

The Effects of Riparian Trees on Straight Natural River Mechanics

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Keywords: Straight Natural River, Riparian Trees, Bed profile, Velocity along the channel

Abstract. Floods are natural disasters have become frequent events in the world and historically major flood in Malaysia took place in Kuala Lumpur in 1971. Among the adverse effects of floods are damages to buildings, roads, bridges, crops, human suffering and even loss of lives. Emergent vegetation or trees on floodplain are either live naturally or planted to function as soil erosion control measure. Deforestation or removal of trees to acquire additional available land for other uses has become permanent forest destruction. This activity leads to natural damages and has increased the level of flood devastation. In the engineering, it is important to understand the influence of riparian or floodplain vegetation on the natural river mechanics during flooding. Therefore, a laboratory experimental study was carried out to investigate the effects of riparian trees on flow resistance, main channel cross sections and velocity profiles in a natural straight channel during non-flooding and flooding events. 5 mm diameter steel rods as the trees were installed on one of riparian zones in a natural river system. Temporal changes of main channel cross sections and streamwise velocity were measured at selected locations along the river. It was found that the Manning's n for vegetated cases increased by 33% as compared to non-vegetated cases. It can also be concluded that the main channel cross section and velocity were significantly influenced by the presence of riparian trees during flooding.

Introduction

Rivers are natural water body flow towards to lakes, rivers, oceans or sea. Rivers can be names such as stream and mostly responsible for Earth's landscapes shapes. At the same time the river flows into the ground and will be dry at the end of its course without reaching surface of river and rivers also functions to carry water and sediment from high elevations to downstream. The land area draining to a river is defined as watershed. When rain falls in a watershed, it will evaporates, infiltrates into the soil or runs off the land surface. Moreover, during the surface runoff move to the downslopes, it will forms small stream channel when carrying water during rainfall runoff. In geomorphology classification of river, there are three basic pattern which are meandering, braided and straight channel. Many straight and meandering channel exist in Malaysia. Channel are categorized as compound channel when flood occurs. In compound channels, three types of flow can occurs: overbank, bankfull and inbank. Overbank occurs when flow overspill into the flood plain, bank full occurs when main channel is filled with water flow and inbank flow occurs when water flow within the main channel. Hence, bankfull and inbank can be stated as safe condition.

Nowadays, flood is a common natural disaster that occurs and affected many areas including Malaysia. Floods cause damages to bridges, building roads, human suffering and loss of life. A flood caused by a combination of heavy rainfall causing ocean or rivers to over flow through their banks. Generally floods develop over a period of days, when there is too much rainwater to fit in the rivers and waters spreads over the next to it which is floodplain. In the floodplain, and also along the bank of river, vegetation such as trees and shrubs might occurs either as naturally present or they are design for the purpose of erosion prevention, habitat creation or landscape or recreational purpose which plays important role on the hydrodynamics behaviour, on the equilibrium and on the original flow characteristics of the river. The presence of vegetation also causes increasing increment of water depth on floodplain due to flooding. As far as flow resistance is concerned, the vegetation can be classified into submerged, non-submerged or flexible and stiff or emergent vegetation.

Malaysia is a country which have climate equator namely hot and humid year round with higher an average annual rainfall. They are many different sources of water in rivers and most rivers flow quickly in the steeply sloping sections near their source. Rivers start as very small streams and gradually get bigger when more water is added. Heavy rains add so much water to rivers that it will overflow the banks and flood the landscapes' surrounding. Although floods are natural phenomena because of rainfall overwhelming, however uncontrolled development activities in watershed areas along river floodplain can increase the severity of floods. Flood is occurred at both floodplain and main channel. It is characterized through the flow of water. The rivers have lots of small channels that generally split and join. The channel are usually wide and shallow. It can form on fairly steep slopes where the river bank is easily to erode. Thus when the floodplain has been vegetated, the velocity of channel reduced very rapidly. Generally, the velocity in the channel can automatically give impacts on the discharge of flow in the channel.

The objectives of the research are to design and construct a natural river model in the laboratory and to investigate the characteristics of natural river during flooding with or without presence of riparian trees with staggered emergent vegetation. Understanding the natural process of river channels development are important, so constructing lab scale development of natural rivers shows the mechanism of river channel behaviour with or without presence of riparian trees during flood event. The study reviewing the case study before from other researcher one of the scope. Other than that, planning and design of physical model are the main of study to make preliminary test, check technical problem and collect the data for analysis. The research is carried out in the Hydraulics and Hydrology Laboratory, Faculty of Civil Engineering Malaysia, Johor Bharu. A physical model known as "Natural River Model" was constructed in the laboratory. This is the first model were made for this research study. Based on the objective of the research, the scopes of the experimental work are design the natural river model with AutoCAD 2013 and SketchUp 2014 Software with appropriate available material and apparatus that can be access in Peninsular Malaysia and provided space in Faculty of Civil Engineering laboratory.

Finally, constructing the model follow the selected proposal of models' design with following dimension 1.2 m wide, 0.6 m high and 4.0 m long with a bed slope 1:500 and double floodplain. The research which is limited to: certain discharge, and certain slope on vegetated and non-vegetated during flood event. A few adjustment are made to get the slope of bed fix to 0.002 and replicate the arrangement of staggered vegetation along the edge of the floodplain. The steel rods of 5 mm diameter (d) are used as vegetation in the emergent condition. They are arranged in two-line along the single floodplain in staggered manner with spacing of $4d$. For data collection, the depth of water and the level of channel bed are recorded to determine the uniformity of the water flow. Velocity in the main channel is recorded at 9 cross-sections in the channel to determine the average of flow along the channel. Graph of temporal changes of river profile and average Manning's n coefficient are plotted.

Literature Review

An attempt has been made in this chapter to draw together various aspects of past research in hydraulic engineering concerning the behaviour of rivers. Prior to the early Sixties, very little was known of the complex flow patterns which exist between a channel and its associated flood plains, but more recent developments have led to a clearer understanding of the hydraulic mechanisms involved, at least at the level of model studies. Natural river channel are can be typical curved or meandering channel forms Flow in meandering and braided channels is increasing because this type of channel is common for natural rivers, and research work regarding flood control, discharge estimation and stream restoration need to be conducted for this type of channels. It has exposed from investigators that the flow structure of channels is unpredictably more complex than straight channel due to its velocity distribution as stated in Dash [1].

Nowadays, the study of river characteristics by using method is very important in order to provide sufficient strategic in prevention of earth disaster such as flood that obviously harmful to living things and affecting the development process. The impact of floods has been increased due to

number of factors, with rising sea levels and increased development on floodplain as stated in Jalonon [2]. In many areas, flooding cannot be allowed because of infrastructure and also the channel cannot be oversized. Effect from enlargement sized of the channel would lead to channel instabilities, erosion and sedimentation problem. Landuse and land cover changes will increase surface runoff and higher sediment yield as stated in Chang [3]. Retention time for the flow might be reduced and thus will accelerate the flow due to reduced roughness and channel length as stated in Helmiö [4]. Numerous variable such as shape and slope of the channel, the type of material resistance, discharge and the velocity of flow are influence the flow characteristic through the channel.

Types of flow

Open channel flow should have a free water surface which is subjected to atmospheric pressure. Classification of open channel flow can be made into various types and also can be described in various ways. The following classification is made according to the change in flow depth with respect to time and space. The flow can be classified in two conditions which are steady flow and unsteady flow. Steady flow condition in open channel can be recognized if the depth of flow does not change or if it can be assumed to be constants during the time interval under consideration as stated in Chow [5]. Furthermore, according to Subramanya [6], a steady flow occurs when the flow properties such as the depth and the discharge at the section do not change with time. As a corollary, if the depth or discharge changes with time of the flow is termed as unsteady.

Meanwhile the unsteady flow condition occurred if the depths change with time. In most open channel problems, it is necessary to study flow characteristics only under steady conditions. However, if change in flow condition with respect to time is a major concern, the flow should be treated as unsteady as stated by [5]. [6] stated that some example of unsteady flow is when flood flows in the river and rapid-varying streams in channel. Unsteady flows are considerably more difficult to analyse than steady flows. Open channel flow can be categorized into uniform flow and varied flow. Open channel flow is said to be uniform just when the depth of flow is the same at every section of the channel. The criterion of uniform flow which is steady or unsteady flow depends on whether or not the depths change with time. In open channel hydraulics, steady uniform flow is the time interval under consideration. The establishment of unsteady flow would require that the water surface fluctuate from the time while remaining parallel to the bottom channel as stated by Chow [5].

The behaviour of the flow pattern in a compound channel with rigid floodplain vegetation depends on vegetation parameter as stated by Naot [7]. The parameter is the shading factor and the wave length. The shading factor depends on the increase of vegetation diameter and density. According to Bailly [8], increasing of density vegetation cause the discharge of river decreasing along the channel. Meanwhile, the wave length will be influenced by the increasing of vegetation diameter and decreasing of vegetation density. According to Pasche and Rouve [9] when the vegetation is very dense, the friction factor at the boundary of the main channel and the floodplain might be increase when the width of floodplain decrease and a . Therefore, the velocity reduction due to the vegetation on the floodplain is not sufficient to describe the change in the friction factor of the boundary.

Besides that, [5] stated that vegetation may be regarded as kind of surface roughness; it reduces the capacity of the channel and retards the flow. The effect depends mainly on height, density, distribution and types of vegetation. It is very important in designing channel. Normally, floodplain of river basins are densely vegetated. Therefore, vegetation density has influenced the roughness of a channel and floodplain. The major roughness reaches when densely vegetated on floodplain. To manage optimum floodplain considering river restoration, erosion control and flood control, full percent vegetation planting in floodplain is not recommended. The floodplain with vegetation will decrease the velocity in the floodplain and also increase in the main channel as stated in Sadeghi [10]. From the observation of velocity distribution, the maximum flow velocity occurs in the central

of main channel region which decreases towards the side banks and bottom directions as illustrate in Figures 1 and 2.

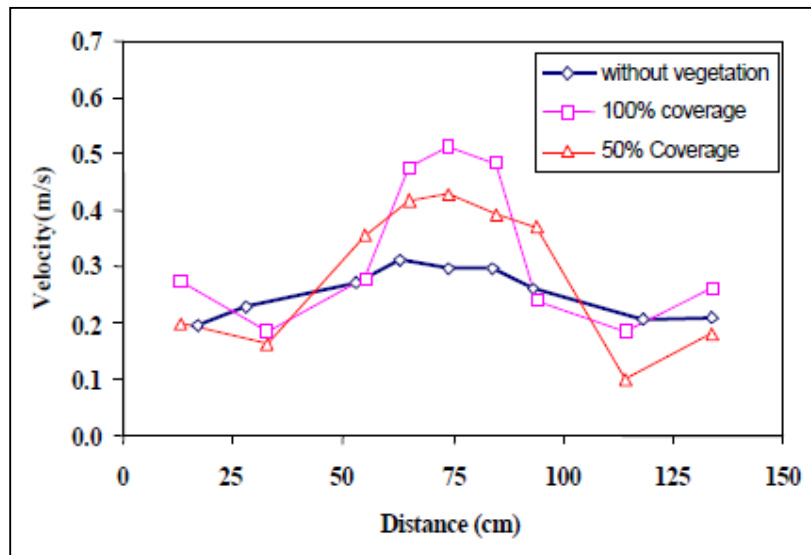


Figure 1: Variation of cross-section velocity [4]

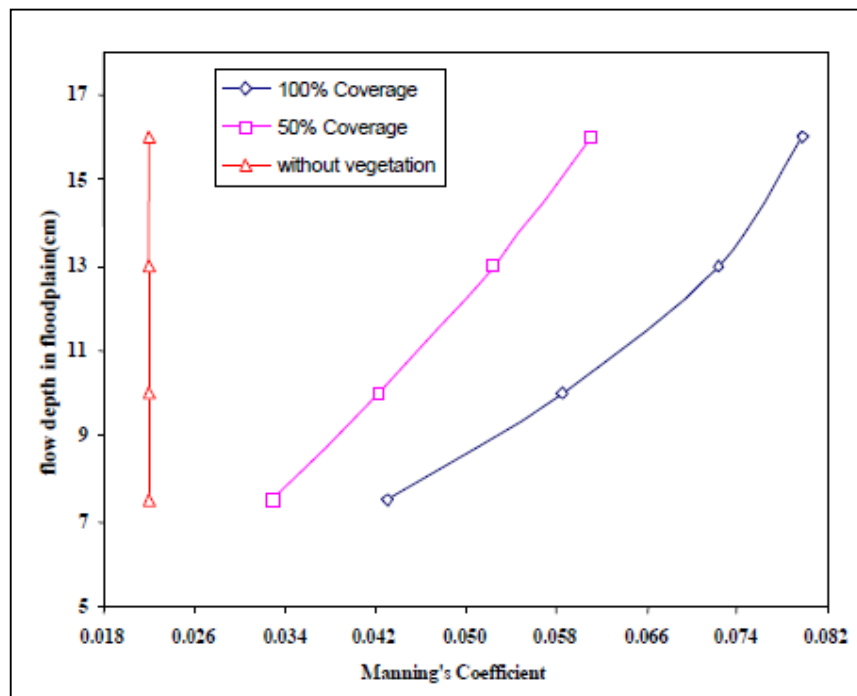


Figure 2: Variation of Manning's coefficient in different vegetation condition and flow depth [4]

Manning's n Roughness Coefficient

The Manning formula has become the most widely used for all uniform-flows formula for open channel flow calculations. The exponent of the hydraulic radius in the Manning formula is varies in a range depend on the channel shape and roughness as stated in Chow [5]. The average Manning's n coefficient for vegetation case is higher compared to non-vegetation case. The roughness coefficient, where it is not controlled by the size of individual particles, is affected by the concentration of suspended sediment, larger concentrations being associated with smaller value of roughness. Generally, the resistance involved in the channel, causing by the contact between flow

water and channel surface. As far as this experiment is being concerned, the effect of the roughness in bank channel is taking into account and excluding the effect of floodplain as stated in Blench and Thomas [11].

Methodology

This chapter is very important in order to discuss and describe the experiment set up, instrument used, laboratory experiments and the experimental procedure to archiving the objectives in this study. The aim of this study is to determine the characteristics in a straight natural compound channel with or without vegetation during flood event. The study is involved data collection through experimental investigation by using a rectangular flume. The flow characteristics are studied and shown through the river profile, velocity along the channel and outflow discharge. The study of flow characteristics in a straight natural channel with staggered emergent vegetation has been conducted in the Hydraulics and Hydrology Laboratory, Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM), Johor Bahru. Thus the experimental research has been conducted is completely accomplish the objective of this study. Figure 3 illustrates the research implementation.

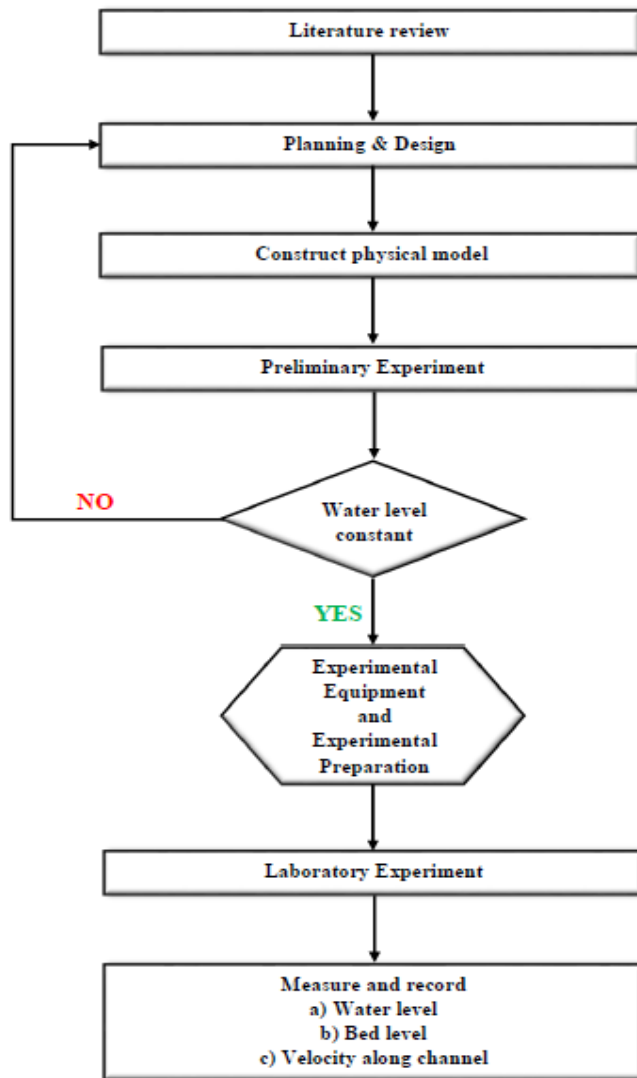


Figure 3: Completed Research Implementation

The study involved data collection through experimental investigation using a rectangular flume, as present in Figure 4. The dimension of a physical model is 8.0 m length and 1.2 m width, which consists of V-shape main channel with 0.08 m width and 0.05 m depth located at middle of a double floodplain. Figure 5 and Figure 6 displays a cross-section and plan view of a straight natural river channel. This experiment observed by two-line staggered emergent vegetation on floodplain condition with bed slope 1:500. Wooden rods of 5 mm diameter (d) are used to simulate the emergent floodplain vegetation. A spacing of $4d$ is adopted in the study.



Figure 4: Natural river model

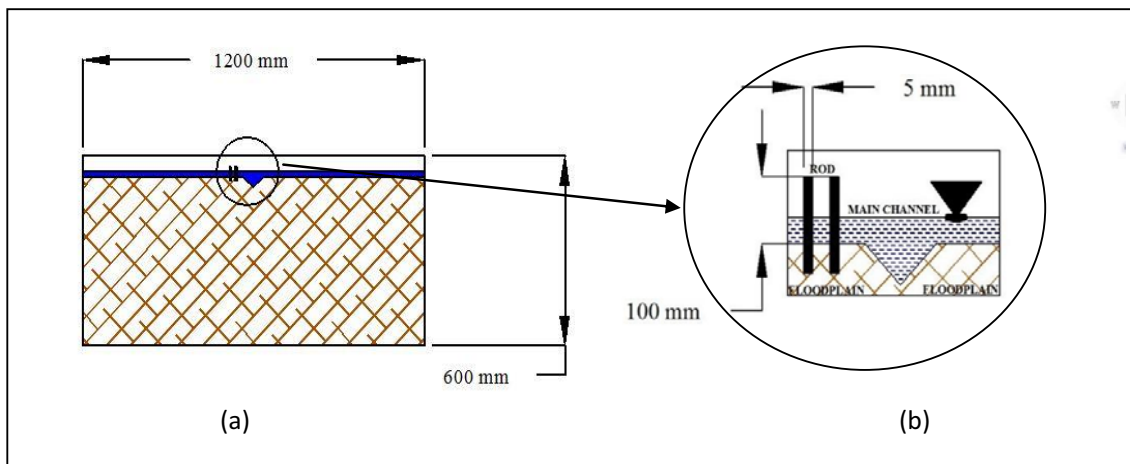


Figure 5: Cross-section of model (a) Cross-section (b) Zoom main channel

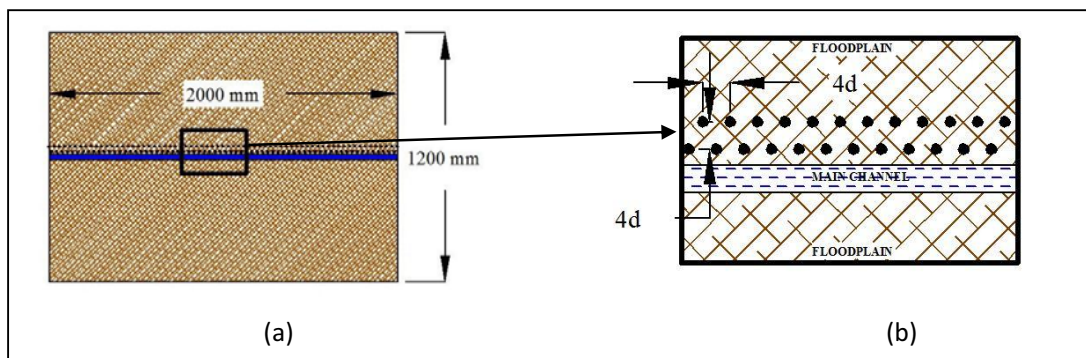


Figure 6: Plan view of model (a) Plan view (b) Zoom main channel

The model covered by canvas that waterproof with water and connection between plywood must be sealed with silicon to make sure there is no leakage during the testing. Hence, the plywood surface is painted with orange colour to avoid water entered in the cavity of plywood. Constructed the water tank with a frame of steel with same colour and the body with a transparent perspex to make sure easy to observe the regulation of water during testing. The sump is located at the downstream of the channel.

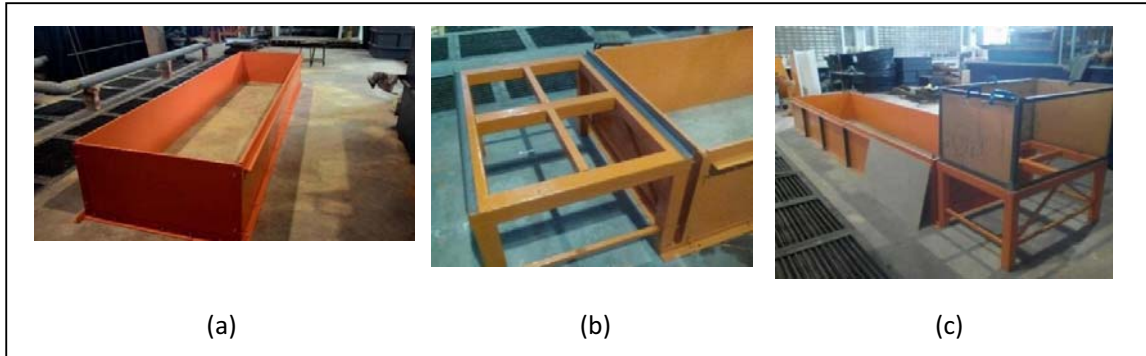


Figure 7: Constructing physical model (a) rectangular channel (b) Foundation water tank (c) Frame water tank

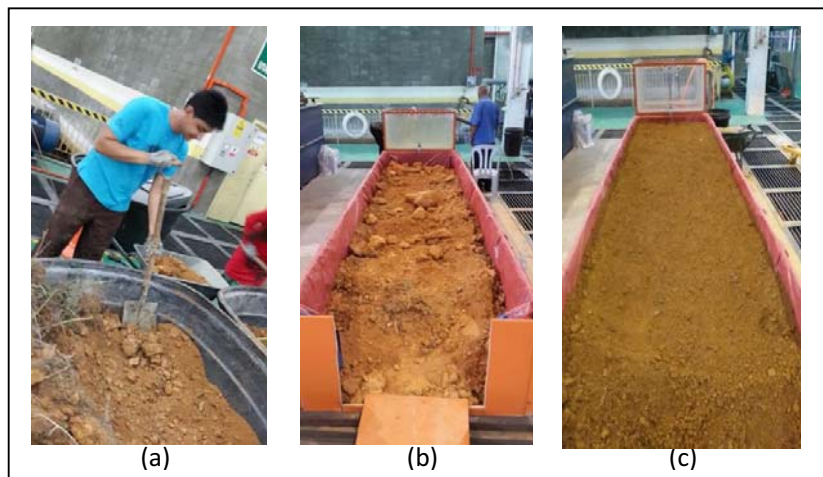


Figure 8: Implant soil in model (a) Pour soil sample in rectangular channel (b) First layer (c) Final layer

Small sump is used to locate all the outlet water for taking outflow testing before washed out to the laboratory tank as shown in Figure 9 and it represent the soil sample inside the model was levelled. Therefore, if there is any surface not smooth because it is non-prismatic channel due to characteristics of soil sample.

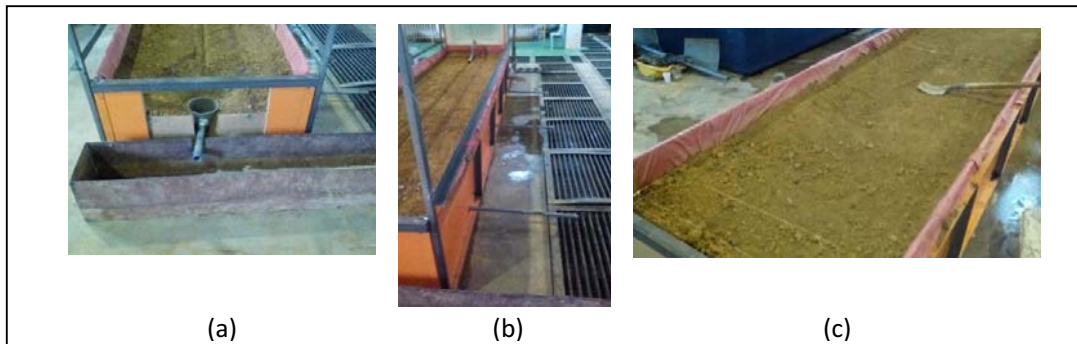


Figure 9: Levelled and installed weep holes and outlet (a) Outlet (b) Weep holes (c) Level the slope channel

The experimental work is carried out with fixed channel bed slope of 1/500. Surveying work has been conducted to levelling the channel bed slope. The surveying equipment such as theodolite, tripod and levelling staff are used to achieve 1/500 channel bed slope. Figure 10 displays the surveying equipment involves in this surveying work.



Figure 10: Surveying equipment such as theodolite, tripod and levelling staff

The flow depth is obtained by using a manual point gauge. The point gauge is mounted on the carriage that could be moved along rails attached to the top of the flume side walls. The point gauge has an accuracy level up to ± 0.1 mm. the flow depth is obtained at any point which every section of chainage are taken in order to obtain reliable mean readings of flow depth as displays in Figure 11. The measurement of flow depth is taking for every 0, 4320 and 8640 minutes to ensure that flow is in non-uniform condition. Figure 10 shows the point gauge is used in the experiment. Velocities in the channel were measured at each chainage across the main channel and floodplain for different depth. The point of velocity is measured by using a miniature current meter as shown in Figure 12.



Figure 11: Point gauge



Figure 12: Miniature current meter

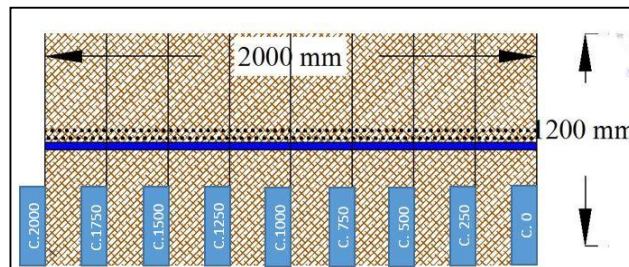


Figure 13: Selection point for collecting data

Velocities are measured from each chainage along the flume as illustrates in Figure 13. The point velocities are measured at different stage of flow at the main channel and the floodplain areas. After experimental equipment and instrument is set-up, model is tested and all data from experiment are recorded. There are several procedures have been conducted in the experiment in order to obtain data regarding bed profile and velocity along the channel in a staggered emergent

compound channel. The procedure is divided into two parts which are steady flow establishment and data collection.

The experiment investigation is carried out to determine the flow characteristics of river, bed profile and velocity along the channel with or without riparian trees during flood event. The several collected data from a certain points and sections are used to determine classification flow, Manning's n coefficient, Froude Number and Reynolds Number. Therefore, all collected data has been analysed by the following equations are used in data analysis:

$$n = \frac{A R^{2/3} \sqrt{S_o}}{Q} \quad (1)$$

where n is Manning's roughness coefficient; A is area of water flow (m^2); R is hydraulic radius (m); S_o is bed slope of channel; Q is discharge (m^3/s); and P is wetted perimeter of flow (m).

$$F_r = \frac{U_m}{\sqrt{gD}} \quad (2)$$

where F_r is Froude Number; U_m is mean velocity (m/s); g is acceleration of gravity (m/s^2); D is hydraulic depth (m).

$$R_e = \frac{4U_m R}{\nu} \quad (3)$$

where R_e is Reynolds Number; U_m is mean velocity (m/s); R is hydraulic radius (m); ν is kinematic viscosity (m^2/s).

Result and Analysis

This chapter mainly presents the results of the experimental investigation which has been conducted in Hydraulic and Hydrology Laboratory, Faculty of Civil Engineering. The experimental has been conducted steady flow in non-uniform flow and concentrated on a straight natural river with staggered vegetation along the single floodplain. The data collected from this study are analysed based on the objectives of study. The experimental results describe the characteristics of flow in the channel consists of classification of flow, relative depth, bed slope, Manning's n , Reynolds Number Re and Froude Number Fr .

In order to obtain the results and data collection, two equipment are involved which is point gauge to measure the water level and bed level; meanwhile miniature meter has been utilized to collect the point of velocities for each section. The experiment has been conducted under steady flow in non-uniform flow condition in order to apply theory in the analysis. The non-uniform flow is achieved when slope of water surface (S_w) is not equal to slope of channel bed (S_o) at all time. The classification of flow in a channel is turbulence for Reynolds number exceeds 2,000 and subcritical flow (low velocity) condition occurs when Fr is less than 1. Both of approach explained that the regime of flow classified as subcritical-turbulence for this study of a straight natural river channel.

Soil Distribution

Sieve analysis was performed to determine the percentage of different grain sizes contained within soil. The mechanical or sieve analysis was performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles. The distribution of different grain sizes affects the engineering properties of soil. Grain size analysis provides the grain size distribution, and it is required in classifying the soil as shown in Figure 14. The distributions showed the soil is mix of gravel fine, sand coarse and silt coarse.

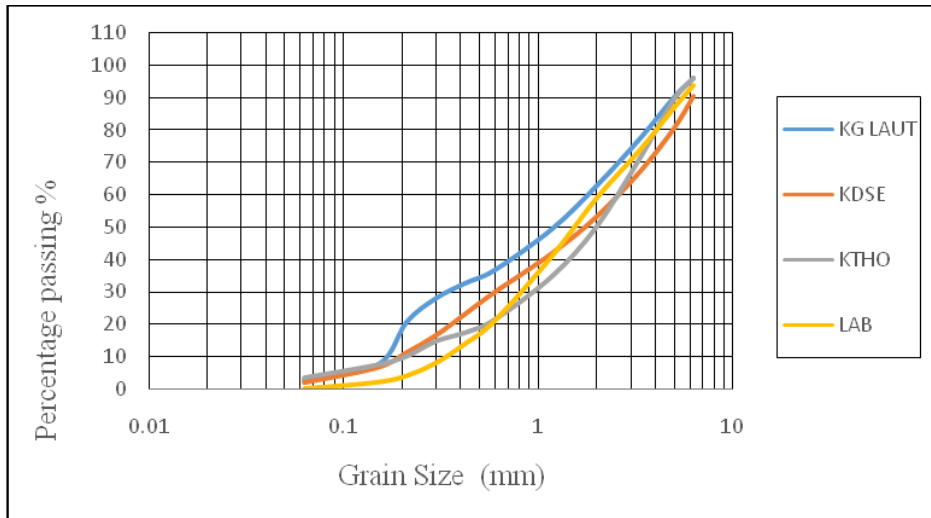


Figure 14: Soil distribution

Bed Profile

The channel is divided into nine sections because the dimension of channel might inaccurate due to error during the construction process of model. The average value of each section is taken in order to overcome the irregularity of size and dimension of the channel. However, readings are not taken near the upstream and downstream of the channel because of interruption of flow. At upstream and downstream, flow has tendency to fluctuate and unstable flow formed. Hence, unstable water level is produced and non-uniform flow condition is tough to achieve. Figure 15 and 16 displays the channel bed slope within time due to non-uniform flow for each cases.

All channel bed levels values are measured by using point gauge. The reading has been taken from chainage 0 mm to chainage 2000 mm at every 250 mm distance. These sections are selected due to establish channel bed slope from each section within time. Since, the channel bed slope is fixed to 0.002 after undergoing the laboratory test the channel bed slope changing to specific value depends on vegetation. The process of slope changing shows there is discrete particle that wash away by the water through the outlet channel. Figure 15 illustrates the slope of channel become shallower where the slope decreasing from 1:100 to 1:200 due to sediment transport from upstream to downstream and Figure 15 shows the slope become deeper where the slope increasing from 1:200 to 1:100 where the flow of water was in straight channel due to vegetation characteristics.

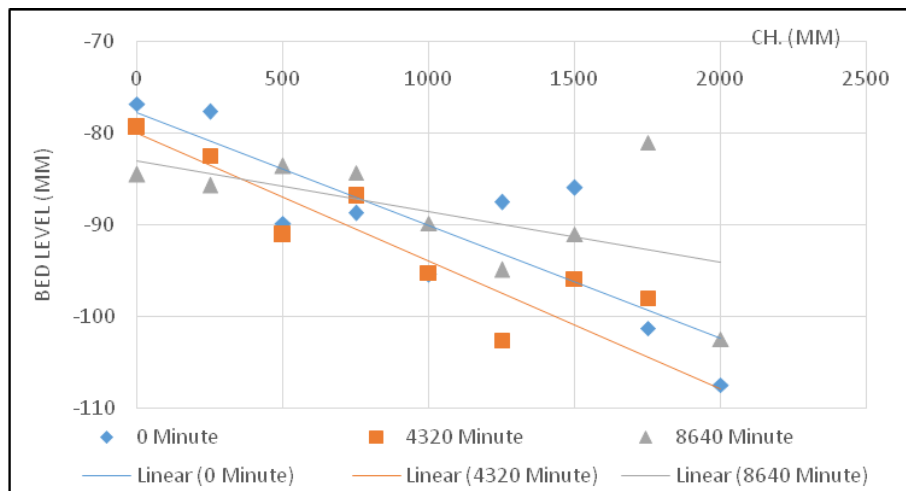


Figure 15: Non-vegetated channel bed slope

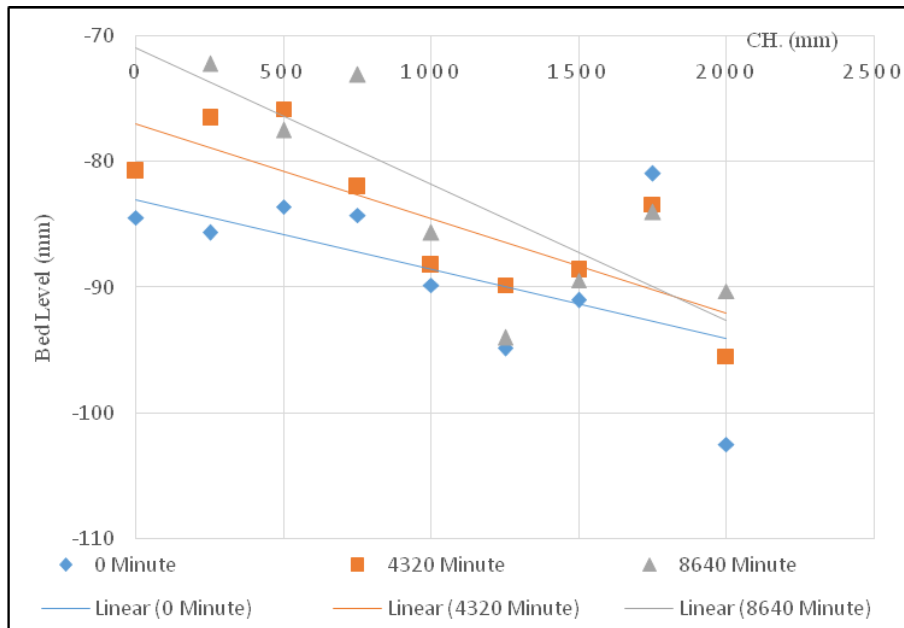


Figure 16: Vegetated channel bed slope

Manning's n Coefficient

The flow resistance in a channel is represented by the Manning's coefficient, n value as shown in Figure 17. The Manning's n starting increase when overbank flow where the relative depth is increase too but during non-vegetated condition the roughness coefficient not linear. This been found that the manning's n value for overbank non-vegetated condition is lower than vegetated condition. The roughness surface occurs due to imperfect condition during the construction of the model. In reality, the value of n is highly variable and depends on a number of factors as stated in Chow [5].

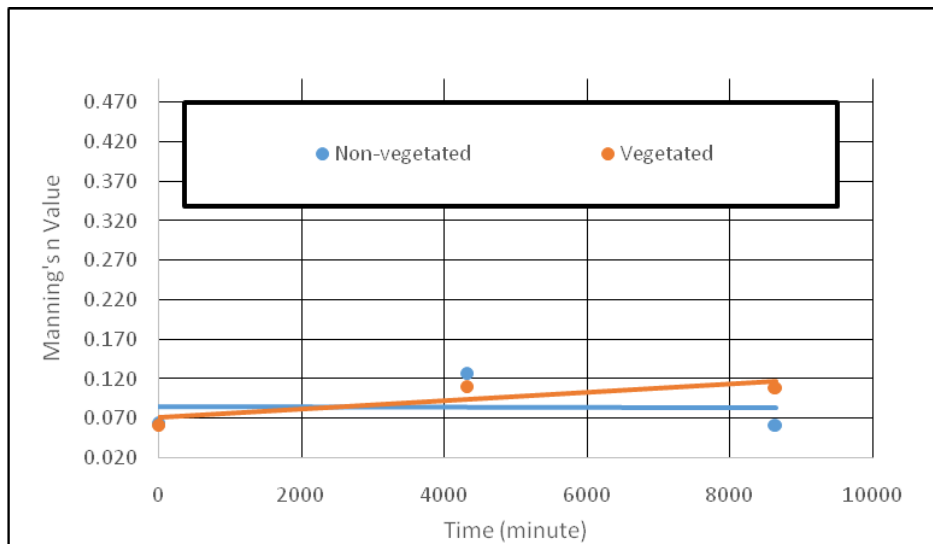


Figure 17: Manning's n coefficient in the channel

Non-vegetated case shows the sediment transport from upstream to downstream cause the river become shallow and this value match with scattered brush heavy weeds (0.035-0.070) on site experiment as stated in Chow [5]. Meanwhile, on vegetated case manning's value is increasing and match with heavy stand of timber, a few trees, little undergrowth, flood stage below branches (0.080-0.120) on site experiment [5].

Reynolds Number

Determination of Reynolds Number, Re for different case of vegetation can be referred on Table 1 and 2. The table shows the summary of Reynolds Number, Re for non-vegetated and vegetated cases. Based on the table, it has indicates that the Reynolds Number for each case more than 2000 which can be categorised as turbulent flow. These experiment were achieved in turbulent flow condition.

Table 1: Summary Reynolds Number non-vegetated case

Time (minute)	U_m (m/s)	R (m)	V (m ² /s)	Re
0	0.147	0.009	8.592×10^{-7}	6547
4320	0.074	0.009	8.592×10^{-7}	2680
8640	0.075	0.006	8.592×10^{-7}	1821

Table 2: Summary Reynolds Number vegetated case

Time (minute)	U_m (m/s)	R (m)	V (m ² /s)	Re
0	0.075	0.006	8.592×10^{-7}	1821
4320	0.077	0.012	8.592×10^{-7}	4292
8640	0.067	0.0085	8.592×10^{-7}	2244

Froude Number

The flow condition is determined based on the Froude Number, which is:

- i. $Fr = 1$: Critical flow
- ii. $Fr < 1$: Subcritical flow (low velocity)
- iii. $Fr > 1$: Supercritical flow (high velocity)

Table 3: Summary Froude Number non-vegetated case

Time (minute)	U_m (m/s)	A (m ²)	T (m)	$D=A/T$	Fr
0	0.145	0.003	0.30	0.011	0.440
4320	0.074	0.003	0.30	0.011	0.230
8640	0.075	0.002	0.30	0.007	0.279

Table 4: Summary Froude Number vegetated case

Time (minute)	U_m (m/s)	A (m ²)	T (m)	$D=A/T$	Fr
0	0.075	0.002	0.30	0.007	0.279
4320	0.077	0.004	0.30	0.014	0.207
8640	0.067	0.003	0.30	0.010	0.218

Cross-section of channel

Cross-section of each chainage shows changes on its bed level within time being. Chainage 0, Chainage 1000 and Chainage 2000 were selected on observation. Figure 17 (a) and 17 (b) show for Chainage 0, Figure 18 (a) and 18 (b) show Chainage 1000 and 19 (a) and 19 (b) show for Chainage 2000. The reading of bed level using point gauge and recorded within 0, 4320 and 8640 minute. Overall from Figure 19 until Figure 20 the process of straight natural river for non-vegetated case and vegetated case shows the depth of main channel become shallow due sedimentation from upstream to downstream and the width of channel become wider due to erosion at the floodplain. The changes of main channel can be differentiate from non-vegetated to vegetated condition, where the quantity of sediment transport from upstream to downstream become lower cause of vegetation position disturbed the flow of water. It shows these experiments are achieved in purpose due to the lowering the changes of channel and decreasing the flow of water.

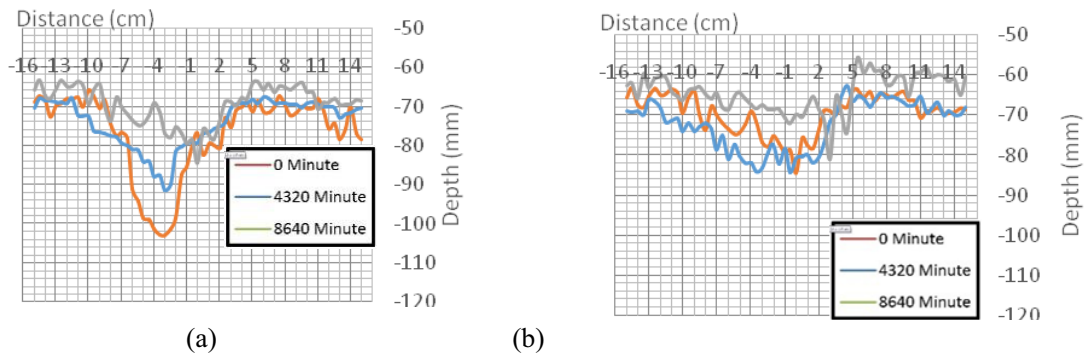


Figure 18: Temporal changes on channel cross-section for CH 0 (a) Non-vegetated (b) Vegetated

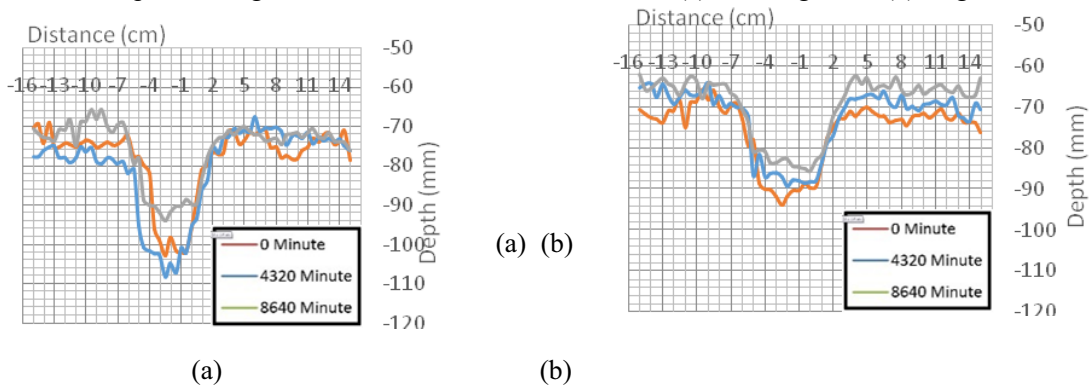


Figure 19: Temporal changes on channel cross-section for CH 1000 (a) Non-vegetated (b) Vegetated

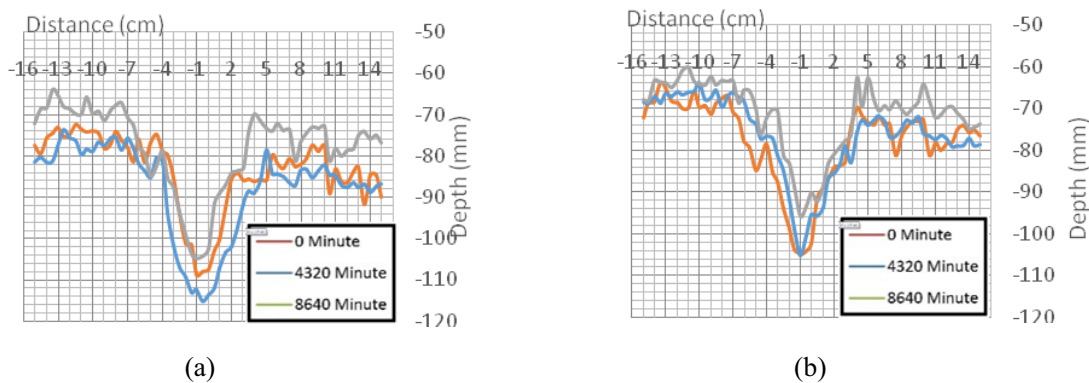


Figure 20: Temporal changes on channel cross-section for CH 2000 (a) Non-vegetated (b) Vegetated

Conclusion

Based on analysis of this experimental investigation in a laboratory, a summary of the findings and general conclusion drawn from the present study are listed below:

- i. A natural river model was constructed in the hydraulic laboratory
- ii. Vegetation on floodplain disturbed the water flow which has been created extra roughness that contributes to flow velocity reduction. Hence it reduces the water surfaces for water to flow and give impact to the overall discharge. Therefore, for vegetated compound channel, there is increase in water depth compared to the smooth channel.
- iii. Vegetation along the floodplain edges significantly affects the behaviour of overall flow resistance in straight compound channels. The flow velocity on the floodplains is slower than a main channel due to the different in water depth and surface roughness because of non-prismatic channel. The value of manning's n obviously increase with increases the roughness of vegetated floodplain than channel with smooth floodplain.
- iv. Vegetation along the floodplain edges significantly affects the behaviour of overall the shape of channel. Vegetation lower the quantity of sediment transport process than non-vegetated floodplain condition. Increasing of vegetation density decrease the process of transport sediment form upstream to downstream.

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