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EXPERIMENTAL STUDY OF BAR FORMATION IN SAND BED CHANNEL

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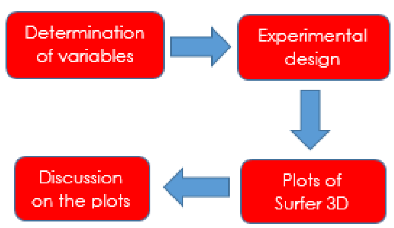
Graphical abstract



Abstract

A large number of studies both theoretical and experimental have been devoted to understand the physical mechanisms underlying the bar formation. This can be investigated by carrying out an experimental work in an erodible sand bed channel using a large-scale physical river model. The study included the various hydraulic characteristics with steady flow rates and sediment supply. An experimental work consists of four matrices of flow rate and channel width with other variables namely grains size and bed slope were kept constant. Details of bar profile development that generated using *Surfer,* a software used for 3D elevation plots are included.

Keywords: Bar formation, bar profile, *Surfer* software

1.0 INTRODUCTION

Channel geometry, flow and sediment transport in rivers interact and vary in time and space, resulting in erosion and deposition therefore cause the growth and bar migration. An understanding of this interaction is important in modern environmental and engineering problems such as water supply, flood risk evaluation, dispersion of pollutants, sedimentation in navigated channels and reservoirs, bank erosion, channel migration and sediment dredging operations. Generally, the aim of this study to identify the bar formation in term of bar height. This can be investigate by carried out an experimental works with varies flow rate and channel size. The objective of this paper was to establish the plots of channel and bar profiles with respect to various experimental conditions using computer software *Surfer.*

The studies of bar formation have been widely explored by previous researchers. Efforts have been made to simulate behaviour of bar formation through the use of numerical and physical models. Numerical approach under the pretext of computational fluid dynamics is an approach that uses fundamental theory of fluid mechanics and hydraulics that simulates flow behaviour. The use of physical models is usually carried out under a more regulated environment with few variables which are kept constant.

Many studies in the recent years were based on [1] have been devoted to investigate the physical mechanisms underlying the occurrence and development of river bars and to predict the conditions for their formation [2-3]. The usage of various channel types and dimensions with different experimental characteristics such as flow rate, initial bed slope and grain sizes had been studied by a large number of researchers. Nevertheless, in most experiments, there is scarcity of knowledge on the processes of channel variation by the use of bank erodible stream channels.

Characteristics of the stream channel change processes have been made clear gradually through experimental studies. Previous experiments using small sized channels have resulted a brief process, while those by large sized channels needed great efforts to be carried out and were too difficult to control experimental conditions. Presently, hydraulics studies have progressed using large sized channels under a more controlled conditions. According to [4] who had conducted an experiment on a large flume size of 243m length and 7.5m width, the accumulation of data is significant to establish a similar process of the natural river, compare with other experimental results on small sized channel.

The process underlying bar development in cohesionless channels has been built up through a large number of theoretical and experimental works [5]. The relationship between fluvial process and form are extremely difficult to quantify using conventional field and numerical computational techniques. Many efforts in fluvial geomorphology involve complex and multivariate situations at large spatial and temporal scales. These topics have traditionally been addressed through detailed fieldwork combined with theoretical and numerical modelling.

[6] stated that physical modelling offers a complementary technique to simulate complex processes and feedbacks in many geomorphic phenomena. He concluded the formative processes of physical modelling can usually be observed in a reduced time frame, within a controlled boundary conditions and manageable laboratory environment. It may allow combination of various variables which have nonlinear effects. Although, the model scaling will simplify the reality which have higher temporal and spatial scales, it is important to establish the nonlinear processes and effect in their scaling between model and prototype.

[7] had undertaken an experiment to model real natural rivers for numerical model development. The predictions of channel characteristics and evolution processes by numerical model shows good agreement with the physical model for different flow rates and channel sizes. A sensitivity analysis showed that the secondary flow and bank strength are key parameters in the fluvial channel evolution. He had also included some calibration works applicable for other conditions that is more complex in natural rivers.

2.0 EXPERIMENTAL

Experiments were carried out on a physical river model located in the dry sediment pond at the Universiti Teknologi Mara Puncak Alam, Shah Alam, Malaysia. Experimental equipment consists of flume of reinforced concrete, equipped with measuring instrument pipe for recirculation of flow and a tank for water supply. The 40 m long, 2.4m wide and 1.8 m deep of flume has a slope of 0.006. The bed was filled with a thick layer of graded coarse sand with sizes range from 0.5mm to 2 mm at 30 cm deep. The average sediment size d_{50} and the corresponding standard deviation obtained through sieve analysis are 1.15mm and 0.43 respectively. Flow is regulated by means of a tank and a V-shape weir (60° V-notch) constructed across the upstream (about 3.6m) from the point of discharge. This is to ensure more uniform flow with minimum turbulence at the point of entry into the test length.

Water is circulated by means of a pump located downstream of the physical river model. Figure 1 shows a photo of the flow supply pipes of various sizes. (102mm, 76mm, 290mm and 76mm). At any one operation, the supply of water comes from one of the pipes in accordance to the flow required for each experiment. Flow each pipe is regulated by means of a valve. Smaller diameter pipes are for smaller flows and bigger diameter pipes for bigger flows. A constant water discharge was supplied from a head tank into the channel and returned to the storage tank by means of a re-circulation pump system shown in Figure 2.

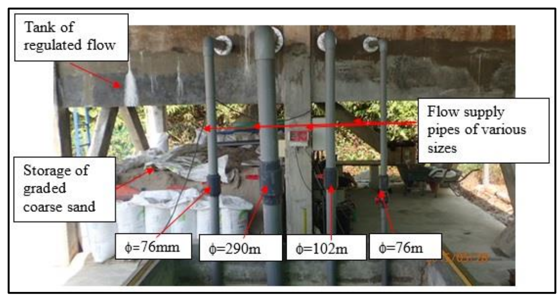


Figure 1 Flow supply pipes of various sizes

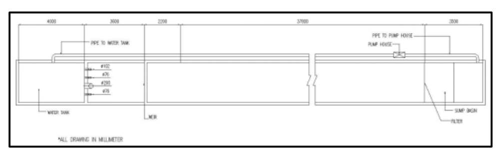


Figure 2 The schematic diagram of physical river model

The channel bed comprises of 3 layers of sediments, boulders (bottom most layer), aggregates (middle layer) and graded sand (top most layer) of thickness 200mm, 200mm and 400mm respectively. The total full width of the channel is 2.4m wide. The channel bed was initially compacted through the natural process to replicate the natural river. Natural compaction was achieved through exposure of the channel bed to natural weather conditions at the site. To ensure that the sediment layers (boulder, aggregate and sand) are fully compacted and saturated to prevent infiltration through these layers, ponding of the channel was carried out for a few days. This has helped the removal of debris and other suspended particles from the channel bed. Figure 3 shows the dimensions of the channel. The sand bed was flattened using a wide sand scraper to the prescribed slope determine by the stick levelling gauge attached to the inner side walls as shown in Figure 4.

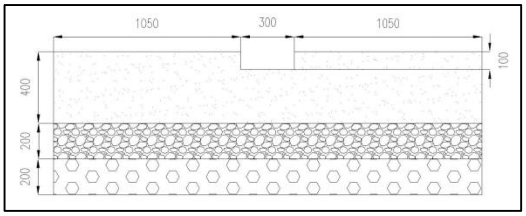


Figure 3 Channel geometry

Figure 4 Stick levelling gauge attached to the inner side wall of river model

An initial straight channel of rectangular shape was formed in the cohesionless sloping surface by a hand-operated grader and trowels as shown in Figure 5. Dry sand was fed into the experimental channel at a controlled rate using a volumetric sediment feeder equipment as shown in Figure 6. The sediment was feed in the upstream channel to accelerate the bar forming process. The sand was dropped into the channel via a pipe hose. This is to minimize losses of sand. The sediment was fed into the channel at a uniform rate of 0.021m^3/hr in pulses. The sediment feeding point is after the V-notch weir location point.

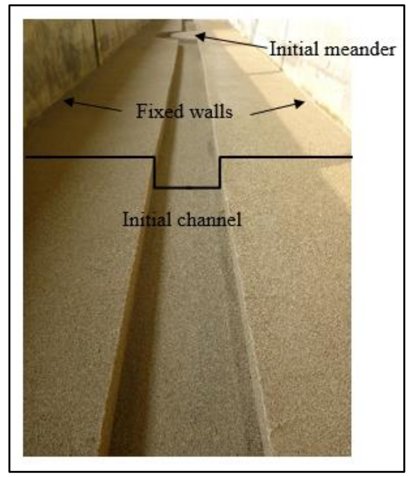


Figure 5 Initial configuration of the channel

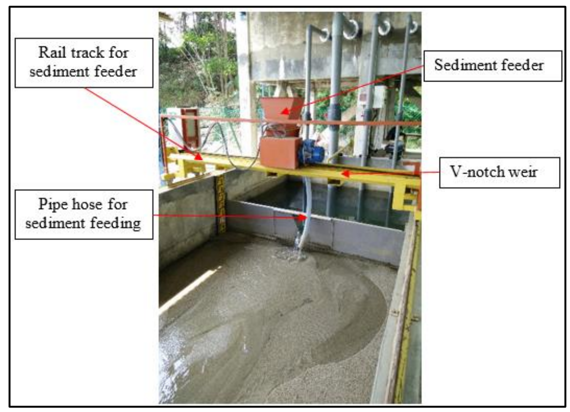


Figure 6 The sediment feeder fed the sand into the channel

3.0 RESULTS AND DISCUSSION

Bar profile development of the different matrices of flow rates and channel width were generated using *Surfer,* a software used for 3D elevation plots. Results of the generation are shown in Figures 7 through Figure 9. While Figure 8 shows Comparison of 30 cm channel width with different flow rate (flow from left to right). Description of bar profile development and changes observed for three different channel width with respective flow rates used are Q1= 4.97m^3/hr, Q2= 6.64m^3/hr, Q3= 8.62m^3/hr and Q4= 10.91m^3/hr.

3.1 Channel Width= 20cm

The lowest flow rate of Q1= 4.97m^3/hr shows no significant changes was observed at the end of day 1. At day 2, the expansion of the upstream bend was observed between distances 5.5m to 7.0m. No significant change from day 2 in terms of width but bed profile has undergone local changes. At day 5, local deposition at distance 11m was observed. Deposition grew in size and remained stable when the top surface had emerged above the water level as can be seen at day 6.

For flow rate Q2 = 6.64m^3/hr, a slight meandering was observed at the end of day 1. The higher flow has caused cut-off at the upstream bend and complicated bed profile was observed at day 3. Due to the higher flow introduced, some sediments were transported and deposited downstream. This is evident by the deposition observed between 10m to 12m distance at day 4. Deposition remained stable with no significant changes in deposition size and profile.

The same phenomenon for Q2 = 8.62m^3/hr, indicates slight meandering was observed at the end of day 1. At day 2, overflowing of the bank was observed with evidence of bend cut-off. Complicated braiding features was observed between 5m to 10m distance. A small local deposition was also observed at 11m distance downstream of the channel at day 3. At day 6, deposition remained stable but had grew in size in comparison to day 3.

For the highest flow rate Q4 = 10.91m^3/hr illustrates no significant meandering but channel had widen width at the end of day 1. At day 2, overflowing of the bank, complicated braiding features at the upstream bend with local deposition noted at 13m distance. The next day indicates deposition was observed between 13m to 15m distance had grown in size due to channel widening and reduced velocity.

3.2 Channel Width =30cm

No significant change at the end of day 1 for lowest flow rate of Q1 = 4.97m^3/hr. Some braiding was observed at the upstream section at day 2. At day 3 braiding width increased at the upstream section and the next day shows local deposition was observed at 11m distance. Deposition grew in size at 11m distance at the end of experiment.

For flow rate Q2 = 6.64m^3/hr illustrates a slight meandering was observed at the end of day 1. Channel width widen with complicated braiding features at day 2. The following day indicates a complicated braiding feature, widening of the channel width and deposition was observed at 12m distance. Deposition grew in size at 12m distance. Deposition remained stable in terms of size and location at the end of day 7.

For flow rate Q3 = 8.62m^3/hr, meandering was observed at the end of day 1. Complicated and wider braiding channel width were observed at day 2. The same features remain at the following day. At day 6 illustrates a large deposition across the channel width was observed at 13m distance.

For the highest flow rate Q4 = 10.91m^3/hr, meandering was observed but channel width is wider in comparison to Q3 at day 1. Complicated braiding and wider channel width were observed at day 2. At day 3 complicated braiding was observed with a small deposition was observed at 10m distance. At the end of experiment, deposition grew in size between 10m and 13m distance and remained stable when the top surface had emerged above the water surface.

3.3 Channel Width =40cm

Flow rate Q1 = 4.97m^3/hr indicates no significant change at the end of day 1. Some braiding features were observed at day 2. At day 3, the channel has wider with similar braiding features as in day 2. At day 5, the cut-off occurred at the upstream bend that leads to widening of the upstream section and the deposition was observed at 11m distance in the final profile.

Small increase in the width was observed for flow rate Q2 = 6.64m^3/hr. No significant change in the bed configuration at day 1. Widening of channel and braiding was observed at day 2. The following day shows complicated braiding features. At day 4, deposition was observed between 12m and 13m distance and became stable at day 7.

Flow rate Q3 = 8.62m^3/hr illustrated meandering of channel was observed at the end of day 1. Increased channel width with complicated braiding features occurred at day 2. Braiding occur until 10m and the bar start to accumulate at 11m. Channel width has expanded to the full cross-section with complicated braiding features. Deposition was observed between 11m to 13m distance at day 3. A new stream (cut-off) was formed with deposition between 7m and 13m observed at day 6.

The highest flow rate, Q4 = 10.91m^3/hr shows meandering of channel was observed at the end of day 1. At day 2 illustrates an increasing of channel width with complicated braiding features. Close to full expansion of channel width with complicated braiding features was observed at day 3. Deposition was observed between 13m and 15m distance. Full expansion of channel width with complicated braiding features. Deposition was more evident between 13m and 15m distance at day 4.

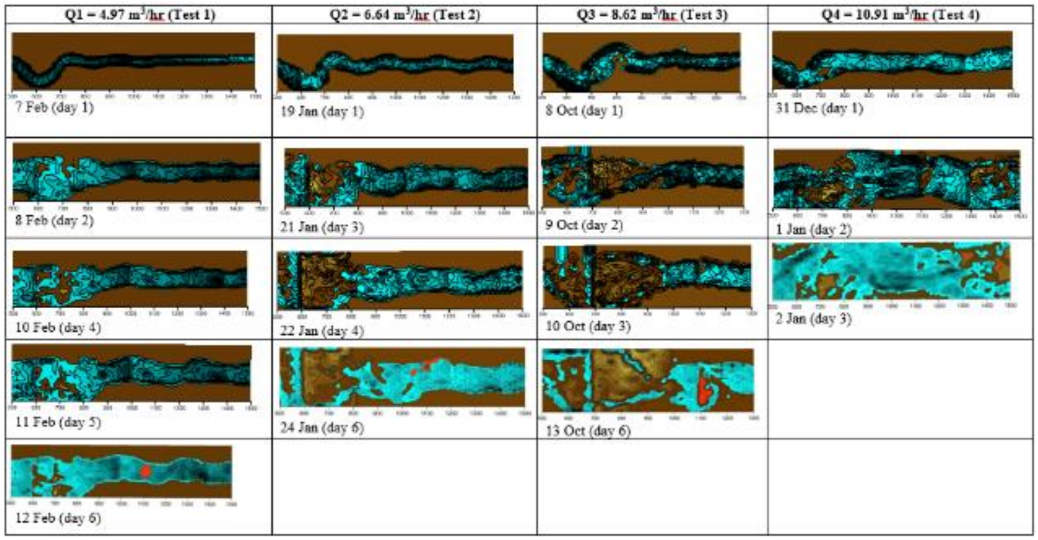


Figure 7 Comparison of 20 cm channel width with different flow rate (flow from left to right)

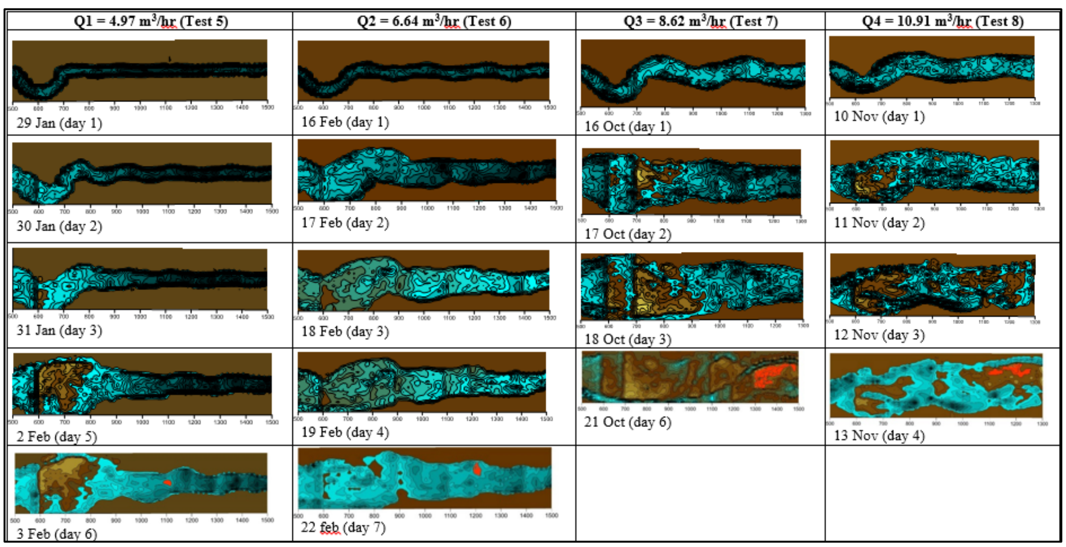


Figure 8 Comparison of 30 cm channel width with different flow rate (flow from left to right)

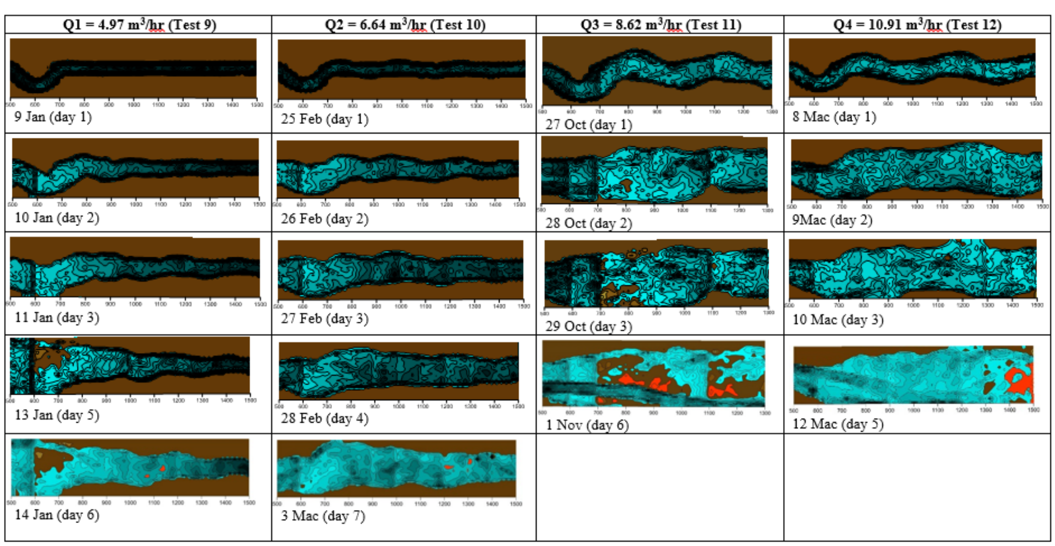


Figure 9 Comparison of 40 cm channel width with different flow rate (flow from left to right

4.0 CONCLUSION

The Surfer profile shows a significant difference for planform view between $Q1=4.97m^3/hr$ to $Q4=10.91m^3/hr$. Cut-off at the upstream bend that leads to widening of the upstream section. The complex braiding features is evident at the upstream section for flow rates $Q1=4.97m^3/hr$ and $Q2=6.64m^3/hr$, while full expansion of channel width with complicated braiding features evident at flow rates $Q3=8.62m^3/hr$ and $Q4=10.91m^3/hr$. The formation of the complex braiding features is accelerated by the sediment feed at the upstream section. The above have subsequently caused larger and higher bar formation for flow rates $Q3=8.62m^3/hr$ and $Q4=10.91m^3/hr$.

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