Journal of Hydrology 517 (2014) 1154–1161

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Evaluation of genetic programming-based models for simulating friction factor in alluvial channels

Kiyoumars Roushangar [a], Dominique Mouaze [b], Jalal Shiri [c,*]

[a] Department of Civil Hydraulics Engineering, University of Tabriz, Tabriz, Iran
[b] Morphodynamique Continentale et Côtière, Université de Caen Basse-Normandie, UMR CNRS 6143, 2-4 rue des Tilleuls, 14000 Caen, France
[c] Water Engineering Department, Faculty of Agriculture, University of Tabriz, Tabriz, Iran

ARTICLE INFO

Article history:
Received 13 May 2014
Received in revised form 23 June 2014
Accepted 25 June 2014
Available online 2 July 2014
This manuscript was handled by Geoff Syme, Editor-in-Chief

Keywords:
Alluvial channel
Friction factor
Genetic programming
Sensitivity analyses

SUMMARY

The bed resistance is one of the most complex aspects of water flow studies in natural streams. Most of the existing non-linear formulas for describing alluvial channel flows are based on dimensional analysis and statistical fitting of data to the parameters considered in the functional relationships implicitly, which are partially valid. The present study aims at developing genetic programming (GP) – based formulation of Manning roughness coefficient in alluvial channels. The training and testing data are selected from original experiments, performed in a hydraulic flume using a sand mobile bed. A comparison was also made between GP and traditional nonlinear approaches of resistance modeling. The obtained results revealed the GP capability in modeling resistance coefficient of alluvial channels' bed.

1. Introduction

There are multitudes of bed forms for alluvial channels, namely ripples (at low shear stress with progressive developments of dunes), washed out dunes (transition), flat bed, anti-dunes, and standing waves with increasing shear stresses or velocities. The corresponding resistance (which depends on their dimensions as well as flow and sediment characteristics), is significant in some cases. Accurate estimation of this resistance in alluvial channels is important for watershed and flood studies, river engineering and planning issues and designing hydraulic structures. Due to the importance of the bed form resistance in determining the overall resistance of sand-bed flows, the prediction of bed-from geometry as an essential component of flow resistance and water level estimation during flood periods is of crucial importance. Early important works on dune geometry carried out by Yalin (1964), Raudkivi (1998), Ranga-Raju and Soni (1976) and Allen (1978) considering dune height as a function of bed shear stress and other variables according to experimental and field data. van Rijn (1984) expressed shape resistance as equivalent sand diameter and derived an exponential relation based on dune height and flow depth. Bruschin stated Manning coefficient as a function of sediment diameter, hydraulic radius and energy slope (Raudkivi, 1998). Karim and Kennedy (1990) derived friction factor ratio f/f_0 (f_0: grain friction factor and f: total friction factor), as a function of relative dune height. Karim (1999) applied regression and dimensional analysis for computing the Manning coefficient as a function of mean grain size (d_{50}) and f/f_0. The complexity of the underlying physical process can be attributed to several factors, e.g. a large number of interrelated governing variables, three-dimensional (3D) nature of bed-form development, lag in bed-form adjustment in response to variable flow conditions, and practical difficulties in measuring bed-flow dimensions particularly in field conditions. Recognizing that continuing research efforts will be needed for the accurate formulation of this complex process, a new method is proposed in this paper as a modest but incremental step toward achievement of this goal. This study employs heuristic genetic programming (GP) technique for modeling bed resistance.

So far, GP has been applied for rainfall- runoff modeling (e.g. Kisi et al., 2013a; Savic et al., 1999), derivation of unit hydrographs of urban basins (Rabunal et al., 2006), suspended sediment modeling (e.g. Kisi and Shiri, 2012; Kisi et al., 2012a), velocity prediction in compound channels (Harris et al., 2003), modeling vegetation resistance (Rodrigues et al., 2007), determining chezy resistance factor (Giustolisi, 2004), predicting longitudinal dispersion coefficients in streams (Azamathulla and Ghani, 2011), analyzing real time operation of reservoir systems (Fallah-Mehdipour et al., 2012), predicting groundwater level fluctuations (Fallah-Mehdipour

* Corresponding author. Tel.: +98 4113340081.
E-mail addresses: kroshangar@yahoo.com (K. Roushangar), j_shiri2005@yahoo.com (J. Shiri).

http://dx.doi.org/10.1016/j.jhydrol.2014.06.047
0022-1694/

et al., 2013; Shiri and Kisi, 2011; Shiri et al., 2013), development of stage-discharge curve (Azamathulla et al., 2011), modeling evaporation rates (Izadifar and Elshorbagy, 2010; Shiri et al., 2012, 2014a,b), precipitation forecasting (Kisi and Shiri, 2011), forecasting urban water demand (Nasseri et al., 2011), flood routing (Sivapragasam et al., 2008), lake water level forecasting (Kisi et al., 2012b), forecasting discharge time series (Wang et al., 2009) and modeling flow and water quality variables in watersheds (Kisi et al., 2013a,b; Preis and Otsfeld, 2008) as well as modeling energy dissipation over spillways (Roushangar et al., 2014a) and modeling total bed material load (Roushangar et al., 2014b). The literature survey by the authors showed that only limited studies (e.g. Azamathulla, 2012; Azamathulla and Jarrett, 2013; Azamathulla et al., 2013; Giustolisi, 2004) deal with modeling friction factor in alluvial channels with unstable bed materials. The present paper aims at GP-based modeling of friction factor in alluvial channel through application of some dominant factors governing the flow on dunes. Consequently, different input configurations of dominant factors were built and applied as GP inputs for simulating the friction factor. Nevertheless, the object function (targets) in this paper were defined as observed manning's coefficients as well as its modified versions, which makes it possible to compare the models accuracies for modeling friction factor.

2. Materials and methods

2.1. Experimental setup

Sediment and flow variables comprising flow depth and velocity, water surface gradient, sediment diameter, distribution and type are the main parameters influencing the bed forms. A 5 m long, 0.15 wide, and 0.25 m tall rectangular pollex glass flume located in the hydraulic laboratory of Caen University was utilized as shown in Fig. 1.

Sediment particles used in the experiments were natural quartz sand with specific gravity of 2.65 and uniform average diameters of 0.15 mm and 0.4 mm. Water flow was supplied by a pump, re-circulating between the upstream and downstream tanks. At the beginning of each experiment, sediment particles were saturated to provide natural conditions and prevent incipient motion of dry particles. They were then placed on the bed of the test section. Then, sediments were distributed and smoothed on the bed by a T-shaped device without any compaction to obtain a sediment layer with a 3 cm thickness. In these experiments, discharge rate controlled by a valve in the discharge pipe of the pump and sediment was re-circulated and water depth and bed variations measured by using image processing. Subsequently, a digital camera was used for taking pictures in different times and locations and then surfer8 software was used for image processing and obtaining accurate data. Sand wavelets were generated within a few minutes (for example around 4 min according to Coleman and Melville, 1994). Dune height was measured 15–30 min after commencement of the run (see Fig. 2). By changing the flow depth and discharge, different average velocities and Froude numbers could be obtained. The water depth and discharge rate were set in a manner so that dunes formed on the bed according to Karim (1999). In these experiments, a major difficulty was measuring the water surface gradient S_w, because the water surface fluctuated spatially and temporally due to bed forms. To overcome this problem, firstly a thin sensitive wire gauge (with high sensitivity to voltage variations) set to F shape instrument and used for measuring water surface slope through a special voltage-meter and computer program with 200 data in second (see Fig. 1).

2.2. Non-linear approaches for modeling alluvial channel resistance

Unlike to the linear superposition approaches, the resistance coefficient is not divided into grain and bed form roughness in the nonlinear approaches, but is kept as a single factor instead. Most nonlinear approaches are based on dimensional analysis and statistical fitting of data to the parameters through functional relationships. Some representative investigations are listed in Table 1. They can be identified as four groups: (a) methods considering the resistance coefficient as a dependent variable, (b) methods based on shear stress, (c) methods giving an equation of the mean velocity whose coefficients are related to resistance, and (d) the energy approach derive from Bagnold's stream power concept (Bagnold, 1966) for expressions of velocity that could be used to calculate the resistance. Most of them implicitly assume the flow to be steady-uniform with equilibrium sediment transport. Unlike the linear separation methods, there is no need to a prior knowledge of the bed configuration for applying nonlinear approaches. Among others, only the first group (a)

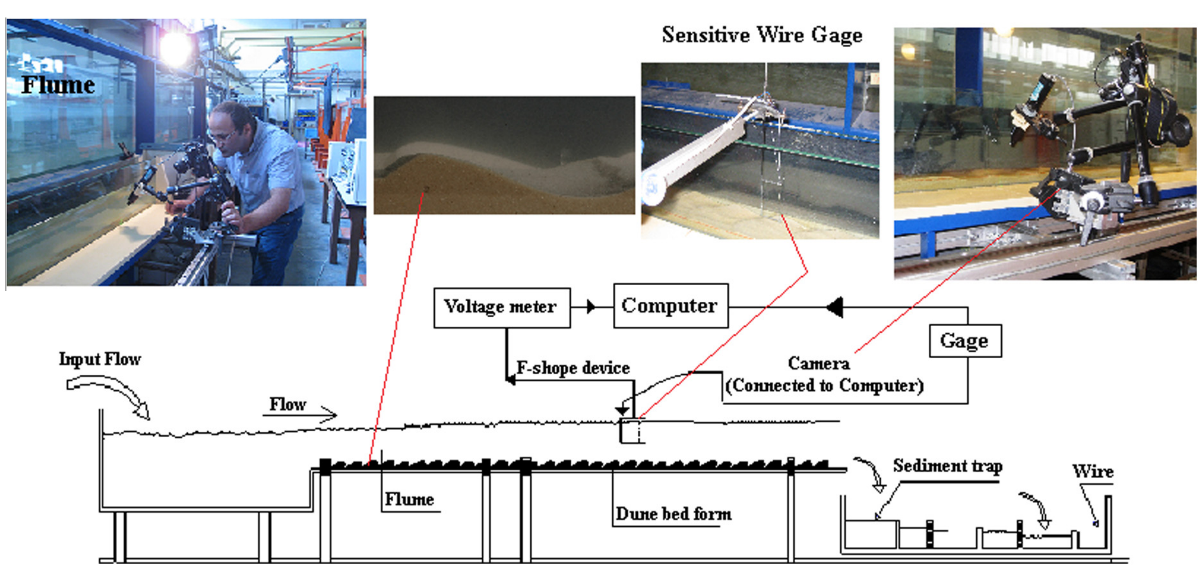

Fig. 1. Experimental set up of the study.