Sediment Transport Rate and Bed Formation in Straight Compound Channels

Mazlin Jumain, Zulhilmi Ismail, Zulkiflee Ibrahim and Nur Atiah Zaini

Faculty of Civil Engineering,
UniversitiTeknologi Malaysia 81310 UTM Skudai Johor Malaysia

Abstract: Researches on compound channel hydraulics have been carried out for many years, yet few are concerned with sediment transport. In order to prevent sediment problem, the sediment transport process and the influence of bed form on the roughness of the river flows must be understood. An experimental investigation on the flood flow characteristics and sediment transport in straight compound channel have been undertaken. The effects of mobile-bed channels on flow characteristics and sediment transport were studied by using flumes in the Hydraulics and Hydrology Laboratory, Faculty of Civil Engineering, UniversitiTeknologi Malaysia (UTM). The flume is 4.0 m long, 0.6 m wide and configured into a 0.3 m wide and 0.05 m depth of rectangular main channel with a single floodplain. A mobile-bed channel is composed of uniform graded sand with a d50 of 0.8 mm. The findings on sediment transport rate and bed formation of the bed channel for overbank flows in straight rectangular compound channels are presented in this paper. It has been found that the maximum velocity zone is observed to be in the main channel where sediment transportation takes place. Thus, the bed formation change after the sedimentation and erosion occur at the channel bed which is also influenced by the higher velocity in the main channel.

Key words: Straight compound channel · Overbank flow · Velocity · Sediment transport · Bed formation

INTRODUCTION

The structure of the overbank flow in mobile bed channel becomes more complex than non-mobile bed channel. The bedform of the mobile channel influenced thoroughness and change with discharge or water depth [1]. The roughness of non-mobile beds is noticeably less than those of mobile beds [2-5]. It is important to understand the sediment transport process and the influence of bed form on the roughness in order to maintain the rivers as safe from the sediment problem during flooding.

Myers and Brennan showed that the resistance coefficients distorted by the presence of the momentum transfer mechanism [6]. Besides that, Rajaratnam and Ahmadi [7] and Rhodes and Knight [8]stated that the vertical velocity distribution deformed by momentum transfer process. Due to momentum transfer between main channel and floodplain, the flow conveying capacity increases gradually with the flow depth [9].

Ackers predicted that the sediment transport will increase in most rivers up to bankfull discharge, but the sediment transport may diminish with further increase in discharge and roughness on overbank condition [10]. Ayyoubzadeh [11], Atabay et al. [12] and Tang and Knight [13] investigated and found that a very similar way as predicted by Ackers. It is due to significant influence of the interaction effect between main channel and floodplain. The rates of sediment transport also indicate the effects of overbank flow on bed formation of the main channel [10].

Experimental investigation on the flood flow characteristics and sediment transport in straight mobile bed rectangular compound channel has been undertaken. The effects of a uniform sand bed channel were studied by using flume in the Hydraulics and Hydrology Laboratory, Faculty of Civil Engineering, UniversitiTeknologi Malaysia (UTM). The aim of this study is to enhance knowledge on the river hydraulics and the sediment transport problem during flooding. Thus, the objectives of the experimental study is to investigate the flow resistance, sediment transport and bed formation in straight mobile-bed compound channel.
Fig. 1: Plan view of channel.

Fig. 2: Cross-section of channel.

Research Methodology: The study involved data collection through experimental investigation by using a rectangular flume as shown in Figure 1. The flume consists of single floodplain and main channel. The dimension of a flume is 4.0 m long and 0.6 m wide, which consists of 0.3 m wide rectangular main channel with depth of 0.05 m. The slope of bed channel is fixed to 1/500. The flume consists of 0.3 m wide rectangular main channel with depth of 0.05 m. The slope of bed channel is fixed to 1/500 and uniform graded sand with a d₅₀ of 0.8 mm used as its bed material. Figure 2 shows a cross-section of a straight compound channel.

The experimental has been conducted under uniform flow condition in order to apply uniform flow theory in the analysis. The uniform flow has been achieved when slope of water surface (Sₑ) is equal to slope of channel bed (Sₜ) at all time. The classification of flow in a channel is turbulence for Reynolds number (Re) exceeding 4,000 and subcritical flow (low velocity) condition occurs when Froude number (Fr) is less than unity. From both bed approaches, the results are explained that the regime of flow can be classified as subcritical-turbulence of a straight compound channel.

The different equipments have been used for this experimental study for measuring different types of data. Water depth and the level of sand surface in the main channel are measured by using a digital point gauge. Meanwhile, the velocities in the main channel are measured using a miniature current meter. The discharge in the main channel has been calculated using the values of the measured velocity through the conventional “mid-section” method. A sand trap is used to collect sediment which is been transported from main channel because of the water flow. The mass of sediment transport are determined using digital scale. The transported sediments are collected in every 2 minute interval for durations of 40 minutes. The equation (1) is used for determine the sediment transport rate, meanwhile equation (2) is used to determine the sediment concentration as below:

$$q_s = \frac{M}{t}$$

where $q_s$ is rate of sediment transport (kg/s); $M_s$ is mass of sediment transported (kg) and $t$ is time taken (s).

$$X = \frac{q_s \times 10^4}{Q_m \cdot \rho}$$

where $X$ is sediment concentration (ppm), $q_s$ is rate of sediment transport (kg/s), $Q_m$ is discharge of main channel (m³/s) and $\rho$ is the water density (kg/m³).

RESULTS AND DISCUSSION

In this study, results of sediment transport rate and bed formation in different cases of relative depths (DR) are discussed.

Based on this study, the increasing of DR are significantly influenced in decreasing of velocity, the mass and rate of sediment transport. Therefore, the concentration and rate of sediment transport are affected due to the change of velocity in the main channel. Figure 3 illustrates the temporal patterns of sediment transport rate. Figure 4 shows the temporal patterns of...
Fig. 3: Temporal patterns of sediment transport rate for different relative depths.

Fig. 4: Temporal patterns of sediment concentration for different relative depths.

Fig. 5: Longitudinal bed profiles at y = 0.03 m along the main channel for different relative depths.

Fig. 6: Longitudinal bed profiles at y = 0.15 m along the main channel for different relative depths.

sediment concentration for different DR. Based on both of figure, the lowest DR (DR=0), the rate of sediment transport and the sediment concentration are higher than the other DR.

It is due to the higher velocity in the main channel for lower DR where no momentum transfer process occurs to distribute the velocity from the main channel to the floodplain. It is also due to roughness surface between main channel wall and bed channel surface. Thus, the higher sediment transport rate occurs at lower DR.

For overbank condition (DR=0.16 and DR=0.21), the flows are well-dispersed in main channel and floodplain at higher relative depth. The flow distribution from main channel into floodplain has been creates an additional resistance to flow hence contributing to higher Manning's. The roughness of main channel wall and floodplain also can increase resistance of flow along the channel. Tang and Knight [13] stated that the sediment transport rate decreases even further as the roughness of the channel increase. Hence, the rate of sediment transport and the sediment concentration are decreases due to increases of the flow resistance in the channel. The decrement of sediment transport rate and concentration are about 28 and 95 percent for overbank condition (DR=0.16 and DR=0.21) versus bankfull condition (DR=0), respectively.

Channel bed formation occurs due to velocity of water flow in the main channel. During the water flow, there are sedimentation and erosion of the sand. The changing of sand surface level from the earlier level due to the sedimentation and erosion phenomenon. Most of the sand erosion and sedimentation in the main channel are governed by the higher velocity. The sand that eroded is mostly occurred in the middle of the main channel because of higher velocity in the middle and based on the findings, the bed formation is determined as ripples. According to Yang [14], ripples are small bed forms with heights less than 5 cm and the profiles are approximately triangular, with long gentle upstream slope and short, steep downstream slope.
Figures 5, 6 and 7 show the longitudinal bed profiles of the main channel after the water flows for 40 minutes. It has been found that the differences in bed profiles for each interval of y-direction is due to different of flow velocity. Figure 6 shows the similarity pattern of longitudinal bed profiles along the main channel. It is due to the maximum velocity takes place in the center region of the main channel. Velocity decreases when the flow close to the channel wall and bed surface. It is because of the interruption between channel wall and bed occurs, which is tend to disturbed the flow. As a result, most of the sand is eroded and sedimented on this part of the main channel. Therefore, the ripples of bed formation are have clearly been seen and identified.

CONCLUSIONS

This paper presents the sediment transport rate and the bed formation in mobile bed straight compound channel flow. The hydraulics of compound straight channel with mobile bed was studied in the laboratory using a small-scale physical model. From the experimental had been done, the conclusion are based on the: (i) the higher concentration of water in the main channel during bankfull condition are produced higher sediment transport rate than the overbank condition, (ii) sedimentation and erosion of sand are mostly occurred in the main channel due to higher velocity of water flow in the main channel and (iii) the type of bed form has been identified as ripples.

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REFERENCES

