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Experimental Study on Depth-Averaged Velocity and Bed Profile in a Braided Channel with a Mid-Bar

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ABSTRACT

Braided alluvial rivers with a mid-bar are common features occurred in alluvial river that consists of bifurcation and confluence channels. The formation of the mid-bar will affect the hydraulics of river systems in terms of velocity and bed morphology. The studies corresponding to the typical braided river with a mid-bar are still ongoing. This paper is to present the finding of depth-averaged velocity, U_d and bed profile at the bifurcation and confluence channel. A channel with a mid-bar and erodible bed was used in this research. The experimental work was carried out in the Hydraulic Laboratory at Universiti Teknologi Malaysia, (UTM). In the experiment, two types of flow which are low flow and high flow rates were considered. The study found that depth-averaged velocity distributions are influenced by flow discharge and varied at the braided channel. The highest U_d velocity is 0.35 m/s occurred at the bifurcation area and the lowest U_d is 0.2 m/s that was occurred at the confluence area. This genesis to more erosion occurred at the bifurcation area compared to the confluence area.

1. Introduction

Braided rivers are common features that occurred in alluvial rivers. The braided river with a mid-bar is composed of bifurcation at the mainstream, two curved streams and confluence as shown in Figure 1. The bifurcation is described as the divergence of the mainstream into distributaries and confluence is defined as the meeting locations of two or more streams, these mechanisms affect the hydraulics river system in terms of flow and bed profile. Mid-bar is a one of the typical natural river patterns. It is categorised as a bed feature in alluvial rivers, especially for the braided river. These features are the key to controlling local bed profiles, the routing of sediment and water, and bank stability [1-4]. These mechanisms could occur in all types of river channels such as straight, meander and braided. The development of sand bar much depends on several factors such as the flow of

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water, the sediment transport and the erodibility of the floodplain [5]. The flow and sediment became more complex in these areas to produce extremely changing conditions in terms of river planform. Most of the channel became wider in these areas as the banks were eroded to reach the equilibrium state of the channel reach. Many researchers have studied the characteristic of river bifurcation and confluence [6-8]. Serger and Nikolay [9] stated that the flow decreased at bifurcation as the flow was separated but it increased at the confluence as the flow converged from multiple channels and this has been agreed upon by many researchers.

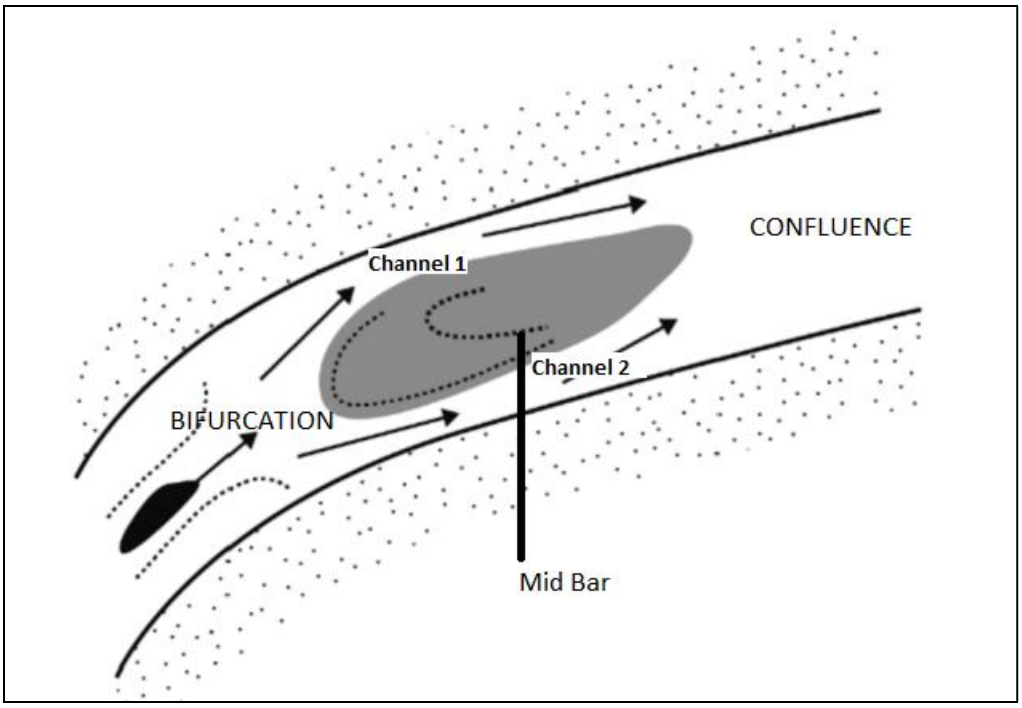


Fig. 1. Braided river with a mid-bar [10]

Hua and Gu [11] studied the flow characteristic at bifurcation and confluence channels with a different width ratio of point bar to channels 1 and 2. The flow at the bigger size remains in the direction of the upstream main channel flow, because the channel with a bigger size is gradually close to the main channel width, so it is easy for water in that channel to hold the direction of the main channel. Braided rivers can be defined as having a number of alluvial channels with bars or islands between meeting and dividing again and presenting from the air the intertwining effect of a braid [12-15].

The occurrences of multiple flow threads in a single alluvial channel can produce a morphological process and will create bifurcation, confluence and braiding. Sediment bar migration or transport from the upstream to downstream will affect the flow characteristic of the river [16-19]. At the area of separation zone, with high velocity of water flowrate will cause high turbulence occurs at these places because of the strong shear [20-21].

Bed Morphology of braided rivers is influenced by flow and sediment transport rate. If the sediment from the upstream supplies an appropriate amount of sediment, the width/depth ratio of the river will become greater, this process will progress the river into a braided river easier [22-24]. Peter Ashmore [25] concise the braiding processes by conducting flume experiments that focused on the bed profile deviations of the braided river under different flow rates. The result of bar formation can be shown into four mechanisms, which are central bar formation, transverse bar formation, chute cutoff and multiple bar dissection. When the bed shear stress is close to the critical from sediment transport movement, it will be lessened the sediment transport volume of the flow produced by the widening of the downstream river and the central bar will be formed in this stage. Transverse bar mostly occurs when the sediment transport rate is high, it mostly happens where the shear stresses of the bottom bed are higher than the critical shear stress. Meanwhile, the chute cutoff sediment bar mostly occurs at the curve or bend of the river, when the river bend was developed, and the concave bank stability will collapse and the convex bank acquires that making the water flow to deflect. Multiple Bar was formed when the river is wider at downstream. The flow will flood the surface of the sand bars with lower elevation and erode the sandbar body.

Bed morphology and sedimentation processes in braided rivers need to be understood in more detail in the formation aspect behaviour. The understanding of river bed morphology is important for the formation and sedimentation conditions in a braided river [26-29].

The aim of the study is to enhance the understanding and knowledge of the flow characteristic at the braided channel with a mid-bar in two conditions of flow. This study focused on the relationship between flow discharge with depth-average velocity patterns and bed profile changes in a braided channel with a mid-bar.

2. Methodology

This study focused on the observation of experimental works that used a physical river model in the Hydraulics Laboratory at Universiti Teknologi Malaysia (UTM). The experiment was conducted in a straight rectangular flume channel model with 10 m long, 1 m wide and 0.6 m height. The longitudinal slope was set at 1:500. The channel bed was set up as an erodible where all parts of the channel bed were composed of uniform graded sand d_{50}= 0.8 mm. The sidewalls of the flume were built using Perspex sheets and water was supplied from a sump via a centrifugal pump. Filters were provided in the inflow tank at upstream of the channel to reduce the turbulence effect during the experiment. A tailgate at downstream was used to control the flow depth in order to establish uniform flow conditions during the experiment work. Figure 2 shows the Experimental setup for the study. An ellipse shape of a mid-bar was located at the middle of the flume channel with dimension of 2.0 m long, 0.4 m width and 0.3 m height. The bar was located at the middle of the channel as the location for the formation of the braided channel.

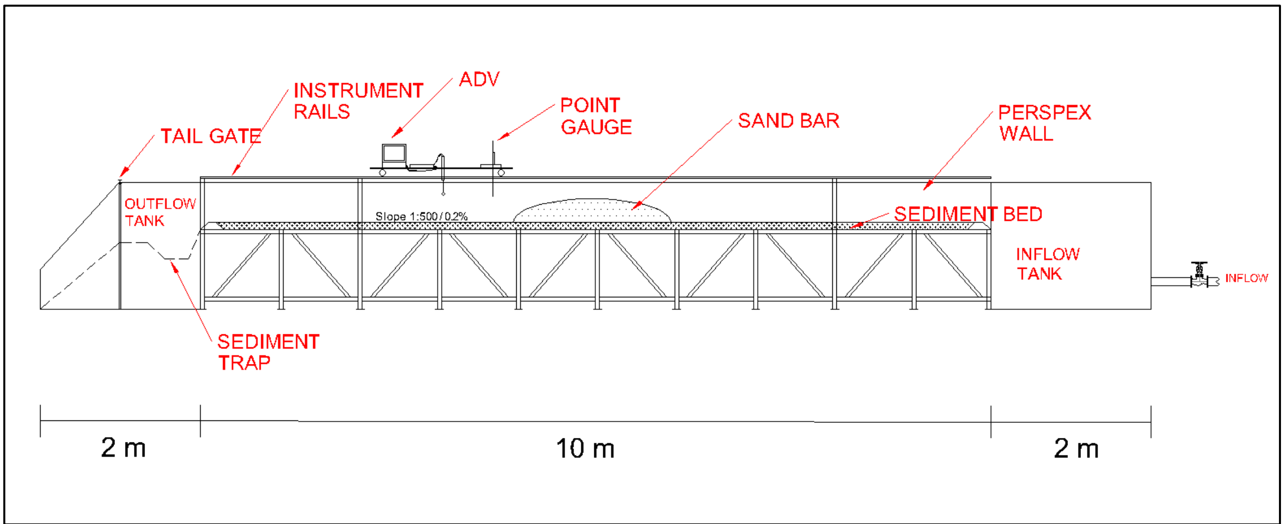


Fig. 2. Experimental setup

A Micronics Portaflow PF330 flow meter was used to measure the flow rate of water. The Flow Meter instrument was attached to the supply pipe to measure the discharge when the water was supplied to the channel. Two experiments were conducted with a low flow discharge of 15 L/s and a high flow discharge of 30 L/s. Table 1 presents the list of experiment cases that have been conducted in this study.

Table 1
List of experiment cases

Case	Experiment case	Flow discharge (L/s)	Water depth (m)
A	Low flow	15	0.08
B	High flow	30	0.13

The water surface level was measured until uniform flow was achieved by using a digital point gauge that have been placed at guide rails. The point gauge could be read 0.1 mm. An Acoustic Doppler Velocimeter (ADV) was used for the measurement of water velocities. This instrument was operated with three-dimensional velocity components u, v and w in the X, Y and Z directions respectively. The flow velocities were taken at three cross-sections which are cross-sections A, B and C as shown in Figure 3.

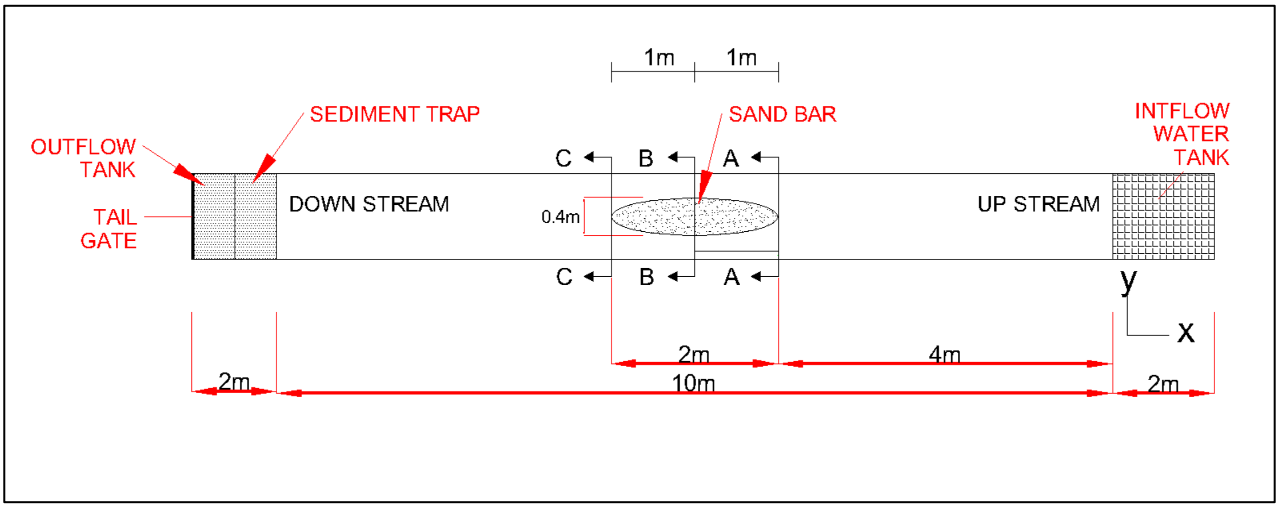


Fig. 3. Channel layout

The point velocities at cross-sections A and C were measured every 10 cm on the y-axis and 1 cm on the z-axis. For cross-section B, the measurement of point velocities was collected every 5 cm on the y-axis and 1 cm on the z-axis due to the presence of the mid-bar as shown in Figures 4 and 5.

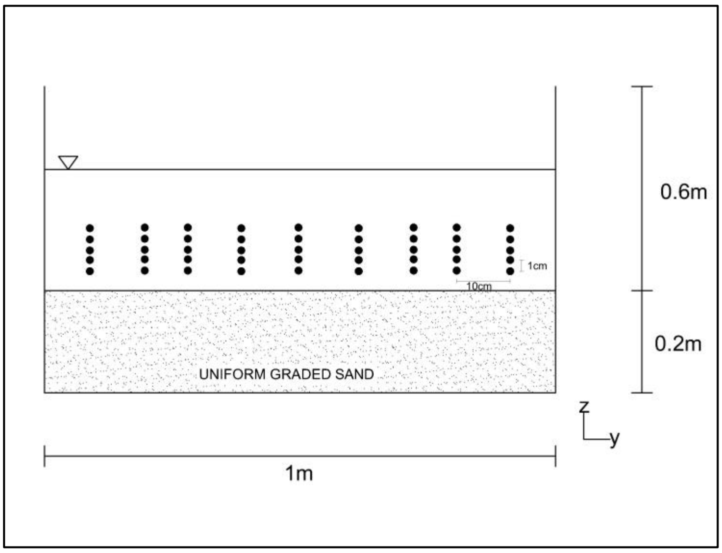


Fig. 4. Example point velocities collection at cross-sections A and C

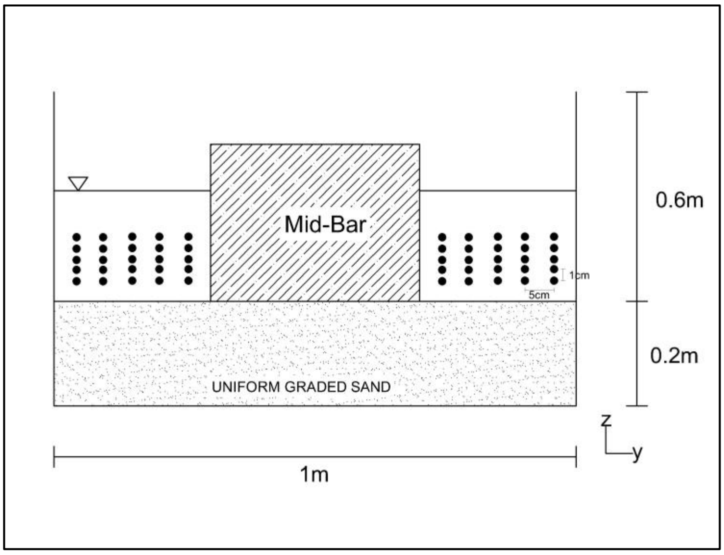


Fig. 5. Example point velocities collection at cross-section B

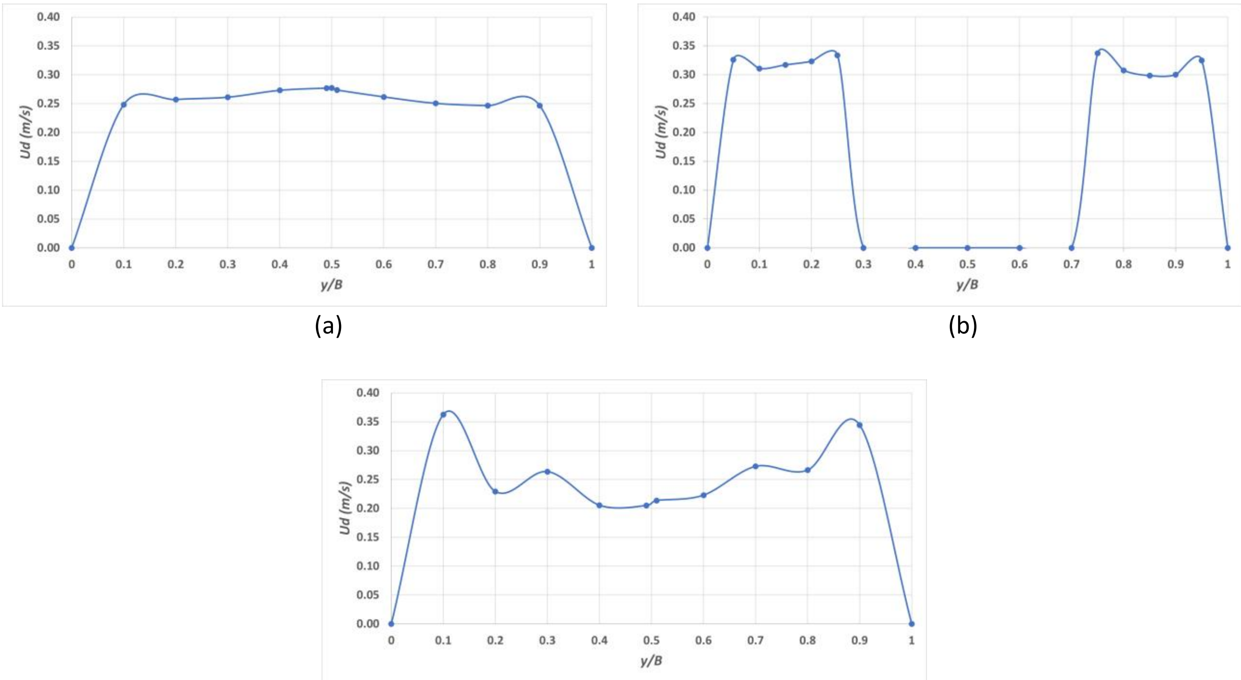
3. Results

3.1 Depth-Averaged Velocity

This section discusses the results obtained from the Acoustic Doppler Velocimeter where the measurements were carried out at cross-sections A, B and C. The cross-section of the width channel is presented as a normalised width channel *y/B* where *y* is the latitudinal distance and *B* is total length of width channel. At cross-sections A and C, the velocities were collected along the width of channel y/B = 0 to 1, but at cross-section B the velocities were collected at *y/B*= 0 to 0.3 and 0.7 to 1, due to the presence of mid-bar.

3.1.1 Low flow

Figure 6 illustrates the distribution of depth-averaged velocity, *Ud* for low flow of 15 L/s at cross-sections A, B and C. It can be noticed that at cross-section A the maximum U_d occurs at the centre of channel *y/B*= 0.5 which is 0.28 m/s while the lowest *Ud* is 0.25 m/s which occurs at *y/B*= 0.1 and 0.9. The velocities increase from the channel bank to the centre of the channel. At cross-section B, the high-velocity zone is located at the inner bank which is 0.34 m/s while the *Ud* at the outer bank is 0.32 m/s. The *Ud* at cross-section B is higher compared to the *Ud* at cross-section A, this is because the channel width at cross-section B is narrow compared to the width of channel at cross-section A due to the presence of a mid-bar. As the flow approached cross-section C which is from narrow channel to wide channel, the size of the velocity *Ud* is smaller at the center of the channel which is 0.20 m/s and the core goes on increasing to the channel bank.



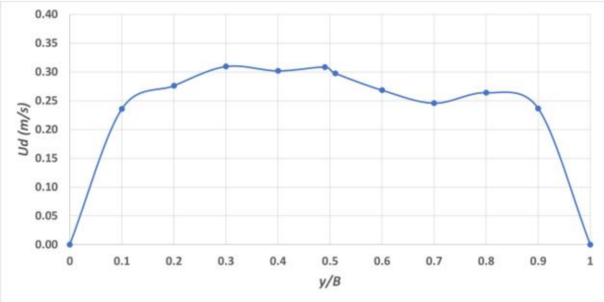
(a) (b)

(c)

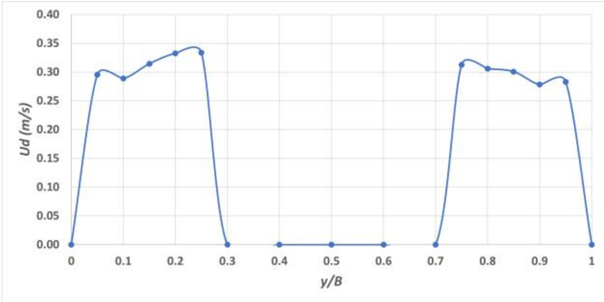
Fig. 6. Depth-averaged velocity, U_d for low flow of 15 L/s at (a) Cross-section A, (b) cross-section B and (C) cross-section C

3.1.2 High flow

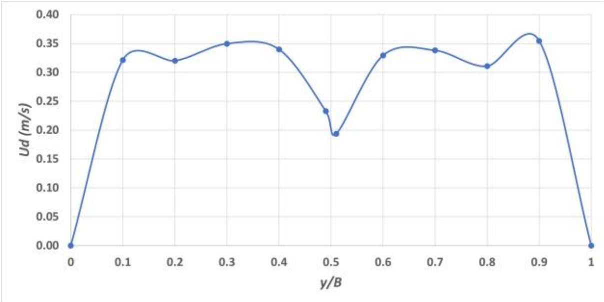
Figure 7 shows the distribution of depth-averaged velocity, U_d for high flow of 30 L/s at cross-sections A, B and C. The U_d pattern for high flow is almost same as low flow condition, but the maximum U_d for high flow is higher compared to the low flow condition. A similar result was observed by Liu and Shan [30]. The *Ud* pattern at cross-section A was distributed uniformly but the U_d at cross-section B is higher at the inner bank compared to the outside bank while at cross-section C the U_d is smaller at centre of the channel and becomes larger at the channel bank. This is due to the presence of mid-bar.



(a)



(b)



(c)

Fig. 7. Depth-averaged velocity, U_d for high flow of 30 L/s at (a) Cross-section A, (b) cross-section B and (C) cross-section C

3.2 Bed Profile

The experimental investigation has been conducted under mobile bed conditions in order to observe the change in bed profile in experiments Case A and B by using the Structure from Motion Technique, (SfM). Figure 8 shows the final bed profile for low flow and high flow conditions in Case A and B respectively at cross-sections A, B and C. The blue colour indicates the bed profile for Case A in low flow condition while the orange colour indicates the bed profile for Case B in high flow condition. At cross-sections A and B, more erosion occurs in Case B compared to Case A, this is because the discharge in Case B is higher compared to Case A. At cross-section A, more erosion occurs at *y/B* = 0.4 to 0.6 while at cross-section B more erosion occurs at inner bank *y/B* = 0.2 to 0.3 and 0.7 to 0.8. At cross-section C, only at *y/B* = 0.1 and 1 erosion occurred, the accretion of sediment was occurred at *y/B* = 0.2 to 0.9. The lowest contour is at inner bank cross-section B which is -0.09 m from Case B and the highest contour is at cross-section C which is 0.05 m. It can be concluded that cross-section A and B is the erosion zone and cross-section C is the deposition zone. This is because at cross-sections A and B the channel becomes narrow and by referring to Figure 7 and 8, the location of higher erosion occurred at the higher velocity U_d.

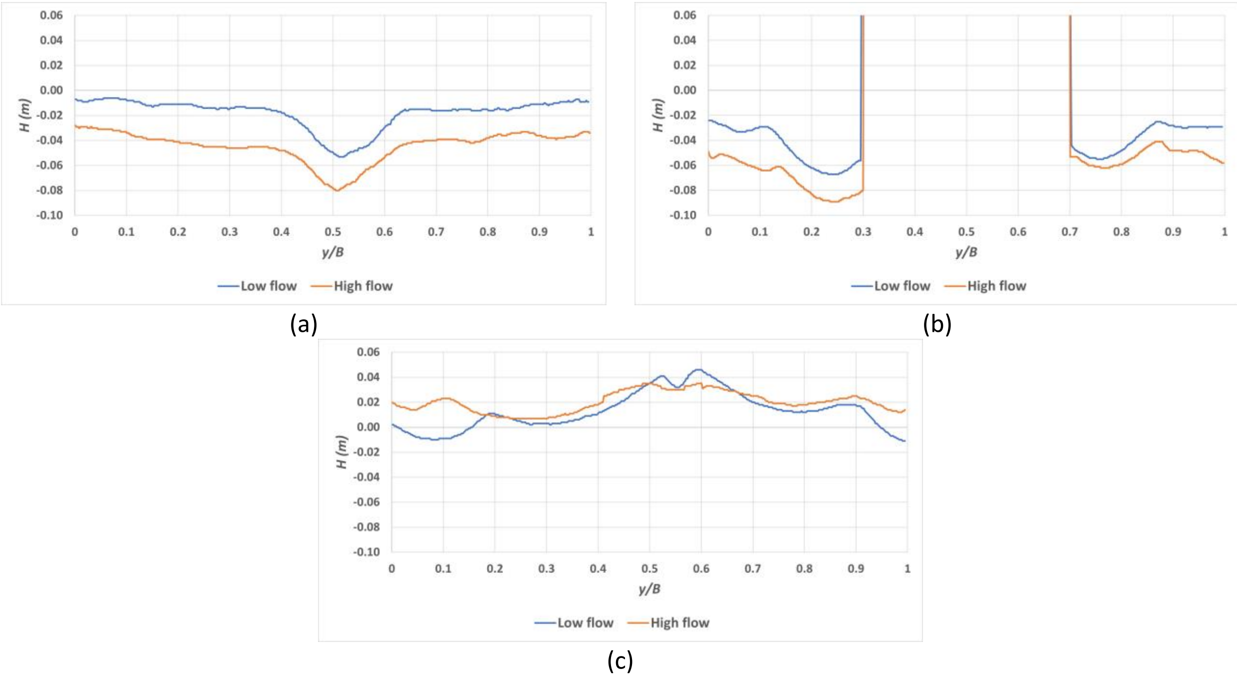


Fig. 8. Final bed profile for low-flow and high-flow at (a) cross-section A, (b) cross-section B and (c) cross-section C

4. Conclusions

The flow depth-averaged velocity U_d and bed profile at the braided river with a mid-bar had been investigated through flume simulation. The result can be shown from the experimental study that depth-averaged velocity distributions are influenced by flow discharge and varied at the braided channel. At the bifurcation area, depth-averaged velocity is higher compared to the confluence area. The U_d at the bifurcation area is higher at the centre of the flume channel or at the inner bank area compared to the outer bank area. Meanwhile, at the confluence area, the U_d is higher at the outer bank compared to the centre of the flume channel.

Sediment erosion occurs at bed profile cross-sections A and B while sediment deposition occurs at bed profile cross-section C. This is due to the depth-averaged velocity being higher at bifurcation compared to the confluence area. The bed profile result at the bifurcation area also shows more erosion occurred at the centre flume or at the inner bank compared to the outer bank, this is because the U_d at the inner bank was higher compared to the outer bank. However, the bed profile at the confluence area is higher at the centre of the flume channel compared to the outer bank channel, this resulted from the small U_d was occur in the centre flume channel.

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