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Variation of Local Friction Factor in an Open Channel Flow

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Abstract

Objectives: This present paper investigated experimentally on the variation of local friction factor over the cross section in channels of different geometries. The dependency of the variation of friction factor with aspect ratio has been well compared with the results of other researchers and natural river data. **Methods/Analysis:** Experiments have been conducted on trapezoidal and rectangular open channel for different geometry, hydraulic and roughness conditions. The local friction factors along every vertical interface have been carried out. The actual prediction of boundary shear stress and depth averaged velocity distribution have been calculated by finding the changes of these indispensible parameters, from wide range of data collected from previous literatures. Also the experimental depth averaged velocity and boundary shear stress have been carried out for assessing the friction factor. **Findings:** The global friction factor f_g and local friction factors f_l were calculated based on the measured depth-averaged velocity and boundary shear stress. The local friction factor does not remain constant across the channel as it depends upon the geometry and roughness parameter. The paper describes the variation of friction factor for both smooth and rough channels under different flow condition. Local boundary shear stress around the wetted perimeter τ_b, and depth averaged velocity, U_d, data are used to evaluate local friction factor, f_l. **Applications/Improvement:** Local friction factor variation analysis is a very rare factor that few researchers are taken into consideration. But it has a more importance for flow characteristics which is studied in this paper.

Keywords: Boundary Shear Stress, Depth Averaged Velocity, Eddy Viscosity, Local Friction Factor

1. Introduction

River flow resistance i.e., friction factors have significant influence on river's conveyance capacity and sediment transport. Darcy's friction factor f is a important factor which helps to predict the stage discharge relationship in open channel channel[1]. Flow resistance in rivers and open channels is of enormous importance in river engineering and dynamics[2]. Accurate estimation of river flow resistance is of importance to predict the stage-discharge relationship in rivers, thus to evaluate the likelihood of river flooding and issue warning of flooding. The issue of deciding the flow velocity and depth in a channel, for a known discharge remains a frequently revised topic in fluvial engineering. One of the important causes is the trouble in deciding precisely friction factors in river channel.

Some researchers investigated the local friction factor is a function of flow depth as well as dependent upon the Froude number and the global friction factor decreased as flow discharge increased[3]. Also he examined local and global friction factor in a V-shaped bottom open channel flow. Coolebrrok-White equation used to represent the variation of local friction factor across the section of channel[4]. Many researchers stated that secondary flows vary from compartment to compartment depending upon the bottom roughness and the variability of lateral flow depths[5]. Manning's roughness coefficient can be used to calculate the friction factor. In rectangular channel friction factor increased in magnitude close to the wall[6]. Certain resistance phenomena can be demonstrated with the inner and outer laws of boundary layer theory[7]. The outstanding change in the expectation of the Darcy-Weisbach friction factor, especially in the area of high f, where sediment transport is well on the way to happen with the most astounding intensity[8]. In the numerical models of the hydrodynamic simulations, any of the parameters ought to be calibrated in the resistance coefficient of

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Natural River's bed which characterized as keeping an eye on manning coefficient or chezy coefficient[9].

2. Theoretical Analysis

The friction factor has an important role to evaluate from depth averaged velocity and boundary shear stress in an open channel flow. In this paper global friction factor and local friction factor were evaluated from experimental study with different geometry conditions. The procedure of evaluating those friction factors are given below.

The depth averaged velocity U_d were computed for the entire in bank cases incase of both trapezoidal and rectangular simple channels by using the Equation (1)

$$U_d = \frac{1}{H}\int_0^H u\, dz \tag{1}$$

Where: u is the point velocity at a vertical line. U_d is depth averaged and H is flow depth. Depth averaged velocities were calculated at each vertical point by integrating all local velocities at the same point over a flow depth H.

The boundary shear stress distribution (ô) across the wetted perimeter of the flow section of simple main channel was measured by Preston tubes. This simple technique, as per[10] has been developed a number of mathematical formulae for observing local shear stress by pitot tube (or Preston tube) placed in contact along the surface of wetted flow perimeter. Assesement of near wall velocity distribution is empirically calculated from pressure difference between static and dynamic head from the pitot tube readings at each location of succesive experimental points. Author in[10] suggested a number of matematical equations with a range of y^* from 0 to 5.3.

For mathematical computations of the boundary shear stress, relationships which are as follows

$$y^* = 0.5x^* + 0.037 \text{ , for: } 0 \le y^* < 1.50 \tag{2a}$$

$$y^* = 0.8287 - 0.1381x^* + 0.1437x^{*2} - 0.006x^{*3}\text{, for: } 1.50 \le y^* < 3.50 \tag{2b}$$

$$x^* = y^* + 2\log_{10}(1.95y^* + 4.02)\text{, for: } 3.50 \le y^* < 5.30 \tag{2c}$$

with
$$x^* = \log_{10}\left(\frac{(\Delta p)d^2}{4\rho v^2}\right) \tag{2d}$$

and
$$y^* = \log_{10}\left(\frac{\tau_b d^2}{4\rho v^2}\right) \tag{2e}$$

Where, d is the external diameter of the Preston tube, í is the kinematic viscosity for the liquid, Δp is Preston tube pressure difference, x^* is log of dimensionless pressure difference and y^* is log of dimensionless shear stress.

Boundary shear (τ) from point to point along the bed of the channels are found out using Preston tube techniques by using Patel's calibration Equation (2a) to Equation (2e). Boundary shear stress τ_b can be evaluated in lateral direction from point to point by using the equation (2e).

Knowing the depth averaged velocity and boundary shear stress, the global friction factor is evaluated for respective flow conditions of channels are found out using the Equation (3).

$$f_g = \frac{8\tau_{b,avg}}{\rho U_{mean}{}^2} \tag{3}$$

Where: $\tau_{b,avg}$ is boundary shear stress over whole channel wetted perimeter, f_g is global friction factor, ρ is density of water and U_{mean} is mean velocity of the flow for a particular flow depth.

Then local friction factor is evaluated for respective flow conditions of the channels from point to point along the bed as per equation given below:

$$f_l = \frac{8\tau_{b,local}}{\rho U_d{}^2} \tag{4}$$

Where: $\tau_{b,local}$ is boundary shear stress of any local/desire point , f_l is local friction factor, ρ is density of water and U_d is depth averaged velocity.

3. Experimental Setup and Procedures

The experimental investigation has been carried out in the fluid mechanics laboratory at National Institute of Technology, Rourkela for this present study. Experiments were conducted with two different channel i.e. trapezoidal channel and rectangular channel. The whole channel was cast inside a rectangular steel tilting flume about 12 m in length. First Experiment was carried out in a straight

Trapezoidal both in simple and rough channel with10 m long 0.33 m wide, 0.11 m deep and side slope 1:1(1V:1H) in both side (45^0 lateral bank slope) and second Experiment was carried out in a rectangular channel was casted inside a steel tilting flume about 15 m long with a section of straight rectangular simple channel with 20 m long 0.34 m wide, 0.113 m deep. The data were recorded over half of the cross-section because of the symmetry along the centre and the test reach is 8 m away from the bell mouthed entrance. The channel bed was made up of trowel polished smooth cement concrete of manning's *n* is 0.011 for smooth trapezoidal channel and its longitudinal slope is 0.001 m/m and for rough trapezoidal channel stones were used of size ranges from 1.2 cm to 1.8 cm of manning's *n* is 0.0122 and manning's *n* for rectangular smooth channel (i.e., Perspex acrylic sheets) is 0.01. A movable bridge has been fitted with all instruments, for example, point gauge (least count 0.001 m), a micro pitot tube and Micro ADV were furnished over the flume to both span wise and stream wise developments of personnel and instrument over the channel region. It takes estimations at every area on the arrangement of channel sufficiently. An entire re-circulating system for the supply of water was set up in laboratory. Three parallel pumps were accustomed to pumping the water from the underground sump to over head tank. To make the stream uniform and steady the stilling chamber was given at the entrance and after that the water was permitted to flow under gravity all through the experimental test channel. Toward the end of the experimental channel the water was permitted to flow through a tail gate and put away in a volumetric tank from where this stream is permitted to backtrack to underground sump. From the sump the water was pumped back to the over head tank and in this way finishes a re-circulating arrangement of water supply.

4. Results and Discussions

4.1 Variation of Global Friction Factor with Lateral Distance

The global friction factors for smooth rectangular and trapezoidal experimental channels have been computed using the Equation (3). The distribution of global friction factors against aspect ratio for data sets of own experimental channel and other investigators channel have been graphically demonstrated in Figure 2(a) and 2(b) and figure 3(a) and 3(b) respectively. The results show that the global friction factors are of increasing in magnitude with aspect ratio. This is due to the influence of flow depth i.e., when the flow depth decreases leading to a rise in aspect ratio, the magnitude of friction factor increases. At shallow flow depth due to the effect of boundary roughness and wall roughness, the resistance to flow increases leading to a higher friction factor. But for cases of higher flow depth, the influence of frictional resistance developed at the bed and wall is smaller compared to the cross sectional flow area. So at lower

Table 1. Summary of experimental data sets

Channel Type	Width (m)	Flow Depth (m)	Average Manning's n
Trapezoidal Channel (Smooth), NITR	0.33	0.08-0.11	0.011
Trapezoidal Channel (Rough), NITR	0.33	0.07-0.09	0.0122
Rectangular smooth Channel, NITR	0.34	0.076-0.107	0.01
Rectangular smooth Channel, Atabay(1998)	0.398	0.026-0.060	0.009
Rectangular smooth Channel,Tang(1999)	0.398	0.0104-0.094	0.009
Rectangular rough Channel,Tang(1999)	0.398	0.0324-0.1981	0.0351

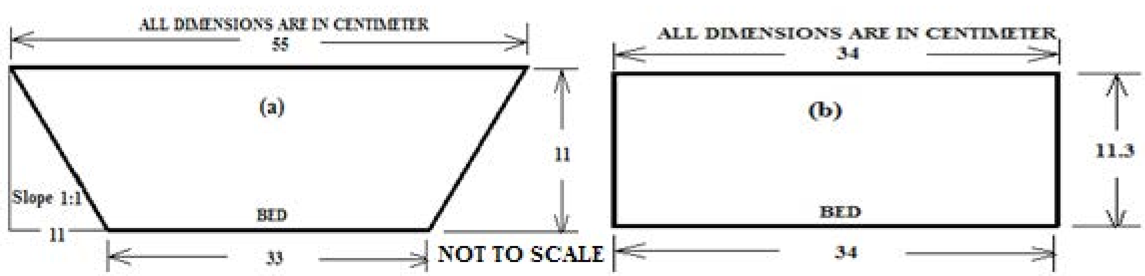
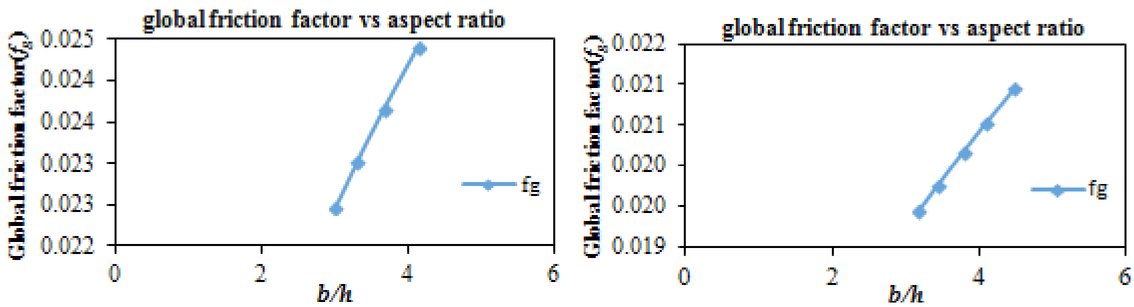
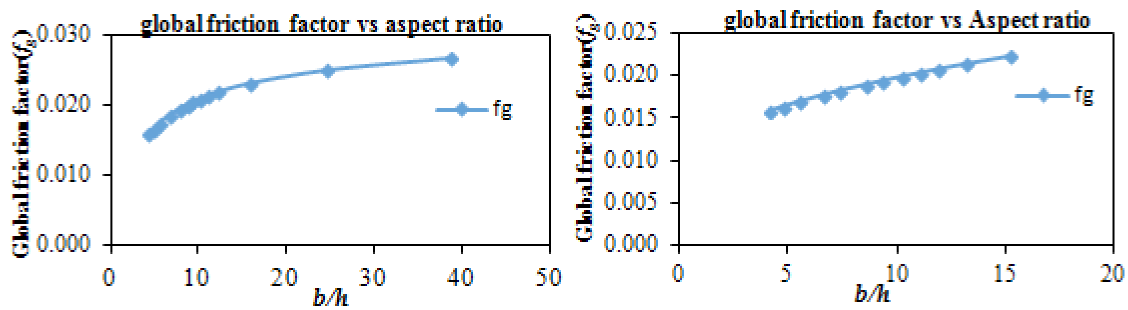


Figure 1. Cross-section of testing channels. (a)Trapezoidal,NITR. (b) Rectangular, NITR.



(a) (b)

Figure 2. (a) Trapezoidal smooth channel, NITR. (b) Rectangular smooth channel, NITR.



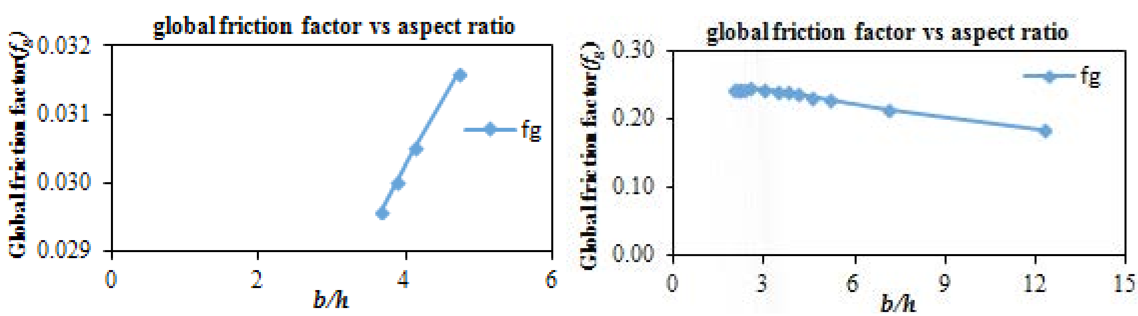
(a) (b)

Figure 3. (a) Rectangular smooth channel[12]. (b) Rectangular smooth channel[11].

aspect ratio, (i.e., the higher flow depth), the friction factor is less. The results of own experimental data sets (Figure 2) and other investigators data sets (Figure 3) show a similar trend of the variation of global friction factor with aspect ratio. But when the bed materials in the channel are having high roughness, the friction factor variation against aspect ratio is showing a upward trend for own experimental series (Figure 4(a)) however a reverse trend has been observed for the[12] data series (Figure 4(b)). This is because of the higher roughness (averaged manning's $n = 0.035$) of[12] data as compared to the own experimental data series (averaged manning's $n = 0.012$).

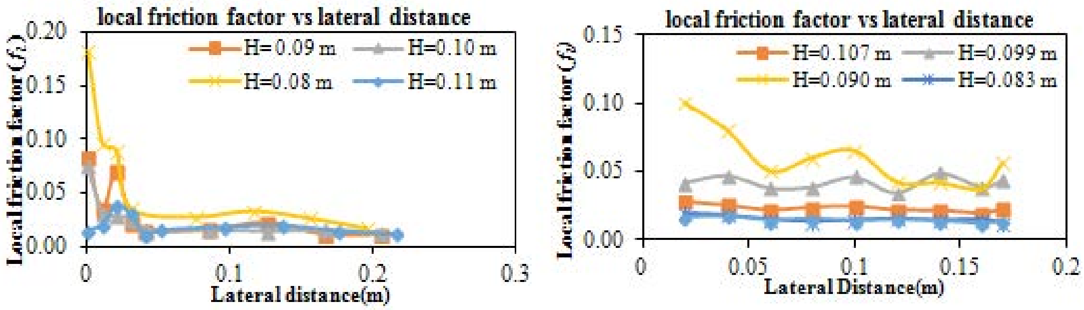
4.2 Variation of Local Friction Factor with Lateral Distance

The local friction factors for each vertical interface along the half cross channel distance of rectangular and trapezoidal experimental channels have been computed using the Equation (4). The distribution of local friction factors for each flow depths for all data series (own experimental series and other investigators series) have been graphically demonstrated in figure 5(a) to 5(b) and Figure 6 respectively. The results show that the magnitude local friction factor is higher at side bank than bed portion in trapezoidal channel however for rectangular channel



(a) (b)

Figure 4. (a) Trapezoidal rough channel, NITR. (b) Rectangular rough channel[12].



(a) (b)

Figure 5. (a) Trapezoidal smooth channel, NITR. (b) Rectangular smooth channel, NITR.

this variation of local friction factor remains constant along the whole lateral cross section.

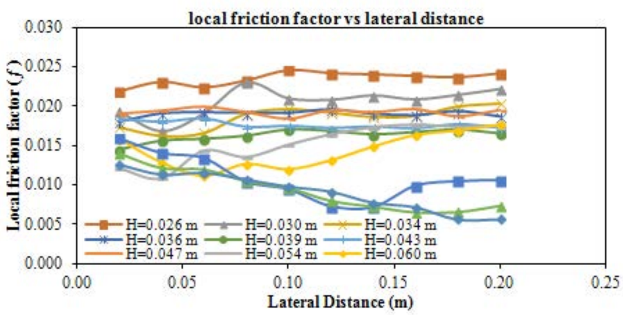


Figure 6. Rectangular smooth channel[11].

5. Conclusions

In this paper the results of local and global friction factors for different geometry and roughness conditions are presented. On the basis of results already presented in earlier section, the major findings and conclusions on this paper are drawn below:

- The global friction factors are of increasing in magnitude with aspect ratio in smooth trapezoidal and rectangular channel.
- In rough channel cases, the variation of global friction factor against aspect ratio is showing a upward trend for own experimental series however a reverse trend has been observed for the other investigators data, because of the very high roughness as compared to lower roughness used in the own experimental data series.
- The variation of local friction factors for each flow depth is higher at side wall regions than bed regions in trapezoidal channel and it remains constant along the lateral cross section of rectangular channel.

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