STUDY ON EFFECT OF SEDIMENT SUPPLY CONDITIONS ON POROSITY AND GRAIN SIZE CHANGES OF RIVER BED

Jazaul Ikhsan¹

¹ Civil Engineering Dept., Muhammadiyah University of Yogyakarta, Jl. Lingkar Selatan, Tamantirto, Yogyakarta 55183
Email:jazaul Ikhsan@umy.ac.id, jzl_ikhsan@yahoo.co.id

ABSTRACT

Sediment production rate in a volcanic basin is not constant, and it depends on the volcanic eruptions. The sediment production often gives problems, so that the sediment should be managed. Effect of sediment management is changes in qualitative and quantitative of the sediment. Effect of sediment management on sediment changes quantitatively is often studied, but study on qualitative sediment changes is still few. Therefore, influences of human activity and natural condition on changes in sediment qualitatively are needed to be studied. This study is conducted by experimental and numerical methods. Porosity and grain size are used as parameters to describe sediment quality. Numerical method uses One Dimensional Bed Porosity Variation Model. This research is conducted using three cases. Case 1 is without sediment supply, Case 2 is with log normal distribution sediment supply, and Case 3 is with uniform distribution sediment supply. Based on the result, Case 1 shows that river bed becomes coarser and the porosity tends to increase due to no sediment supply from upstream cause by natural process or human activity. The grain size distribution changes from lognormal type to Talbot type. In Case 2, if there is sediment supply from upstream due to an eruption, the river bed elevation increases. Grain size distribution changes from Talbot type to lognormal type and the porosity decreases. In Case 3, grain size distribution changes from lognormal type to uniform and the porosity increases. The comparison between porosity and grain size changes in the experimental and the numerical results has shown in a good agreement.

Keyowrds: sediment production, management, grain size, porosity

1. INTRODUCTION

A sediment production in a basin river system is not constant, because it depends on the triggering factors. In a volcanic basin, especially in a volcanic active area, the sediment production depends on the volcanic activities. Volume of the sediment production closely related to the eruptions. The sediment production will give the problems on the environmental and societal aspects, if amount of sediment production is too little or too much. Under the both conditions, sediment is needed to be managed. Due to the transported sediment of a river system on a basin is continuous, changes in quantitative or qualitative of the sediment in the upper reach of the basin can affect on the characteristic of sediment at many kilometres downstream.

The sediment management in rivers has a long history, but it has still tended to deal with quantitative issue, usually associated with excessive or deficit amounts of sediment (Owens, 2005). The link between sediment and ecology of aquatic systems has become important in recent years. Sediment plays an important role for the river basin and offers a variety of habitats for many aquatic species. The specific role of sediment in aquatic ecosystems is porosity (Mancini et. al., 2008). It indicates that the study of qualitative sediment, such as porosity and grain size change by natural condition or human activity, is important in the recent decade. The study on change of qualitative sediment, due to the human activity or natural condition in this research is conducted by experimental and numerical studies.

2. EXPERIMENTAL STUDY

A flume experiment as shown in Figure 1 is conducted to observe the processes of porosity and grain size changes. The experiment is performed in a flume with a width of 0.40 m, a depth of 0.40 m and a working length of 7.0 m. The flume walls are made of clear acrylic. The slope of the flume is adjusted to 0.009. Water is circulated and the water discharge is attempted nearly constant during the experiment. A continues sediment mixture is originally placed in the working section and scraped flat. The thickness of the sediment layer over the channel bottom is 6.0 cm. The original bed material is composed of fractions from 0.125 mm to 11.2 mm and the mean diameter, dm, is 2.8 mm.

The experiment consists of three cases, Case 1, Case 2 and Case 3. In Case 1, no sediment is supplied and the case is continued until the flow brings little sediment. Case 1 is followed by Case 2 and the condition of channel bed in the
end of Case 1 is used as the initial condition of Case 2. In Case 2, grain size of sediment that is the same as the original bed material in Case 1 is fed constantly from the upstream end of the flume by a conveyor belt. Case 2 is continued until sediment discharge relatively constant and elevation of the channel bed is the same as the initial channel bed in Case 1. Case 2 is followed by Case 3 and the condition of channel bed in the end of Case 2 is used as the initial condition of Case 3. In Case 3, uniform sediment with 2 mm diameter is fed constantly from the upstream end of the flume by a conveyor belt. Case 3 is continued until the time when the mean diameter of sediment discharge becomes the same as the mean diameter of fed sediment.

The experimental conditions are summarized in Table 1. The water depth, h, and the velocity, v, are the initial average water depth and velocity in each run, respectively. The surface bed material is sampled at the upper, middle, and lower locations before Case 1 and at the end of each case by surface excavation. The sampling points are located at 1 m, 3.5 m and 6 m downstream of the upper end of the flume. The bed material is excavated up to a depth corresponding to the coarsest grain size. All samples are air dried, weighed, and then sieved to get the grain size distribution of the surface layer.

![Figure 1. Sketch of the experimental flume test](image)

**Table 1. Conditions for experimental runs**

<table>
<thead>
<tr>
<th>Exp</th>
<th>Qₜ (m³/s)</th>
<th>qₛ (10⁻⁶m³/s)</th>
<th>h (m)</th>
<th>v (m/s)</th>
<th>Fr</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>0.0131</td>
<td>0</td>
<td>0.037</td>
<td>0.869</td>
<td>1.242</td>
<td>15, 30, 60, 120, 180, 240, 300, 360, 420</td>
</tr>
<tr>
<td>Case 2</td>
<td>0.0131</td>
<td>32.57</td>
<td>0.051</td>
<td>0.632</td>
<td>0.56</td>
<td>5, 15, 30, 40, 45, 50, 55, 55.60, 65</td>
</tr>
<tr>
<td>Case 3</td>
<td>0.0131</td>
<td>25.54</td>
<td>0.038</td>
<td>0.841</td>
<td>1.147</td>
<td>10, 20, 30, 40, 50</td>
</tr>
</tbody>
</table>

3. **ONE DIMENSIONAL BED POROSITY VARIATION MODEL**

One dimensional bed porosity variation model is one of numerical simulation methods for bed deformation. The difference between the proposed model with others previous numerical model is the model to analyze the change of porosity as well as the bed variation (Sulaiman, 2008). The porosity is assumed as a function of characteristic parameters of grain size distribution. The model is analyzed by the continuity equation of water, the energy equation of flow and the continuity equation of sediment. The basic equations are as follows:

(a) **Continuity of water**

\[
\frac{\partial Bh}{\partial t} + \frac{\partial Q}{\partial x} = 0
\]

where \( B \) = channel width, \( h \) = water depth, \( Q \) = water discharge, \( t \) = time and \( x \) = distance in stream wise direction.

(b) **Energy equation of water**

\[
\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( \frac{1}{2} g Bh^2 + \frac{Q^2}{Bh} \right) = g Bh (i_j - i_i)
\]
where \( g \) = gravity acceleration, \( i_b \) = bed slope and \( i_f \) = energy gradient. The energy gradient can be expressed as follows:

\[
i_f = \frac{n^2 v^2}{R^2}
\]

(3)

where \( n \) = Manning coefficient, \( v \) = average water velocity, and \( R \) = hydraulics radius.

(c) Continuity equation of total sediment

Using the equation of continuity of sediment discharge shown below, the change of bed elevation is calculated.

\[
\frac{\partial}{\partial t} \left( 1 - \frac{\lambda}{1} \right) d z + \frac{1}{B} \frac{\partial Q_s}{\partial \xi} = 0
\]

(4)

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

(d) Continuity equation of each sediment fraction

Continuity equation of sediment mixtures is written as:

\[
\frac{\partial}{\partial t} \left( 1 - \frac{\lambda}{1} \right) p_j \left( 1, x, z \right) d z + \frac{1}{B} \frac{\partial Q_{sj}}{\partial \xi} = 0
\]

(5)

where \( j \) = grade of sediment fraction, \( p_j \) = mixing ratio of \( j \)-th fraction in bed material, and \( Q_{sj} \) = sediment discharge of \( j \)-th fraction.

(e) Porosity and grain size distribution

In the bed-porosity variation model, the porosity is assumed as a function of characteristic parameters of grain size distribution.

\[
\lambda = f_j(\Pi_1, \Pi_2, \Pi_3,...)
\]

(6)

where \( \Pi_1, \Pi_2, \Pi_3,... \) = characteristic parameters of grain size distribution.

4. ESTIMATION OF POROSITY

To calculate the porosity values of bed material is carried out by these following steps. First, the bed material at each point representing the upper, middle and lower part are sieved to get the grain size distribution. Furthermore, the type of grain size distribution is determined based on value of parameter \( \gamma \) and \( \beta \), which are calculated by the following equations:

\[
\gamma = \log \frac{d_{\text{max}}}{d_{\text{min}}} - \log \frac{d_{50}}{d_{50}}
\]

(7)

\[
\beta = \log \frac{d_{\text{max}}}{d_{\text{max}}} - \log \frac{d_{\text{peak}}}{d_{\text{peak}}}
\]

(8)

where \( \gamma \) and \( \beta \) are geometric parameters.

After the values of \( \gamma \) and \( \beta \) are known, type of grain size distribution can be found by using the diagram proposed by Sulaiman (2008). Furthermore, the value of the porosity is calculated by the following equations:

a. Log normal distribution

\[
\sigma_i^2 = \sum_{i=1}^X \left( \ln d_i - \ln d_i^* \right)^2 p_i
\]

(9)

\[
\lambda = (0.1414\sigma) + 0.3445 \text{ if } 1 < \sigma < 1.25
\]

(10)
\[ \lambda = (-0.1058 \sigma) + 0.3088 \quad \text{if } 0.75 < \sigma < 1.0 \]  

(11)

where \( \sigma \) is standard deviation, \( d \) is grain diameter, \( j \) is class of grain size, \( p_j \) is proportion of class \( j \) and \( \lambda \) is porosity.

b. Talbot distribution

\[ n_T(z_{100}) = \frac{\ln \left( \int d \frac{f(d)}{d_{100}} \right)}{\ln \left( \frac{\log d_{100} - \log d_{\text{min}}} {\log d_{\text{max}} - \log d_{\text{min}}} \right)} \]  

(12)

\[ n_T(z) = \frac{\pi_T(10\%) + \pi_T(25\%) + \pi_T(50\%) + \pi_T(75\%) + \pi_T(84\%)}{5} \]  

(13)

\[ \lambda = 0.0125n_T + 0.3 \]  

(14)

where \( f(d) \) is cumulative of percent finer, \( n_T \) is Talbot number.

5. RESULTS AND DISCUSSION

Experiment

The grain size distributions of surface bed material at the upstream point (\( x = 1 \) m), the midstream point (\( x = 3.5 \) m) and the downstream point (\( x = 6 \) m) are shown in Figure 2. These samples are taken before run Case 1 and the end run of Case 1. The initial grain size distribution at all points is the lognormal type. The mean diameter of surface bed material at the upstream point, middle point, and lower point are 2.74 mm, 2.85 mm and 2.52 mm, respectively. In Case 1, no sediment supply from upstream end, so that the bed level goes down along the channel until equilibrium static condition is achieved. The fine sediment in the bed surface moves from the upstream region to downstream region. If the equilibrium static condition is reached, the surface material along the channel becomes coarser and the porosity of bed surface material increases. As a result, the grain size distribution at all points becomes the Talbot type. The mean diameter of surface bed material in Case 1 is 6.19 mm; 6.63 mm and 6.08 mm at the upstream, midstream and downstream, respectively. The porosity of surface bed material also changes, from 0.2 to 0.34 at the upstream point, from 0.2 to 0.37 at the midstream and from 0.19 to 0.35 at the downstream point, respectively.

Figure 3 presents the grain size distributions of surface bed material at the upstream point (\( x = 1 \) m), the midstream point (\( x = 3.5 \) m) and the downstream point (\( x = 6 \) m) in Case 2. Sediment feeding in Case 2 (lognormal type) makes the bed material changing from Talbot type to lognormal type. The mean diameter of surface bed material changes from 6.19 mm to 2.62 mm at the upstream point, from 6.63 mm to 2.65 mm at the midstream point and from 6.08 mm to 3.11 mm in the downstream point. The porosity of surface bed material in Case 2 is 0.17; 0.18 and 0.19; at the upstream point, the midstream point and the downstream point, respectively. The result describes that if sediment supply due to an eruption comes into downstream region, the sediment supply can recover the bed level, as well as the material of bed channel, to the initial condition.

The grain size distributions of surface bed material at the upstream point (\( x = 1 \) m), the midstream point (\( x = 3.5 \) m) and the downstream point (\( x = 6 \) m) in Case 3 are shown in Figure 4. Sediment supply from the upstream boundary in Case 3 causes the surface bed material changing, although the type of grain size distribution is still lognormal. As a result, the mean diameters of surface bed material at the upstream point, the midstream point, and the downstream point change from 2.62 mm to 2.77 mm, from 2.65 mm to 2.88 mm and from 3.11 mm to 3.23 mm, respectively. Even though, these mean diameters change slightly, but the changes in porosity value are quite different. The porosity of surface bed material in Case 3 at the upstream point, the midstream point, and the downstream point are 0.29; 0.28 and 0.24; respectively.
Figure 2. Grain size distributions of surface bed material at the upstream (x = 1m), the middle stream(x = 3.5 m) and the downstream (x = 6 m) in Case 1.

Figure 3. Grain size distributions of surface bed material at the upstream (x = 1m), the middle stream(x = 3.5 m) and the downstream (x = 6 m) in Case 2.

(a) Upstream
(b) Midstream
(c) Downstream
Figure 4. Grain size distributions of surface bed material at the upstream (x = 1 m), the middle stream (x = 3.5 m) and the downstream (x = 6 m) in Case 3.

Simulation results

Figure 5 shows the comparisons between the simulation results and the experimental results on the grain size changes of surface bed material at the upstream point, midstream point and downstream point. In Case 1, the surface bed material changes from the lognormal type to the Talbot type. Figure 5 (a) shows that the grain size of the simulation result and the grain size of experimental result are similar at the upstream point. However, the simulation result is not similar with the experimental result at the midstream and downstream points, as shown Figure 5 (b) and Figure 5 (c). In the experiment, most grain sizes are transported by flow, even though the finer grain tends to be transported more than the coarser grain. In the sediment mixture, the critical friction velocity of coarse material tends to decrease, but the critical friction velocity of the fine material tends to increase. As a result, the both material can move to downstream together. In the simulation, the flow can select perfectly the grain size to be transported based on the critical friction velocity of each grain size. As a result, the mean diameter of surface bed material in the experiment changes faster than in the simulation, especially in the midstream and the downstream. It also means that the porosity in the experiment changes faster than that in the simulation.

Figure 6 shows the comparisons of the simulation results with the experimental results in Case 2. By sediment feeding, the grain size distribution of surface bed material can change to new type. The fine sediment fills the void between the coarse sediment. It causes the increase in the proportion of finer sediment in the surface layer and the decrease in porosity. As a result, the grain size type of surface layer will change from the Talbot type to the lognormal type. The decrease in porosity in the upstream region is larger than the midstream and downstream. In the experiment, the increase in the proportion of finer sediment in the surface layer is faster than that in simulation. The condition may be caused by the effect of sediment burial process. As the result, porosity of the surface layer in simulation is higher than that in the experiment.

Figure 7 shows the comparison between grain size change in the experiment and that in the simulation in Case 3. Uniform sediment supply can increase in the proportion of the grain size in the surface layer that is the same with sediment feeding, so that the material of surface layer tends to be uniform material and porosity increases. In the simulation, even if the sediment feeding can increase the proportion of the fraction that same as sediment feeding, but the coarse sediment remains in the surface layer, so that the uniform sediment cannot be formed. Consequently, porosity of surface layer in the experiment is higher than that in the simulation.
Figure 5. Experiment and simulation results on grain size distributions of surface bed material in Case 1

Figure 6. Experiment and simulation results on grain size distributions of surface bed material in Case 2
CONCLUSION

To determine the impact of sediment management on riverbed material can be used one dimensional porosity variation model. The model can simulate the riverbed variation, grain size change, and porosity of riverbed material. Based on the verification using the experiment, the model can simulate an unimodal grain size distribution. Regarding simulation on grain size and porosity change of riverbed material, the simulation result has given a good trend. In Case 1, it shows that river bed becomes coarser and the porosity tends to increase due to no sediment supply from upstream cause by natural process or human activity. In Case 2, if there is sediment supply from upstream due to an eruption, the river bed elevation increases. In Case 3, grain size distribution changes from lognormal type to uniform and the porosity increases.

REFERENCES


Figure 7. Experiment and simulation results on grain size distributions of surface bed material in Case 3