Experimental Study of Flow Characteristics in A Rectangular Gravel Bed Channel

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Abstract. In an open channel flow, the characteristics of flow resistance are greatly affected by the roughness of the base and the walls of the channel. The existence of an object or other material, including gravel, also influenced the resistance of flow, therefore the purpose of this study is to examine the flow characteristics (flow velocity and flow resistance) in gravel open channel by using experimental study. A laboratory study to explore the effect of channel bed in terms of roughness of types of sediment on the hydraulics flow in 8 m length x 40 cm width a rectangular channel is presented. The study consists of an extensive set of rectangular flume experiments for flows with certain slope and sediment bed. The study was using the Before After Control Impact (BACI) method by set up five different scenarios. The results show that the lowest flow velocity (\(v=0.3041\) m/sec) was occurred in the scenario 3 (50%sand and 50%gravel). Based on the Manning’ coefficient (\(n\)), it was also found that at the 100% discharge flow condition, the highest value of friction factor (\(f=0.0780\)) within 5 scenarios was scenario 3 with the sediment consisted of 50%sand and 50%gravel. Whereas the value of the lowest friction factor(\(f=0.0652\)) was scenario 1 with the sediment only gravel within. It concluded that the results gave the lower value of Manning’ coefficient (\(n\)) compared to the table of Manning’s coefficient (\(f= 0.04\)) for the channel with gravel base condition.

1. Introduction
In recent years, rapid development and the changing land-use are major factors causing frequent floods and become an issue of growing concern around the world[1–3]. Floods generally can be caused by natural and human factors[4–6]. Natural factors included heavy rainfall intensity and the other hydrologic responses[7]. It also depends on the physiographic characteristics (slope, soil texture, cover land, rocks permeability, and profile curvature) of the affected area. Meanwhile, human factors included blocking of channels or aggravation of drainage channels, improper land-use, deforestation in upper watersheds, etc. An open channel both in natural channel and human-made channel is a waterway, drainage channels or conduit in which a liquid flow with a free surface. An open channel flow describes the fluid motion in open channel such as rivers or streams. In natural channels, the characteristics of flow resistance are greatly affected by the roughness of the base and the walls of the channel[8–10]. The existence of an object or other material, including gravel, also influenced the
resistance of flow, therefore the purpose of this study is to examine the flow characteristics (flow velocity and flow resistance) in gravel open channel by using experimental study.

2. Methods
In this study, we addressed this problem by proposing experimental study that set up at Hydraulic Laboratory, Civil Engineering Department, Maranatha Christian University. A laboratory study to explore the effect of channel bed in terms of roughness of types of sediment on the hydraulics flow in 8 m length x 40 cm width a rectangular channel is presented (Figure 1 and 2). The study consists of an extensive set of rectangular flume experiments for flows with certain slope and sediment bed. The study was using the Before After Control Impact (BACI) method by set up five different scenarios. (Table 1).

![Figure 1. Rectangular Channel: Physical Model (a)](image1)

![Figure 2. Rectangular Channel: Physical Model (b)](image2)
Table 1. Results of Sieve Analysis

| Scenario | Type of material       |
|----------|------------------------|
| 1        | 100% coarse            |
| 2        | 100% sand              |
| 3        | 50% coarse 50% sand    |
| 4        | 30% coarse 70% sand    |
| 5        | 70% coarse 30% sand    |

2.1. Preliminary Study

There are two main analysis in preliminary study that should have been completed for analyzing the flow characteristics (Manning coefficient, Chezy Coefficient and friction factor):

2.1.1. Discharge Rating Curve.

The purpose of drawing the discharge rating curve is to determine the maximum discharge from a channel and to obtain a defined discharge in experimental study. A rating curve is a graph of discharge versus stage for a given point on a stream or open channel. The results of discharge rating curve in this study can be seen in Figure 3.

![Figure 3. Discharge Rating Curve](image)

2.1.2. Sieve Analysis.

The purpose of conducting the sieve analysis is to determine the grain size of the soil, to classify the soil, and to obtain the uniformity coefficient (Cu) and gradient coefficient (Cc) from the grain size curve distribution. This research uses gravel and sand aggregates which are then placed in the rectangular channel. To classify the aggregate of gravel and sand, it is necessary to do the sieve analysis process first. The sieve analysis is carried out by set up the weighed aggregate into a set of pre-arranged sieves. Then a set of filters is inserted into the vibrating device for 15 minutes. After the sieve analysis test is carried out, the weight data needs to be processed in order to obtain the retained percentage and D_{10}, D_{30}, D_{60} which will be used for sediment classification. Initial aggregate weight is 1000gr. The results of sieve analysis can be seen on Table 2.

![Chart showing sieve analysis results](image)
Table 2. Results of Sieve Analysis

| Sieve No. | Sieve Opening (mm) | Weight Soil Retained (gr) | Percent Retained (%) | Percent Cum Retained (%) | Percent Finer (%) |
|-----------|--------------------|---------------------------|----------------------|-------------------------|-------------------|
| 4         | 4,750              | 378                       | 40,170               | 40,170                  | 59,830            |
| 10        | 2,000              | 189                       | 20,085               | 60,255                  | 39,745            |
| 20        | 0,850              | 108                       | 11,477               | 71,732                  | 28,268            |
| 35        | 0,500              | 70                        | 7,439                | 79,171                  | 20,829            |
| 100       | 0,150              | 86                        | 9,139                | 88,310                  | 11,690            |
| 200       | 0,075              | 54                        | 5,739                | 94,049                  | 5,951             |
| pan       |                    |                           | 5,951                | 100,000                 | 0,000             |
| Total     |                    | 941                       | 100,000              |                         |                   |

Figure 4. Grain Size Distribution

From Graph in Figure 4, it is $D_{10}$, $D_{30}$ dan $D_{60}$ to calculate uniform coefficient ($C_U$) and gradation coefficient ($C_C$):

$$C_U = \frac{D_{60}}{D_{10}}$$
$$C_C = \frac{D_{30}^2}{D_{10} \times D_{60}}$$

with: $D_{60} = 60\%$ finer (mm), $D_{10} = 10\%$ finer (mm), and $D_{30} = 30\%$ finer (mm). Therefore, the analysis of $C_U$ and $C_C$:

$$C_U = \frac{D_{60}}{D_{10}} = \frac{4,75}{0,12} = 39,583$$
$$C_C = \frac{D_{30}^2}{D_{10} \times D_{60}} = \frac{0,95^2}{(0,12 \times 4,75)} = 1,583$$

From the graph in Figure 4 shows that the relationship between grain size and percent finer so that the results is $D_{60} = 4,75$mm; $D_{30} = 0,95$mm; $D_{10} = 0,12$mm. Furthermore, $C_U = 39,583$ and $C_C = 1,583$. By using Soil Classification Chart, it is classified that sediment is categorized in Poorly Graded Sand.

2.2 Flow Rate Velocity Analysis.

The flow rate velocity is taken by several positions both x and y direction. Position A, B, and C were located in cross section area with the distance between the points is 100mm and B1, B2 and B3 were...
located in horizontal direction of the channel with (Figure 5). Furthermore, considering the flow rate velocity in depth, the study used 0.2h, 0.6h, and 0.8h.

### Table 3. Results of Flow Rate Velocity Based on Scenarios

| Scenario | Position | Depth | Flow Velocity (m/sec) |
|----------|----------|-------|-----------------------|
|          |          | 0.2h  | A 0.326 B 0.335 C 0.330 |
|          |          | 0.6h  | A 0.337 B 0.345 C 0.340 |
|          |          | 0.8h  | A 0.333 B 0.325 C 0.333 |

This study used the current-meter to measure the flow rate velocity. The propeller type is 2-141579 with diameter 50mm and pitch 0.10. The equation is \( V = 0.1023 * n + 0.016 \) for \( n \leq 9.33 \), or \( V = 0.1008 * n + 0.030 \) for \( 9.33 \leq n \leq 19.54 \), with \( n \) = lap/time. In the beginning, the hypothesis of this
study is the characteristics of flow resistance are greatly affected by the roughness of sediment due to type and diameter measurement. Therefore, the average of flow rate velocity can be seen on Table 4.

![Figure 5. Location of velocity points](image)

**Table 4. Results of The Average of Flow Rate Velocity Based on Scenarios**

| Discharge Position | Flow Rate Velocity (m/sec) |
|--------------------|----------------------------|
| Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 |
| B1 | 0.3354 | 0.3240 | 0.3077 | 0.3212 | 0.3252 |
| B2 | 0.3289 | 0.3051 | 0.2956 | 0.3149 | 0.3199 |
| B3 | 0.3331 | 0.2989 | 0.3088 | 0.3115 | 0.3171 |
| Average | 0.3325 | 0.3094 | 0.3041 | 0.3159 | 0.3207 |

2.3 Flow Resistance Analysis.

The further analysis is flow resistance analysis to find out the value of roughness of sediment. Several equations were performed to calculate the flow resistance analysis. The results can be seen Table 5.

**Table 5. Results of Flow Resistance Analysis**

| Scenario | Flow Velocity V (m/sec) | Koef. Manning n | Koef. Chezy C | Friction Factor f |
|----------|-------------------------|-----------------|---------------|------------------|
| 1        | 0.3325                  | 0.0194          | 34.6272       | 0.0652           |
| 2        | 0.3094                  | 0.0208          | 32.2965       | 0.0754           |
| 3        | 0.3041                  | 0.0212          | 31.6871       | 0.0780           |
| 4        | 0.3159                  | 0.0204          | 32.9298       | 0.0723           |
| 5        | 0.3207                  | 0.0201          | 33.4212       | 0.0701           |

3. Discussions

Based on the Manning’ coefficient (n), it was also found that at the 100% discharge flow condition, the highest value of friction factor (f=0.0780) within 5 scenarios was scenario 3 with the sediment consisted of 50%sand and 50%gravel. Whereas the value of the lowest friction factor(f=0.0652) was scenario 1 with the sediment only gravel within. It concluded that the results gave the lower value of Manning’ coefficient (n) compared to the table of Manning’s coefficient (f= 0.04) for the channel with gravel base condition.
4. Conclusions
This study aims to examine the flow characteristics (flow velocity and flow resistance) in gravel open channel by determining flow resistance in environmentally acceptable channels. Special emphasis was placed on addressing the hydraulic effects of gravel as sediment. For this reason, laboratory flume studies with scenarios were employed. The most notable finding was that, when compared to 5 scenario conditions, the presence of sediment increased the friction factor. This was strongly dependent on the flow rate velocity. In addition, the linkage between flow resistance, channel properties, and other physical condition was investigated. Further recommendation, in this study the parameters for the cross-sectional geometry and flow resistance were found to be simple but nonetheless valuable in evaluating the success of a field project which aims to restore local hydraulics. It is necessary to modify geometric parameters in the future study.

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