

Effect of Non-Migrating Bar to Planform Migration

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Abstract

A study to determine on the effect of non-migrating bar to lateral movement was carried out on large scale river physical model at the Universiti Teknologi MARA, Puncak Alam, Selangor, Malaysia with special focus. This paper explains the methodology for measurement and and illustrates the effect of non-migrating bar on planform migration for different flows, 13.53 m³/hr, 10.91 m³/hr, 8.62 m³/hr and 6.64 m³/hr. The experiment was designed with a steady non-uniform flow with uniform grain size channel bed, uniform rectangular cross-section, and a constant slope. Planform of channel migration and the rate of width change are highlighted.

Keywords: river physical model, lateral migration, mid-bar

INTRODUCTION

The dynamic process of a river forms is attributed to its responses to variability of water and sediment discharges impacted upon them. Human activities have been identified as one of the key factors that accelerate changes in river profile.. Changes in flow and

sediment composition generate changes in width, depth, slope and planform due to water and sediment load. (Knighton, 1998). Shifting or migrating of bankline and meander development warrant special intention because such movement often threatens adjacent property and infrastructure.

Basic concept of lateral migration

Lateral migration is the process of river movement in which water flows to erode the riverbank at the outer layer and will move the deposit to the inner bank. Lateral movement can take different forms depending on the input condition. The river is subject to the possibilities of narrowing, widening, avulsion and cutoffs. (Richard, 2001). Narrowing is the result of the sedimentation near one bank in excess of erosion rate of the opposite bank. Alternately, widening is a result of erosion on one bank in excess of sedimentation near the opposite bank. (Julien, 2002). As a result, river meandering is a net outcome between erosion and deposition.

Research on meandering river has been regularly conducted in the last decades. Measurements have been taken through on-site investigations, time-sequence maps and laboratory tests to gather specific data such as hydraulic parameters, channel or bed properties, historical data, and channel planform geometry. The pioneer research for river physical model on meander migration was done by Friedkin (1945). The purpose of this research was to investigate the effect of discharge, slope, initial cross-section, sediment, angle of attack and sediment feeding to meander channel. In recent years, numerous studies on experimental work on lateral migration with meander channel have been done i.e Bertoldi and Tubino (2005), Park (2007), Yeh (2009) and Kuang (2011). In these studies, lateral migration that occurs in the channel is observed and established. This includes channel cross-section, secondary flow, channel width, radius of curvature, angle of channel bank, and bankline profile in their experiment because these parameter were influenced to the lateral migration.

Prediction of migrating channel using an empirical model was identified and proposed by Nanson and Hickin (1983,1984,1986), Richard (2005), and Yeh et al (2011). Nanson and Hickin (1983) suggested that sediment transport as well as the ratio of radius of bend curvature channel width influence the migration rates. Unfortunately, the sediment transport was not considered during the field study by Hickin and Nanson (1984) because of the condition of the field study, whereas the sediment load is likely to be determined largely by local bank erosion and channel migration. Therefore, it was suggested that the migration rates are dependent on stream power per unit area of the

bed. In 1986, Nanson and Hickin found that the volume of sediment eroded from the outer bank of meander influenced the bank erosion and channel migration. Thus, bank resistance and the size of sediment at the base of the outer bank were the important variables as an accurate predictive model relationship. Richard (2001) suggested the migration rate is significantly associated with measures of flow energy and ratio of active channel width to total channel width. Park (2007) named five coefficients in order to predict the maximum lateral migration with regard to the ability of flow to erode the channel bankline and is denoted as excessive Froude Number. In addition to that to the above, the angle of channel bend affects the maximum migration distance. Lateral migration should be highly considered in designing bridges, highways, or any structure standing nearby a river. Channel migration will scour at excess bridge pier and abutment, pose threats to bridge and infrastructure nearby, worsen debris problem and impede transportation through the bridge. (Lagasse et al, 2004).

Bars in river

Bars refer to large bed form configuration that is often exposed during low flows. In a normal circumstance, they are submerged and can be viewed as alluvial bed deposition. Bars can be transported easily under the high flow. Three types of bars are alternate bars, point bars and tributary bars. Mid-bar or middle bar, also a main concern for this research, is truncated from point bar and associated with erosion of the outer bank and lateral migration of the river. During major floods or heavy flow, point bar can be transported to form chute cutoffs. At low flow, chute cutoffs can lead sedimentation in both river branches. (Julien, 2002). Schuurman (2015) has documented that the developed mid-bar will form a bifurcation which divides discharge and sediment over the downstream of the bar. The sediment will then be transported in the main channel instead of over the bar due to the non-linear relation between flow velocity and sediment transport rate. Thus, the channel will become wider because of bank retreatment, as sediment transport was concentrated in the center of the main channel. This fact supports Ashworth's (1996) finding. Furthermore, water depth will also be decreased. There are two types of bars in the river channel, migrating and nonmigrating bar (Lanzoni, 2000 and Wu et al, 2011). The nonmigrating bar can develop and replace migrating bar in long term and re-main in constant discharge.

An extensive studies on migrating bar and interactions with bed morphology in the field study had been done by Leopold and Wolman (1957), Asworth, (1992) and Richardson

and Thorne (2001), and an experimental work studies had been done by Lazoni (2000), Asworth (1995) and Federici and Paola (2003). Lazoni (2000) had carried out an experimental investigation on bar formation in straight channel. The experiment shows various aspects of alternate bar development. Few more studies by Asworth (1996) have focused on mid bar development after post-confluence.

However, investigation performed on the effects of non-migrating mid-bar with regard to lateral migration is limited. Therefore, the present study investigates river morphology on lateral migration in the upstream and downstream of a non-migrating bar. It is hope that the phenomena of lateral migration in assessing the impact of human activity upon the river basin/ floodplain area can be fully understand.

EXPERIMENTAL SETUP

The experiment was conducted in a concrete flume measuring 45m long, 2.4m wide and 1.8m deep, located at Universiti Teknologi MARA. Three (3) main types of equipment had been installed, which are water pump, to recirculate water from sump to the water tank, V-notch angled at 60 degrees at the entrance of flume to control designed flow rate, and pipes with varied sizes ranging between 102 mm to 76mm diameter. To ensure the initial slope, three (3) sticks levelling gauge were installed along the side of the brick wall.

The experiment was conducted in a wide and shallow flume of sufficient size to permit the stream to meander freely. The initial channel was molded with 10m long, 0.4m width and 0.15m deep which is rectangular cross-section. The flume is connected with a water tank (6m long, 6m wide and 1.8m height) through connected pipes supply as mentioned above. This channel was designed with a size large enough to accommodate the channel to migrate either to the left or the right of the bank. The channel was carved using a mold on the sand bed to simulate the natural process of meander of a natural river. Figure 1 shows the schematic diagram of the channel equipped with the other accessories.

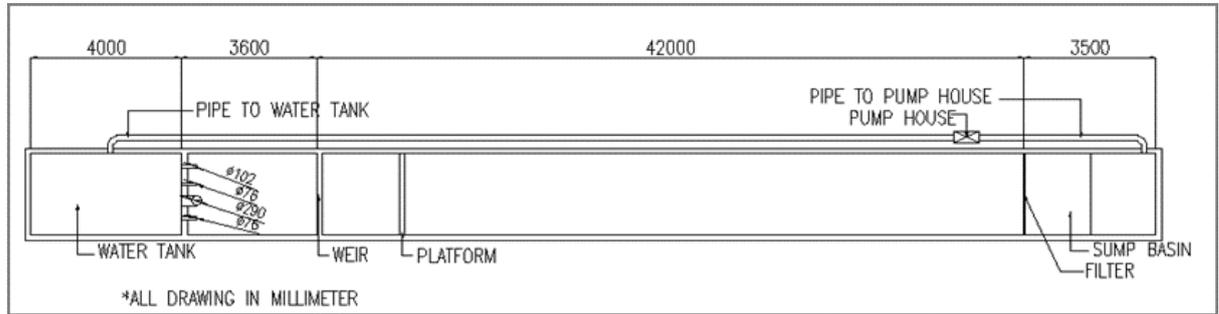


Figure 1: Schematic diagram of river physical model

For the channel bed and bank material, uniform size of sediment was filled in the flume with average median grain diameter, d_{50} value of 0.348 mm. The grain size distribution curve was obtained from sieve analysis in accordance to British Standard Methods of Test for Soils for Civil Engineering Purposes BS1377: Part 2:1990 as shown in Figure 2. The grain size distribution is important to be applied with shear stress in relation to the mobility of sediment. The threshold motion of sediment, which exerts forces, tends to initiate particle motion. For this, Shields diagram (modified after Yalin and Karahan, 1979) (Julien, 2010) grain shear Reynolds number, Re^* and critical value of the Shields parameter, τ^*c should be considered. From the Shields diagram, the values for Re^* and τ^*c are 6.055 and 0.054 respectively. These values have exceeded the threshold limits. The initial velocity of 0.802 m/s is evident that erosion is expected at the bankline.

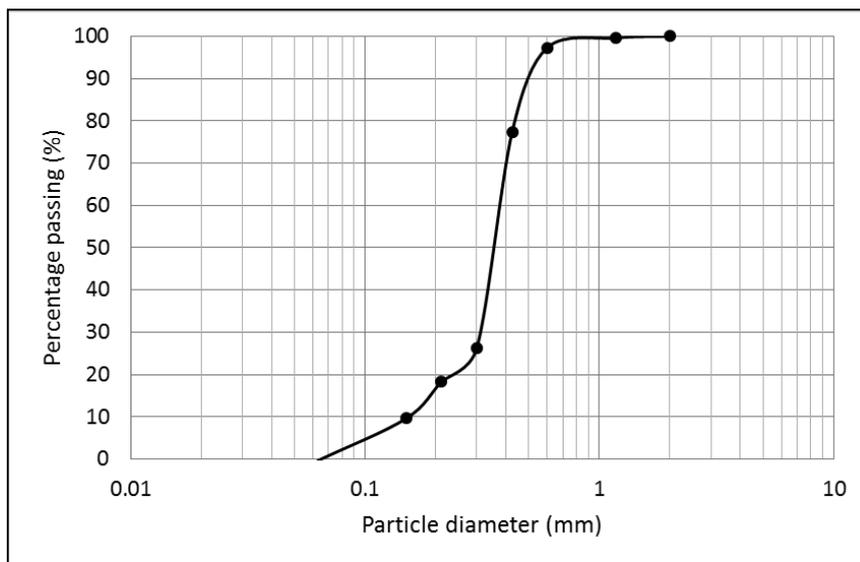


Figure 2: Typical grain size distribution curve

The sediment with different layers of material as shown in Figure 3 was naturally compacted to replicate natural river by soaking the sediment for 24 hours. From the compaction test implemented, results show that the sediment layers are fully compacted and saturated with 85% compaction.

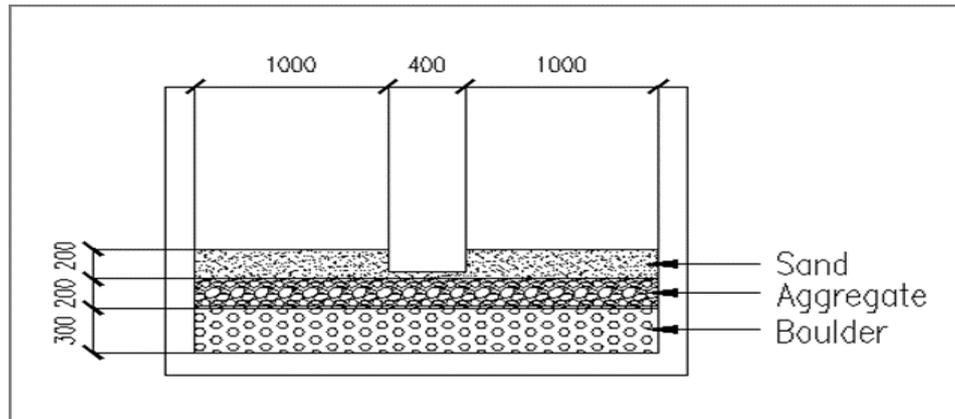


Figure 3: Layers of sediment in the flume

The channel was designed to fit the scale with the maximum flume. The first 5m from the V-notch was disregarded because the flow needs to be fully-developed before entering the curve bend. Initially, the experiment was conducted with a bend curve of 38° at the entrance followed by a straight channel downstream as shown in Figure 4. A mid-bar was constructed at a distance of 1.5 m from the entrance curve. The mid-bar was designed with bar aspect ratio (width-length ratio) (Schuurman, 2015) of 1:2 which is 200mm width and 400mm length. Dimension of the constructed mid-bar was replicated from several mid-bars in Sungai Kelantan, Kelantan, Malaysia. Construction of the mid-bar at 1.5 m after the bend (shown in Figure 6) is to ensure that flow will take place naturally without obstruction. The channel has a rectangular cross-section (400mm width and 150mm depth), sloping 0.01 with uniform mean particle size of sediment (0.348mm) for bed and bank. The other parameter for initial condition for this study are as shown in Table 1.

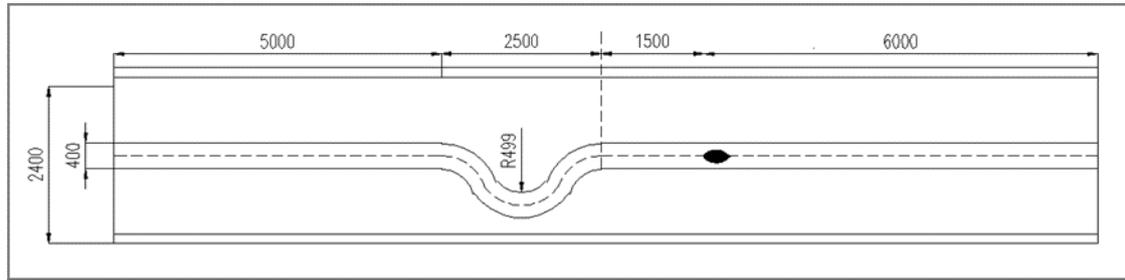


Figure 4: Schematic of designated channel

Table 1: Initial condition of the experiment

Experiment/ Parameter	1	2	3	4	5	7	8	9	10	11	12
Flow rate (m ³ /hr)	13.53	13.53	10.91	8.62	6.64	6.64	10.91	8.62	10.91	8.62	6.64
Mid-bar ratio	1:2								1:4		
Type of channel	Straight					Meander			Straight		
Location of constructed mid-bar (CH)	9.1					8.1			9.1		

During data collection, flow depth, velocity, bed profile and river bankline marks were taken. Nixon Streamflow Velocity Meter model 430, connected with probes type 403 (suitable for low-speed velocity – from 5.0 cm/s up to 150 cm/s), was used to measure mean velocity at each cross-section along the channel. Laser distance meter was used to measure bed profile. Measurement of the range of the Laser mEssfix ranges from 0.05m to 50m and has a tolerance of +/- 1.5mm. These sets of equipment were mounted at point gauge which is attached to a movable platform. The experiment set-up is as shown in Figure 5.

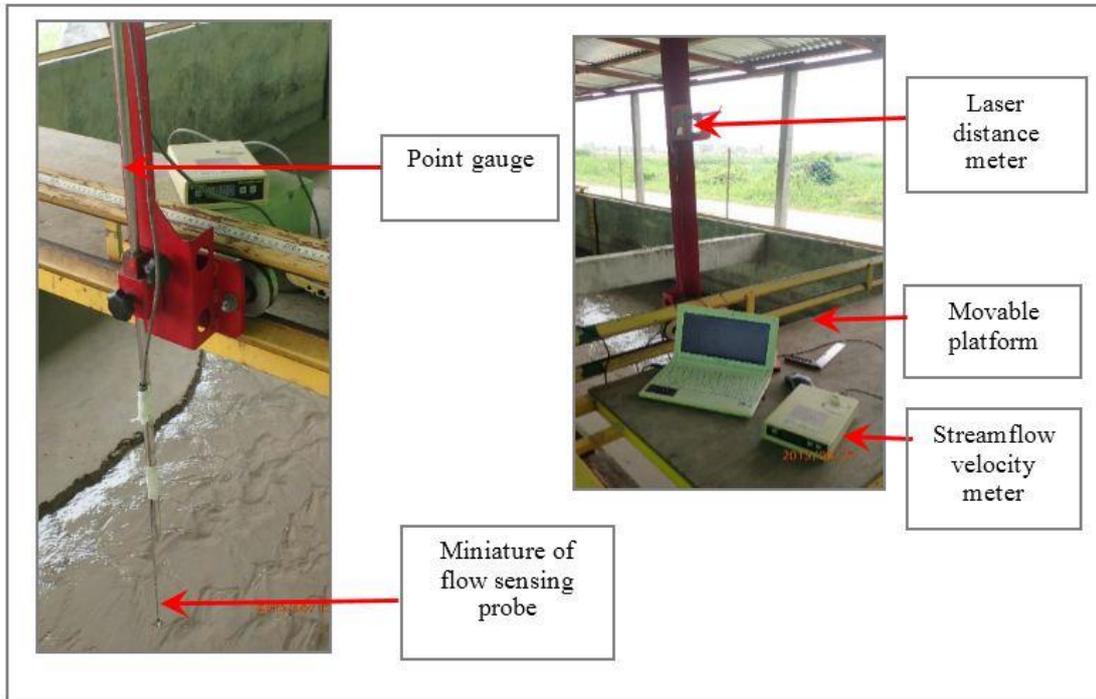


Figure 5: The arrangement of the equipment

By using laser distance meter as mentioned above, the bed profile data was collected using grid method. Point gauge was moved in longitudinal, transverse and vertical direction (bed profile) to represent X, Y and Z axis respectively. The bed elevation data was captured every 20cm interval at X direction and 5 cm interval at Y direction. Data was collected starting from CH 5.0 until CH15 as mentioned above. Figure 6 shows the layout of the grid method.

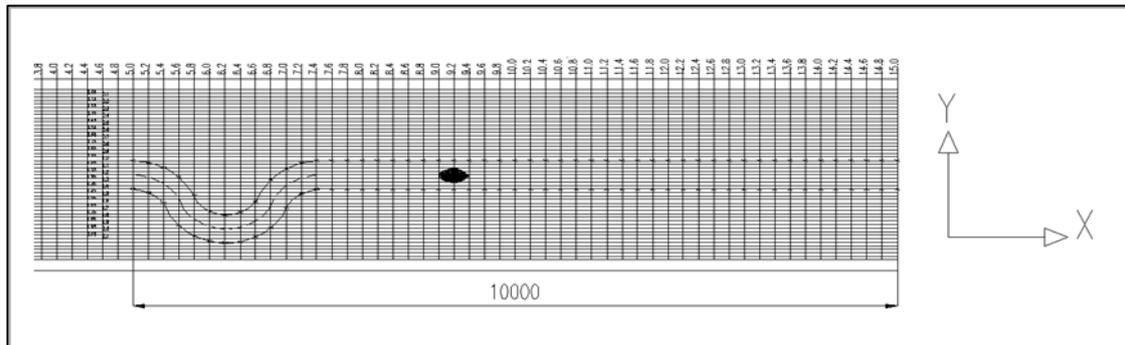


Figure 6: The Layout of the grid system

For this study, the experiment was set-up with various flowrates. Flow was allowed to run for half hour to remove any loose sediment before measurement began. Data was

recorded at every 0, 6, 30 and up to 54 hours throughout the experiment. Based on Friedkin, (1945), the absence of sediment supply at the upstream of the channel does not prevent the channel from meandering, as sediment supply can come from the bank and transported downstream. At the end of the experiment, erosion process was stopped when the channel reached the equilibrium state. In addition, inability of the channel to meander because of the limitation of the space led to the abrupt end of the experiment. On the other hand, Experiment 1, shows values of Re^* and τ^*c are 5.588×10^{-3} and 2.739×10^{-3} respectively after 30 hours. Referring to the Shields Diagram (modified after Yalin and Karahan, 1979) (Julien, 2010) the values show that there is no sediment motion. Thus, there was no erosion process and the channel reached the equilibrium state after 30 hours.

RESULT AND DISCUSSION

Channel migration

The morphology behavior of a straight and meander channel with a constant flowrate was examined for every experiment. The experiment was set up with various flowrate as mentioned above, whereas the designated flow was a steady non-uniform flow. The bed and the river bank of the channel were designed with a 0.01 slope along the channel. Figure 7 (a), (b), (c) (d) and (e) illustrate the planform of channel migration after 30 hours. These figures show a comparison on the channel planform for four different flowrates. There is evidence of erosion throughout the channel on both sides of the bank. Large bank retreat occurred before the non-migrating bar and proceeded downstream with broadened channel width. In experiment 5 and 12, the channel exhibit a more uniform migration at lowest flowrate. Nevertheless, experiment 7, 8 and 9 exhibit different features with broadened width at low flowrates. Thus, channel progression takes place laterally. This development promotes meandering of the channel as documented by Nagata et al in 2000. At the end of the experiment, the constructed mid-bar was fully covered with deposited sand as bank material is get eroded and transported to downstream.

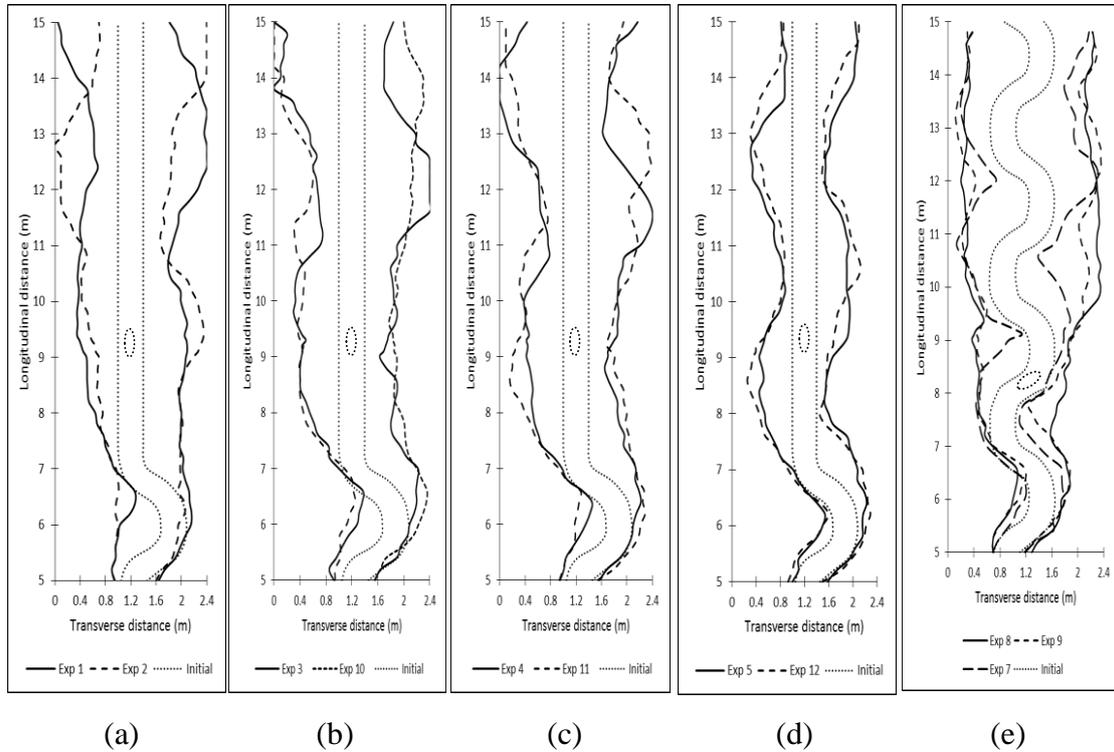


Figure 7: The planform of channel migration based on different flowrates and type of channel (a) $13.53 \text{ m}^3/\text{hr}$ (b) $10.91 \text{ m}^3/\text{hr}$ (c) $8.62 \text{ m}^3/\text{hr}$ (d) $6.64 \text{ m}^3/\text{hr}$ for straight channel (e) all the flowrate for meander channel

Rate of width change

Width of the channel was measured at every cross-section. The total channel width, W_{tot} including mid-bar and island were measured. The changes of W_{tot} respond to water and sediment, and planform adjustment of bar size. The total channel width rate of change, dW_{tot} , can be calculated from the difference between the initial total width of the time period and the total width at the end of the period, divided by the length of the period. (Richard, 2001).

Figure 8 shows the rate of width change for experiment 1 and 5. $dW_{\text{tot}6}$ and $dW_{\text{tot}30}$ denote rate of width change for 6 and 30 hours respectively. Illustrations feature aggressive increase and decrease in rate of width for the first 6 hours after the running of the experiment. While, after 30 hours, the rate had decreased.

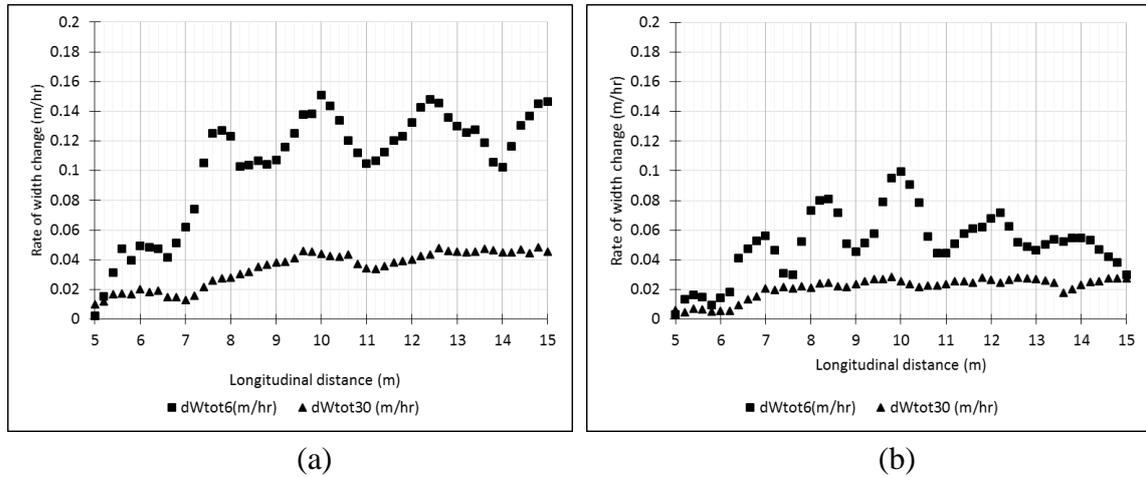


Figure 8: The rate of width change based on (a) experiment 1 with $13.53 \text{ m}^3/\text{hr}$ (b) experiment 5 with $6.64 \text{ m}^3/\text{hr}$

The average rate of change in total width or rate of width change, dW_{tot} for all experiments are shown in Figure 9. The graphs indicate a widening of the channel. The profile in the rate of width change is volatile along the channel. Flowrate will be affected the rate of width change even though the width change occurred slowly and uniformly. Furthermore, non-migrating mid-bar also influenced the rate. The rate are slightly increased at the constructed mid-bar

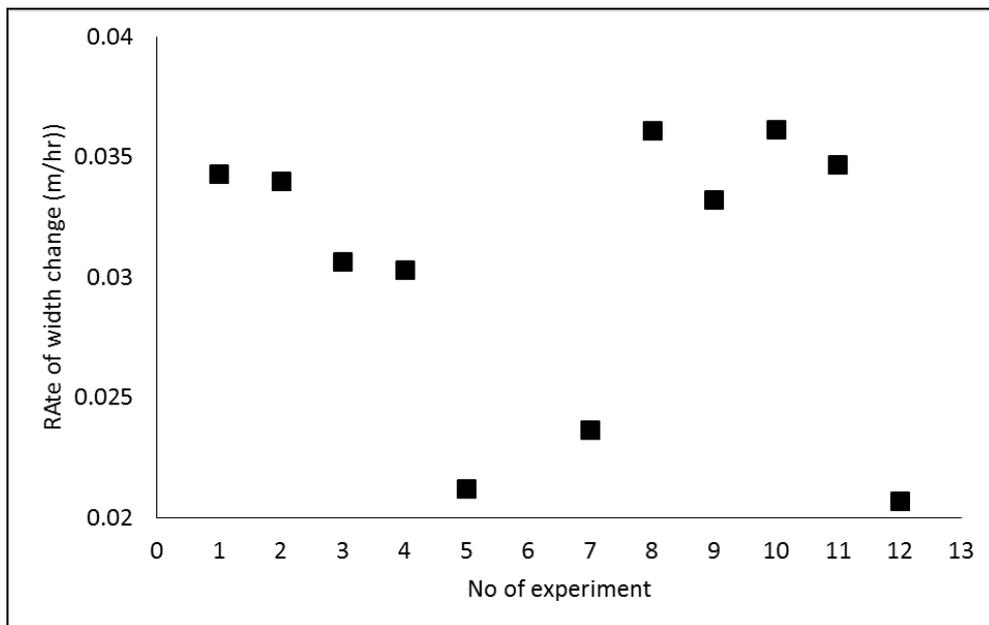


Figure 8: Average rate of width change for each experiment

CONCLUSION

The aim of this study is to investigate river morphology for lateral migration influenced by non-migrating mid-bar at the upstream and downstream of the channel. The experimental works were conducted in a rectangular straight channel with constant flow rate and constant mean grain size of sediment. The channel moved laterally and the width of the channel had broaden alternately along the channel. When the channel began to reach the equilibrium state, the rate of channel became constant until the end of the experiment. The rate was affected at mid-bar point (CH 9.0 onward) and downstream of the channel.

The findings help to improve future experiment, with various condition of initial discharge and ratio of the constructed mid-bar implemented to achieve varying results. The initial discharge should be an appropriate design so that the miniature of flow sensing probe could be used in all cases. The layout of the channel will be improved, especially the constructed mid-bar. The mid-bar will be lifted up slightly higher than the riverbank to ensure that the mid-bar is not fully covered by the deposited sediment, especially during the highest discharge.

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REFERENCES

- [1] Ashworth, P.J. (1991). How do gravel-bed rivers braid. *Journal Earth Science*, Vol.28, 326-341.
- [2] Ashworth, P.J. (1992). Measurement in a braided River Chute and Lobe 2. Sorting of bed load during entrainment, transport and deposition. *Water Resources Research*, 28(7), 1887-1896.
- [3] Ashworth, P.J. (1996). Mid-channel bar growth and its relationship to local flow strength and direction. *Journal of Earth Surface Processes and Landforms*, vol. 21, 103-123.

- [4] Bertoldi, W., and Tubino, M. (2005). Bed and bank evolution of bifurcation channels. *Water Resources Research, Vol 41*.
- [5] Federici, B. and Paola, C. (2003). Dynamics of channel bifurcation in noncohesive sediments. *Water Resource Research, Vol 39*, 1162
- [6] Friedkin, J.F. (1945). *A laboratory study of the meander of alluvial rivers. U.S. Army water-ways experiment station, Vicksburg Mississippi*.
- [7] Hickin, E J. and Nanson, G. C.(1984). Lateral Migration Rates of River Bends. *Journal of Hydraulic Engineering. 110(11)*, 1557-1567.
- [8] Julien, P.Y. (2002). *River mechanics*. Cambridge University Press. UK.
- [9] Julien, P.Y, (2010). *Erosion and sedimentation*. Cambridge University Press.
- [10] Kuang, H. (2011). Physical and Numerical modelling Study of meandering in fluvial rivers, Cardiff University. (Doctoral dissertation)
- [11] Knighton, D. (1998). *Fluvial form and processes – A New Perspective*. John Wiley & Sons. Inc, New York.
- [12] Lagasse, P.F., Zevenbergen, L.W., Soitz, W.J. and Thorne, C.R. (2004). Methodology for predicting channel migration. *Transportation Research Board of The National Academies*.
- [13] Lanzoni, S. (2000). Experiment on bar formation in a straight flume – uniform sediment. *Journal of Water Resources Research, 36(11)*, 3337-3349.
- [14] Leopold, L.B. and Wolman, M.G. (1957). River channel patterns: braided, meandering and straight. *Geological survey professional paper 282-B. United State, 29:2*, 465-475
- [15] Nanson, G. C. and Hickin, E. J. (1983). Channel migration and incision on the Beatton River. *Journal Hydraulic Engineering, 109*, 327-337.
- [16] Nanson, G. C. and Hickin, E. J. (1986). A statistical analysis of bank erosion and channel migration in western Canada. *Geological Society of America Bulletin, 97(4)*, 497-504.
- [17] Nagata, N., Hasoda, T. and Muramoto, Y. (2000) Numerical analysis of river channel processes with bank erosion. *Journal Hydraulic Engineer, 126(4)*, 243-252.
- [18] Park, N. 2007. *A prediction of meander migration based on large-scale flume test clay*. Texas A&M University. (Doctoral dissertation)
- [19] Richard, G. A. (2001). *Quantification and prediction of lateral channel adjustments downstream from Cochiti Dam, Rio Grande, NM*. Colorado State University. (Doctoral dissertation)

- [20] Richard, G. A. (2005). Statistical analysis of lateral migration of the Rio Grande, New Mexico. *Geomorphology*, 71(1-2), 139-155.
- [21] Richardson, W. R. and Thorne, C. R. (2001). Multiple threads flow and channel bifurcation in a braided river: Brahmaputra-Jamuna River, Bangladesh. *Journal of Geomorphology*, 38, Pp 185-196.
- [22] Schuurman, F. (2015). *Bar and channel evolution in meandering and braiding rivers using physicsbased modeling*. Utrecht University. (Doctoral dissertation)
- [23] Yeh, P.H. (2009). Channel meander migration in large-scale physical model study. Texas A&M University. (Doctoral dissertation)
- [24] Yeh, P.H., Park, N., Chang, K.A., Chen, H.C. and Briaud, J.L. (2011). Prediction of time-dependent channel meander migration based on large-scale laboratory experiments. *Journal of Hydraulic Research*, 49(5), 617-629.
- [25] Wu, F.C., Shao, Y.C., Chen, Y.C., (2011). Quantifying the forcing effect of channel width variations on free bars: morphodynamic modeling based on characteristic dissipative Galerkin scheme. *Journal of Geophysical Research*, 116.