Non-Flooding and Flooding Characteristics of a Natural Straight River

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Abstract. Floods happen when the flow of water exceeds the river banks and flow through the floodplain area, which is known as overbank flow. Flood causes damage to infrastructure and buildings and loss of life. Therefore, this paper investigates the characteristics of pattern river development; width, depth, and flow within the channel. This physical modelling discusses the pattern of the river by employing the current meter and point gauge equipment to collect and record the data along the channel. The discharge of 0.2 L/s and 0.5L/s were used for non-flooding and flooding cases. The non-flooding and flooding cases were identified by using a rectangular flume known as “Flexible Channel Flume”. The flume used in this study has 4.95 X 0.69 X 1.26 m of the rectangular main channel with a non-fixed-bed. As a result, the flooding case shows the depth of the channel increasing at the upstream and decreasing at the downstream compared to the non-flooding case with changes of velocity and manning’s roughness coefficient n.

1. Introduction

Rivers are the major sources by which this excess water flows to the ocean. The sources of rivers are part of the hydrological cycle process [1]. Surface runoff from the hydrological cycle will flow on the land from the upstream to the downstream nearby the rivers, lakes, springs and oceans [2]. The water flow in river depends on the channel surface and flow resistance that influenced by gravity fraction and friction [3]. Furthermore, if the volume of water exceeds the capacity of river channel, it could create a flood disaster that cause damages in infrastructures and affect developing country civilizations. A river flood happens when the river overspills from its bank which is the floodplain areas, whereas the flow of river overspill from the river channels area [4]. The water will flow through the floodplain when the water level reaches above the capacity river volume. Most of floodplains in river normally adjacent to the main channel [4–7]. The interface between main channel and floodplain produces momentum transfer due to different velocity distribution at both conditions [2]. Generally, the velocity distribution in main channel of river is bigger than velocity distribution in floodplain area boundaries [8]. The velocity distribution is zero at the boundaries and gradually increased with the distance from the boundaries and the maximum velocities happen at a certain distance from the below of free surface [3,9].

The changes of velocity distribution were effected due to the secondary current which is the aspect ratio (ratio of depth to width) of the channel [10-11]. In addition, the changes of velocity distribution depend on other factors, such as unusual shape and the roughness of the channel [12-13]. The maximum velocity distribution may often found in free surface at smooth channel, rapid and shallow
stream [14]. Manning formula was used for all flow in channel and the hydraulic radius in the Manning formula is depends on the shape and roughness of channel [14]. The average Manning’s n value for non-flooding case is lower compared to flooding case. The roughness of channel is affected by the concentration of sediment; whereas smaller concentration of sediment being associated with bigger value of roughness [6,8,15]. The sediment transport occurred in the straight channel of main channel experiment [6,7,16]. The sediment transport will decrease when the velocity distribution decrease in the main channel. However, the velocity at main channel and floodplain area were difference due to the depth and surface roughness, respectively [3,4,7–10]. The velocity at river channel affects the erosion and depositions of sediments due to the movement of water [16]. It may results on modification of bed profile surface from upstream to downstream of river channel [15]. In addition, deposition of sediments on bed profile gives a higher resistance; whereas induces velocity reduction [4,15,17]. There are many researchers studied on flood issues [7,15,17–20] with different parameter such as velocity distribution, bed profile for erosion and sedimentation process. The knowledge of characteristic of pattern river development during flooding and non-flooding cases is necessary. Therefore, the objectives of this study are to investigate the mechanics of sustainable straight flume river in flooding and non-flooding cases by characterizes the river pattern development: (i) Width (ii) Depth (iii) Flow within the channel.

2. Material and Method

This study involves data collection through a physical experiment by using a flexible channel flume in a straight channel. The natural laterite soil was collected from latitude 1°33'44.5"N and longitude 103°37'26.8"E in the Farm of Universiti Teknologi Malaysia at Skudai, Johor. The laterite soil was obtained about 1 meter below the ground surface to prevent weathered soil and dried soil sample collected. The sustainable flume was constructed using L-steel as structure and plywood as the wall of the flume based on the dimension requirement as shown in Figure 1 (a). The flume was covered with canvas and every connection of plywood with L-steel was sealed with silicon to prevent any leakage during testing. Figure 1 displays the rectangular flume with dimension of 4.95m x 0.69m x 1.26m (length x width x depth) and bed slope 0.002. The channels consist of a v-shape channel and a double floodplain. Several equations (Froude Number, Manning’s n roughness, and Reynold Number) and equipment were used to achieve the objective of this study. Current meter flow and point gauge were used to determine the flow rate and bed profile of the channel. Accurate data can be obtained through precise computation and equation in this study, whereas such as relative depth, Manning’s roughness coefficient, Froude number, and also Reynolds number. In addition, the experiment is conducted under non-steady flow condition. The flow rate and bed profile were recorded at a different stage of flow (S1 until S9) as shown in Figure 1 (b).

2.1. Hydraulic Characteristics

Water depth was measured and recorded using a point gauge in steady flow at a different stage. Manning’s n represents the roughness applied to the flow of the channel as shown in Equation 1. The relationship of velocity with respect to inertia can be summarized as the Reynolds Number whereas dimensionless digit value through the dimensional analysis of the flow of channel as mentioned in Equation 2. In contrast, the Froude Number is calculated between gravity and inertial forces in the flow state as display in Equation 3. The Reynold Number is identified based on the flow condition as stated as: laminar flow (Re < 2000), transition flow (2000 < Re < 4000) and turbulent flow (Re < 4000). The Froude number can be classified; equal to 1 as critical, less than 1 as subcritical, and more than 1 as supercritical flow.

\[
n = \frac{2}{AR^2S_0.5} Q^{1/2}
\]  

(1)
where, $Q$ is discharge ($m^3/s$), $A$ is cross-sectional flow area ($m^2$), $V$ is the velocity ($m/s$), $R$ is the 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 ($m$).

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

where, $U_m$ is an average velocity ($m/s$) of the main channel, $v$ represents fluid kinematic viscosity ($m^2/s$) and $R$ is the hydraulic radius ($m$).

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

Where $g$ represents as a gravitational acceleration ($m/s^2$) and $D$ is hydraulic depth ($m$).

Figure 1. Sustainable Flume with Straight Channel.
3. Analysis and Results
The experiment has been conducted under steady flow conditions. The classification of flow in a channel is turbulence with subcritical flow conditions whereas Reynolds number more than 4000 and subcritical flow condition occurs when Fr is less than 1. Therefore, the regime of flow classified as subcritical-turbulence for the straight compound channel. The sustainable straight flume on non-flooding and flooding cases in experimental is briefly discussed in the following subsequent sections.

3.1. Flume and Profiler Rails Calibration
Profiler rails calibration in the straight flume is needed for accuracy of measurement reading especially on the water surface and bed profile. In order to obtain the bed profile, leveling has been conducted along the main channel and floodplain surface. The leveling process was taken from upstream until downstream with a 250mm pre-determined interval. The bed slope of the straight flume is obtained and approximately 0.002 values through the best line fit as shown in Figure 2.

![Bed Slope Channel Profile Calibration](image)

**Figure 2.** Bed Slope Channel Profile Calibration.

3.2. Flume and Profiler Rails Calibration
The flow of water and bed profile of channel were measured and recorded at a pre-determined time. The recorded results of data were used to calculate the velocity, flow rate, and erosion sedimentation along the channel. Figure 3 illustrates the water depth and bed channel profile pattern with different cases which are non-flooding and flooding. It is clearly seen flooding case shows the channel bed profile increases 25% compared to non-flooding case. The changes of channel bed slope due to the flow rate by the process of erosion and deposition interact with the channel as shown in Figure 3(b). It is valid as stated by [21] the normal shape of channel tends to make a change with flood effect.
3.3. Manning’s Roughness Coefficient

Manning’s roughness coefficient $n$ is the friction or roughness to the flow of the channel. Table 1 and Table 2 display the Manning’s roughness coefficient $n$ for non-flooding and flooding cases. It is observed that the roughness coefficient is increasing in-bank either in non-flooding or flooding cases. Meanwhile, the roughness coefficient for the flooding case is higher compared to the non-flooding case. The changes of roughness coefficient due to the particle size movement to the downstream. As the particles in transit become small enough, the configuration of the bed finally tends to govern, and a further decrease in particle size promotes a tendency for increased roughness.
Table 1. Manning Roughness n Value for Non-Flooding Cases for each Section.

| Sections | H (m) | A (m²) | S₀ | n   |
|----------|-------|--------|----|-----|
| S1       | 0.0778| 0.0029 | 0.001| 0.0452|
| S2       | 0.0774| 0.0025 | 0.001| 0.0301|
| S3       | 0.0765| 0.0025 | 0.001| 0.0230|
| S4       | 0.0766| 0.0027 | 0.001| 0.0299|
| S5       | 0.0787| 0.0022 | 0.001| 0.0325|
| S6       | 0.0781| 0.0024 | 0.001| 0.0269|
| S7       | 0.0790| 0.0027 | 0.001| 0.0513|
| S8       | 0.0798| 0.0023 | 0.001| 0.0504|
| S9       | 0.0841| 0.0021 | 0.001| 0.0238|

Table 2. Manning Roughness n Values for Flooding Cases for each Section.

| Sections | H (m) | A (m²) | S₀ | n   |
|----------|-------|--------|----|-----|
| S1       | 0.0651| 0.0037 | 0.007| 0.0395|
| S2       | 0.0665| 0.0037 | 0.007| 0.0297|
| S3       | 0.0664| 0.0043 | 0.007| 0.0386|
| S4       | 0.0667| 0.0039 | 0.007| 0.0922|
| S5       | 0.0660| 0.0046 | 0.007| 0.1564|
| S6       | 0.0675| 0.0053 | 0.007| 0.1705|
| S7       | 0.0683| 0.0052 | 0.007| 0.1907|
| S8       | 0.0694| 0.0046 | 0.007| 0.1824|
| S9       | 0.0736| 0.0048 | 0.007| 0.1797|

3.4. Indicating the corresponding author’s e-mail

Figure 4 and Figure 5 illustrates the graph of the main channel versus chainage for non-flooding and flooding cases. It has been found that the difference in velocity between the main channel due to the difference of roughness coefficient n and depth of the main channel. The flow of velocity increased with respect to the flow of depth. The velocity increase when the resistance of the channel decrease due to the suspended load. The channel known as non-prismatic channel, the cross sectional shape and bed slope differ along the channel due to erosion and sedimentation process. Generally, the increase of discharge from upstream will increase the velocity and the depth of flow in the main channel with the sedimentation suspended load as shown in Table 1 and Table 2.

Figure 4. Graph of Main Channel Velocity versus Chainage for Each Section for Non-Flooding Cases.
Figure 5. Graph of Main Channel Velocity versus Chainage for Each Section for Flooding Cases.

4. Conclusion
The objectives of this study are to determine the Manning’s roughness coefficient Froude Number and Reynold Number parameters. These parameters completely answered the characteristics of the non-flooding and flooding cases. As a result, the channel bed slope of the sustainable flume with flooding case is shallow compared to non-flooding case. The changes of channel bed slope influenced by the Manning’s roughness coefficient. Manning’s roughness coefficient \( n \) increased rapidly when the discharge increased in flooding cases compared to non-flooding cases. In addition, Manning’s roughness coefficient \( n \) is increased at the end of chainage sections for each case. Changes of velocity in the main channel from 0 chainage to 2000 chainage are because of the flowrate from the upstream. The flow of water affected the suspended load at the upstream, and it will undergo erosion and sedimentation process. In conclusion, flooding cases could affect the soil erosion and sedimentation based on the height of surface channel. It will lead to increasing water depth and critical on the flood. Physical modelling of sustainable flume channel helps the government and consultancy to overcome the issue of flood in Malaysia and understanding the characteristics of the river pattern.

5. References

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**Acknowledgments**

This study was supported by the Research Management Centre (RMC), Universiti Teknologi Malaysia under the Research University Grant, UTMFR vote number Q.J130000.2521.21H26. The authors would like to thank their respective Hydraulic and Hydrology Laboratory, School of Civil, Faculty of Engineering, Universiti Teknologi Malaysia for the cooperation given for this research. Highest appreciation is also expressed towards the Kings’ Scholarship and UTMLead for supporting this research study and all whom were involved either directly or indirectly.