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Research paper

Effect of bed roughness on grain-size distribution in an open channel flow

Debasish Pal*, Koeli Ghoshal

Department of Mathematics, Indian Institute of Technology Kharagpur, Kharagpur 721302, India

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Abstract

Grain-size distributions of suspended load were studied in a laboratory flume over five sediment beds having different values of bed roughness at three different flow velocities. The experiments had been performed to investigate the influence of bed roughness, flow velocity and suspension height on the grain-size distribution in suspension. This study focuses on the determination of the proportionality parameter β_n in suspension which is the ratio of sediment diffusion coefficient to the momentum diffusion coefficient of the nth grain-size class. An empirical equation for β_n has been proposed which is valid for a wide range of normalizing settling velocity of sediment particles and bed roughness. Also, the bed roughness effect is studied on the parameter β for total concentration in suspension and on the reference concentration, which is very important in suspension studies. The Rouse equation with modified β_n and β was surveyed to know the grain-size distribution and total concentration in suspension that agreed well when compared with the experimental data.

Keywords: Bed roughness; Diffusion coefficient; Flow velocity; Grain-size distribution; Rouse equation; Suspended load

1. Introduction

In an open channel sediment-laden turbulent flow, the transport of non-cohesive sediments over a sediment bed is divided into two broad categories: bedload and suspended load. The coarser fractions of the sediment which move very close to the bed by sliding, rolling and saltation, are known as bedload. The suspended load are the comparatively finer fractions which are transported through suspension surrounded by the fluid and come in contact with the bed occasionally. During transportation, the grain-size distributions of suspended sediment in open channel flow, have received much attention from sedimentologists and hydraulic engineers. Einstein (1950) studied in detail the relation of sediment transport to stream mechanics. Sengupta (1975) had shown by flume experiments that the controlling factors of grain-size distribution of suspended particles are flow velocity and suspension height over a sand bed of given composition. McLaren and Bowles (1985) presented a simple model for the distributions of sediment in transport which are related to their source by a sediment transfer function. Kuhnle (1993) had done a series of experiments over sand, gravel and sand-gravel mixture beds and concluded that all grain-size classes of sand and gravels begin to move at nearly the same bed shear stress. Lanzoni and Tubino (1999) experimentally showed that the mobility of different grain-size classes modifies the sediment transport capacity and also induces a longitudinal and a transverse pattern in sorting. Mazumder et al. (2005b) theoretically studied the grain-size distribution in suspension over sediment bed and verified by experimental data. The experimental data of grain-size distribution in suspension was studied by Ghoshal et al. (2011) from statistical view points. Among all the advection–diffusion approaches, the Rouse (1937) equation is one of the most widely used equation to determine the vertical concentration in suspension which treates the steady state suspended load over erodible sediment

* Corresponding author. Tel.: +91 7407989510.
E-mail addresses: bestdebasish@gmail.com, best1debasish@gmail.com (D. Pal).

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bed. The parameter β in the Rouse equation is an interesting topic of research for its physical interpretation and it depends on various factors of sediment-laden flow.

1.1. Previous work on β and β_n

Many investigations have been done on β which reported that it usually depends on particle characteristics, flow conditions, bed forms, suspension heights and various other factors. By experimental data from flume and field studies, Einstein and Chein (1955) suggested that β should be greater than unity. But Majumdar and Carstens (1967) experimentally showed that for fine particles $\beta \cong 1$ and for coarse particles $\beta < 1$. Van Rijn (1984b) proposed β, a function of normalizing settling velocity as $\beta = 1 + 2(\omega_s/u_*)^2$ within the range $0.1 < \omega_s/u_* < 1$ where u_* is the shear velocity and ω_s is the settling velocity of sediment particle in clear fluid. Graf and Cellino (2002) concluded that for small particles β is less or greater than unity over a movable bed without or with bedforms respectively and derived that $\beta = 0.3 + 0.75(\omega_s/u_*)$ where $0.2 < \omega_s/u_* < 0.6$. Wren et al. (2005) empirically derived $\beta = 1 + (y/d)^2$ as a function of flow depth where y is the vertical height and d is the flow depth. But all these above mentioned works are not concerned with the bed roughness effect on β. Regarding grain-size distribution, Mazumder et al. (2005a) investigated the bed roughness effect on β_n only for a limited set of data over different sediment beds and inconclusive on the behaviour of β_n with the change of bed roughness and other factors. A large number of articles on β are available in the literature, but for β_n the available literature is not that wide. It's a challenge to the researchers to study the effect of bed roughness on β_n and β in sediment-laden flow and to examine if there exists any mathematical relation between them or not.

In this article, the effect of bed roughness and other factors are extensively studied on β_n and β with the help of a large experimental data set. The main purpose of this present study are: 1) To study the effect of bed roughness, suspension height and flow velocity on β_n. 2) To examine that how β_n is mathematically related to bed roughness. 3) To modify the Rouse equation in terms of the new expression of β_n for determining the actual amount of grain-size classes in suspension and to verify with the experimental data. 4) To study the bed roughness effect on β for computing the total concentration in suspension as well as on the computed reference concentration together with verification of experimental data.

2. Experimental procedure

2.1. Experimental channel

Experiments were conducted in a re-circulating close-circuit open channel (Ghoshal, 2005; Mazumder et al., 2005a) designed at the Fluvial Mechanics Laboratory (FML) of Indian Statistical Institute (ISI) at Kolkata. The experimental channel has the dimension 10 m long × 50 cm wide × 50 cm high and the walls of the channel are made of perspex window to investigate the clear view of the movement of sediment particles. By the arrangement of pumps and valves the flow could be set at any desired speed up to 1.30 m/s. The

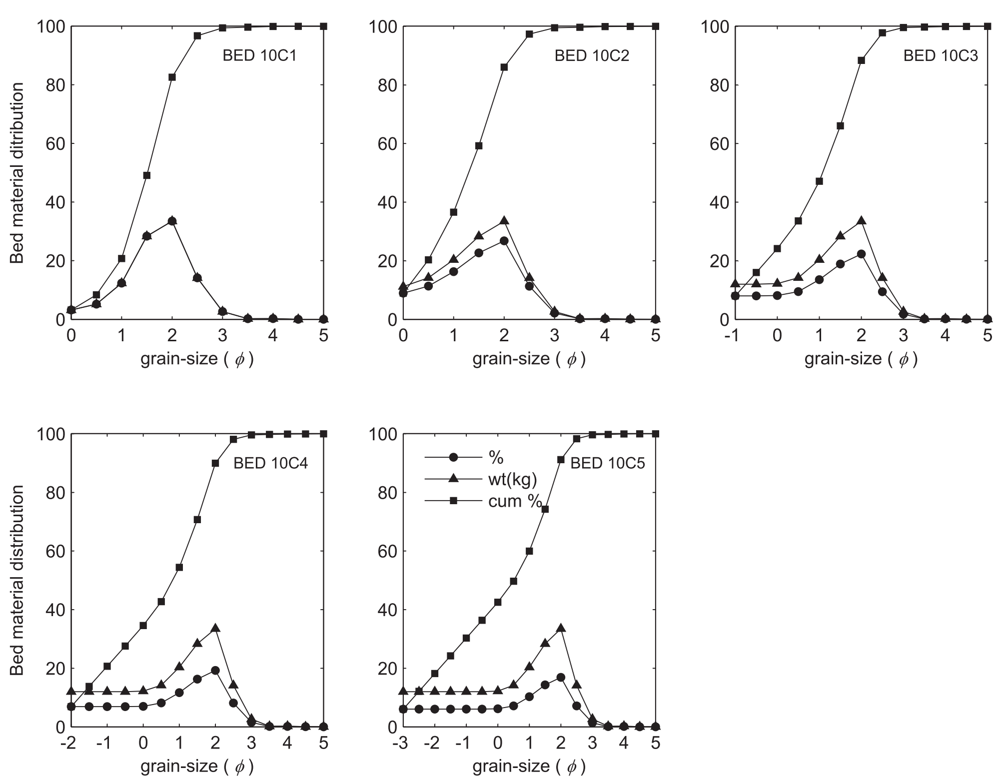

Fig. 1. Size distributions of five sediment beds in percentage (%), weight (kg) and cumulative percentage plots versus grain-size (Ghoshal, 2005).