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Development of a 3D Model for Continuous Bed-Load Saltation Process

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Abstract

Saltation is the dominant mode of the sediment transport in rivers. The focus of the present study is on the development of an accurate particle saltation model for the range of sand to gravel in the Lagrangian approach. The model includes the non-linear drag force, the shear lift force, Magnus force, the buoyancy force, the added mass force, the Basset history force and torque. A sub-model for the random process of the particle impact and rebound from the channel bed is also included (i.e. particle–bed collision or splash model). The results of the developed model were validated against experimental data. By using the developed model, the mechanism of particle–bed collision was investigated under rough and smooth bed conditions. The results showed that sediment saltations are quickly disappear under horizontal smooth bed surface. Therefore, the consideration of a bed roughness model is essential for the simulation of the continuous bed-load saltation process.

Keywords: Lagrangian model, non-cohesive sediment, Successive saltation, particle–bed collision, rough and smooth bed.

1. INTRODUCTION

Flow and sediment transport are important in relation to alluvial rivers and channels issues like the sedimentation and erosion around hydraulic structures, design of stable channels, estimation of transport rates and the corresponding change of the river-bed topography [1, 2].

The transport of sediments can be classified in three categories including; suspended load, wash load, and bed load [3]. The posterior type of the transport consists of three modes: (a) sliding, (b) rolling and (c) saltating. Among them, the saltation is the dominate mode [4]. In the bed load transport (e.g. saltation motion), the sediment grains keep a quasi-permanent contact with the bed surface in a very narrow region, commonly defined as a few grain diameters thick [5]. Therefore, it is very important to consider a process for taking to account bed-particle interaction, efficiently.

First of all, it should be stated that for developing a complete particle-wall collision algorithm two parts must be adopted: (1) a series of equations to describe the grain velocity after the rebound and (2) a bed roughness model for simulating inherent randomness of the collision-rebound phenomenon. In this regard, Garcia and Nino [6] developed a simple two-dimensional (2D) bed-particle rebound model, which has been widely used in the numerical simulation of sediment transport (e.g. [7], [8], [9] and [10]) because it can simulate bed-particle interactions randomly. The channel bed composed of uniformly packed spheres in the model. Lee et al. [11] extended this model to a three-dimensional (3D) model. It should be stated that none of 2D and 3D models do not take into account grain rotation in the moment of the collision with the bed while the particle rotation has important effects in this process, especially for relatively large particles [12].

If the impulse equations were considered in the particle–bed collision model, both translational and angular velocities of the moving particle after collision can be calculated using the collision angle, friction and restitution coefficients [13]. Therefore, some other studies were used such procedure for the simulation [5] and [14]. It is notable that all of the aforementioned models do not considered a real bed structure. However, some researchers presented more realistic stochastic models using a rough bed formed by irregular