Comparison Between 5 Methods to Calculate Boundary Shear Stress Distribution in Open Channel

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Abstract

In 1999, Merged Perpendicular Method (MPM) was developed by Khodashenas & Paquier in order to compute the distribution of boundary shear stress across irregular straight channels. For examination and validation of MPM, 4 methods are studied and compared with MPM. Guo & Julien and Prasad & Manson calculated the average bed and sidewall shear stress in smooth rectangular open channel. Berlamont et al, and Knight & Sterling calculated the average bed and sidewall shear stress in partially filled pipes open channel. Comparison with experimental data and 4 other methods shows that M.P.M matches well with the experimental data and provides good estimation of shear stress. Two advantages of MPM are: the determination of local shear stress and practicable in any shape of cross section.

Key words: ***Boundary shear stress, River engineering, Empirical methods.***

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1-Introduction

Boundary shear stress is an important parameter in open channel flow. In order to model the evolution of the shape of natural river channels, it is necessary to compute the distribution of boundary shear stress in the vicinity of riverbank. Boundary shear distribution depends on secondary flows, shape of the cross-section and non-uniform roughness distribution around the wetted perimeter. Precise computation is extremely difficult even for simple cases. Empirical or simplified computational methods thus constitute a popular alternative.

Shear stress is often assumed to be proportional to the water depth or proportional to the area between two verticals. If the transversal slope of the bottom is steep, it appears somewhat better to compute shear stress by measuring the depth on perpendiculars to the bottom .A more consistent method is the Normal Area Method in which shear stress corresponds to the area between two perpendiculars to the bottom. However, if the cross section is deep or the slope of the banks steep, results of these simple methods are less satisfactory.

More complex methods are available. They also suffer several limitations. Parker (1978) said, how extension of Lundgren and Jonsson's method (1964) can be only applied to gently curving banks. Knight et al (1984) proposed an empirical method to compute the average of shear stress on bed and wall in straight, symmetrical rectangular smooth channel. Flintham & Carling (1988) extended Knight’s method to rough trapezoidal channel. Knight & Sterling (2000) examined the Knight’s empirical formula for prismatic channel in partially full circular pipes. Ramana Prasad & Russel Manson (2002) developed an analytical expression for percentage shear force on walls of smooth rectangular open channel in terms of width-depth ratio which is basically derived from Kuelegan’s model. Berlamont et al (2003) calculated the boundary shear stress in partially filled pipes using computational fluid dynamics. Guo & Julien (2005) computed the average bed and sidewall shear stress in smooth rectangular open channel flows after solving the continuity and momentum equation. These models have successfully been used to simulate flows in straight and curved rectangular flumes. However, they were not specifically designed to simulate flows in channels with irregular cross section, and therefore they cannot be applied without modification to natural streams. Pizzuto (1991) analyzed the limitations of some methods computing boundary shear stress and proposed a very complex numerical model for computing the distribution of velocity and boundary shear stress across an irregular straight open channel.

One way to pass from sediment transport to change in the form of an alluvial channel is the use of boundary shear stress. For engineering purposes, sediment characteristics are not accurately known. Thus, shear stress should be computed by a simple and rapid method rather than an accurate one.

Khodashenas & Paquier (1999) developed a geometrical method to compute the shear stress in an irregular cross section. This method called Merged Perpendicular Method (MPM) was derived from the normal area method but gave more precise results. The advantages of this method are, the determination of local shear stress and practicable in any shape of cross-section.

In this paper another examination for validation of MPM has been done. 4 methods (Guo & Julien (2005), Berlamont et al (2003), Prasad (2002), Knight & Sterling (2000)) are studied and compared with MPM.

2-Comparison between MPM with experimental data and other methods

2.1-Comparison with Guio & Julien's method

The average bed and sidewall shear stresses in smooth rectangular open channel flows were determined by Guio & Julien (2005). As a first approximation, they determined the boundary shear stress by using conformal mapping, after neglecting secondary currents and assuming a constant eddy viscosity. In second approximation they introduced two lumped empirical correction factors for the effects of secondary currents, variable eddy viscosity and other possible effects.

Table 1 shows the shear velocities calculated by Guio & Julien’s method and MPM with measurements in smooth flumes reported in literature. The average relative error for Guio & Julin’s method is 3.5% and for MPM is 1.5%.

Table1: *Comparison of calculated bed shear velocities with measurements in smooth flumes*

Bed shear Velocity (cm/s)	Coleman(1996)				Lyn(1986,2000)	Muste & Patel(1997)		
	C1	C2	C3	C4		C_{w01}	C_{w02}	C_{w03}
Measured	4.10	3.10	3.70	3.60	4.30	2.92	2.92	2.98
Guio & Julien	4.14	3.05	3.49	3.5	4.06	2.78	2.82	2.89
MPM	4.10	3.15	3.60	3.61	4.19	2.84	2.88	2.95

In term of the average bed shear stress and side wall shear stress, comparison between Guio & Julien's method and MPM with the experimental data in smooth open channels is shown in Figure (1).

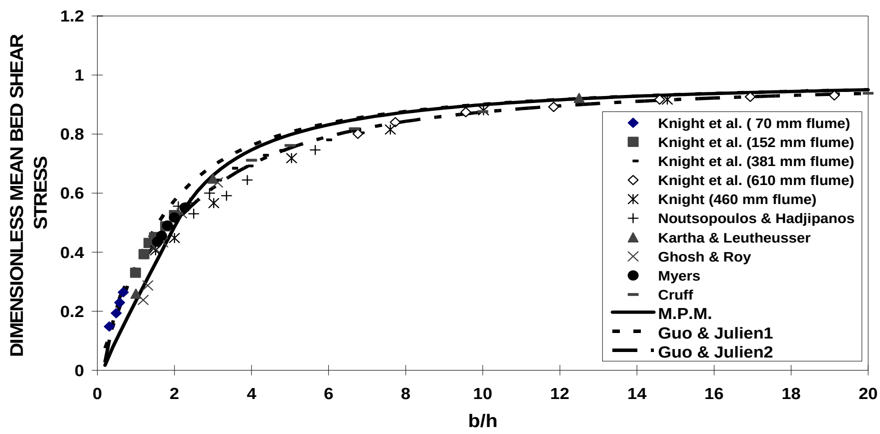

Figure 1: *Comparison of dimensionless shear stress computed by MPM and two approximations of Guio & Julien with measurement*

1.2-Comparison with Berlamont's method

Berlamont et al (2003) calculated the boundary shear stress for circular pipes with a flat sediment bed using computational fluid dynamics.

The Figure (2) shows comparison between the results calculated by Berlamont's method and MPM Total relative deviation for the average shear stress is 5.5%, for the bed average shear stress is 12.7% and for the maximum shear stress is 29.1%.

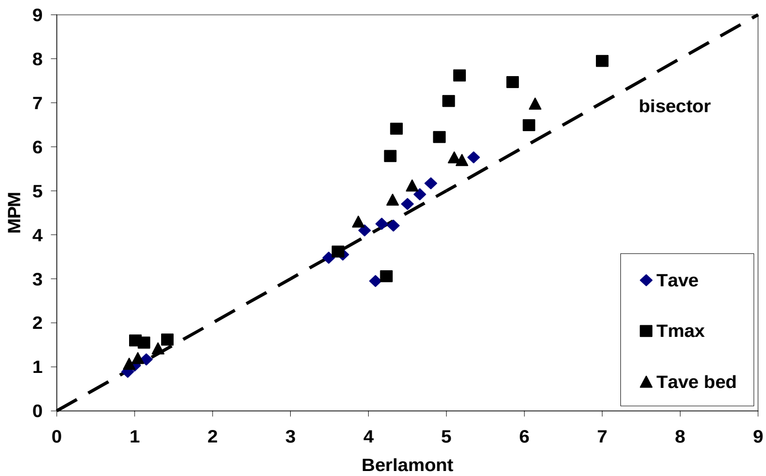

Figure 2: *Comparison between the shear stress computed by MPM and Berlomant for the average shear stress (T_{ave}), maximum shear stress (T_{max}) and average bed shear stress (T_{avebed})*

1.3-Comparison with Ramana Prasad & Russel Manson's method (2002)

Ramana Prasad & Russel Manson (2002) developed an analytical expression for percentage shear force on walls in terms of width-depth ratio which is basically derived from Kuelegan's model. A comparison between the results computed by MPM and the method of Ramana Prasad & Russel Manson shows in Figure (3). The results of MPM have been shown to agree well with Ramana Prasad & Russel Manson's method.

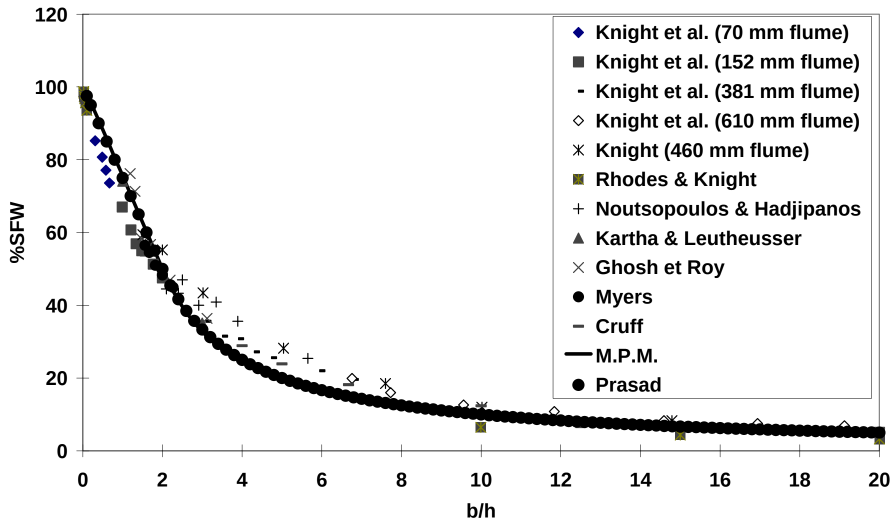

Figure 3: *Comparison between percentage shear force on walls computed by MPM and Prasad's method with experimental data*

1.4-Comparison with Knight & Sterling's method

Knight & Sterling (2000) studied the distribution of boundary shear stress in circular conduits flowing partially full, with and without a smooth flat bed. In thier paper the results have been analyzed in terms of the variation of local /global shear stress versus perimetric distance and the percentage of the total shear force acting on the wall or bed of the conduit. Knight's empirical formula (Knight et al 1984) has been examined for prismatic channel. The comparison between the results calculated by Knight's method and MPM with experimental data has been shown in Figures (4)-(5).

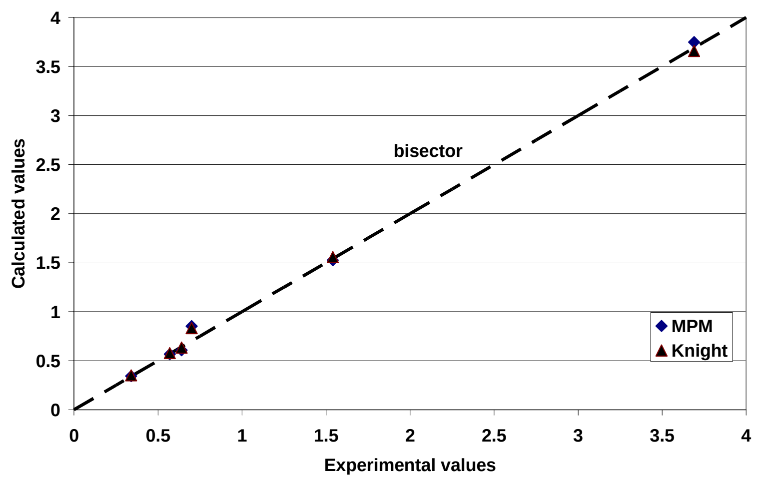

Figure 4: *Comparison between the average bed shear stress computed by MPM and Knight's method with measurement*

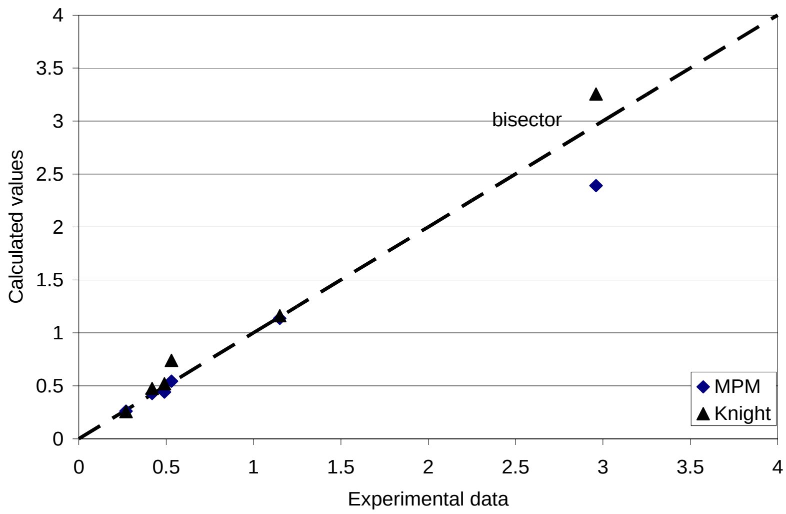

Figure 5: *Comparison between the average wall shear stress computed by MPM and Knight's method with measurement*

The table 2 shows percentage of average deviation between the measurement and the results computed by MPM and Knight's method.

Table 2: *Percentage of average relative deviation between Knight's method and MPM with experimental data.*

Type of Shear stress	Knight	MPM
Bed shear stress	4.3	5.2
Wall shear stress	12.4	6.3
Percentage of the total shear force acting on the wall	4.3	5.0

3- Conclusion

The method developed, called Merged Perpendicular Method (MPM) computes the distributions of boundary shear stress across irregular cross sections. Computational results for circular conduits flowing partially full and rectangular sections were successfully compared with experimental results and 4 other method. MPM reproduces distribution of boundary shear stress around wetted perimeter similar to four other methods. This comparison shows that MPM matches well with the experimental data and provides good estimation of shear stress.

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