

PAPER • OPEN ACCESS

Experiment on fundamental behaviours of wavelength and height of vegetated alternate bar in river

To cite this article: Mohd Zulkhairi Mat Salleh *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **646** 012037

View the [article online](#) for updates and enhancements.

You may also like

- [Effect of Vegetation on the Flow of a Partially-Vegetated Channel](#)
Xiaonan Tang, Yutong Guan, Yujia Zhang et al.
- [Noise-induced phenomena in the dynamics of groundwater-dependent plant ecosystems with time delay](#)
Zheng-Lin Jia and Dong-Cheng Mei
- [Emissions of atmospherically reactive gases nitrous acid and nitric oxide from Arctic permafrost peatlands](#)
Hem Raj Bhattarai, Majja E Marushchak, Jussi Ronkainen et al.



ECS The Electrochemical Society
Advancing solid state & electrochemical science & technology

241st ECS Meeting

Vancouver, BC, Canada. May 29 – June 2, 2022

ECS Plenary Lecture featuring
Prof. Jeff Dahn,
Dalhousie University

Register now!

Experiment on fundamental behaviours of wavelength and height of vegetated alternate bar in river

Mohd Zulkhairi Mat Salleh^{1,2*}, Zulkiflee Ibrahim², Radzuan Saari², Mazlin Jumain², Zulhilmi Ismail², Muhamad Effandi Mohd Shariff², Nurdalina Syuhada Zulkifli² and Che Ku Ahmad Lukman Mazlan²

¹Faculty of Civil Engineering, Universiti Teknologi MARA Pasir Gudang, 81750 Masai, Johor, Malaysia.

²School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

Email: mohdz7418@uitm.edu.my

Abstract. The study on the alternate bar has been implemented by many researchers previously. However, the detailed analysis of the formation of the vegetated alternate bar is still not sufficient, especially on the bar wavelength, height, and width. Therefore, this present study provides an analysis of the experimental approach on the vegetated alternate bar formations. The focus was on the characteristics of wavelength, height, and width of the alternate bar. The objective of the study is to investigate the relationship of these parameters for three different conditions of alternate bar formations of non-vegetated, full and half patches of vegetation alternate bar. The flume of 10 m long and 1 m wide with erodible bed and fixed banks were used for the experiments with uniform bed sediment of size 0.8 mm. The wavelength and height of both full and half vegetated alternate bars increased compared to non-vegetated thus stabilized the formation of the alternate bar in the channels. The vegetation also reduced the value of the shield parameter to produce high deposition on the bar. The width of the bar increased at the head and body of the vegetated bar however it was decreased in the area of bar edge. Therefore, it could say that vegetation gives positive impacts on the alternate bar formation characteristics especially on its formation and stability in the rivers.

1. Introduction

Bars in the river can be categorized into two main categories namely migrating and non-migrating bars. Migrating bars or free bars occur mainly from instability reactions between morphodynamics and flow characteristics [1]–[3]. Different from the migrating bars, the non-migrating bars or forced bars to come from permanent flow deformation factors such as river bend, width variation, structure, or groin [4]. The characteristics of these bars are differed as migrating bars usually not stable as they periodically changing and migrates downstream with a smaller size compared to non-migrating bars. According to Crosato *et al.* [5], Migrating bars are two times shorter than non-migrating bars. Besides, the non-migrating bars are more stable and not migrates downstream as it occurs in a steady condition [2], [6]. Alternate bar and point bars are an example of migrating and non-migrating bar respectively. The free bars occurs first in the channel before it was followed by the formation of steady bars when the experiment was started. Many researchers have agreed that bars in rivers acted as an initial factor for meandering channels as it acted as one of the forced factors changing the river planform characteristics [7], [8].



1.1. Dimensional and dimensionless analysis of alternate bar

Bars in the river commonly characterized based on its dimensional and dimensionless characteristics. Ikeda, [7], had studied the characteristics of the alternate bar based on its wavelength and bar height. He had defined that the bar wavelength (λ) as the length of bars in the longitudinal section while bar height (h_b) is the difference in elevation between the highest and lowest point in a bar unit. Stefano Lanzoni & Tubino [9], had investigated the relationship between bar growth rates with shear stress. They had found that low shear stress may induce partial transport of sediment where coarser sediment remains, and finer sediment transported downstream. The increase of shear stress can cause a fully mobilize sediment in the channel. The alternate bar also defined based on its sediment heterogeneity as it could reduce the bar growth rates, shortened bar wavelength, and changing a damping migration speed in small values of shield parameter. In the study from Defina [10], he discussed that the bar also can be interpreted in terms of bar celerity where wavelength, height, and celerity of bar are related to each other. The main parameters that mainly influence the formation of bars are width to depth ratio (β), relative grain roughness (d_s), and shield parameter (θ) [1], [11]–[15]. According to Colombini *et al.* [11], and Colombini & Tubino, [12], in the analysis of linear and weakly non-linear theories, the bars formed when the width to depth ratio (β) is larger than critical width to depth ratio (β_c) and depending on the shield parameter (θ) and relative grain roughness (d_s). The parameters of width to depth ratio, grain ratio, and shield parameter can be determined in the equations (1)-(3) respectively.

$$\beta = \frac{B}{D} \quad (1)$$

$$d_s = \frac{d_{50}}{D} \quad (2)$$

$$\theta = \frac{\tau}{(\rho_s - \rho)gd_{50}} \quad (3)$$

B is the width of the channel. D_{50} is the mean grain size of the sediment. D is the average flow depth. τ is the bed shear stress. ρ_s is the density of sediment. ρ is the density of water and g is a specific gravity acceleration.

The neutral curved established to analyze the relationship between these parameters. Previous investigators determined the limitation of alternate bar formations through the neutral curved analysis. The free alternate bar formed when the value of width to depth ratio (β) is higher than the threshold value of width to depth ratio (β_c) because at this state the bed perturbation occurred due to the unstable bed deformation. If the value of width to depth ratio (β) lower than the threshold width to depth ratio (β_c), the bed is stable and free bars may not occur. This could explain that the width to depth ratio (β) plays an important role in determining the formation of free alternate bars. The graph for neutral curved was shown in figure 1. However, Crosato and John, [2], had provided further investigation on the related free alternate bar formations. They had found that the bars could form even the value of width to depth ratio (β) is lower than the critical width to depth ratio (β_c) if an intrinsic alternate bar occurs. Intrinsic condition is depending on the resonant condition. The resonant is defined as the curve line in a neutral curve. Super and sub resonant are the areas of the width to depth ratio (β) higher and lower than resonant line respectively. Intrinsic alternate bar happened in sub-resonant conditions. The resonant condition also can be determined based on the damping coefficient analysis of the Struksma Model. If the damping coefficient ($1/L_D$) equal to 0, it reached a resonant condition. If $(1/L_D) > 0$ it is sub-resonant, $(1/L_D) < 0$ is for super resonant. Therefore, it could be explained that the width to depth ratio larger than resonant value pertains to positive spatial growth rates. However, the bar still could form in intrinsic condition but with slower bar growth rates.

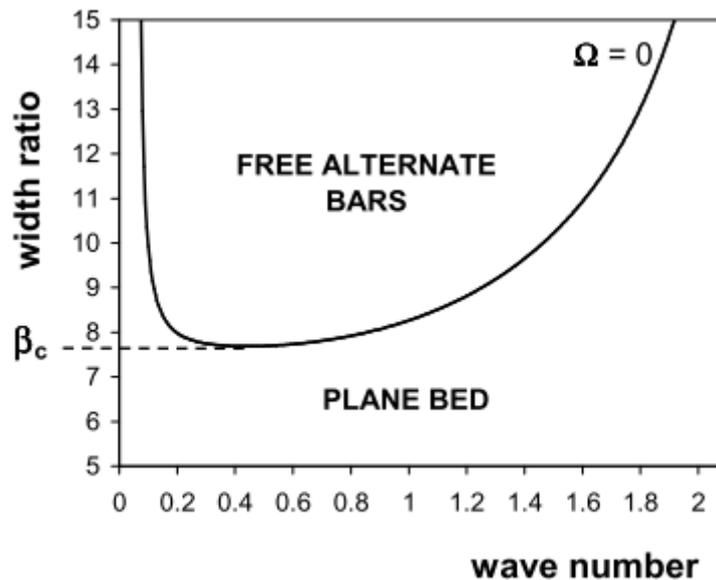


Figure 1. A typical neutral curved predicted for alternate bar formation (After Bertoldi, 2004).

The linear theories provided an analysis of temporal growth rates, migration speed, wavelength, and spatial damping coefficient. It used to determine the early development of alternate bars. Other than linear theories, Colombini *et al.* [11] had developed further analysis known as the weakly non-linear theories to improve the analysis of alternate bar formation that used to determine the amplitude of bars. However, Schielen [17], had proved that weakly non-linear theories cannot be used to analyze strong nonlinearities because of it only significant in predicting bar height. Therefore, Lanzoni & Tubino, [1] had developed a new non-linear theory to predict the final development of alternate bars with a more accurate analysis. This prediction had been evaluated in terms of its analysis accuracy through the experiment by Lanzoni & Tubino, [13]. The bars also only form when the transported sediment dominantly in bedload transport. The bar growth rates decreased if the suspended sediment is dominant in the channel [6].

1.2. Effect of vegetation to alternate bar development

Vegetation is another parameter that considered in determining the behavior of alternate bar formations. Many previous researchers have studied this factor as they knew that both the bed and flow field changed with the presence of vegetation [6]. Rominger *et al.* [18], had discovered that flow direction could diverge when additional vegetation occurred that results in raising flow at the patch edge which promoted erosion in this area. On the other hand, vegetation also may induce flow resistance to lower the depth-averaged streamwise velocity over the bar and increased it in the open region. Therefore, the deposition could actively occur within the patch of vegetation. In a further study of Li *et al.* [19], they had proved that the vegetation could increase the bed roughness on the bar body to cause suspended load deposited in this area. The findings were strengthened again by Iwasaki *et al.* [20] and Jaballah *et al.* [21] where they proved that the vegetation on the bar surface reduced soil erosion as the resistance to flow was increased to stabilize river bars and banks. Other than that, Bywater-Reyes *et al.* [22] had agreed that the vegetation of seed density and stage plays an important role in stabilizing the banks, driving flow characteristics to give an impact on morphodynamic developments. They also have provided further details of vegetation impacts where the uniform vegetation could promote the sinuosity of meander bends, and produce secondary flow. Calvani *et al.* [23] showed that most of the study in the experiment used a rigid cylinder and real vegetation for the analysis. This method also had been used by Ibrahim Z *et al.* [24], and Jumain M *et al.* [25]. Jourdain *et al.* [26] stated that the vegetation development

on bars could increase the bar wavelength and reduced bar width. This happened because the vegetation on the bar concentrated the flow velocities and sediment transport intensity in the active channel. Also, Serlet *et al.* [27] had analyzed that the full vegetation on top of the bar could prevent the bar migration process. In summary from the findings of the previous study, it could say that vegetation plays an important role in the development of a bar in the river. Most of them agreed that vegetation stabilizes the bar formation. However, the evidence to support that statement is not sufficient especially on the effects of vegetation to the alternate bar wavelength, height, and width. Therefore, this present study provides an analysis of alternate bar formation that impacted the presence of vegetation. The objective of the investigation is specifically to determine the development of alternate bar wavelengths, height, and width that affected by the vegetation.

2. Methodology

The study focused on the experimental investigations by using a flume channel with a size of 10 m long and 1 meter wide that located in hydraulic and hydrology laboratories of Universiti Teknologi Malaysia (UTM). The channel was set up with the condition of an erodible bed and fixed banks. The bed channel was filled with a 10 cm thickness of uniform sediment with a mean grain size of 0.8 mm. The initial bed of the channel was set up in a flat condition with a slope of 0.2 %. The discharge used was 15 L/s. The water was flowed into the channel from upstream to downstream and was recirculated until the experiment was completed. The flume was continuously operated until the bed reached its equilibrium state. The non-vegetated alternate bar was firstly formed at this stage as no vegetation was installed yet. This stage was marked as experiment 1. After that the rigid cylindrical rods of diameter 5 mm installed over this bare alternate bar. The uses of cylindrical rods represent as vegetation stem as align with the condition of real plants in term of flow resistance in the area [28]. The experiment was stopped again when the channel reaches its equilibrium for the second time and the data was obtained as experiment 2. The procedure was repeated for the half vegetation cover on top of the bar where the full vegetation on the bar head was removed to let only the bar edge installed with vegetation. The final changes in bed were monitored properly and it was remarked as experiment 3. The digital camera was used to capture the continuous changes of the bedform. The photos from the digital camera were exported into a topographic software that used to align all captured photos into only one completed photo. This software also processed the photos into the DEM model that used to identify the bed elevation. The formation of the vegetated alternate bar than analyzed properly. Figure 2 showed the detail of the flume experiments used in the study with three different cross-sections considered for the analysis. While figure 3 showed the condition of the cylindrical rod as vegetation that installed on the alternate bar.

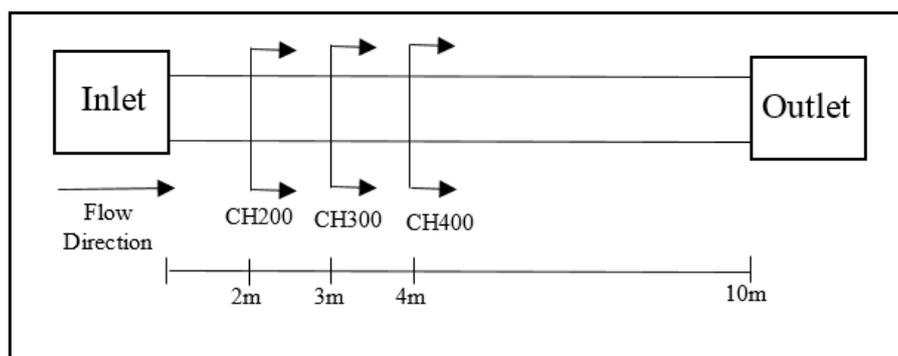


Figure 2. Detail of the flume channel used in the experiments.



Figure 3. The condition of cylindrical rods installed in the channel as vegetation.

3. Results and analysis

The study provided an investigation on the wavelength, height, and width of the alternate bars affected by the presence of vegetation. The alternate bar visible in all experiments with different geometrical characteristics. At the first stage, the flatbed was started to develop into ripples and dunes. The alternate bar only formed after a few hours of experiment with a small size of the formation. The bar was still not stable and migrates downstream. The bed channel was stable after 12, 8, and 10 hours of experiments 1, 2, and 3 respectively. Figure 4 showed the condition of alternate bar formation in the experiments for the condition of non, full, and half patches of vegetation. Meanwhile, figure 5 showed the detail of bed topography in the contour line version for all experiments.

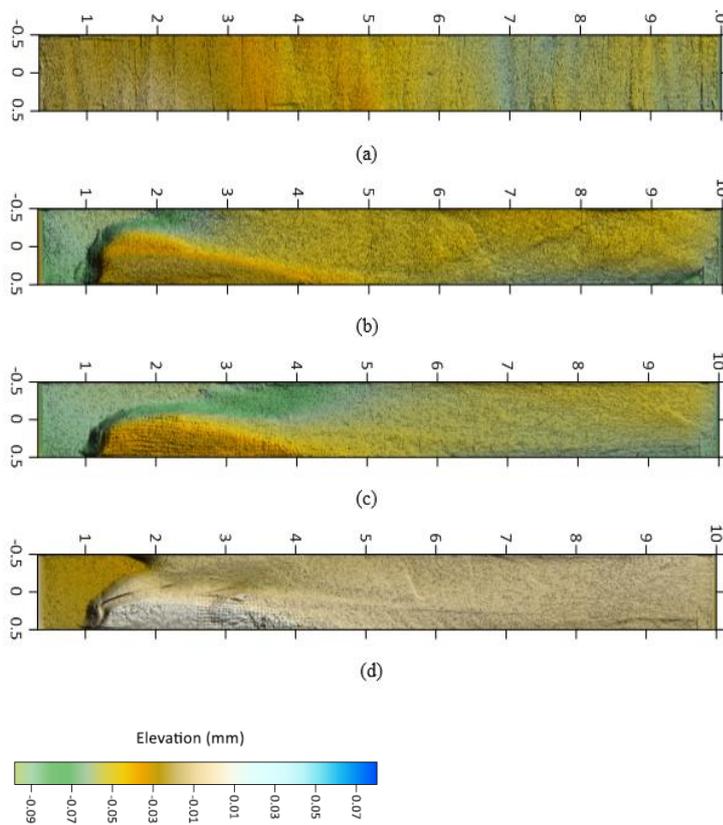


Figure 4. (a) initial bed condition of the channel. (b) Non-vegetated alternate bar. (c) Full vegetated alternate bar. (d) half vegetated alternate bar.

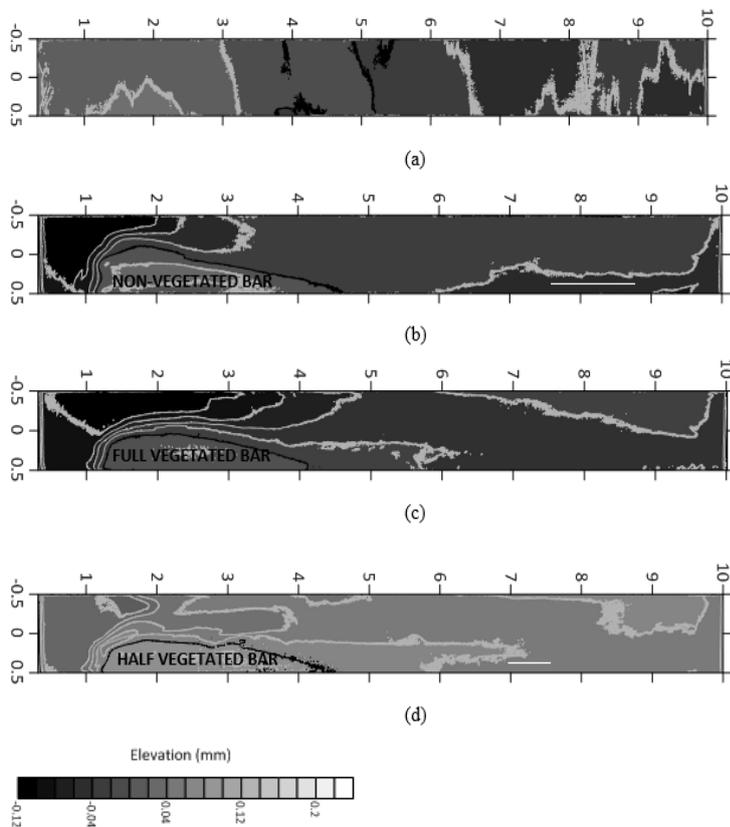


Figure 5. Bed topography conditions in the contour line version. (a) Initial bed. (b) Non-vegetation alternate bar. (c) Full Vegetated alternate bar. (d) Half vegetated alternate bar.

3.1. Relationship of vegetation with shield parameter

Reynolds Number used in the experiments were more than 2000 to keep the flow in a turbulent with the sub-critical condition as the Froude number less than 1. Both alternate bars formed in the area of the upstream channel and kept in that location until the experiments were finished. It was shown in figures 3 and 4. This was proved that a steady alternate bar formed at the final development of an alternate bar as it could become stable. The width to depth ratio increased from non-vegetated, half vegetated, and full vegetated alternate bars respectively. The range of values from 26 – 43 as agreed in Qian *et al.* [29]. They said that the alternate bars seemly active to form in the range of width to depth ratio of 10-50. The present study has proved these findings. They also said that the braiding mechanisms started to occur when the width to depth ratio is more than 50. However, it depended on the value of the relative grain roughness and shield parameter. The study also has discovered that the added vegetation on top of bars gives impacts on the value of bed shear stress where it was reduced when the vegetation was present. The lower bed shear stress could decrease the value of the shield parameter in the area of vegetation as agreed by Rominger *et al.* [18]. They found that the lower shield parameter intends to increase the deposition process and reduced the erosion process. This condition also happened in the present investigation as the shield parameter decreased with vegetation existence. Therefore, it could say that vegetation on top of bar promoting deposition thus stabilizing the bar geometries such as wavelength and height. Besides, the shield parameter was increased again when half of the vegetation on top of the bar head was removed. This is to significantly prove again that larger vegetation area increases the deposition process. Table 1 showed the detail of the values of parameters obtained from experiments.

Table 1. Detail of parameters obtained from both three experiments.

Exp.	Q (L/S)	D (m)	S %	β	d(mm)	ds	Re	Fr	τ	θ	λ (m)	H _b (cm)
1	15	0.038	0.2	26	0.8	0.048	13157	0.647	0.7	0.058	3	8.6
2	15	0.023	0.2	43	0.8	0.029	13157	0.913	0.5	0.035	3.8	9.5
3	15	0.028	0.2	35	0.8	0.035	13157	0.687	0.5	0.042	4.8	6.5

3.2. The wavelength of alternate bar

Many numbers of alternate bars form but only one chosen in each experiment based on its fastest bar growth rates used in many previous studies. The bars developed differently from non-vegetation to full and half patches of vegetation especially in terms of bar wavelength. The wavelength of the non-vegetated alternate bar was smallest with only 3 m lengths. It then was followed by a full and half vegetation alternate bar of 3.8 m and 4.8 m respectively. Therefore, the longest bar wavelength occurred in a half vegetated alternate bar. This could be explained that the non-vegetated bar reaches its equilibrium first with a wavelength of 3 m. However, when the rigid cylindrical rods fully installed on the top of this bar as shown in experiment 2, it became unstable again as all the parameters involved such as relative grain roughness and shield parameter were gradually changed and it developed to reach a new equilibrium with different bar wavelength. Thus, we could see that the final bar wavelength increased in full vegetation alternate bar. The presence of vegetation has caused the development of bar elongation at the bar edge thus lengthen the bar wavelength. The elongation process continuously happened even half of the rigid cylindrical rods were removed on top of the bar head as shown in experiment 3. However, the head of the bar was eroded because it was not covered by vegetation. Because of that, we could see that the bar wavelength in half vegetation condition has the longest bar wavelength compared to other experiments. As a summary, we could say that the presence of vegetation increased the bar wavelength.

3.3. Height of alternate bar

The height of the alternate bar was measured from the lowest to highest longitudinal elevation. Alternate bar in experiment 2 with full vegetation-covered had the highest height of bar followed by the bar in experiments 1 and 3 respectively. It could say that the vegetation increased the height of bars thus induce bar stability. However, when half of the vegetation removed at the area of bar head, the height reduced lower than the non-vegetation alternate bar even there was still another half of the bar area cover with vegetation at the bar edge. It was proved in experiment 3 as the alternate bar become more unstable when the vegetation was removed. The height of the bar reduced to promote bar elongation toward downstream of the channel. The erosion occurred at the bar head when the vegetation was removed to produce sediment material that transported toward the bar edge. The erosion than was reduced at the bar edge as the vegetation was still present to cause the sediment deposited toward downstream of this area. If we consider the peak of bed elevation we could see that the highest elevation occurs in experiment 3. However, there was some sediment deposited in the open regime to increase the lowest elevation in this channel. As the height of the bar is measured based on the difference between lowest and highest elevation, therefore it showed that the height of the bar lowest in this channel even has the highest peak bed elevation. Figure 6 showed the comparison of a longitudinal section of bed elevation of all experiments.

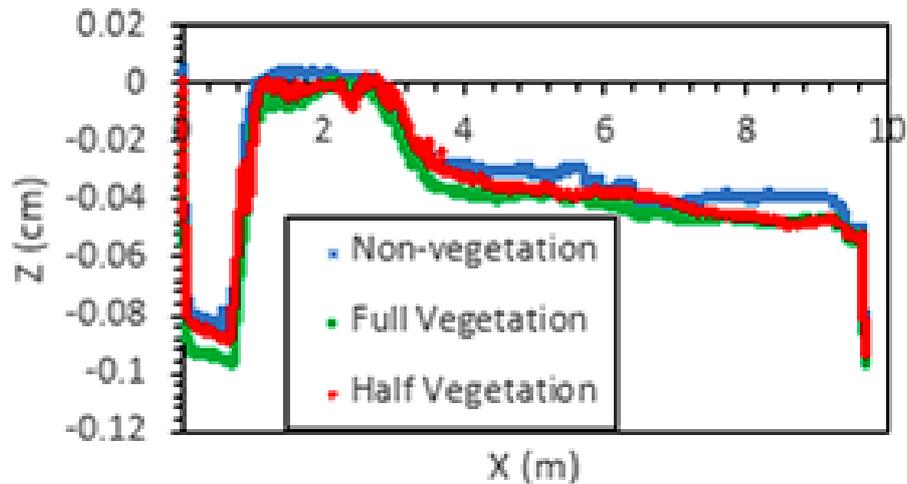


Figure 6. Longitudinal sections of bed elevations for all channels.

3.4. Width of alternate bar

This present study not just analysed the alternate bar in terms of wavelength and height but also in terms of width characteristic. The width was measured based on the cross-sectional wavelength of the alternate bar. Three cross-sections were selected in the area of alternate bar formation. It was labelled as CH200, CH300, and CH400 of 2 m, 3 m, and 4 m from upstream respectively. Those cross-sections were considered as the area of alternate bar formed for bar head, bar body, and bar edge respectively. At bar head, the highest width was in the non-vegetated bar followed by half and full vegetation respectively. Thus it explained that the vegetation reduces the width of alternate bar at head area. This happened because the added vegetation increased the velocity within the thalweg and at the edge of the vegetation patch. An erosion occurred as velocity increased to erode those areas. This was proved in experiment 2 for the station CH200 that has the lowest elevation compared to others. At the bar body, the larger width was still in the non-vegetated bar and the condition was almost similar to the condition of bar head for both three channels. The difference only occurred in the bar edge area as the highest width formed in full vegetation alternate bar followed by half and non-vegetation. It showed that the vegetation keeps the width stabilize at the edge of the bar. Figures 7 to 9 showed the comparison of alternate bar width at the head, body, and edge of alternate bar respectively. While table 2 showed the values of alternate bar width for each section of measurements.

Table 2. Comparison of alternate bar width for all experiments at each section.

exp	Width CH200 (m)	Width CH300 (m)	Width CH400 (m)
1	0.9	0.875	0.275
2	0.75	0.675	0.75
3	0.85	0.85	0.6

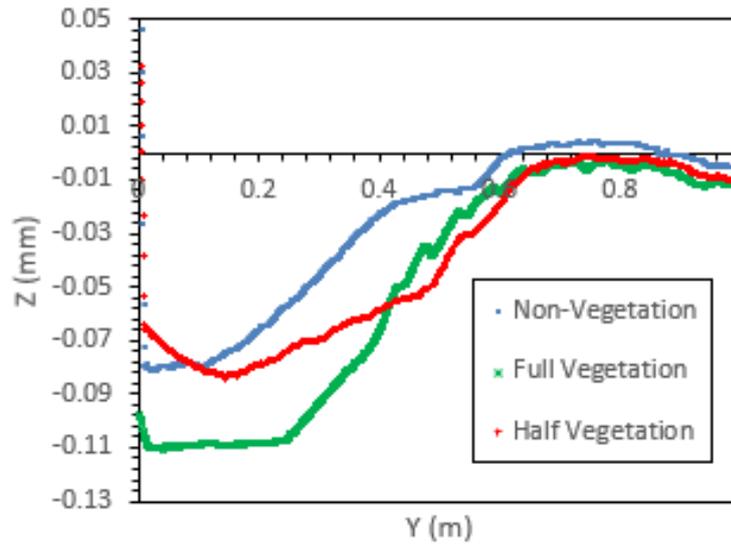


Figure 7. The bed elevation of the bar head at CH200.

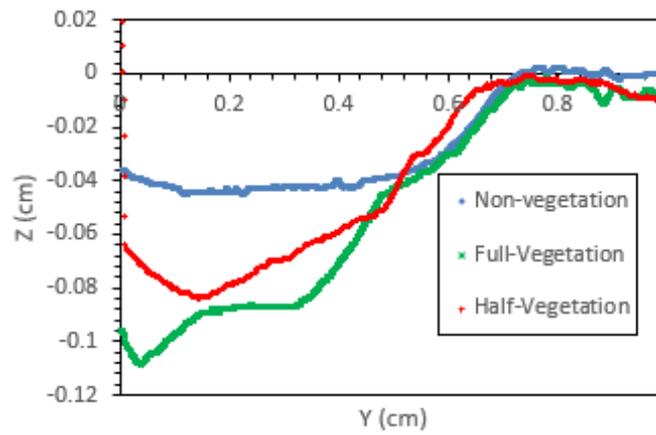


Figure 8. The bed elevation of the bar body at CH300.

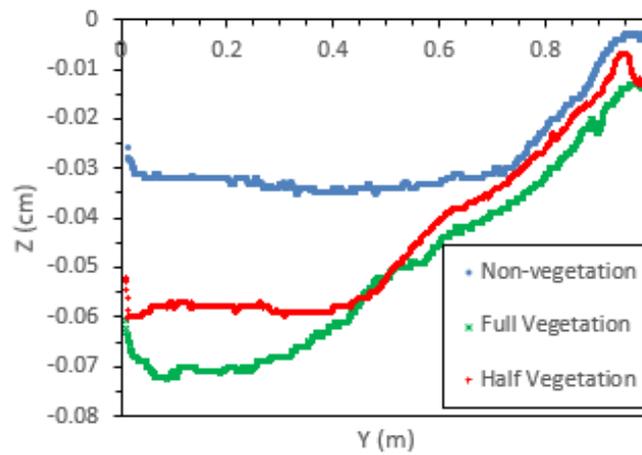


Figure 9. The bed elevation of the bar edge at CH400.

4. Conclusion

The study has shown the detail of investigations related to alternate bar formation that affected the existence of vegetation on top of the bar. The comparisons were made based on the bar wavelength, height, and width. From the present analysis, we can summarize that:

1. The vegetation reduced the values of the shield parameter to promote the deposition process on top of the bar thus stabilized its physical formation.
2. The adding vegetation increased the bar wavelength and induced bar elongation toward downstream of the channel.
3. The height of the bar increased affected by the vegetation existence as the erosion process actively occurred in the deepest regime to reduce bed elevation near the alternate bar.
4. The width of the alternate bar decreased at bar head and body when the vegetation presence. However, the width was increased at the bar edge compared to non-vegetation.

Acknowledgment

This study is a collaborated research between Universiti Teknologi MARA Pasir Gudang Branch and Universiti Teknologi Malaysia. The research was funded under the Fundamental Research Grant Scheme (FRGS) and UTM grant of references FRGS No. 5F089, and UTM GUP No. 15J61 respectively. We would like to acknowledge all who involved directly and indirectly in this project, especially to UiTM Pasir Gudang and UTM for providing us research facilities and manpower.

References

- [1] Lanzoni S and Tubino M 1999 Grain sorting and bar instability *J Fluid Mech* **393** 149–174
- [2] Crosato A and John C, 2011 Experimental observations on long-term behavior of migrating alternate bars *River Coastal and Estuarine Morphodynamics* 1–11
- [3] Duro, Crosato A, and Tassi P, 2015 Numerical experiments to explore bar management by channel width variations, *E-proceedings 36th IAHR World Congr 2* 28–31
- [4] Crosato A, Desta F B, Cornelisse J, Schuurman F, and Uijttewaal W S J, 2012 Experimental and numerical findings on the long-term evolution of migrating alternate bars in alluvial channels, *Water. Resour.* **48**(6)
- [5] Crosato A, Getaneh A A, Desta F B, Uijttewaal W S J, and Le U, 2010 Long-duration laboratory experiment of slow development of steady alternate bars, *River Flow*, 1035–1039
- [6] Wintenberger C L, Rodrigues S, Claude N, and Villar M, 2015 Dynamics of nonmigrating mid-channel bar and superimposed dunes in a sandy-gravelly river (Loire River, France), *Geomorphology* **248** 185–204
- [7] Ikeda S, 1984 Prediction of Alternate Bar Wavelength, *J Hydraul Eng* **110**(4) 371–386
- [8] Chang H H, 1985 Formation of Alternate Bars, *J. Hydraul. c Eng.* **111**(11) 1412–1420
- [9] Lanzoni S and Tubino M, 2000 Experimental observations on bar development in cohesionless channels *Excerpta of the Italian Contributions to the Field of Hydraulic Engineering* **14** 119–152
- [10] Defina A, 2003 Numerical experiments on bar growth, *Water. Resour.* **39**(4) 1–12
- [11] Colombini M, Seminara G, and Tubino M, 1987 Finite-amplitude alternate bars *J. Fluid. Mech.* **181** (1)213
- [12] Colombini M and Tubino M, 1991 *Finite amplitude free-bars: a fully nonlinear spectral solution, Sand transport in Rivers, Estuaries and Seas, Rotterdam, In: Euromech 262 Colloquium on Sand Transport in Rivers, Estuaries and the Sea*, Wallingford Balkema, A A 163
- [13] Lanzoni S, 2000 Experiments on bar formation in a straight flume: 1. Uniform sediment, *Water. Resour.* **36** (11) 3337–3349
- [14] Welber M, Bertoldi W, and Tubino M, 2012 Physical modelling of in-channel wood dynamics in braided rivers *Rivers*, 1–3
- [15] Zen S, Zolezzi G, and Tubino M, 2004 A theoretical analysis of river bars stability under changing channel width *Adv. Geosci.* **39** 27–35

- [16] Bertoldi W, 2004 Bed and bank evolution of River Bifurcations *Water. Resour. Res.* **41**(7) 1-12
- [17] Schielen B R, 1993 On the nonlinear dynamics of free bars in straight channels *C. U. P.* **252** 325–356
- [18] Rominger J T, Asce S M, Lightbody A F, Asce A M, and Nepf H M, 2010 Effects of Added vegetation on Sand Bar Stability and Stream Hydrodynamics *J. Hydraul. Eng.* 994–1002
- [19] Li Z, Wang Z, Pan B, Zhu H, and Li W, 2014 The development mechanism of gravel bars in rivers *Quat. Int.* **336** 73–79
- [20] Iwasaki T, Shimizu Y, and Kimura I, 2016 Numerical simulation of bar and bank erosion in a vegetated floodplain: A case study in the Otofuke River *Adv. Water. Resour.* **93** Part A 118–134
- [21] Jaballah M, Camenen B, Pénard L, and Paquier A, 2015 Alternate bar development in an alpine river following engineering works *Adv. Water. Resour.* **81** 103–113
- [22] Bywater-Reyes S, Diehl R M, and Wilcox A C, 2018 The influence of a vegetated bar on channel-bend flow dynamics *Earth. Surf. Dyn.* **6** (2) 487–503
- [23] Calvani G, Francalanci S, and Solari L, 2018 Flume experiments on vegetated alternate bars, *E3S Web of Conferences* **40** 02034 1–6
- [24] Ibrahim Z, Zulkiflee Ibrahim, Zuhlilmi Ismail, Sobri Harun, Koji Shiono, Nazirah Mohd Zuki, Md Ridzuan Makhtar, Mazlin Jumain, Mohd Suhaimi Abd Rahman, Mohamad Hidayat Jamal, Flood hydraulics due to emergent vegetation along a riparian zone in meandering channels *J. Teknol.* **78** (9–4) 99–107
- [25] Jumain M, Ibrahim Z, Ismail Z, Samsudin M F A, M Zubair T H, S Makhtar, M Ridzuan R, M Suhaimi A, 2016 Fluvial processes in compound straight channels: A laboratory investigation *J. Teknol.* **78** (7) 141–148
- [26] Jourdain C, Claude N, Antoine G, and Tassi P, 2018 Influence of flood regime on riparian vegetation dynamics in rivers with alternate bars, *E3S Web of Conferences* **40** 02025 1–8
- [27] Serlet A, Koch A, and Zolezzi G, 2018 *Observations of morphological and vegetation A dynamics in regulated rivers with alternate bars*, 12th ISE 2018, Tokyo Japan
- [28] Vargas-Luna A, Crosato, Calvani G, and Uijtewaal W S J, 2016 Representing plants as rigid cylinders in experiments and models, *Adv. Water. Resour.* **93** 205–222
- [29] Qian H, Cao Z, Liu H, and Pender G, 2017 Numerical modelling of alternate bar formation, development and sediment sorting in straight channels, *Earth. Surf. Process. Landf.* **42** 4 pp 555–574