CALIBRATING A HEC-RAS MODEL OF V-NOTCH WEIR AS INLINE STRUCTURE USING OPEN CHANNEL FLUME FLOW METHOD AND ITS APPLICATION FOR SEDIMENT TRANSPORT

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Report submitted in partial fulfilment of the requirements
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DEDICATION

Praise be to Allah, the Lord of the World
Who says (in the interpretation of meaning)

"My Lord, enable me to be grateful for Your favor which You have bestowed upon me and upon my parents and to do righteousness of which You approve. And admit me by Your mercy into [the ranks of] Your righteous servants"
[An-Naml: 19]

I dedicated the research to my beloved family Ruslan bin Ghazali and Nor Azian bte Abdul Majid for opening my eyes to the world and my supervisor, friends for the endless help, guidance, patience and encouragement.

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ABSTRACT

The Hydrologic Engineering Center's River Analysis System (HEC- RAS) is a one-dimensional computer model intended to perform hydraulic calculations for a network of open channels. This model is widely available, free of cost and the most commonly used hydraulic model in the United States. Most HEC-RAS models are steady state. Unsteady flow analysis in HEC-RAS differs in many ways from the traditional steady state analysis. The main objective of this study is to compare the results of the water surface profile between HEC-RAS and the laboratory experiment. The procedure and methodology to collect the data are described. HEC-RAS will determine the water surface profile with three different discharge and manning value. The data is collected along the flume with V-notch weir is placed at fixed point. After the laboratory work is done, the computational work will obtained the result and the comparison is made. HEC-RAS's result will determine whether it is reliable to use. The prediction of sediment transport in the upstream is determined in this study. From the result and discussion the appropriate manning value is 0.010 $s/m^{1/3}$ with the value of root mean square error of 0.026358m from the upstream. The sediment transport is occur at the upstream. This research can be conclude that HEC-RAS is reliable to be used.

ABSTRAK

Hydrologic Engineering Center's River Analysis System (HEC- RAS) adalah model komputer satu dimensi yang bertujuan untuk melakukan pengiraan hidraulik untuk rangkaian saluran terbuka. Model ini boleh didapati secara meluas, bebas daripada kos dan model yang paling biasa digunakan hidraulik di Amerika Syarikat. Kebanyakan model HEC-RAS adalah keadaan mantap. Analisis aliran tak mantap dalam HEC-RAS banyak berbeza daripada analisis keadaan mantap tradisional. Objektif utama kajian ini adalah untuk membandingkan keputusan profil permukaan air di antara HEC-RAS dan eksperimen makmal. Prosedur dan kaedah untuk mengumpul data adalah seperti yang dinyatakan. HEC-RAS akan menentukan profil permukaan air dengan tiga pelepasan yang berbeza dan nilai pengendalian. Data yang dikumpul sepanjang flum dengan empang V-takuk diletakkan pada titik tetap. Selepas kerja-kerja makmal yang dilakukan, kerja-kerja pengkomputeran akan mendapat keputusan dan perbandingan itu dibuat. Hasil HEC-RAS akan menentukan sama ada ia boleh dipercayai untuk digunakan. Ramalan pengangkutan sedimen di hulu yang ditentukan dalam kajian ini. Dari hasil dan perbincangan nilai pengendalian yang sesuai adalah 0.010 $s/m^{1/3}$ dengan nilai punca min kuasa dua ralat 0.026358m dari hulu. Pengangkutan sedimen adalah berlaku di hulu. Kajian ini boleh membuat kesimpulan bahawa HEC-RAS boleh dipercayai yang akan digunakan.

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Q	discharge (m^3/s)
C_d	discharge coefficient
H	head above weir (m)
G	gravitational constant
V	velocity of flow (m/s)
g_2	gravitational acceleration
y	depth of flow (m)
y_1	depth at section 1 (m)
y_2	depth at section 2
E_1	Energy at section1
E_2	Energy at section 2
ΔE	Difference of energy between section 1 and section 2

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The Hydrologic Engineering Center's River Analysis System (HEC- RAS) is a one-dimensional computer model intended to perform hydraulic calculations for a network of open channels. This model is widely available, free of cost and the most commonly used hydraulic model in the United States. Most HEC-RAS models are steady state. Unsteady flow analysis in HEC-RAS differs in many ways from the traditional steady state analysis. The largest difference involves the ability to input a full hydrograph to analyze the response of the river system to flows that vary with time.

1.2 BACKGROUND OF STUDY

Manning value plays an important role in river analysis. It will determine the flow of the water and also the height of the water surface profile. The complex nature of the flow, standard hydraulic modeling tools, such as HEC-RAS program, could not be used accurately to determine the flow.

Laboratory experiment is carried out to compare the result of the HEC-RAS program. Prediction of sediment transport using HEC-RAS to determine whether there is transport in the inline structure.

1.3 PROBLEM STATEMENT

HEC-RAS have been used for almost 20 years and up till today HEC-RAS has difficulty in the stimulation of a steep channel or stream. Besides that, many users around the world find instability numerical unsteady flow. It is 1 dimensional hydrodynamic modeling and might not be able to work well in multi-dimensioning modeling. HEC-RAS is used to stimulate Tawau design spillway design and it is found that the results obtained in the hydraulic jump and water surface profile does not same as in manual calculation.

1.4 OBJECTIVES

The objectives of this research are:

i. To determine the water surface profile height at upstream of V-notch weir by using different.

ii. To compare the results of the water surface profile height between HEC-RAS and laboratory experimental.

iii. To obtain the appropriate manning value.

iv. To predict the sediment transport pattern in the upstream of V-notch weir.

1.5 SCOPE OF STUDY

A prototype model of an open channel is constructed in laboratory for testing purpose. The water flow through the V-notch weir model indicates the actual flow of water from the reservoir. Study scopes that have been fixed are:

i. Experiment is conducted in Hydraulic & Hydrology Laboratory of Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang.
ii. The model structure associated with a V-notch weir.
iii. Take into account of various water discharge and Manning value.

Once experiment conducted, the result will be compared with the HEC-RAS. In addition, HEC-RAS will determine the sediment transport in the upstream.

1.6 RESARCH SIGNIFICANCE

HEC-RAS is an important tool for engineers to make decisions and to stimulate the design. It is widely used by the engineers around the world for steady flow water surface profile computation, unsteady flow simulation, movable boundary sediment transport computation and water quality analysis. Besides that, this software is freely distributed which make it more people using it. The comparison between HEC-RAS and laboratory experiment is used to determine the accuracy of the manning value. HEC-RAS also provide the other utilities such as one dimensional Quasi-Unsteady Sediment Transport and to predict whether there is sediment transport in the inline structure.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will divided into two parts. First part is the open channel. It will subdivide into manning equation, hydraulic jump, flume and v-notch weir, Froude number and water surface profile. Second part is HEC-RAS. It will subdivide into Root Mean Square Error, Finite Difference Method and sediment transport.

2.2 OPEN CHANNEL

Open channel flow can be said to be as the flow of fluid (water) over the deep hollow surface (channel) with the cover of atmosphere on the top. Examples of open channels flow are river, streams, flumes, sewers, ditches and lakes etc. we can be said to be as open channel is a way for flow of fluid having pressure equal to the atmospheric pressure. While on the other hand flow under pressure is said to be as pipe flow. In example, flow of fluid through the sewer pipes.

Open-channel flow is usually categorized on the basis of steadiness. Flow is said to be steady when the velocity at any point of observation does not change with time; if it changes from time to time, flow is said to be unsteady. At every instant, if the velocity is the same at all points along the channel, flow is said to be uniform; if it is not the same, flow is said to be non-uniform. Non-uniform flow which is also steady is called as varied flow; non-uniform flow which is unsteady is called as variable flow. Flow occurs from a higher to a lower concentration by aid of gravity. Another important characteristic of open channel flow is the extreme variability encountered in cross-sectional shape and roughness, Terry W. Sturm (2001).

Figure 2.1 : An example of open channel flow eventually go to the river or ponds.

Source: (http://ceephotos.karcor.com/2011/06/23/small-open-channel-flow/)

2.2.1 Manning Equation

One the most commonly used equations governing Open Channel Flow is known as the Mannings's Equation. It was introduced by the Irish Engineer Robert Manning in 1889 as an alternative to the Chezy Equation. The Mannings equation is an empirical equation that applies to uniform flow in open channels and is a function of the channel velocity, flow area and channel slope.

It can also be used to calculate values of other uniform open channel flow parameters such as channel slope. Manning roughness coefficient or normal depth, when the water flow rate through the open channel is known. An example set of calculations includes average flow velocity determination and water flow calculation for a given channel and flow depth. The Manning equation applies to open channel flow in natural channels as well as to man-made channels. For example, river discharge can be related to the depth of water flow and river parameters like slope, width and cross-sectional shape.

The Manning equation is:

$$Q = VA = \frac{(1)AR^{\frac{2}{3}}\sqrt{S}}{n} \tag{2.1}$$

Where:

V= velocity (m/s)

A= flow area (m^2)

R= hydraulic radius (m)

S= channel slope (m/m)

n= manning roughness coefficient

2.2.2 Manning Roughness Coefficient

The Manning roughness coefficient, n, is an experimentally determined constant. It value depends depends upon the nature of the channel and its surface. Tables giving values of *n* for different man-made and natural channel types and surfaces are available in many textbooks, handbooks and on-line. The table below gave by Chow (1959) an idea of variability to be expected in Manning's, *n.* Manning roughness coefficient values for several surfaces commonly used for open channel flow. In general smoother surfaces have lower Manning roughness coefficient values and rougher surfaces have higher Manning roughness coefficient values

.

Table 2.1 : Manning Roughness Coefficient

Type of Channel and Description	**Minimum**	**Normal**	**Maximum**
Natural streams - minor streams (top width at floodstage < 100 ft)			
1. Main Channels			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. same as above, but more stones and weeds	0.030	0.035	0.040
c. clean, winding, some pools and shoals	0.033	0.040	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.050
e. same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. same as "d" with more stones	0.045	0.050	0.060
g. sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
a. bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
b. bottom: cobbles with large boulders	0.040	0.050	0.070
3. Floodplains			
a. Pasture, no brush			
1.short grass	0.025	0.030	0.035
2. high grass	0.030	0.035	0.050
b. Cultivated areas			
1. no crop	0.020	0.030	0.040
2. mature row crops	0.025	0.035	0.045
3. mature field crops	0.030	0.040	0.050
c. Brush			
1. scattered brush, heavy weeds	0.035	0.050	0.070
2. light brush and trees, in winter	0.035	0.050	0.060
3. light brush and trees, in summer	0.040	0.060	0.080
4. medium to dense brush, in winter	0.045	0.070	0.110
5. medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. dense willows, summer, straight	0.110	0.150	0.200
2. cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120

Table 2.2 : Manning Roughness Coefficient (*continue*)

5. same as 4. with flood stage reaching branches	0.100	0.120	0.160
4. Excavated or Dredged Channels			
a. Earth, straight, and uniform			
1. clean, recently completed	0.016	0.018	0.020
2. clean, after weathering	0.018	0.022	0.025
3. gravel, uniform section, clean	0.022	0.025	0.030
4. with short grass, few weeds	0.022	0.027	0.033
b. Earth winding and sluggish			
1. no vegetation	0.023	0.025	0.030
2. grass, some weeds	0.025	0.030	0.033
3. dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. earth bottom and rubble sides	0.028	0.030	0.035
5. stony bottom and weedy banks	0.025	0.035	0.040
6. cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged			
1. no vegetation	0.025	0.028	0.033
2. light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. smooth and uniform	0.025	0.035	0.040
2. jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. dense weeds, high as flow depth	0.050	0.080	0.120
2. clean bottom, brush on sides	0.040	0.050	0.080
3. same as above, highest stage of flow	0.045	0.070	0.110
4. dense brush, high stage	0.080	0.100	0.140
5. Lined or Constructed Channels			
a. Cement			
1. neat surface	0.010	0.011	0.013
2. mortar	0.011	0.013	0.015
b. Wood			
1. planed, untreated	0.010	0.012	0.014
2. planed, creosoted	0.011	0.012	0.015
3. unplanned	0.011	0.013	0.015
4. plank with battens	0.012	0.015	0.018
5. lined with roofing paper	0.010	0.014	0.017
c. Concrete			

Table 2.3 : Manning Roughness Coefficient (*continue)*

1. trowel finish	0.011	0.013	0.015
2. float finish	0.013	0.015	0.016
3. finished, with gravel on bottom	0.015	0.017	0.020
4. unfinished	0.014	0.017	0.020
5. gunite, good section	0.016	0.019	0.023
6. gunite, wavy section	0.018	0.022	0.025
7. on good excavated rock	0.017	0.020	
8. on irregular excavated rock	0.022	0.027	
d. Concrete bottom float finish with sides of:			
1. dressed stone in mortar	0.015	0.017	0.020
2. random stone in mortar	0.017	0.020	0.024
3. cement rubble masonry, plastered	0.016	0.020	0.024
4. cement rubble masonry	0.020	0.025	0.030
5. dry rubble or riprap	0.020	0.030	0.035
e. Gravel bottom with sides of:			
1. formed concrete	0.017	0.020	0.025
2. random stone mortar	0.020	0.023	0.026
3. dry rubble or riprap	0.023	0.033	0.036
f. Brick			
1. glazed	0.011	0.013	0.015
2. in cement mortar	0.012	0.015	0.018
g. Masonry			
1. cemented rubble	0.017	0.025	0.030
2. dry rubble	0.023	0.032	0.035
h. Dressed ashlar/stone paving	0.013	0.015	0.017
i. Asphalt			
1. smooth	0.013	0.013	
2. rough	0.016	0.016	
j. Vegetal lining	0.030		0.500

Source:
(http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm)

2.2.3 Flume And V-Notch Weir

Flume is an artificial channel conveying water. Many flumes took the form of wooden troughs elevated on trestles, often following the natural contours of the land. Originating as a part of a mill race, they were later used in the transportation of logs in the logging industry. They were also extensively used in hydraulic mining and working placer deposits for gold, tin and other heavy minerals. Flumes are not to be confused with aqueducts, which are built with the goal of transporting the water, whereas a flume would use the flowing water to transport other materials.

The v-notch weir is one type of sharp crested weir. Utilizing the same approach as for the derivation of the head-discharge relationship for rectangular sharp-crested weir. It can be shown that the head-discharge relationship for a V-notch weir as

$$Q = Cd\ \frac{8}{15}\sqrt{2g}\tan\frac{\theta}{2}H^{5/2} \tag{2.2}$$

Where;

Q= discharge (m^3/s)

C_d= discharge coefficient

H = head above weir (m)

g= gravitational constant (m^2/s)

The weir crest is the top of the weir. For a v notch weir it is the point of the notch, which is the lowest point of the weir opening.. The drawdown is the decrease in water level going over the weir due to the acceleration of the water. The head over the weir is shown as H in the diagram; the height of the weir crest is shown as P; and the open channel flow rate or discharge is shown as Q.

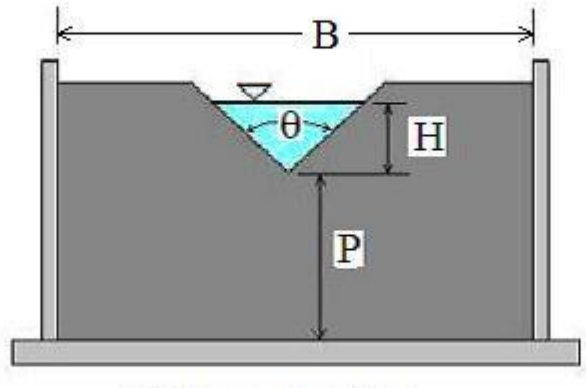


Figure 2.2: V-notch crested weir

Source : (http://www.engineeringexcelspreadsheets.com/2011/04/v-notch-weir-calculator-excel-spreadsheet/)

2.2.4 Hydraulic Jump

An Italian engineer, Bidone (1818) found that hydraulic jump is the phenomenon when supercritical stream meets a subcritical stream of sufficient depth. The supercritical stream jumps up to meet the alternate depth. The hydraulic jump serves as an energy dissipater to dissipate the excess energy of flowing water downstream of hydraulic structure.

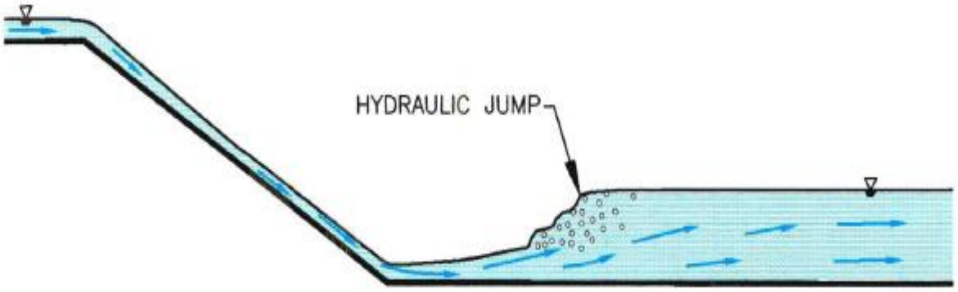
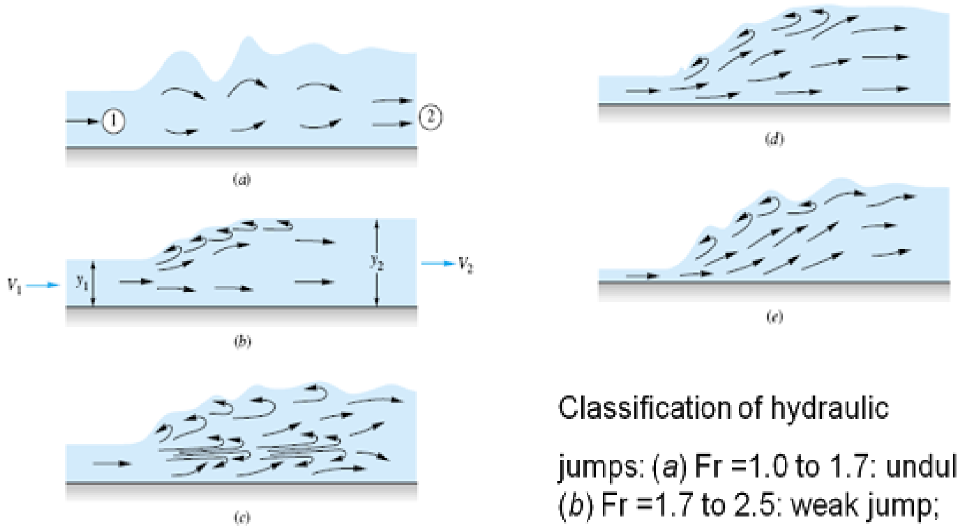


Figure 2.3: The phenomenon hydraulic jump

Source : (krcproject.groups.et.byu.net)



Classification of hydraulic

jumps: (*a*) Fr =1.0 to 1.7: undular jumps;
(*b*) Fr =1.7 to 2.5: weak jump;

(*c*) Fr =2.5 to 4.5: oscillating jump;

(*d*) Fr =4.5 to 9.0: steady jump;

(*e*) Fr =9.0: strong jump.

Figure 2.4: Appearance of hydraulic jump for different Froude number ranges

Source : (http://optimist4u.blogspot.com/2011/04/hydraulic-jump-and-its-practical.html , 2011)

2.2.5 Froude Number

Froude Number is a dimensionless number define as the ratio of a characteristic velocity to gravitational velocity. Named after William Froude, the Froude number is based on the speed-length ratio as below:

$$Fr = \frac{v}{\sqrt{gy_c}} \qquad (2.3)$$

where;

v = velocity of flow (m/s)

g = gravitational acceleration(m2/s)

y = depth of flow (m)

Table 2.4: Classification of hydraulic jumps according to Froude Number

Fr1 <1.0	Jump impossible, violates second law of thermodynamics**.**
Fr1=1.0 to 1.7	Standing-wave, or undular, jump about 4y2 long; low dissipation, less than 5 percent.
Fr1=1.7 to 2.5	Smooth surface rise with small rollers, known as a weak jump; dissipation 5 to 15 percent.
Fr1=2.5 to 4.5	Unstable, oscillating jump; each irregular pulsation creates a large wave which can travel downstream for miles, damaging earth banks and other structures. Not recommended for design conditions. Dissipation 15 to 45 percent.
Fr1=4.5 to 9.0	Stable, well-balanced, steady jump; best performance and action, insensitive to downstream conditions. Best design range. Dissipation 45 to 70 percent.
Fr1>9.0	Rough, somewhat intermittent strong jump, but good performance. Dissipation 70 to 85 percent.

When Froude number approaches $\frac{V}{\sqrt{gy}}$:

$$\frac{y2}{y1} = \frac{1}{2}(-1 + \sqrt{1 + 8F^2}) \tag{2.4}$$

Where as energy loss can be find by

$$\Delta E = \frac{(y_2 - y_1)^3}{4y_1y_2} \tag{2.5}$$

Where:

y_2= depth at section 2 (m)

y_1= depth at section 1 (m)

Fr_1= Froude number at section 1

E_1= Energy at section1 (m)

E_2= Energy at section 2 (m)

ΔE = Difference of energy between section 1 and section 2 (m)

2.2.6 Water Surface Profile

The water surface profile is a measure the depth flow longitudinally. It is classified between actual water depth (y), normal depth (y_n) and critical depth (y_c). Normal depth is the depth of flow that would occur if the flow was uniform and steady, and is usually predicted using the Manning's Equation. Critical depth is defined as the depth of flow where energy is at a minimum for a particular discharge.

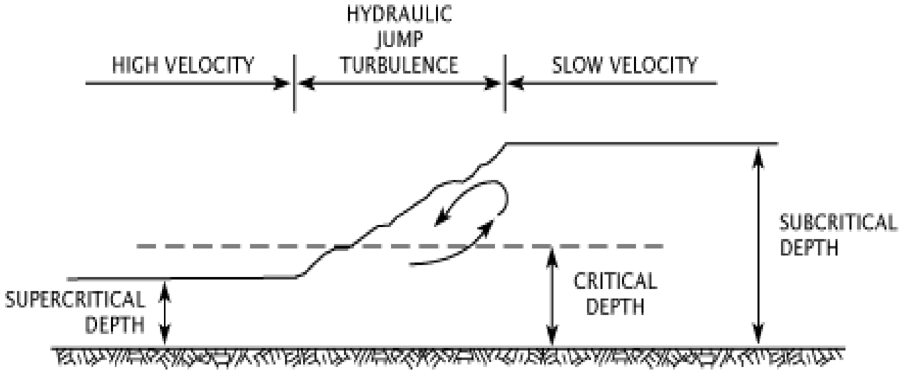


Figure 2.5: Water surface in an open channel when water flowing at high velocity

Source : (http://www.owp.csus.edu/glossary/hydraulic-jump.php)

Table 2.5: Description of hydraulic curve

Type 1 curve	Depth is greater than y_c and y_n flow is subcritical.
Type 2 curve	Depth is between y_c and y_n, flow can be either subcritical or supercritical.
Type 3 curve	Depth is less than both $y_c$and y_n, flow is supercritical.

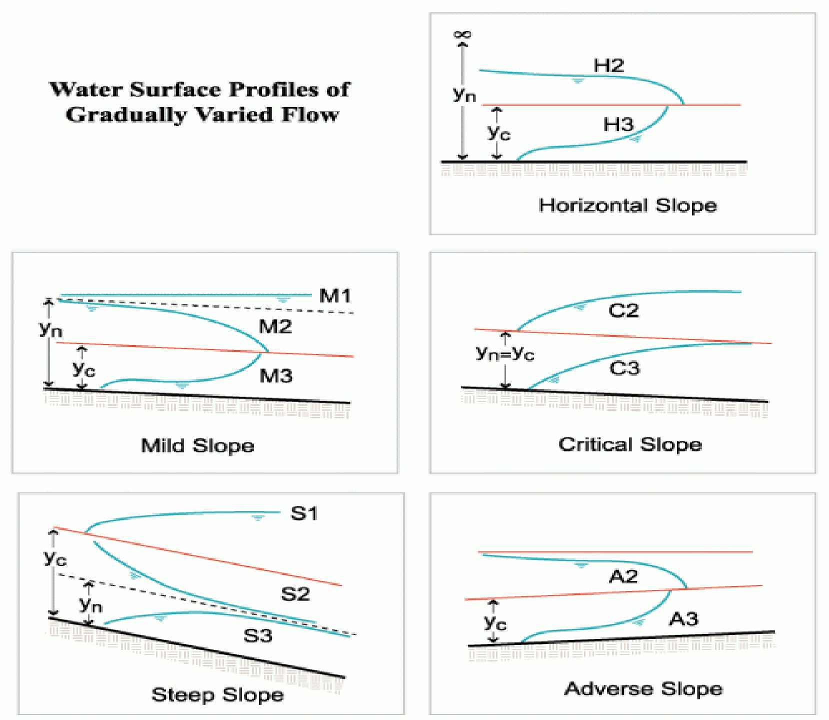


Figure 2.6: Water surface profile in gradually varied flow

Source:(http://www.fsl.orst.edu/geowater/FX3/help/4_Calculations/Classification_of_Water_Surface_Profiles.htm)

Hydraulic Curve classifications are used to describe the shape of the water surface profile at a specific flow. The curves are based on the Hydraulic Slope (Adverse, Horizontal, Critical, Mild, or Steep) and the relative position of the actual flow depth to normal and critical depth as designated by the numbers 1, 2, and 3.

Supercritical flow is influenced by inertial forces and acts as rapid or unstable flow. Supercritical flow transition to subcritical through a hydraulic jump which represents a high energy loss with erosive potential.

Table 2.6: Description of Froude number

Subcritical	• Occurs when actual water depth is greater than critical depth. Subcritical flow is influenced by gravitational forces and act in a slow or stable way. • Fr < 1
Supercritical	• Actual depth is less than critical depth. It is influenced by inertial forces and acts as rapid or unstable flow. Supercritical flow transition to subcritical through a hydraulic jump which represents a high energy loss with erosive potential. • Fr > 1
Critical	• Transition or control the flow that enforce the minimum possible energy for the flow rate. • Fr = 1

2.3 HEC- RAS

HEC-RAS is a shortened from Hydrologic Engineering Centers River Analysis System (HEC-RAS). Its is a computer program that models the hydraulics of water flow through natural rivers and other channels. The program is one-dimensional, meaning that there is no direct modeling of the hydraulic effect of cross section shape changes, bends, and other two- and three-dimensional aspects of flow. The program was developed by the US Department of Defense, Army Corps of Engineers in order to manage the rivers, harbors, and other public works under their jurisdiction; it has found wide acceptance by many others since its public release in 1995.

The Hydrologic Engineering Center (HEC) in Davis, California developed the River Analysis System (RAS) to aid hydraulic engineers in channel flow analysis and floodplain determination. It includes numerous data entry capabilities, hydraulic analysis components, data storage and management capabilities, and graphing and reporting capabilities.

HEC-RAS system ultimately contain three one-dimensional hydraulic analysis components for steady flow water surface profile computation, unsteady flow simulation and movable boundary sediment transport computations. A key element is that all three component will use a common geometric data representation, common geometric and hydraulic computation routines. In addition, to the three hydraulic analysis components, the system contains several hydraulic design features that can be involved once the basic water surface profile are computed.

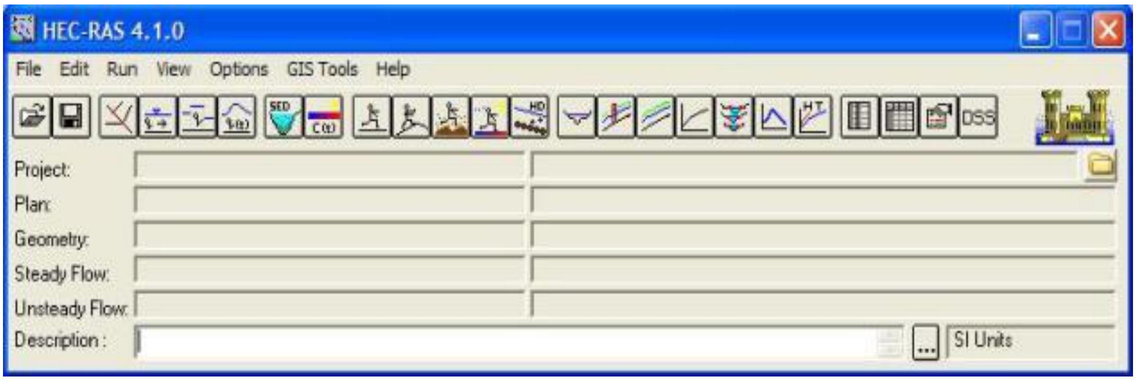


Figure 2.7 : The overview of HEC-RAS

2.3.1 Unsteady Flow

Unsteady flow also called *transient*, occur in an open channel. Velocity and depth changes with time at any fixed spatial position in an open channel. Open channel flow in natural channel always unsteady. It often analyzed in a quasi-steady state for channel design. Unsteady flow in open channel by nature is non-uniform as well as unsteady because of the free surface. Two dependent flow variables (velocity and depth or discharge and depth) are functions of both distance along the channel and time for one dimensional application.

2.3.2 Root Mean Square Error

The Root Mean Square Error (RMSE) is a measure the average of error, weighted according to the square of error. RMSE is influenced much strongly by large errors than small errors. The range is from 0 to infinity. 0 been the perfect score.

The purpose of root mean square error is to measure the difference between values predicted by a model and the values actually done in the laboratory. RMSE is a good measure of accuracy but it is only to compare forecasting errors.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(h_{model} - h_{observed})^2} \tag{2.6}$$

h_{model} is express as HEC-RAS value and $h_{observed}$ is expressed laboratory results.

2.3.3 Finite Difference Approximation

$$y_{i+1} = y_i + f'(x_i)(x_{i+1} - x_i) + f''(x_i)\frac{(x_{i+1} - x_i)^2}{2!} + \cdots \tag{2.7}$$

One dimensional Saint Venant equation is commonly used to model passing open channel flow and surface runoff. The simplication of two dimensional Saint Venant equation is usage for shallow water equations. The 1-D simplication is designed exclusively for HEC-RAS. The applications of 1-D include dam break analyses, storm pulses in an open channel. Subramanya (2009) claimed that finite difference scheme classified to explicit and implicit methods.

In explicit method, St Venant equations are converted to a set of algebraic equations. The unknown terms at the end of time step expressed by known terms at the beginning of the time step. Better accuracy with the diffusion scheme by following other scheme such as Leap-Frog or Lax-Wendroff scheme.

In implicit finite difference method, the derivative and coefficients are replaced in terms of value of the variable at known and unknown time level. The unknown variables before appear implicitly in the algebraic equations. Because of large number of time steps required by an explicit method to route a flood in a channel, implicit method which can use large time steps without any stability problems are preferred. Several implicit finite difference scheme have been proposed which is Preissman Scheme.

2.3.4 Sediment Transport

Sediment transport is defined as finer materials such as clay and silts can be transported easily once they enter the channel and wash through with only one trace amounts left in bed. HEC-RAS can used to determine whether erosion and deposition occurs. HEC-RAS can perform mobile bed sediment routing computation with quasi steady flow series data. For each flow in the time series, a water surface profile is calculated. Hydraulic parameters required for sediment transport is also calculated. The greater the flow, the more sediment that will be conveyed.

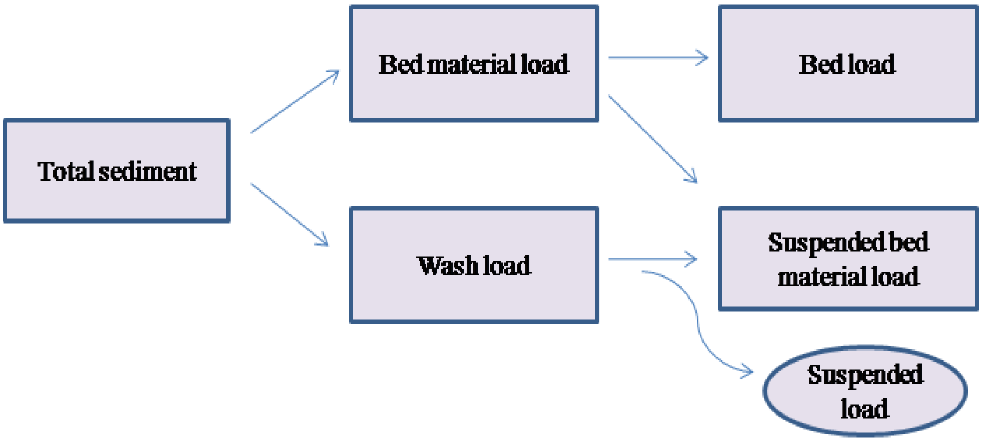


Figure 2.8 : Sediment transport definition

Table 2.5 : Non-transported sediment: Bed material (stationary sediment of the same size constituting the bed-material load)

Sediment Load	**Material in suspension and/or in transport**
Bed Material Load	Total rate at which bed material is transported by a given location on a stream (both bed load and suspended load)
Bed Load	Material moving near the stream bed rolling, sliding and sometimes making burst excursions into the flow a few diameter above the bed
Wash load	Part of total load suspended load that is finer than bed material
Suspended load	Includes both suspended bed material load and wash load. Sediment that moves in suspension.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter will be described the process on handling laboratory experiment and computational work. The procedure and method in handling the process are described details below.

3.2 RESEARCH DESIGN

The methodology that used to run the research is the HEC-RAS software. It is the simulation experiment that is very economical and effective to analyze the water surface profile of a stream or channel. The research is divided into four phase, which are laboratory work, Manning Value specification, computational work and analyze result.

3.3 FLOW CHART OF PROJECT METHODOLOGY

Figure 3.1 shows a project methodology which involved the steps that have been taken to complete this study.

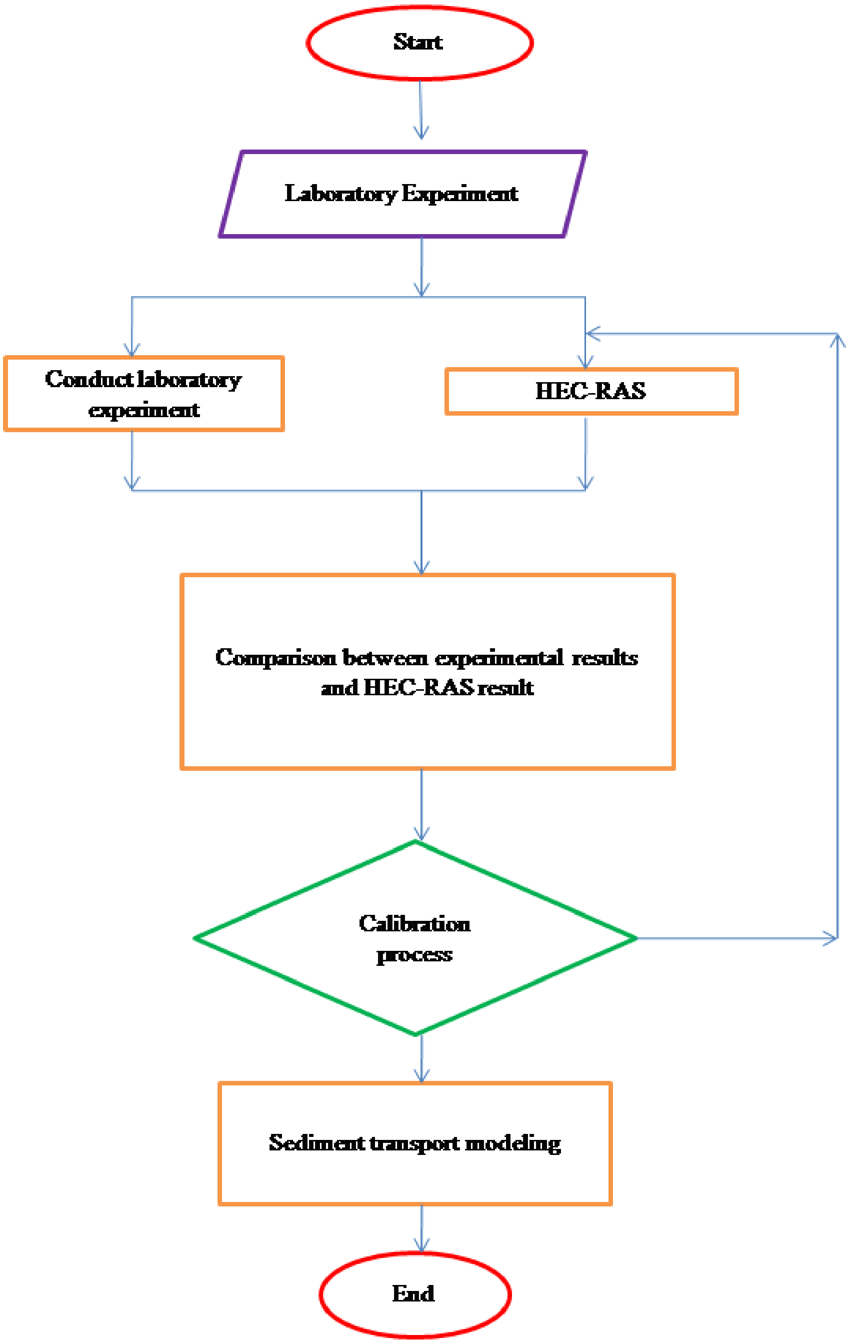


Figure 3.1 : Project Methodology

3.4 LABORATORY WORK

Erosion occurs at the depth of 0.47m as shown in figure 4.22. It occurs at 11m from the upstream as the distance is longer that actual flume dimension. In order to calibrate HEC-RAS, it needs laboratory experiment and HEC-RAS. The preparation needs a laboratory where the dimension of open channel is measured. The dimension is referred to the height, width and length of the structure as shown on figure 3.2. Different value of discharge and manning value is determined and applied on the flume. The water flow will show the water surface profile

Figure 3.2: Open channel that is located at the Hydraulic and Hydrology Laboratory

Figure 3.3: Water started to flow along the flume

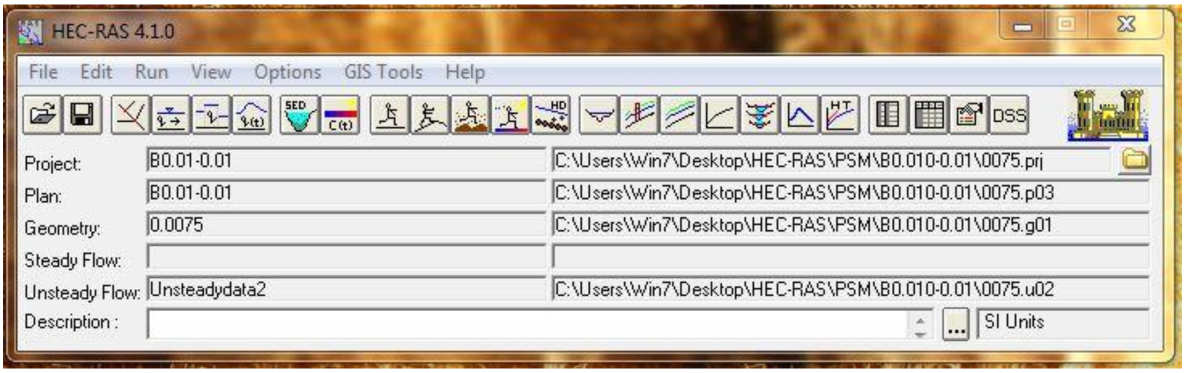
Figure 3.3 shows the water started to flow across the flume from the upstream. Three different discharges are obtained which are 0.005 m^3/s, 0.010 m^3/s and 0.015 m^3/s. The water started to flow from the upstream as illustrated in figure 3.3. Figure 3.4 V-notch weir of 90^o angle is located at the 4.57m from the upstream. Hydraulic jump is occurred after the weir as shown in figure 3.5.

Figure 3.4: Flow of water across the V-Notch weir.

Figure 3.5: Hydraulic jump

3.5 COMPUTATIONAL WORK

HEC-RAS is used as the method in computational work. It is used to determine the water surface profile. Manipulative variable for this research is discharge, manning value and coefficient of the flume. The first step in using HEC-RAS is to construct geometric data. It represented the dimension of the flume itself. Next, insert the manning value and coefficient of the flume. Last step is key-in the value of discharge same as used in laboratory experiment. After all those value has been added, the calibration begun to create the water surface profile. Next step in HEC-RAS is the prediction of sediment transport. As flume is too small in prediction sediment transport, the dimension of flume is adjusted in HEC-RAS is order to obtain the sediment transport.

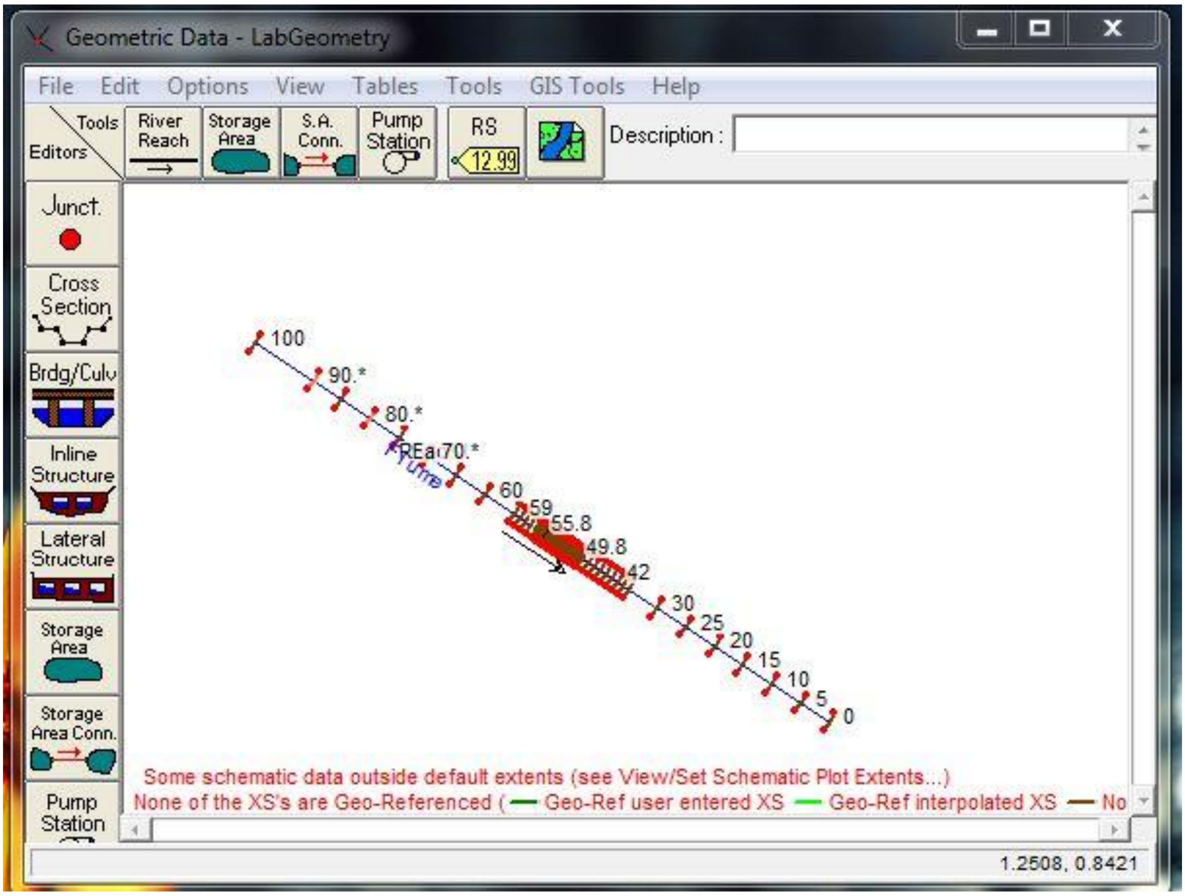


Project: B0.01-0.01 C:\Users\Win7\Desktop\HEC-RAS\PSM\B0.010-0.01\0075.prj
Plan: B0.01-0.01 C:\Users\Win7\Desktop\HEC-RAS\PSM\B0.010-0.01\0075.p03
Geometry: 0.0075 C:\Users\Win7\Desktop\HEC-RAS\PSM\B0.010-0.01\0075.g01
Steady Flow:
Unsteady Flow: Unsteadydata2 C:\Users\Win7\Desktop\HEC-RAS\PSM\B0.010-0.01\0075.u02
Description : SI Units

Figure 3.6 The overview of HEC-RAS

3.5.1 Geometric Data

Dimension of flume is constructed in HEC-RAS. Length of the flume is 10m, 0.3m width and 0.45m height. The geometric data is constructed as shown in figure 3.7. Station 100 is set up as upstream and station 0 as the downstream as shown on figure 3.8. Manning value is set for 0.009, 0.010 and 0.011 to generate data. Manning coefficient of roughness has to be determined exactly as shown in figure 3.8. The slight change of Manning Value will give different results. The first condition requires the flume properties. The second condition requires that the flume roughness coefficient to be determined.



Some schematic data outside default extents (see View/Set Schematic Plot Extents...)

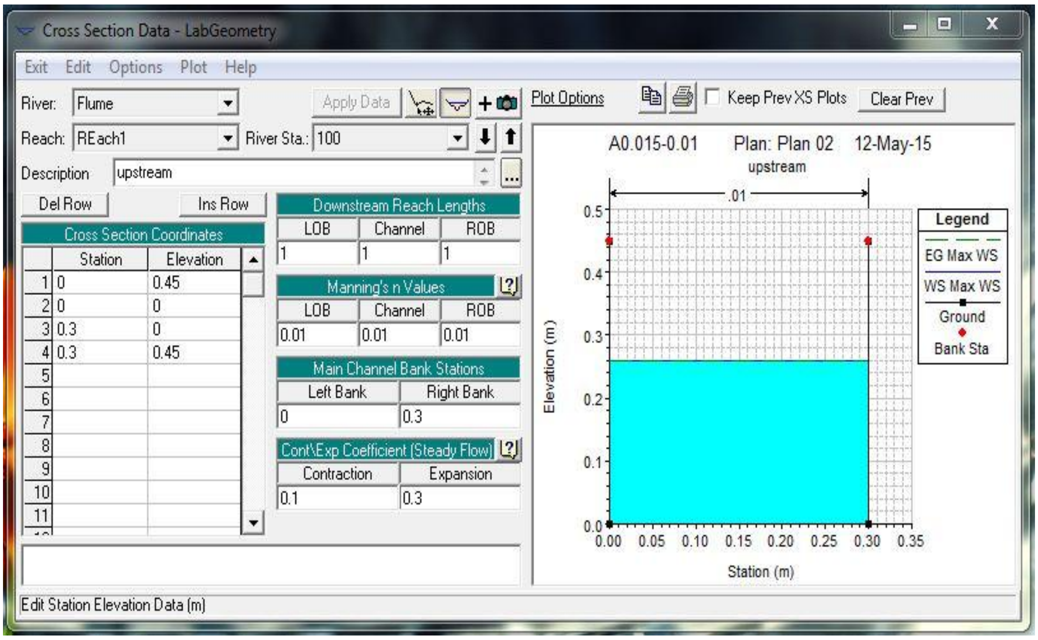
None of the XS's are Geo-Referenced (— Geo-Ref user entered XS — Geo-Ref interpolated XS — No

1.2508, 0.8421

Figure 3.7 Geometric data of HEC-RAS

The second condition requires that the flume roughness coefficient to be determined.

Each station construct in HEC-RAS is similar as the location data taken at the laboratory. For distance at 5.6m from upstream to 4.8m the data taken at 0.02m interval. At station 54.4 from the upstream, the inline structure of V-notch weir with 90^o is placed as shown in figure 3.9.



River: Flume

Reach: REach1

River Sta.: 100

Description: upstream

Cross Section Coordinates

	Station	Elevation
1	0	0.45
2	0	0
3	0.3	0
4	0.3	0.45
5		
6		
7		
8		
9		
10		
11		

Downstream Reach Lengths

LOB	Channel	ROB
1	1	1

Manning's n Values

LOB	Channel	ROB
0.01	0.01	0.01

Main Channel Bank Stations

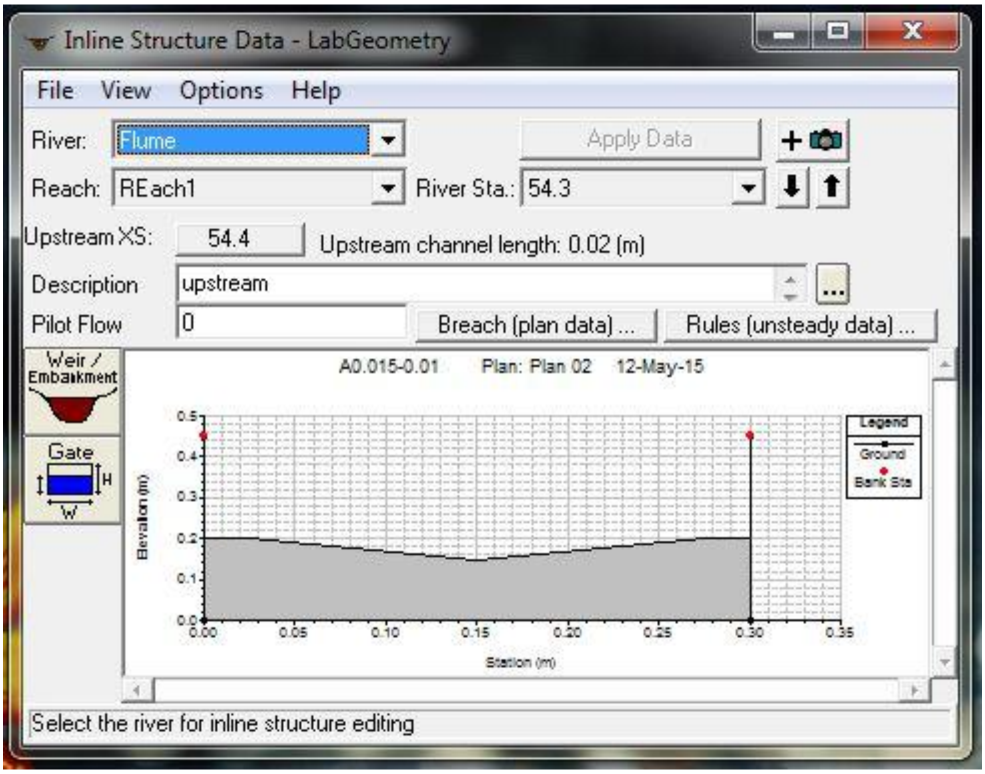
Left Bank	Right Bank
0	0.3

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Edit Station Elevation Data (m)

Figure 3.8 Cross section data at river station 100 from upstream



River: Flume

Reach: REach1

River Sta.: 54.3

Upstream XS: 54.4

Upstream channel length: 0.02 (m)

Description: upstream

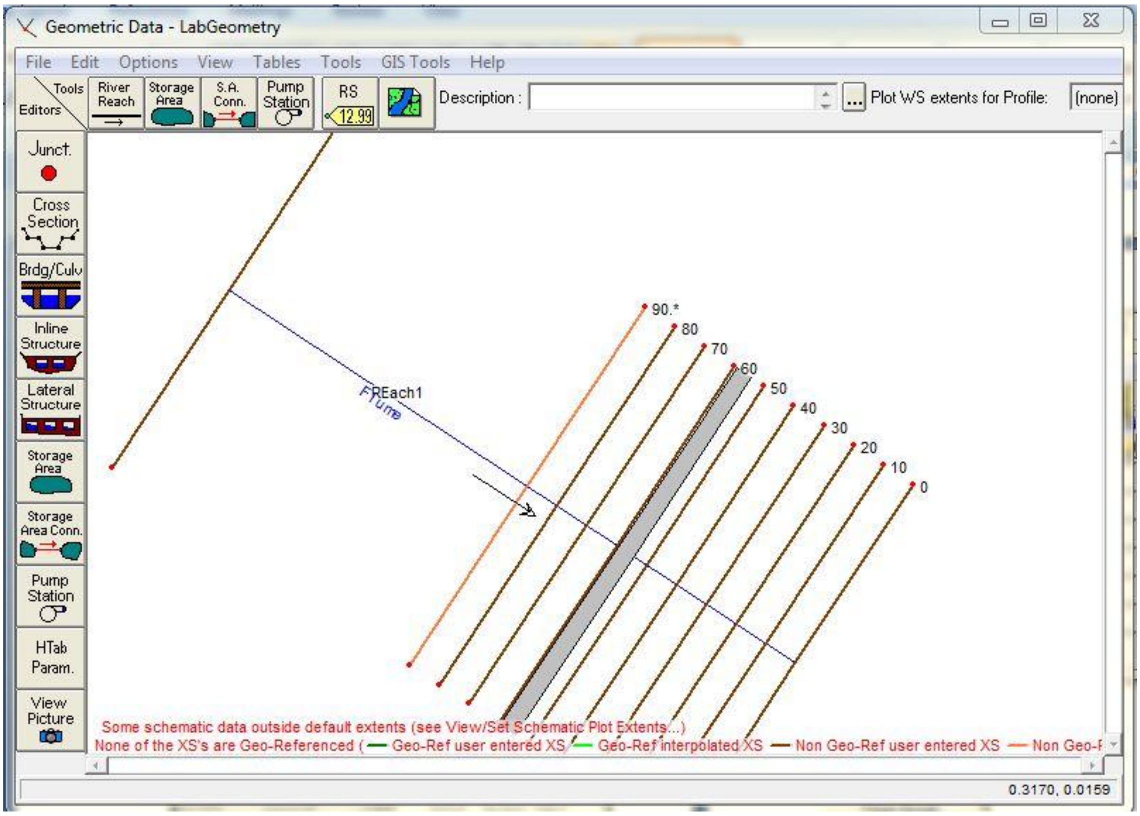
Pilot Flow: 0

Select the river for inline structure editing

Figure 3.9 An inline structure at station 54.3 from upstream

3.5.2 Sediment Transport

Prediction of sediment transport has been applied to the dimension of flume. Due to the size of flume that cannot carry the sediment, the dimension of the flume has been enlarged 40 times than actual dimension as shown in figure 3.10.



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None of the XS's are Geo-Referenced (— Geo-Ref user entered XS — Geo-Ref interpolated XS — Non Geo-Ref user entered XS — Non Geo-F

Figure 3.10 :Cross sectional of flume that has been enlarge to predict sediment transport

3.7 ANALYZE RESULT

After the result is obtained from computational work and laboratory experiment, the comparison has to be made. Based on comparison, the appropriate manning value is determined. From analysis, it can be determine whether HEC-RAS is applicable and reliable to be used.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter is to determine the effectiveness of HEC-RAS. Comparing the laboratory experimental and computational work by using different manning value and water surface profile. Prediction of sediment transport using seven different transport function which is Ackers-White, Toffaletti, Yang, Laursen, Meyer Peter Muller, Wilcock and England Hansen.

4.2 RESULT AND DISCUSSION

Open channel is used as an apparatus at the laboratory with inline structure of V-notch weir. The maximum discharge for open channel is 30 L/s or equivalent to 0.03m^3/s. By using different discharge of 0.005 m^3/s, 0.01 m^3/s and 0.015 m^3/s the water surface profile is obtained from the laboratory experiment. Different manning value is applied in HEC-RAS software and the graph below shows the result of laboratory experimental and computational work.

4.2.1 Experimental Laboratory Work

Table 4.1 : Laboratory experimental water surface profile at discharge 0.005 m

Length (m)	Height (m)	Length (m)	Height (m)	Length (m)	Height (m)	Length (m)	Height (m)
0	0.200	4.52	0.200	4.86	0.006	5.2	0.0028
1.0	0.200	4.54	0.200	4.88	0.006	5.3	0.0033
1.5	0.200	4.56	0.200	4.9	0.005	5.4	0.0024
2.0	0.200	4.58	0.171	4.92	0.005	5.5	0.0019
2.5	0.200	4.6	0.165	4.94	0.005	5.6	0.0017
3.0	0.200	4.62	0.155	4.96	0.005	5.7	0.0016
3.5	0.200	4.64	0.14	4.98	0.005	5.8	0.0018
4.0	0.200	4.66	0.121	5.0	0.005	5.9	0.0031
4.1	0.200	4.68	0.094	5.02	0.005	6.0	0.0026
4.2	0.200	4.7	0.071	5.04	0.005	6.5	0.0029
4.3	0.200	4.72	0.039	5.06	0.005	7.0	0.0025
4.4	0.200	4.74	0.019	5.08	0.005	7.5	0.003
4.42	0.200	4.76	0.012	5.1	0.005	8.0	0.0032
4.44	0.200	4.78	0.011	5.12	0.006	8.5	0.0039
4.46	0.200	4.8	0.009	5.14	0.004	9.0	0.0032
4.48	0.200	4.82	0.008	5.16	0.0023	9.5	0.0029
4.5	0.200	4.84	0.007	5.18	0.0026	10	0.0029

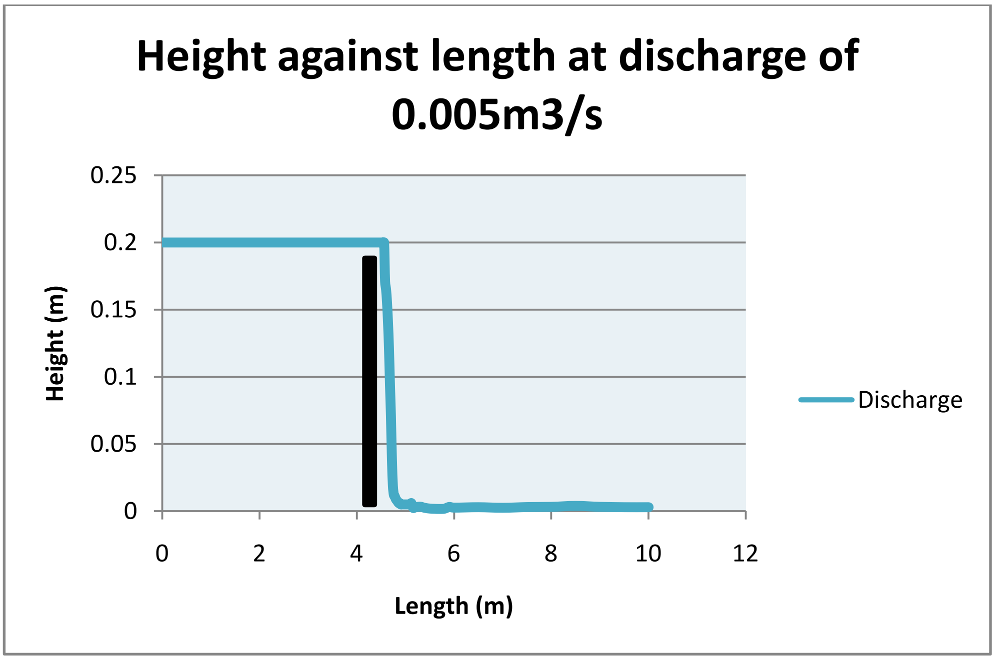

Figure 4.1: Graph of laboratory experimental at discharge 0.005 m^3/s

Table 4.2: Laboratory experimental water surface profile at discharge 0.01 m^3/s

Length (m)	Height (m)	Length (m)	Height (m)	Length (m)	Height (m)	Length (m)	Height (m)
0	0.22	4.52	0.209	4.86	0.013	5.2	0.047
1.0	0.22	4.54	0.208	4.88	0.013	5.3	0.044
1.5	0.22	4.56	0.205	4.9	0.014	5.4	0.038
2.0	0.22	4.58	0.199	4.92	0.013	5.5	0.032
2.5	0.22	4.60	0.194	4.94	0.013	5.6	0.028
3.0	0.22	4.62	0.186	4.96	0.013	5.7	0.025
3.5	0.22	4.64	0.174	4.98	0.013	5.8	0.027
4.0	0.22	4.66	0.159	5.0	0.013	5.9	0.045
4.1	0.22	4.68	0.142	5.02	0.013	6.0	0.052
4.2	0.22	4.70	0.122	5.04	0.015	6.5	0.035
4.3	0.22	4.72	0.101	5.06	0.016	7.0	0.043
4.4	0.22	4.74	0.071	5.08	0.018	7.5	0.036
4.42	0.22	4.76	0.045	5.1	0.025	8.0	0.039
4.44	0.22	4.78	0.028	5.12	0.036	8.5	0.044
4.46	0.22	4.80	0.021	5.14	0.039	9.0	0.04
4.48	0.22	4.82	0.016	5.16	0.042	9.5	0.047
4.5	0.211	4.84	0.015	5.18	0.047	10	0.044

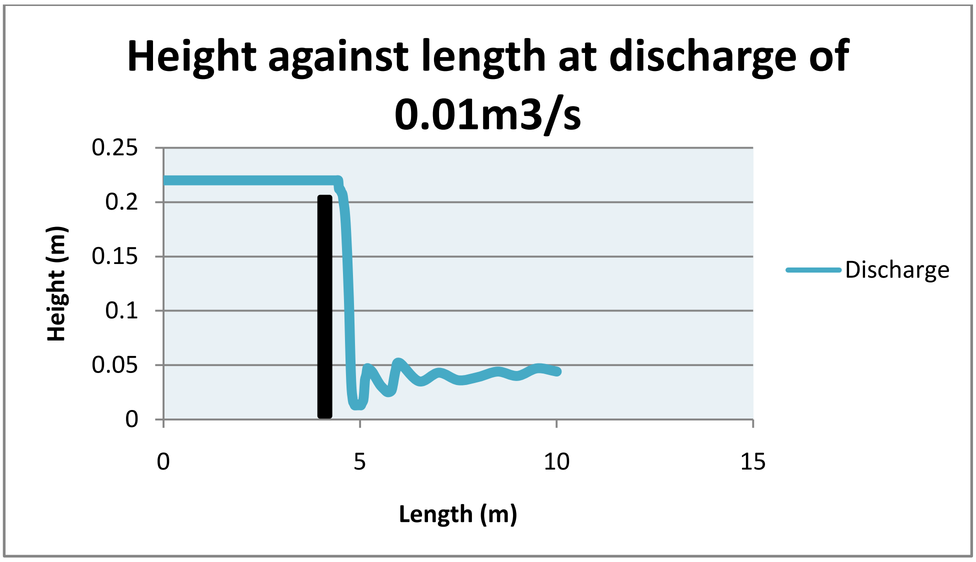

Figure 4.2: Graph of laboratory experimental at discharge 0.01 m^3/s

Table 4.3 : Laboratory experimental water surface profile at discharge 0.015 m^3/s

Length (m)	Height (m)	Length (m)	Height (m)	Length (m)	Height (m)	Length (m)	Height (m)
0	0.244	4.52	0.228	4.86	0.021	5.2	0.059
1.0	0.244	4.54	0.225	4.88	0.018	5.3	0.065
1.5	0.244	4.56	0.222	4.9	0.019	5.4	0.054
2.0	0.244	4.58	0.219	4.92	0.016	5.5	0.043
2.5	0.244	4.6	0.212	4.94	0.016	5.6	0.035
3.0	0.244	4.62	0.204	4.96	0.016	5.7	0.034
3.5	0.244	4.64	0.192	4.98	0.016	5.8	0.034
4.0	0.244	4.66	0.183	5.0	0.016	5.9	0.05
4.1	0.244	4.68	0.166	5.02	0.018	6.0	0.065
4.2	0.244	4.7	0.148	5.04	0.015	6.5	0.052
4.3	0.244	4.72	0.125	5.06	0.017	7.0	0.041
4.4	0.231	4.74	0.106	5.08	0.022	7.5	0.041
4.42	0.231	4.76	0.079	5.1	0.024	8.0	0.043
4.44	0.231	4.78	0.057	5.12	0.029	8.5	0.047
4.46	0.231	4.8	0.041	5.14	0.034	9.0	0.054
4.48	0.229	4.82	0.031	5.16	0.038	9.5	0.059
4.5	0.229	4.84	0.026	5.18	0.05	10	0.059

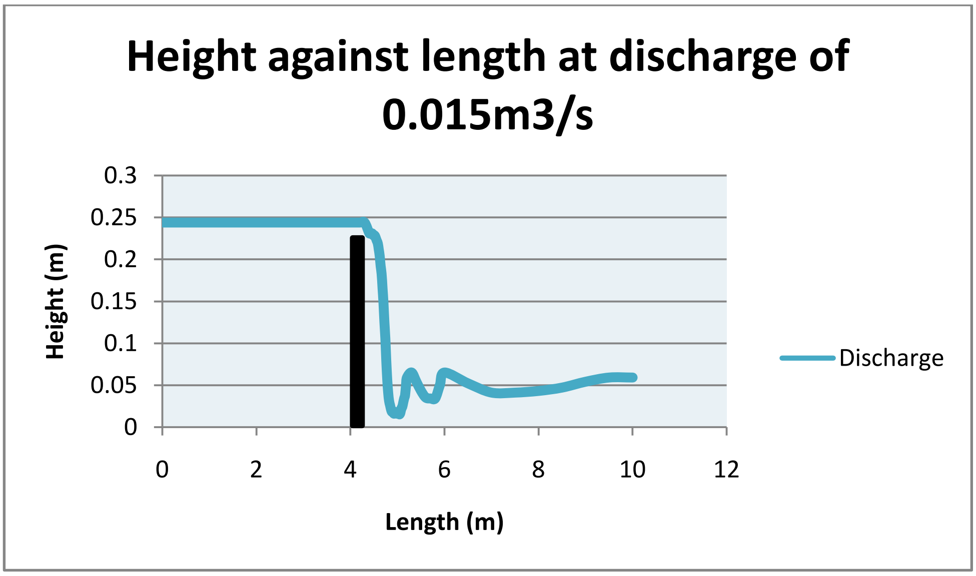

Figure 4.3: Graph of laboratory experimental at discharge 0.015 m^3/s

From figure 4.1 to 4.3 shows that the water surface profile with the different discharge of 0.005 m^3/s, 0.010 m^3/s and 0.015 m^3/s. The water surface profile at the upstream seems similar at the beginning of the station. It gives 0.200m, 0.220m and 0.244m. Different discharge gives slight different water surface profile at the upstream. Constant value until the

Unsteady pattern of graph after the weir gives the clear visualization of hydraulic jump that occurs after the weir. In the downstream, it does not give constant height which the impact of after the weir. Table 4.1 to 4.3 shows clearly the result of the water surface profile for each station data taken.

4.2.2 HEC-RAS

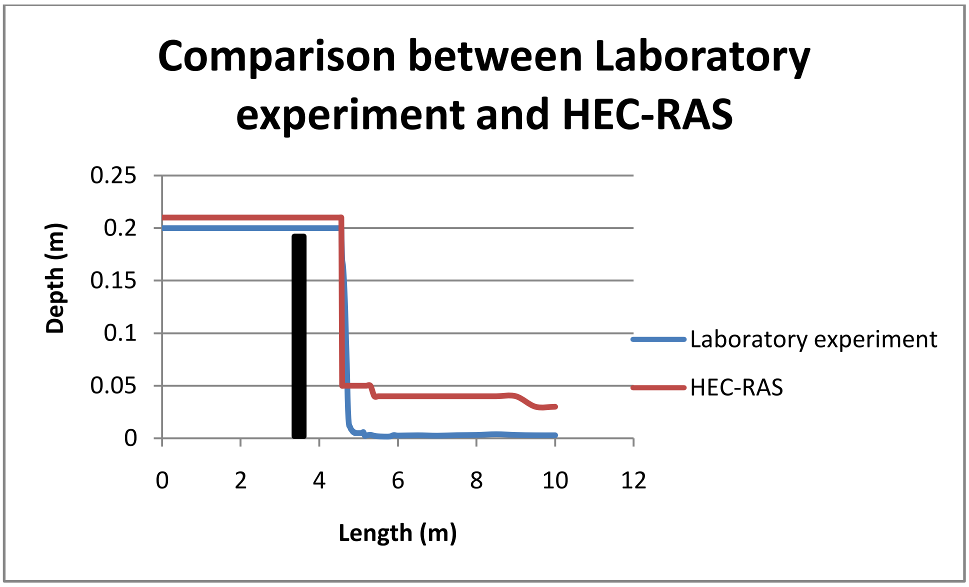

Figure 4.4: Comparison of water surface profile between HEC-RAS and Laboratory Experiment with the discharge of 0.005 m^3/s with the Manning value of 0.010 s/m$^{1/3}$

The discharge value is 0.005 m^3/s. At the upstream, the value of water surface profile is 0.2m. The data gives constant height of water surface profile until the position of V-notch weir. After the position of the V-notch weir, the height of water surface profile is different. The height is 0.171m and it gives different value at different location cause the phenomenon of hydraulic jump as shown in figure 4.4.

HEC-RAS give slight change the value of water surface profile. At the upstream, the water surface profile is 0.21m. The value gives the constant height of water surface profile until the position of the V-notch weir. After the position of V-notch weir, the height of water surface profile is different. The height is 0.005 until certain position. The value is slightly changes at each point cause by the hydraulic jump.

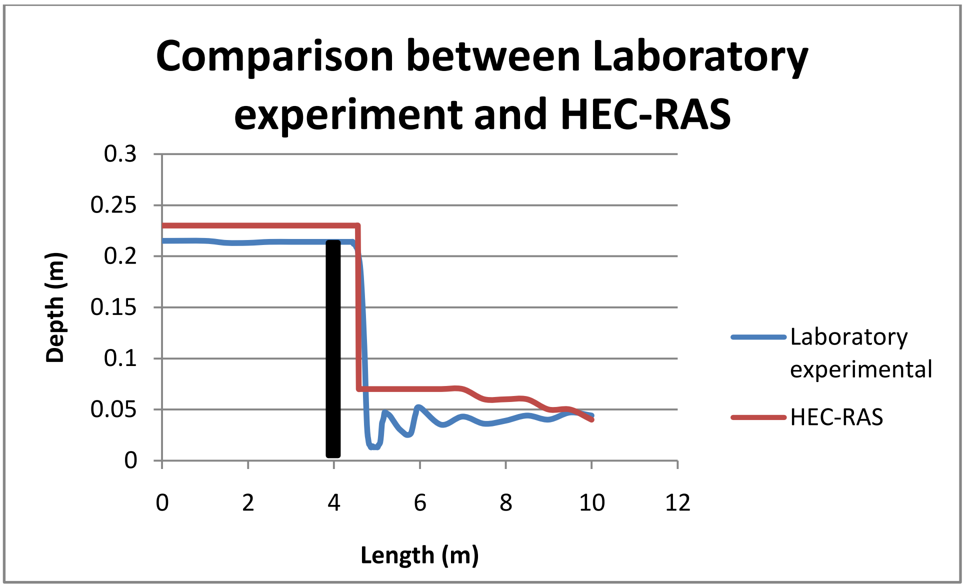

Figure 4.5: Comparison of water surface profile between HEC-RAS and Laboratory Experiment with the discharge of 0.01 m^3/s with the Manning value of 0.010 $s/m^{1/3}$

The discharge value is 0.010 m^3/s. At the upstream, the value of water surface profile is 0.22m. The data gives constant height of water surface profile until the position of V-notch weir. After the position of the V-notch weir, the height of water surface profile is different. The height is 0.199m and it gives different value at different location cause the phenomenon of hydraulic jump as shown in figure 4.5.

HEC-RAS give slight change the value of water surface profile. At the upstream, the water surface profile is 0.23m. The value gives the constant height of water surface profile until the position of the V-notch weir. After the position of V-notch weir, the height of water surface profile is different. The height is 0.007m until certain position. The value is slightly changes at each point cause by the hydraulic jump. The pattern of hydraulic jump in HEC-RAS does not same laboratory experiment. As it gives constant height for few positions unlike laboratory experiment the pattern seems like a wave.

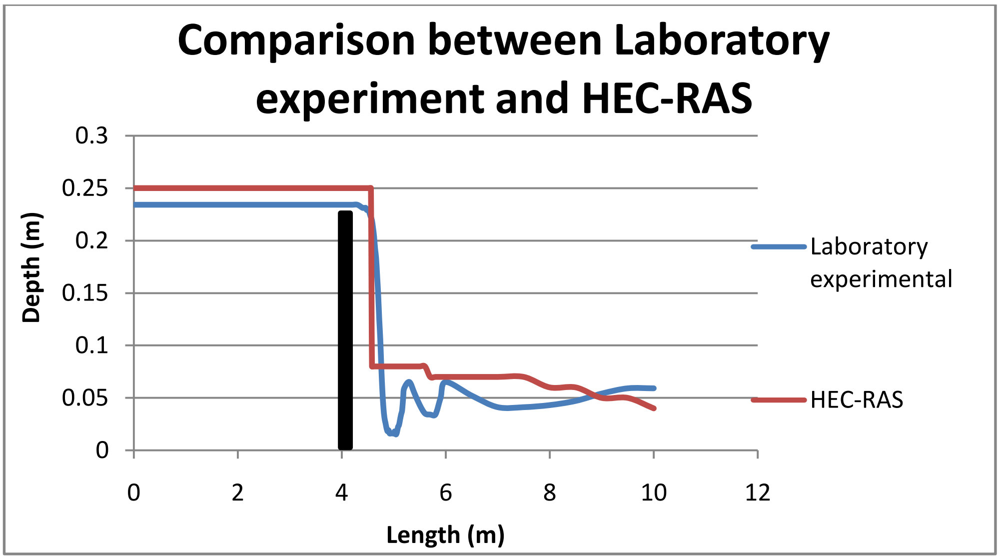

Figure 4.6: Comparison of water surface profile between HEC-RAS and Laboratory Experiment with the discharge of 0.015 m^3/s with the Manning value of 0.010 $s/m^{1/3}$

The discharge value is 0.015 $m^3/$. At the upstream, the value of water surface profile is 0.244m. The data gives constant height of water surface profile until the position of V-notch weir. After the position of the V-notch weir, the height of water surface profile is different. The height is 0.219m and it gives different value at different location cause the phenomenon of hydraulic jump as shown in figure 4.6.

HEC-RAS give slight change the value of water surface profile. At the upstream, the water surface profile is 0.25m. The value gives the constant height of water surface profile until the position of the V-notch weir. After the position of V-notch weir, the height of water surface profile is different. The height is 0.008 until certain position. The value is slightly changes at each point cause by the hydraulic jump. The pattern of hydraulic jump in HEC-RAS does not same laboratory experiment. As it gives constant height for few positions unlike laboratory experiment the pattern seems like a wave.

4.2.3 Root Mean Square Error

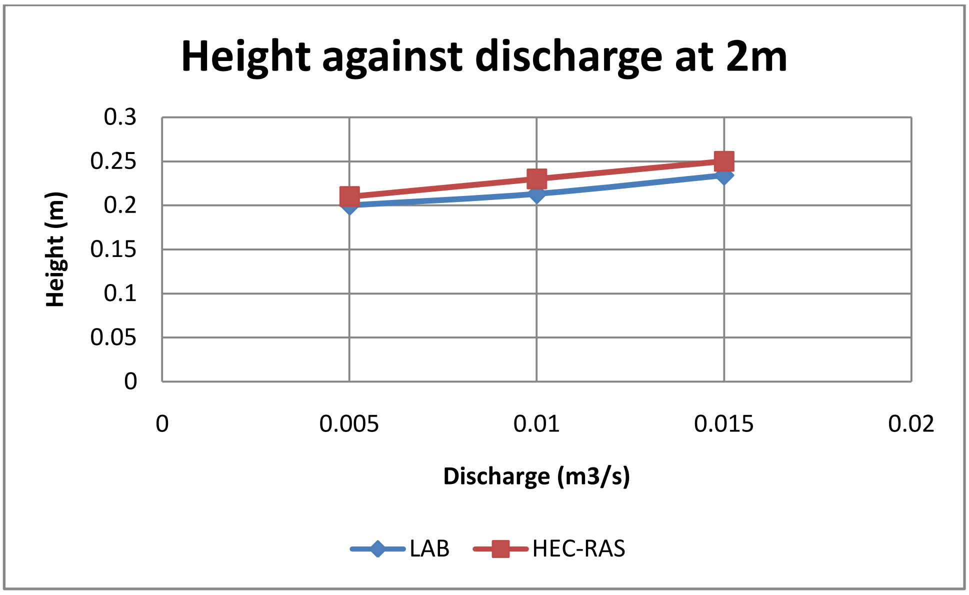

Figure 4.7: The height of the water surface profile against discharge when the Manning value is 0.009 s/m$^{1/3}$ at 2m from upstream

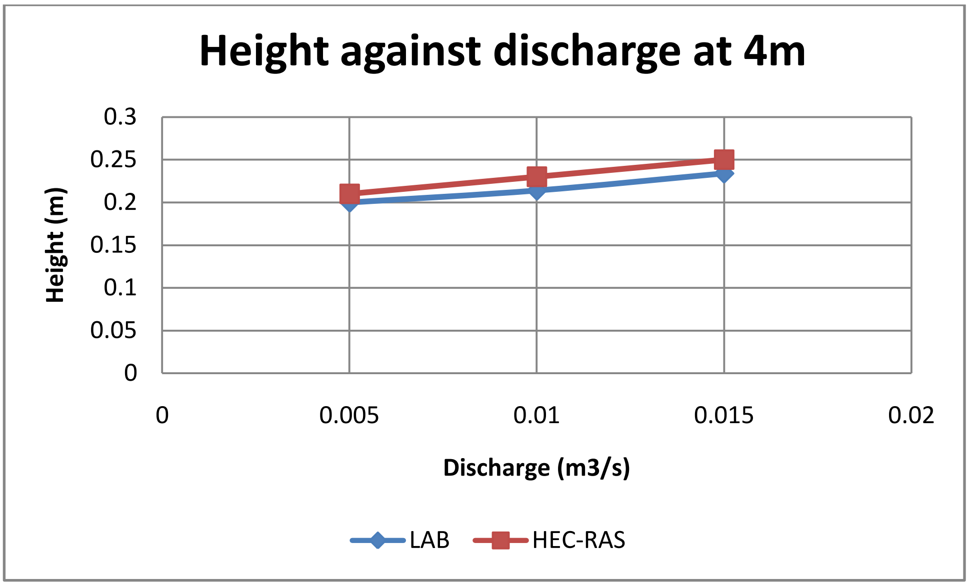

Figure 4.8: The height of the water surface profile against discharge when the Manning value is 0.009 s/m$^{1/3}$ at 4m from upstream

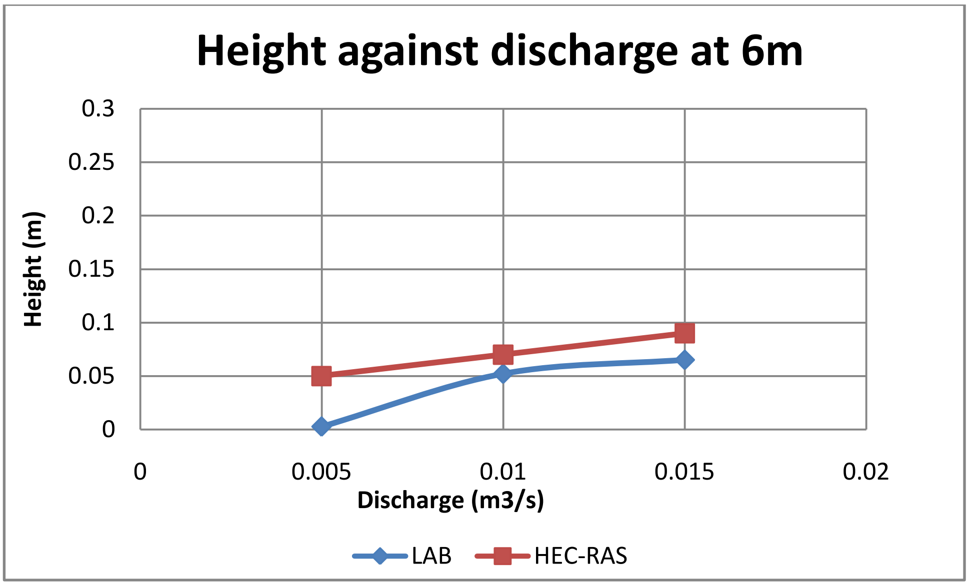

Figure 4.9: The height of the water surface profile against discharge when the Manning value is 0.009 s/m$^{1/3}$ at 6m from upstream

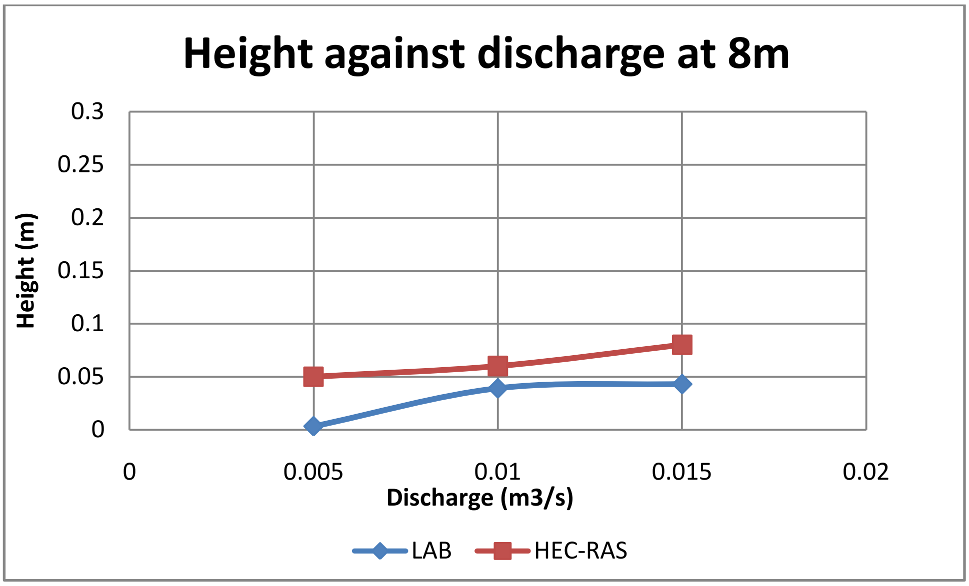

Figure 4.10: The height of the water surface profile against discharge when the Manning value is 0.009 s/m$^{1/3}$ at 8m from upstream

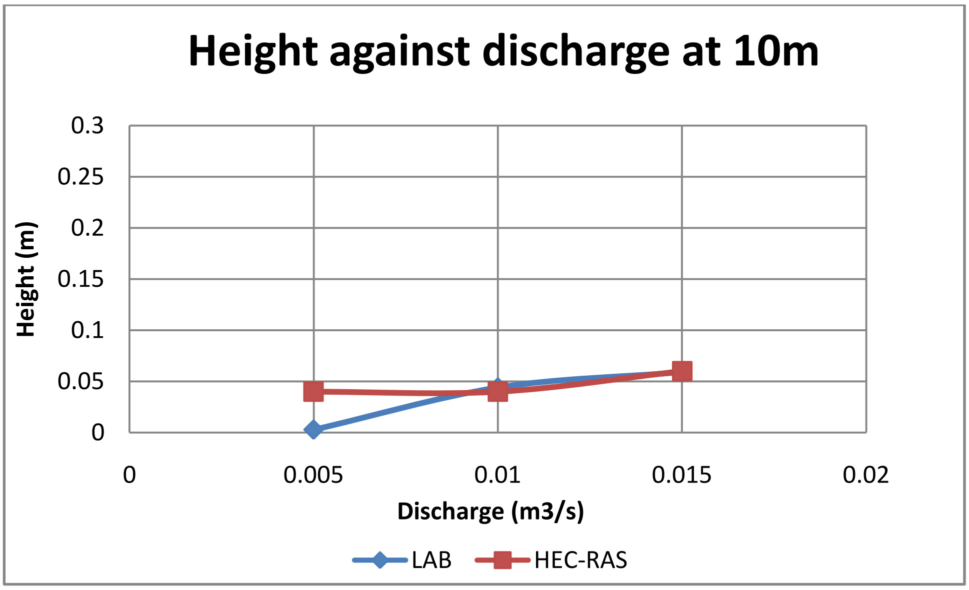

Figure 4.11: The height of the water surface profile against discharge when the Manning value is 0.009 s/m$^{1/3}$ at 10m from upstream

From the figure 4.7 to figure 4.11 shows the root mean square error for the height against the distance of 2 m, 4 m, 6 m, 8 m and 10m from the upstream of the flume. The root mean square error at 2 m is equal to 0.0216121m while the roots mean square error at 4 m is equal to 0.014283 m. For the distance of 6 m and 8 m, the root mean square error is 0.032638m and 0.036516 m. At the downstream, the root mean square error is 0.021552m. The Manning value for HEC-RAS is maintained at 0.009 s/m$^{1/3}$.

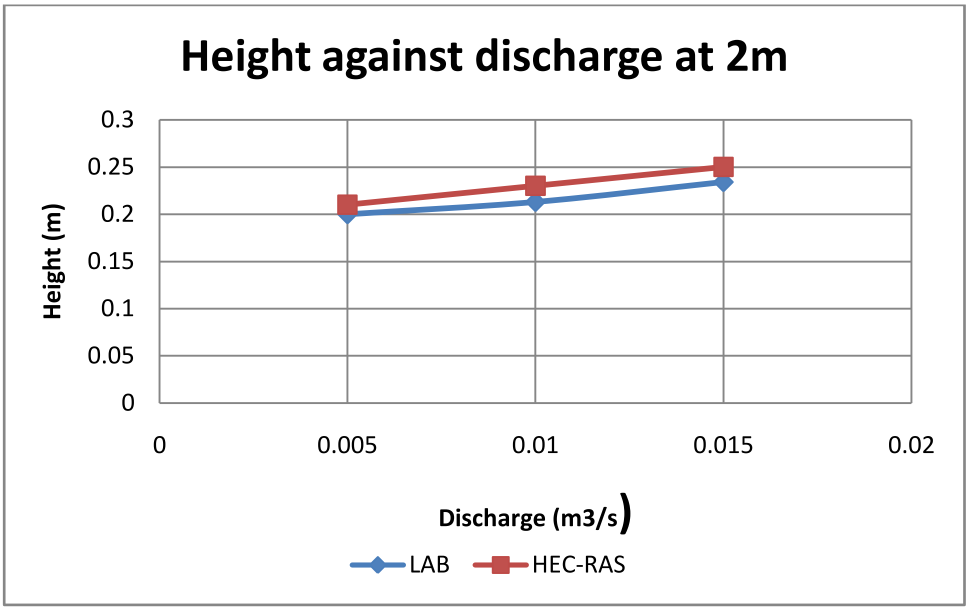

Figure 4.12: The height of the water surface profile against discharge when the Manning value is 0.010 s/m$^{1/3}$ at 2m from upstream

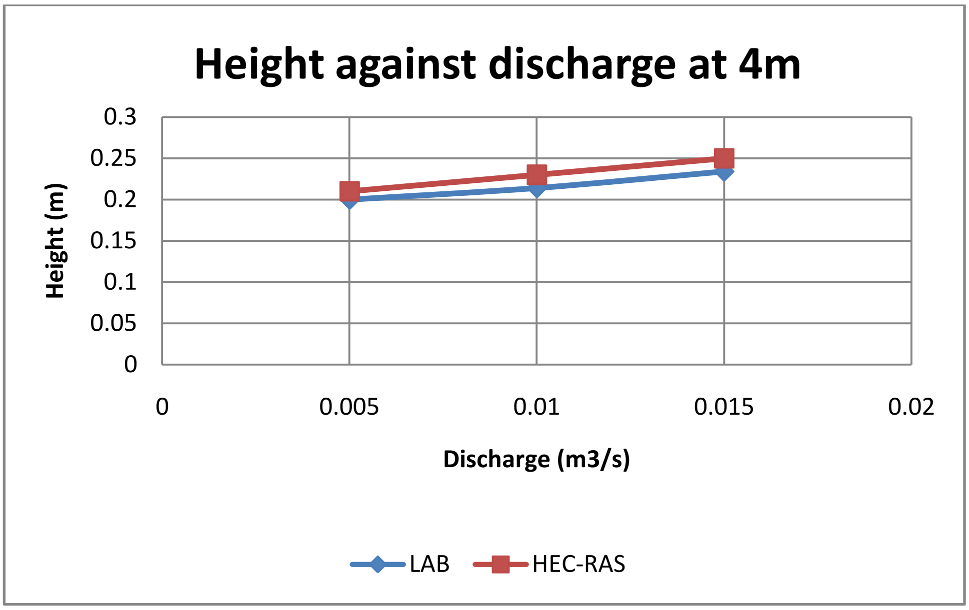

Figure 4.13: The height of the water surface profile against discharge when the Manning value is 0.010 s/m$^{1/3}$ at 4m from upstream

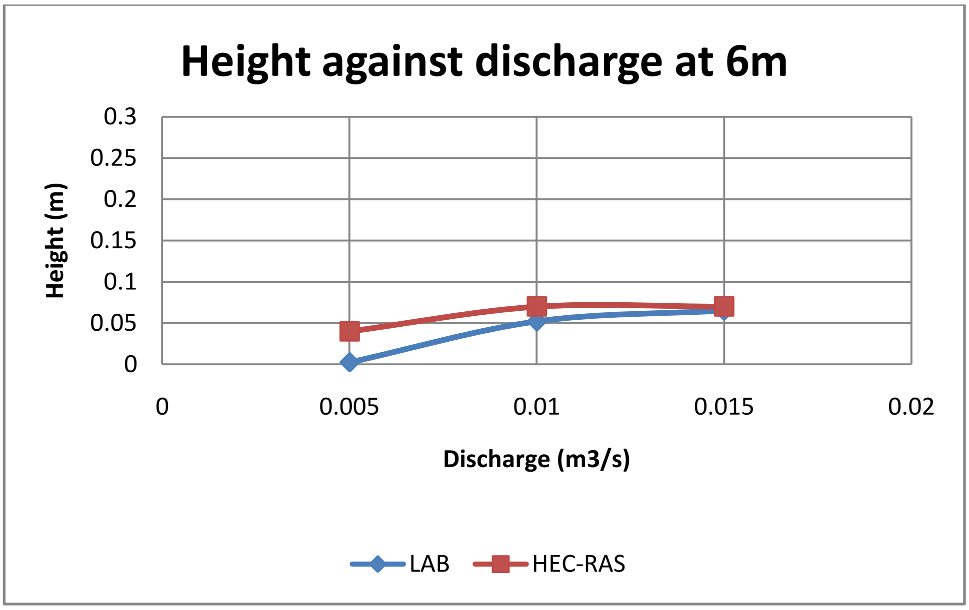

Figure 4.14: The height of the water surface profile against discharge when the Manning value is 0.010 s/m$^{1/3}$ at 6m from upstream

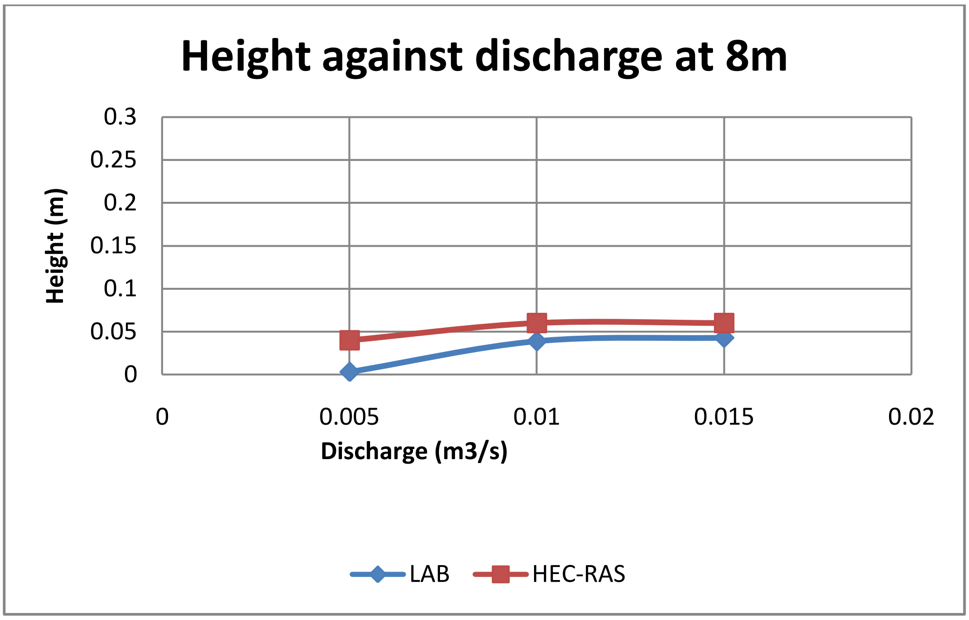

Figure 4.15: The height of the water surface profile against discharge when the Manning value is 0.010 s/m$^{1/3}$ at 8m from upstream

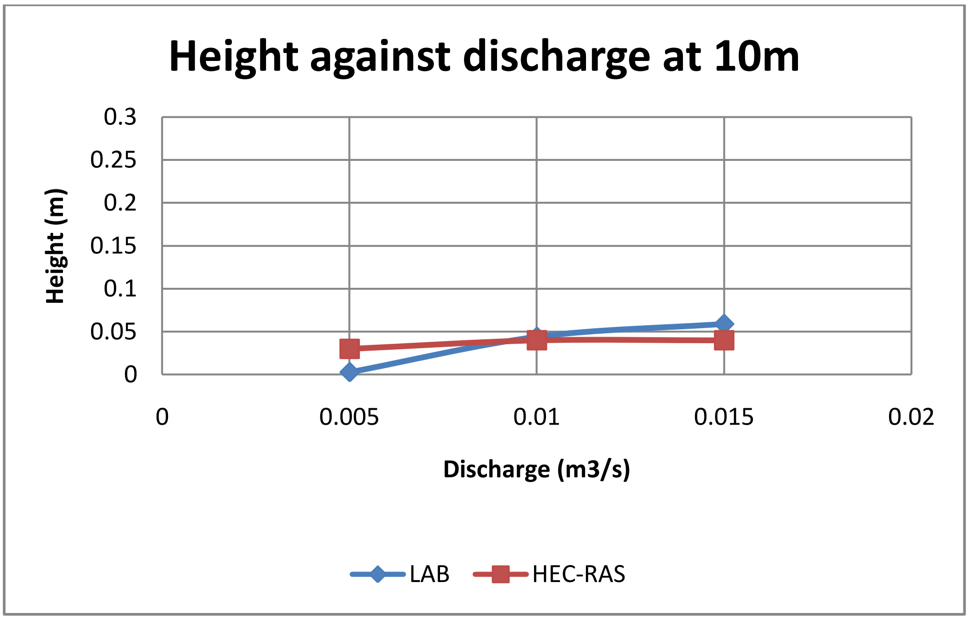

Figure 4.16: The height of the water surface profile against discharge when the Manning value is 0.010 s/m$^{1/3}$ at 10m from upstream

From the figure 4.12 to figure 4.16 shows the root mean square error for the height against the distance of 2 m, 4 m, 6 m, 8 m and 10m from the upstream of the flume. The root mean square error at 2 m is equal to 0.014663m while the roots mean square error at 4 m is equal to 0.014283 m. For the distance of 6 m and 8 m, the root mean square error is 0.024137m and 0.026358 m. At the downstream, the root mean square error is0.019248m. The Manning value for HEC-RAS is maintained at 0.010 s/m$^{1/3}$.

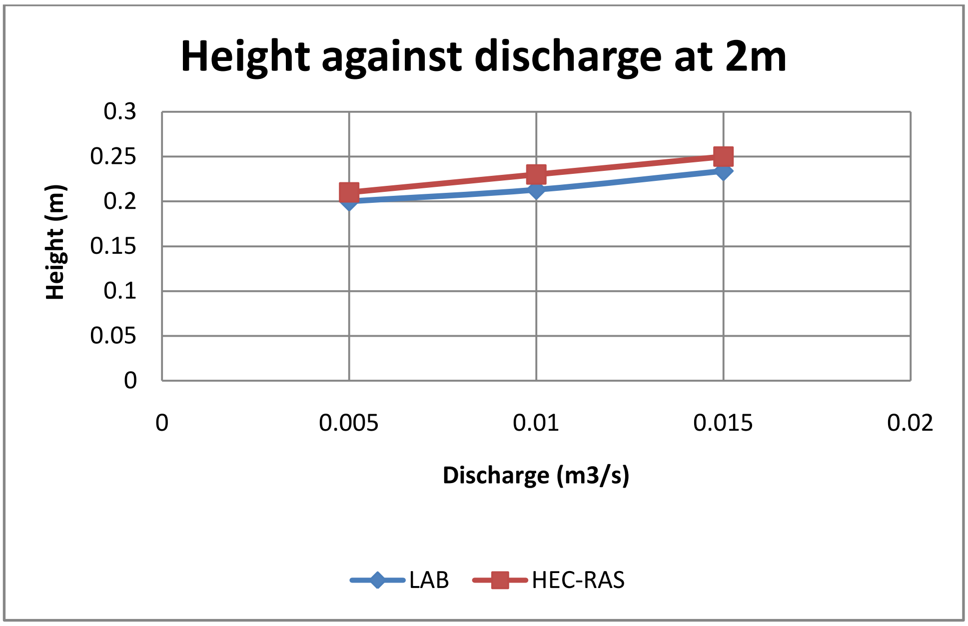

Figure 4.17: The height of the water surface profile against discharge when the Manning value is 0.011 s/m$^{1/3}$ at 2m from upstream

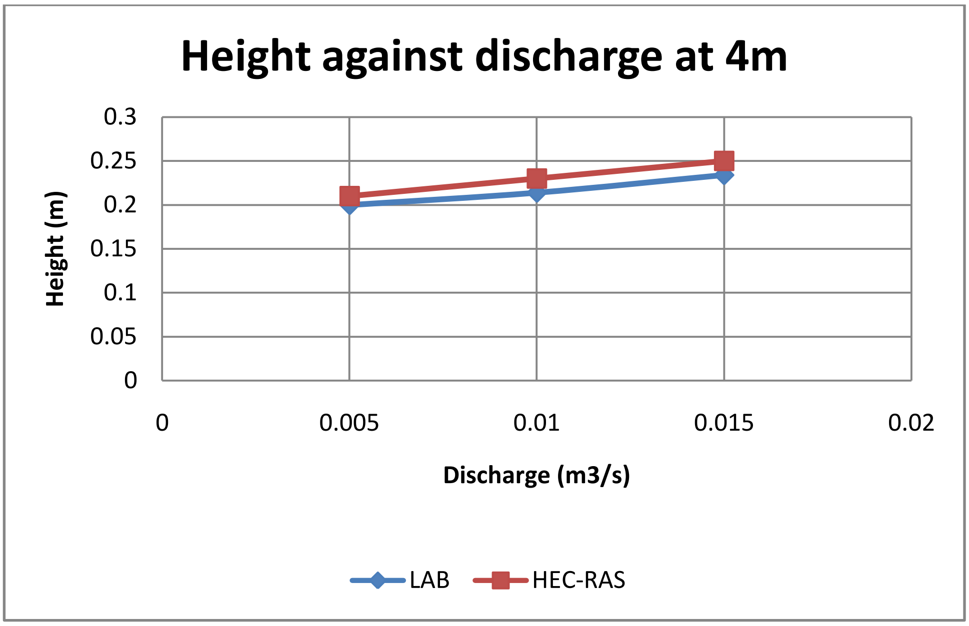

Figure 4.18: The height of the water surface profile against discharge when the Manning value is 0.011 s/m$^{1/3}$ at 4m from upstream

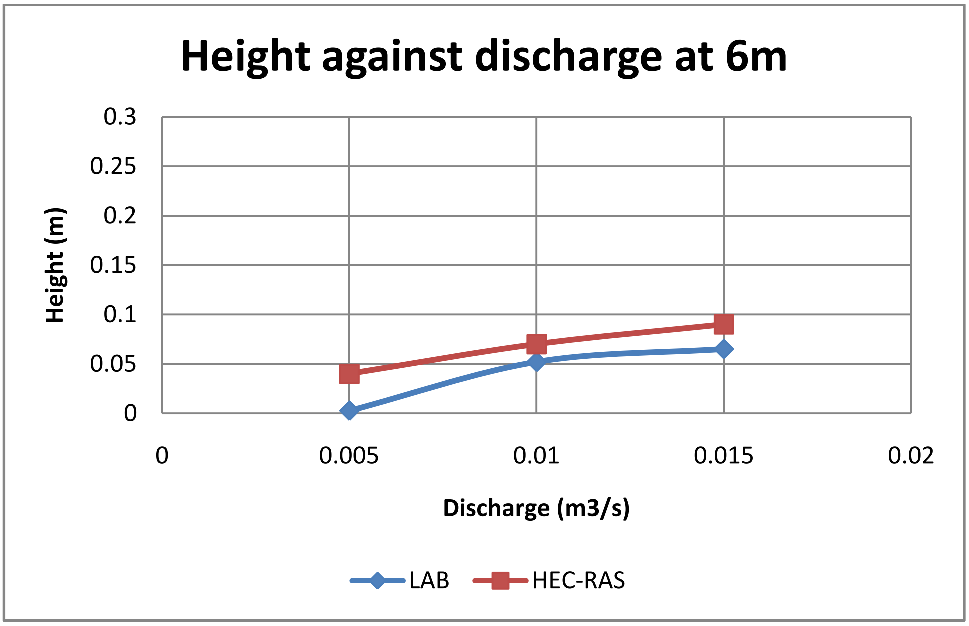

Figure 4.19: The height of the water surface profile against discharge when the Manning value is 0.011 s/m$^{1/3}$ at 6m from upstream

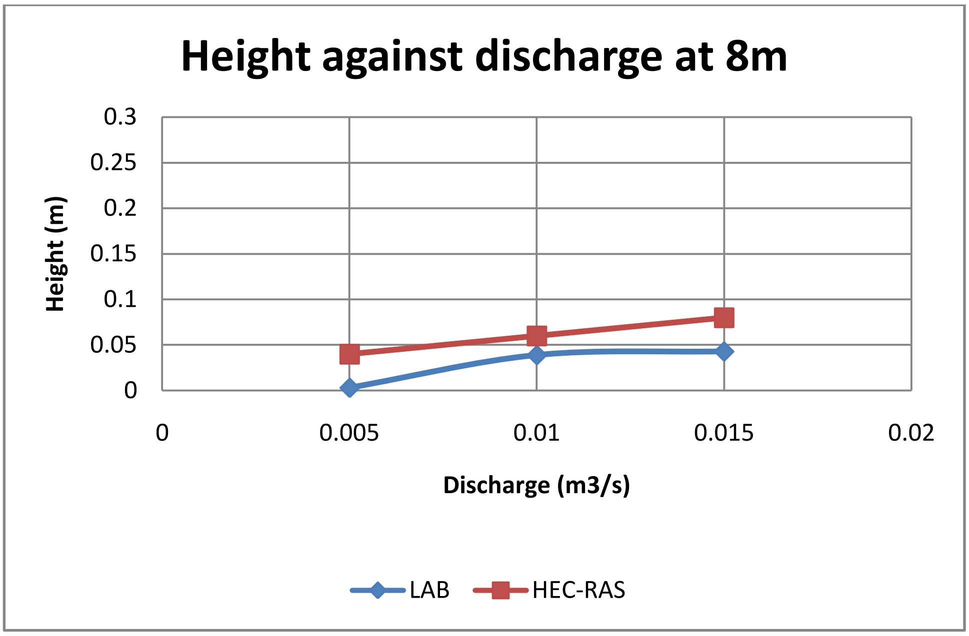

Figure 4.20: The height of the water surface profile against discharge when the Manning value is 0.011 s/m$^{1/3}$ at 8m from upstream

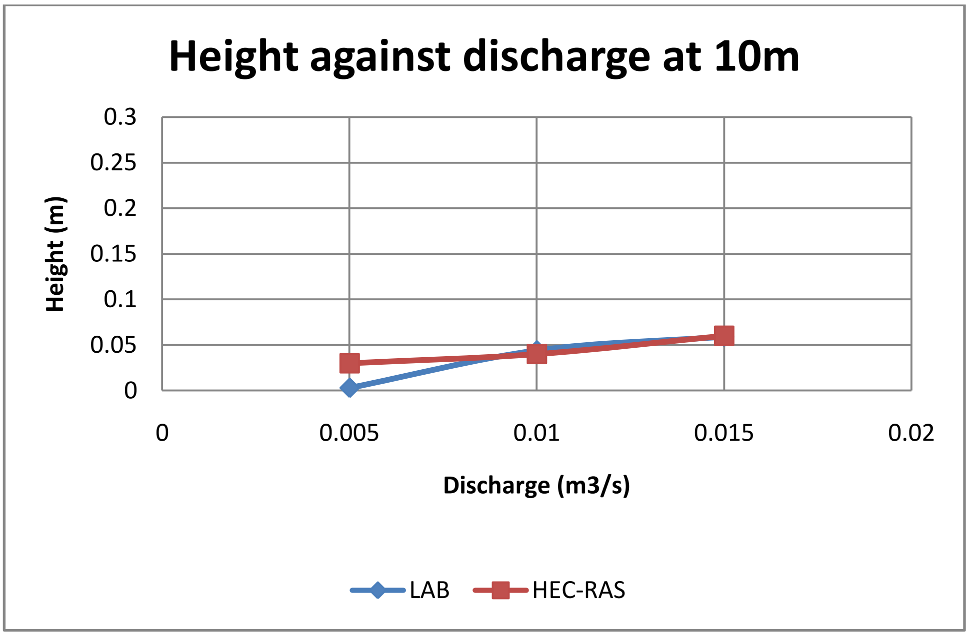

Figure 4.21: The height of the water surface profile against discharge when the Manning value is 0.011 s/m$^{1/3}$ at 10m from upstream

From the figure 4.17 to figure 4.21 shows the root mean square error for the height against the distance of 2 m, 4 m, 6 m, 8 m and 10m from the upstream of the flume. The root mean square error at 2 m is equal to 0.014663m while the roots mean square error at 4 m is equal to 0.014283 m. For the distance of 6 m and 8 m, the root mean square error is 0.027975m and 0.032477 m. At the downstream, the root mean square error is0.015826 m. The Manning value for HEC-RAS is maintained at 0.011 s/m$^{1/3}$.

Table 4.3: Comparison of RMSE between Manning value and the height of water surface profile at 2m, 4m, 6m and 8m

Manning value / Distance (m)	0.009 s/m$^{1/3}$	0.010 s/m$^{1/3}$	0.011 s/m$^{1/3}$
2	0.216121	0.014663	0.014663
4	0.014283	0.014283	0.014283
6	0.032638	0.024137	0.027975
8	0.036516	0.026358	0.032477
10	0.021552	0.019248	0.015826

In the table 4.3 shows the summary of root mean square error (RMSE) that occurs at five different points which is 2m, 4m, 6m, 8m and the downstream. By using three different manning value of 0.009 s/m$^{1/3}$, 0.010 s/m$^{1/3}$ and 0.011 s/m$^{1/3}$. Comparison between laboratory experimental and computation shows the difference of value RMSE. According to this both of result, the appropriate of manning value is determined. Manning value of 0.010 s/m$^{1/3}$ has the lowest value of RMSE. Therefore, the appropriate manning value for this study is 0.010 s/m$^{1/3}$.

4.3 SEDIMENT TRANSPORT

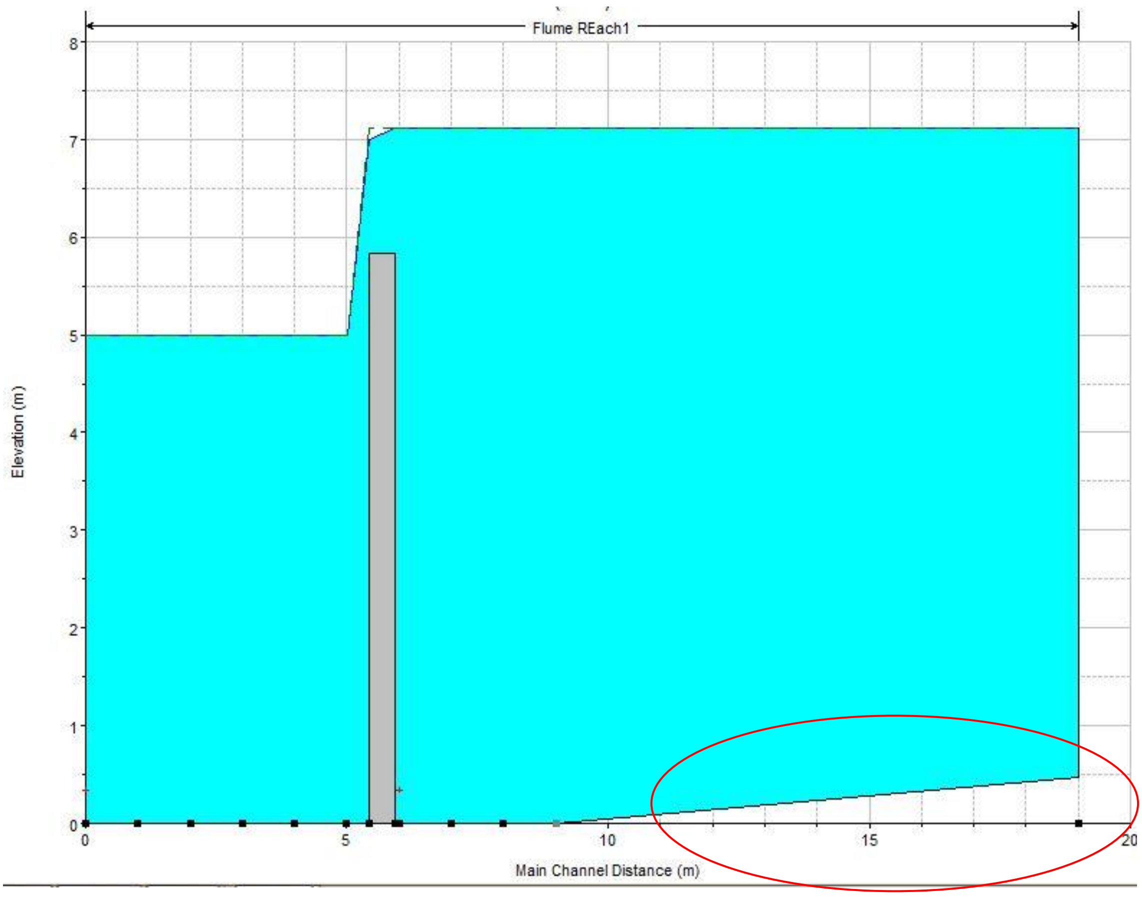

Figure 4.22: Sediment transport occurs at the upstream

Sediment transport is handling on computational work only. Due to lack of equipment, it cannot be carried out in the experiment laboratory. HEC-RAS is used to analyze the sediment transport for this research study based on a river with the dimension similar to flume. In the dimension of this river is increase 40 times of the flume so that there is significant sediment transport and the Manning value is change to similar river bed Manning value of 0.030 s/m$^{1/3}$. By using specific gravity 2.65, density of sand 1489 kg/m^3, density of silt 1041 kg/m^3 and density of clay 480 kg/m^3. Erosion occurs at the depth of 0.47m as shown in figure 4.22. It occurs at 11m from the upstream as the distance is longer that actual flume dimension.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

From this study, the comparison between laboratory experimental and computational work is made. HEC-RAS helps the engineers to understand better in using this software. This research has achieved four goals which is to determine the water surface profile from the upstream to the downstream of the flume. The results from laboratory experimental is compared with the result from HEC-RAS. HEC-RAS has proved that it is still reliable to use even it gives slight different result from manual calculation. Three different manning value is used to achieved the goal which is 0.009 $s/m^{1/3}$, 0.010 $s/m^{1/3}$ and 0.011 $s/m^{1/3}$. From the result of HEC-RAS, it shows that 0.010 $s/m^{1/3}$ is the most lowest of root mean square error (RMSE) among the three. Therefore, the most appropriate manning value in this study is that 0.010 $s/m^{1/3}$. The prediction of sediment transport is occurred at the upstream of the flume after increasing the dimensions of the flume 40 times from the actual dimension of the flume.

Sediment transport occurs at the upstream of the structure. It gives 0.47m of sediment transport by using Meyer Peter Muller (MPM) transport function. MPM is developed in 1948. It can carry bed load which size range of 0.40mm – 30.00mm and it can developed from flume data. The function was calibrated for coarse sand and gravel.

5.2 RECOMMENDATIONS

Based on this study, there are few recommendations that need to be highlighted. First, in conducting experimental laboratory, the position of the V-notch weir must be properly attached to the flume. If it is not, the leaking of the water will flow at the bottom of the weir. Therefore, it will give inaccurate result of the water surface profile. The location of the weir must be determined in order to get the value water surface profile from the upstream.

Secondly, in using HEC-RAS, select the System International (SI unit) to generate the data. Improper selecting will give inappropriate result. SI unit set the metric system to generate the data in the software. The standardization in using the unit will give the proper result.

Thirdly, in the prediction of sediment transport, the dimension of the real dimension of open channel cannot give the results of sediment transport. Therefore, increasing the dimensions will give the result of sediment transport.

In a nutshell, HEC-RAS is reliable to use. Before generate the data, study the background of HEC-RAS and what condition it can be used.

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APPENDIX A1

Table 6.1: Comparison between experimental data and HEC-RAS at 0.005m^3/s

Length (m)	Height (m)	HEC-RAS (m)	Length (m)	Height (m)	HEC-RAS (m)
0	0.2	0.21	4.86	0.006	0.05
1	0.2	0.21	4.88	0.006	0.05
1.5	0.2	0.21	4.9	0.005	0.05
2.0	0.2	0.21	4.92	0.005	0.05
2.5	0.2	0.21	4.94	0.005	0.05
3.0	0.2	0.21	4.96	0.005	0.05
3.5	0.2	0.21	4.98	0.005	0.05
4.0	0.2	0.21	5.0	0.005	0.05
4.1	0.2	0.21	5.02	0.005	0.05
4.2	0.2	0.21	5.04	0.005	0.05
4.3	0.2	0.21	5.06	0.005	0.05
4.4	0.2	0.21	5.08	0.005	0.05
4.42	0.2	0.21	5.1	0.005	0.05
4.44	0.2	0.21	5.12	0.006	0.05
4.46	0.2	0.21	5.14	0.004	0.05
4.48	0.2	0.21	5.16	0.0023	0.05
4.5	0.2	0.21	5.18	0.0026	0.05
4.52	0.2	0.21	5.2	0.0028	0.05
4.54	0.2	0.21	5.3	0.0033	0.05
4.56	0.2	0.21	5.4	0.0024	0.04
4.58	0.171	0.05	5.5	0.0019	0.04
4.6	0.165	0.05	5.6	0.0017	0.04
4.62	0.155	0.05	5.7	0.0016	0.04
4.64	0.14	0.05	5.8	0.0018	0.04
4.66	0.121	0.05	5.9	0.0031	0.04
4.68	0.094	0.05	6.0	0.0026	0.04
4.7	0.071	0.05	6.5	0.0029	0.04
4.72	0.039	0.05	7.0	0.0025	0.04
4.74	0.019	0.05	7.5	0.003	0.04
4.76	0.012	0.05	8.0	0.0032	0.04
4.78	0.011	0.05	8.5	0.0039	0.04
4.8	0.009	0.05	9.0	0.0032	0.04
4.82	0.008	0.05	9.5	0.0029	0.03
4.84	0.007	0.05	10.0	0.0029	0.03

Table 6.2: Comparison between experimental data and HEC-RAS at 0.010m^3/s

Length (m)	Height (m)	HEC-RAS (m)	Length (m)	Height (m)	HEC-RAS (m)
0	0.22	0.23	4.86	0.013	0.07
1	0.22	0.23	4.88	0.013	0.07
1.5	0.22	0.23	4.9	0.014	0.07
2	0.22	0.23	4.92	0.013	0.07
2.5	0.22	0.23	4.94	0.013	0.07
3	0.22	0.23	4.96	0.013	0.07
3.5	0.22	0.23	4.98	0.013	0.07
4	0.22	0.23	5	0.013	0.07
4.1	0.22	0.23	5.02	0.013	0.07
4.2	0.22	0.23	5.04	0.015	0.07
4.3	0.22	0.23	5.06	0.016	0.07
4.4	0.22	0.23	5.08	0.018	0.07
4.42	0.22	0.23	5.1	0.025	0.07
4.44	0.22	0.23	5.12	0.036	0.07
4.46	0.212	0.23	5.14	0.039	0.07
4.48	0.212	0.23	5.16	0.042	0.07
4.5	0.211	0.23	5.18	0.047	0.07
4.52	0.209	0.23	5.2	0.047	0.07
4.54	0.208	0.23	5.3	0.044	0.07
4.56	0.205	0.23	5.4	0.038	0.07
4.58	0.199	0.07	5.5	0.032	0.07
4.6	0.194	0.07	5.6	0.028	0.07
4.62	0.186	0.07	5.7	0.025	0.07
4.64	0.174	0.07	5.8	0.027	0.07
4.66	0.159	0.07	5.9	0.045	0.07
4.68	0.142	0.07	6	0.052	0.07
4.7	0.122	0.07	6.5	0.035	0.07
4.72	0.101	0.07	7	0.043	0.07
4.74	0.071	0.07	7.5	0.036	0.06
4.76	0.045	0.07	8	0.039	0.06
4.78	0.028	0.07	8.5	0.044	0.06
4.8	0.021	0.07	9	0.04	0.05
4.82	0.016	0.07	9.5	0.047	0.05
4.84	0.015	0.07	10	0.044	0.04

Table 6.3: Comparison between experimental data and HEC-RAS at 0.015m^3/s

Length (m)	Height (m)	HEC-RAS (m)	Length (m)	Height (m)	HEC-RAS (m)
0	0.244	0.25	4.86	0.021	0.08
1	0.244	0.25	4.88	0.018	0.08
1.5	0.244	0.25	4.9	0.019	0.08
2	0.244	0.25	4.92	0.016	0.08
2.5	0.244	0.25	4.94	0.016	0.08
3	0.244	0.25	4.96	0.016	0.08
3.5	0.244	0.25	4.98	0.016	0.08
4	0.244	0.25	5	0.016	0.08
4.1	0.244	0.25	5.02	0.018	0.08
4.2	0.244	0.25	5.04	0.015	0.08
4.3	0.244	0.25	5.06	0.017	0.08
4.4	0.231	0.25	5.08	0.022	0.08
4.42	0.231	0.25	5.1	0.024	0.08
4.44	0.231	0.25	5.12	0.029	0.08
4.46	0.231	0.25	5.14	0.034	0.08
4.48	0.229	0.25	5.16	0.038	0.08
4.5	0.229	0.25	5.18	0.05	0.08
4.52	0.228	0.25	5.2	0.059	0.08
4.54	0.225	0.25	5.3	0.065	0.08
4.56	0.222	0.25	5.4	0.054	0.08
4.58	0.219	0.08	5.5	0.043	0.08
4.6	0.212	0.08	5.6	0.035	0.08
4.62	0.204	0.08	5.7	0.034	0.07
4.64	0.192	0.08	5.8	0.034	0.07
4.66	0.183	0.08	5.9	0.05	0.07
4.68	0.166	0.08	6	0.065	0.07
4.7	0.148	0.08	6.5	0.052	0.07
4.72	0.125	0.08	7	0.041	0.07
4.74	0.106	0.08	7.5	0.041	0.07
4.76	0.079	0.08	8	0.043	0.06
4.78	0.057	0.08	8.5	0.047	0.06
4.8	0.041	0.08	9	0.054	0.05
4.82	0.031	0.08	9.5	0.059	0.05
4.84	0.026	0.08	10	0.059	0.04