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Profiles of Streamwise Velocity and Bed Topography in Area of Non-vegetated and Vegetated Sand Bars

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Abstract: Sand bar is one of the bed features occurs resulting from the instability of flow and sediment in river. The existence of sand bar could alter the river channels in terms of channel geometry and flow properties. The sand bar can be formed in non-vegetated and vegetated conditions. The streamwise velocity and bed topography continuously changing at this bar as the flow and sediment were unstable. The profiles of the streamwise velocity and bed topography need to be observed to enhance the understanding on the effect of vegetated sand bars to the river system especially in terms of hydraulics and morphology. This study was conducted to provide an analysis of the streamwise velocity and bed topography in non-vegetated and vegetated sand bars. The study was based on the experimental approach. A straight flume channel with a size of 10 m long and 1 m wide was used. The bed and velocity profile as well as wavelength and height of bar were measured. It was found that the streamwise velocity reduced at the sand bar as the flow depth lower and increased at the opposite area. The presence of vegetation significantly increased flow resistance thus induced sediment deposition. The sand bars have shown an increasing approximately 15% for wavelength and up to 100% for height after vegetation was applied. Therefore, the sand bar was actively developed when vegetation grew on it.

Keywords: Sand bar, wavelength and height, bed profile, vegetation, streamwise velocity.

1. Introduction

The sand bar is one of the bedforms that occurs in the river. There are various types of sand bars such as alternate bars, mid-channel bars, and braided bars [1]. The sand bar is defined as the lateral deposition of sediment in the channel resulting from the bed instability due to the erosion and sedimentation processes. Flow and sediment are the main factors that contribute to the formation of sand bars [2] - [3]. Among all types of sandbars, the alternate bar is the most complex to understand as it is spatially and temporally unstable. Some researchers have also called it a periodic bar [4] - [5].

The sand bar usually develops starting with the formation of ripples, dunes, and scours [6] - [7]. Its formation depends on many factors such as flow characteristics, the cohesiveness of sediment, bedload and suspended load, sediment supply, slope and uniformity of channel, and vegetation condition [8]–[17]. These factors normally affected the geometry and stability of the sand bar. The sand bar initially forms without vegetation on its surface. However, the vegetation starts to grow when the drifted vegetation seeds are deposited and the sand bar is then known as the vegetated sand bar [9], [18]. The existence of a vegetated sand bar produced complex hydraulics and morphology of the river thus needs to be interpreted significantly. The objective of this study is to determine the profiles of streamwise velocity and bed topography of the river due to the formation of sand bars in non-vegetated and vegetated conditions.

1.1. Properties of Sand bar

The sand bar is commonly described based on geometrical conditions such as wavelength (L) and height (h_b)[19]. According to Ikeda et. al, [20] the wavelength of the bar is defined as the distance between consecutive, corresponding points along the flow direction. Meanwhile, the bar height is defined the vertical distance between the lowest bottom of the pool and the top of the bar surface. Figure 1 describes the definition of the wavelength and height of the bars and how the measurements is made in the experiments.

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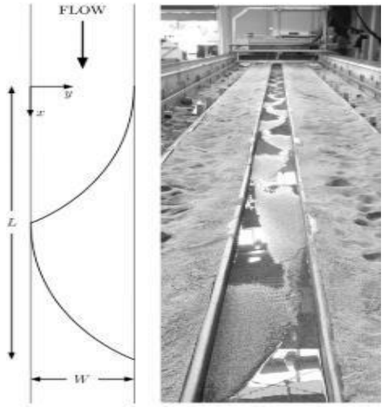
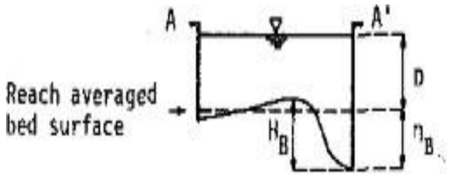


(a)



(b)

Fig 1 - Definition of the bar wavelength and bar height measured in the experiment. (a) bar wavelength, (b) bar height.

1.2. Vegetated Sand bar

The vegetated sand bar was referred as the sand bar that was covered with vegetation. The vegetation normally grew on the steady sand bar that developed under stable conditions. The presence of vegetation in a river commonly alters the flow and morphological characteristics of the river [14], [21]. The streamwise velocity and bed topography change according to the sand bar conditions whether in non-vegetated or vegetated cases. The presence of vegetation also altered the bed shear stress due to the higher density of vegetation [22] – [26]. These characteristics may change the conditions of streamwise velocity and bed topography which would result in different formation of its profiles. Therefore, this study was conducted to compare the conditions of streamwise velocity and bed topography in two conditions of sand bars which are non-vegetated and vegetated cases.

2. Methodology

The study was based on the experimental investigation. A straight channel was utilized in the Hydraulics and Hydrology Laboratory of the University Teknologi Malaysia (UTM). The details of the methods and procedure of the experiment are explained further in the next section.

2.1. Tilting Flume

A channel with 10 m long and 1 m wide was utilized for the experiment. It was filled with uniform sand of size 0.8 mm as bed material under flatbed conditions. The slope was fixed at 0.002 m/m. The channel was equipped with a tailgate at the outlet used to control the flow depth and maintain uniform flow. The water flowed into the channel with two different discharges of 15 L/s and 20 L/s. The discharges were maintained and recirculated until the experiment was completed. The sediment feeder was attached at the inlet of the channel and maintained to supply 11.1 g/s of sediment to the channel.

2.2. Measurement Process

For the measurement process, four transverse stations were created along the channel that was used to determine the bed profile and streamwise velocity. These stations were marked as Ch200 to Ch500. The bed topography was measured using the digital photogrammetry technique. The control points (CPs) were established along the wall of the flume and were used as reference points. A Sony A70 digital camera equipped 1.5 m above the flume was used to capture the bed topography. The pictures taken were exported into topographic software namely Agisoft Photoscan Software for processing the digital terrain model (DTM) to provide morphology analysis. Meanwhile, the streamwise velocity was measured at each section using an Electromagnetic Current Meter (ECM). Figure 2 shows the locations of the transverse stations created along the channel.

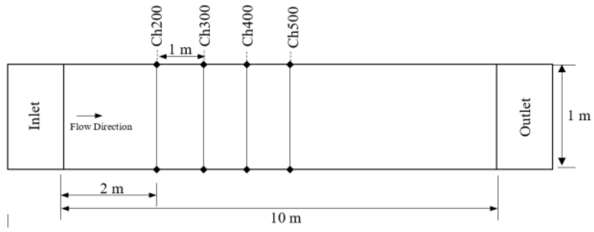


Fig 2 - Location of transverse stations established in the experiments.

2.3. Experimental Process

The experiment started by flowing the water into the channel. The initial flatbed was immediately changed after the experiment started. The experiment was stopped every 2 hours for the measurement of bed topography. The experiment was continued again after the measurement of bed topography was completed and it was carried out until the sand bar form and channel reached its equilibrium condition. After that, the cylindrical rods with a diameter of 5 mm were installed on the sand bar surface in tandem condition with 50 mm spacing. These rods acted as a rigid vegetation stem that grew on the sand bar with a density of 441 stem/m^2. The experiment was continued and the procedure was repeated until the channel became stable. Two conditions of bed formation can be obtained from the experiment namely the non-vegetation case (NV), which was referred as the bed topography before the installation of cylindrical rods. Another case was full vegetation (FV) referred as the bed topography after the steel rod installation. Figure 3 shows the non-vegetated and vegetated bed channels for the study. Meanwhile, details of the parameters used in the study are shown in Table 1.

(a) (b)

Fig 3 - The condition of bed channel before and after the installation of steel rods over the bar surface. (a) Non-vegetated, (b) Full vegetated.

Exp No	Channel Slope m/m	D_{50} (mm)	Q (L/S)	Sediment Supply Rate (g/s)	Vegetation	F_r	D_0 (m)	Re	β	d_s
1a	0.002	0.8	15	11.1	NV	0.39	0.047	9690	21	0.01
1b	0.002	0.8	15	11.1	FV	0.36	0.047	12750	21	0.01
2a	0.002	0.8	20	11.1	NV	0.36	0.069	21113	17	0.01
2b	0.002	0.8	20	11.1	FV	0.35	0.065	18809	17	0.01

3. Results and Discussion

The results focused on the three main analyses which are the wavelength and height, bed topography, and streamwise velocity of non-vegetated and vegetated sand bars. Two steady sand bars formed in the channels that were marked as Bars 1 and 2. Bar 1 formed in experiments 1a and 1b, meanwhile Bar 2 formed in experiments 2a and 2b. These sand bars were maintained until the experiment was stopped to show that they were stable and did not vanish. Experiment 2 had a flow rate of 20 L/s higher than Experiment 1. Experiments 1a and 2a were conducted in non-vegetated conditions, meanwhile, Experiments 1b and 2b were conducted under vegetation. Thus, Bars 1 and 2 in Experiments 1a and 2a were indicated as non-vegetated and Bars 1 and 2 in Experiments 1b and 2b were indicated as vegetated bar. Figure 4 shows the conditions of sand bar formation in both channels of non-vegetation and vegetation cases.

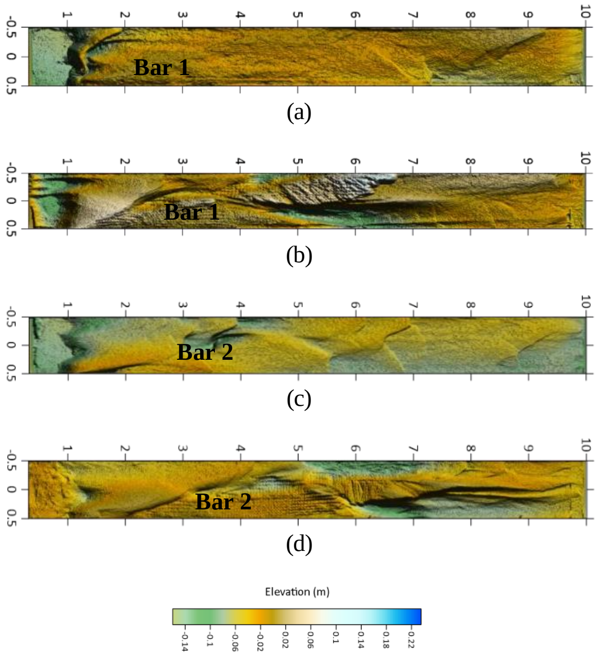


Fig 4 - Final bed topography of the channel for the experiments. (a) experiment 1a for non-vegetation, (b) experiment 1b for vegetation, (c) experiment 2a for non-vegetation, (d) experiment 2b for vegetation.

3.1. Channel Wavelength and Height of Sand bar

Wavelength and height are among the most important parameters in determining the behaviour of sand bars. Figure 5 shows the conditions of the wavelength and height of the sand bar for both non-vegetated and vegetated cases. It was found that the wavelength for all sand bars increased in a vegetated case compared to a non-vegetated case. This is shown in Figure 5(a). Bars 1 and 2 in vegetated cases increased up to 15%, and 15.5%, respectively. The presence of vegetation increased the flow resistance thus, induced deposition of bed sediment and lengthening the wavelength of the bar. The increase in wavelength proved that the vegetation increased the stability of the formation of sand bars. A similar condition occurred for the height of the sand bars where all sand bars showed an increase in height in a vegetated case compared to a non-vegetated case as shown in Figure 5(b). The height of Bars 1, and 2 in vegetated case increased by 100%, and 50%, respectively. The significant reduction in bed level in the opposite area of the sand bars increased the bar height.

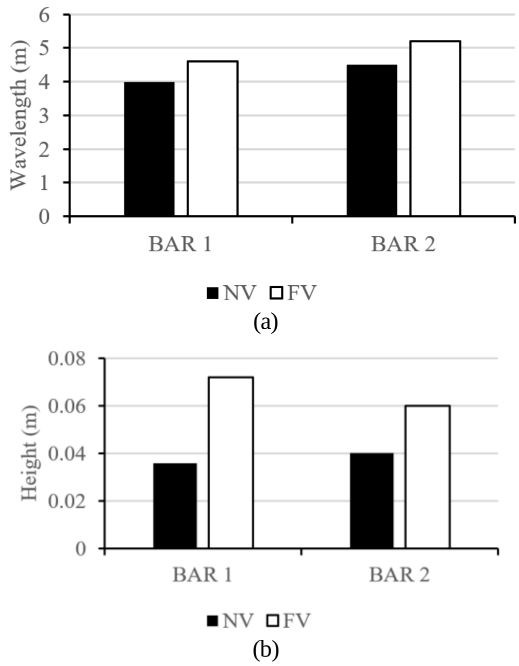


Fig 5 - Comparison of wavelength and height of the sand bar for both conditions of non-vegetated and vegetated cases. (a) Bar wavelength, (b) bar height

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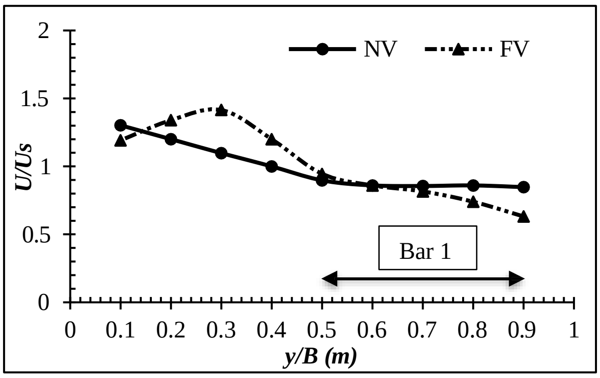
3.2. Streamwise Velocity Profile

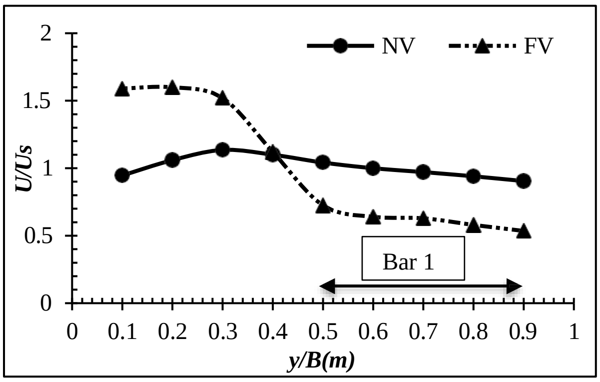
This study also provides an analysis of the streamwise velocity profile in the area of sand bars. The analysis was based on the four stations established as discussed in the methodology section. The erosion and deposition occurred at the higher and lower flow velocities, respectively. The vegetation acted as flow resistance to reduce flow velocity. Thus, deposition significantly occurred in the vegetation area. The sand bar positively developed in the vegetation area as proved for Bars 1 and 2 according to the wavelength and height.

Figure 6 shows the streamwise velocity profiles for both Experiments 1a and 1b under the conditions of non-vegetation and vegetated cases. The analysis was based on the U/U_s, where U is the recorded mean streamwise velocity and U_s is the specific mean sectional velocity at each section. It was found that the low velocity formed at the right side of the channel that covered the area y/B of 0.5 to 0.9 at station Ch200 to Ch400 as shown in Figures 6(a) to 6(c). This area was a location for the formation of Bar 1. It was also found that the U/U_s in these areas were lower in vegetated channel as compared to non-vegetated case. This happened as the vegetation increased flow resistance on sand bars and reduced velocity. The U/U_s in Ch500 was uniform in the NV case as the sand bars were not formed at this station. The U/U_s reduced at y/B 0.1 to 0.5 for the FV case as the new sand bar formed and this sand bar was not discussed in this study. However, the reduction of U/U_s in the area of this new bar proved again that the vegetation played an important role in the development of the streamwise velocity profile.

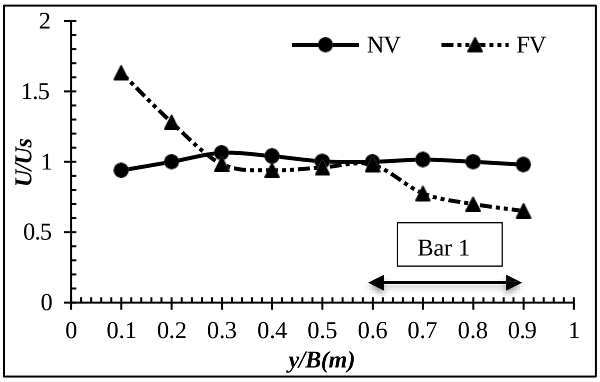
A similar condition occurred for Bar 2 in which the U/U_s were lower at its area of y/B 0.5 to 0.9. The U/U_s significantly reduced again in the vegetated case as shown in Figures 7(a) to 7(d) for stations Ch200 to Ch500, respectively. The relationship between flow and vegetation was important in determining the streamwise velocity profile. Since the U/U_s was lower in the vegetated sand bar, thus this sand bar was more stable compared to the non-vegetation case because an erosion process could not easily occur.



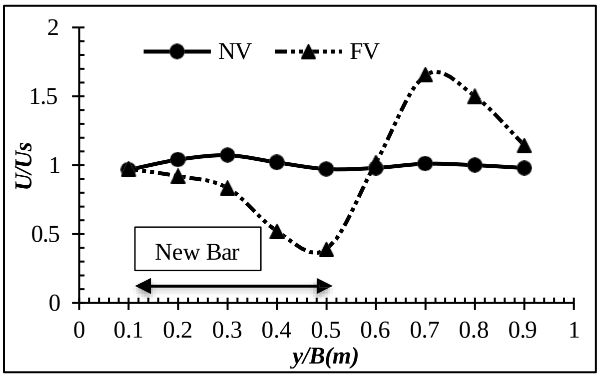
(a) Ch200



(b) Ch300



(c) Ch400



(d) Ch500

Fig 6 - The U/U_s produced at each measured station for experiment 1a and 1b. (a) Ch200, (b) Ch300, (c) Ch400, (d) Ch500.

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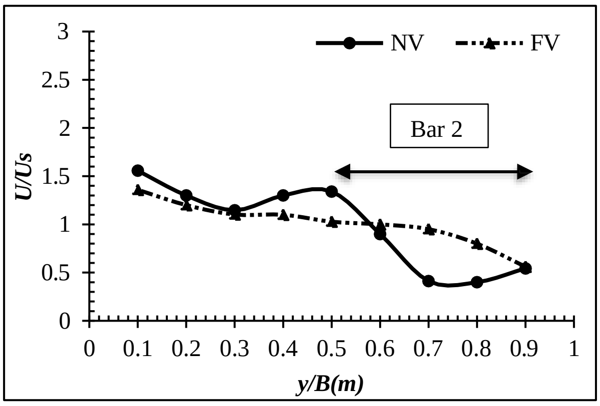
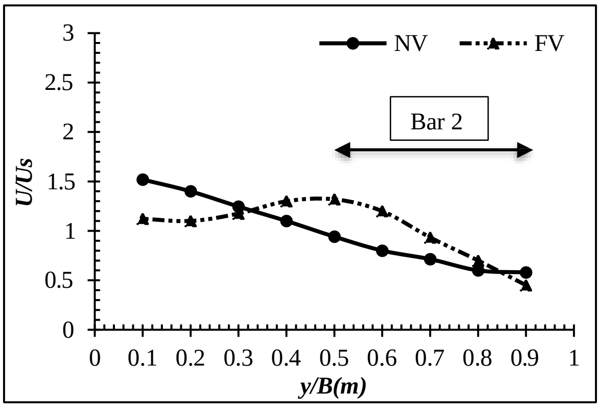
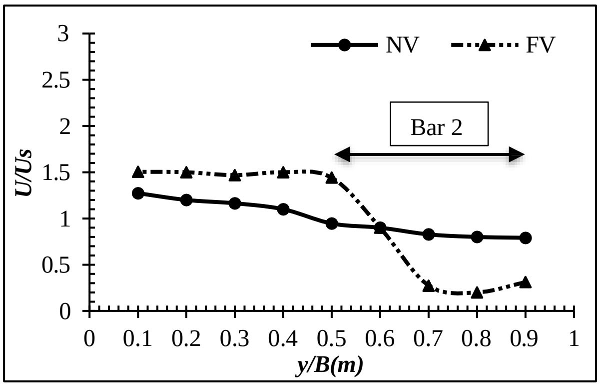


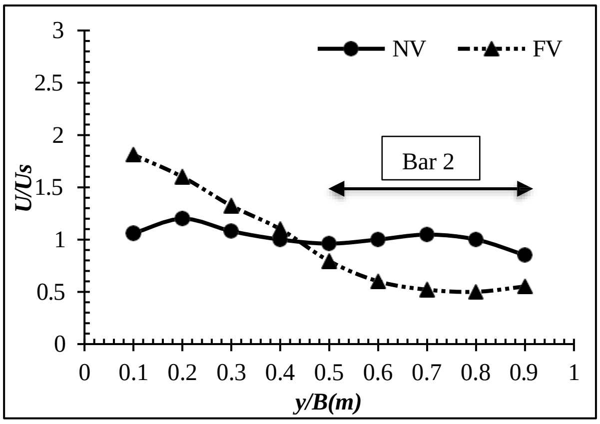
(a) Ch200



(b) Ch300



(c) Ch400



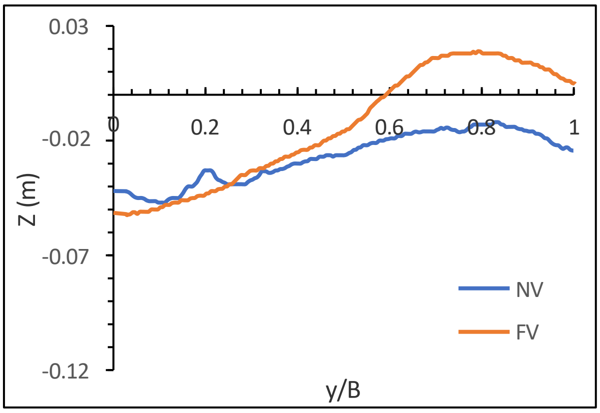
(d) Ch500

Fig 7 - The U/U_s produced at each measured station for experiments 1a and 1b. (a) Ch200, (b) Ch300, (c) Ch400, (d) Ch500.

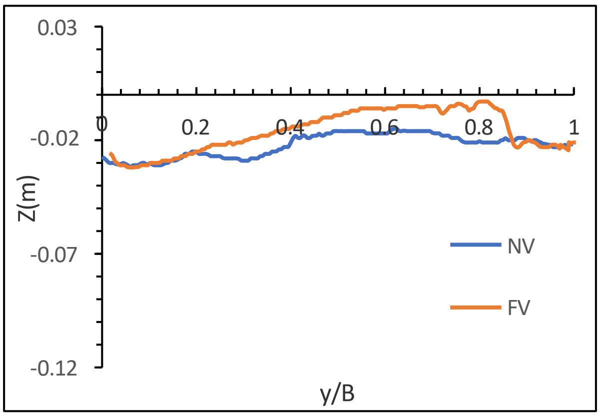
3.3. Bed Topography of the Channel

The changes in bed topography are normally reflected in the instability of flow and sediment. The data on bed topography were obtained in this study through the digital close-range photogrammetry method. The bed profile was measured based on the four stations established as explained in the methodology section. It was found that the deposition process was not evident in the NV case as the bed elevation at all stations was lower than the initial bed. However, Bar 1 formed at the right side of the channel that covered the area of Ch200 to Ch400 with *y/B* from 0.5 to 1 as shown in Figures 8(a) to 8(c). This proved that the formation of Bar 1 came from the erosion process rather than the deposition process. The formation of Bar 1 happened as the bed elevation in this area faced a minor erosion process as compared to the bed elevation in the opposite area. Thus, it became higher than the opposite side to form Bar 1. The bed elevation at the opposite side reduced significantly as the U/U_s was higher and promoted an active erosion process. A similar situation happened for Bar 2 where the bed elevation was higher at this location as the U/U_s was higher in the opposite area.

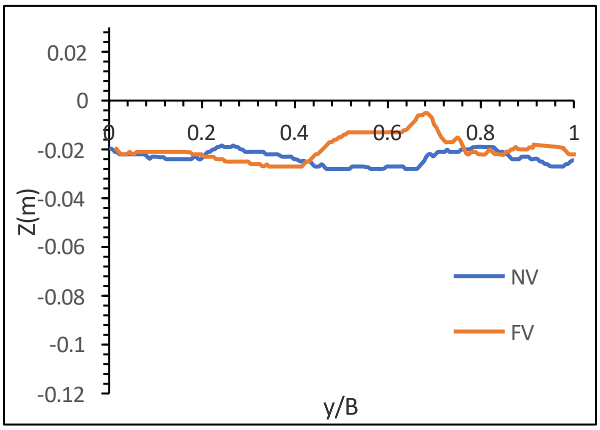
In the vegetation case, the presence of vegetation changed the hydrodynamics and morphology of the channel. In Experiment 1b, the bed elevation increased at Bar 1 as compared to the non-vegetation case, especially at station Ch200. The deposition process was evident at this station as the bed elevation was higher than the initial bed. The decreasing flow velocity induced sediment deposition thus promoting the formation of sand bar. In Experiment 2b with higher flow rates, a similar condition occurred as the bed elevation increased at the sand bar after the vegetation was applied. Figures 9(a) to 9(d) show the bed elevation of Bar 2.



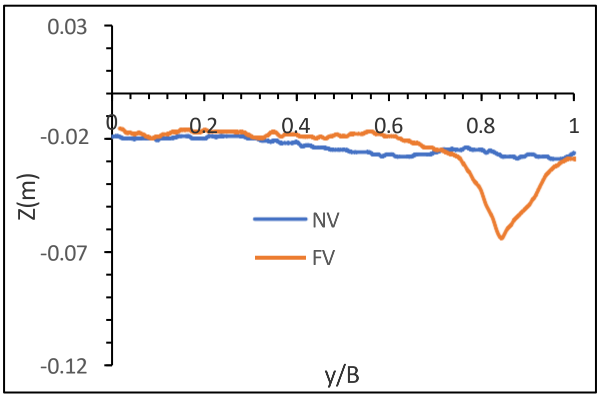
(a) Ch200



(b) Ch300

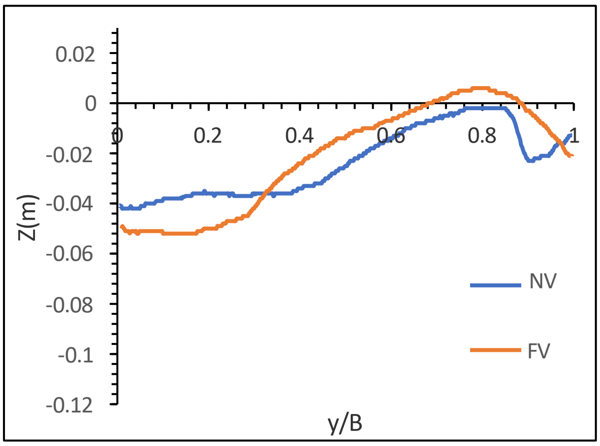


(c) Ch400

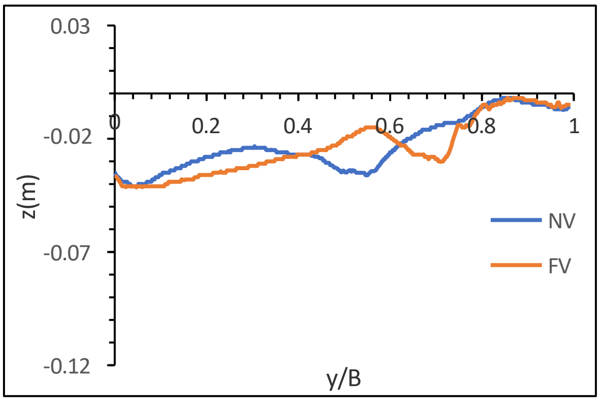


(d) Ch500

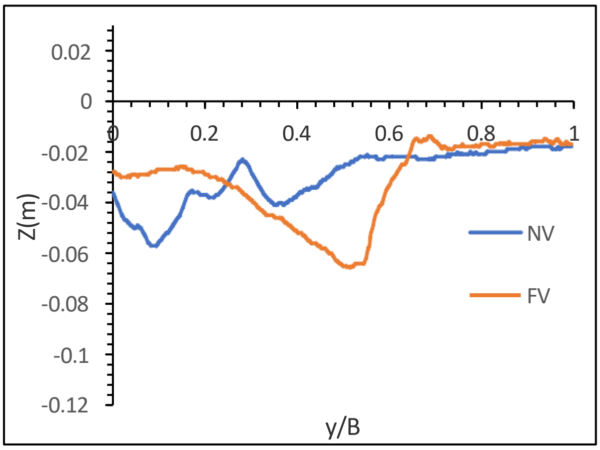
Fig 8 - The formation of final bed topography at each measured station for experiments 1a and 1b. (a) Ch200, (b) Ch300, (c) Ch400, (d) Ch500, (e) Ch600, (f) Ch700.



(a) Ch200



(b) Ch300



(c) Ch400

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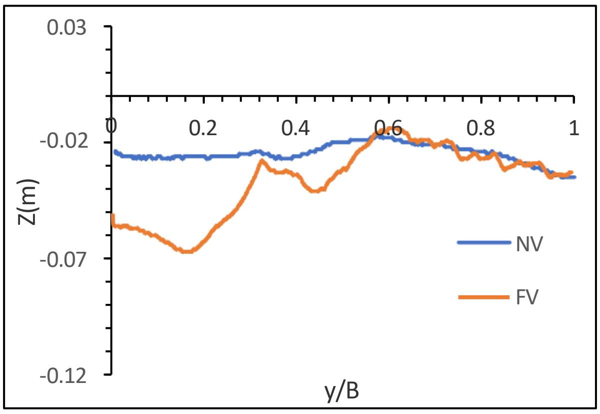

(d) Ch500

Fig 9 - The formation of final bed topography at each measured station for experiments 2a and 2b. (a) Ch200, (b) Ch300, (c) Ch400, (d) Ch500, (e) Ch600, (f) Ch700.

4. Conclusion

The profiles of streamwise velocity and bed topography were obtained related to the sand bar under non-vegetated and vegetated cases. The streamwise velocity reduced on the sand bar area and increased at the opposite side dependent on the flow depth conditions. The streamwise velocity is higher at deeper bed topography and lower at the lower flow depth. The erosion process actively occurred at deeper bed levels to erode bed material and transport it downstream. The deposition of sediment downstream produced sand bar formation. This mechanism explained how the sand bar formed in the river. The presence of vegetation over the bar produced a significantly lower velocity. Therefore, the vegetated sand bar was more stable than the non-vegetated condition. The obtained analysis of wavelength and height shows positive development of sand bars when the vegetation is established. They were increased significantly to promote the higher development of sand bars.

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