Simulation of Flow Profile Response to Alternate Bar Formation in Rivers

Mohd Zulkhairi Mat Salleh, Zulkiflee Ibrahim, Mazlin Jumain, Radzuan Saari, Muhammad Farid Muhammad Fathullah, Zulhilmi Ismail and Muhammad Hidayat Jamal

Abstract Alternate bars are common in alluvial rivers. The formation of alternate bars is derived from the instability of flow and sediment in the channel. The formation of the alternate bars causes the changes in hydrodynamics condition in the channel. This study presents the analysis on the impact of alternate bar formation on the characteristic of flow in the channel. The objective of the study is to investigate the effect of alternate bars on the flow distribution. The study was observed through 2D computer simulation analysis by using Nays2DH solver in iRIC software. The length and width of the channel used were 12 and 0.5 m, respectively. The channel bed was initially set to be flat. The discharge was kept constant with different sediment sizes. The study found that the direction of the velocity of water was diverted away from the alternate bars after these bars were formed. Furthermore, the variation of sediment size does not majorly affect the conditions of the alternate bar; thus not also affected the flow profile. However, the velocity was progressively increased from upstream to downstream in the channel with a bigger size of bed material. Additionally, the velocity also was higher at the center but lowered on both sides of the channel. The profiles of velocity were mainly parallel with the bed level, where the velocity was higher as the bed level increased.

Keywords Alternate bars · Flow profile · Sediment · River · Velocity distribution

M. Z. M. Salleh · M. F. M. Fathullah · M. H. Jamal
Faculty of Civil Engineering, Universiti Teknologi MARA Pasir Gudang Campus, 81750 Masai, Johor, Malaysia

M. Z. M. Salleh (✉) · Z. Ibrahim · M. Jumain · R. Saari · Z. Ismail
School of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia
e-mail: kayzul00@gmail.com

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1 Introduction

Alternate bars are among the types of river bars which occurred in natural rivers, and it is commonly formed in straight rivers. The studies on alternate bars are progressively conducted until today [1, 3, 7, 10, 11]. However, the findings on its impact are still insufficient since it does not describe the real effect of bars in natural watercourses. Most of the researchers have agreed that flow and sediment plays an essential role in alternate bars formations [5, 8]. The alternate bars is only formed when the flow is slow, and its depth is shallow [6]. This condition can be described based on the width to depth ratio analysis [2]. The uniform flow in the river may change to non-uniform flow when the alternate bars are present. The irregularity characteristic of flow pattern for non-uniform flow capable of inducing active erosion and deposition process. As such, this process causes the bed perturbation, thus produces an unstable bed level. The presence of alternate bars potentially creates secondary flow in the channel that changes the condition of river morphology [7]. The migrations of alternate bars produce an unbalanced flow profile since the bed level continuously changes and as the flow migrating downstream. This situation causes difficulty in determining the characteristic of flow. To compound this matter, the flow pattern becomes much more complex if the vegetation cover occurred over the river bars [1]. In term of roughness analysis, the flow resistance can occur from bed roughness such as form roughness, the grain roughness, and the vegetation drag coefficients. These parameters affect the conditions of flow in the channels. This paper focuses on the analysis of the flow profile modified by the formation of alternate bars in the lateral and longitudinal analysis along the channels. This study provides the results from computer simulations analysis with different sediment size for each simulation. The impacts of flow formation are observed based on the changes of bed sediment sizes.

2 Methodology

2.1 *Description of the River Model*

The river model of the straight channel with 12 m length and 0.5 m wide was created by using Nays2DH solver provided by iRIC Software. This dimension was chosen based on the suitable width to depth ratio analysis for alternate bar formation as discussed by [2, 9]. Three measurement points were observed laterally at 2, 6, and 10 m, respectively. The bed was constructed by using different sediment sizes of D_{50}: 0.4, 0.5, and 0.6 mm, respectively. The flow of water was fixed at 0.03 m^3/s for each experiment. The initial bed condition was flat with a channel slope of 0.002. The bed was set to be moveable while the bank of the channel was fixed at its position. Manning's Roughness coefficient values (N value) are

Table 1 Details of the variables used in the simulation

Run	Channel size (m)	Discharge (m^3/s)	Average flow depth (cm)	Sediment size, D_{50} (mm)	Manning's roughness coefficient (mm)	Slope
Channel 1	12 × 0.5	0.03	5	0.4	0.02	0.002
Channel 2	12 × 0.5	0.03	5	0.5	0.022	0.002
Channel 3	12 × 0.5	0.03	5	0.6	0.023	0.002

ascertained based on the mean grain size used as followed by Cowan [4] as shown in Eq. (1). The details of the variables used are shown in Table 1.

$$n = (n_1 + n_2 + n_3 + n_4 + n_5)m \quad (1)$$

n_1 is the base value for a straight uniform channel;
n_2 is the additive value due to the effect of cross-section irregularity;
n_3 is the additive value due to variations of the channel;
n_4 is the additive value due to the relative effect of obstructions;
n_5 is the additive value due to the type and density of vegetation; and
m represents a value for the degree of meandering used to multiply the sum of the previous values.

2.2 Measurement Method

The measurements were made based on the simulation observations. Three sections namely Point A–A (2 m from upstream), Point B–B (6 m from upstream), Point C–C (10 m from upstream) were measured laterally along the channel with the distance between each station was 2 m respectively. The results in longitudinal sections of the left and right side of the banks and the center of the channels are also recorded. The bed profile was measured laterally and longitudinally at each station. Each simulation was set to run for 24 h. Figure 1 shows the details of the river model used in the simulations.

3 Result and Discussion

Results from the analysis of Nays2DH software were obtained in term of flow magnitude, lateral velocity profile, and longitudinal flow profile. After the simulations were completed, it could be observed that the alternate bars were formed on both three channels. Most of these bars were formed at the downstream channels. The red color in the channel for Figs. 2, 3 and 4 defined as the alternate bar formations.

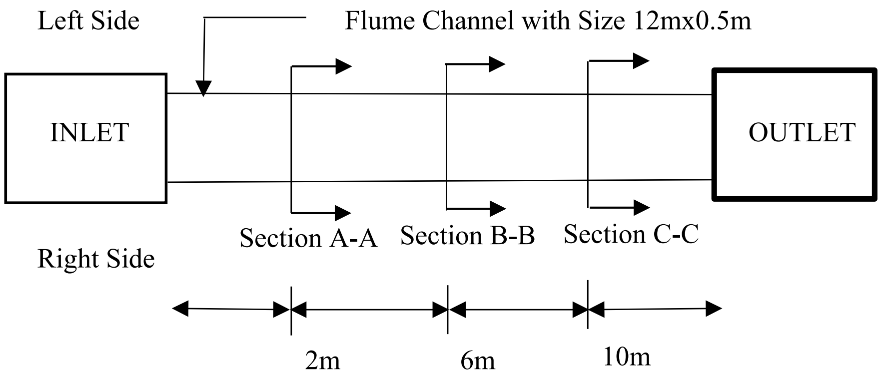

Fig. 1 The channel used in the simulation and locations of measuring stations. (The bed of the channel is covered with the sediment size of 0.8 mm along the channel)

Fig. 2 The initial condition of bed and velocity distribution for the channel in simulation

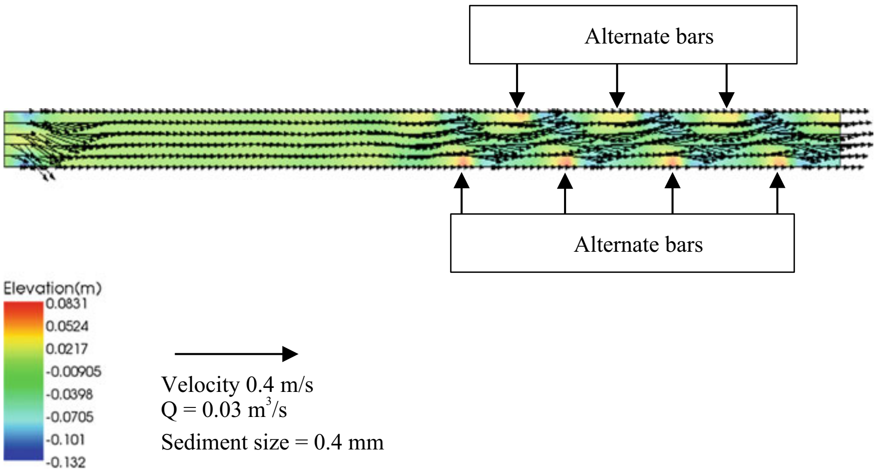

Fig. 3 The velocity distribution in channel 1(dimension of channel 12 m × 0.5 m, t = 24 h)

3.1 Flow Magnitude Analysis of the Channels

The flow stands in uniform condition at initial simulation as the alternate bars were still not formed. This has been shown in Fig. 2. The flow started to change when the time simulations reach at 5940, 6100, and 6230 s in channel 1, 2 and 3,

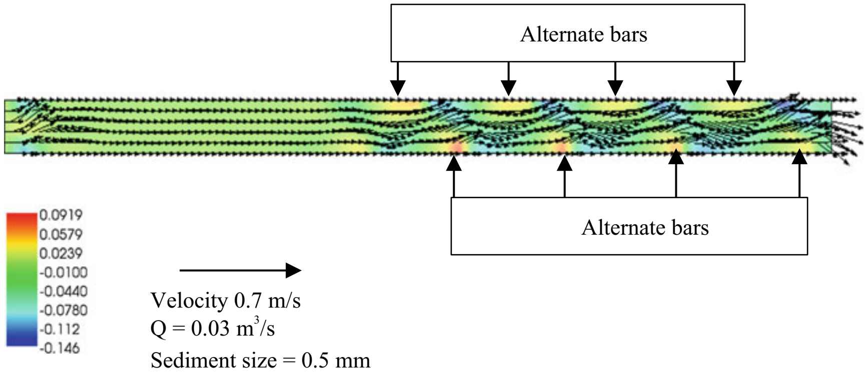

Fig. 4 The velocity distribution in channel 2 (dimension of channel 12 m × 0.5 m, t = 24 h)

respectively. The change of flow was reflected from the evolutions of bed level of channels. It had changed in term of its profile and magnitude. The flow was stood in uniform in the upstream area; however, its turn to non-uniform in the downstream area. Figures 3, 4 and 5 show the magnitude of flow produced from the formation of alternate bars. Both three channels produced an almost similar pattern of flow profile, which the flow diverted away from alternate bars and flowed towards to another side of the channels that have no bars. These mechanisms repeatedly happened in each of the bar formation areas. Therefore, it shows that the flow magnitude was formed alternatingly as followed by the formation of alternate bars. The figures also show that even the bed sediment has differed in its sizes, the condition of alternate bars formed were still almost similar and the flow magnitude also not much differed. As such a situation proved that the sediment size alone could not affect so much on the formation of alternate bars and flow magnitudes. However, the profiles of velocity were affected both laterally and longitudinally, as shown in Figs. 6, 7 and 8.

3.2 Longitudinal Flow Profile Analysis of the Channels

The analysis also was made based on the comparison of velocity profile with the bed elevation in longitudinal conditions. The measurements were made at longitudinal section at 2 cm from the left and right sides of boundaries and the center of the channel. As the alternate bars not formed at the upstream of the channel, it could see that the velocity at upstream was more regular in its pattern and flow uniformly. However, the velocity started to change at 50 cm of the channel and turned to non-uniform toward the downstream. The conditions of velocity were parallel with the formation of bed channels. Figures 6 and 7 show the velocity profile in the longitudinal section for both three channels based on the bed level conditions.

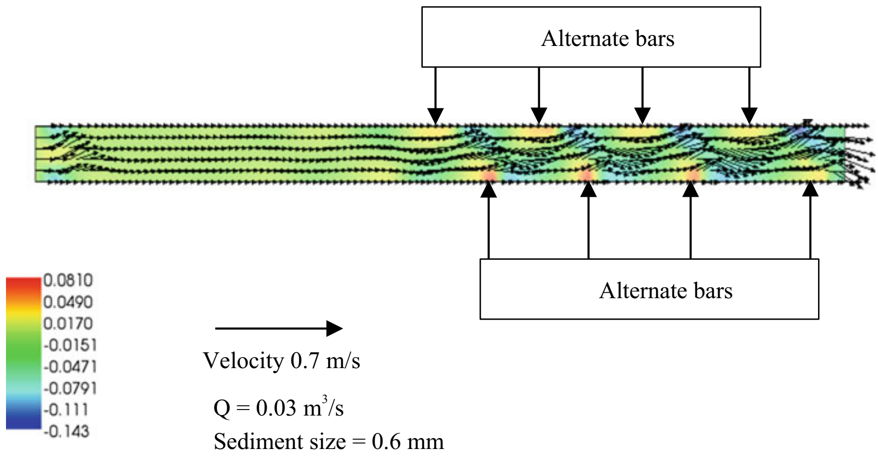

Fig. 5 The velocity distribution in channel 3 (dimension of channel 12 m × 0.5 m, t = 24 h)

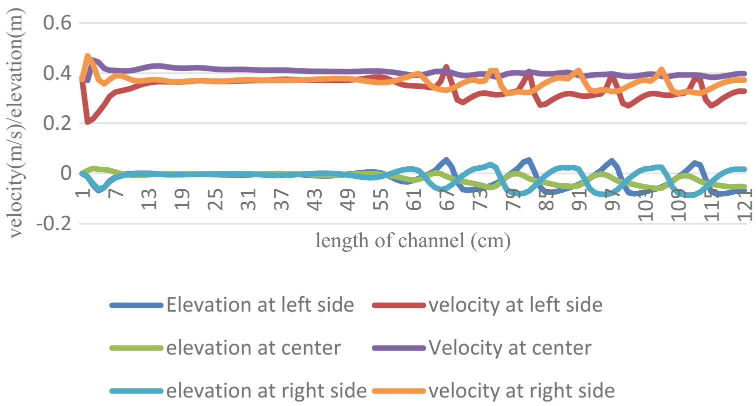

Fig. 6 Bed level and velocity profile along the longitudinal section of the channel 1

From these figures, it could see that the velocity was higher on the area of alternate bars formations, and it decreased when the bed level decreased. The velocity was more uniform at the center of channels even there was a corrugated bed profile formed. This condition happened on both three channels. Also, the average velocity decreased from upstream to downstream in the channel 1, but the opposite conditions occurred in other channels. This happened because the amplitude of alternate bars was higher in channel 1 and to prove that the sediment of 0.4 mm induced higher bar amplitude. Since the alternate bars were among the flow resistance parameters; thus, it resists the flow to decrease its velocity.

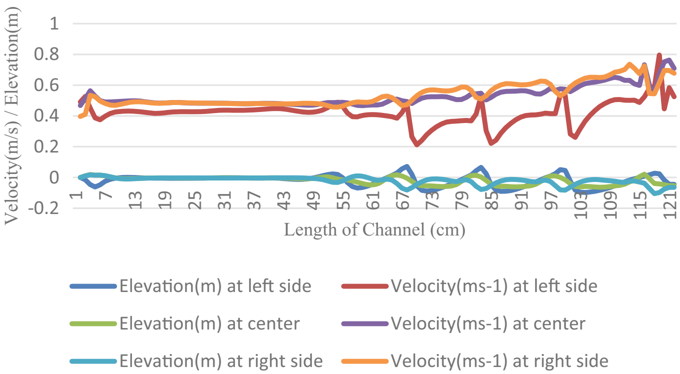

Fig. 7 Bed level and velocity profile along the longitudinal section of the channel 2

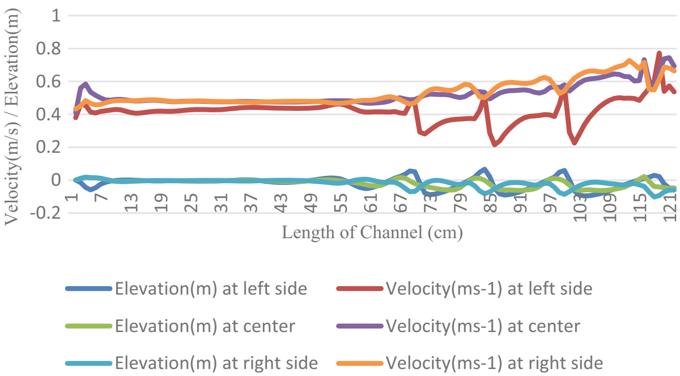

Fig. 8 Bed level and velocity profile along the longitudinal section of the channel 3

3.3 Lateral Flow Profile Analysis of the Channels

The study also investigates a relationship of the traversed distribution of velocity with the alternate bars. The velocity profiles were observed based on three measurement points at section A–A, section B–B, and section C–C. At section A–A, the lowest velocity occurred in channel 1 and higher in both channel 2 and 3. However, the velocities in channel 2 and channel 3 were almost as the velocity lower at channel sides and higher at the center. The velocity profile for both three experiments also not much differed between each other as the lowest velocity occurred at near boundary channel and increased when far from it. The boundaries of channel play an important role as it could resist the flow by its boundary surface roughness and produced higher shear stress. The velocity decreased when the shear stress was higher. The alternate bars were not formed at section A–A as the shear stress was induced the erosion process. Therefore, it could say that the formation of the

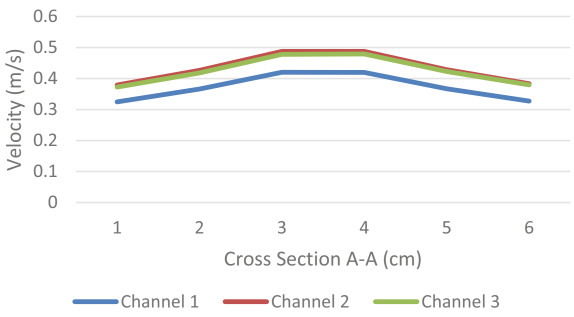

Fig. 9 Velocity profile at 2 m from upstream for the channels

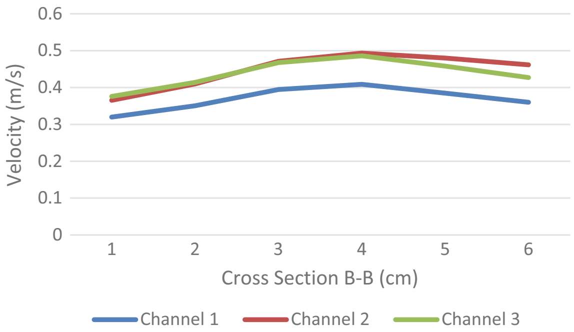

Fig. 10 Velocity profile at 6 m from upstream for the channel

velocity profile at this area not affected by the alternate bar formations. Figure 9 shows the conditions of velocity at section A–A.

For section B–B that located 6 m from upstream, the velocity profile at the right side of the channel was increased in both channels. However, the highest velocity was still at the center of the channels. The alternate bars were started to form in this section, as proved in Figs. 3, 4 and 5. This could be stated that the presence of alternate bars altered the condition of velocity. The alternate bars cause the flow depth decreased over the bars areas that increased the average depth velocity. This condition agreed with the concept of non-uniform flow where the sub-critical flow occurred in higher flow depth, but it changed into supercritical if the flow depth decreased. The velocities at right boundaries were still lower than the velocities at the center because the effect of boundary channels was still applied in this area (Fig. 10).

The last section that considered for analysis was at section C–C that located 10 m from upstream. This location located most downstream of the channels. At this section, alternate bars actively formed with higher bar amplitude, and they were visible in both three channels. The velocity was again altered by alternate bars at this section. The profiles differed from the section B–B. The average depth velocity at the right side was increased; however, it critically decreased at the left side. The velocity at the center was still higher than the other areas. It described that the resistance from the channel boundaries still influenced the condition of flow

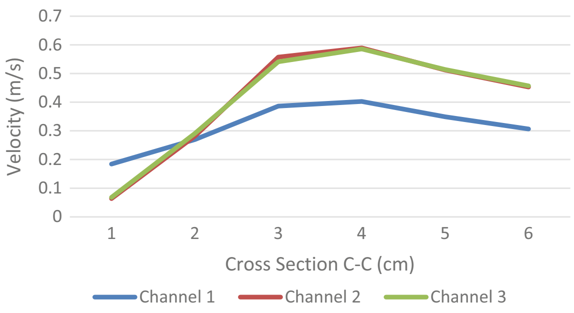

Fig. 11 Velocity profile at 10 m from upstream for the channel

velocities. The velocities at the left side decreased significantly to explain that the bed channel was eroded to produce scours. The presence of scours increased the flow depth that potentially changed the condition of flow from shooting to tranquil. The conditions of velocity for channel 2 and channel 3 are constantly similar for both sections to show that the different size of sediment of 0.5 mm and 0.6 mm were not much affect the flow of channels. However, the velocity in channel 1 was constantly lower since the amplitude of alternate bars at this section was higher (Fig. 11).

4 Conclusion

Alternate bars changed the conditions of flow in rivers. It could transform a uniform flow to non-uniform flow as the bed elevations were varied. The alternate bars actively formed in the downstream part of channels; thus, they affect the profile velocity at this area. The varying bed sediment size could produce different conditions of the alternate bar formations and velocity distribution. The presence of alternate bars diverted the flow away from its wavelength to accumulate at the deeper flow depth. The velocity was higher at the center of the channels; even there were bars formed. The velocity was lower at the side of the channel, that affected from shear stress of boundary channels.

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