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MODELING THE CONTROL OF RIVER BEND BED EROSION BY INSTALLING IMPERMEABLE CRIBS

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Abstract

Characteristic of water flow in the river bend is very dynamic, on the erodible base river usually occurring erosion and sedimentation and the dynamic move and the river groove going be dynamic move. These conditions are dangerous and threatening to the infrastructure around it. The purpose of this research is to evaluate of cribs installation configuration that most effective in erosion control in the bending bed of the river. The method of this research is built impermeable cribs with four alternatives installation. With those four installation alternatives can be evaluated: first velocity reduction rate, and second erosion reduction rate and sedimentation increase on upstream of the cribs. And then be compared with erosion and sedimentation result from the Surface Water Modelling System (SMS) software simulation. In this case be simulated four alternatives installation impermeable cribs with 25 years return period design flood equivalent to 2,440 m^3/seconds. The results on each alternative of cribs installation configuration are monitored on five points observations to obtain: velocity reduce effectiveness, erosion reduce effectiveness and sedimentation increasing. The analysis and evaluation of four installations cribs alternative model has obtained the alternative model 1 are the most effective inflow velocity reduction and the alternative model 4 is best to reduce erosion. River bend bed erosion control should be used by combining alternative models 1 and 4.

Keywords: Dynamic flow, Erodible river bottom, Increasing sedimentation, Reduction of flow velocity.

1. Introduction

Herein, the research was conducted in a real-case scenario on the bend of a river in the tropical climate of Indonesia. Both banks of the river were characterized by a hard rock while the river bottom was sandy gravel. The real case scenario in the erosion control at the bend of the river by installing impermeable cribs in Batui River on Sulawesi Island in Indonesia. As an illustration we made the location map and river groove condition, and we arrange in Fig. 1(a) shows the investigated catchment area and (b) depicts the condition of sedimentation and erosion problems. To ensure efficient river conservation in the area, this research aimed to proffer a protective solution to the hydraulic structure built across the river and against erosion at the bottom of the river [1]. Generally, the movement of the river bend is influenced by lateral instability [2]. To prevent river bottom erosions, the stable channel [2, 3] or hard rock cliffs at the bends were assessed, whereas to reduce the flow velocity, the installation of impermeable cribs at varied positions was examined.

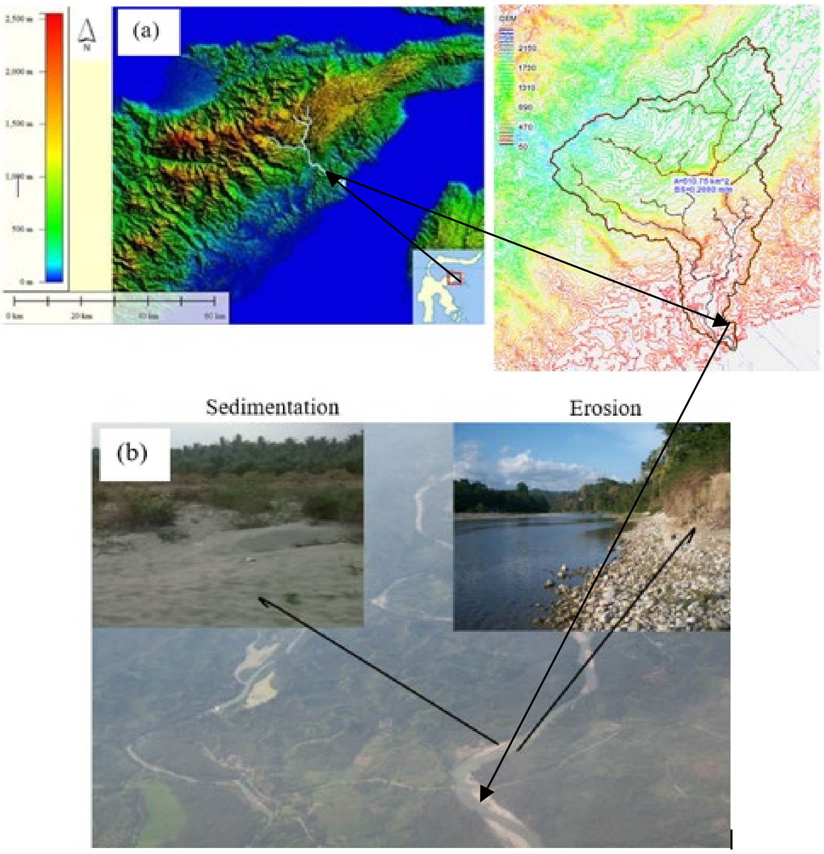

Fig. 1. (a). Maps showing the study location and catchment area (b). Pictures of the planform, sedimentation, and erosion problems in the study area.

Three types of flow velocities are attributed to river water flow: streamwise, spanwise, and vertical velocities [4]. Found that streamwise velocity was 4 to 10 times higher than spanwise velocity, whereas spanwise velocity was 2 to 10 times higher than vertical velocity. Later, they reported that streamwise velocity contributed 50% and 25% to the mean flow velocity along the banks and along the centreline of the river, respectively [5].

The tropical river system in Indonesia is height dynamic and complex because of the significant difference (such as lateral river movement, sediment load, and low-gradient floodplains) between the rainy season and the dry season. For a protective structure to be built in a river, scientific predictions of probability and intensity of erosion and sedimentation are important [6, 7]. For instance, the cross-sectional river model is useful for such purposes because of its closeness to real-life conditions [8, 9].

The river flow is controlled by a gradient, the power of the river current, and the strength of the bank [10]. Impermeable bank protection structure response of the river bend using alternative crib placements has been studied [11, 12]: stream and morphology responses vary with river sinuosity [12, 13]. Additionally, the fluvial flow can cause sediment transportation and change river morphology, subsequently changing the river flow pattern. Thus, the sediment's morphology, size, and transportation are interrelated [14]. Erosion along the riverbank is key to geomorphology. It influences the process of the channelling of rivers [15].

In contrast, the rate of material transport in the riverbed depends on the stream tractive force, the condition of the river bottom, and the sediment grain size [16]. Within a certain period, rivers run into natural balance by forming a slope. Then, its geometry shape corresponds to the required discharge, wet area, wet perimeter, hydraulic radius, flow velocity, D_{50}, riverbed slope, water depth, arc angle, and relative angle [13]. Both erosion and deposition occurred during flooding. The magnitude of their impact is greater during the height discharge period than in the low-discharge period [17]. The change in the geometric shapes is driven by the flow pattern and its interaction with the sediment, courtesy of variation in slope, wideness, attributes, and roughness [18].

In recent years, methods for measuring migration of riverbanks have been used to investigate the process of river planform evolution [19]. Impermeable groynes case, impermeable groynes were installed along the outer-bank beginning from the apex. The normalized bed evolution erosion depth for no groynes case of each channel. Positive values indicate deposition and negative shows erosion [20]. Thus far, the results are unclear to predict the patterns of river bottoms and banks [21]. Aims of this research is to get a solution to thus problems by proposing impermeable cribs configuration.

The purpose of this research is to get the best cribs configuration for erosion, sedimentation, and flow velocity control in the river bend. Many research for support this research like movement of the regular river meanders on constant discharge [13] and hydrodynamic and morphologic effects on hydraulic structure [22]. With many problems in damage caused by erosion and sedimentation in river bend then configuration cribs determination is very important.

2. Materials and Methods

2.1. River planform and sediment characteristics

The scope of the current research of the river planform, which causes erosion and sedimentation at the bend [23] is shown in Fig. 2. To control the erosion at this river bend, we install four impermeable cribs and measure sedimentation in upstream of the cribs, and then compare with running results of surface water modelling system (SMS). We validated the published experiment data before applying the data in the four impermeable crib models already prepared in different positions. We used an already existing river model without any crib, it is served as a control for our model.

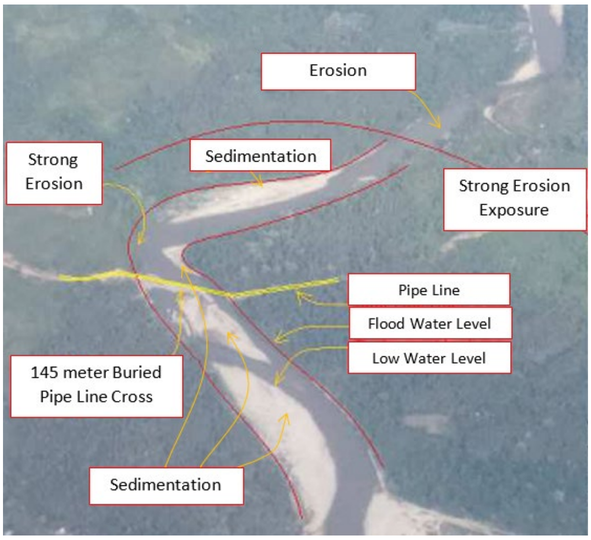

Fig. 2. River planform and sediment transport characteristics of the study area.

2.2. Soil and sediment sampling

The soil and sediment bed samples were obtained by drilling 15 m depth. Sampling sediment in a normal water flow look like in Fig. 3., the water levels in flood conditions were up to 4 m. Sampling sediment by Transportation and Geotechnical Laboratory, Department of Civil Infrastructure Engineering, Institut Teknologi Sepuluh Nopember Surabaya [22].

Fig. 3. Downstream view of soil and sediment sampling in the current work [22] modification.

2.3. Status properties of the samples

Briefly, the properties of the sampled soil layer are shown in Fig. 4(a), while the grain size analysis results of the soil and sediment samples are provided in Fig. 4(b). This data obtained free of charge from Transportation and Geotechnical Laboratory, Department of Civil Infrastructure Engineering, Institut Teknologi Sepuluh Nopember Surabaya [22] modification.

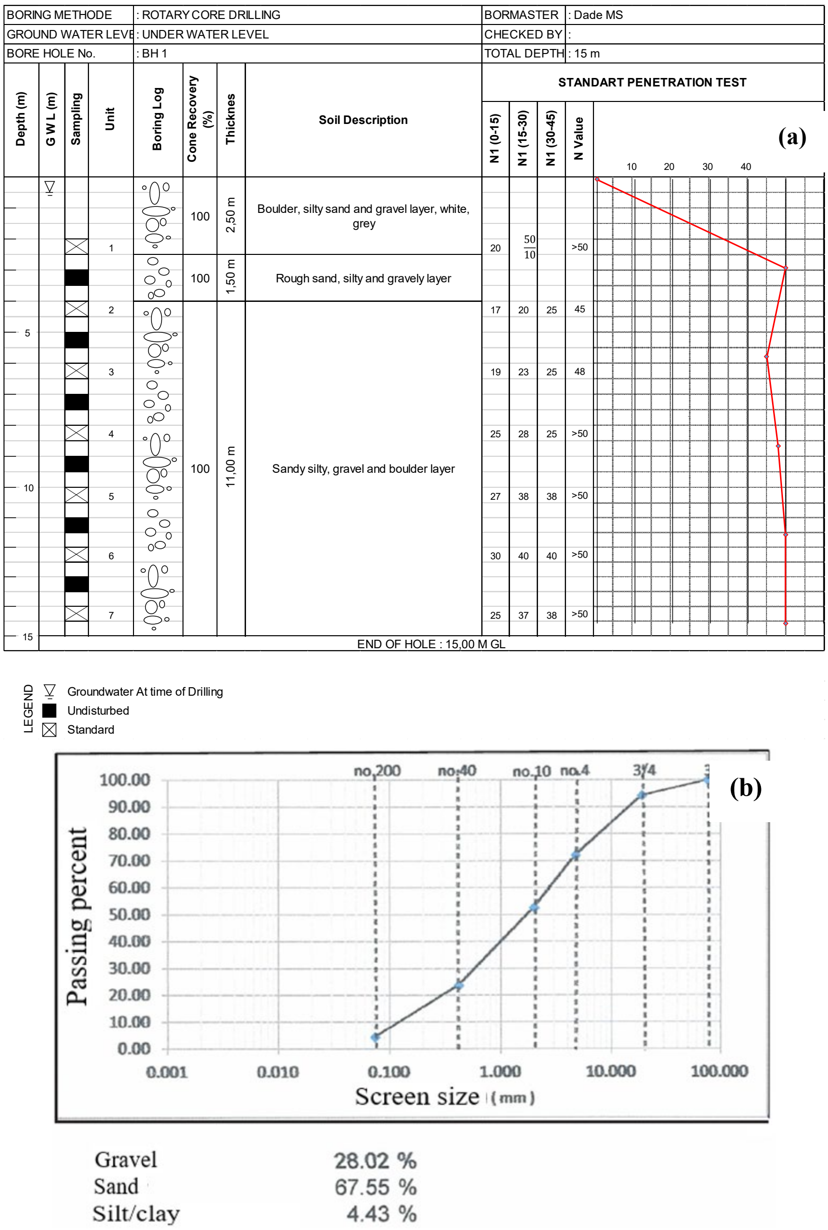

Fig. 4. (a) The characteristics of the soil and bed-load sediment samples, and (b). The particle grain size analysis.

2.4. Surface water modeling system (SMS)

SMS is a software that is designed to be completed in an integrated way against the dynamic flow equations and sediment transportation horizontal two dimensions. To describe flow analysis in a stream used software RMA 2, in problems solution of sediment transport so the analysis involving two sub software the RMA 2 and FESWMS. RMA 2 as sub program for the two dimensions dynamics flow equation and FESWMS for solution of sediment transport equation. Governing equations is provided in Eqs.(1) and (2).

$$h\frac{\partial u}{\partial t}+hu\frac{\partial u}{\partial x}+hv\frac{\partial u}{\partial y}-\frac{h}{\rho}\left(E_{xx}\frac{\partial^2 u}{\partial x^2}+E_{xy}\frac{\partial^2 u}{\partial y^2}\right)+gh\left(\frac{\partial u}{\partial x}+\frac{\partial h}{\partial x}\right)+\frac{gun^2}{\left(1.486h^{1/6}\right)^2}\left(u^2+v^2\right)^{1/2}-\xi V_a^2\cos\psi+2h\omega v\sin\phi=0 \quad (1)$$

$$\frac{\partial h}{\partial t}+h\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=0 \quad (2)$$

2.5. Computational conditions

Table 1 lists the predefined computational conditions for the modelling of channels, sediments, and hydraulic parameters. This data obtained free of charge from Transportation and Geotechnical Laboratory, Department of Civil Infrastructure Engineering, Institut Teknologi Sepuluh Nopember Surabaya [22].

Table 1. Modelling parameters of the channels, sediment, and hydraulics of the river.

Parameter	Note and magnitude
Suspended load sediment	Mayer Peter Muller Theory
Bed-load sediment porosity	0.4
Sediment specific gravity	1.9
Water temperature (°C)	20
Kinematic viscosity (m^2/s)	1.0×10^{-6}
Erosion rate factor	1.0
Sediment diameter D_{50} (mm)	2
Active bed layer (m)	0.02
Deposition bed layer (m)	1
Total bed layer (m)	2.5
Bottom stresses	Manning's equation
Duration (h)	24
Velocity (m/second)	2
Discharge (m^3/second)	2400

2.6. Modeling the control of river bend bed erosion

In this research, the cribs were fitted to control the water direction, flow velocity, and river bottom erosion. The assumed conditions for the crib installation model are as follows.

- Cribs were fitted in perpendicular spur dike to maximize sedimentation in the area originally experiencing erosion.
- The cribs were arranged such that the distance between them would reduce the flow velocity, which is most effective for erosion control.

- The single crib was fitted such that it produced maximum sedimentation where the erosion originally occurred.
- The crib crest elevation was at the same level as the water in full bank discharge.
- Limitation of this model is in the bend of the river reach observation point 1 up to observation 5.
- The x=0 m corresponds to the left bank of the river when facing downstream.

After the preliminary running of the SMS 11.2 model, five observation points for the erosion outlet were identified for further assessment (Fig. 5.).

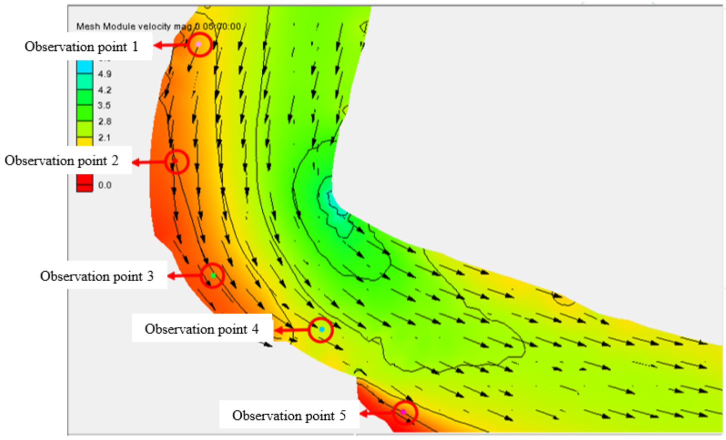

Fig. 5. Five observation points for modelling the erosion scenario at the river bend.

3. Model Verification and Validation

This current work model should be verified based on published similar experimental data. Fig. 6(a) shows sedimentation pattern in outer river bend from series impermeable structure model simulation [20], while Fig. 6(b) is sedimentation pattern of real model simulation result in current work. This both models have similarities sedimentation patterns, therefore simulation model on crib installation with other alternative arrangement based on this verification.

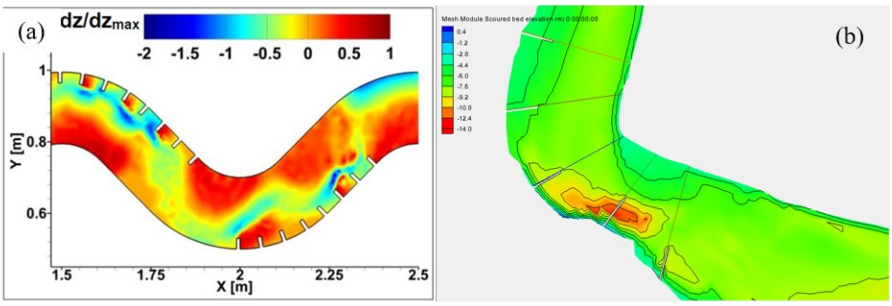

Fig. 6. Model validation using (a) an established model (b) the real model in current work.

The next step performed validation model by compare the simulation current work model results with the measurement results. The location erosion and sedimentation are also nearly the same in both the experiments as well as the simulation. Therefore, this model could be applied to other alternative impermeable cribs arrangement.

4. Results and Discussion

The results simulation SMS model compared to the measurement results on observation points indicated in Appendix A, B and C, for the validation model and subsequent research.

4.1. Modeling of existing conditions

The patterns of flow velocity from the existing model (without crib) and flow velocity at each observation point (Arc) are shown in Fig. 7.

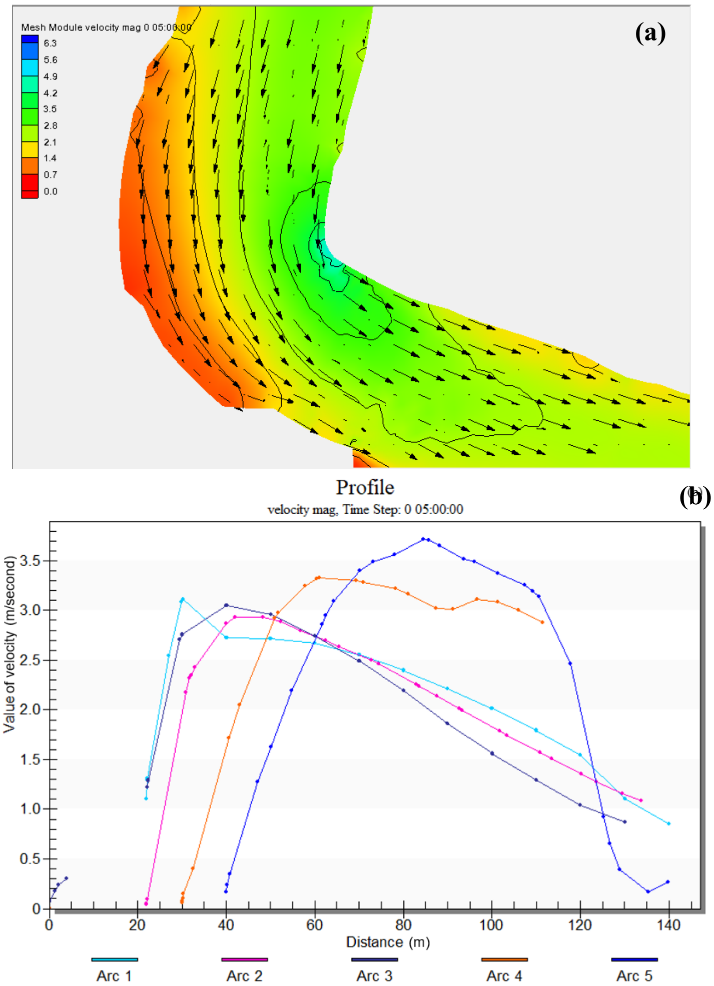

Fig. 7. Average flow velocity pattern (a) of the existing condition model and (b) of the observation points (Arc) 1 to 5 using the existing model.

Furthermore, the sediment pattern using the existing model is shown in Fig. 8(a), and the sedimentation or erosion profile at each observation point is shown in Fig. 8(b).

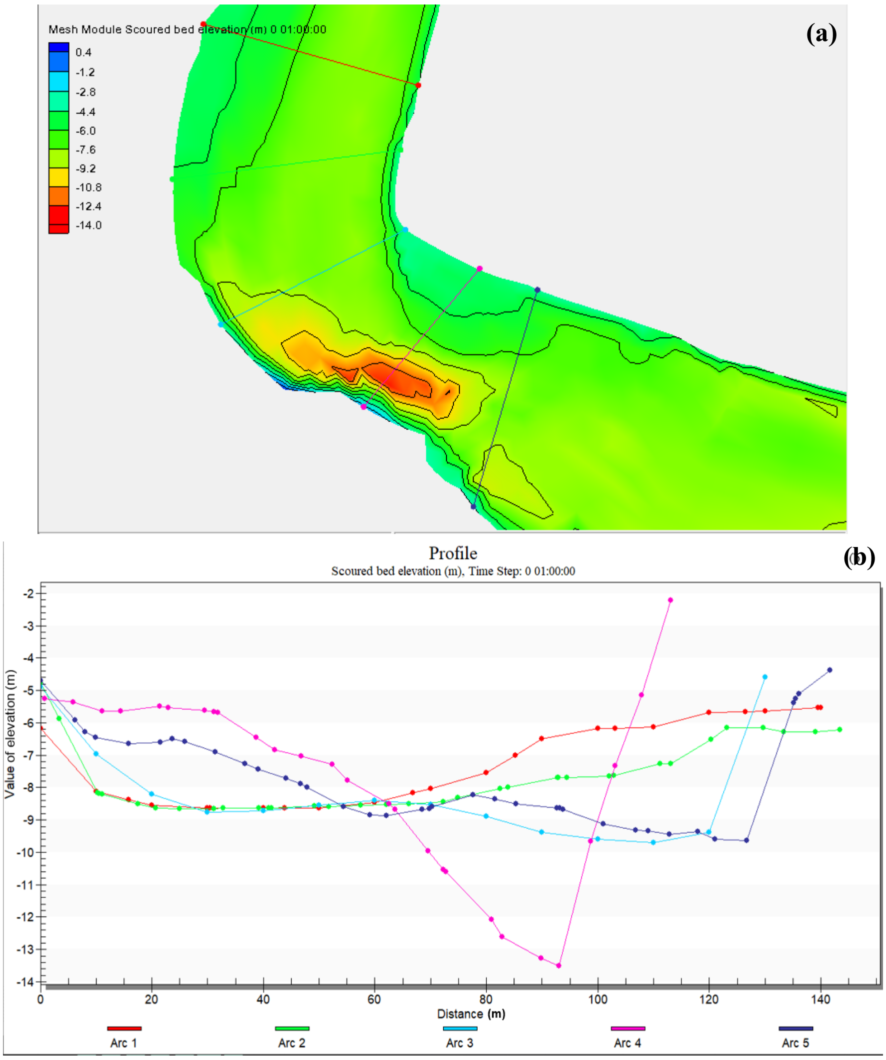

Fig. 8. (a) The sedimentation model derived from running the model on the existing condition, (b) The riverbed elevation on each observation point (Arc) from 1 to 5 on the existing condition.

4.2. Modeling of impermeable crib alternative 1

The Alternative 1 model had five impermeable cribs laid perpendicular spur dike in the outer bend of the river with a crib length between 30 and 45 m. The derived flow pattern is depicted in Fig. 9(a), and the flow velocity at each observation point (Arc) is shown in Fig. 9(b).

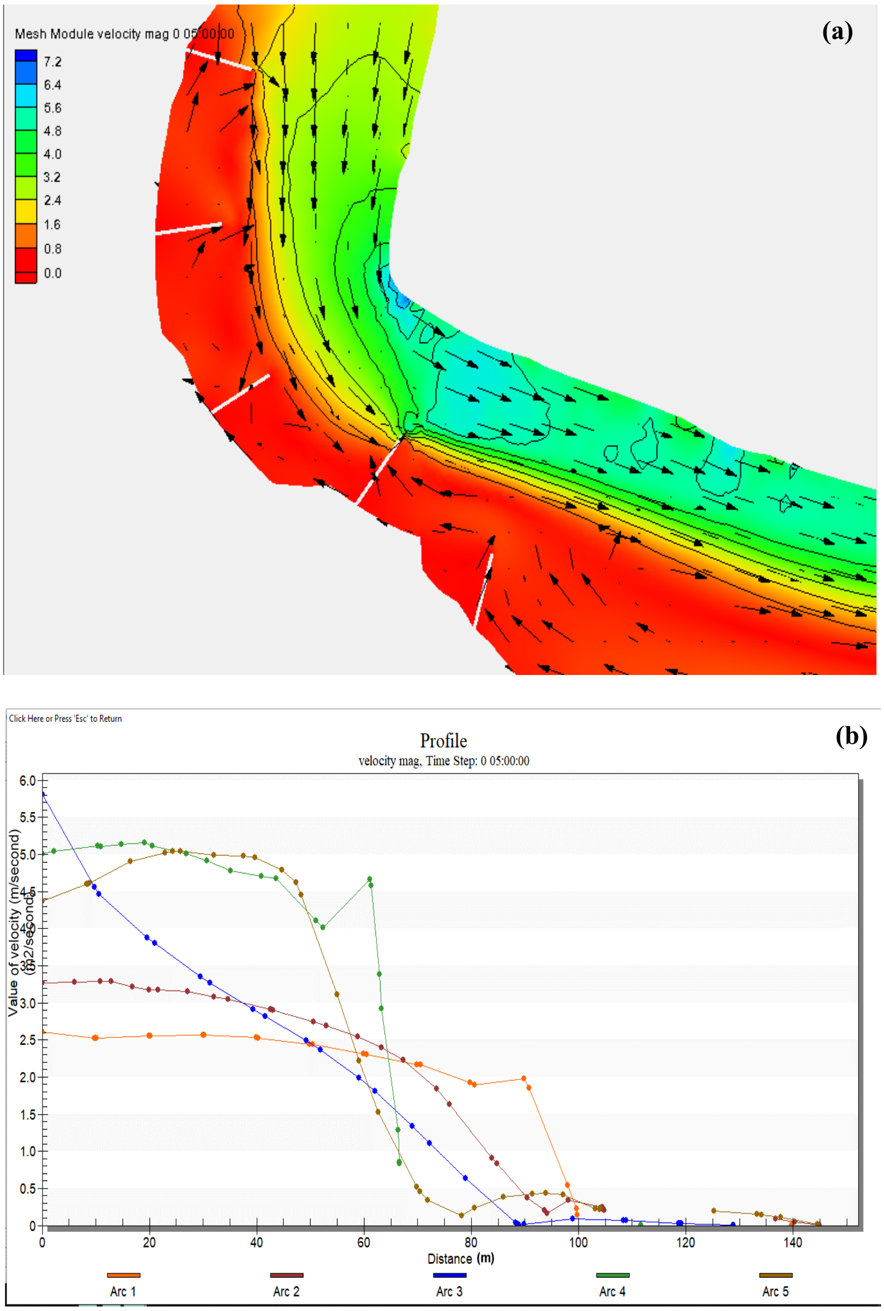

Fig. 9. The Alternative 1 model average flow velocity pattern (a) using the impermeable crib and (b) at each observation point.

We observed 81%, 84%, 52%, 97%, and 96% velocity reduction by switching from the use of the existing model to using Model 1.

The sediment pattern from simulation the impermeable crib Alternative 1 model is provided in Fig. 10(a), and the sedimentation or erosion at each observation point is shown in Fig. 10(b).

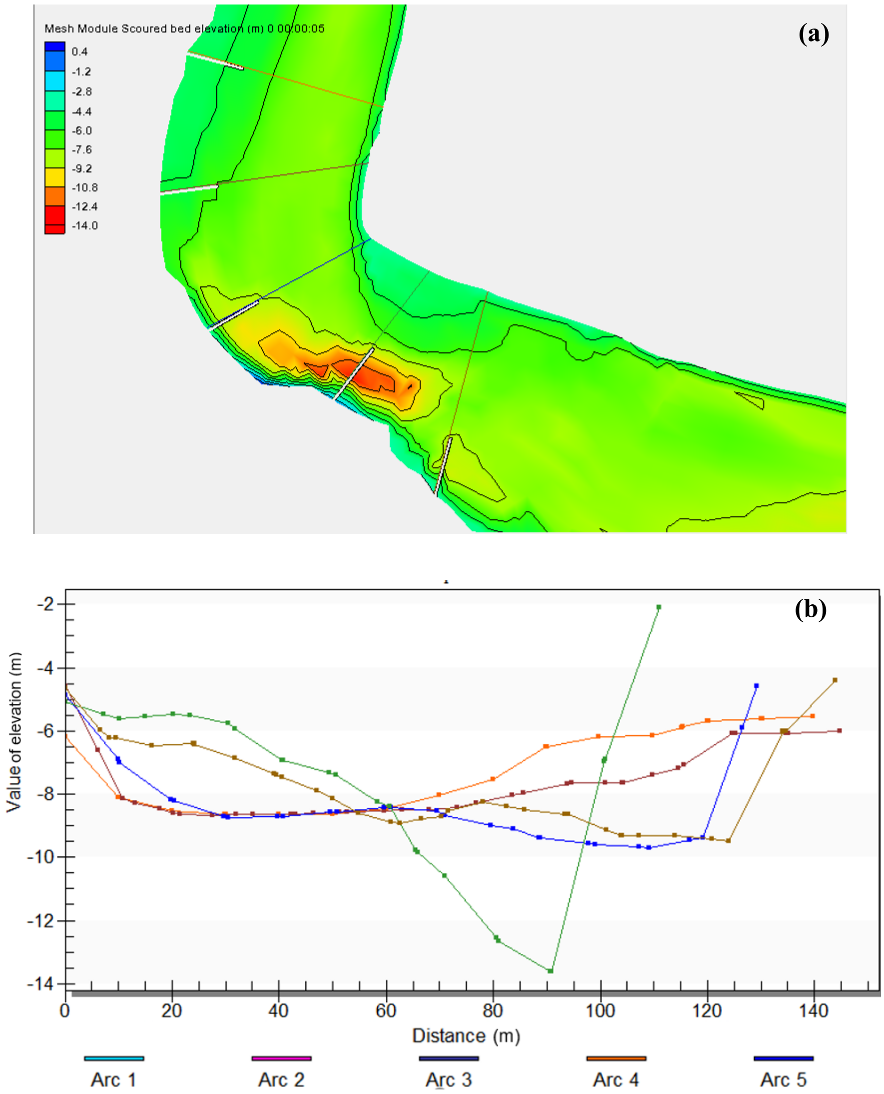

Fig. 10. Alternative 1 modelling of (a) sedimentation on impermeable crib; (b) sedimentation or erosion at each observation point.

Herein, a general increase was observed in sedimentation or erosion when we switched from using the existing model to using Model 1. From observation points 1 to 5, the differences were 0.00022, 0.02989, 0, 0.00286, and 0.02560 m, respectively.

4.3. Modeling of impermeable crib alternative 2

The Alternative 2 model entailed five impermeable cribs, with two and three cribs laid perpendicular spur dike in the inner bend and on the outer bend of the river, respectively (Fig. 11). The length of the crib was 30-45 m. The flow pattern on the Alternative 2 model and the flow velocity at each observation point are shown in Fig. 11.

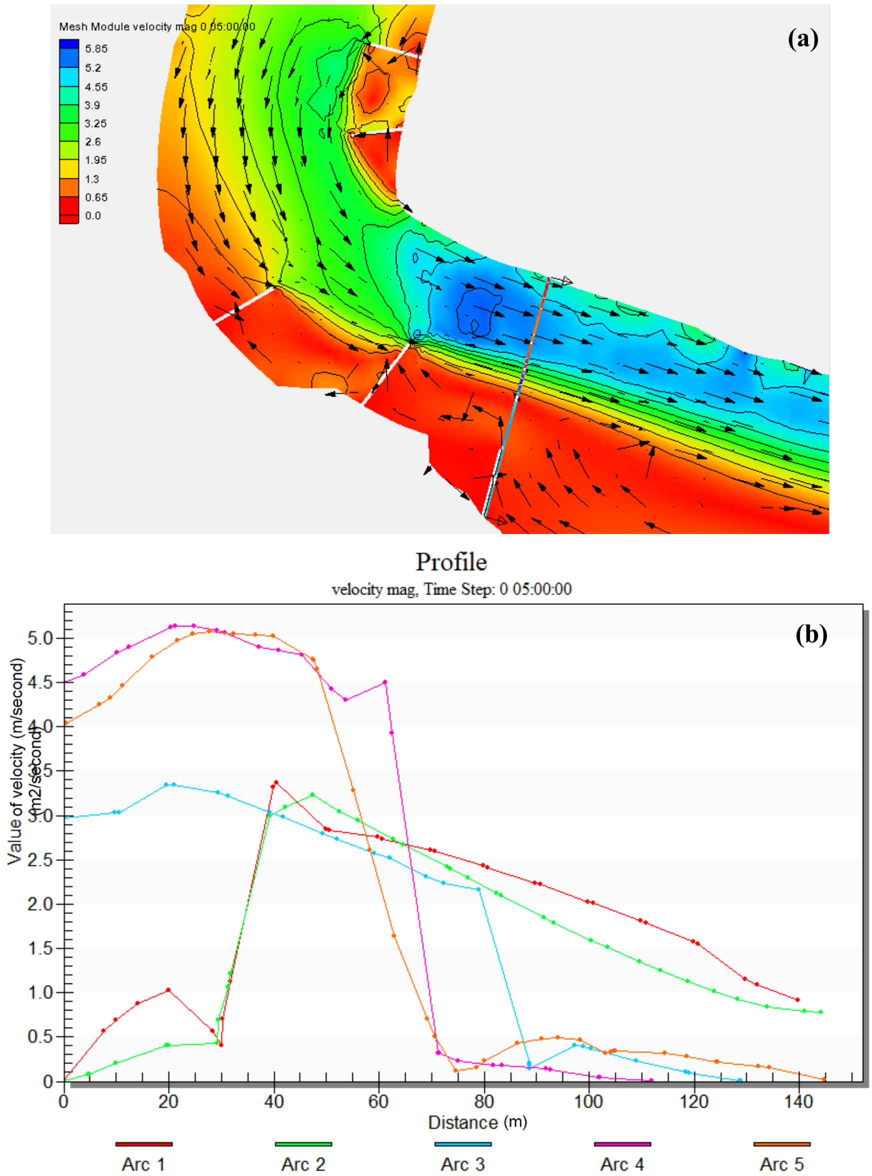

Fig. 11. Alternative 2 model average flow velocity pattern (a) using the impermeable crib and (b) at each observation point.

From Fig 11, we deduced a positive change in velocity (0.49, 0.35, 0.32, 1.15, and 0.67) from the corresponding velocity reduction of 47%, 49%, 48%, 64%, and 94% at observation points 1, 2, 3, 4, and 5, respectively.

For the sedimentation pattern, simulation, the impermeable crib Alternative 2 model yielded the result depicted in Fig. 12(a), and the sedimentation or erosion in each observation point is shown in Fig. 12(b).

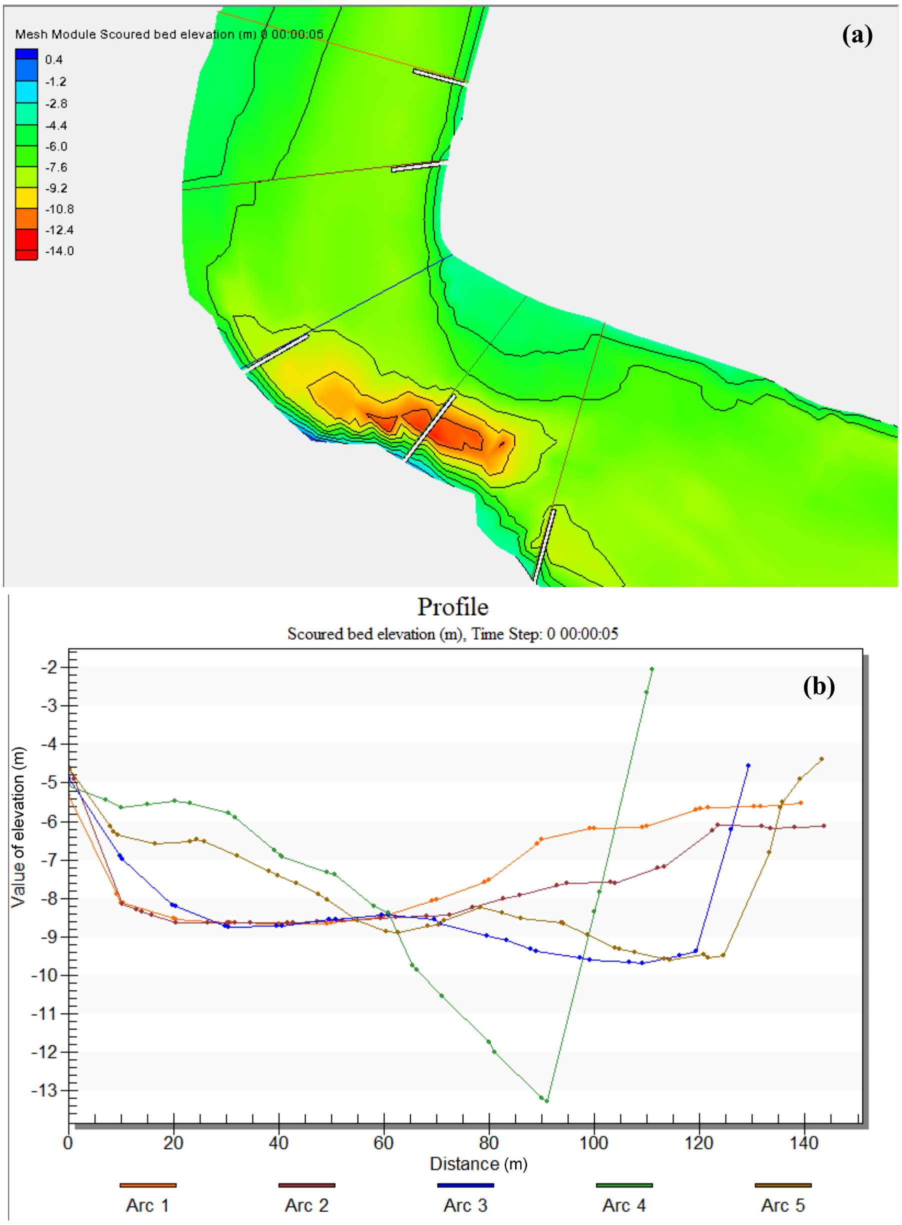

Fig. 12. Alternative 2 modelling of the sedimentation.
(a) Impermeable crib; (b) erosion at each observation point.

From Fig. 12, the differences between the existing model and Model 2 in estimating the sedimentation or erosion were 0.00161, 0.01473, 0, 0.00286, and 0.02560 from observation points1 to 5, respectively

4.4. Modeling of impermeable crib alternative 3

Furthermore, an Alternative 3 model, in which the three impermeable cribs were placed perpendicular spur dike but wider to fit the river bend, was modelled (Fig. 13). The flow pattern on the Alternative 3 model is shown in Fig. 13(a), and the flow velocity at each observation point is provided in Fig. 13(b).

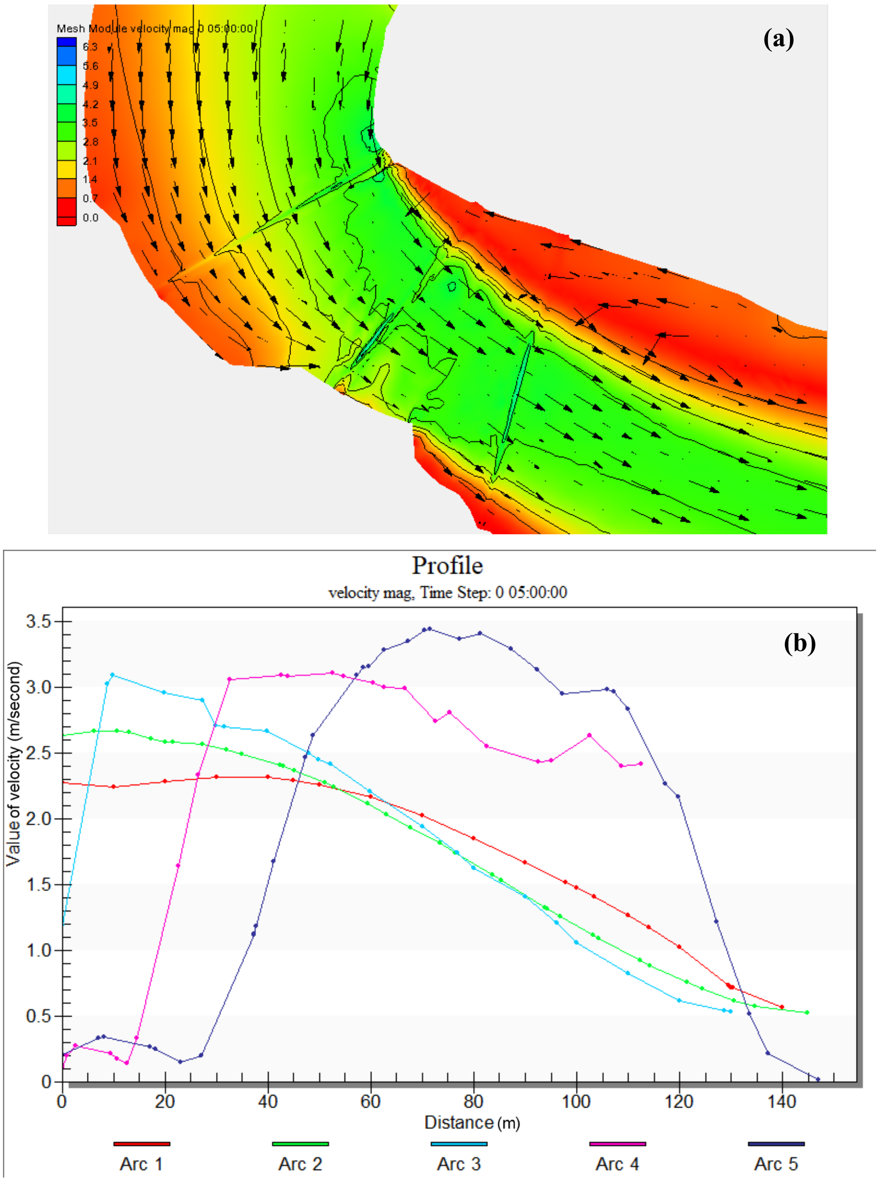

Fig. 13. Alternative 3 model average flow velocity pattern.
(a) Using the impermeable crib and (b) at each observation point.

Based on the Alternative 3 model, the observed percentage reductions in the flow velocity of the river at observation points 1 to 5 were 5%, 1%, 9%, 19%, and 84%, respectively. Besides, the sediment pattern from Alternative 3 model simulation and sedimentation or erosion at each observation points are provided in Fig. 14. Only at observation points 2, 4, and 5 we noticed sedimentation. Besides, the sedimentation reductions at these points were 0.00217, 0.00286, and 0.02560, respectively.

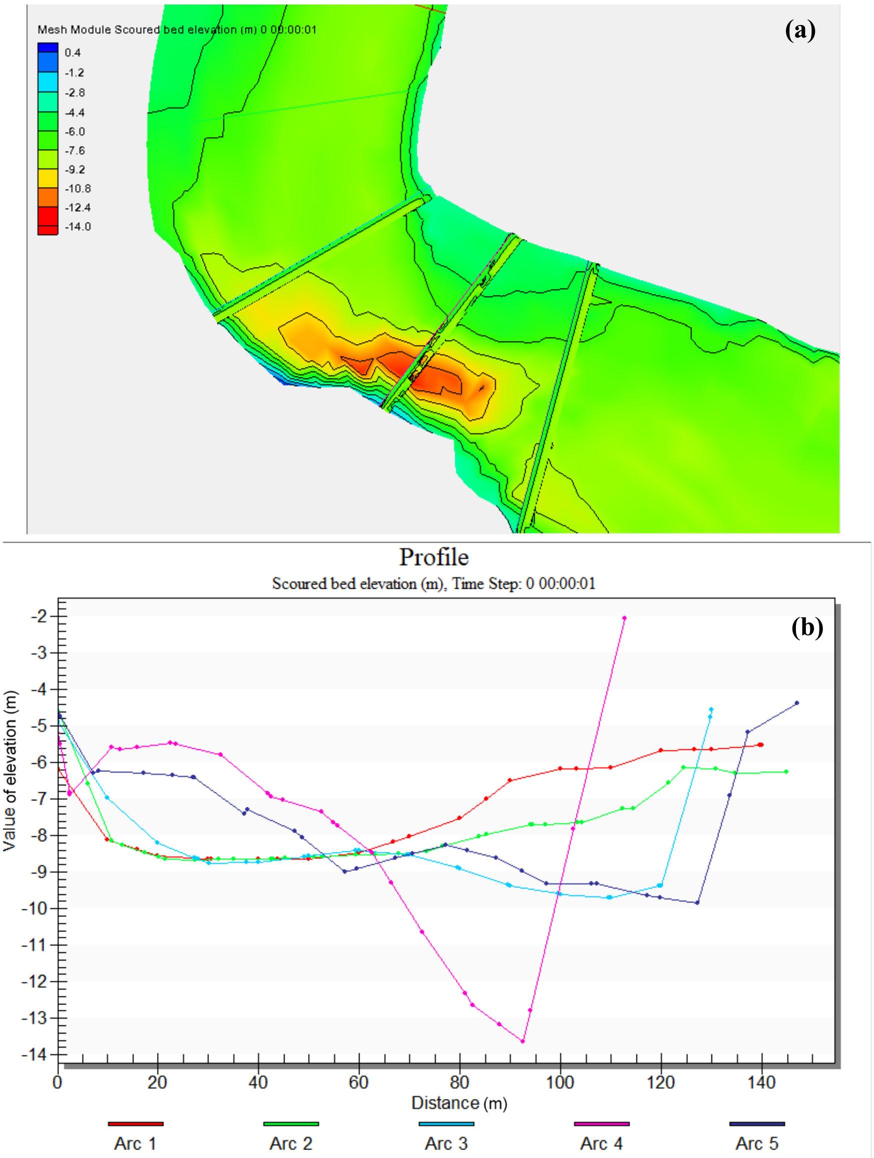

Fig. 14. Alternative 3 modelling. (a) Sedimentation on impermeable crib; (b) sedimentation or erosion at each observation point.

4.5. Modeling of impermeable crib alternative 4

Finally, the Alternative 4 model was a single impermeable crib fitted at the cross-section of observation point 5. The derived flow pattern and the flow velocity at each observation point are shown in Fig. 15.

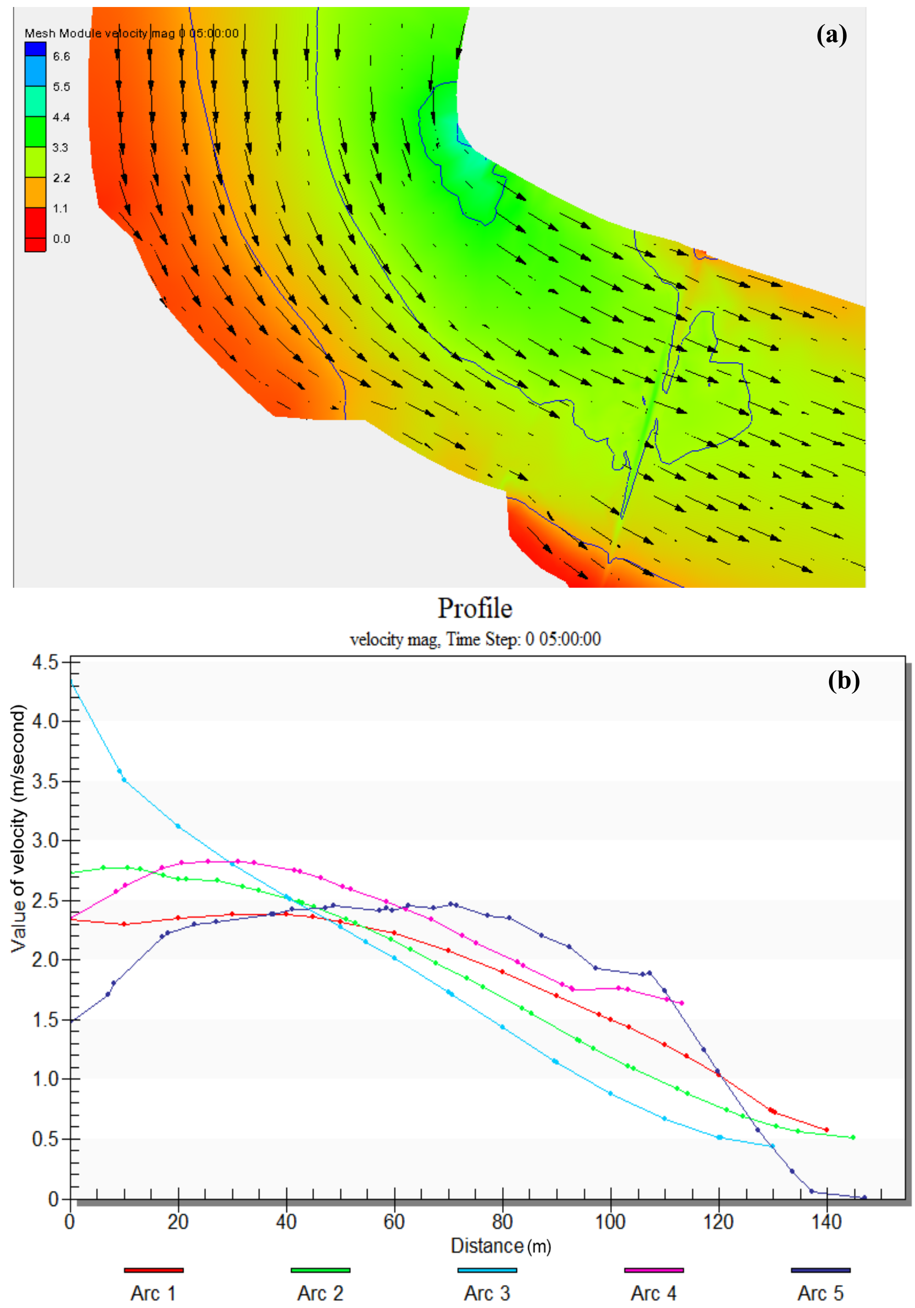

Fig. 15. The Alternative 4 model average flow velocity pattern (a) using the impermeable crib and (b) at each observation point.

From the Alternative 4 model, the observed percentage reductions in the flow velocity of the river at observation points 1 to 5 were 3%, 3%, 2%, 1%, and 3%, respectively. The sediment pattern using the Alternative 4 model is shown in Fig. 16(a) and sedimentation or erosion at the observation point shown in Fig. 16(b).

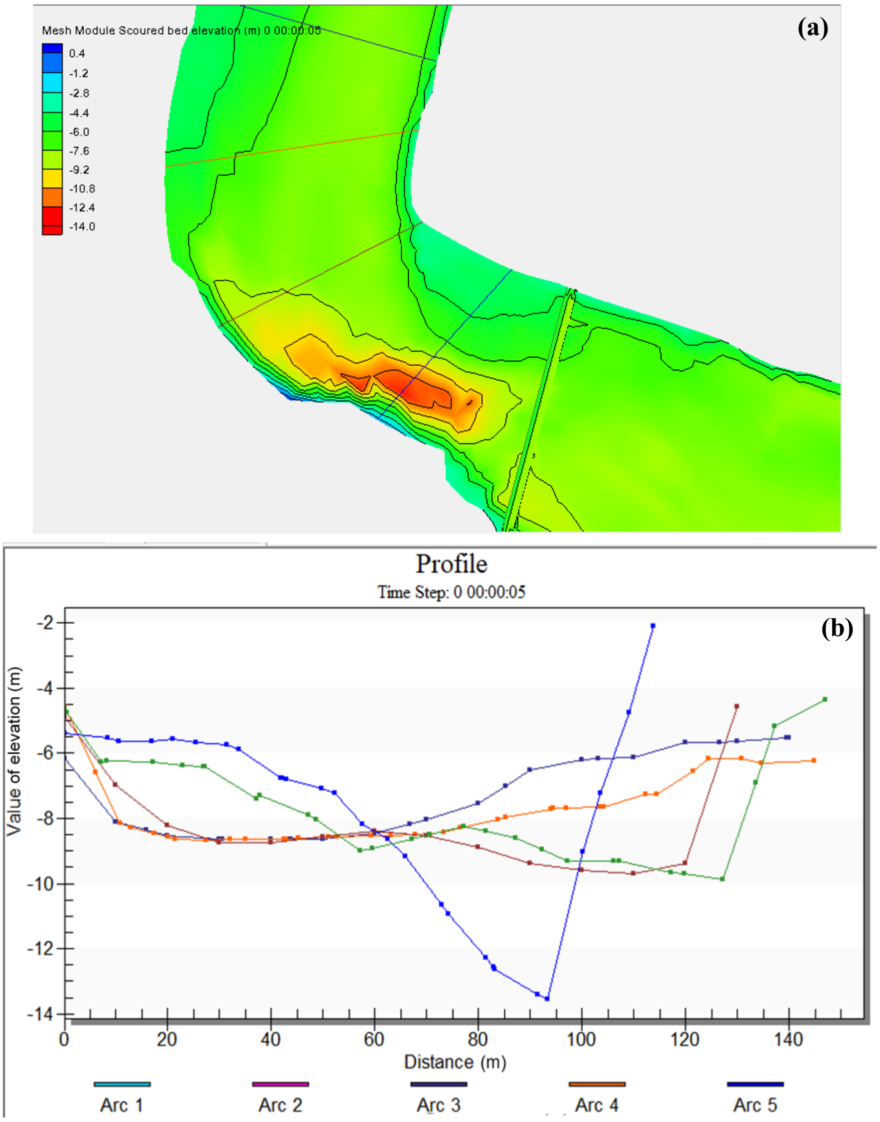

Fig. 16: Alternative 4 modelling. (a) Sedimentation on impermeable crib; (b) sedimentation or erosion at each observation point.

5. Model Effectively Test

5.1. Effectiveness of flow velocity reduction test

Here, we summarize our findings based on the effectiveness of the river bend bed erosion control model on the flow velocity. After simulation four alternative models, we observed that the Alternative 1 model was the most effective, having velocity reductions between 52% and 97%. For flow velocity reduction, the order of efficiency was Alternative to model 1 > 2 > 3 > 4 (Table 2). Therefore, Alternative model 1 is best suited for the flow velocity control model.

Table 2. The effectiveness of flow velocity reduction test measurement and simulation by the Alternative models.

Observation point	Velocity reduction (%)							
	Alt. Model 1		Alt. Model 2		Alt. Model 3		Alt. Model 4	
	Measurement	Simulation	Measurement	Simulation	Measurement	Simulation	Measurement	Simulation
1		81		47		5		3
2		84		49		1		3
3		52		48		9		2
4		97		64		19		1
5	97	96	94	94	84	84	3	3

5.2. Effectiveness of sedimentation test

Finally, the effectiveness test of the river bend bed erosion control model was also assessed based on the largest sediment quantity. Similar to that of the velocity test (subsection 4.6.2), four sets of results were obtained (Table 3). All the models evinced similar erosion control at observation points 3, 4, and 5, with sedimentation magnitudes of 0.000, 0.286, and 2.560 cm, respectively. Additionally, at observation point 2, the most effective sedimentation using model 4 (with sedimentation magnitude 3.702 cm) was achieved. Thus, the Alternative 4 model was the optimized model chosen as the erosion control model based on sedimentation.

Table 3. Sedimentation effectively test measurement and simulation.

Observation point	Sedimentation (cm)							
	Alt. Model 1		Alt. Model 2		Alt. Model 3		Alt. Model 4	
	Measurement	Simulation	Measurement	Simulation	Measurement	Simulation	Measurement	Simulation
1		0.022		0.161		0.000		0.000
2		2.989		1.473		0.217		3.702
3		0.000		0.000		0.000		0.000
4		0.286		0.286		0.286		0.286
5	0.025	0.022	2.500	2.560	2.400	2.560	2.560	2.560

6. Comparison to the results of the previous river bend research

Impermeable groynes reduced the erosion near the bank area, scour around the groynes was higher compared to no groynes case. The scour near the tip of groynes was relatively lower. Immediately downstream of the last groynes in both the series, considerable deposition occurred [20]. In previous riverbank band research stated flow velocity reduce, erosion reduce and sedimentation effectivity just in quality but not in quantity. In this research, all of those stated in quantity and in percentage. In this research we can be easier to evaluate and compare some models to get the most effective in flow velocity reduce, erosion reduce and sedimentation effectivity.

7. Conclusions

After implementing four alternative models to examine the reduction of erosion at a river bend, based on the flow velocity and the rate of sedimentation, we draw the following inferences. For flow velocity reduction, the alternative 1 model was most effective, particularly when the five impermeable cribs (length of 30-45 m) were laid perpendicular at the outer bend of the river. For sedimentation, the alternative 4 model was the most effective, particularly when a single impermeable crib was cited at observation point 5. River bend bed erosion control should be used by combining Alternative models 1 and 4. We recommend in future for construction of buildings (such as highway routes, railway routes, and bridges) across the river to avoid river band, if it not be avoided safe the building from erosion attack, control sediment movement in the arch of the river caused by erosion and sedimentation with good impermeable cribs configuration.

Nomenclatures

E_{xx}	x direction of effeciency or sediment removal ratio soil loss, Eqs. (1) and (2)
E_{xy}	y direction of effeciency or sediment removal ratio soil loss, Eqs. (1) and (2)
g	acceleration of gravity
h	water depth
n	Manning roughness coefficient
t	time (equation 1. and 2.)
u,v	velocity on x and y direction (equation 1. and 2.)
x,y	Cartesian coordinate (equation 1. and 2.)

Greek Symbols

ϕ	internal angle of repose
ρ	liquid density
ψ	shear stress intensity
ω	settling velocity
ξ	roughness parameter

Abbreviations

FESWMS	Finite-Element Surface Water Modelling System
RMA	Resource Modelling Associates
SMS	Surface Water Modelling System

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Appendix A

Representation SMS simulation results on river bend bed

Results of the SMS software simulation on the existing condition are provided in Table A-1 to A-2.

Table A-1. Flow velocity from the existing model.

No.	Note	Distance (m)	Velocity (m/s)
1	Observation point 1	0+130	1.05
2	Observation point 2	0+133	0.70
3	Observation point 3	0+120	0.66
4	Observation point 4	0+120	1.80
5	Observation point 5	0+133	0.71

Table A-2. Sedimentation or erosion from the existing model.

No.	Note	Distance (m)	Sedimentation (m)
1	Observation point 1	0+110	0.00000
2	Observation point 2	0+139	-0.02989
3	Observation point 3	0+120	0.00000
4	Observation point 4	0+123	0.00286
5	Observation point 5	0+119	0.02560

Appendix B

Representation simulation SMS results on river bend bed

Results of the SMS software simulation on river bend bed for alternative models 1 to 4 on each observation point 1 to 5 are shown in Table B-1 to B-8.

Table B-1. Flow velocity simulation and measurement from Impermeable Crib Alternative 1 model.

No.	Note	Velocity (m/s)			Reduction (%)	
		Existing	Simulation	Measurement	Simulation	Measurement
1	Observation point 1	1.05	0.20		81	
2	Observation point 2	0.70	0.11		84	
3	Observation point 3	0.66	0.32		52	
4	Observation point 4	1.80	0.06		97	
5	Observation point 5	0.71	0.03	0.027	96	97

Table B-2. Sedimentation or erosion simulation and measurement from running Impermeable Crib Alternative 1 model.

No.	Note	Sedimentation or erosion (m)			ΔH (m)	
		Existing	Simulation	Measurement	Simulation	Measurement
1	Observation point 1	0.00000	0.00022		0.00022	
2	Observation point 2	-0.0299	0.00000		0.02989	
3	Observation point 3	0.00000	0.00000		0.00000	
4	Observation point 4	0.00286	0.00000		0.00286	
5	Observation point 5	0.00000	0.00022	0.00025	0.00022	0.00025

Table B-3. Flow velocity simulation and measurement from Impermeable Crib Alternative 2 model.

No	Note	Velocity (m/s)			Reduction (%)	
		Existing	Simulation	Measurement	Simulation	Measurement
1	Observation point 1	1.05	1.54		47	
2	Observation point 2	0.70	1.04		49	
3	Observation point 3	0.66	0.34		48	
4	Observation point 4	1.80	0.65		64	
5	Observation point 5	0.71	0.04	0.04	94	94

Table B-4. Sedimentation or erosion simulation and measurement from running Impermeable Crib Alternative 2 model.

No	Note	Sedimentation or erosion (m)			ΔH (m)	
		Existing	Simulation	Measurement	Simulation	Measurement
1	Observation point 1	0.00000	0.00161		0.00161	
2	Observation point 2	-0.0299	-0.01516		0.01473	
3	Observation point 3	0.00000	0.00000		0.00000	
4	Observation point 4	0.00286	0.00000		0.00286	
5	Observation point 5	0.02560	0.00000	0,00000	0.02560	0.02560

Table B-5. Flow velocity simulation and measurement from Impermeable Crib Alternative 3 model.

No	Note	Velocity (m/s)			Reduction (%)	
		Existing	Simulation	Measurement	Simulation	Measurement
1	Observation point 1	1.05	1.00		5	
2	Observation point 2	0.70	0.69		1	
3	Observation point 3	0.66	0.72		9	
4	Observation point 4	1.80	2.14		19	
5	Observation point 5	0.71	1.56	1.566	84	84

Table B-6. Sedimentation or erosion simulation and measurement from running Impermeable Crib Alternative 3 model.

No	Note	Sedimentation or erosion (m)			ΔH (m)	
		Existing	Simulation	Measurement	Simulation	Measurement
1	Observation point 1	0.00000	0.00000		0.00000	
2	Observation point 2	-0.0299	0.03206		0.00217	
3	Observation point 3	0.00000	0.00000		0.00000	
4	Observation point 4	0.00286	0.00000		0.00286	
5	Observation point 5	0.02560	0.00000	0.02000	0.02560	0.02000

Table B-7. Flow velocity simulation and measurement from Impermeable Crib Alternative 4 model.

No	Note	Velocity (m/s)			Reduction (%)	
		Existing	Simulation	Measurement	Simulation	Measurement
1	Observation point 1	1.05	1.02		3	
2	Observation point 2	0.70	0.68		3	
3	Observation point 3	0.66	0.67		2	
4	Observation point 4	1.80	1.79		1	
5	Observation point 5	0.71	0.73	0.75	3	3

Table B-8. Sedimentation or erosion simulation and measurement from running Impermeable Crib Alternative 4 model.

No	Note	Sedimentation or erosion (m)			ΔH (m)	
		Existing	Simulation	Measurement	Simulation	Measurement
1	Observation point 1	0.00000	0.00000		0.00000	
2	Observation point 2	-0.0299	0.00713		0.03702	
3	Observation point 3	0.00000	0.00000		0.00000	
4	Observation point 4	0.00286	0.00000		0.00286	
5	Observation point 5	0.02560	0.00000	0,00000	0.02560	0.02560

Appendix C

Resume of simulation SMS results of effectively of flow velocity reduction test and erosion or sedimentation effectively test

Resume of SMS software simulation on river bend bed for alternative models 1 to 4 on each observation point 1 to 5 of effectively of flow velocity reduction test is provided on Table C-1 and the erosion or sedimentation effectively test is shown in Table C-2.

Table C-1. The effectively of flow velocity reduction test on simulation and measurement.

No	Note	Velocity reduction (%)			
		Model Alt. 1	Model Alt. 2	Model Alt. 3	Model Alt. 4
1	Observation point 1 (simulation)	81	47	5	3
2	Observation point 2 (simulation)	84	49	1	3
3	Observation point 3 (simulation)	52	48	9	2
4	Observation point 4 (simulation)	97	64	19	1
5	Observation point 5 (simulation)	96	94	84	3
6	Observation point 5 (measurement)	97	94	84	3

Table C-2. The erosion or sedimentation effectively test on simulation and measurement.

No.	Note	Erosion or Sedimentation (cm)			
		Model 1	Model 2	Model 3	Model 4
1	Observation point 1 (simulation)	0.022	0.161	0.000	0.000
2	Observation point 2 (simulation)	2.989	1.473	0.217	3.702
3	Observation point 3 (simulation)	0.000	0.000	0.000	0.000
4	Observation point 4 (simulation)	0.286	0.286	0.286	0.286
5	Observation point 5 (simulation)	2.560	2.560	2.560	2.560
6	Observation point 5 (measurement)	2.54	2.56	2,00	2.56