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A bed-porosity variation model and its application

○ Muhammad Sulaiman, Masaharu Fujita, Daizo Tsutsumi

1. Introduction

A numerical simulation method for bed variation is one of the tools for assessing the riverbed deformation. So far, engineers and researchers have conventionally assumed that the porosity of bed material is a constant in their bed variation models, regardless of whether the particle size of the bed material is uniform. As the void of bed material plays an important role in fluvial geomorphology, infiltration system in riverbeds and river ecosystem, a structural change of the void with bed variation is one of the concerned issues in river management. Thus, a bed-porosity variation model is strongly required and it is expected that the model contributes the analysis of those problems as a tool for integrated sediment management.

2. Bed-porosity variation model

As the porosity of bed material is not constant and dependent on the grain size distribution, the time differential term on the porosity in the continuity equation of sediment must be considered (Eq.(1)).

$$\frac{\partial}{\partial t}\int_{z_o}^{z_b}\{1-\lambda(t,x,z)\}dz+\frac{1}{B}\frac{\partial Q_S}{\partial x}=0 \qquad (1)$$

where λ = porosity of bed material, z_b = bed level, z_0 = a reference level, z = a vertical axis, and Q_s = sediment discharge.

Porosity is dependent on the grain size distribution of bed material and its compaction degree. In this study, the compaction degree is considered empirically and the porosity is assumed to be a function of characteristic parameters of grain size distribution (Eq.(2)).

$$\lambda = f_n(\Pi_1,\Pi_2,\Pi_3,.......) \qquad (2)$$

where Π_1,Π_2, Π_3….= characteristic parameters of grain size distribution.

There are some types of grain size distribution such as lognormal distribution and modified-Talbot distribution. Lognormal distribution has one characteristic parameter ($\Pi_1=\sigma_L$) and modified-Talbot distribution has two characteristic parameters ($\Pi_1=d_{max}/ d_{min}$, $\Pi_2=n_T$), where σ_L = standard deviation of ln$d$, d_{max} = maximum grain size, d_{min}= minimum grain size and n_T= Talbot number. To determine the type of grain size distribution, the grain size distribution is analyzed geometrically by using indices β and γ that defined as (Eq.3) and (Eq.4), respectively, designating the relative locations of the grain size d_{peak} for the peak probability density and the median grain size, d_{50}, between the minimum size d_{min} and the maximum size d_{max}.

$$\beta=\frac{\log d_{max}-\log d_{peak}}{\log d_{max}-\log d_{min}} \qquad (3)$$

$$\gamma=\frac{\log d_{max}-\log d_{50}}{\log d_{max}-\log d_{min}} \qquad (4)$$

The porosity of various kind of grain size distribution can be obtained by means of a packing simulation model and an experimental method. As a result, the relations between characteristic parameters and the porosity are obtained and introduced into the bed variation model.

3. Application

The presented bed-porosity variation model is applied to the bed variation in a channel with a length of 15 m and a width of 0.5 m. Simulation is carried out to observe the bed and porosity variation under two conditions; one is no sediment supply condition and another is sediment supply condition. The initial channel slopes are 0.01. The end of the channel is fixed. The initial bed material has a grain size distribution ranging from 1.0 mm to 10 mm. The distribution type of initial bed material is lognormal for the first condition and modified Talbot type for the second condition. The water is supplied at a rate of 0.02 m^3/s. Under this condition, the maximum grain can not be transported.

4. Results

The simulation results showed the model can produce a reasonable distribution of porosity of the riverbed material as well as bed variation. No sediment supply causes the bed degradation, and the increase in both of the mean grain size distribution and the porosity of surface layer. The grain size distribution becomes progressively coarser and coarser. Sediment supply can cause the degradation in the channel due to the increase in the transport capacity; and reduce both the mean diameter and the porosity of surface bed material.