Porosity of Sediment Mixtures with Different Grain Size Distribution

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1 INTRODUCTION

Reservoir sedimentation, flushing of reservoir sediment and the removal of dams, usually influence the qualitative features of riverbed as well as the topographical and morphological features. Among a lot of qualitative features of bed material, grain size distributions and void structure seem to be important for habitat of aquatic living things. Therefore, from an ecological point of view, it is essential to evaluate their changes when we make a plan of sediment runoff control.

The objective of this study is to investigate the porosity changes of sediment mixtures in the bed material with different grain size distribution. A packing model of spherical particle was developed to analyze relationship between the particle size distribution and the porosity of particle mixtures. The simulation result on a relation between porosity and grain size distribution is introduced into a bed variation model to obtain qualitative changes of bed material porosity. An experimental study was carried out to observe the changes of grain size distribution in the surface layer of bed materials and provide a test of the riverbed variation model.

2 PARTICLE PACKING MODEL

A particle packing simulation model was developed to derive the void ratio within bed materials assuming spherical particles. Simulation was conducted to elucidate a relation between the porosity of sediment mixtures whose grain size distribution is lognormal distribution and the standard deviation. The simulation model involves four stages: a) preparing a set of random values, b) calculating the particle diameter according to the specified particle size distribution for each random value, c) packing the particle into a hypothetical vessel, and d) calculating the volume of voids. Porosity of a sediment mixture depends on not only the grain size distributions but also the compaction. The compaction, however, can not be intentionally controlled in the model. A laboratory experiment was conducted, to assess the validity of the simulation model.

3 RIVERBED VARIATION MODEL

A continuity equation of sediment shown in Eq.(1) is usually employed for one-dimensional numerical simulation model of bed variation. It is recognized that numerical simulation using these equations could create a reliable result on bed variation, however, can not explain the change in void ratio with bed variation because it assumes that porosity is always constant. From an ecological point of view, such a qualitative analysis is needed. For such an analysis, the change of porosity should be considered, therefore Eq.(2) was employed instead of Eq.(1). Porosity of sediment mixtures is assumed dependent only on the grain size distribution.

$$\frac{\partial z}{\partial t}+\frac{1}{(1-\lambda)B_S}\frac{\partial Q_B}{\partial x}=0 \qquad (1)$$

$$\frac{\partial}{\partial t}\left\{\int_0^z(1-\lambda(t,x,z))dz\right\}+\frac{1}{B_S}\frac{\partial Q_B}{\partial x}=0 \qquad (2)$$

where t = time, x = flow direction, z = bed elevation, λ = porosity of bed material, B_s = channel width, Q_B = sediment discharge.

4 EXPERIMENT AND SIMULATION

The experiments were conducted in the flume of 0.40-m width, 0.40-m depth, and 7.0-m working length. The slope of the flume was adjusted to 1/50. A 5.3 cm-thick of sediment mixture was placed in the 7.0-m-long working section and screeded flat. A 10 cm-height wood dam was placed at the end of the working section channel. The sediment was used in the experiment consisted of coarse fraction from 4.75 to 26.5 mm, and the fine fractions from 0.5 to 4.75 mm. Fine fraction sediment used also as supplied sediment.

This experiment consisted of two runs and was carried out continuously. In run 1, fine fraction sediment was not fed to the flume; only water was flowed. The water flows as surface flushing that removes fine fraction from bed surface without entrained the coarse fraction. In run 2, fine sediment was fed constantly into the upstream end of the flume. Experiment conditions are given in Table 1. The elevations of the sediment bed and water surface relative to the flume floor were measured. The bed surface of each run was sampled by surface excavation at the initial condition and at the end of each run. All samples were air-dried, weighed and then sieved, providing the size distribution of the bed surface layer. Simulation on the change of porosity in the bed materials was carried out by using the same parameters used in experiment.

Table 1 Experiment conditions

Experiment	Q_w (m^3/s)	Q_s (m^3/m/s)	Duration [total duration] (min)
Run 1	0.0136	0	250 [t=250]
Run 2	0.0136	0.0000318	82 [t=332]

5 RESULT AND DISCUSSION

5.1. Relationship between the particle size distribution and porosity

The void ratios were calculated using the particle packing simulation model for 12 different standard deviations with lnσ from 0.0 to 1.5. The relationship between the standard deviation, lnσ, and the calculated porosity is shown in Figure 1. The porosity increased to 0.38 when the standard deviation lnσ increase slightly from 0.0 to 0.01. This means that the porosity increases drastically if particles with a different size are put into a uniform material. The porosity decreases to 0.156 when the standard deviation lnσ increases to 1.50. When the particle size was widely distributed, the porosity takes much smaller value than 0.4. The porosity decreased with an increasing size distribution due to the reduction of the open space by large particles.

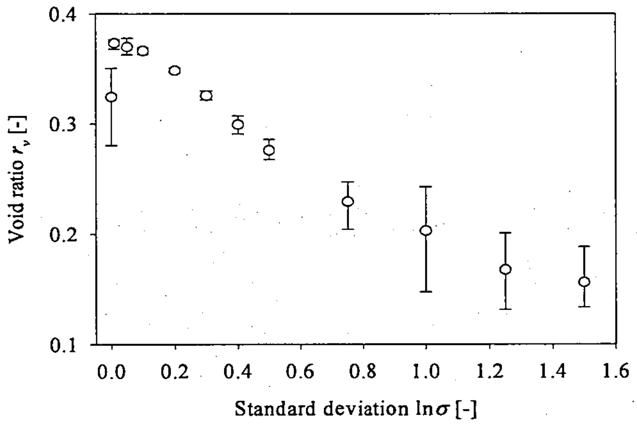

Fig.1 Relationship between the standard deviation of sediment mixtures and the porosity.

5.2. Fine Sediment Proportion

Measured and simulated fine sediment proportions of bed material were shown in Figure 2. For experimental results, the percentage value of fine sediment (f_s) in the initial condition was between 0.21 ~ 0.37. At the end of run 1 (t=250 min), the fine sediment proportions observed at upstream and midstream part have reduced to value of 0.045 from 0.37, and 0.081 from 0.26. At the downstream part, the fine sediment proportions have increased to value of 0.26 from 0.215. These results reveal that significant amounts of fine fraction sediments were removed from bed surface at upstream and midstream part and deposited at the downstream part. At the end of run 2 (t=332 min, after 82 min fine sediment supplied), the fine sediment filled in the surface layer in the upstream and midstream part and cover the surface layer in the downstream part. Fine sediment proportions have increased to value of 0.49, 0.64, and 0.93 at the upstream, midstream and downstream part respectively. There were some discrepancies between the experiment and simulation result. These discrepancies may be due to the sampling performance.

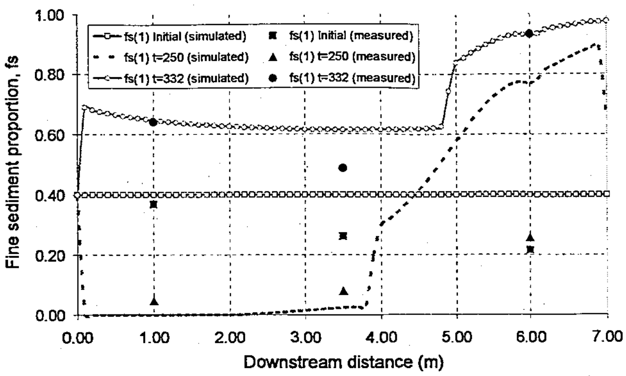

Fig.2 Measured and simulated fine sediment proportions of bed material

5.3. Porosity of bed material

The simulation result on longitudinal porosity changes of bed surface layer is shown in Figure 3. At the end of run 1, in the upstream to the midstream part fine fraction sediments were removed from bed surface, only coarse sediment remained and grain size distribution become uniform, therefore the porosity increase up to 0.4. The porosity decreases in the end of midstream part, its causes by mixing the fine sediment and coarse sediment. The porosity decreases when the particle size is widely distributed. In the downstream part, the porosity increases, its causes by fine sediment deposition on the bed surface layer. At the end of run 2, the porosity of surface layer in the upstream to the midstream part decrease due to infiltration of fine sediment to the bed-material. In the end of downstream part, all bed surface cover by fine sediment and grain size of surface layer become uniform, therefore, porosity increase up to 0.38.

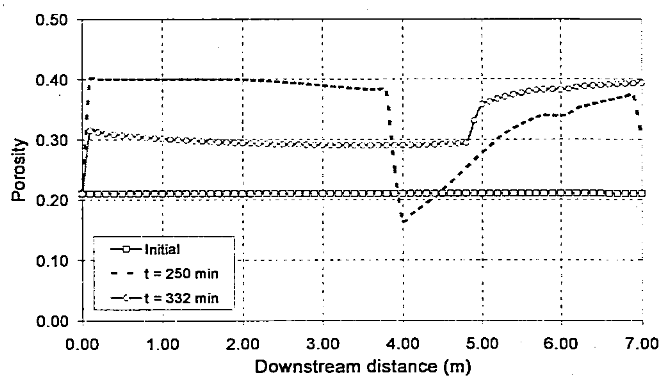

Fig.3 Simulation result on longitudinal porosity changes of bed surface laver.

6 CONCLUSION

The porosity of two component mixtures depends on the fractional concentrations of each particle size population. A porosity minimum is observed for a combination of the two components in the mixture.