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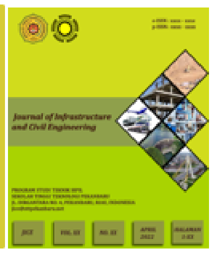

Flow Characteristics in an Open Channel Flume Based on Bed Slope Variation at the Civil Engineering Laboratory of Universitas Lancang Kuning

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Abstract

This study aims to analyze the effect of bed slope variation on flow characteristics in an open channel flume at the Civil Engineering Laboratory of Universitas Lancang Kuning. The research was conducted experimentally using a laboratory flume with constant discharge conditions. Three slope variations were applied, namely 0.001, 0.003, and 0.005. The observed parameters include flow velocity and flow depth. In addition, the Froude number was calculated to determine the type of flow regime. The results indicate that increasing the bed slope leads to an increase in flow velocity from 0.20 m/s to 0.33 m/s. Meanwhile, the flow depth tends to decrease as the slope increases. The calculated Froude number ranges from 0.201 to 0.343, indicating that the flow regime remains in subcritical conditions. These results provide empirical insight into the relationship between bed slope and hydraulic characteristics in open channel flow and can serve as reference data for hydraulic laboratory experiments.

Keywords: *open channel flow, flume experiment, bed slope, flow velocity, Froude number*

1. Introduction

Open channel flow is an important topic in hydraulic engineering and commonly occurs in natural and artificial water systems such as rivers, irrigation canals, and drainage channels. In open channel flow, the water surface is exposed to atmospheric pressure, and gravitational force becomes the dominant factor controlling flow characteristics [1].

One of the most influential parameters affecting open channel flow behavior is the channel bed slope. The slope determines the distribution of potential and kinetic energy within the flow. An increase in bed slope generally leads to an increase in flow velocity because the gravitational force component along the flow direction becomes greater [2].

Several previous studies have investigated the relationship between bed slope and flow characteristics. Triyono et al. reported that increasing the channel slope significantly increases flow velocity while reducing flow depth in laboratory flume experiments [3]. Similarly, Satria and Kurnia found that slope variations influence the Froude number, which determines the flow regime in open channel flow [4].

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Rahman et al. conducted an experimental study using a laboratory flume and demonstrated that bed slope has a significant influence on velocity distribution and energy characteristics of open channel flow [5]. Nugroho et al. also reported that slope variation affects turbulence intensity and energy losses in laboratory channels [6].

Although many studies have examined the relationship between slope and flow characteristics, most of them were conducted in laboratories with different flume configurations. As a result, experimental data from each laboratory may produce different hydraulic characteristics. However, experimental data related to the flume facility at the Civil Engineering Laboratory of Universitas Lancang Kuning are still limited.

Therefore, this study aims to analyze the influence of bed slope variation on flow velocity, flow depth, and Froude number using an open channel flume experiment at Universitas Lancang Kuning.

2. Methodology

2.1 Research Design

This research was conducted using an experimental laboratory approach. The experiment was carried out in a laboratory flume with constant discharge while varying the channel slope. For each slope setting, flow velocity was measured using a current meter positioned at the mid-depth of the flow at the central cross-section of the flume, while flow depth was measured using a point gauge mounted on the flume rail. To ensure data accuracy and repeatability, each measurement was repeated three times at every slope condition after the flow had reached a steady-state condition, and the reported values represent the average of the three repetitions. The maximum deviation between repeated measurements was kept below 5%, and any reading exceeding this threshold was discarded and re-measured.

2.2 Research Location

The experiment was conducted at the Hydraulic Laboratory of the Civil Engineering Department, Universitas Lancang Kuning. The laboratory flume used in this study is a rectangular, tilting-bed open channel flume with a length of 5 m, a width of 0.30 m, and a depth of 0.40 m. The flume is constructed with a steel frame and transparent glass side walls to allow direct visual observation of the flow, and the bed slope can be adjusted using a manual tilting mechanism equipped with a slope indicator. Flow depth was measured using a point gauge with a reading accuracy of 0.1 mm, while flow velocity was measured using a current meter, and discharge was regulated and monitored using a control valve connected to a calibrated flow meter at the inlet of the flume.

2.3 Research Variables

The variables used in this study include:

a. Independent variable
   1) Channel bed slope (S)
b. Dependent variables
   1) Flow velocity (V)
   2) Flow depth (h)
   3) Froude number (Fr)
c. Controlled variables
   1) Flow discharge
   2) Channel geometry

3) Channel surface roughness

The channel bed slope, as the independent variable, was set and adjusted using the flume tilting mechanism and verified with the slope indicator prior to each experimental run. Flow velocity and flow depth, as the dependent variables, were measured directly using the current meter and point gauge, respectively, as described in Section 2.2. The Froude number was subsequently derived from the measured velocity and depth using Equation (1). Among the controlled variables, the flow discharge was maintained constant throughout all slope variations by keeping the inlet control valve at a fixed opening and continuously monitoring the flow rate with the calibrated flow meter, while channel geometry and surface roughness were kept unchanged since the same flume was used for all experimental runs.

2.4 Slope Variations

The three slope values of 0.001, 0.003, and 0.005 were selected to represent the typical range of mild to moderate bed slopes commonly encountered in irrigation and drainage channels, and are consistent with the slope ranges commonly adopted in previous laboratory flume studies [3], [5]. This range was also chosen to ensure that the resulting flow remained within the subcritical regime, which is representative of ordinary open channel conditions, while still being sufficiently distinct to reveal measurable changes in flow velocity, flow depth, and Froude number.

Table 1. Slope variations used in the experiment

No	Bed Slope
1	0.001
2	0.003
3	0.005

2.5 Froude Number Calculation

The Froude number was calculated using the following equation, based on the standard formulation for open channel flow [1]. The flow velocity (V) and flow depth (h) used in this calculation were obtained from the direct field measurements described in Section 2.1, using the current meter and point gauge, respectively, prior to the calculation:

$$Fr = \frac{V}{\sqrt{g \times h}} \tag{1}$$

Where:
V = flow velocity (m/s)
h = flow depth (m)
g = gravitational acceleration (9.81 m/s^2)

The flow regime classification is defined as:
Fr < 1 → Subcritical flow
Fr = 1 → Critical flow
Fr > 1 → Supercritical flow

3. Results and Discussion

The experimental results obtained from the open channel flume experiment are presented in Table 2. The experiment was conducted using three different bed slope variations, namely 0.001, 0.003, and 0.005, while maintaining a constant discharge. As explained in

Section 2.1, each value reported in Table 2 represents the average of three repeated measurements taken under steady-state flow conditions, with a maximum deviation of less than 5% between repetitions, thereby providing a reasonable basis for assessing the reliability of the experimental results despite the limited number of slope conditions tested.

Table 2. Flow characteristics at different bed slopes

Slope	Velocity (m/s)	Depth (cm)	Froude	Flow Type
0.001	0.20	10.11	0.201	Subcritical
0.003	0.30	10.80	0.292	Subcritical
0.005	0.33	9.45	0.343	Subcritical

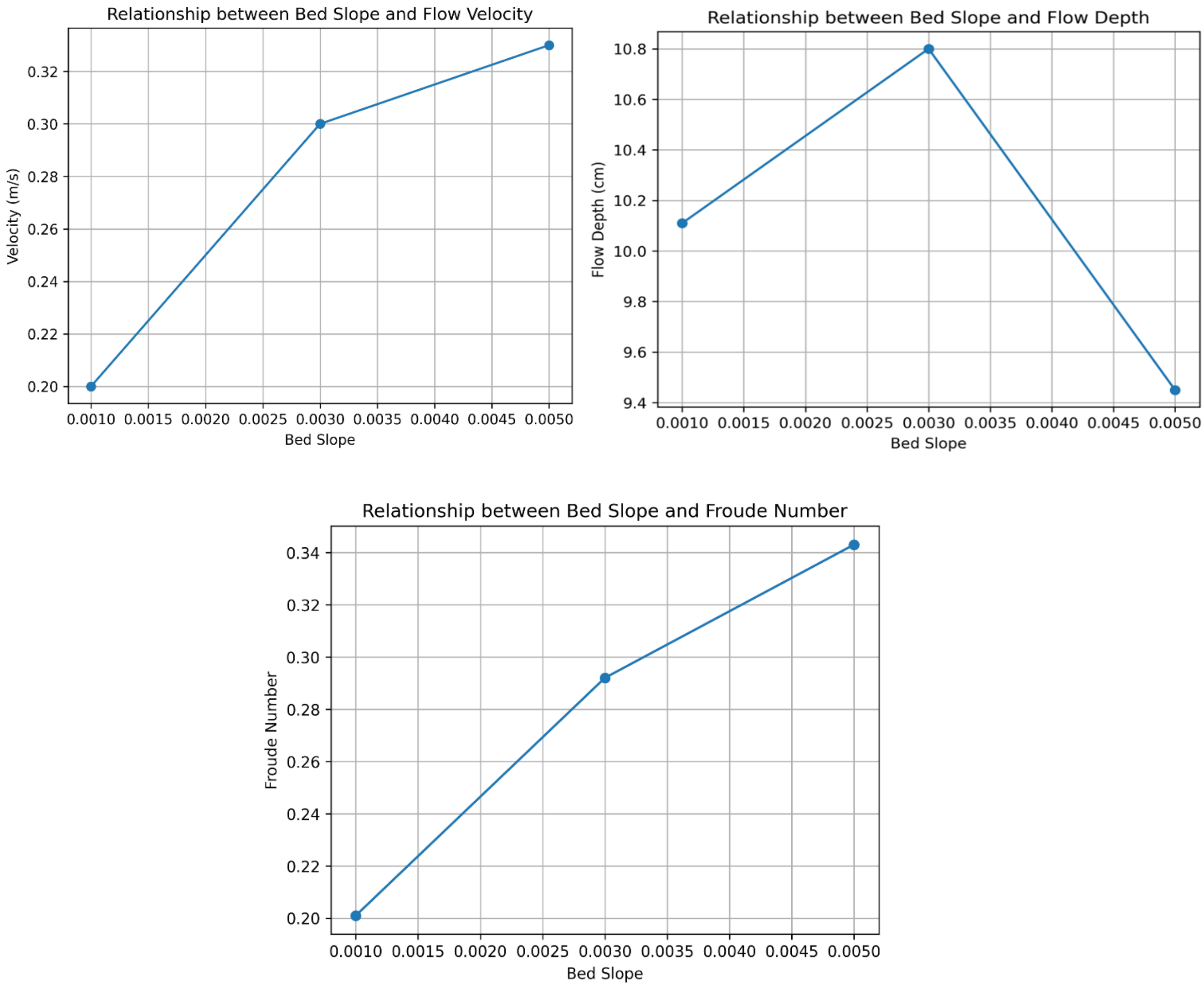

Figure 1. Effect of bed slope on flow velocity and flow depth

Based on the experimental results, it can be observed that increasing the bed slope leads to an increase in flow velocity. When the slope increases from 0.001 to 0.005, the velocity increases from 0.20 m/s to 0.33 m/s. This occurs because the gravitational force component acting along the channel becomes larger, resulting in greater kinetic energy of the flow. From an energy perspective, a steeper bed slope increases the rate at which potential energy is converted into kinetic energy along the length of the flume, which is consistent with the specific energy concept in open channel hydraulics, where, for a constant discharge, an increase in velocity head must be accompanied by a corresponding reduction in flow depth to conserve the specific energy of the section.

In addition, the flow depth tends to decrease at higher slopes. At a slope of 0.005, the flow depth decreases to 9.45 cm compared to the previous slope conditions. This phenomenon indicates that faster flow velocities lead to lower water depth in the channel.

The calculated Froude number ranges from 0.201 to 0.343, indicating that all flow conditions remain within the subcritical regime ($Fr < 1$). However, the increasing trend of the Froude number suggests that steeper slopes move the flow condition closer to the critical flow regime, since a greater bed slope simultaneously raises the velocity term in the numerator and lowers the depth term in the denominator of the Froude number equation. This behavior confirms that bed slope acts as a controlling factor of the flow regime and not merely of the flow magnitude, and it indicates that, at slopes considerably steeper than those tested here, the flow in this flume could potentially approach or exceed the critical condition ($Fr = 1$).

Figure 1 further illustrates the relationship between bed slope, flow velocity, and flow depth described above, showing the consistent increasing trend in velocity and the corresponding decreasing trend in depth as the bed slope becomes steeper.

These findings are consistent with previous studies which reported that increasing channel slope generally increases flow velocity while reducing flow depth in open channel experiments. The velocity increase of approximately 65% observed in this study as the slope increased from 0.001 to 0.005 is comparable in trend, although smaller in magnitude, to the velocity increase reported by Triyono et al. [3] and Rahman et al. [5] under steeper slope conditions, while the subcritical flow regime obtained here is also in agreement with the flow classification trend reported by Satria and Kurnia [4]. The relatively smaller magnitude of change observed in the present study compared to those earlier works is likely attributable to differences in flume configuration, cross-sectional dimensions, and discharge conditions, as well as the narrower and gentler range of slope values (0.001–0.005) tested at the Universitas Lancang Kuning flume compared to the wider slope ranges and different measurement techniques used in the referenced studies.

4. Conclusion

This study analyzed the influence of bed slope variation on flow characteristics in an open channel flume experiment. The results show that increasing the bed slope affects the hydraulic behavior of the flow.

An increase in bed slope from 0.001 to 0.005 increased the flow velocity while the flow depth tended to decrease, and all tested conditions remained within the subcritical flow regime. This trend confirms that bed slope governs not only the magnitude of flow velocity and depth but also how close the flow condition approaches the critical regime, which is a key consideration in the hydraulic design and safe operation of open channels such as irrigation and drainage canals.

The results of this study provide useful experimental data for understanding the relationship between bed slope and flow characteristics in open channel hydraulics. The novelty of this study lies in providing new, site-specific empirical hydraulic data from the flume facility at the Civil Engineering Laboratory of Universitas Lancang Kuning, which had previously been unavailable. These findings can also serve as reference material for hydraulic laboratory experiments and practical applications such as the hydraulic design of irrigation and drainage channels. Future studies are recommended to test a wider range of slope values, including steeper slopes that may induce critical or supercritical flow, and to incorporate additional variables such as channel roughness and sediment transport.

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