Centerline Bed Elevation Profile of Sand Bed Channel due to Bar Formation

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Abstract: Numerous data on bar formation have been accumulated yet the methods to predict bar geometry especially bar height are still insufficient. Objectives of this study to determine the trend in term of a significant difference of centreline bed elevation profile along the longitudinal distance. This can be investigate by carried 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. Analysis have included the discussion on a significant difference of centreline bed elevation profile along the longitudinal distance. As a conclusion the higher velocity in the smaller channel width have induced erosion of the banks that resulted in elevation increase while the larger flow rates have contributed to higher elevation.

Keywords: Bar formation, bar profile, physical river model.

1. Introduction
The flow in a straight channel with erodible bed is unstable and large-scale migrating bedforms may develop. These bed forms usually called alternate bars that height and wavelength are scale to the flow depth and channel width respectively [1][2]. Basically there are three general types of bars include mid-channel bars also called braid bars, point bars and mouth bars. The mid-channel bars usually common in braided rivers, which point bars are normally formed in meandering rivers and mouth bars are usually found in river deltas. The locations of bars are greatly influenced by the geometry of the river and the flow rate [2]. Point bars formed on the inside of meander bends in meandering river because the shallow flow and low shear stresses reduce the amount of material that can be carried away. The excess material falls out of transport and bars are eventually formed. The aims of this paper is to discuss the trend in term of a significant difference of centreline bed elevation profile along the longitudinal distance.

2. Literature Reviews
For the purpose of explanation of stream channel processes, many experiments have already been implemented as indicated in Table 1. The type and characteristics for each experimental condition is being stated clearly. Most of the study used rectangular cross section and straight channel for their initial experimental condition. [3][4] carried out experimental work in the largest physical model under various conditions in order to clarify the fluvial processes of alluvial river channels in macro scale. The results indicate that channel under complicated conditions have common aspects to those under simple conditions.
Table 1. Studies on bar formation using physical simulation by selected investigators.

| No. | Researchers (year)       | Flume size (m) | Channel cross section | Channel type | Channel size (m) | Flow rate (L/s) | slope | Max flow (l/s) | Grain size (mm) | Sediment supply |
|-----|--------------------------|----------------|-----------------------|--------------|------------------|----------------|-------|---------------|----------------|----------------|
| 1   | Hong and Davies (1979)   | 2              | rectangular           | straight     | 0.1             | 4.03           | 0.4   | 0.005 to 0.013| 0.05 to 0.1     | 50             | 0.17           | 0.05 to 0.015 to 0.05 kg/min |
| 2   | Fujita and Muramuto      | 7.3            | trapezoidal           | straight     | 0.25 to 1       | 42.3           | 0.9   | 0.005 to 0.002| 0.10 to 0.01    | 100            | 0.61           |
| 3   | Fujita and Muramuto      | 12             | rectangular           | straight     | 0.55 to 0.65    | 10             | 0.10  | 0.01 to 0.05  | 8              | 50             | 0.59           | 0 to 3.55 cm/s |
| 4   | Iida (1934)              | 0.5            | rectangular           | straight     | 0.5             | 1.00           | 1.3   | 1.0 to 1.5    | 1.3             |
| 5   | Isagi (1984)             | 0.3            | rectangular           | straight     | 0.5             | 0.09           | 0.52  |
| 6   | Fujita and Muramuto      | 0.66           | rectangular           | straight     | 0.55 to 0.65    | 10             | 0.99  |
| 7   | Ashmore (1993)           | 2              | rectangular           | straight     | 0.5             | 1.60           | 0.88  |
| 8   | Lanzoni (2000a)          | 1.5            | rectangular           | straight     | 0.5             | 0.15           | 0.88  |
| 9   | Federici and Paola       | 2 m            | trapezoidal           | straight     | 0.5             | 0.15           | 0.88  |
| 10  | Bartolli and Tuhino      | 0.66           | trapezoidal           | straight     | 0.60 to 0.12    | 12             | 0.17  | 0.01 to 0.02  | 0.01 to 0.1     | 100            |
| 11  | Egashira and Aoshima     | 0.5            | trapezoidal           | straight     | 0.15 to 0.2     | 0.01            | 0.15  | 0.05 to 0.02  | 0.01 to 0.1     | 70             |
| 12  | Bartolli et al. (2000a)  | 0.5            | trapezoidal           | straight     | 0.15 to 0.2     | 0.15            | 0.15  | 0.05 to 0.02  | 0.01 to 0.1     | 84             |
| 13  | An et al. (2013)         | 0.5            | rectangular           | straight     | 0.5             | 0.01            | 0.15  | 0.05 to 0.02  | 0.01 to 0.1     | 100            |

Note: The sediment supply values are given as ranges or specific values depending on the study.
[5] concluded that in undivided channel, a short submerged central bar is deposited during a high flow. Because of some local conditions not all transported through this particular reach and some accumulate in the centre of the channel. According to [5] the bar formation will initiate braiding as the bed shear stress slightly above the critical value. However, finding by [6] indicates that at a higher bed shear stress the narrow channel bed begins to deform by a more obvious alternating bar which leads to braiding by chute cutoff mechanism. [7] found that the central bar formation had only occur at the restricted width or it will depend on the presence of bed particles large enough (relative to flow depth) to form a nucleus for bar development. [8] studied the mechanisms of evolution of bifurcations within a single channel. They observed that flow divergence invariably leads to the formation of central bars for any Froude number and aspect ratio (width/depth) of the incoming stream. The relatively high value of Shields stress ($\tau^* > 0.15$) contributes to stable bifurcation and for low values of Shields stress ($\tau^* < 0.15$), a bifurcation display an oscillatory instability. [9] used the Hurst index by [10] to examine the relationship between the length and width of bars. The results indicate that river with larger width promotes river bank constraint on bar reduction. With complete development of river width, river tends to eliminate bank constraint and leads to a wide shape bar in a large braided river.

3. Methodology

The experimental setup consists of three sets of experimental case with four different flow rates. Three channel widths, 20 cm, 30 cm and 40 cm were used. The initial experimental channel was designed with a $45^\circ$ bend at the upstream to facilitate flow. The initial conditions for each experiment were set as shown in Table 2.

| Variables                     | Range                      |
|-------------------------------|----------------------------|
| Water flow rate, $Q_w$        | 4.97 m$^3$/hr, 6.64 m$^3$/hr, 8.62 m$^3$/hr and 10.91 m$^3$/hr |
| Channel width                 | 20 cm, 30 cm and 40 cm     |
| Sediment supply, $Q_s$        | 0.021 m$^3$/hr             |
| Bed slope, $S$                | 0.006                      |
| Grain sizes, $d_s$            | 1.15 mm                    |

V-notch weir was located upstream of the physical river model to regulate flow. Calibration of the flow depth to flow rate was carried out prior to the experiment graduations. Graduations scales on the left indicates the flow depth and on the right indicates flow rate. The graduations were placed slanted along the V-notch face. During the experiment run, if a flow of 4.97 m$^3$/hr is achieved, one can simply read from the graduation on the right. The amount of flow required and the corresponding flow depth can be read from the graduation on the left of the V-notch face. Dimensions of the V-notch weir is shown in Figure 1.

![Figure 1. V-notch weir dimensions.](image)
The flow rate was calculated using the following relationship:

\[
Q = 4.28C \tan\left(\frac{\theta}{2}\right)\left(h + \frac{k}{2}\right)^{\frac{3}{2}}
\]  

(1)

Where \(Q\) is discharge, \(C\) is discharge coefficient (0.607), \(\theta\) is notch angle equal to 60º, \(h\) is height of water above the V-notch.

Velocity was measured using a Nixon Streamflo Velocity Meter model 430 as shown in Figure 2. Calibration of velocity meter was conducted with the aid of an Acoustic Doppler Velocimetry (ADV). The ADV uses the Acoustic Doppler Effect to measure velocity by measuring the velocity of small particles in water and has been widely used to measure the velocity of water in a wide variety of hydraulic research. The calibration was also carried out by using the same model of Nixon Streamflo to check on the accuracy of the readings as shown in Figure 3.

A miniature flow sensing probe was used to measure velocities as low as 5.0 cm/s with the channel depth at least 2 cm. The probe was lowered into the channel with the propeller placed perpendicular to the flow to avoid readings error as depicted in Figure 4. The measured velocities were recorded using a digital velocity measuring device.

![Figure 2. Nixon Streamflo Velocity Meter model 403.](image1)

![Figure 3. Calibration of Nixon Streamflo Velocity Meter.](image2)

![Figure 4. Digital velocity measuring devices.](image3)
4. Results and Discussions

Data acquisition during the test included flow depth and bed elevation. Flow depth was measured at the channel centreline using a ruler attached to the adjustable profiler as shown in Figure 5. The bed profile was surveyed periodically using the laser distance meter device attached to the gauge on a regular grid spacing 5cm in the transverse direction and 20 cm in the longitudinal direction. The equipment was moved manually along the platform for a study reach of 10 m beginning 5 m downstream of the entrance weir as to minimize any turbulence flow entrance and sediment feed effects on the channel pattern. This 10 m length is more than 10 times the average wetted width of the braided channels which provides sufficient length to average out local variations and sampling effects on braided pattern and braiding intensity measurements.

Data on channel pattern development were collected along the study reach and was stopped at the equilibrium condition when bar features have shown nearly constant values. Bar profiles development for the different matrices of flow rates and channel width were generated using Surfer, a software used for 3-Dimensional elevation plots. The experimental run being conducted continuously until the bar had developed and remained stable at a certain location. It is observed that for lower flow rates took the longer duration of the bar formation process that is until day sixth. Each experimental run followed the same method and sequence of measurement, until bar formation occurred. The initial dry bed elevation was measured and recorded as the datum for the channel. Flow was imposed into the channel and the sediment was fed into the channel at the weir front. Initial depth of water and velocity were recorded at 1m interval. Measurement was recorded daily and stopped as the formation of mid bar became stable. This is indicated by zero water flow on top of the bars as the bar top were exposed. Longer durations were recorded for lower flow rate with the experiments stopped when the channel had reached the side walls of the model.

![Adjustable profiler for flow depth measurement.](image)

4.1 The Elevation of Centreline Profiles along Longitudinal Distance

The centreline profile of the channel were plotted from the first day until the end of experiment. Figure-6 (a) through Figure-6 (c) depicts the changes of bed elevation along the longitudinal distance. The datum of the initial bed taken as 0 cm and the initial bank height was 10 cm. The centreline axis was assumed to represent the bed elevation changes along the channel. The average elevation different between the initial and the final elevation was summarized in Table 3.

| Flow rates Q (m³/hr) | Different in average elevation (cm) |
|---------------------|-----------------------------------|
|                     | Channel width B = 20 cm | Channel width B = 30 cm | Channel width B = 40 cm |
| Q1 = 4.97           | 2.74                  | 5.50                  | 6.80                  |
| Q2 = 6.64           | 2.60                  | 4.35                  | 5.70                  |
| Q3 = 8.62           | 1.80                  | 3.35                  | 3.50                  |
| Q4 = 10.91          | 0.80                  | 2.30                  | 2.80                  |

For lower flow rates, Q1 = 4.97 m³/hr and Q2 = 6.64 m³/hr depict the decreasing plotting line trends towards the downstream section. Flowrates Q3 = 8.62 m³/hr and Q4 = 10.91 m³/hr indicate more complex...
configuration as it shows more fluctuating plotting line compare to $Q_1 = 4.97\ m^3/hr$ and $Q_2 = 6.64\ m^3/hr$.

Centreline profile along the longitudinal distance depicts that the average elevation for 20 cm channel width yield the highest average elevation. The difference in average elevation indicates the same trend for the four flow matrices. This evidence by larger differences from day 1 until the end of experiment for the smaller flow rates while smaller difference for the larger flow rates.

The average elevation difference between the initial and the final profile indicates higher different for 40 cm channel width as compared to 20 cm channel width. The higher velocity in the 20 cm channel width has induced erosion of the banks that resulted in the rapid elevation increase. This leads to small changes in average elevation from first day to final day of the experiment. Erosion in 40 cm channel width occurs gradually, thus lead to higher changes of elevation as compared to 20 cm channel width.

It can also be noted that, changes in the average elevation for higher flow rates are smaller as compared to lower flow rate. The above can be attributed to the initial bank collapse as a result of the high flow. The eroded material is transported downstream by the high flow and subsequently deposited along the test length of the channel.

**Figure 6(a).** Elevation for centreline profile along the longitudinal distance for channel 20 cm width for (a) 4.97 m$^3$/hr (b) 6.64 m$^3$/hr (c) 8.62 m$^3$/hr and (d) 10.91 m$^3$/hr.

**Figure 6(b).** Elevation for centreline profile along the longitudinal distance for channel 30 cm width for (a) 4.97 m$^3$/hr (b) 6.64 m$^3$/hr (c) 8.62 m$^3$/hr and (d) 10.91 m$^3$/hr.
Figure 6(c). Elevation for centreline profile along the longitudinal distance for channel 40 cm width for 
(a) 4.97 m$^3$/hr (b) 6.64 m$^3$/hr (c) 8.62 m$^3$/hr and (d) 10.91 m$^3$/hr.

5. Conclusions
Analysis on the bed configuration profiles for Q3 = 8.62 m$^3$/hr and Q4 = 10.91 m$^3$/hr indicates more complex configuration compare to Q1 = 4.97 m$^3$/hr and Q2 = 6.64 m$^3$/hr. This can be attributed to the higher flow rate transporting sediment from the upper reach. Centreline profile along the longitudinal distance depicts that the average elevation for 20 cm channel width yield the highest average elevation. The higher velocity in the smaller channel width have induced erosion of the banks that resulted in elevation increase. The larger flow rates have contributed to higher elevation.

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