = 8cm and 10cm. The weir height, P = 10cm were select in order to make the effect of bottom boundary diminish. So the discharge coefficient, C_d will become independent to the value of h/P. The value of discharge coefficient, C_d has shown in the figure 2.11.

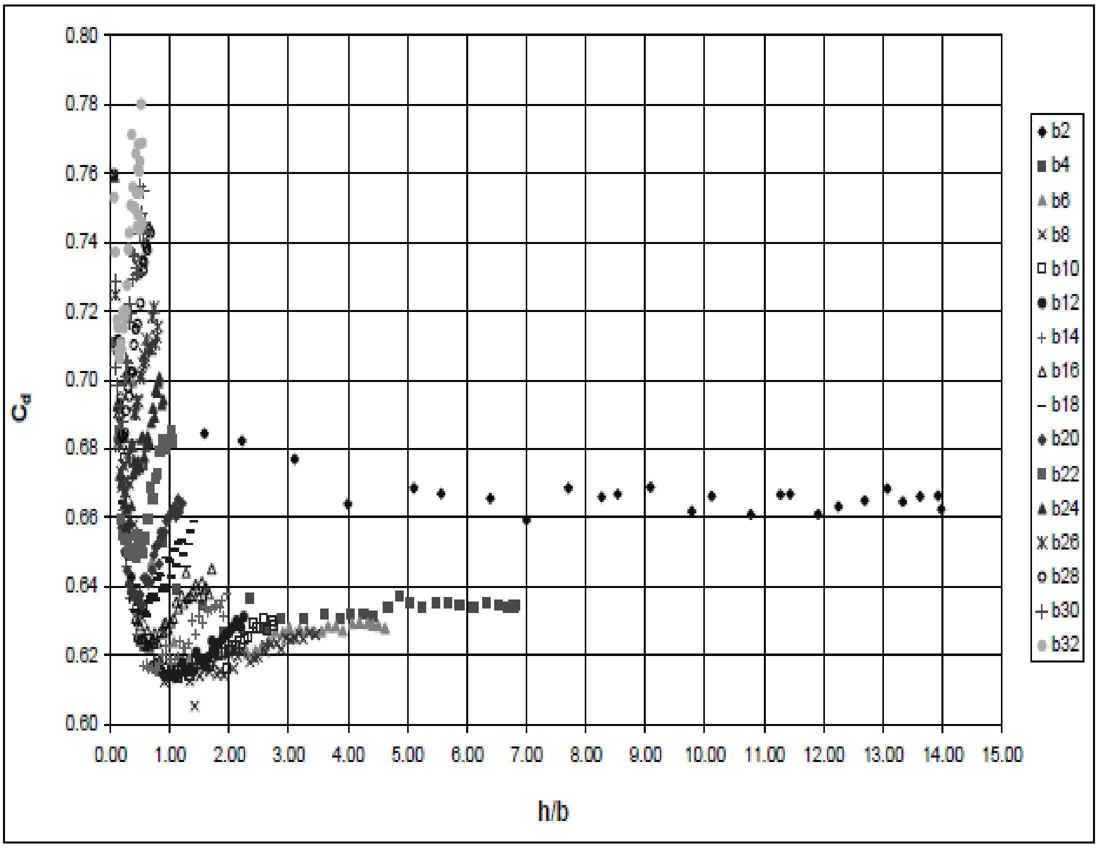

Figure 2.11: Discharge Coefficient, C_d vs *h/b*

Source: Sisman, 2009

In the study, a few conclusions were determined. First, the head over weir must not less than 2cm. This is because the non aerated flow must be avoided. Then, the stationary surface of the water flow is almost about 1.20m from the weir. That means, the drawdown effect can be neglect at the upstream from $3h_{max}$ to $4h_{max}$ weir location. The weir height, P = 10cm were selected as the weir height in order to neglect the effect of boundary.

2.4.2 SARA BAGHERI ET AL EXPERIMENT

In the study of Sara Bagheri et al, 2010, they have considered the equation (2.2) that show below.

$$Q = C_d \frac{2}{3}\sqrt{2g}bh^{\frac{3}{2}} \tag{2.2}$$

Where: C_d = discharge coefficient, b = length of the weir, h = water head over the weir. Francis has indicated that the effect of the lateral contraction can be considered by reducing the value of sharp crested length, b in the equation (2.2) by $0.2h$ (Brazer et al., 1996). In this study, there are a few theoretical have been considered. First in order to derive the head discharge equation, it is assumed that sharp crested weir have the similar behaviour to an orifices with a free surface. According to the statement, the following assumption was made. There are:

I. The height of the water level above the weir crest is h.
II. There is no contraction.
III. Mean flow velocity over the weir crest is almost horizontal.
IV. The approaching velocity head ($V_0^2/2g$) is neglected.

This study uses the free vortex theory in order to get the discharge coefficient of the weir. The experimental result illustrated that the developed equation presented reasonable result for the range $0 < h/P < 10$. Figure 2.12 show the sectional cross of the rectangular sharp crested weir that has design in the study.

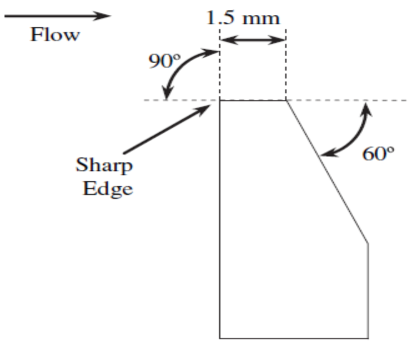

Figure 2.12: Sectional Cross of the rectangular sharp crested weir

Source: Bagheri et al, 2010