Assessment of Friction Factor in Open Channel Flow With Bedload Movement

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Abstract

The friction factor is observed to depend on hydraulic and geometric parameters such as relative depth, hydraulic radius, bed shear velocity, u * , water density, ρ, Froude number, F, average vertical velocity, u, Reynolds number, R and relative roughness, K. In this paper, Different parameter like width(m), Slope(m/m), Discharge(m^3/s), Mean flow velocity (m/s), Depth of flow (m), Hydraulic radius (m), Diameter of particle(D_{50}) has used of a various researcher to make calculation of Relative depth(R/D_{50}), ratio of depth of flow to the width of channel, Froude number(Fr), Shear velocity(u^*), Reynold's number(Re), Roughness reynold's number(Re*), and friction factor under bed load condition using model of various researcher. In open channel variation of friction factor with a various factor which affects the open channel flow has studied for different data set of various researcher also a variation of friction factor of different researcher for different data set has studied. An error has found out for a different model and comparision has been done for various model of a friciton factor.

Keywords: Open Channel, Shear Velocity, Flow Resistance, Relative Depth, Mean Flow Velocity, Shear Stress.

1. Introduction:

Generally, open channel flows are complexed. The depth of flow, the discharge, and the bottom slope of the channel are totally dependent upon the prediction of depth and velocity of free surface flow. Friction factors have a significant influence on open channel sediment transport. The Darcy Weisbach friction factor f is not a constant, it depends on such things as the characteristics of the pipe (diameter D and roughness height ε), the characteristics of the fluid (its kinematic viscosity ν), and the velocity of the fluid flow $\langle v \rangle$ also it proportional to the square of the mean flow velocity, in case of pipe Darcy friction factor depends strongly on the relative roughness of pipe's inner surface. Darcy-Weisbach friction factor f is found to decrease with the increase of aspect ratio (ratio of the width of the channel to the depth of flow) (A.Recking et al. 2008).

1.1 Velocity distribution in open channels

Velocity in an open channel flow continuously fluctuates because of friction generated from the boundary. The velocity distributions in open channels are usually unsymmetrical due to the presence of the free surface and bed surface.

In case of very wide-open channels the velocity distribution in the central region of the section must have the same as it would be in a rectangular channel of infinite width. In wide-open channels, the sides of the channel have practically no influence on the velocity distribution in the central region.

1.2 Boundary shear stress distribution in Open Channel

Boundary shear plays a very important role in estimating the flow carrying capacity of a channel, sediment transportation, erosion of the river. For smooth and rigid channels boundary shear has been studied by many researchers.
In the case of mobile beds of sand or other granular material at the lower boundaries of channel behave in distinctly different ways because the dimensionless shear stress at the boundary is increased (Kenneth C. Wilson 1989). This dimensionless stress or Shields ordinate, Y, is defined as

$$Y = \frac{\tau}{\rho_f} * g * (S - 1) * d \qquad (1)$$

Where τ is boundary shear stress, ρ_f is the density of the fluid, g is acceleration due to gravity , S is the ratio of the density of solid to the density of fluid, and d is the diameter of particle . When Y exceeded from some critical value the movement of solid particle occurred i.e it could be noted that until Y didn't exceeded some critical value till movement of bed the couldn't occurred.

1.3 Sediment Transport

Sedimentation is a naturally occurring process, because of that control over it is very difficult. The problem of sedimentation occure in an open channel flow consists of (1). Erosion at the place of the source (2). Transportation of sediment through the water.(3). Deposition in the channel where the velocity of the fluid is less.

1.4 Friction Factor

The friction factor is considered another important resistance parameter that affects the flow in an open channel. The values of the friction factor depend on various parameters and mainly on those parameters that affect Manning's roughness coefficient. Amongst a host of factors, the vegetation, sediment, sand and its type, height and density are the basically principal factor that influences the magnitude of friction factor.

2. Theoretical Background

2.1 Reynolds number

$$Re = UR/\vartheta \qquad (2)$$

Reynolds number value for laminar flow should be below 500 and for turbulent flow same must be more than 2000.In the case of rough flows, the friction factor *f* is not dependent on the Reynolds number.

2.2 Roughness Reynolds numbers

$$Re^* = u^* k_s/\vartheta \qquad (3)$$

It is used to define the resistance due to the flow viscous effects on the channel boundary elements, where u* (Shear velocity=$\sqrt{gRS}$) and ϑ is kinemathe tic viscosity of water (Tetsuro Tsujimoto).
For the cases of flow in the transition zone it ranges 5<Re^* >70 and for fully rough turbulent flow regimes $Re^* \geq 70$.

2.3 Froude numbers

$$Fr = \frac{U}{\sqrt{gH}} \quad (4)$$

indicate a few subcritical flows (*Fr*<1), a few critical flows (*Fr*»1), and mainly supercritical flows (*Fr*>1).

2.4 Friction Factor by Darcy (1939)

Darcy–Weisbach equation is an empirical equation, which relates the head loss, or pressure loss, due to friction along a given length of pipe to the average velocity of the fluid flow for an incompressible fluid. The equation is named after Henry Darcy and Julius Weisbach.

The Darcy-Weisbach relation is usually preferred in research experiments as it is nondimensional.

$$\sqrt{8/f} = \frac{U}{u^*} = \frac{U}{\sqrt{gRS}} \quad (5)$$

Where *f* is the friction factor,$u^*=\sqrt{gRS}$ shear velocity, U is the mean flow velocity and *R* is the hydraulic radius.,for uniform flow in open channels, the energy slope *S* is the geometric slope S_0 (Nikuradse et al. 1933).

2.5 Friction Factor by Nikuradse - Keulegan (1938)

$$\sqrt{\frac{8}{f}} = E + 5.75\log(\frac{R}{k_s}) \quad (6)$$

Keulegan(1938) showed that E might vary on a small scale with the shape of the channel which lies between 6 to 6.25.

Where the mean diameter D is often used for and Nikuradse equivalent grain roughness concept k_s is usually assumed to be proportional to representative sediment size d_x.

2.6 Friction Factor by Engelund and hansan (1966)

$$\sqrt{\frac{8}{f}} = 4.27 + 5.75\log(\frac{R}{D_{65}}) \quad (7)$$

This is a semi-logarithm equation in which D_{50} has been used in place of D_{65}.

2.7 Friction Factor by Cao (1985)

$$\sqrt{\frac{8}{f}} = 3.75 + 5.91\log\left(\frac{R}{D}\right) \quad (8)$$

The equation is valid for bed load transport with semi-logaritm coefficient 5.91.

2.8 Frictiion Factor by Julien(2002)

Julien (2002) had developed a model for bed load sediment rate which could be expressed as, q_0> 0.1.

$$\sqrt{\frac{8}{f}} = 5.75\log\left(\frac{2R}{D}\right) \quad (9)$$

Where 5.75 is semi-logarithm coefficient.

2.9 Friction Factor by A.Recking(2008)

Two equation has given below which develop by Recking(2008).

$$\sqrt{\frac{8}{f}} = -1 + 9.5\log(\frac{R}{D}) \tag{10}$$

This semi-logarithm equation is valid for R/D<16.9.

$$\sqrt{\frac{8}{f}} = 3.6 + 5.75\log(\frac{R}{D}) \tag{11}$$

This semi-logarithm equation is valid for R/D>16.9.

2.10 Friction Factor by Sumit Kumar Banerjee (2016)

This semi- logarithm equation is valid for a range of R/D value less than 16.9, also values even less than 2.

$$\sqrt{\frac{8}{f}} = 3.55\ln(\frac{R}{D}) + .29 \tag{12}$$

3. About Data Set

G.K.Gilbert et al.(1915)

The slope of experimental setup i.e flume was constant also the floor of flume was level, and the sideboards that formed the banks of the channel were just above the upstream end and decreased in steps toward the downstream end. In flume sediment was put in by gravity through a feed system where the sand was made mobile by having a small amount of water coming in on top of the sediment storage tank. During studied, it founded that depend variable was the slope of debires bed. During experiment mean velocity was computed from discharge, width and depth.

A.S.Paintal et al.(1971)

The bedload experiment had carried out in a tilting flume of St. Anthony. Falls Hydraulic Laboratory. The water had taken from the Mississippi river through the laboratory supply system to the entrance of the flume entrance chamber.
Manning's rugosity coefllcient for the inside surface was founded 0.00923. The flume is rectangular in cross-section. It approximate inside dimension was, length = 50 ft, width = 3 ft and depth = 1.25 ft. The flume was a steel structure with painted side walls forming a hydraulically smooth surface.

Grame M. Smart et al. (1983)

The experiment had done in a tilting laboratory flume, the flume had its own water circuit with a pump. During experiment considerable quantities of sediment had handled because of that two pairs of exchangabl e sediment hoppers were used . When the upper hoppers emptied the experiment was halted and the hoppers exchanged. The f lume was 6 m long and 0.2 m wide.

Graf and Suszka et al. (1987)

Flume experiments carried out in a 0.4m wide and 12m long flume with a variable slope. Three types of gravels were used to construct flat beds in the flume. The diameters of the used gravels were 7.29, 9.5 and 12.0mm. The flow measurements were carried out through a propeller current meter (the diameter of the propeller is 3mm). The flow was introduced to the flume from a constant-head tank through a variable valve, and the flow discharge was measured by a triangular wier at the end of the flume. During experiment , S=0.001-0.01, Re=1000-4000, Fr=0.12-0.82 and h/d=0.6-15.0 and uniform flow condition was maintained.

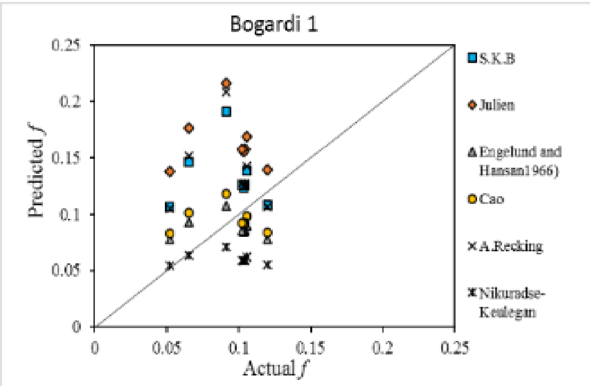
Dieter Rickenmann et al.(1992)

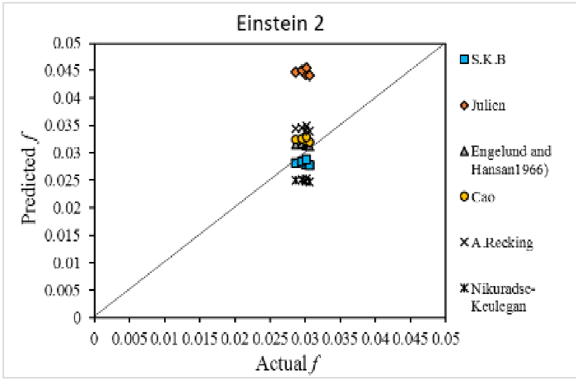
Experimets conducted in a 20.1 cm wide and 5 m long flume. During experiment commercially available opalinus clay was added to the water so as to obtained different clay concentration levels. The maximum density of clay suspension was about 1.36g/cm^3. During experiment bed slope S was varied between 7% to 20% and fluid flow rate Q between 10 to 30l/s.

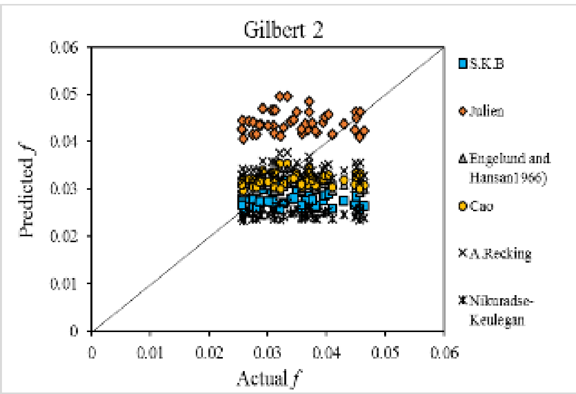
Table 1 Parameter of Various Anthers

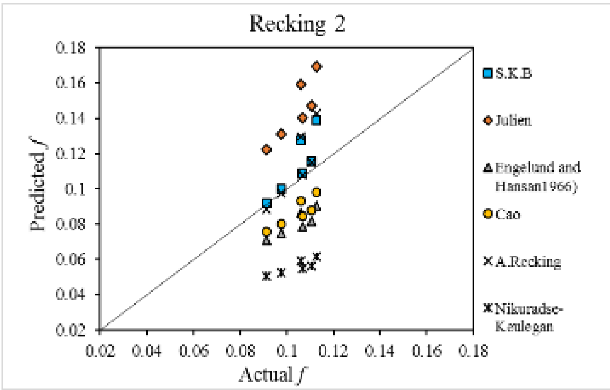
Data Set of Auther		Width(m)	Slope(m/m)	U(m/s)	H(m)	R(m)	D(mm)
Bogardi	1	0.3-0..823	0.0104-0.0160	0.69-1.06	0.04-0.087	0.0389-0.0721	6.8
	2	0.823	0.0172-0.0245	0.74-0.92	0.034-0.054	0.0332-0.0517	6.8
	3	0.3-0.823	0.0119-0.0176	0.79-1.04	0.086-0.129	0.083-0.112	10.3
	4	0.3-0.823	0.017-0.0245	0.84-1.07	0.059-0.092	0.0506-0.089	10.3
Einstein	1	0.307	0.0128-0.0187	1.89-2.05	0.119-0.133	0.0979-0.1023	0.3
	2	0.307	0.014-0.0173	1.9-2.02	0.128-0.141	0.0909-0.0984	0.9
	3	0.307	.0034-0.0258	0.73-2.22	0.093-.12	0.0706-0.908	1.3
Gilbert (1915)	1	0.366-0.598	0.0039-0.0055	0.75-0.90	0.055-0.074	0.045-0.07	0.5
	2	0.201-0.597	0.0056-0.0065	0.77-1.07	.045-.091	0.0450-0.068	0.5
	3	0.201-0.6	0.0055-0.008	0.75-1.13	0.040-0.068	0.030-0.070	0.5
	4	0.201-0.403	0.0080-0.0089	0.67-1.02	0.037-0.080	0.033-0.058	0.5
Graf Suszka (1987)	1	0.6	0.005	1.01-1.22	0.16-0.259	0.14-0.2126	12.2
	2	0.6	00.75	0.92-1.38	0.11-0.237	0.1078-0.2	12.2
	3	0.6	0.009	0.92-1.37	0.107-0.199	0.0993-0.1732	12.2
	4	0.6	0.01	0.93-1.43	0.104-0.192	0.0969-0.1679	12.2
	5	0.6	0.0125	0.92-1.31	0.08-0.157	0.0754-0.1368	12.2
A.S. Paintal (1971)	1	0.914	0.00117-0.00152	0.39-0.61	0.083-0.113	0.0764-0.113	2.5
	2	0.914	0.0015300.00163	0.51-0.76	0.082-0.167	0.0751-0.1427	2.5
	3	0.914	0.00172-0.00189	0.41-0.65	0.061-0.102	0.061-0.102	2.5
	4	0.914	0.002-0.00216	0.53-0.85	0.054-0.116	0.0518-0.1077	2.5
	6	0.914-0.919	0.0045-0.0047	0.53-0.85	0.053-0.117	0.054-0.109	8
A.Recking (2008)	1	0.25	0.01	0.75-0.8	0.053-0.075	0.0467-0.0648	2.3
	2	0.1	0.02	0.5-0.71	0.02-0.035	0.018-0.0294	2.3
	3	0.1	0.03	0.4-0.66	0.013-0.024	0.0118-0.0216	2.3
	5	0.1	0.07	0.5-0.67	0.012-0.015	0.0117-0.0146	2.3
	6	0.1	0.03	0.57-0.6	0.025-.027	0.025-0.027	4.9
Grame M. Smart (1983)	3	0.2	0.1	1.25-2.17	0.02-0.058	0.019-0.0514	2
	5	0.2	0.2	2.31-2.56	0.022-0.039	0.0202-0.036	2
	7	0.2	0.5	1.2-1.63	0.042-0.061	0.0382-0.0536	4.2

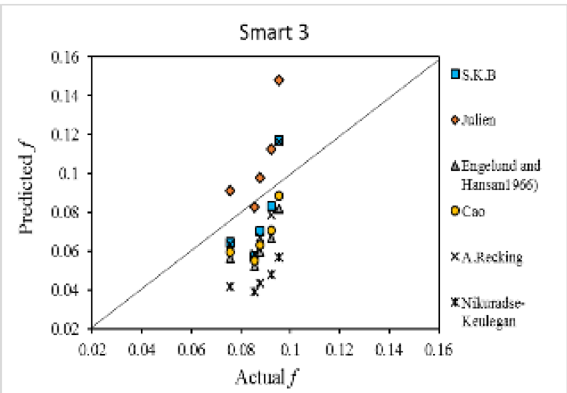
	9	0.2	0.1	0.98-2.48	0.026-0.06	0.0246-0.0526	4.2
Cao(1985)	1	0.6	0.005	1.01-1.3	0.166-0.218	0.1434-0.1755	11.5
	2	0.6	0.0075	1.05-1.28	0.127-0.182	0.1142-0.1573	11.5
	3	0.6	0.01	0.99-1.42	0.102-0.177	0.0946-0.1544	11.5
	4	0.6	0.01-0.03	1.64-1.25	0.091-0.256	0.0921-0.2149	22.2
	5	0.6	0.05	0.97-1	0.059-0.077	0.057-0.0755	22.2
Dieter Rickenman (1992)	1	0.2	0.07	1.16-1.46	0.055-0.086	0.051-0.0608	10
	2	0.2	0.1	1.11-2.18	0.045-0.078	0.040-0.0706	10
	3	0.2	0.15	1.18-2.22	0.038-0.074	0.0364-0.0686	10
	4	0.2	0.2	1.25-2.75	0.032-0.061	0.0304-0.0562	10
Sumit Kumar Banerjee (2016)	1	0.77	0.0025	0.07-0.405	0.014-0.1004	0.013-0.08	6.5

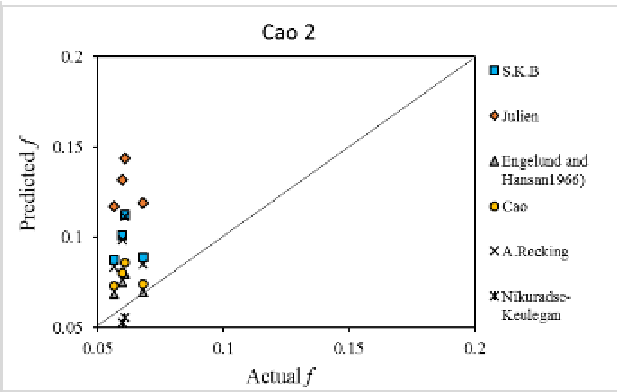












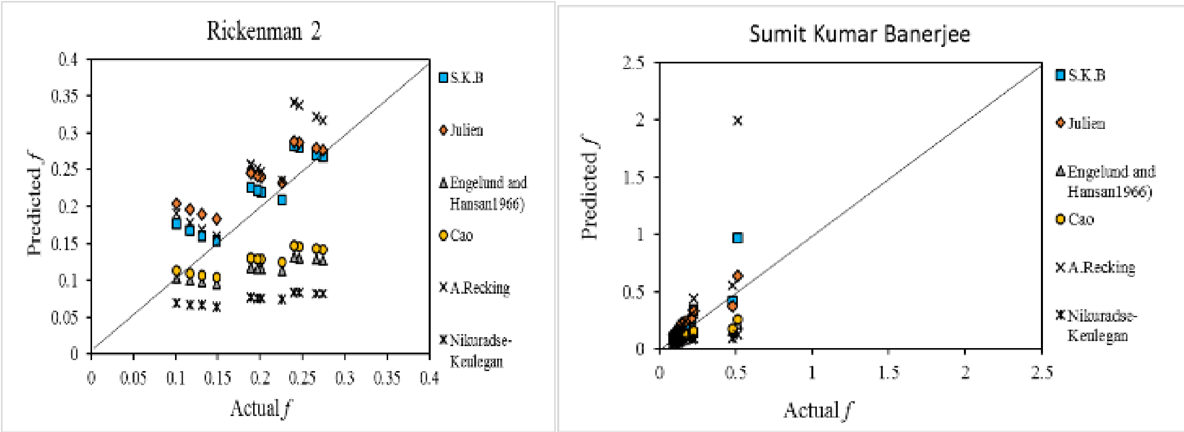


Fig Set 2: Few figures of various researchesr represent the variation of actual *f* vs predicted *f* for various data set.

4.Result and Discussion:

When H/W increases friction factor found to decreases because the increase of the flow depth causes decrase in boundary friction factor.

For higher H/W values through **Julien(2002)** method founded low friction factor value also among all method **Julien(2008)** method provided the highest error because the method is taking care depth of flow.

Low Reynolds number value except **Julin (2002)**, **Sumit Kumar Banerjee (2016), A.Recking(2008)** give satisfactory friction factor value with less error because these method take care of inertia effect where as among **Engelund and hansan (1966)** , **Cao(1985), Nikuradse- Keulegan (1938)** show very less friction factor value with high error because it is not taking inertia force.

Out of this method of friction factor computation of an open channel flow **Cao (1985)** shows the least error for **Gilbert (1915)** data set, **Nikuradse- Keulegan (1938)** method show less error for **Bogardi (1939)** and **A.S.Paintal (1971)** data set, **A.Recking(2008)** shows less error for maximum data of **Sumit kumar Banerjee (2016)** and **G.M.Smart (1983)** , **Engelund and hansan (1966)** shows less error among model of other auther for **Dieter Rickenman (1992)** and **Cao (1985)** data set because the method takes to care for supercritical flow with higher roughness value. The Nikuradse- Keulegan (1938) method show a high error for **sumit kumar Banerjee (20016)**, **A. Recking(2008), Dieter Rickenman (1992)** and few data set of **Cao(1985). Julien(2002)** method show a high error for **Gilbert(1915)**, **G.M. Smart(1983)** and **A.S.Paintal** data set. **A.Recking(2008)** show a high error for **Einstein(1950)** data set which should not use for friction factor calculation for higher Froude number and roughness Reynolds number.

5. Conclusion:

we observed that friction factor decrease with there is an increment in H/W value of various auther.Data set which having high H/W value that data set show high error. These method is taking care of intertia effect is show less error. Among all model A.Recking (2008) model is the best model for friction factor calculation.

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