Boundary Shear Stress distribution in Compound Meandering Channel

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ABSTRACT

Investigation of flow parameters in a meandering channel is both challenging and interesting for research dealing in river engineering. With curiosity, research has been undertaken to investigate the variation of velocity profiles both in longitudinal and lateral directions in the main channel and flood plain at various sections in a meandering compound channel with various discharges. It is necessary to observe the variation of longitudinal velocities and boundary shear stress distribution at various relative depths in meandering compound channels from in-bank to overbank flow due to its complexity in nature. The present experimental work is conducted at the Hydraulic engineering lab of the National Institute of Technology, Rourkela on a compound meandering channel.

Keywords: *Meandering, Boundary shear stress, Velocity contours, Compound channels*

1. INTRODUCTION

Meandering is very common to the rivers and it plays a vital role in affecting the flow parameters in river engineering. Rivers carry the products of erosion as well as water, and in meanders, some sediment is transported by scouring and fill. Scour usually takes place at the outer banks of the bends and gets deposited at the inner banks most of the sediment eroded from one bank is deposited on the point bar on the same side of the channel in the next bend downstream. Meandering in natural rivers are asymmetrical. The deepest part of the channel is on the outside of each bend. Water flows faster in these deeper sections and erodes material from the river bank. Water flows more slowly in the shallow areas near the inside of each bend. The slower water can't carry as much sediment and deposits its load on a series of point bars.

Presence of floodplains is characteristic of a river. Under the normal condition of low flow, the water flows within the main channel region, and so the water in the river channel stays below the bank full level. However, in the case of a prolonged period of heavy rainfall, the river extracts high amount of surface runoff from the surrounding catchment resulting in a flood. This situation renders the main channel unable to carry the volume of runoff, and the water overtops the main channel banks. This making the channel section compound, various geometrical parameters of a meandering compound channel as shown in the Fig.1.

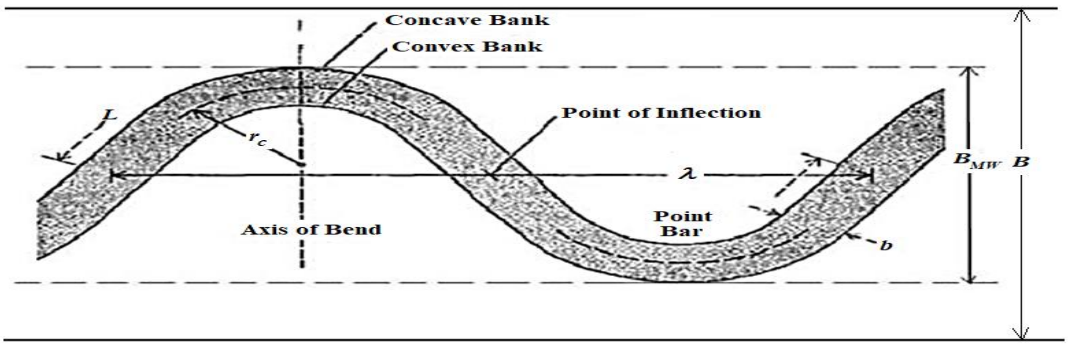

Fig. 1 Various Geometrical Parameters of Meandering Compound Channel

Patra and Kar (2000) performed experiments on compound meandering channels having straight and meandering floodplains covering aspects on boundary shear force and discharge. They used five non dimensional parameters to develop an equation for shear force carried by the floodplain. Khatua (2007) had carried out experiments on two types of sinuous channel having sinuosity of 1.44 and 1.91, and width ratio of 4.81 and 16.08, respectively. They developed an equation for the prediction of discharge for the straight compound channel. They had also analyzed the shear force, boundary shear stress, characteristics of discharge from the laboratory dataset and developed an equation for the percentage of shear force in the floodplain. Hossein Afzalimehr and Vijay (2009) did field experiment on the meandering cobble bed Beneshtabad river. They measured velocity, shear velocity in the meandering in five different reaches with 7-10 cross sections and Influence of Relative Curvature and Relative Submergence on the Velocity Distribution also the values of shear velocity computed using the parabolic law and Boundary layer characteristics methods were compared. Mohanty (2013) analyzed meandering effect on the flow in compound channel having sinuosity of 1.11 and with ratio of 11.97. He studied the distribution of boundary shear force and discharge in meandering compound channel. Pradhan and Khatua (2017a) experimented on highly sinuous channel having sinuosity (s) of 4.11 which comprised of bank full depth of the main channel (h), bottom channel widths (b) and top width (T) of the main channel as 0.06 m, 0.33 m and 0.46 m, respectively. The bed slope of the meandering channel (S_o) was 0.00165. The amplitude (μ) and meander belt width (B_{MW}) of the channel were 1.66 and 3.65 m, respectively. Struve et al., (2003) Wu and Marsooli (2012) Guan and Liang (2017) proposed the prediction of depth-averaged two-dimensional model for the prediction. This aim of paper is to investigate experimentally the variation of velocity distribution profiles, boundary shear stress distribution, shear force distribution and flow resistance in a meandering compound channel at four various relative flow depths (β) 0.13, 0.2, 0.3 and 0.38 respectively.

2. PLAN OF EXPERIMENTAL SETUP

Experimental investigations were carried out in meandering compound channel with sinuosity of main channel (S_{mc}) and flood plain (S_{fp}) as1.06 and 1.0 respectively and the channel was made of Perspex sheet of 6-10mm thickness, roughness *n as* 0.01. The flume has dimensions of 10m ×1.7 m× 0.25m. The flume is equipped with a re-circulation system which includes an overhead tank to maintain a constant head in the channel for a particular discharge. Water delivers into a stilling chamber at the upstream of the flume which holds a baffle wall arrangement to the water surface level.

The conventional discharge estimation methods are inaccurate in predicting the discharge in such compound channels, this is primarily because these methods ignore the effect of apparent shear at the interfaces between the main channel and the channel interfaces. To sort out this error of discharge estimation, the conventional Divided channel method (DCM) is adopted. As it is necessary to divide the channel cross section of compound channel in such a way that they take care of the hydraulic homogeneity in flow computations (Knight et al. 1984; Wormleaton et al. 1982)

Table 1: Experimental channel parameters

Parameters	**Value**
Type of Bed surface	Smooth
Bed Slope of the Channel (S_o)	0.001
Angle of Arc of main channel (ϕ_m)	30°
Sinuosity of the main channel (s_{mc})	1.06
Sinuosity of the Floodplain (s_{fp})	1
Wavelength of the channel (λ)	2.23m
Bank full Depth of main channel (h)	0.12m
Width of outer Floodplain (b_o)	0.52m
Width of inner Floodplain (b_i)	0.87m
Meander Belt Width (B_{MW})	0.61m

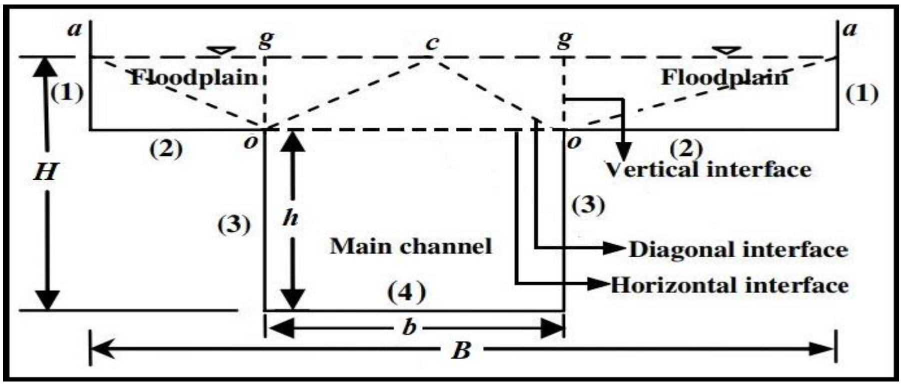

Fig. **Error! No text of specified style in document.** Horizontal, Vertical and Diagonal interface of a compound channel in DCM approach
(Khatua et.al. 2011a).
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3. EXPERIMENTAL PROCEDURE

In the present research work, the bed slope of the channel was determined by the help of peizometric tube which was a water level indicator. By taking reference as bed of the channel peizometric water level was recorded at both upstream and downstream of the channel which was 10 m apart. Water is allowed to flow through channel for a 4hr duration to ensure flow depth as uniform this helps to achieve water surface level measured at various points in the channel by using a point gauge.

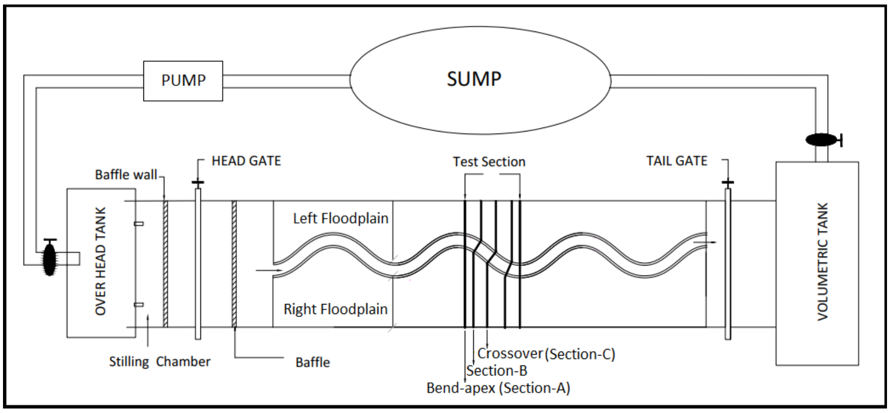


Fig. 3 Plan geometry of the experimental setup

Manning's n for the perspex sheet channel boundary is experimentally determined as 0.01. For this, the in-bank flow in the meandering main channel is collected in a volumetric tank located at its end. From the time-rise data of the water level in the volumetric tank, the discharge rate is computed. By knowing the channel cross-sectional area and the wetted perimeter, Manning's n is computed for four consecutive depths of flow, and the mean value of n is computed as 0.01 [(0.0088+0.0096+0.0104+0.012)/4]. The flow resistance is usually represented through a resistance coefficient such as the Manning's roughness coefficient n, Chezy's coefficient C or Darcy-Weisbach friction factor f (Martin et al. 1991; Yang et al. 2007; Yen 2002). These coefficients are interrelated as

$$n = \frac{R^{1/6}}{C} = \sqrt{\frac{fR^{1/3}}{8g}} \qquad (1)$$

Manning's equation is used to compute the value of n, which is given as

$$n = \frac{R^{\frac{2}{3}} S_o^{\frac{1}{2}}}{V} \tag{2}$$

where V is the mean velocity of flow for the compound channel, S_o the bed slope of the channel, and R the hydraulic radius. The measurments were taken by the pitot tube and preston tube to determine the streamwise velocity and distribution of boundary shear stress at the Bend apex (section A) and Crossover(section C) Fig. 3 at four different relative depths (D_r) and further the data analysed and results were compared. Fig. 4 shows the grid arrangment of velocity measurements. The non-dimensional relationship between Preston tube reading, ΔP, and the shear stress, τ is of the form

$$\frac{\tau d^2}{4\rho \vartheta^2} = F\left(\frac{\Delta P d^2}{4\rho \vartheta^2}\right) \tag{3}$$

where d = outer diameter of Preston tube and F = function determined experimentally. The total discharge in the compound channel is computed by DCM method and it is cross checked by rate of water collected by per unit time.

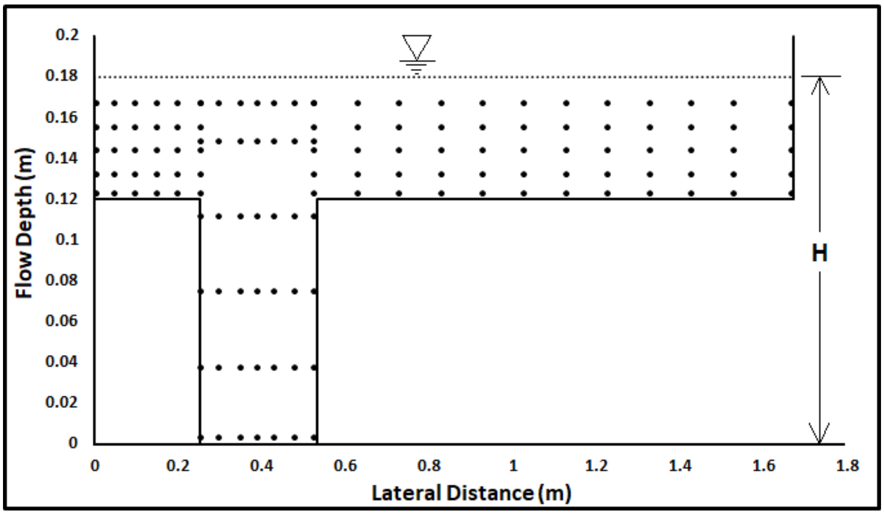
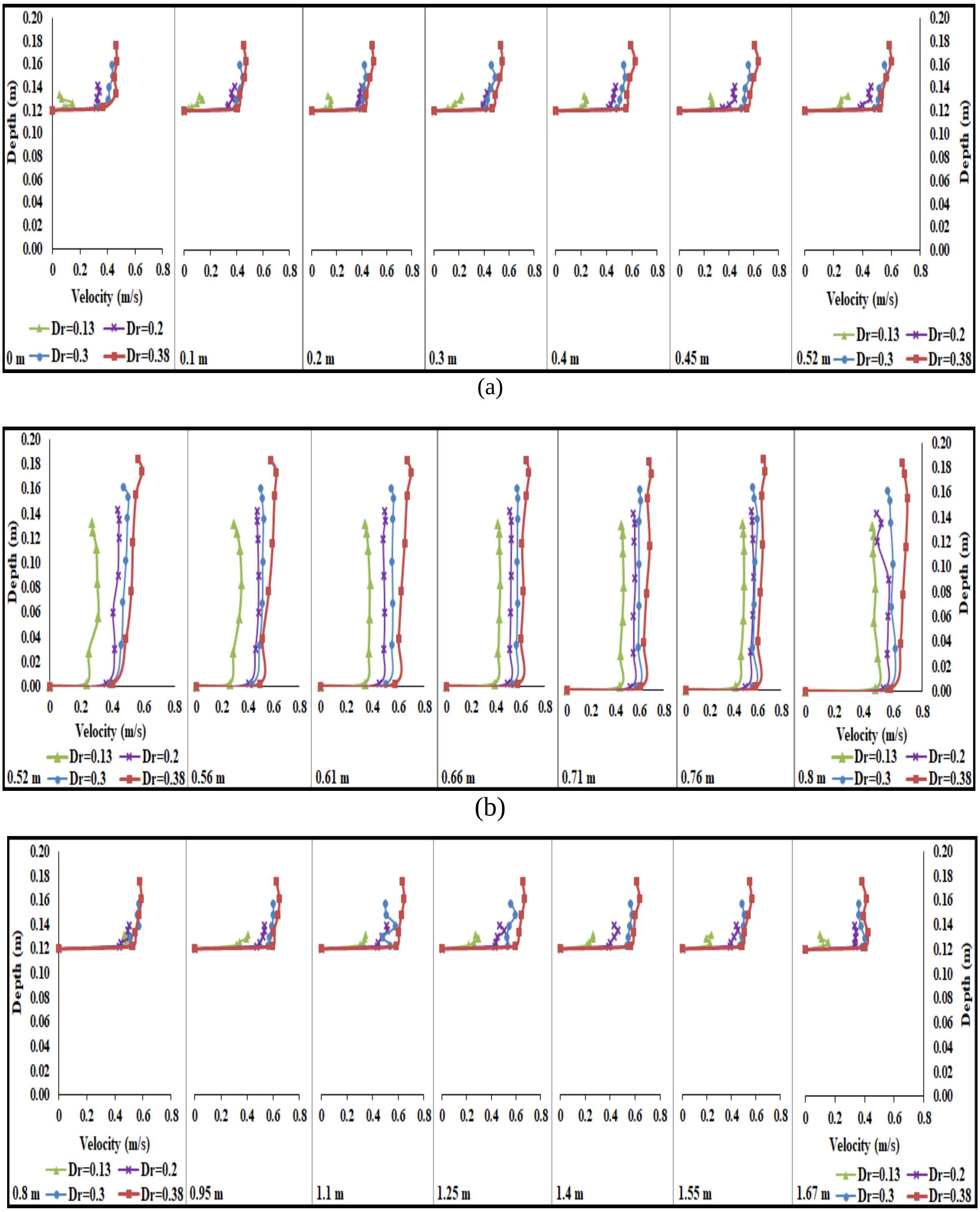


Fig. 4 Velocity measurement gird across the channel section

4. RESULTS AND DISCUSSIONS

For the present study, the local velocities were measured across the entire cross section, laterally at 50mm interval and vertically at 0.2*h*, 0.4*h*, 0.6*h*, 0.8*h*, 0.9*h* level where '*h*' is the height of water at a particular section in the channel. Different position of experimental measuring grid points at a particular section is shown in Fig. 4. Plot between depth of flow versus the depth-averaged velocity for an overbank flow were shown graphically in the Fig. 5.



(a)

(b)

(c)

Fig. 5 Lateral distribution of longitudinal velocity profile at Bend-apex for various relative depths for overbank flow at (a) Outer floodplain; (b) Main channel; (c) Inner floodplain

From the lateral distribution of depth averaged velocity graphs, inner flood plain accounting a higher velocity as reference of outer flood plain and sudden drop of velocity at the interaction point of main channel with outer flood plain and it gradually increasing in lateral direction (i.e. inner flood plain) due to momentum transfer at relative depths (Dr) 0.13, 0.2, 0.3 and 0.38.

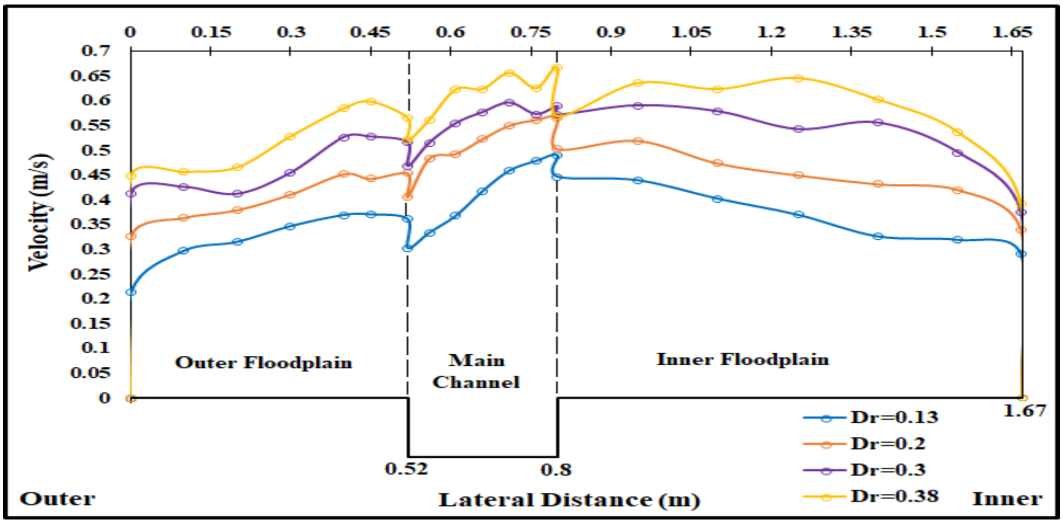


Fig. 6 Lateral distribution of depth averaged velocity for overbank flow meandering channel at bendapex.

From the contours of longitudinal velocities for the meandering compound channels, concluded that the water moves faster around the wall region on the left outer wall with in the main channel for the main channel for the bend apex section. The central region also shows regions of water moving faster, and the fluid decelerates when it flows near the bed of the channel. The maximum value of stream wise velocity lies near the free surface and towards the inner flood plain.

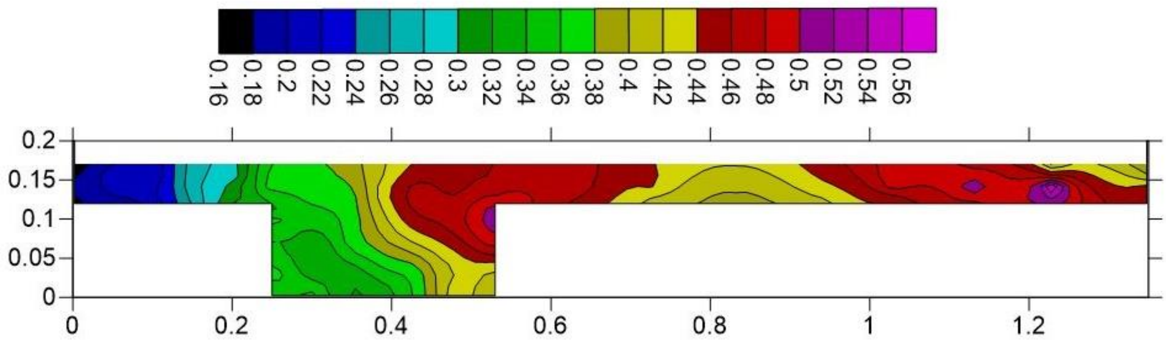


Fig. 7 Velocity contours for the depth ratio (Dr) as 0.3 of a meandering channel at bendapex.

For the present experimental runs of overbank flow conditions, the boundary shear stress distribution is shown across the channel beds and side walls at bendapex for various stages of flow conditions for depths of 0.138m, 0.15m, 0.17m and 0.195m i.e. relative flow depths (β) as 0.13, 0.2, 0.3 and 0.38 respectively.

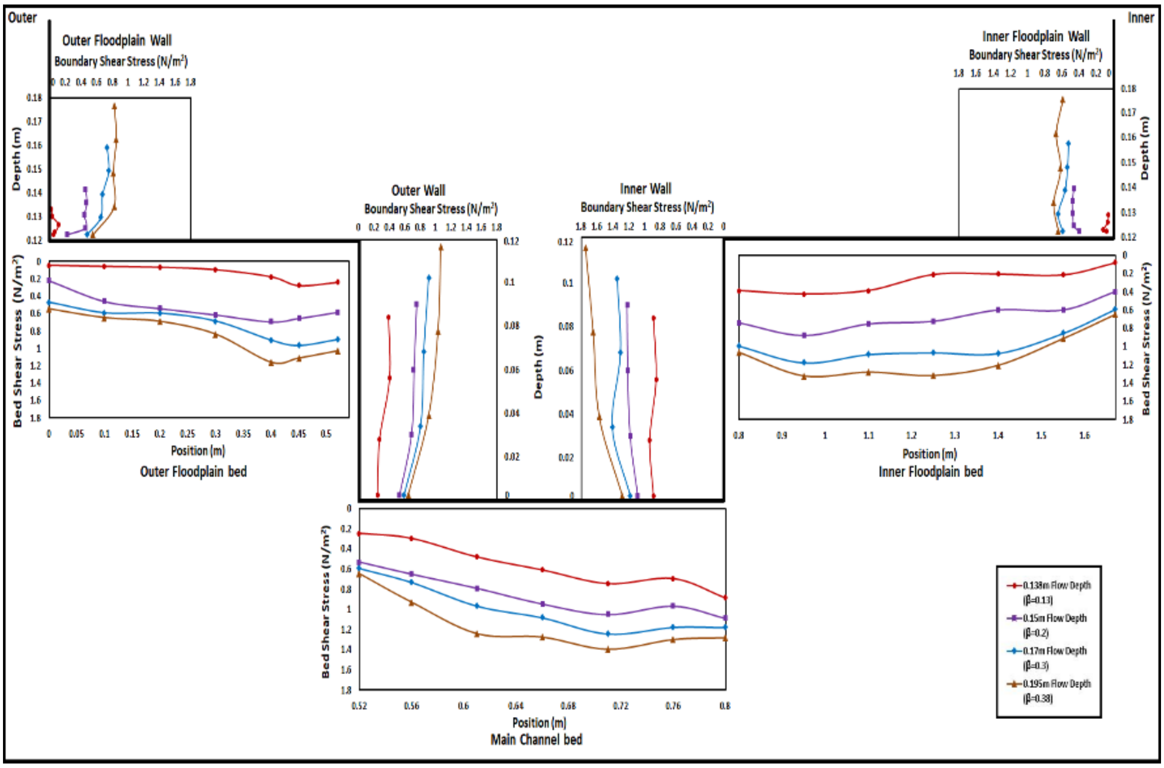


Fig. 8 Boundary shear stress at bendapex

5. CONCLUSIONS

From the present experimental observation, the following graphs can be drawn. From the Velocity contours it can be concluded that representing variation of the longitudinal velocities across the bend apex cross section. Drop of depth average velocity is maximum at the interaction points in inner flood as comparatively with the outer flood plain. From the boundary shear stress distributions, it is observed that by increasing flow depth, the boundary shear also increases. Due to variation of water level or flow depths, variations of shear stress in these sections are seen to be inconsistent. At bend-apex, the shear stress although remaining higher towards the inner wall, shear stress between the inner and outer walls is observed to be gradual variation.

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