Experimental Study for Determination of Bed Roughness in Open Rectangular Channel

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Abstract. The experiments are carried out in a straight rectangular compound channel with fixed and nonaggregated bedding. The objectives of this study are to determine the bed roughness and flow characteristic in the open rectangular channel. This study was conducted in the hydrology and hydraulic lab at University Tun Hussein Onn Malaysia. Flume was divided into five parts starting from 1.25m to 6.25m. There are three parameters that tested in a flume with a clear channel, crushed and coarse aggregates. The flow rate was observed with three different values of 0.007m³/s, 0.011m³/s, and 0.015m³/s. The data collected was taken by three parameters that were clearly, crushed and coarse aggregate. From the study, the value derived from the bed acquired in the study was between 0.008 to 0.018 for a clear channel, 0.030-0.013 for the crushed aggregate and 0.016-0.041 which was crushed for coarse aggregate.

1. Introduction
According to Subramanya [1], Manning’s n is the most popular and mostly used by the researchers until this 21st century. This equation was obtained in 1891 by Robert Manning, an Irish engineer, for uniform flows in open vessels. This is mainly dependent on the blackness of surfaces and factors such as a cross area, silting channel, blocking, and flow depth. The bed roughness in open channels has also been studied by many researchers, such as Myer [2], Shiono [3], and Yang et. al [4]. Based on Mohan [5], the influence of the width ratios of main channel to floodplain on the redistribution of flow resistance. The n value was presented for a different rough surface. Laboratory and natural channels may have different roughness in different parts of the wetted perimeter. The lab channel may have glass on the side of the wall with a rough bed. The canal of the water rope sometimes has been lined at the top. The natural tract or river usually has a sand bed in the main part of the channel and the flood on both sides may have plants as the value of n in different parts along the perimeter may different [6].

Laboratory studies can use special equipment to find out which procedures or treatments may be researched on a useful site. The use of hydraulic theories to artificial tract will produce fair results near real and practical conditions for practical design purposes. Yong Mei et.al [7] mentioned in a rectangular channel, the use of common parameters is the height of dams for dam heads resulting in improper changes in variable dimensionless variables, where the flow rate is considered dependent.

Normally, a problem occurs when the downstream velocity is high. Other than that, water that overtopped the roadway affects the damage system due to erosion [8]. This can be observed after a few years been operated. This problem often occurs at the channels end defect such as crack and break can easily be found in culverts that discharge water for rivers and wetlands. According to Knight [9], velocity
is sturdily related to one of the most important elements in the relations between fluid flow and the channel boundary which flows resistance.

Velocity will always fluctuate due to the depth of the channel and also the surface of the channel. Mostly, the surface of the channel has existing sediments, vegetation and also aggregates or stones that could affect the flow characteristic. Therefore, the study needs to be done to determine the flow characteristic in the rectangular channel. Besides that, another common problem normally occurs is when the channel is unable to accommodate the volume of water. This normally happens in the area with a rapid growth environment. Moreover, with the high volume of water flow, there will be a formation of scour at downstream of a discharge channel due to high velocity that creates a hydraulic jump phenomenon, stated by French [10]. The water will spill out from the channel, due to the above-mentioned defect; some amount of water will be absorbed by the soil and reduced the slope stability. Generally, most of the previous studies focused on the behaviour of flow structure in channels with either aggregates or non-aggregate on bed roughness. It is however noticed that when flow increases in a channel, the bed roughness also increases. Even though there are existing studies that describe bed roughness–flow patterns, their successful application in real situations is still rare because of limited specifics or description of the effects on the flow structure caused by the bed roughness in most natural channel system. This study was hence prompted by a necessity for a detailed understanding in flow behaviour in channels affected by bed roughness with different types.

This main focused of this study is to study the bed roughness and flow characteristic in the open rectangular channel. Experiments were conducted under two different types of bed roughness using the rectangular open channel flume in the Laboratory of Water Resources, Universiti Tun Hussein Onn Malaysia. The value of $n$ is commonly based on bed roughness [11].

2. Material and methods

2.1. The experiment setup and conditions
The experimental study was carried out in the Hydraulic and Hydrology Laboratory of Water Resources in Universiti Tun Hussein Onn Malaysia. A rectangular horizontal flume, which dimension of 10 m long, 0.3 m wide and 0.45 m deep glass-walled flume is used along the experiment process as shown in Figure 1. The size of this rectangular channel was used in this experiment so that other variables could be kept the same for instance channel shape and velocity of flow. Water was supplied from the storage provided in the laboratory using the pump. Side weirs of the rectangular channel were made of glass.

![Figure 1. Schematic diagram of the rectangular channel.](image-url)
There are three types of roughness that had been used in this experiment which are a channel with a gravel bed, channel with corrugated bed and clear channel (bed of the flume). The length for each gravel bed and the corrugated bed is 0.835 m length as shown in Figure 2 and Figure 3 below. Each consists of three modules arranged to cover a 2.505 m length. The uniform flow was determined by considering that the water still in the storage tank. The average speed was taken at three different locations and the average value was used to acquire the bed roughness coefficient. The aggregate bed sample was placed into the rectangular open channel. Several value for discharge were used in this experiment which is $Q = 0.007 \text{ m}^3/\text{s}$, $0.011 \text{ m}^3/\text{s}$ and also $0.015 \text{ m}^3/\text{s}$. The time was recorded using an electronic alarm clock. This step was repeated by using gravel and corrugated bed and with a clear channel for controlling data. Data was collected and analyzed using the bed roughness equations and then tabulated into the table and the graph was plotted.

3. Results and discussions
The result from three different discharge values, $Q$ which is $0.007 \text{ m}^3/\text{s}$, $0.011 \text{ m}^3/\text{s}$ and $0.015 \text{ m}^3/\text{s}$ were analyzed using three different types of beds which are a clear channel (no bed channel), gravel bed and corrugated bed (Figure 4-6).

3.1 (a) Data analyzed by using a clear channel (no bed channel) as controlling

![Figure 4. Time vs distance obtained from three different flow rate, $Q$ ($\text{m}^3/\text{s}$).](image-url)
(b) Data analyzed by using gravel bed

![Figure 5](image1.png)

**Figure 5.** Time vs distance obtained from three different flow rate, Q (m³/s)

(c) Data analyzed by using corrugated bed

![Figure 6](image2.png)

**Figure 6.** Time vs distance obtained from three different flow rate, Q (m³/s).

Based on Figure 5 and Figure 6, by using gravel bed and corrugated bed, the range of average time was stated at 1.2 sec to 2 sec with distance 0.8m to 2.5 m when flow rate at 0.007m³/s. While at Q = 0.015 m³/s and 0.011 m³/s, it shows the value of 1 sec to 1.5 sec at a distance of 0.8m to 2.5m. When using the controlling bed with the clear bed, the time stated between the range of 0.8 sec to 1.4 sec for Q=0.007 m³/s, Q=0.011 m³/s, and Q=0.0015 m³/s respectively as stated in Figure 4.

3.2. Graph of bed roughness/Manning’s n and flow rate

The graph in Figure 7 shows that the value of bed roughness, n is inversely proportional to the flow rate. Based on the graph, it stated that the value of flow rate is increased rapidly with decreased of bed roughness in clear channel. The range of bed roughness with gravel bed is between 0.014 to 0.016 while with a corrugated bed, the value of bed roughness ranges from 0.007 to 0.008. This is proved by the Manning’s equation, $Q = \frac{1}{n}AR^{2/3}\sqrt{S}$ when the flow rate increased, the bed roughness was decreased.
3.3. Graph of bed roughness and velocity

From the graph obtained in Figure 8, it is proved that the bed roughness value is inversely proportional to the velocity, V of the flow in the flume. Each type of bed used shows the same result. Based on the graph obtain, the value of bed roughness when using gravel bed and the corrugated bed is between 0.014 – 0.016 and 0.015-0.018 respectively. While with a clear channel, it shows the value of bed roughness between 0.007-0.008. This is shown based on the formula equation of \[
V = \frac{10}{n} \left( \frac{A}{P} \right)^{2/3} \sqrt{S}.
\]

3.4. Graph of flow depth and velocity

The plotted graph in Figure 9, stated that the depth of water increased rapidly with the increase in the value of velocity. The purpose of computing this graph was to investigate the different depth of water when using a different result for the velocity of water flow in the channel. This result was supported by the equation from \( V = \frac{Q}{A} \), where the value for depth of water will affect the value of the area of the channel, which also eventually increases the value of the velocity of the flow. Summary of experimental analysis was plotted in Table 1.
### Table 1. The summary of the analysis.

| Type of bed roughness | Flow Discharge, Q (m³/s) | Average calculated flow discharge, Q\textsubscript{average} (m³/s) | Average velocity, A\textsubscript{average} (m/s) | Average range of bed roughness n | Value for n provided by MSMA |
|-----------------------|--------------------------|---------------------------------------------------------------|---------------------------------|-------------------------------|-------------------------------|
| Clear channel         | 0.007                    | 0.022                                                         | 0.616                           | 0.0074 – 0.0083               | Less than 0.0083              |
|                       | 0.011                    | 0.036                                                         | 0.746                           |                               |                               |
|                       | 0.015                    | 0.067                                                         | 1.005                           |                               |                               |
| With gravel bed       | 0.007                    | 0.056                                                         | 0.544                           |                               |                               |
|                       | 0.011                    | 0.074                                                         | 0.630                           | 0.0151 – 0.0181               | Between 0.015 to 0.035       |
|                       | 0.015                    | 0.107                                                         | 0.754                           |                               |                               |
| With corrugated bed   | 0.007                    | 0.048                                                         | 0.543                           |                               |                               |
|                       | 0.011                    | 0.070                                                         | 0.656                           | 0.0141 – 0.0161               | Between 0.012 to 0.017       |
|                       | 0.015                    | 0.093                                                         | 0.746                           |                               |                               |

### 4. Conclusions

Experimental work has been analyzed into two different bed material with different slope and discharge. Based on the data obtained and analysis, it can conclude that the value of the bed depends on the condition, the open channel features and the presence of flow resistance. According to the graph obtained, if a higher-velocity reading and flow rate, it will cause a lower value for Manning’s n coefficient. It was found that the flow resistance coefficient is between 0.0074 – 0.0161, depends on the type of bed roughness use and the value of flow discharge that has been used. The flow resistance coefficient generally depends on the flow depth. When the flow depth increase, the n value also increases. Channel with gravel bed recorded bed roughness value in between 0.0151 – 0.0181 while for a channel with corrugated bed recorded Manning’s coefficient value in between 0.0141 – 0.0161. As for blank data, it recorded the value in between 0.0078 – 0.0083. This proves that the bed roughness presence gives a high impact on the open channel in terms of roughness, velocity, and flow. The roughness of the open channel is influenced by the density distribution, flow depth and physical characteristics of the bed roughness itself.
5. References

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