The Mechanics of Natural Straight River during Flooding and Non-flooding

Nurul Liyana Binti Roslan[1, a] and Zulkiflee Ibrahim[1, b]

[1]Faculty of Civil Engineering, Universiti Teknologi Malaysia, Malaysia.

[a]nurulliyanaroslan@yahoo.com.my, [b]zulkfe@utm.my

Keywords: Flood, rainfall, velocity distribution

Abstract: Frequent occurrences of flood in Malaysia are due to an average rainfall of high rainfall intensity. Floods happen when the water exceeds the river banks and starts to flow into the floodplain area which is also known as overbank flow. Floods tend to cause loss of life, human suffering damages to building, crops, and also infrastructures. This study focuses on the experimental work that was conducted in the Hydraulic and Hydrology Laboratory, Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM). The objectives of this study are to investigate the characteristics of natural river during flooding and non-flooding. The non-flooding and flooding cases were identified by using rectangular flume known as "Natural River Model" The flume used in this study has 4.95 m long, 0.69 m wide and 1.26 m depth of rectangular main channel with non-fixed-bed. The results on flow and channel bed profile, Manning's n and velocity distribution were discussed in this report. It has been found that the bed level and velocity are significantly affected by the discharge during flooding and non-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 down slopes, it will forms small stream channel when carrying water during rainfall runoff. In geomorphology classification of river, there are three basic patterns which are meandering, braided and straight channel. Many straight and meandering channel exist in Malaysia. Channels 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 spread 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 channels 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 and non-flooding. Understanding the natural process of river channels development are important, so constructing lab scale development of natural rivers shows the mechanics of natural straight river during flooding and non-flooding. 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 0.69 m wide, 0.6 m high and 4.95 m long with a bed slope 1:500 and double floodplain. The research which is limited to: certain discharge, and certain slope during flooding and non-flooding events. 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.

Literature Review

Rivers are part of the hydrological cycle. If the quantity of water exceeds the capacity of rivers, it may create flood disaster which can cause human suffering and damages infrastructures. Therefore, the research on the characteristic of a river is necessary in order to know the pattern of river during flooding and non-flooding cases. A lot of studies had been conducted regarding flood hydraulics behaviour with different parameter such as velocity distribution, and Manning's n by Chow [4], Subramanya [3] and Blench [5].

Velocity Distribution

The influence of the channel geometry is apparent where the velocity is zero at the solid boundaries and gradually increased with the distance from the boundary. The maximum velocity of the cross section occurs at a certain distance below the free surface. The dip of the maximum velocity point for a give surface of velocities is less than the maximum velocity. This is due to secondary currents and is function of the aspect ratio (ratio of depth to width) of the channel. The maximum velocity pint from the water surface will be much lower at the deep and narrow channel compared to a wider channel of the same depth as stated in Subramanya [3]. According to Chow [4], the roughness of the channel will cause the curvature of the vertical velocity distribution curve to increase as shown inFigure 1.

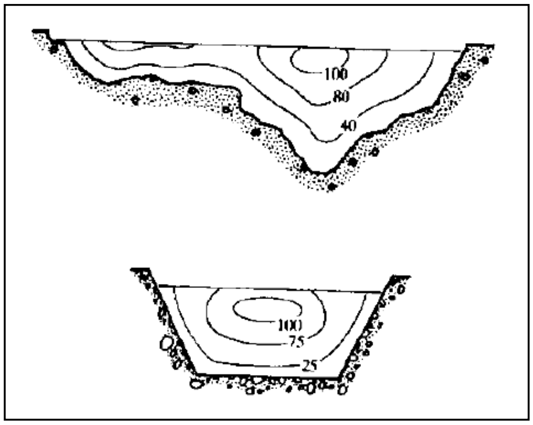


Figure 1: Pattern of velocity distribution

The velocity distribution in a channel section depends also on the other factors, such as the unusual shape of the section, the roughness of the channel and the presence of bends. In a broad, rapid and shallow stream or in a very smooth channel, the maximum velocity may often found in free surface as stated in Chow [4].

Manning's 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 [4]. According to Blench [5], the average Manning's *n* for flooding case is higher compared to non-flooding case.

The channel roughness is not controlled by the size of individual particles, but it 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 [5].

Sediment Transport

Sediment properties of a single particle that are important in the study of sediment transport are particle size, shape, specific weight, and velocity. Understanding on sediment transport is important as it deals with the interrelationship between the flowing water and sediment particles. There are several modes of sediment transport including bed- load transport, suspended load transport, and total load transport.

The sediment transport only occurred in the main channel for the straight channel experiments. As stated in Kalimuddin [6], the velocity decrease, sediment transport rate also decreases as sediment transport rate is directly related with the velocity in the main channel. According to Ismail [7], the difference in velocity between the main channel and floodplain is due to the different in depth and surface roughness. For the flooding cases, an increase in suspended load tends to decrease channel resistance and thus causes an increases in velocity. So, Hjulstrom [9], have come out with the relationship between the sediment size and average flow velocity as shown if Figure 2 in order to find the channel characteristics either it undergo erosion, transportation, or sedimentation.

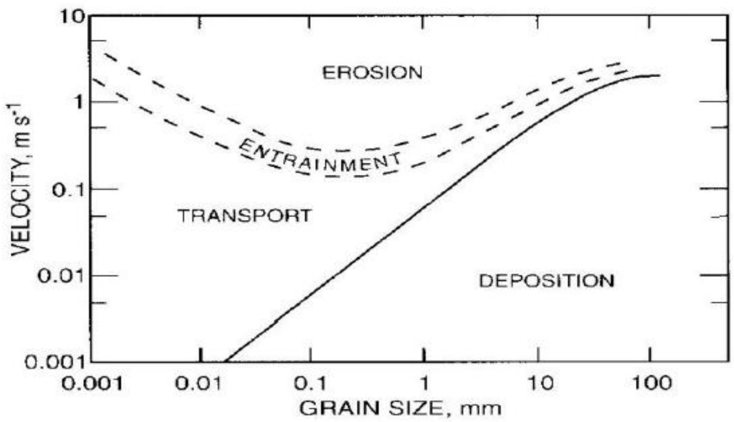


Figure 2: Relationship between sediment size and average flow. [9]

Research Methodology

This research involves data collection through experimental investigation by using rectangular compound channel. Several equations and equipment were used to achieve the objectives. Figure 3 can be used to summarise the research implementation.

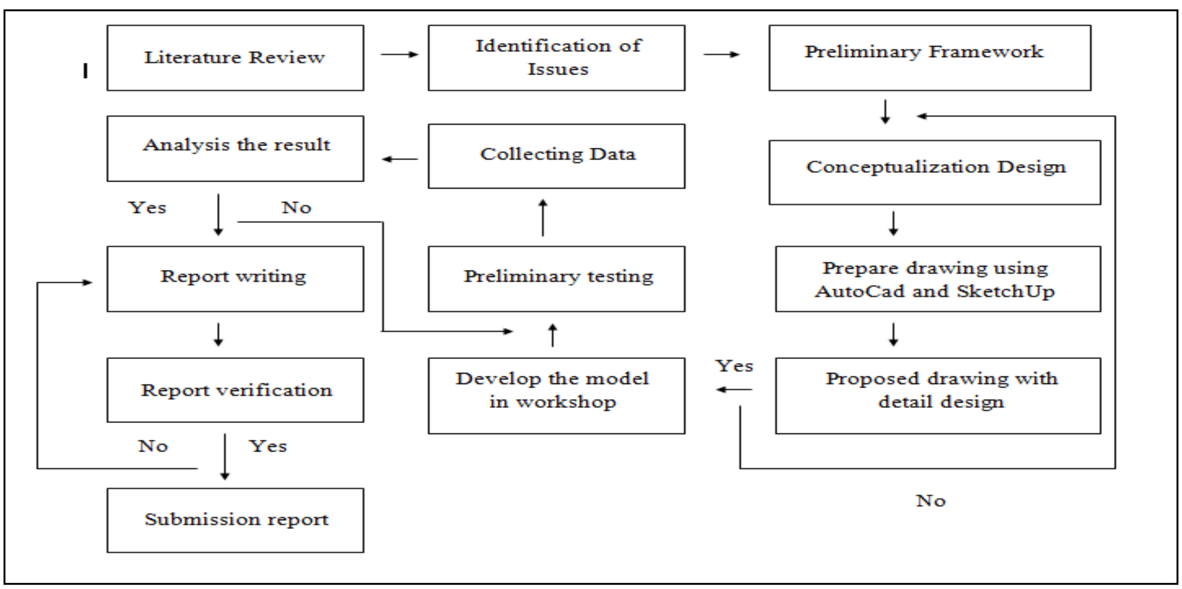


Figure 3: Completed Research Implementation

A rectangular flume was used in this study to simulate the actual natural river condition as shown in the Figures 4 and 5. Flume used in this study has 4.95 m long, 0.69 m wide and 1.26 m depth of rectangular main channel with unfixed bed slope 0.002. The compound channel consists of a straight channel V- shape and double floodplain. The floodplain has been used constructed by using sample of soil that taken from Universiti Teknologi Malaysia farm. The model constructed using plywood based on the dimension requirement. The flume 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 tested. The experiment is conducted under steady flow condition.

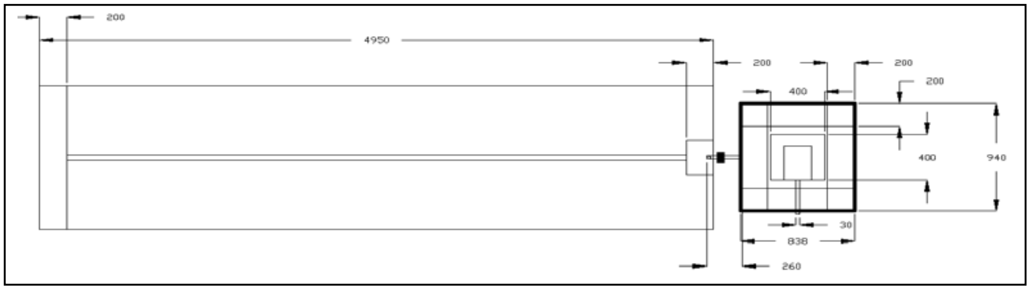


Figure 4: Plan view of main channel (unit: mm)

Figure 5: Natural River Model (a) Natural River model using plywood (b) Implant soil inside the model.

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 6 the soil sample inside the model must be levelled. Therefore, if there is any surface not smooth because it is non-prismatic channel due to characteristics of soil sample.

Figure 6: (a) Outlet (b) Groundwater flow using pipe UPVC

The flow depth is obtained by using a manual point gauge. The point gauge is mounted on the carriage that would be moved along rails attached to the top of flume side walls. The point gauge has an accuracy level up to ± 0.1mm. The flow depth is obtained at any point which is every section of chainage are taken in order to obtain reliable mean readings of flow depth. The measurement of flow depth is taking for every 3120, 4440, and 9960 minutes to ensure that the flow is in non-uniform condition. Figure 7 shows that point gauge is used in the experiment. Velocities in the channel are measured at each chainage across the main channel and floodplain for different depth. The point of velocity is measured by using miniature current meter as shown in Figure 8.

Figure 7: Point gauge

Figure 8: Miniature current meter

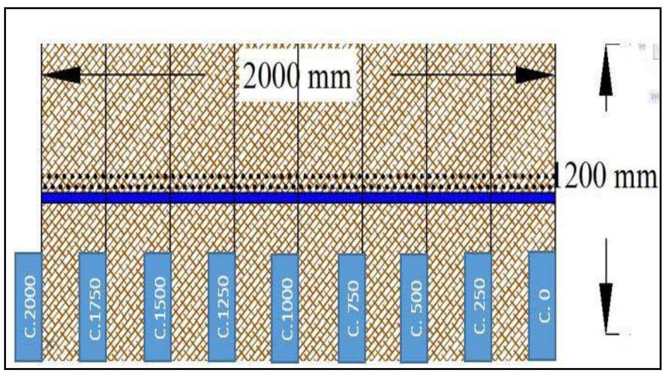


Figure 9: Location velocities measurement

After the instrumentations are completed setup, the experiment can be started and tested for recorded the data. The following are the procedure to conduct the experiment in which each step must be in correct order to achieve the accurate data.

Data Collection

The accurate data can be obtained by using the precise computation and equation. Several equations need to be considering in this research such as relative depth, Manning's roughness coefficient, Froude number and also Reynolds number.

Water depth is measured from point gauge after the water totally stabilized and steady flow is formed. The Manning's n in Equation 1 is a coefficient which represents the roughness or friction applied to the flow by the channel.

$$n = \frac{AR^{\frac{2}{3}} S_O^{\frac{1}{2}}}{Q} \quad (1)$$

where, Q is discharge (m^3/s), A is cross sectional flow area (m^2), V is velocity (m/s), R is hydraulic radius (A/P) (m), S is channel bed slope (m/m), n is manning's roughness coefficient ($sm^{-1/3}$), and P is wetted perimeter (m).

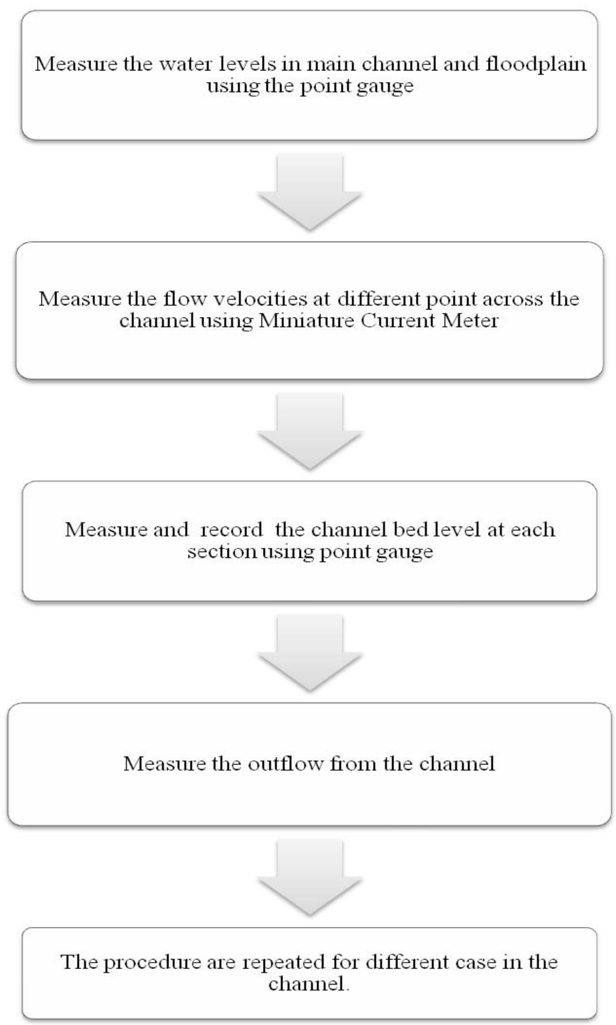
The relative effects of velocity to inertia can be represented by the Reynolds number which is dimensionless number derived through dimensional analysis of the flow. The Reynolds number for open channel flow is given by Equation (2). Moreover, Froude number is defined as a dimensionless number which indicates the relative effects of gravity and inertial forces on the state of flow. The formula of Froude number is written as in Equation (3):

$$Re = \frac{4U_m R}{\nu} \quad (2)$$

where, U_m is the main channel average velocity (m/s) and v is the kinematic viscosity (m^2/s) of the fluid and R is hydraulic radius (m). The flow condition which is classified based on the Reynolds number is stated as: laminar flow (Re < 2000), transition flow (2000 < Re < 4000) and lastly turbulent flow (Re < 4000).

$$Fr = \frac{U_m}{\sqrt{gD}} \quad (3)$$

where, U_m is average flow velocity (m/s), g is gravitational acceleration (m/s^2) and D is hydraulic depth (m).). The Froude number can be categorized as critical, subcritical and supercritical flow. If the Froude number is less than 1, the flow is subcritical. The flow will become supercritical if Froude number is greater than 1. Otherwise, the flow is critical when Froude number reach 1.



Discussions and Results

The experiment has been conducted under steady flow condition. 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.

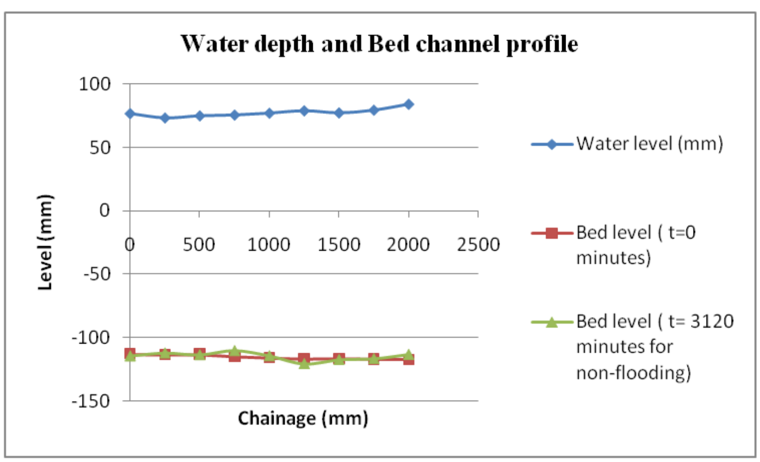
In order to obtain the results and data collection, two equipment are involved which is point gauge to measure the water level and bed level; meanwhile miniature meter has been utilized to collect the point of velocities for each section. The experiment has been conducted under steady flow in non-uniform 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 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.

Water Flow and Channel Bed profile

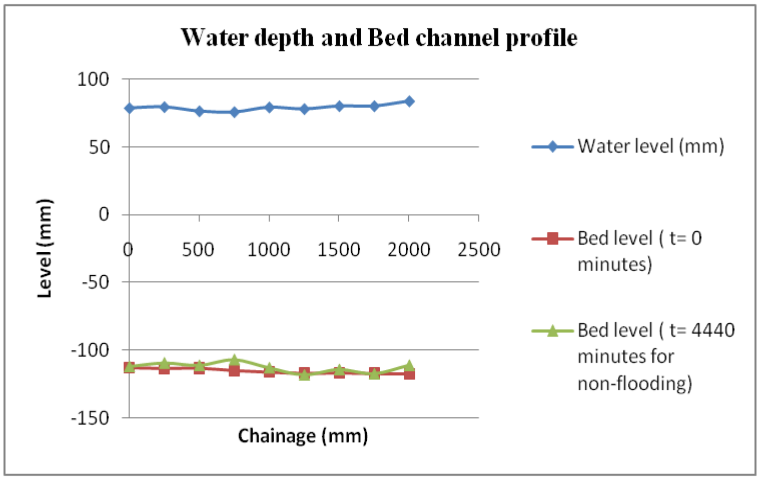
The experiment has been conducted under steady flow because the smaller streams were unstable and out of phase with the steady state condition in the main stream. The channel is divided into nine sections because the dimension of channel might inaccurate due the error during the construction process 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.

Figure 10 and 11 shows that, the comparison water depth and the bed channel profile pattern based on the differences cases which are non-flooding and flooding cases. It is clear that an increase in velocity and decreased depth would require increases in channel slope or decreases of roughness or both. Furthermore the figures show that, the slope for flooding cases steeper slope compare to the slope for non-flooding cases by 25%. This is because the slope is the dependent factor which can be adjusted by the process of erosion and deposition interacts with channel hydraulics.

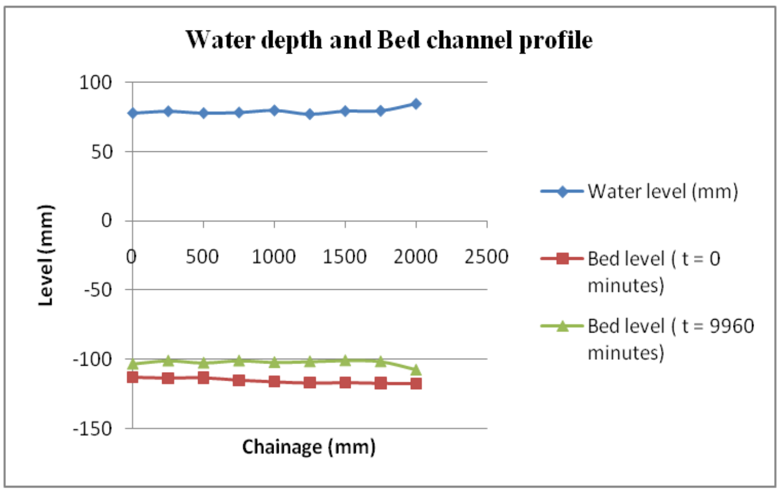
According to Vanoni [8], during the passage of a flood through a given river cross section, the slope of water surface does change. In any given reach slope tends to be steeper during a flood rise than a recession. The steeper slope on the flood rise is due to the fact that the rise at a given cross section precedes the rise at any section downstream. It will be noted, however, that the normal shape of flood hydrograph tends to make the most marked change to slope coincide closely with the passage of the flood crest in a given reach.



(a)

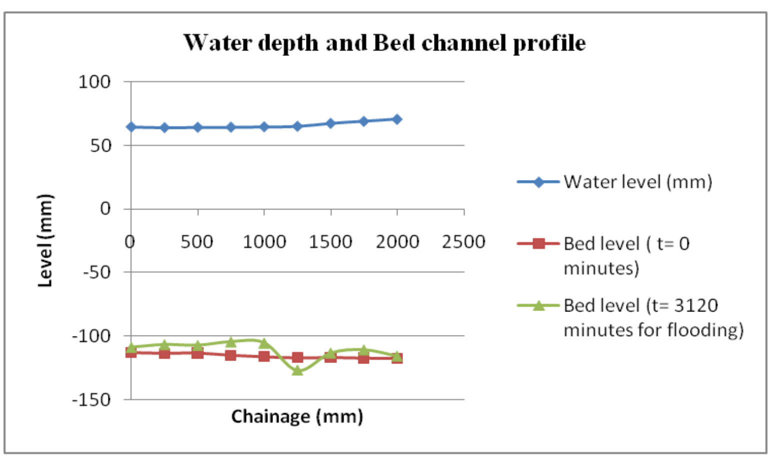


(b)

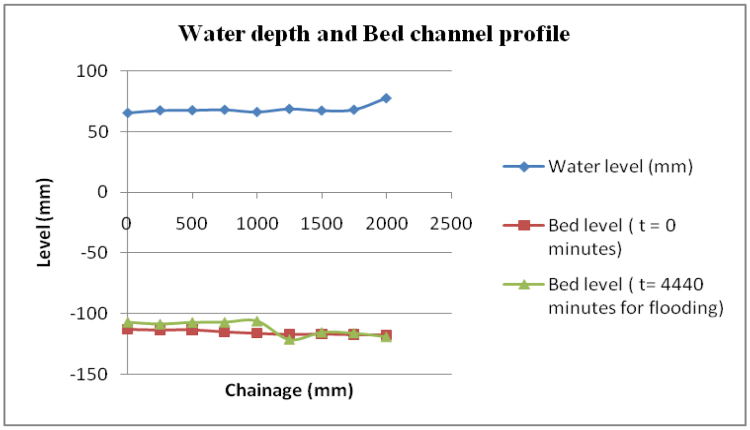


(c)

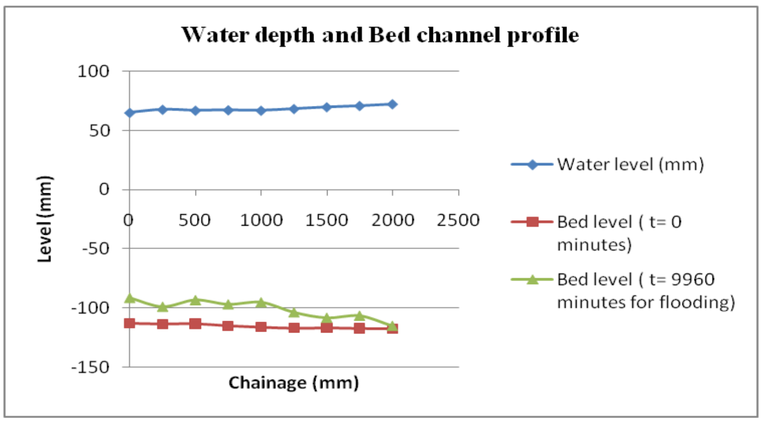
Figure 10: The Water Depth and Slope Profile for non-flooding cases (Q =0.2 L/s)
(a) t = 3120 minutes, (b) 4440 minutes, (c) 9960 minutes.



(a)



(b)



(c)

Figure 11: The Water Depth and Slope Profile for flooding cases (Q =0.6 L/s)
(a) t = 3120 minutes, (b) 4440 minutes, (c) 9960 minutes.

Manning's Roughness Coefficient

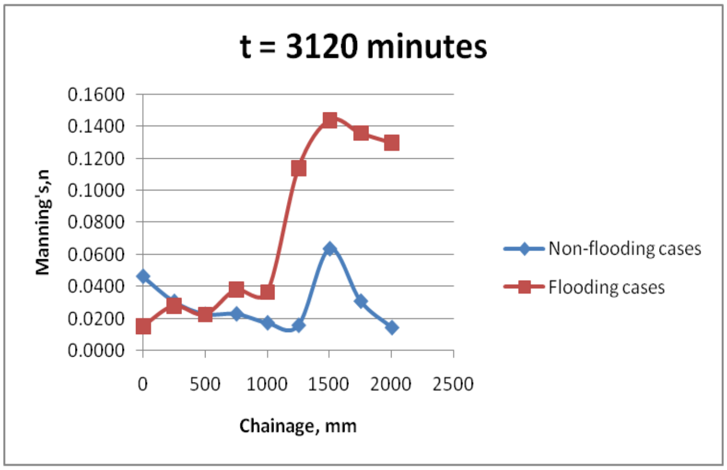
Summary of Manning's roughness coefficient, n relative to stage discharge relationship for non-flooding and flooding cases is tabulated in Table 1 and 2 .The relationship is plotted as in Figure 12 and 13 based on difference times.

Table 1: Summary of channel properties and discharges consideration for non-flooding cases (Q = 0.2 L/s)

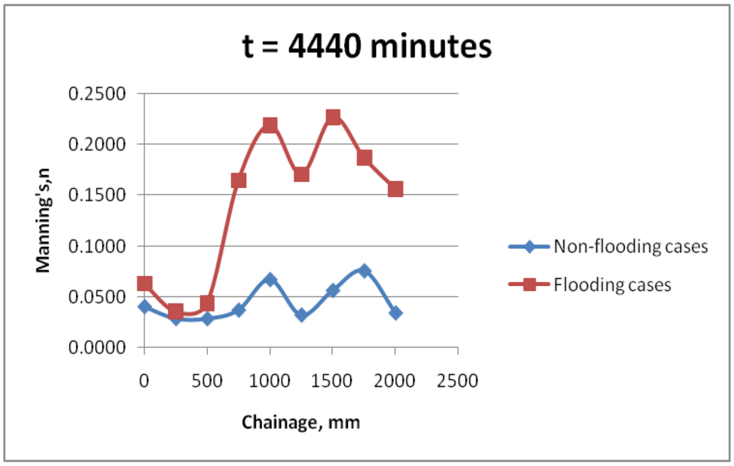
Chainage	H (m)	A (m^2)	So	n
0	0.0778	0.0029	0.001	0.0452
250	0.0774	0.0025	0.001	0.0301
500	0.0765	0.0025	0.001	0.0230
750	0.0766	0.0027	0.001	0.0299
1000	0.0787	0.0022	0.001	0.0325
1250	0.0781	0.0024	0.001	0.0269
1500	0.0790	0.0027	0.001	0.0513
1750	0.0798	0.0023	0.001	0.0504
2000	0.0841	0.0021	0.001	0.0238

Table 2: Summary of channel properties and discharges consideration for flooding cases (Q = 0.6 L/s)

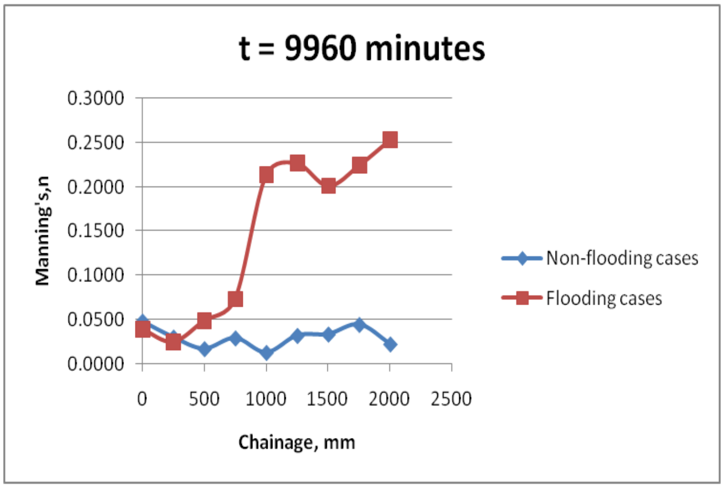
Chainage	H (m)	A (m^2)	So	n
0	0.0651	0.0037	0.007	0.0395
250	0.0665	0.0037	0.007	0.0297
500	0.0664	0.0043	0.007	0.0386
750	0.0667	0.0039	0.007	0.0922
1000	0.0660	0.0046	0.007	0.1564
1250	0.0675	0.0053	0.007	0.1705
1500	0.0683	0.0052	0.007	0.1907
1750	0.0694	0.0046	0.007	0.1824
2000	0.0736	0.0048	0.007	0.1797



(a)



(b)



(c)

Figure 12:Manning's, n for non-flooding and flooding cases based on the difference times (a) t = 3120 minutes, (b) t = 4440 minutes, (c) t = 9960 minutes

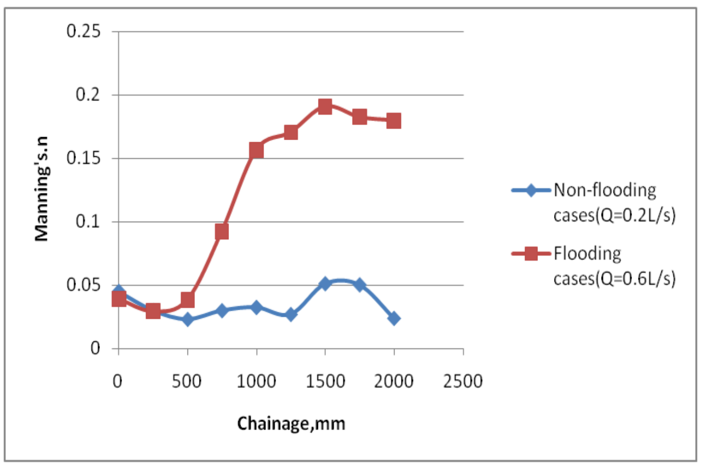


Figure 13: Summary Manning's Roughness for Non-flooding and flooding cases.

Based on Figure 13 for flooding cases shows that, the Chainage distance, mm versus Manning's roughness coefficient, n are increase rapidly due to effect of the inbank flow change to the overbank flow at discharge and at the downstream the value of Manning's roughness are decreased. This is because the tendency for particle size to decrease downstream leads to a tendency for roughness to decreases downstream. As the particles in transit become small enough, the configuration of the bed finally tends to governs, and a further decrease in particle size promotes a tendency for increased roughness. Meanwhile, for the non-flooding cases shows that, the value of Manning roughness's, n versus the distance Chainage, mm are lower compare to the flooding cases. This is because the decrease roughness is caused by the tendency toward increased concentration of suspended sediment as stated in Blench [5].

Velocity distribution

Velocity flow data for particular section have been measured using the Miniature Meter. Velocity distribution is very important to analysis the velocity behaviour in the channel especially between main channel and floodplain.

From the Figure 14 and 15 show that the distribution velocity versus chainage distances. Based on the figure, it has been found that the difference in velocity between the main channel and floodplain is due to the different in depth and surface roughness. This figure also illustrated the increases of flow velocity with respect to flow depth. As the result, for the non flooding cases, clearly show that the maximum flow velocity occurs at the left hand side channel region due to the increase in suspended load. Vanoni [8] observed similar results which are increases in suspended load tend to decrease channel resistance and thus causes an increases in velocity.

For the flooding cases, the velocity distribution on the floodplain is found near to zero due to the effect of decreasing sediment concentration. Generally, the particles rates of increases velocity and depth with increases of discharge downstream required for transport of the load are, therefore, maintained by the downstream decrease of slope.

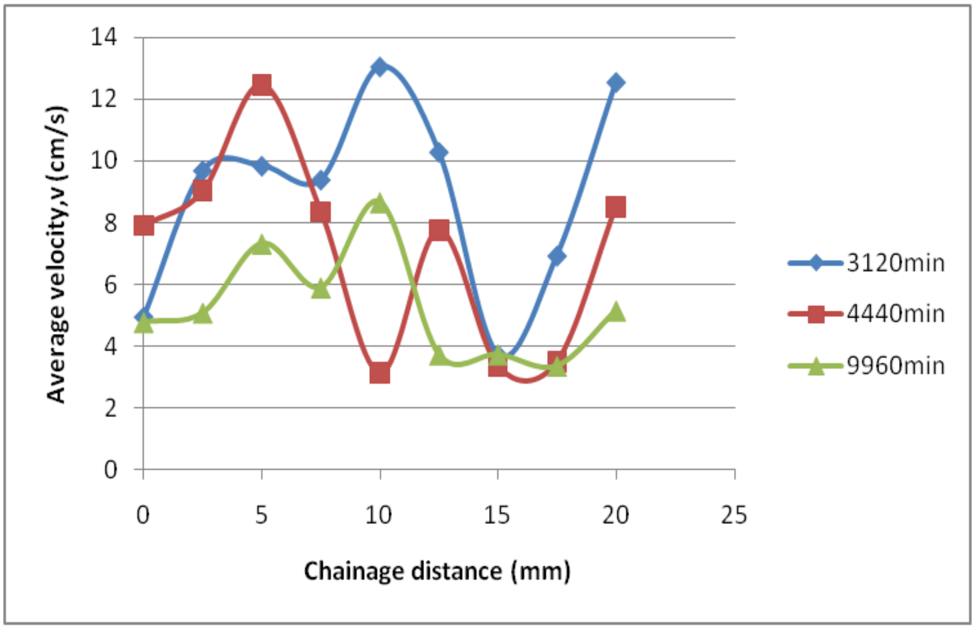


Figure 14: Average velocity distribution for non-flooding cases (Q = 0.2 L/s)

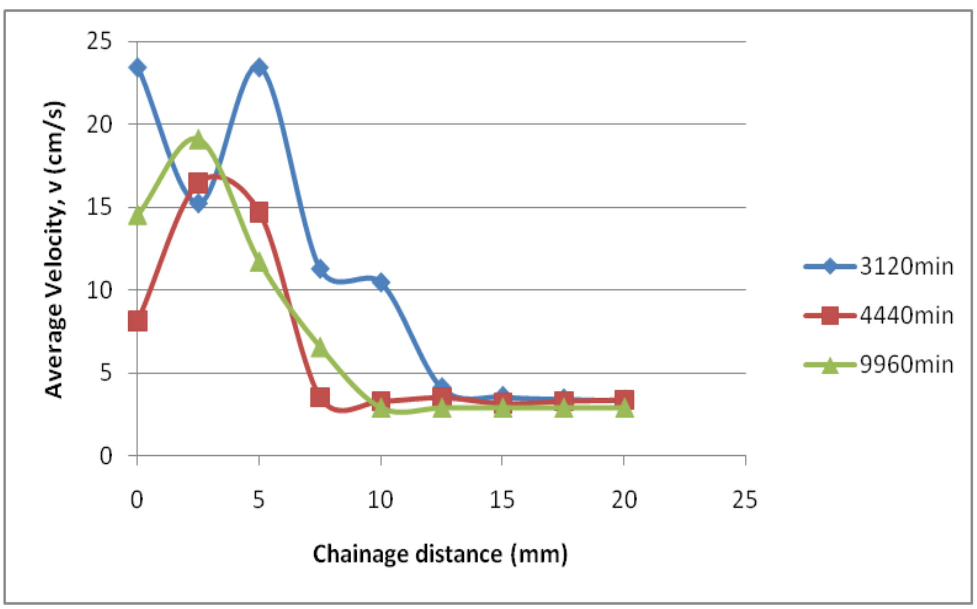


Figure 15: Average velocity distribution for flooding cases (Q = 0.6 L/s)

Conclusion

This study is presented the mechanics of natural river during non-flooding and flooding. The findings of this study are:

(i) A natural river model was constructed in the hydraulic laboratory

(ii) The effect of the slope due to the process of erosion and deposition interacts with channel hydraulics. It's depends on the amount of discharge. So, for flooding cases the discharge is higher than non-flooding cases. Therefore, the slope for flooding steeper than the non-flooding due to the process of erosion and deposition.

(iii) The flow characteristics for compound channel, it experienced turbulent flow which is proved by the Reynolds number that is more than 2000. While for Froude number it falls on the subcritical flow with is less than 1.

(iv) The flow depth increases as the Manning's n increases. This is because the effect of wetted area, A as well as hydraulic radius, R. the manning's roughness n values were found in the range of 0.0238 and 0.1907. According, to Chow, the factor that exert the greatest influenced upon the coefficient of roughness depends on many factors such as surface roughness, vegetation, channel alignment and channel irregularity.

(v) An increase in suspended load tends to decrease channel resistance and thus cause an increases in velocity. Therefore, for flooding cases, the velocity at the downstream near to the zero due to the effect of decreasing sediment concentration.

References

[1] Zulhilmi I., Sobri H. and Zulkiflee I. (2009). *Determination of Flow Characteristics in the Vegetated Compound Channels* (UTM IRGS vote no. 78286), Final Report, October 2009, 66.

[2] Zakaria(2007).*Pengurusan Sungai Mapan: Dan Perspektif Kejuruteraan Pengangkutan Endapan Dan Keseimbangan Sungai*. (http://www.redac.eng.usm.my/html/syarahan_prof/sinopsis AGG pdf.

[3] Subramanya K (1997), *"Flow In Open Channel"*. Tata McGraw-Hill Publishing Company Limited New Delhi.

[4] Chow, V. T. (1959). *Open-Channel Hydraulics.*McGraw-Hill Book Company.Inc., New York.

[5] Blench, Thomas, 1951a, *Hydraulics of sediment bearing canals and rivers*, Evans Industries Lts., Vancouver, B. C., Canada.

[6] Kalimuddin, N. M. (2012), *Flow Charadteristic for Shallow and Deep Flows in A Non-Vegetated Meandering Channel*. Final Year Project Report. Universiti Teknologi Malaysia.

[7] Ismail, Z., and Shiono, K. (2006). *The Effect of Vegetation along Cross-Over Floodplain Edges on Stage Discharge and Sediment Transport Rates in Compound Channels.*Proceeding of the 5th WSEAS International Conference on Environmental, Ecosystems and Development, Venice, Italy, November 20-22, pp. 407-412.

[8] Vanoni, V. A., 1941, *Some experiments on the transportation of suspended load:* Am. Geophys. Union Trans., pt. 3, pp. 608-620.

[9] Hjulstrom (1935). Hjulstrom and ASCE Studies. In Chih Ted Yang. *Sediment Transport Theory and Practical*.(pp. 24-26). McGraw-Hill.