Impact of Influential Parameters on the Formation of Alternate Bars

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Abstract

At lower discharge rates, channelized alluvial streams frequently exhibit alternate bars. In this study, bar bed forms were regenerated, and checked the sensitivity of parameters governing the formation process of these peculiar bedforms. Resulted water depth, the number of bars, and bar dimensions were measured by varying flow rate, channel slope, and mean grain size of the bed material. The ratio of Shield number to critical Shield number ranged between 2-11, which agreed with previous research findings. The bar length-to-width ratio of alternate natural bars was compared with modeled outputs, which showed an acceptable resemblance. Results revealed that the highest number of bars could be observed for intermediate discharge values ($5 - 8cm^3/s$) when the bed slopes were maintained between $4.5° - 7°$. The formation process of these bedforms was signified once particle Reynold number concentrates towards 20. The bar formation process was curtailed beyond a threshold discharge irrespective of the favorable slope and particle Reynolds number, highlighting the sensitivity of the discharge for this phenomenon. Research outputs can be deployed to predict the possibility of bar formation based on the fluid dynamic and morpho-dynamic characteristics of the desired entity when designing reservoirs, hydropower generating schemes, irrigation water supply systems, etc.

Keywords— *Alternate bars, River environment, River morpho-dynamics, Sensitivity parameters*

Introduction

The elevated region of sediments, such as sand or gravel, deposited by the flow in channelized alluvial streams at lower flow stages is called an alternate bar. This bar pattern alternates crests and troughs between the channel banks[1]. Bars are a common characteristic of river channels and have lengths with channel widths and heights that scale with water depths, generally producing two-dimensional shapes[2]. It is simple to see this vast sediment accumulation at low flow stages. Bars might be localized or periodic[3]. Traditional classifications of river bed bars include "free bars" and "forced bars". River beds mainly have three types of bars: point bars and other local bars, free bars resulting after characteristic morphodynamical uncertainty, and stationary bars forced by a local steady perturbation but resulting in a free morpho dynamic response in a larger area. Thus, this terminology has become problematic[2].

Local bars are substantial silt accumulations that scale with river width and are compelled by an ongoing, finite distortion of the water flow. This distortion can be brought on by a groyne-like construction, a natural bend, or a change in the channel's width. These bars are known as "forced bars" because they are dependent on the presence of a forcing and their size is related to the forcing. Large sediment deposits known as periodic bars depend on morphodynamic instability to occur; unless the system is not within the range of instability, periodic bars do not form. "Free" and "hybrid" periodic bars can be distinguished based on the mechanism of formation. Free bars appear within the system's morpho-dynamic instability region as soon as the flow or bed level is disturbed. They form naturally without coercion and typically migrate[2]. The word "hybrid" conveys that these bars feature both forced and free characteristics. Instability in morpho-dynamics gives rise to hybrid bars. Nonetheless, they also need forcing because that fixes their phase at a certain point along the river axis[2, 4] . Table 1 depicts the definition and description of alternate bars termed by previous scholars.

According to the explanation of Jaeggi[6], since meandering and alternate bar creation are closely related, it may be assumed that flow-induced periodic perturbations of the lateral velocity profile are to cause of alternate bar formation.

The start of the meandering process can be perceived as the alternate bar formation. Middle bars are similarly related to river braiding

Figure 1 depicts the alternate bars and aerial photographs of a meandered river. Migrating bars in-

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Received: March 16, 2023, **Published:** October 06, 2023

Table 1: *Classification of alternate bars[2]*

Bar type	Appearance	Mechanism	Termed as
Forced	Local	Permanent forcing	"Point bars, Local deposits, Curvature-driven bars"[7]
Free	Periodic	Morphodynamic instability	"Free bars"[8]
Hybrid	Periodic	Permanent forcing +Morphodynamic instability	"Forced bars"[8]
			"Free bars"[3]
			"Spatial bars"[8]
			"Hybrid bars"[2]

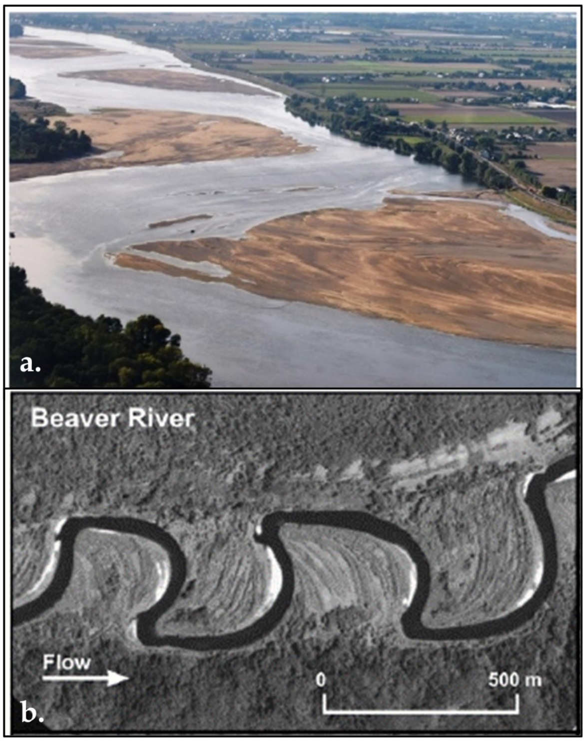

Figure 1: *Alternate bars in the Loire River[2] b. meandering of Beaver River[5]*

fluence channel widening, and steady bars mainly lead to bank erosion and bend growth. Further, the steady alternate bars are a prerequisite to forming the meandering of alluvial rivers[3]. Moving bars contribute to channel expansion in erodible banks; stable bars to localized bank erosion and bend development. Owing to this cause, the development of stable bars inside straight river channels has been linked to the beginning of meandering[9]. In rivers with mild slopes ($< 2\%$), it has been observed that alternate bars migrate downstream, but this has not been seen in channels having steeper slopes[10]. Where alternate bars developed, significant scouring led to expensive maintenance work. Nevertheless, alternate bar development has the advantage of producing riffle-pool sequences at low flows, which are crucial for river ecology[6].

The literature reports several experimental[11], observational[12], modeling-based research attempts[13] to investigate the formation and evolution of the bar shape bedforms. Nonetheless, experimental investigations aiming at the exploration of the sensitivity of the key governing parameters of the alternate bar formation, are rarely reported thus far.

Literature Review

Alternate bars and meandering process

It is vital to study the meandering phenomenon and subsequent alternate bar formation before the design and implementation of new constructions such as bridges, treatment intakes, pipeline crossings, and or handling the problems related to river morphodynamics, sub-aerial environmental ecology, and renaturalization[14]. Since sand bars are made up of a variety of components, including vegetation, bare regions, side pools, and other components, it is important to identify the factors involved in the ecological processes of alternate bar sections while managing sandy rivers. Additionally, sandbars also purify water through subsurface flow[15].

Formation of alternate bars results in periodic deformations of the vertical and horizontal velocity profiles creating changes in the structure of turbulence and inducing roughness against the flow, which accounts for the river meandering[5, 6]. Alternate bar formation can be regarded as the beginning of the meandering process. Braiding is the natural morphology of alluvial streams, while meandering has been considered the interim stage that formed as a result of suppressing the river's desire to braid[5].

The braiding morphology of the alluvial streams is, firstly, chute cut-offs started to develop from the stage of uniform bends. Then, the main flow is separated into a set of smaller channels. The channel eventually developed into a braided state.[14]. Further, the formation process of these different bed cuts and the subsequent river meandering has been studied based on the sediment deposition discrepancies in the river banks, composed of a combination of cohesive and non-cohesive materials, resulting in a slump block effect as well[14].

Formation of alternate bars

The various morphological factors govern alternate bar formation. Different researchers have nourished the sequel to the alternate bar formation phenomenon with morpho-dynamic and hydrodynamic correlations. In straight alluvial channels, the ratio between the stream flow and its width is a governing parameter for the alternate bar formation[1], and channel slope, channel width-to-water depth ratio, and grain size control the alternate bar formation in a given channel for any discharge. If the Shields stress (θ) is lower than the critical Shields stress (θ_C), alternate bars and other bed forms do not form based on the shear stress. The lower bound for alternate bar development is thus given by Equation 1.

$$\frac{\theta}{\theta_c} = 1 \tag{1}$$

The rigid banks will confine the stable width if it is bigger than the channel width at a higher discharge, where the stable width is directly proportional to discharge. In this case, the lack of mobility for stream slope modification at the equilibrium state prevents meanders or alternate bars from forming. In the second scenario, the stable width is smaller than the channel width. A smaller stable width is caused by either a lower discharge or a wider channel. Therefore, it was predicted that alternate bars might appear if the stable width is less than the channel width ($Bs < B$)[1].

Kinoshita and Miwa[16] presented a first approximated condition for alternate bar formation as the channel width-to-depth ratio should be within 5 to 20 ($5 < B/D < 20$). Sukegawa[17] found a condition for alternate bar formation as Equation 2.

$$\frac{B}{R} \geq \frac{1}{125}\left(\frac{\theta}{\theta_c}\right)^2 \frac{1}{S} \tag{2}$$

Where B is channel width, R is the hydraulic radius, S is channel slope, θ represents dimensionless shear stress or Shields stress, and θ_C stands for critical Shields stress[1]. Dulal et al[14] explained the occurrence of bed deformation and the concept of armoring model as depicted in Figure 2.

Alternate bars are typically seen at low flow rates if the channel width is less than the small stable width. When the stable width is greater than the channel width, there is a strong correlation between the disappearance of alternate bars and higher discharge.

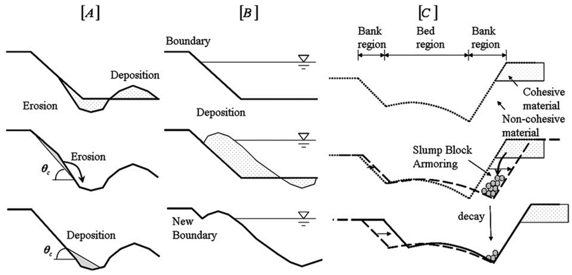

Figure 2: *Bed deformation and concept of the armoring model[14]*

The researchers have tested experimental, numerical, and mathematical methods to elucidate the formation process of alternate bar bedforms and the sensitivity of the numerous hydrodynamic and morpho-dynamic parameters that govern this phenomenon[18]. Literature reveals that the most significant method for examining the fundamental mechanics of alternate bar formation and the subsequent river meandering dynamics is the laboratory experiment-based approach[14]. Experiments have been carried out with a fixed bed and fixed walls, erodible bed and fixed walls, and erodible bed and erodible wall[19] with the use of cohesive and non-cohesive sediments, while replicating the natural riverine conditions like vegetation, sediment transport, fluvial entrainment and mass failures[14, 20, 21] to demystify this natural morpho-dynamic evolution.

Though there are successful attempts to elucidate the alternate bar formation and governing parameters, that has not been investigated the sensitivity of the influential parameters for the inception or carving of the alternate bars, when an erodible sediment bed exposes to a natural flow in a laboratory flume. This research has been designed to address the particular research gap.

Materials and Methods

Laboratory experiments were carried out in two casted laboratory flumes changing the bed material compositions, flow rates, and bed slopes. In light of trial experiments conducted before the actual experiments began, it was realized the suitable combination of bed preparation materials. The investigations were initiated with the particular combination and gradually enhanced the cohesiveness of the bed material. A trial experiment was devised to understand the bar formation process clearly. Based on the previous research findings[14], a set of trial experiments was performed to check the regenerating ability of the alternate bar bedforms in a laboratory environment, exposing an erodible bed to a controlled water flow.

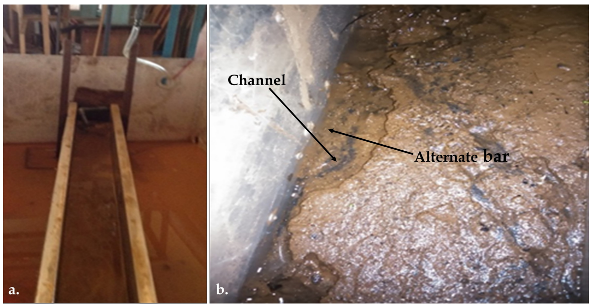

Figure 3: *a. Experimental flume 1, b. Alternate bar and channel*

Experimental procedure – flume 1

Initially, it used a flume of 2000 mm in length, 120 mm in width, and 50 mm in depth, manufactured with aluminium sheets, comprising the side walls and bottom. The bottom rests on a truss arrangement to bear the load effectively. Required bed slopes were maintained using a hydraulic jack, and controlled water flow was directed over the erodible bed mounted on the flume bottom using a constant head water tank. For the bed preparation, non-cohesive materials extracted from the natural riverine environment were mixed with cohesive materials, and a sample was tailored to the required gradation using sieve analysis.

From the trial experiments, it was observed that after three days of exposure to the water flow, initial carvings for the inception of bar shape bed forms appeared as shown in Figure 3. Hence, decided to expose the channel bed with the selected flows for a minimum of three days.

Once the bar shapes were generated, one parameter was controlled keeping other parameters at constant values. Accordingly, the sensitivity of a particular governing parameter could be observed once other conditions are controlled. Under each experiment, features of the bar shapes, such as bar length (L), bar width (W), and bar height (H), were observed and recorded. The number of days taken for the inception of bar shape bed forms (N_D) and the number of bars carved during the period (N_B) were also noted down. Three types of material combinations for bed preparations were used during the study and are fully non-cohesive, partially cohesive (50% cohesive soil and 50% non-cohesive soil by volume), and fully cohesive soil samples, with the corresponding mean grain diameters of 600 μm, 510 μm, and 420 μm were used for initial experiments. 4.5°, 6.75°, and 8° bed slopes were selected as the suitable bed slopes covering the range of potential slopes suggested in the literature[1]. Table 2 summarizes the observations of conducted experiments for flume 1. Note that the experimental discharge (Q) channel width (B) and depth of the flow (D) near the site where alternate bars were also measured. Initial experiments indicated that after three days, the signs of bar shape bed forms appeared; hence it was decided to expose the channel bed with the selected flows for a minimum of three days.

Further, it was found that a flow rate of 3.5 to 12.5 ml/s and a slope of 4° to 12° are favorable for the bar formation. Fully cohesive bed materials did not entertain the alternate bar formation process, and fully non-cohesive bed materials showed a higher morpho-dynamic potential. Interestingly the width is a constraining factor to the undisturbed formulation of these bedforms and the length of the flume (which is influential in deciding the number of bars) was limited, hence a new flume with sufficient width and adequate length was deployed for the next series of experiments.

Experimental procedure – flume 2

Performed laboratory experiments using flume 1 suggested that the length and width constrict the natural formation mechanism of the alternate bars. Hence, the new flume (Figure 4) with a 4 m length and 0.5 m width was cast with the facility width adjusting capability using a metal plate. Based on the previous laboratory test outcomes obtained using flume 1, materials correspond with 600 μm mean grain size selected for the bed preparations. As in the first set of experiments, features of the bar shapes (bar length, width, and height) were observed and recorded under each trial.

For each experiment, the formation of alternate bars was observed. The length, width, and height of the alternate bars were measured. The Channel width and depth of the flow near the alternate bars also were measured. Table 3 shows the observations of conducted experiments for flume 2. When the bed slopes were maintained at $4.5° - 8.0°$, bar shape bed forms could be observed for the flow rates that are less than 11 cm^3/s. as depicted in Figure 5. 600 μm

Figure 4: *Experimental flume 2*

Table 2: *Experimental observations for flume 1 ($B = 15$ mm, $D = 3$ mm and $S = 8°$)*

$Q(cm^3/s)$	Mean grain diameter: 600 µm				Mean grain diameter: 510 µm			
	No. of bars formed	Average			No. of bars formed	Average		
		L (mm)	W (mm)	H(mm)		L (mm)	W (mm)	H(mm)
3.5	2	26	16	7	1	23	12	11
5.0	2	6	26	12	2	17	16	13
6.5	3	62	25	10	1	22	20	18
8.0	3	51	24	10	1	20	14	7
9.5	1	56	14	8	Eroded			
11.0	Eroded				Eroded			
12.5	Eroded				Eroded			
The channel bed was exposed for three days for the inception of bar shaped bed forms								

Figure 5: *Occurrence of alternate bars in flume 2*

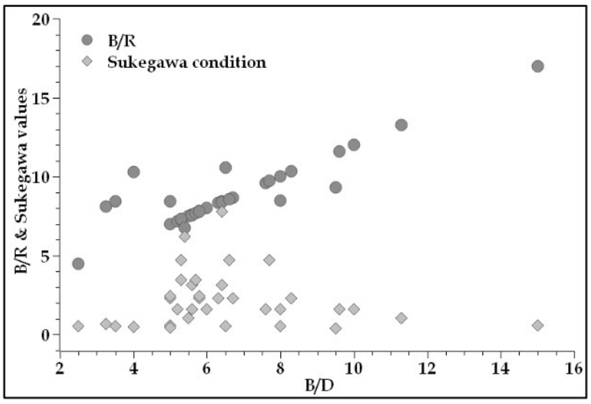

Figure 6: *Variation of B/R ratio and Sukegawa values with B/D ratio*

mean grain size exhibited a higher potential for forming alternate bars. It was evident that higher flow rates (above 12 cm^3/s) do not facilitate this morphodynamic evolution. Discharges less than 3.5 cm^3/s had the potential of emerging those bedforms, but it took a considerable time to start the initial carving. These observations imply that numerous parameters govern the inception of the bar-shaped bed formation process. Among that, the slope, flow rate, and grain size of the sediment played a significant role. During these experiments, the other influential parameters, such as boundary effect and impact from the degree of consolidation of sediment were kept, under control conditions throughout.

Emerged test outcomes were evaluated based on hydrodynamic and morpho-dynamic aspects, using the particle Reynolds number (Re_p Equation 3), Shields number (θ Equation 4), and the Critical Shield's number (θ_C).

$$\mathrm{Re}_p = \frac{\rho V d_{50}}{\mu} \tag{3}$$

Where ρ represents the density of the fluid, V stands for the mean velocity of the flow, and d_{50} denotes the representative particle size for the selected compositions of bed materials[1].

$$\theta = \frac{\tau}{(\gamma_s - \gamma) \cdot d_{50}} \tag{4}$$

τ represents the maximum bed shear stress equivalent with γDS, where γ, D, and S denote the specific weight of water, flow depth at the bar and slope of the channel bed respectively[1]. The critical Shields number has been obtained using the Shields curve. Based on the calculated Shields number and the extracted critical Shields number from the Shield's curve ratio between these two quantities has been determined.

Results and Discussion

Calculations were performed incorporating the observations of experiments conducted for both flume 1 and flume 2 and tabulated in Tables 4 and 5 respectively. Calculated B/D ratios for each successful bar shape generation situation fell into the range of $2.5 - 15$. As the literature suggests, the first approximate condition for forming alternate bars is a channel width-to-depth ratio between $5 to 20$[16], which has been satisfied with this experiment except in four (4) instances. Once the channel bed slope was

Table 3: *Experimental observations for flume 2 (Mean grain diameter: 600μm, $ND = 3$)*

$Q(cm^3/s)$	No. of bars formed	Average				
		B (mm)	D (mm)	L (mm)	W (mm)	H (mm)
S = 4.50						
3.5	2	25	5	345	97	13
5	7	41	6	225	87	10
6.5	6	47	6	168	44	12
8	4	36	5	171	46	9
9.5	2	28	6	185	43	11
11	2	47	5	280	100	10
12.5	Eroded					
S = 6.750						
3.5	2	30	6	255	103	12
5	2	33	6	235	105	13
6.5	2	43	7	170	63	13
8	2	42	7	235	113	16
9.5	1	38	8	140	84	15
11	Eroded					
12.5	Eroded					
S = 80						
3.5	1	45	7	190	40	10
5	2	33	8	138	38	10
6.5	2	58	8	170	53	12
8	2	55	8	153	48	14
9.5	1	44	6	165	60	12
11	Eroded					
12.5	Eroded					

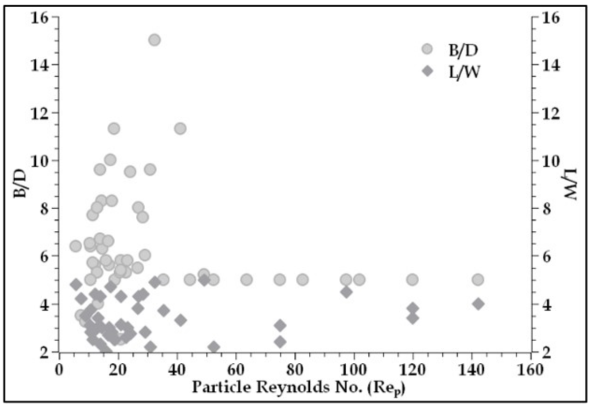

Figure 7: *Variation of L/W and B/D ratios with Particle Reynolds Number (Re_p)*

maintained at 8°, it was noted that this approximate condition converges towards the lower end of this range, i.e., 5, implying the importance of channel bed slope for the bed formulation process overwhelming the other parameters such as flow and channel bed composition. Nevertheless, it is significant to note the slight changes observed in the experiments conducted with the wide flume (0.25 m width and 4 m length), where the B/D concentrates towards a higher range. Convergence of B/D towards a higher range concludes that the higher channel bed slope could generate the alternate bars resulting in lower range B/D ratios lying within the approximate span.

Kinoshita and Miwa[16] presented a first approximated condition for alternate bar formation as the channel width-to-depth ratio should be within $5 to 20$. Sukegawa[17] found a condition for alternate bar formation, as shown in Equation 2. Once the conditions suggested by Sukegawa are analyzed pertaining to the observations made in this study, it was noted that all bar formation conditions agree with Sukegawa's theory as shown in Figure 6.

Figure 7 depicts the behavior of the bar length-to-width ratio (L/W) and channel width-to-depth ratio (B/D) over the particle Reynolds number (Re_p). Based on this analysis, inferences can be made that the tendency to form alternate bars is high when the particle Reynolds number lies in the range of $20 - 25$. According to Figure 7, it is observed that the higher B/D ratios, which indicate the potential formation of alternate bars, as literature reveals, result when the particle Reynolds number falls in the range $20 - 25$, irrespective of the bed slope maintained. With experimental outcomes, it was observed that the Minimum Channel width to Depth ratio

Table 4: *Calculated values for flume 1 (ND = 3, slope = 80)*

Q (cm^3/s)	N_B	B/D	$MeanL/W$ (min, max)	Re_p	θ/θ_c	B/R	**Sukegawa conditions**
Mean grain diameter: 600μm							
3.5	2	5	2.20 (2.2, 2.2)	52.4	4.3	7	1.053
5.0	2	5	2.75 (2.4, 3.1)	74.9	4.3	7	1.053
6.5	3	5	2.50 (1.1, 4.5)	97.4	3.9	7	0.870
8.0	3	5	2.37 (1.5, 3.8)	119.9	3.6	7	0.731
9.5	1	5	4.00	142.3	3.6	7	0.731
Mean grain diameter: 510μm							
3.5	1	5	1.90	44.6	5.0	7	1.429
5.0	2	5	1.00 (1.0, 1.0)	63.7	4.6	7	1.181
6.5	1	5	1.10	82.8	4.2	7	0.992
8.0	1	5	1.40	101.9	3.9	7	0.846
Erosion occurred for flow rates above 8.0 cm^3/s and 9.5 cm^3/s for mean grain diameters of 600 μmand510 μm, respectively.							

Table 5: *Calculated values for flume 2 (Mean grain diameter: 600 μm)*

Q (cm^3/s)	N_B	$Mean$				**Mean (min, max)**	
		B/D	B/R	θ/θ_c	L/W	Re_p	**Sukegawa conditions**
$Slope = 4.50°$							
3.5	2	5.55	7.55	3.577	3.4	21.9 (16.9, 26.80)	1.317 (1.028, 1.606)
5.0	7	7.40	9.40	4.656	2.9	14.4 (10.7, 18.7)	2.267 (1.028, 3.148)
6.5	6	8.60	10.60	4.770	4.1	20.1 (5.7, 32.5)	2.698 (0.578, 2.313)
8.0	4	7.20	9.20	3.776	3.7	48.3 (18.0, 119.9)	1.526 (0.578, 2.313)
9.5	2	5.10	7.10	4.372	4.4	42.4 (35.6, 49.3)	1.960 (1.606, 2.313)
11.0	2	10.50	12.40	3.577	2.8	36.1 (30.9, 41.2)	1.317 (1.028, 1.606)
$Slope = 6.75°$							
3.5	2	5.40	4.00	6.578	2.5	15.3 (11.6, 18.9)	2.948 (2.416, 3.479)
5.0	2	5.60	4.40	7.176	2.5	18.1 (13.0, 23.2)	3.576 (2.416, 4.736)
6.5	2	6.50	5.00	7.774	2.7	17.2 (11.6, 22.8)	4.108 (3.479, 4.736)
8.0	2	6.00	5.20	8.372	2.2	18.8 (16.7, 20.8)	4.736
9.5	1	5.40	5.60	9.568	1.7	21.1	6.185
$Slope = 8.00°$							
3.5	1	3.50	8.40	9.031	4.2	7.5	4.644
5.0	2	3.80	6.50	9.676	3.4	15.9 (10.7, 21.1)	5.355 (4.644, 6.066)
6.5	2	4.90	9.30	10.321	3.3	9.7 (8.9, 10.4)	6.161 (4.644, 7.677)
8.0	2	6.00	9.40	8.870	3.2	13.2 (13.0, 13.3)	4.500 (3.902, 5.097)
9.5	1	9.50	9.30	7.096	2.8	24.3	2.867

for the experimentally-generated alternate bars was 2.5, whereas the highest was 15. The maximum bar length-to-width ratio was 5.0, and the minimum was 1.0. Particle Reynolds number for this series of experiments ranged from $5.7 - 142.3$. Re_p is used to study the sediment transport in fluids, and it determines whether the flow is in the bedload regime or suspended/washload regime. With relatively low particle Reynolds numbers ($Re_p < 1$) flow is more likely to be in the bedload regime. Since the average Rep was found to be around 41, the flow is in suspended regime where sediment particles are carried in suspension by the turbulent flow. This phenomenon shows a resemblance with turbulent nature of river flow. The maximum and minimum ratios of the Shield parameter to Critical Shield parameter were 11.6 and 2.4, respectively. Exceedance of the (L/W) beyond 1 represents the long-wave nature of these bedforms. Thus, it resulted in lower Particle Reynolds numbers highlighting the local deceleration of flow near the potential sites of bed form evolution. Though the bar width is a constricted parameter governed by the width of the flume, the research's primary focus is on the initial carving of these bedforms.

To verify the model formulated bed forms with naturally occurring alternate bars, two alternate bar sites at Mahiyanganaya ($7°19'0'' N, 80°58'58'' E$) along the Mahaweli River and Karawanella ($7°01'33.2'' N, 80°15'23.8'' E$) along the Kelani River were selected

At the Mahiyanganaya site, permanently carved alternate bar bed forms could be seen due to the upstream manipulation of Mahaweli water under multipurpose irrigation projects. Though the prominent alternate bars are visible at these sites, one may distinguish those as permanently deposited sediment banks that have already altered the natural course of the river.

Still, these bar bedforms were used for comparison in this contemporary study, considering their physical nature. The alternate bar length and width ratios of the observed bars were compared with modelled alternate bars' corresponding ratio.

Figure 8 depicts the Length (L) and the width (W) of the observed bar at Kelani River as 150 m and 40 m, respectively, resulting in an L/W of 3.75. Similarly, observed bars at Mahaweli River bear the L/W ratios of $3.65 - 4.5$.

CalculatedL/W based on experimental outcomes varies from $1.0 - 5.0$, indicating that the naturally occurring alternate bar bed forms also fell in the experimentally obtained range of L/W. Further, the shape of the modelled and naturally observed alternate bars are in full agreement. When the movement

Figure 8: *Alternate bar in a. Kelani River at Karawanella, b. Mahaweli River at Mahiyangana*

of the river flow around an alternate bar was observed, it is clear that the deceleration of the flow is a must to entertain the deposition of the sediment, thereby emerging these bedforms. An identical flow behaviour around the bar bed forms could be witnessed during the experiments as well, and the calculated densimetric Froude number further proved that the nature of the flow is sub-critical near the bar showing the sediment depositing nature around the bar. Out of the several experiments conducted only two cases, exhibited the densimetric Froude number exceeding 1 where the maintained bed slopes in the higher range, and the flow rates were more concentrated to the upper bound of the favourable range. Nevertheless, it is noteworthy to distinguish the nature of sediment and sediment supply between the natural rivers and the experimental setup. Natural rivers have pure sand and continuous sediment supply from upstream whereas experimental flume bed consists of partially cohesive sand with limited sediment supply. This infers that the modelled alternate bars bear an acceptable resemblance with naturally occurring bars in terms of shape though the relevant morpho-dynamic time scales are quite different.

Conclusions

This study is conducted with the use of laboratory flume arrangement subjecting an erodible bed to a varying flow condition. The ratio of Shield number to critical Shield number obtained in the experiment was $2.4 - 11.6$, which agreed with previous research outcomes. The formation process of these bedforms was signified once particle Reynold number concentrates towards 20. Conducted experiments concluded that the highest number of bars could be observed for intermediate discharge values $(5 - 8cm^3/s)$ when the bed slopes were maintained at $4.5^\circ - 7^\circ$. The bar formation process is curtailed beyond a threshold discharge irrespective of the maintenance of favourable slope and particle Reynolds number, highlighting the sensitivity of the discharge for this phenomenon. Flow discharge and bed slope were found to be the governing influential parameters for the inception of carving of alternate bars. The bar length-to-width ratio of alternate natural bars found in the Mahaweli River at Mahiyanganaya and Kelani River at Karawanella were compared with model outputs, which showed an acceptable resemblance. These generated outputs of this study can be deployed in predicting the possibility of alternate bar formation based on the fluid dynamic characteristics and morpho-dynamic features of the desired entity when designing reservoirs, hydropower generating schemes, irrigation water supply systems, etc.

Acknowledgment

The authors wish to acknowledge the assistance given by the staff of the Fluid and Environmental Laboratory, Faculty of Engineering, University of Peradeniya during this study.

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