

Research paper

Fractional bed load transport model for nonuniform unimodal and bimodal sediments

S.B. Patel ^a, P.L. Patel ^{a,*}, P.D. Porey ^b^a Department of Civil Engineering, Sardar Vallabhbhai National Institute of Technology, Surat 395007, India^b Sardar Vallabhbhai National Institute of Technology, Surat 395007, India

Received 21 May 2013; revised 16 April 2014; accepted 14 July 2014

Available online 23 September 2014

Abstract

Experimental programme for collection of flume data on bed load transport of unimodal and bimodal sediments is reported. Existing relationships for fractional bed load transport of nonuniform sediments are assessed for their applicability to bimodal sediments using data collected in the present study and those available from past investigations. Keeping in view the inadequate performance of existing relationships for bimodal sediments, parameters for computation of fractional bed load transport rates of unimodal and bimodal sediments are identified; and a new relationship is proposed based on recent developments on critical shear stress of such sediments. The performance of proposed relationship is verified with independent data on flume and field studies.

© 2014 International Association for Hydro-environment Engineering and Research, Asia Pacific Division. Published by Elsevier B.V. All rights reserved.

Keywords: Bimodal; Critical shear stress; Fractional bed load transport; Nonuniform sediment; Unimodal

1. Introduction

Knowledge of sediment entrainment and transport characteristics is required for solving many engineering problems such as design and maintenance of hydraulic structures, protection against erosion and scour, prediction of river bed level variation, stable channel design, site selection for water intakes, assessment of aquatic habitats etc. Starting from the pioneering work of Du Boys (1879), many investigators proposed relationships for computation of bed load transport of uniform sediments, like Meyer-Peter and Muller (1948), Yalin (1963), Ackers and White (1973), Misri et al. (1984), Samaga et al. (1986) etc. Apart from the bed load transport relationships for uniform sediments, several relationships (Ashida and Michiue, 1971; Parker et al., 1982; Diplas, 1987; Bridge and

Bennett, 1992; Patel and Ranga Raju, 1996; Wu et al., 2000; Wilcock and Crowe, 2003; Almedeij et al., 2006; Recking, 2010) were also proposed in the past for computation of bed load transport rates of nonuniform sediments in terms of fluid, flow and sediment characteristics.

Nonuniform sediments could be either unimodal or multimodal depending upon the population of their grain sizes within the bed material. Invariably, unimodal sediments are the characteristics of sand bed rivers while the bimodal sediments are found in gravel bed rivers (Garde and Ranga Raju, 2000). At present, the researchers have made the effort to investigate unimodal and bimodal sediments only. The presence of two modes, typically one of sand size and other of gravel, complicates the prediction of fractional bed load transport rates of bimodal sediments (Kuhnle, 1993; Wilcock, 1993; Wilcock and Crowe, 2003). The traditional approaches for calculation of bed load transport rates using single representative grain sizes (Meyer-Peter and Muller, 1948; Misri et al., 1984; Samaga et al., 1986), such as mean or median sizes, are not appropriate for bimodal sediments as

* Corresponding author.

E-mail addresses: patelsb@outlook.com (S.B. Patel), plpatel@ced.svnit.ac.in, premlalpatel@yahoo.com (P.L. Patel), pdporey@svnit.ac.in (P.D. Porey).

representative size may fall in the gap between the two modes and, therefore, representing a size class containing small percentage of overall sediments (Sambrook Smith et al., 1997). Also, methods based on single representative sizes, are not expected to give satisfactory results for nonuniform (unimodal or bimodal) sediments as the grain size distributions of the bed material and transported material are different for such sediments.

The similarity approach, used by Parker et al. (1982) for development of fractional bed load transport relationship, was used by many researchers like Diplas, 1987; Parker, 1990; Wilcock and Crowe, 2003 etc. In this approach, dimensionless bed load transport parameter (Φ_{Bi}) and dimensionless grain shear stress (τ'_{*i}) are scaled using reference transport parameter and reference shear stress respectively to arrive at a unique relationship for bed load transport of sediment mixture. Here.

$$\Phi_{Bi} = \frac{q_{Bi}}{f_i \rho_s \sqrt{(S_s - 1) g d_i^3}} \quad (1a)$$

$$\text{and } \tau'_{*i} = \frac{\tau'_b}{\rho_w (S_s - 1) g d_i} \quad (1b)$$

Here τ'_b is grain shear stress (N/m^2); q_{Bi} is fractional bed load transport rate per unit width (kg/s/m); $f_i = (p_2 - p_1)/100$, where p_1 and p_2 are percentage finer, by weight, for sizes d_1 and d_2 , defining the size range, such that $d_i = (d_1 \cdot d_2)^{0.5}$; S_s is relative density of sediment defined as the ratio of density of sediment, ρ_s (kg/m^3) to density of water, ρ_w (kg/m^3); g is acceleration due to gravity (m/s^2).

Parker et al. (1982) and Diplas (1987) developed fractional bed load transport relationships on the basis of sub-pavement grain sizes by analyzing the bed load transport data from the field sources. Parker et al. (1982) suggested the use of sub-pavement grain size distribution for computation of bed load transport rates as, in long term; it resembles the grain size distribution of transported bed load in natural rivers.

Patel and Ranga Raju (1996) assessed the performance of Ashida and Michiue (1971), Proffitt and Sutherland (1983), Mittal et al. (1990) and Bridge and Bennett (1992) methods for prediction of fractional bed load transport of extremely nonuniform sediments. Keeping in view inadequate performance of the methods, they developed their own relationship for fractional bed load transport of nonuniform sediments using critical shear stress of arithmetic mean size, computed as per Shields (1936), as one of the scaling parameters. The performance of the method can be improved further by considering the critical shear stress of individual size fractions in a sediment mixture as the scaling parameter. The bed load transport relationships proposed by Ashida and Michiue (1971), Parker et al. (1982), Diplas (1987) and Wu et al. (2000) are based on critical shear stress of individual size fractions. The relationship for critical shear stress of individual size fraction was proposed earlier by Egiazaroff (1965) for rough boundaries by assuming that the velocity at $y = 0.63d_i$

would be equal to the fall velocity, w_{oi} , of the particle size d_i . Here, y is the distance from a nonuniform sediment bed. The relation proposed by Egiazaroff (1965) was, subsequently, modified by Ashida and Michiue (1971) and Hayashi et al. (1980). Wu et al. (2000) proposed hiding and exposure correction factors, using hidden and exposed probabilities, for different size fractions in a nonuniform sediment bed. Based on the said correction factors, they proposed formulae for incipient motion and fractional bed load transport rates of nonuniform sediments.

Almedeij et al. (2006) developed a method for computation of bed load transport of bimodal sediments by separating a sediment mixture into two independent fractions of fine (sand) and coarse (gravel) modes, and considering the dimensionless critical shear stress of both the modes (fine and coarse) in their proposed relationship. Wilcock and Crowe (2003) developed fractional bed load transport model for sand and gravel sediment mixtures based on the measurement of grain size distribution of sediment bed surface under antecedent flow conditions. Recking (2010) also proposed the method for prediction of bed load transport of nonuniform sediments while considering d_{84} and d_{50} sizes of equilibrium sediment bed surface. Almedeij et al. (2006), Wilcock and Crowe (2003) and Recking (2010) methods are based on the grain size distribution of equilibrium sediment bed surface under antecedent flow conditions; and such information is difficult to predict beforehand in prediction of bed load transport of nonuniform sediments for a given flow condition.

The relationships, based on sub-pavement grain size distributions, i.e. Parker et al. (1982), Diplas (1987), Patel and Ranga Raju (1996) and Wu et al. (2000); were primarily developed from the data of unimodal and weakly bimodal sediments; and their performance is still required to be verified for bimodal sediments. The present study has been planned to verify the performance of existing methods for fractional bed load transport of bimodal sediments, and develop a new relationship, based on fractional critical shear stress of bulk grain size distributions of unimodal and bimodal sediments.

2. Experimental programme and data collection

2.1. Experimental flume

The experimental set up, designed and developed as part of present study in the Advanced Hydraulics Laboratory of Civil Engineering Department at Sardar Vallabhbhai National Institute of Technology (SVNIT) - Surat, India, includes a recirculating tilting flume of size $15.0 \text{ m} \times 0.89 \text{ m} \times 0.6 \text{ m}$ ($L \times B \times H$) with complete arrangements like centrifugal pumps, recirculation pipe, digital flow meter, tail gate, sediment traps, sediment feeder with conveyor belt, water level sensors, downstream water collection tank, instrument carriage, pointer gauge and stilling arrangement at the inlet of the flume, see Photograph 1. Also, the line sketch of complete experimental set-up is shown in Fig. 1.

Download English Version:

<https://daneshyari.com/en/article/4493738>

Download Persian Version:

<https://daneshyari.com/article/4493738>

[Daneshyari.com](https://daneshyari.com)