CALIBRATING A HE [illegible] ESTED WEIR AS INLINE STRUCTURE USING OPEN CHANNEL FLUME FLOW METHOD AND ITS APPLICATION FOR SEDIMENT TRANSPORT

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ABSTRACT

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 when using HEC-RAS. Confusion may arise among the engineers whether this software is reliable and appropriate on certain condition. The objective of this study is to compare the results of the water surface profile between HEC-RAS and the experiments in the laboratory. The other main objective of this study is to obtain the appropriate manning value of the open channel in the laboratory. The procedure and the method to collect data with consideration of reliability and feasibility will also be described. The research can be divided into four phases, which are laboratory work, manning value specification, computational work, and analyze results. HEC-RAS software will determine the upstream and downstream water surface profile with different range of discharge and manning value. Once the HEC-RAS and lab experimental result is obtained, comparison is made. Calibration between laboratory experimental result and HEC-RAS's result is to determine whether this software is reliable to be used on certain condition. Prediction of the sediment transport pattern in the upstream and the downstream part of broad crested weir is determined. The duration of HEC-RAS and lab experimental required 2 semesters. From the result and discussion, the appropriate Manning value is 0.009 $s/m^{1/3}$ with the root mean square error of 0.0165 m at the distance of 2 m from upstream and the sediment transport occurs at the upstream. This research has shows that the HEC-RAS is still reliable software on these conditions.

ABSTRAK

HEC-RAS telah digunakan selama 20 tahun dan sehingga hari ini HEC-RAS masih menghadapi masalah rangsangan saluran curam atau aliran. Selain itu, banyak pengguna dari seluruh dunia berpendapat bahawa ketidakstabilan dalam 'numerical unsteady flow' jika mengguna HEC-RAS. Kekeliruan mungkin timbul di kalangan jurutera sama ada perisian ini boleh dipercayai dan sesuai pada keadaan tertentu. Objektif kajian ini adalah untuk membandingkan keputusan profil permukaan air di antara HEC-RAS dan eksperimen di makmal. Objektif utama yang lain dalam penyelidikan ini adalah untuk mendapatkan nilai keanggotaan sesuai saluran di makmal. Prosedur dan kaedah untuk mengumpul data dengan pertimbangan kebolehpercayaan dan kemungkinan juga akan diterangkan. Kajian ini boleh dibahagikan kepada empat fasa, iaitu kerja-kerja makmal, spesifikasi nilai pengendalian, kerja pengiraan, dan menganalisis keputusan. Perisian HEC-RAS akan menentukan profil permukaan air hulu dan hiliran dengan pelbagai jenis pelepasan dan nilai pengendalian. Setelah hasil eksperimen HEC-RAS dan makmal diperolehi, perbandingan dibuat. Penentukuran antara hasil ujikaji makmal dan hasil HEC-RAS untuk menentukan sama ada perisian ini boleh dipercayai untuk digunakan pada keadaan tertentu. Ramalan corak pengangkutan sedimen di huluan dan hiliran sebahagian daripada 'broad crested weir'. Tempoh HEC-RAS dan makmal uji kaji yang diperlukan 2 semester. Dari hasil dan perbincangan, nilai Manning yang sesuai adalah 0.009 $s/m^{1/3}$ dengan punca min ralat kuasa dua adalah 0.0165 m pada jarak 2 m dari hulu dan pengangkutan sedimen berlaku di hulu. Kajian ini mempunyai menunjukkan bahawa HEC-RAS masih perisian dipercayai kepada keadaan ini.

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LIST OF SYMBOLS

A	Area
A	Adverse slope
C	Critical slope
E_2	Energy at section 2
E_1	Energy at section 1
ΔE	Difference of energy between section 1 and section 2
g	Gravitational force
Fr_1	Froude number at section 1
H	Horizontal slope
Lj	Length of jump
M	Mild slope
n	Number of sample
n	Manning value
Q	Flowrate
R	Hydraulic radius
s	Steep slope
t	Time
v	Velocity
x	Width
X	Modelled value
y_2	Depth at section 2
y_1	Depth at section 1
S_o	Bed slope

S_f	Friction slope

LIST OF ABBREVIATIONS

FEM	Finite element method
H	Horizontal
HEC-RAS	Hydraulic engineering centre – river analysis system
MOC	Method of characteristic
RMSE	Root mean square error
V	Vertical
1-D	One dimensional
2-D	Two dimensional
3-D	Three dimensional

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

HEC-RAS is known as Hydraulic Engineering Centre – River Analysis System and was developed by the US department of defence, army corps of engineers and was created in 1995. The HEC-RAS system contain four one –dimensional river analysis component which are steady flow water surface profile computation, unsteady flow simulation, movable boundary sediment transport computation and water quality analysis (Warner et.al., 2010). As Thomas (2007) state despite the widespread use of HEC-RAS, even seasoned engineers can fall victim to some common modelling mistakes using HEC-RAS. Ever since HEC-RAS was introduced in 1995, this program have constantly upgraded with new features and also repaired problems, the latest version is the 4.1.0. However, HEC-RAS users may find numerical unstable problems during the analysis, especially the steep of the channel must not be greater than 10 %.

1.2 BACKGROUND OF STUDY

According to Chow (1959), if the main channel slope is steeper than 5 H:1 V, the Manning value of that main channel is more than 1. Manning value played an important part 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 modelling tools, such as HEC-RAS program, could not be used accurately to determine the flow. Besides that, laboratory experiment is carried out to compare the result of the HEC-RAS program. Implementation 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 modelling and might not be able to work well in multi-dimensioning modelling. In a recent study, HEC-RAS 4.1.0 is used to stimulate Tawau design spillway design and found out that the result shown in the hydraulic jump and the water profile height is not the same as in the manual calculation. Thus, it created confusion whether HEC-RAS is reliable and continue to use it. Apart from that, HEC-RAS 3.1.3 is an older version is used to stimulate the similar design of the spillway and found that hydraulic jump occur in between channel and stilling basin. From there, further research found that the channel slope with greater than 10% is not is not suited to use in designing.

In this study, a range of discharge and manning number applied to HEC-RAS software and compare with lab experiments to determine whether HEC-RAS is reliable and help engineer in the future for use of this software.

1.4 OBJECTIVES

The objectives of this research are:

- To determine the water surface profile height at upstream and downstream of broad crested weir by using different discharge and manning value.
- To compare the results of the water surface profile height between HEC-RAS and laboratory experimental.
- To obtain the appropriate manning value.
- To predict the sediment transport pattern in the upstream and the downstream part of broad crested weir.

1.5 SCOPE OF STUDY

From this study, HEC-RAS software will determine the upstream and downstream water surface profile with different range of discharge and manning value. Once the HEC-RAS and lab experimental result is obtained, comparison is made. Besides that, HEC-RAS software will also determine the sediment transport in upstream and downstream parts of broad crested weir in this research. The duration of HEC-RAS and lab experimental required 2 semesters.

1.6 RESEARCH 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 and more people using it. The comparison between HEC-RAS and laboratory experiment is used to determine the accuracy of the manning value provided by Manning (Chow 1959) In order to avoid false result shown by the HEC-RAS, calibration between laboratory experimental result and HEC-RAS's result to determine whether this software is reliable to be used on certain condition. HEC-RAS also provide the other utilities such as one dimensional Quasi-Unsteady Sediment Transport and to determine whether there is sediment transport in the inline structure.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the literature review will be divided into two parts, which is the open channel (flume) hydraulic and HEC-RAS. Hence, in the first part, Manning value, flume & spillway and hydraulic jump & water surface profile will be discussed. In the second part HEC-RAS introduction, unsteady flow, finite difference approximation and sediment transport. Lastly, a conclusion will be made with all the results from the literature review that has been done and a clear understanding and confirmation will be obtained to run the research further.

2.2 OPEN CHANNEL FLUME HYDRAULIC

Open channel is a type of liquid flow in a conduit with solid boundaries which is not fully enclosed and their surfaces of water are subjected to atmospheric pressure. Cruise, Sherif and Singh (2007) said that bed slope; gravity force constitutes the main driving force for flow in open channels. Subramanya (2009) agreed that the prime motivating force for open channel flow is gravity. Open channel can be divided into two types that is natural channel and artificial or man-made channel. Natural open channels include brooks, streams, river, and estuaries while artificial open channel are exemplified by storm sewers, sanitary sewers, and culverts flowing partly full, as well as drainage ditches, irrigation canals, aqueducts and flood diversion channel by Sturm (2001). Usually most of the natural channels have an irregular geometry while artificial channels have a regular geometry. Channels may be either prismatic or non-prismatic. According to Chow (1959), prismatic channels are those that have a constant cross-section and bed slope with distance. While for non-prismatic, the cross-section and bed slope varies with distance. Open channel can also classified into several types which is steady flow, unsteady flow, uniform flow and un-uniform flow. Based on Mokthar (2000), flow in open channel is steady if the flow depth does not change or can be assumed constant during the time interval being considered and the flow is unsteady if the depth of flow changes with time. Mokthar (2000) also said that in uniform flow, the flow depth is constant along the reach under consideration and in un-uniform flow, the flow depth changes along the reach of the channel. Open channels will also deal with Reynold Number, Manning Equation, hydraulic jump, Froude number and so on.

Manning Equation plays an important role in open channel hydraulic and the equation for Manning is expressed in Eq.(2.1)

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S_{\circ}^{\frac{1}{2}} \tag{2.1}$$

Where;

Q	= Flowrate (m^3/s)
n	= Manning value ($s/m^{1/3}$)
A	= Area (m^2)
R	= Hydraulic radius (m)
$S_{\circ}$	= Bed slope

Besides that there are several other basic equations such as continuity equation in Eq.(2.2)

$$A_1 v_1 = A_2 v_2 \tag{2.2}$$

Where;

A = Area (m^2)

v = Velocity (m/s)

The continuity equation and momentum equations are developed for one dimensional unsteady open channel flows and the person who created the formula for unsteady flow is A J C Barre de-saints Venant in 1871. Therefore the formula was name after him which is known as Saint Venant equation.

2.2.1 Manning value, *n*

Manning value is an important constant coefficient that will be used in Manning's equation. A slight change in the manning value will give a different result. Manning value is also known as roughness coefficients and the purpose of manning value is a represent the resistance of water flood in channel and in flood plains. Subramanya (2007) defined that roughness coefficient, being a parameter representing the integrated effects of the channel cross-section resistance, is to be estimated. Besides that, Subramanya (2007) mentioned that the selection of a value for n is subjective, based on one's own experience and engineering judgment.

Table 2.1: A typical Manning's value for channel

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 2.1: A typical Manning's value for channel (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. unplaned	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 2.1: A typical Manning's value for channel (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_
_Tables.htm

Table 2.2: Manning's value for closed conduit flowing partly full

Type of Conduit and Description	Minimum	Normal	Maximum
1. Brass, smooth:	0.009	0.010	0.013
2. Steel:			
Lockbar and welded	0.010	0.012	0.014
Riveted and spiral	0.013	0.016	0.017
3. Cast Iron:			
Coated	0.010	0.013	0.014
Uncoated	0.011	0.014	0.016
4. Wrought Iron:			
Black	0.012	0.014	0.015
Galvanized	0.013	0.016	0.017
5. Corrugated Metal:			
Subdrain	0.017	0.019	0.021
Stormdrain	0.021	0.024	0.030
6. Cement:			
Neat Surface	0.010	0.011	0.013
Mortar	0.011	0.013	0.015
7. Concrete:			
Culvert, straight and free of debris	0.010	0.011	0.013
Culvert with bends, connections, and some debris	0.011	0.013	0.014
Finished	0.011	0.012	0.014
Sewer with manholes, inlet, etc., straight	0.013	0.015	0.017
Unfinished, steel form	0.012	0.013	0.014
Unfinished, smooth wood form	0.012	0.014	0.016
Unfinished, rough wood form	0.015	0.017	0.020
8. Wood:			
Stave	0.010	0.012	0.014
Laminated, treated	0.015	0.017	0.020
9. Clay:			
Common drainage tile	0.011	0.013	0.017
Vitrified sewer	0.011	0.014	0.017
Vitrified sewer with manholes, inlet, etc.	0.013	0.015	0.017
Vitrified Subdrain with open joint	0.014	0.016	0.018
10. Brickwork:			
Glazed	0.011	0.013	0.015
Lined with cement mortar	0.012	0.015	0.017
Sanitary sewers coated with sewage slime with bends and connections	0.012	0.013	0.016
Paved invert, sewer, smooth bottom	0.016	0.019	0.020
Rubble masonry, cemented	0.018	0.025	0.030

Source:http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_ _Tables.htm

2.2.2 Flume and Broad Crested Weir

Flume is an artificial channel or man-made channel for water from a high ground level flow down by gravity force and where both side will have a wall higher than the water surface. Flume must not be confuse with aqueducts, which the purpose of the aqueducts is to transport water used in Roman era, whereas flume would acts as a transport for materials such as logs, gold, tin and heavy materials.

Broad crested weirs are considered as hydraulic structure which is similar to spillway just that it is in rectangular shape and flat crested structure. Broad crested weir is used to measure the discharge of rivers. The overflow spillway crest on a large dam is also known as weir. Based on Downs and Gregory (2004) said that weirs (or deflectors or sills and vanes) can be used promote morphological diversity in channels, deflect flow from eroding banks, or encourage scour processes in zones subject to sedimentation. According to Sturm (2001), spillways are used on both large and small dams to pass flood flows, thereby preventing overtopping and failure of the dam. Ogee spillways are commonly used in dam structure in the world, it is also known as overflow spillway. Sturm (2001) did also mention that the concrete ogee spillway is used to transfer large flood discharges safely from a reservoir to the downstream river, usually with significant elevation changes and relatively high velocities. Subramanya (2007) agreed that the most extensively used spillway to safely pass the flood flow of a reservoir. Spillways are divided into two types which is controlled and uncontrolled. Controlled spillway will have a mechanical structure known as gates; the purpose of it is to be used as water storage. For uncontrolled spillway, it does not have gates, when the water level reach to the crest, water will flow down the spillway. The purpose is to act as temporary flood storage and cannot be used as water storage due to it normally empty.