BARBS POSITION INDUCED CHANNEL BANK STABILITY: A NUMERICAL SIMULATION

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ABSTRACT

The emphasis of this study is to observe the barbs position on channel bank stability using iRIC-Nays2D, a multi-dimensional computational model for river flow and riverbed variation analysis solver package. The two-dimensional (2D) numerical simulation is represented the alignment of stream barbs on the channel bank erosion prevention. The model was run by two settings: barb installed at one sidewall and at both sidewall of the channel. The numerical simulation reproduced the features of barbs with time at upward side and creates scour holes at the leeward side of the structure. The simulation results confirmed that the vicinity of the barb achieved a substantial reduction in scour at bank sidewall, stream-wise velocity and sediment deposition. Sand bars were formed along the bank-line at the upstream portion of the structures.

Keywords: *Barbs, position, bank stability, numerical simulation, sand bars*

1. INTRODUCTION

The changes of river are interrelated not only with bed deformation but also with bank erosion. This is because of the relationship between water flow and sediment transport. Beside of the bed deformation it is needed to study about how to get suitable bank stability for maintaining river ecosystems and landscape in the field for environmental engineering purpose. Stream burb influenced on straight channel bed configuration a simulation result showed by Mamun Hossain et al. (2013). Stream barbs can provide two hydraulic functions which serve to provide stability to a stream bank such as: (a) divert erosive stream flows away from the bank and (b) encourage deposition at the toe of the bank (NRCS, 2005). Typically, constructed of large angular rock (riprap); barbs protrude into the flow at an angle upstream to the channel sidewall (bank) for the purpose of deflecting current away from the bank and minimizing the erosion potential (Ghodsian & Tehrani, 2001). Barbs are quite similar to spur dikes, groynes (groins), and submerged vanes; they have some distinct features as shown in Figure 1. The most defining feature is the trapezoidal shape of the structure with inclined sides and a wide sloped crest, which allows the barb to behave as a partially submerged structure (weir) when flow is low and fully submerged happened during bank full flow conditions. When pointed upstream the submerged weir section forces the water flowing over the structure into a hydraulic jump (Fox, 2002). The flow separation induced by the hydraulic jump promotes the formation of eddies and sediment deposition on the leeward side of the barb (Lloyd & Stansby, 1997). The approaches to protect stream banks from erosion during periods of high flows including various bio-technical type channel revetments (Schiechtl & Stern, 1997) and groin like structure including bend-way weirs (Davinroy, 1994) and barbs (USDA, 2001).

Figure 1: Photographic view shows the series of stream barbs installed along the river bank during flow season (left side) and low flow season (right side). The red circle indicates sand bars formed after installation of barbs.

Field observation and laboratory result showed by Johnson et al. (2001), Matsuura and Townsend (2004), Kuhnle et. al. (2002) that, the scour depth occurs at the barb end and immediately downstream of the structure. Barbs are currently undergoing limited field test on selected bend of several shallow wide streams in Illions, USA (Matsuura and Townsend, 2004). Moreover, investigation and estimation of the depth of local scour and deposition around a structure, such as a barb, remains a perplex problem for hydraulic and restoration engineers. Most investigations have just reported measurements of the maximum depth of scour without giving any information about the geometry (i.e. shape) of the scour hole and how this geometry changes with time (Kuhnle et al., 2002). Furthermore, it is need to investigate the barbs position on channel bank stability considering uniform flow condition. This paper reports two-dimensional numerical simulation to observe the barbs position on channel bank stability from installed at one sidewall and at both sidewall of the channel with erodible bed among a relatively high width-to-depth ratio.

2. MATERIALS AND METHODS

A 13.3 m long and 0.8 m wide grid channel generated by using iRIC-Nays2D, computation flow model, a multi-dimensional river flow and riverbed variation analysis solver package. Several numerical models have been developed to simulate the deformation of a relatively narrow, deep, straight channel with erodible, non-cohesive banks in the laboratory (Shimizu, 2002). The channel shape was considered as rectangular flat movable bed with simple cross section. The slope of the channel was used as 0.005, as the model is designed by subcritical flow. Grid cells were generated along the longitudinal and lateral direction of hundred and ten numbers, respectively. It was estimated that the change of width of the grid channel in the direction of flow is constant. To evaluate the barbs hydraulic performance in channel bank stability, the model was run two settings: first, barb installed at one sidewall, second at both sidewall of the channel. At first flow approached into the channel and find the velocity vector, flow depth and the elevation of the bed topography, respectively. Before starting flow provided small perturbation value at 5 selected grid nodes that are persuade the bars formation. The elevation set as zero along the whole channel alternately around 2.5 m equal distance. The barb structure is installed as obstacle and it is 4.5 m apart from the upstream end of the channel as shown in Fig.2a and 2b. The length of the barb considered as 24 cm, one-third of the cross-section top width at bank-full stage and build as rectangular riprap shape. According to NRCS (2005), each barb extends from the bank-line to the proposed thalweg location. Generally the length of the barb not exceed one-third of the cross-section top width at bank full stage, as Matsuura and Townsend (2004) observed in their study that, the overall length should not exceed about one quarter the channel-forming flow width. By decreasing the nodes elevation point at the barb end, the structure set as a sloping ridge from the bank to the main channel flow. The barb placed at an angle of 45^0 with the upstream bank of the channel as NRCS (2005) state the horizontal angle between the tangent line placed along the upstream bank and the centerline of the longitudinal axis of the barb have varied from 30^0 to 60^0.

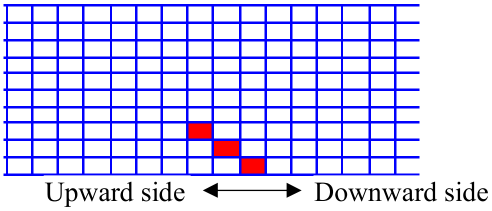

Figure 2a: Riprap barb structure setting sidewall of grid channel bank

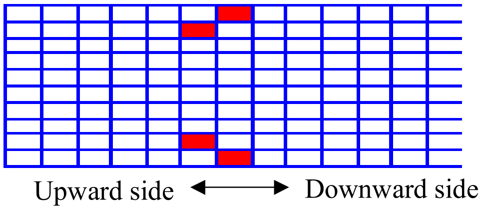

Figure 2b: Riprap barb structure setting on both on grid channel bank sidewall

The generated grid channel was used to set the calculation condition and simulation. The tables 1 below summarize the flow calculation condition for simulation. The symbol *L* represents as the total length, *B* is the internal width and *S* is the slope of the channel, *D* is the normal flow depth, *Q* is the discharge, *U* is the velocity of the flow, *B/D* is the width to average flow depth ratio, C_f is the roughness coefficient correspond to d_{50}, where d_{50} is the mean sediment diameter and Froude number, $F_r = U/\sqrt{gD}$, and g is gravity acceleration. The friction coefficient C_f is found to be expressed as follow:

$$C_f = \left[\frac{1}{K}\ln\frac{11D}{2.5d_s}\right]^{-2} \tag{1}$$

The bottom share stress from the Reynolds equation, $\tau = \rho gDS$ and from the Keulegan relation for turbulent flow, the bed shear stress, $\tau = \rho C_f U^2$, where ρ is the density of water. Considering unit flow depth into the channel then, *U=Q/D*. Using from the relation $\tau = \rho gDS = \rho C_f U^2$, the discharge and velocity is calculated from the equation as follows:

$$\frac{Q}{D} = \sqrt{\frac{gDS}{C_f}} \tag{2}$$

Table 1: Details flow calculation condition

L	B	S	B/D	D	Q	U	C_f	Fr	d_{50}
m	m	m/m	–	m	m^3/s	m/s	–	–	mm
13.3	0.8	0.005	18	0.044	0.028	0.64	0.005423	0.977	0.77

In the calculation condition used the professional solver type with bed deformation. The finite differential methods of advection term was used as CIP method. For calculation of numerical simulation the cyclic boundary condition was used with initial water surface as uniform flow. The upstream velocity and water surface at downstream was also considered as uniform flow. Constant discharge time series were used from the beginning up to 5 hours (Table 1). Output time interval was select as 10 sec. The calculation time step was set according to Courant–Friedrichs–Lewy (CFL) condition as stated as equation (3). The CFL condition is necessary for convergence of flow while solving certain partial differential equations numerically by the method of finite differences (Courant et al. 1956).

$$\frac{\Delta t}{\Delta x / u} \le C \quad \Rightarrow \Delta t = C * \Delta x / u \tag{3}$$

Where *C* is a dimensionless constant and it's vary from $0.1 \square 0.3$. The maximum iteration times of water surface calculation was set as 20. The diameter of the bed material was used as 0.77 mm and bed roughness calculated from the bed materials using equation (1).

3. RESULTS AND DISCUSSION

The result of the flow fields and bed-topographies are presented in this section to understand the morphodynamics resulted from dealings of two settings. In order to compare these results of one sidewall position and both sidewall position result are considered for one hour duration in this numerical simulation. The difference between the results of two settings was considered to be the position of barbs prompted on the channel bank stability. The velocity profile was considered to recognize the flow pattern, bed elevation for identify the sediment deposition and flow depth to know the scour depth from both arrangements. Figures 3 to 7 comparatively illustrated the effects of barbs on velocity vector, water flow depth and bed elevation.

3.1 Velocity field

The velocity vectors at water surface were obtained from simulation for barb installation with one bank sidewall and with both bank sidewall, respectively. Figure 3 shows the simulation result of velocity vector barb structure at one bank sidewall after 1 hour. When the flow approaches into the channel with one barbs, due to the flow separation at barb head return current developed at the upstream side induced zone of subcritical flow and along the stream bank. Figure 4 shows the simulation effect of velocity vector at the water surface by installing barbs at both bank sidewalls after 1 hour. In that case due to the flow separation from both at barb head return current developed at the upstream side induced zone of subcritical flow and along the stream bank. Barb influenced the flow at downstream side and creates a mixing zone just behind the structure along the near bank line. The flow across the structure occur contraction-accelerated discharge at the barb end. The convergence of these flow components result turbulent mixing around the both barb head and vector flow directed towards the center of the channel.

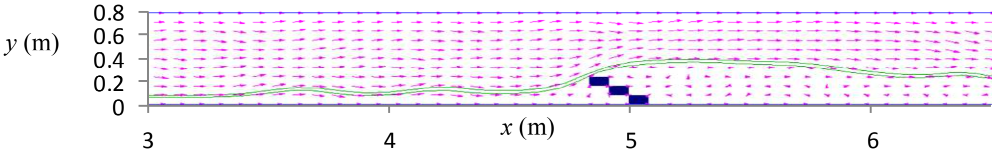

Figure 3: Velocity field simulation result at water surface into the channel with single barb after 1 hour

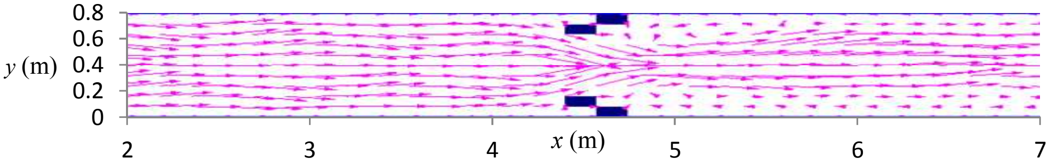

Figure 4: Velocity field with double barb installed at both sidewall of the channel after 1 hour simulation.

3.2 Bed elevation around the structure

The flow patterns with sediment transport were persuaded to build the scour-hole and deposition. Figure 5 shows the simulation result with the depositional contour lines of one barb setting channel after 1 hour. In that case deposition occurred as sand bars along the bank-line at the upstream side of the structures. Bars are formed due to flow and these formation of bars are may becomes more perceptible after long time simulation. Figure 6 shows the simulation result with the depositional contour lines among both bank sidewall barbs after 1 hour. Deposition occurred as sand bars along the bank-line at the upstream side of the structures. Because of potential energy increased in the zone of upstream through backwaters effects. The upstream progression of subcritical reaches in the near bank region controls erosion and ultimately leads to deposition of sediments along the bank-line. At the downstream side of barb especially near the barb head scour occurs due to hydraulic jump and turbulence from flow mixing. The scour depth occurs at the barb end and immediately downstream of the structure because of energy re-distribution away from the outer bank towards the center of the channel results in scour near the ends of the barbs (Matsuura and Townsend, 2004). The remark was that sediment were scoured in the downward portion of the barb and deposited in the upward side of the barb. Figure 7 represents the bed elevation of single and double barb installation in the channel. This result shows clearly the applicability of barbs reduced the erosion around the structure and increases the pool habitat near the thalweg, which can be useful for natural rivers training work.

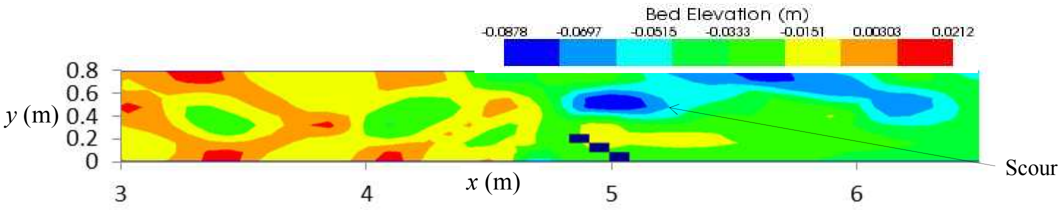

Figure 5: Bed level contour result of the channel with a barb installed at one sidewall of the channel after 1 hour simulation.

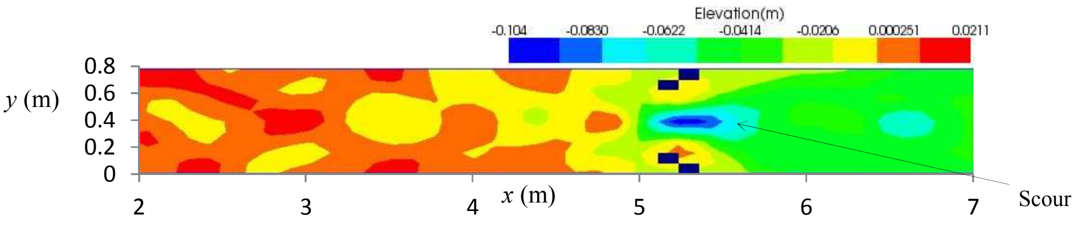

Figure 6: Bed level contour result of the channel double barbs installed at both sidewall of the channel after 1 hour simulation.

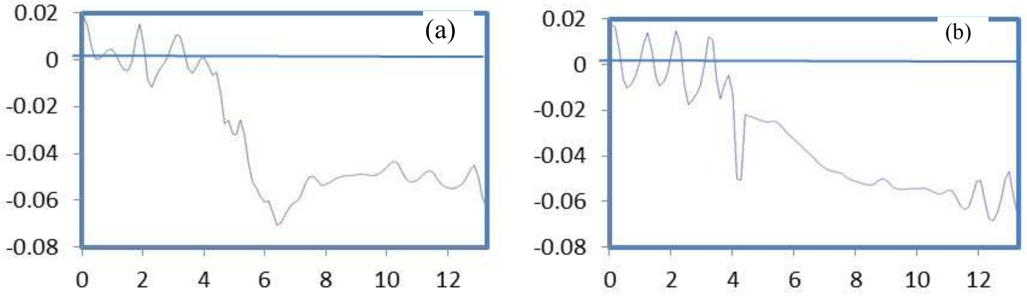

Figure 7: Evolution of bed profile and Comparison with double barbs at both sidewall and single barb at one side installation (a) represents the bed elevation of double barbs after 1 hour and (b) represents bed elevation with single barb after 1hour simulation, respectively.

4. CONCLUSIONS

The study was conducted by two-dimensional numerical simulation to observe the effects of barbs on different setting installed in channel sidewall. Information's were provided regarding flow patterns and bed configuration (scour and deposition). A comparison was done between barbs installed at one bank sidewall and both bank sidewall of the channel with erodible bed among a relatively high width-to-depth ratio. Using nearly uniform sand under controlled steady flow conditions the bars are formed at the upstream portion of the channel. It influenced the flow at downstream side creates a mixing zone just behind the structure and along the near bank line. Potential energy increased in the zone of upstream through backwaters effects. The upstream progression of subcritical reaches in the near bank region controls erosion and ultimately leads to deposition of sediments along the bank-line. This means the barbs would be able to reduce the erosion by forming bars along the near bank of the channel. However, experimental study need to verify simulation result and required to test their general acceptability.

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