Integrated Numerical Simulation Model for Describing Debris Flow, Sediment Sheet Flow, Bedload and Suspended Load in Mountain River

Taro UCHIDA[1*], Wataru SAKURAI[1], Yuki NISHIGUCHI[2], Junya HINA[2], Masato MURAKAMI[2] and Yoshifumi SATOFUKA[3]

[1] National Institute for Land and Infrastructure Management, Japan
[2] CTI Engineering Co. Ltd. , Japan
[3] Ritsumeikan University, Japan.
[*]Corresponding author. E-mail: uchida-t92rv@mlit.go.jp

INTRODUCTION

Numerical simulations can be considered a powerful tool for hazard mapping and countermeasure planning. While, a variety of sediment processes, such as debris flow, sediment sheet flow, suspended sediment, bedload, etc., can be observed in mountain river (**Fig. 1**). Especially, during the heavy rainfall periods, sediment processes can be varied in time and space. So, an integration of variety sediment processes into single model is one of key efforts for hazard mapping due to sediment process in mountain region. However, until now, most of numerical simulation model focused single or few sediment processes in a variety of sediment processes in mountain river. Here we developed new integrated numerical simulation model for describing complex sediment dynamics in mountain river.

GENERAL DESCRIPTION OF MODEL

In our model, sediments have been classified into two in terms of sediment transport behavior. One is sediment behave like a laminar flow, the other is sediment behave like a turbulent flow. It can be considered that grain size of first type was larger than second type, thus, first and second types are called as “coarse sediment” and “fine sediment”, respectively. Grain sizes of both types of sediments should be depended on hydraulic conditions.

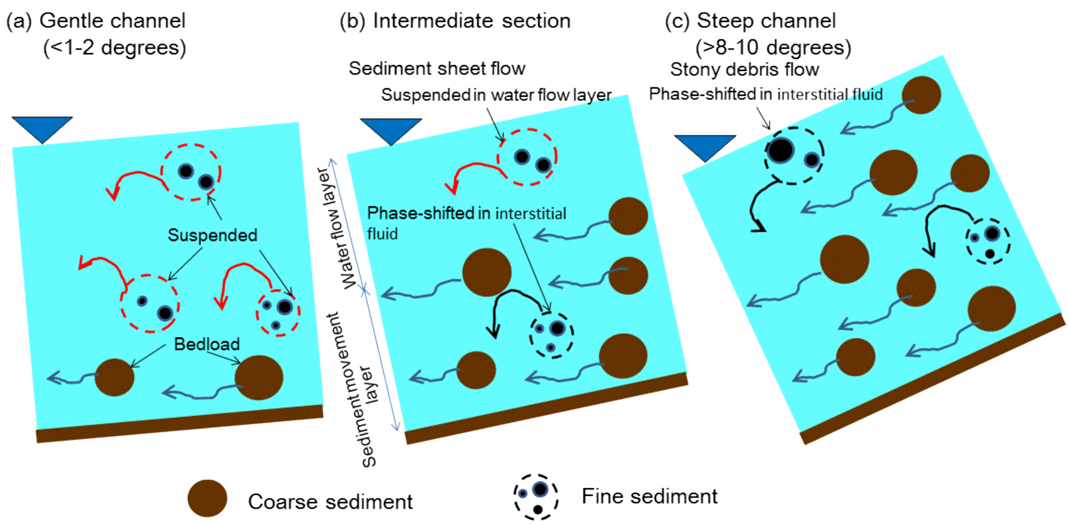

Fig. 1 Schematic illustration of model

BED SHEAR STRESS AND COARSE SEDIMENT DYNAMICS

Previous studies indicated that transport processes of coarse sediment are classified into three conditions. In steep channel, dominant sediment process should be debris flow (**Fig. 1c**), while, bedload is typical sediment process in relatively gentle stream (**Fig. 1a**). Further, intermediate condition, such as sediment sheet flow, can be observed (**Fig. 1b**). The sediment sheet flow consists of two layers, one is sediment movement layer on the channel bed, the other is water flow layer above the sediment movement layer (**Fig. 1b**). Based on these concepts, the equations for momentum, continuity, riverbed deformation, and erosion/ deposition are based on previous studies by Takahashi and colleagues [e.g., Takahashi, 2009 (A review of Japanese debris flow research, International Journal of Erosion Control Engineering, 2, 1–14.)] for describing coarse sediment dynamics in our model.

In our model, bed shear stress is also dependent on the concept of Takahashi. [2009]. So, we modeled that the bed shear stress in debris flow and bedload sections are calculated by stony debris flow concept and Manning's equation, respectively. While, for sediment sheet flow, we used the method proposed by Suzuki et al. [2013] (Resolution of the discontinuity with the changes of sediment transport form in numerical simulation, Journal of the Japan Society of Erosion Control Engineering, 66(2). 21-30) that the bed shear stress of sediment sheet flow was described as combination of stony debris flow of bottom layer and turbulent flow of top layer.

FINE SEDIMENT DYNAMICS

Previous study indicated that the fine sediment in stony debris flow should suspend in interstitial turbulent fluid. This process is called as phase-shift. So, we include the effect of phase-shift in debris flow in our model. In our model, we assumed that the phase-shifted fine sediment did not contribute to solid friction of debris flow and that fluid density became large. We also assumed that if the ratio of settling velocity of sediment with a given diameter to turbulent velocity was smaller than the critical value, the sediment should behave as phase-shifted sediment.

In our model, we assumed that the fine sediment also behave as phase-shifted sediment in sediment movement layer in sediment sheet flow (**Fig. 1b**). Moreover, the fine sediment also should be included in water flow layer as similar to suspended sediment. We applied suspended sediment theory for calculation of fine sediment concentration in water flow layer of intermediate section. We considered that in gentle channel, the fine sediment should behave as suspended sediment and also adopted suspended sediment theory to describe fine sediment dynamics in gentle channel.

CLACURATION AND CONCLUSIONS

We applied our new model for flood in Uono river, Japan, 2011. We confirmed that the simulation results of riverbed change and sediment discharge amount generally agree well with the observed data. So, we concluded that our integrated numerical simulation model is effective for complex sediment behavior in mountain river during heavy rainfall period.

Keywords: Debris flow, Sediment sheet flow, Bedload, Suspended load, Numerical simulation