BED LOAD EFFECT ON FLOW RESISTANCE IN MEANDERING OPEN CHANNEL FLOWS

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ABSTRACT

River flow resistance i.e., friction factors have significant influence on river's conveyance capacity and sediment transport. Darcy's friction factor *f* is an important factor which helps to predict the stage discharge relationship in open channel. Flow resistance in rivers and open channels is of enormous importance in river engineering and dynamics. 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. In this research work, the meander path considered is from one bend apex to the next bend apex which changes its course at the cross-over. Bend apex is the position of maximum curvature and cross-over represents the section at which the sinuous channel changes its sign. In this research work, variation of velocity profile along the width and depth of the channel has been methodically analyzed at different cross-sections along a meander path of a sinuous channel of 60° cross-over angle. Longitudinal velocity distributions along the width and depth of the channel, i.e., the horizontal and vertical velocity profiles are analyzed. The present research work is intended to examine the various flow characteristics of a meandering channel with bed load. Study done on the variation of flow resistance in terms of the Darcy-Weisbach friction factor in meandering open channel flows under bed load condition over different discharges, different flow depths. Analysis done on interdependency of various factors such as Reynolds number (R_e), Roughness Reynolds number (R_{e^*}), Froude's number (F_r), ratio of flow depth to width of main channel y/b, Relative Submergence (R/D) with respect to the friction factor in a meandering channel under bed load condition.

Keywords: *Meandering open channel, Gravel bed, Bed load, Velocity Distribution , flow resistance*

1. INTRODUCTION

A meander, in general, is a bend in a sinuous watercourse. It is formed when the moving water in a river erodes the outer banks and widens its valley. Meandering represents a degree of adjustment of water and sediment load in the river. A stream of any volume of water may assume a meandering course, alternatively eroding sediments from the outside of a bend and depositing them on the inside. Due to this outside bank becomes deeper than the inside bank. The result is a snaking pattern as the stream meanders back and forth across its down-valley axis.Many researchers the flow resistance represented by the Darcy-Weisbach friction factor (*f*). For a uniform flow in open channels, the energy slope *S* is the geometric slope *S0* and this relation is usually encountered in the following form:

$$\sqrt{\frac{8}{f}} = \frac{U}{\sqrt{gRS_o}} = \sqrt{\frac{U}{u*}} \qquad (1)$$

The above equation is the flow resistance equation. The friction factor *f* (also called the friction coefficient) is constant and depends on the (fixed) wall roughness only. It may also be called the resistance coefficient when the resistance equation takes into account additional head losses. This coefficient is related to Manning's *n* and Chezy's *C* coefficients by the following equation (Yen 2002):

$$\sqrt{\frac{f}{8}} = \frac{n}{R^{1/6}}\sqrt{g} = \frac{\sqrt{g}}{C} = \frac{\sqrt{gRS}}{U} \qquad (2)$$

The Darcy-Weisbach relation is usually preferred in research experiments as it is non dimensional (contrary to *C* $[L^{-1/2}T^{-1}]$ and *n* $[TL^{1/3}]$) and the results obtained for a given experimental sets are directly extended to other flow conditions. Moreover, it is clear that the smooth walls exert a resistance to the flow far lower than the gravel bed resistance. Thus the hydraulic radius R calculated from the inlet flow discharge and the measured mean flow velocity U corresponds to an overall flow resistance generated by both the smooth side walls and the gravel bed.

Shukry (1950), Rozovskii (1961) and Onishi et at. (1976) conducted experimental work to identify both the main sources of extra energy losses in channel bends and the parameters which will affect such energy losses. Also it is concluded that the major sources of energy loss in channel bends can be attributed to: a) skin friction along the channel boundaries; b) increased bed friction caused by secondary flows and c) internal fluid friction due to secondary flows. The parameters on which energy loss in a channel bend is deemed to depend are: a) geometrical conditions, such as bend radius r_c, bend angle θ, and the channel cross section shapeb) hydraulic conditions, such as flow depth h, Reynolds number Re and Froude number Fr; and c) roughness condition, i.e. friction factor f, n, C etc.

Khatua (2008) carried out experiments on one straight compound channel has the main channel dimension of 120 mm×120 mm, and flood plain width $B = 440$ mm and two meandering compound channels having sinuosity of 1.44 and 1.91. It is resulted from the variation of the resistance factors Manning's n, Chezy's C, and Darcy –Weisbach's f with flow depths. He found out Stage-discharge relationship ranging from inbank to the overbank flow and stated that flow distribution becomes more complicated due to interaction mechanism as well as with sinuosity.

Recking (2008) investigated a rectangular tilting flume of 10m long and 0.05-0.25m wide with varying slope from 0 to 10%. A total of 143 flow conditions were studied by using bed materials with mean diameter 2.3, 4.9, 9.0 and 12 mm. He approached a simple method for calculating friction factor with respect to the relative depth. Darcy-Weisbach friction factor expressed in terms of hydraulics radius of rough bed, slope, shear velocity and vertical averaged flow velocity.

Wormleaton et al., (2005) performed experiments in a meandering channel with a sinuosity of 1.34,cross over angle of 60^0 and with graded sand beds. They observed that when flow in a meandering channel is at, or below, bankfull, the major source of secondary flow is centrifugal circulation generated around the bend apex.The circulation creates and maintains the point bar on the inner bank. With graded bed material, the smaller size fractions are driven further toward the inner bank around the apex producing a transverse variation in bed material size.

2. EXPERIMENTAL SETUP AND METHODOLOGY

For this study the experimental setup is constructed and made available at the Fluid Mechanics and Hydraulics Laboratory of NIT, Rourkela.

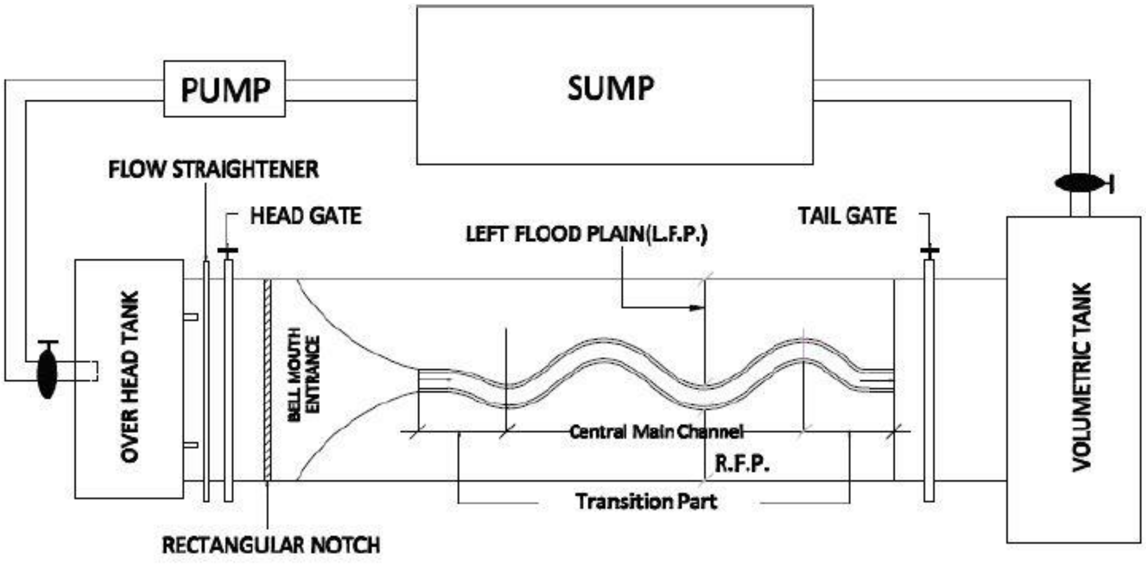


Figure 1. A schematic view of the experimental meandering channel setup

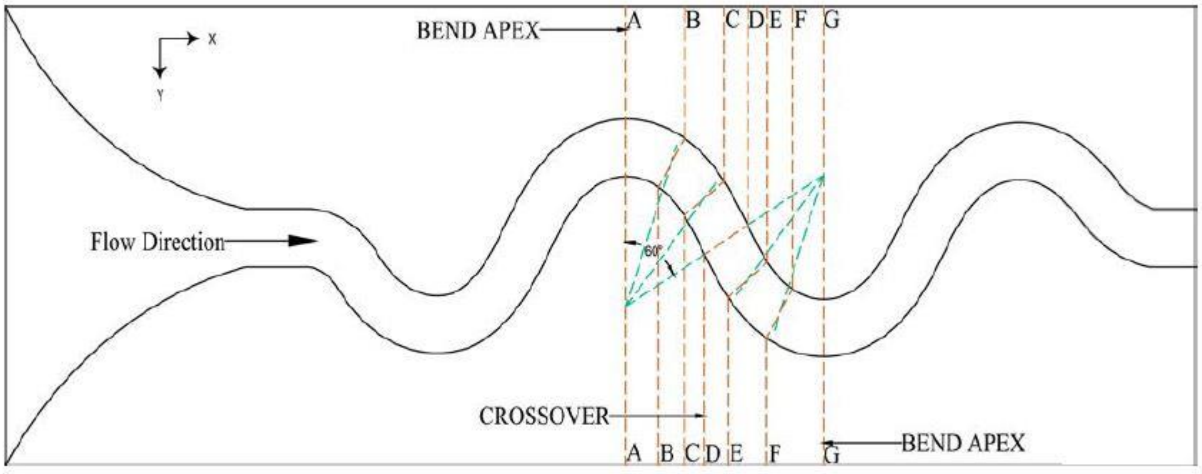


Figure 2. Test sections on the meander for velocity profiles

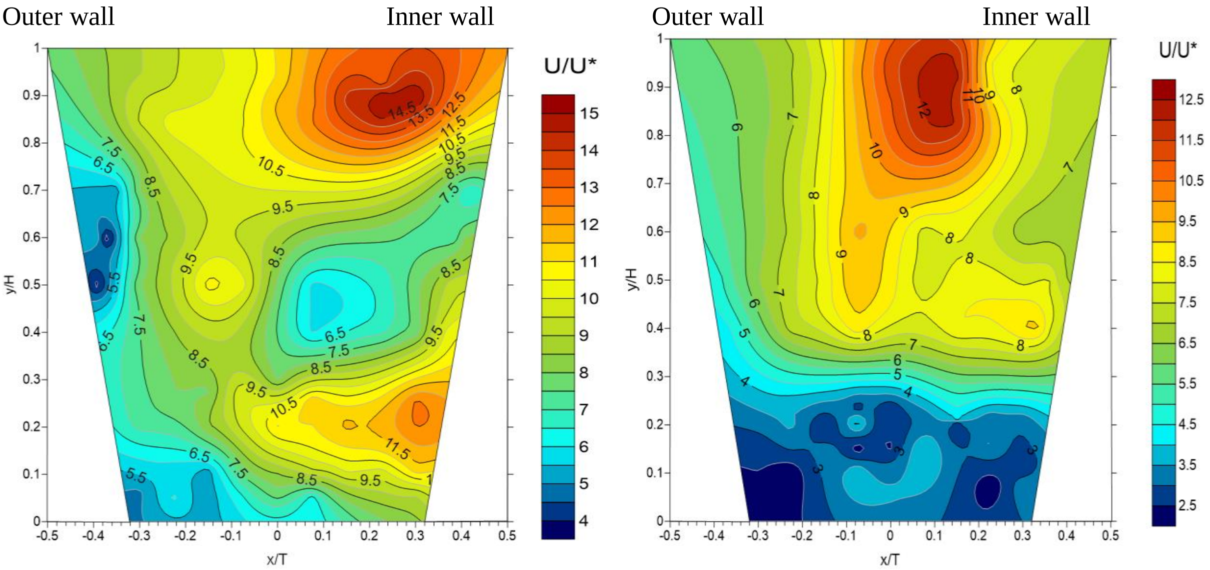
Table 1. Experimental Channel Parameters

Parameter	Value
Sinuosity of main channel, s	1.35
Valley slope, So	0.00165
Main channel width, b	0.33m
Bankfull depth, H	0.125m
Meander belt width, B_{mw}	2.35m
Width of channel, B	3.95m
Wavelength,λ	1.25m
Radius of curvature, r	0.78m
Amplitude, A_m	0.95m

The slope of the flume was measured manually by considering downstream water depth and upstream water depth in the flume and using the length of flume between two sections. The study of open channel flow is generally done under the conditions of uniform flow. In the case of meandering channels, the establishment of uniform flow is quite difficult. So, experiments in meandering channels have to be performed under quasi-uniform flow conditions. The calibration of the rectangular notch was done first. The actual discharge was calculated by measuring the time required for a unit depth increase in the volumetric tank and then multiplying it with the area of the volumetric tank. Indian Standard size of sieve used for sieve analysis as given as for coarse aggregate- 19 mm, 16 mm, 13.2 mm, 11.2 mm, 10 mm,6.3 mm, and for fine aggregate 4.75 mm, 2.36 mm, 2 mm, 1 mm. The whole channel is fabricated using D_{50} value of gravel size 9mm. In this study, the discharge measured using volumetric tank and for drawing velocity contours the measurements were carried out using a micro-Acoustic Doppler Velocimeter (ADV).

3. RESULTS AND ANALYSIS

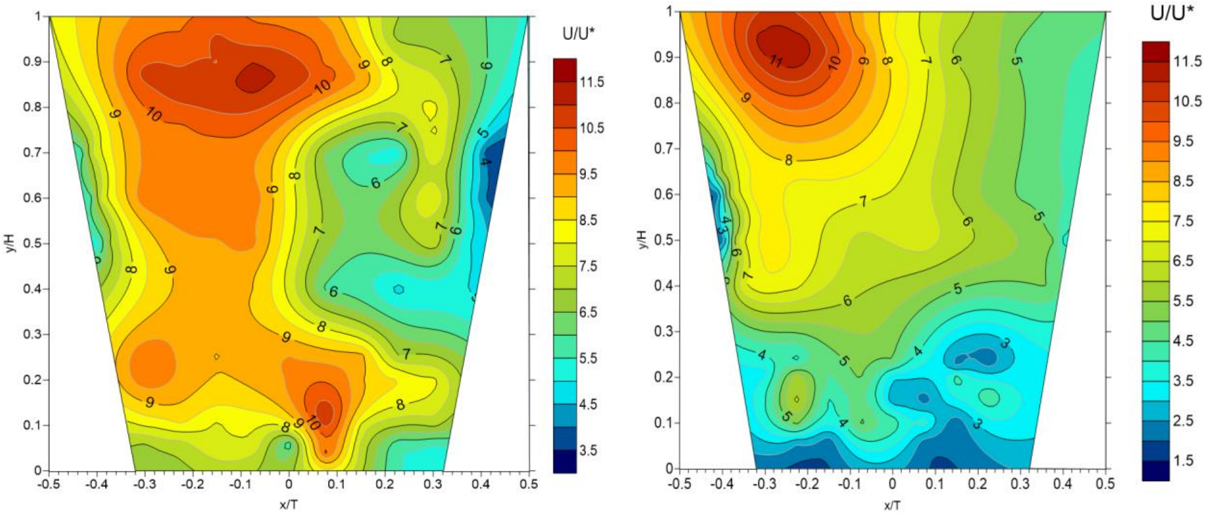
The velocity contours of both clear water (without bed load) and with bed load are shown in below.



(a) Without bed load (b) With bed load

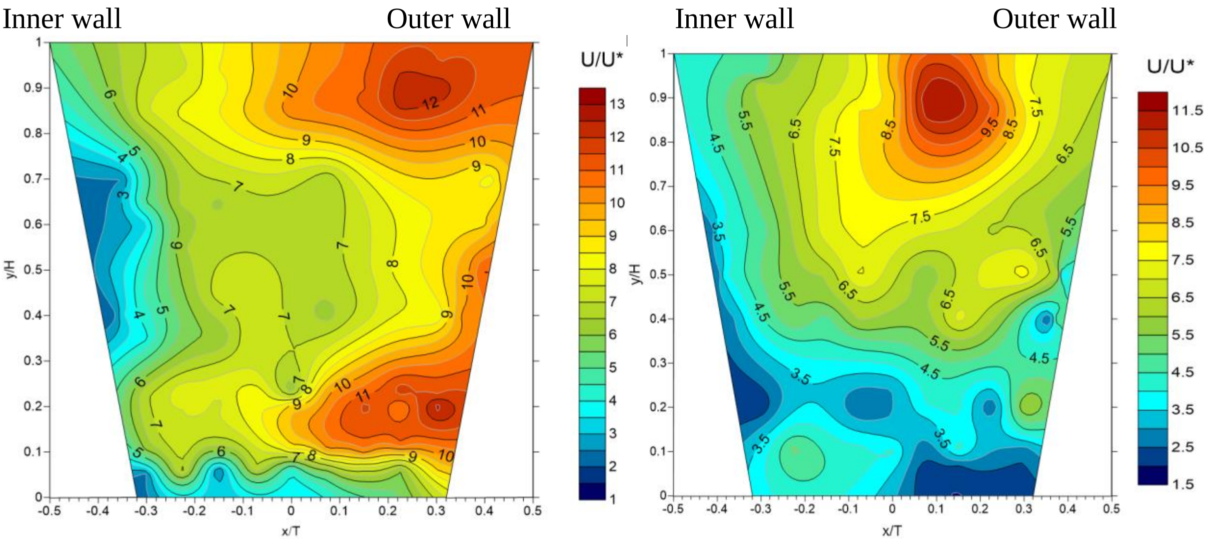
Figure 3. Distribution of normalized streamwise velocity at bend apex A

Cross over region:



(a) Without bed load (b) With bed load

Figure 4. Distribution of normalized streamwise velocity at cross over region D



(a) Without bed load (b) With bed load

Figure 5. Distribution of normalized streamwise velocity at cross over region D

The above velocity contours for without bed load showing that at bend apex A velocity maximum at inner wall, at cross over region D maximum velocity at center, at bend apex G velocity maximum at outer wall. In case of with bedload (D_{50}=9mm) also showing the same pattern but with some variation shown in above figures.

The interdependency of various parameters with friction factor as shown below graphs:

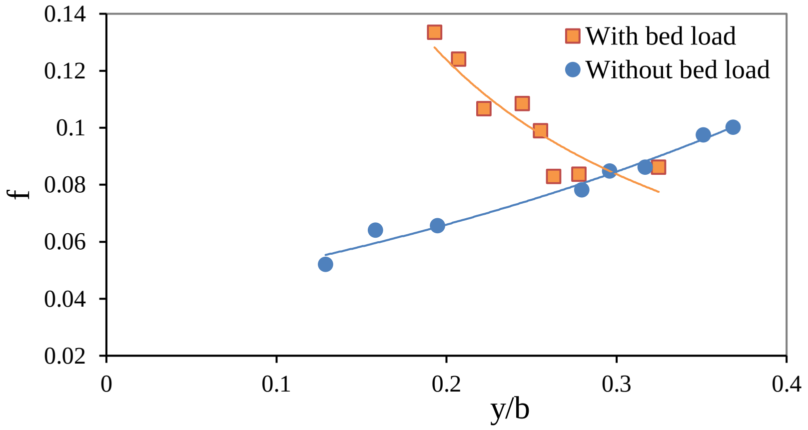


Figure 6. Variation of friction factor with y/b

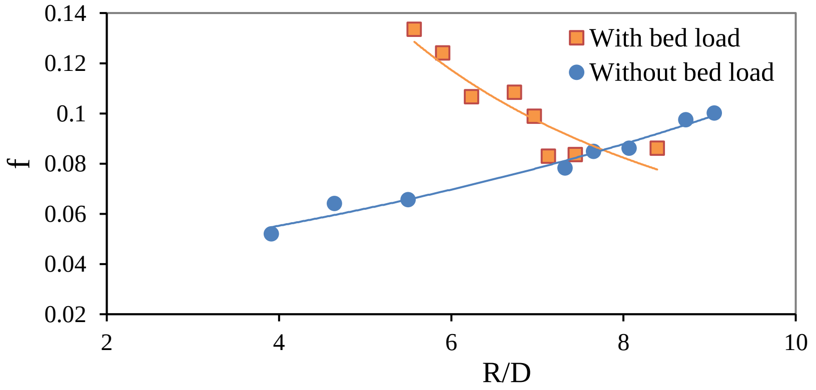


Figure 7. Variation of friction factor with R/D

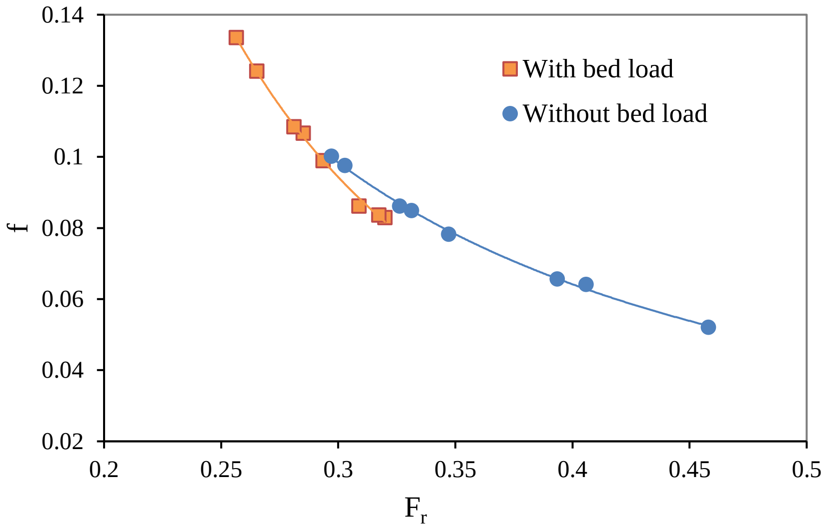


Figure 8. Variation of friction factor with froude's number

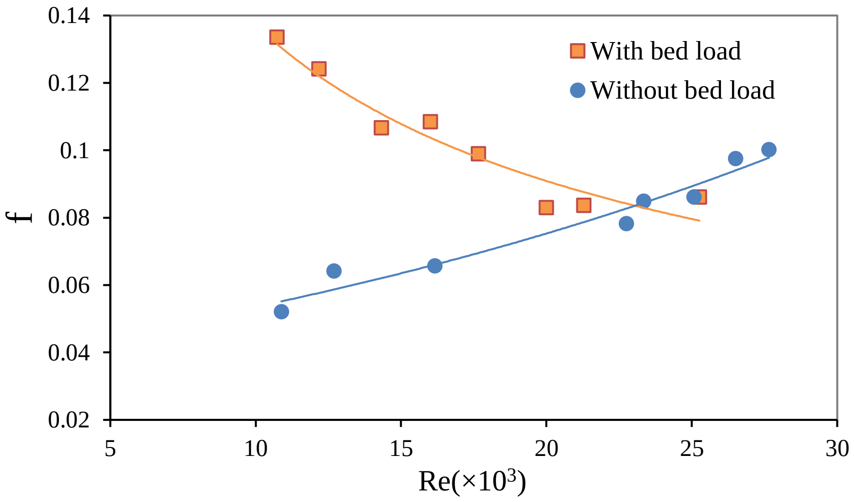


Figure 9. Variation of friction factor with Reynolds number

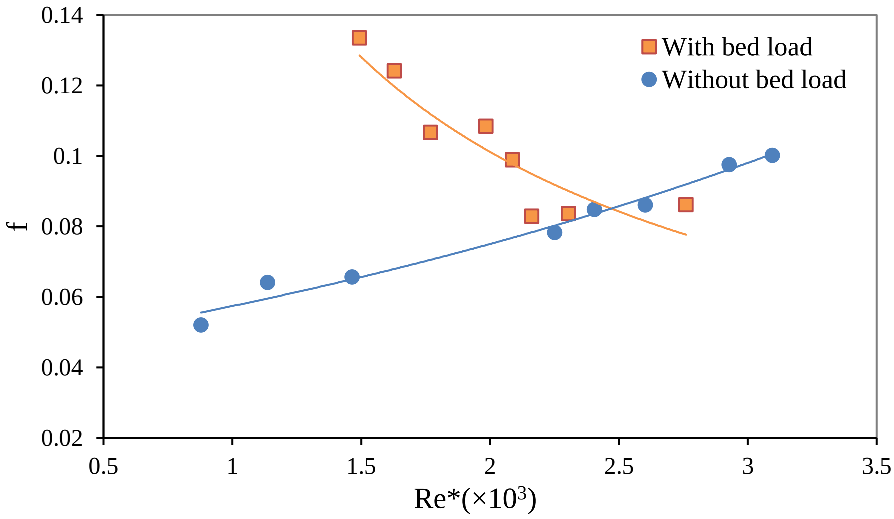


Figure 10. Variation of friction factor with Roughness reynolds number

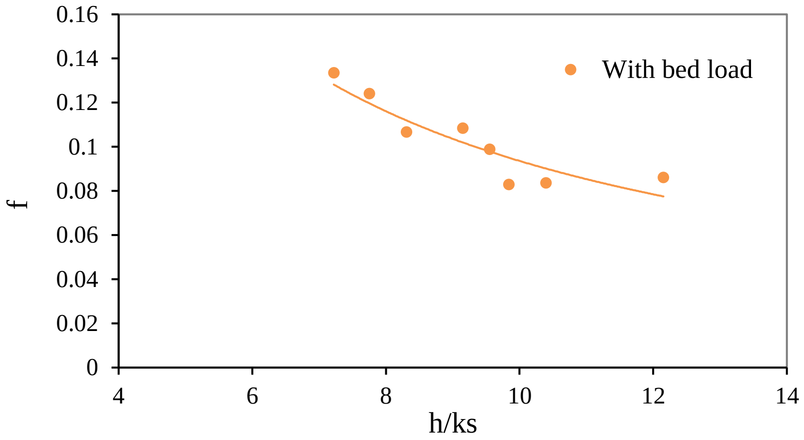


Figure11. Variation of friction factor with relative submergence

4. CONCLUSIONS

The effect of bed load on flow friction factor was studied experimentally in both without and with bed load. Analysis of these data showed that bed load produces a significant additional resistance.

1. The friction factor in clear water flow or without bed load increases with flow depths. In case of bed load condition the friction factor at the bed level maximum and it decreases with flow depths.
2. The velocity distribution for with and without bed load shows significance variation at bend apex A, cross over D, bend apex G.
3. Friction factor found to be functions of velocity, discharge, shear velocity, hydraulic radius, grain size diameter, sinuosity of meandering channel.

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