Available online at www.sciencedirect.com
ScienceDirect
International Journal of Sediment Research 29 (2014) 501-508
INTERNATIONAL JOURNAL OF SEDIMENT RESEARCH
www.elsevier.com/locate/ijsrc

Study on changes in bed characteristics and friction factor in the presence of wash load in suspension

N. K. KHULLAR[1] and Jaspal SINGH[2]

Abstract

Results of an experimental study on the effects of different concentrations of wash load on the size of bed features and resistance to flow in a laboratory flume are presented. The experiments were carried out under different hydraulic conditions in a 30 m long, 0.204 m wide and 0.5 m deep tilting flume under clear water condition and in the presence of different concentration of wash load in the flow. The bed material used consisted of uniform sediment of size 0.96 mm. Analysis of the data indicates that the characteristics of the bed features change and friction factor increases in the presence of different concentration of wash load in the flow. The reasons for changes in the characteristics of the bed features and increase in friction factor in the presence of wash load are identified and a relationship for predicting friction factor in the presence of wash load has been established.

Key Words: Flow resistance, Friction Factor, Suspended load, Wash load, Bed characteristics, Form resistance, Grain resistance

1 Introduction

Flow computations in rigid-boundary channels and alluvial channels require information about resistance to flow. Significant amounts of very fine material load (also termed as wash load) enter rivers during the rainy season. This load is mostly carried in suspension and is known to affect the resistance to flow. The problem of determination of flow resistance in open channels in the presence of such suspended load remains unsolved in spite of numerous investigations carried out during the past 60 years or so. In the presence of suspended load, the resistance to flow decreases, on the one hand, due to damping of turbulence, but it increases, on the other hand, due to more energy loss in the process of suspension and increased viscous resistance (Garde and Ranga Raju, 2000). The net result- either a decrease or an increase in flow resistance- depends on the relative magnitudes of the above two effects. The bed features in alluvial channels also change due to fines in suspension which causes increase in resistance to flow (Khullar, 2003).

2 Review of literature

The flow structure and hence resistance to flow in a porous bed is different from that over a rigid-bed transporting sediment in suspension (Nikora and Goring, 2000). The problem is more complex in alluvial channels as the configuration of the channel bed may also change with the change in concentration of suspended load (Khullar, 2003). The changing bed conditions make it extremely difficult to describe the boundary resistance by a constant value of resistance coefficient (Garde and Ranga Raju, 2000).

Many studies are available in literature concerning the effect of suspended sediment on resistance to flow. Vanoni (1946), Vanoni and Nomicos (1960), Einstein and Chien (1955), Yano and Diado (1965), Gyr (1967), Muller (1967), Kikkawa and Fukuoka (1969), Ippen (1973), Imamato et al. (1977), Pullaiah (1978), Itakura and Kishi (1980), Coleman (1981) and Lau (1983) are amongst the earlier investigators who studied the effect of suspended sediment on resistance to flow. Arora et al. (1986), Khullar et al. (2007) and Khullar and Samaiya (2012) have presented detailed review of these studies.

Khullar et al. (2007) carried out experiments in a 0.204 m wide and 30 m long flume using coarse uniform and nonuniform sediments as bed material and 0.064 mm fine sediment as wash material and pointed out that in the absence of any change in bed features the resistance to flow due to the presence of different concentration of wash load decreases in closely packed nonalluvial and alluvial bed channels (CPNAA channels) and can be computed using

[1] Prof.-cum Head, Department of Civil Engineering, PAU Ludhiana-141004, E-mail: khulrdce@rediffmail.com
[2] Prof., Department of Civil Engineering, PAU Ludhiana-141004, E-mail: jaspalsingh@pau.edu
Note: The original manuscript of this paper was received in May 2013. The revised version was received in Sept. 2014. Discussion open until Dec. 2015.

$1 - \frac{f}{f_o} = 10^{-5}(s-1)\frac{C\omega}{US}$. The value of the coefficient of determination (R^2) for this equation was 0.67. Here f is friction factor in the presence of wash load having volumetric concentration C in the flow, f_o is friction factor in clear water flow, U is the velocity of flow, S is the slope of the channel, s is the specific gravity of the wash material and ω is the settling velocity of the fine sediment. The data of one of the series was excluded while deriving this relationship as the bed features changed during the runs of this series and the resistance to flow increased during these runs. The resistance to flow due to the presence of different concentration of wash load increases and decreases in rigid bed channels depending upon the value of $C^{1/8}\left(\frac{u_* d}{\upsilon}\right)$. Here d is the size of the sediment in suspension. For $C^{1/8}\left(\frac{u_* d}{\upsilon}\right) < 0.65$, the value of friction factor in the presence of different concentration will be less than the value of friction factor for clear water flow and can be computed using $1 - \frac{f}{f_o} = 10^{-12}\left[(s-1)\frac{C\omega}{US}\right]^3 + 10^{-8}\left[(s-1)\frac{C\omega}{US}\right]^2 - 5\times10^{-5}\left[(s-1)\frac{C\omega}{US}\right]$ whereas, for $C^{1/8}\left(\frac{u_* d}{\upsilon}\right) \geq 0.65$ the value of friction factor will be more than for clear water flow and can be computed using $\frac{f}{f_o} = \exp\left(8*10^{-6}(s-1)\frac{C\omega}{US}\right)$. Here υ is the viscosity of water and u_* is the shear velocity.

It can be concluded from the above review that friction factor may increase or decrease due to an increase in the concentration of wash load in suspension in rigid boundary channels. For the closely packed non-alluvial and alluvial channels friction factor decreases in the presence of different concentration of wash load in the flow provided the bed features do not change during the passage of wash load through such channels. If the bed features change then the friction factor increases in the presence of wash load in suspension. For rigid boundary channels, friction factor increases or decreases depending upon the value of $C^{1/8}\left(\frac{u_* d}{\upsilon}\right)$. The method for predicting friction factor exists for the CPNAA channels and rigid bed channels. However no method is available for computing friction factor in the presence of wash load for alluvial channels where the bed feature change due to the change of concentration of wash load in the flow. Khullar (2003) performed experiments using uniform sediment of size 0.96 mm as bed material and with different concentrations of wash load in the flow. The characteristics of bed features and the changes in these characteristics due to presence of wash load were studied. The data of different runs using this bed material was designated as data of series 2UW. Similar data is not available in the literature, so the experimental data of 2UW series of Khullar (2003) is analyzed to develop a method for computing friction factor in the presence of different concentrations of wash load for the channels where the bed features change in the presence of wash load.

3 Experimental set-up and procedure

The experiments were performed in a recirculating tilting flume which was 30 m long, 0.204 m wide and 0.5 m deep. In the flume, there were a steel bottom, a glass wall on one side and a painted mild steel plate on the other side. Water was recirculated using a centrifugal pump located downstream of the tank collecting the out flow from the flume. A tailgate was provided for the adjustment of depth of flow in the flume. The discharge was measured with the help of a calibrated orifice meter located in the return pipe. The channel bed was prepared by spreading uniform sediment designated as 2U with d_{50} = 0.96 mm on the bed. The bed surface was made plane with the help of a wooden template. The thickness of the sediment bed was about 10 cm. The transported bed sediment was collected in a trap placed at the downstream end of the flume. Fine uniform sediment (designated as W) of 0.064 mm size was used as wash material. Other characteristics of the sediments used are given in Table 1.

Table 1 Characteristics of the sediments used in the present study

Sediment Designation	d_a (mm)	d_{50} (mm)	d_{65} (mm)	σ_g	M_k
2U	1.03	0.96	1.2	1.3	0.744
W	–	0.064	–	–	–

In Table 1, d_a is the arithmetic mean size, d_{50} is such a size that 50% of the particles are finer than it by weight, d_{65} is such a sediment size that 65 % of particles are finer than it by weight, σ_g is the geometric standard deviation and M_k = Kramer's coefficient of uniformity. W stands for wash material and 2U stands for uniform size.

3.1.1 Clear-water runs

The flume was first set at the desired slope. The sediment 2U was then poured in the flume and the bed prepared as per the procedure explained above. The sediment-laden bed was first saturated with water. The required discharge was then allowed into the flume and uniform flow conditions were obtained by adjusting the tailgate. The experiments were