Three-dimensional gravel motions in numerical movable bed channel with particles of various shapes and sizes

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ABSTRACT: Sediment transport rate and bed variation in gravel-bed rivers are strongly affected by gravel sizes and shapes in streams. However, measurements of forces acting on sediment particles in active are difficult, especially for rapid gravel-bed rivers. To investigate the dynamic mechanism of gravel moving in streams, we have developed a numerical movable bed channel in which three-dimensional motions of various shape and size gravel particles are calculated individually. The dynamic interaction between particles motions and hydrodynamic forces on movable bed surface in numerical experiment is investigated. It is demonstrated that large gravel particles form static clusters and they have an important role to stabilize gravel-bed surface against hydrodynamic forces of flows.

1 INTRODUCTION

The sediment transport process in gravel-bed rivers during floods is explained that, at first small particles on the bed surface move, next large gravel particles expose and resist mainly hydrodynamic forces (Fukuoka et al. 2007, Osada and Fukuoka 2012). Exposed large particles do not move easily in large floods, rest for a long period, and roll intermittently. However, derivation of sediment discharge formulae for sand assumed that all particles move to a depth of several particle diameters. This sediment transport mechanism differs from that of gravel-bed rivers. Bed variation analysis using sand discharge formulae can not evaluate adequately the sheltering effect of large particles on small particles (Suzuki et al. 1994) and hydrodynamic forces acting on projecting large particles. Therefore, it has been pointed out that an analysis of bed variation in gravel-bed rivers using these sediment discharge formulae is questioned (Osada and Fukuoka 2012).

Many researchers have investigated the sediment transport mechanism in gravel-bed rivers in which large gravel particles move intermittently, and reported that formations of large particles clusters on the bed surfaces contribute to river beds stabilities. Piedra (2012) made experiments for movable bed of graded sediments and investigated the relationship between tractive forces and ratio of large gravel cluster occupying area to the bed surfaces. Hendrick (2010) made field observation and reported distribution of large particles clusters and their changes due to flood events. Characteristic structural arrangements of particles in gravel-bed rivers, such as imbrication, indicates that stabilities of river beds are strongly affected by the sizes and shapes of particles. However, experiments and field observations have difficulty as ways to investigate the dynamic mechanism of gravel transport and how particles are arranged against hydrodynamic forces in gravel-bed rivers in which bed materials are widely distributed in sizes and shapes.

In recent years, progress of computing performances have made possible to analyse the transport mechanism of individual particles motions by the Lagrangian method (Goto et al. 2000). In most of these analyses, hydrodynamic forces acting on particles are calculated using drag coefficient therefore evaluations of hydrodynamic forces have remained inexact. Ushijima et al. (2008) developed numerical method for solid-liquid multiphase flow in which hydrodynamic forces are calculated directly by calculating three-dimensional fluid motion around a solid object using finer computational cells than the object size. Harada et al. (2011) conducted large eddy simulation of solid-liquid multi-phase flow for drifting particles on movable bed of three sizes spheres and investigated vertical sorting process in oscillatory flows. Fukuda et al. (2012) has developed a numerical model evaluating threedimensional gravel particle motions in consideration of various shapes of particles by applying the numerical method of solid-liquid multiphase flow to solid-liquid interactions and combined spheres model (Matsushima et al. 2009) to various shape particles (Fig. 1), and demonstrated that gravel particle trajectories with frequent saltation and lateral migration in experiments could not be



Figure 1. Gravel particles model.

reproduced in the simulation unless the irregular shapes of particles are considered. Using the developed model, a numerical movable bed channel with particles of various shapes and sizes is constructed and mechanism of gravel transport and dynamic effect of gravels to the streams are investigated using the numerical channel.

2 NUMERICAL MODEL

In the present numerical model, fluid motions are simulated with the Eaulerian method and gravel motions are simulated with the Lagrangian method. To take into account the effect of solid phase on liquid phase, fluid motions are simulated by governing equations of multiphase flows (Fig. 2). Fluid forces acting on particles are evaluated directly by integrating the forces acting on particles in the multiphase flow. Gravel particles with various shapes are made by the combinations of several small spheres (Fig. 1). The motions of the particles are simulated as rigid bodies.

2.1 Governing equation of fluid motion

Fluid motion is simulated by one-fluid model for multiphase flow using Smagorinsky model as the subgrid turbulence model:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = g_i - \frac{1}{\rho} \frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j} \left\{ 2 \left(\nu + \nu_t \right) S_{ij} \right\}$$
(2)

$$S_{ij} = \frac{1}{2} \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right)$$
(3)

$$\nu = \mu / \rho \tag{4}$$

$$\nu_t = \left(C_S \Delta\right)^2 \sqrt{2S_{ij}S_{ij}} \tag{5}$$



Figure 2. Concept of the fluid analysis.

where u_i : *i*-direction averaged velocity given weight by the mass within a fluid cell, *P*: total of pressure and isotropic component of SGS stress, ρ : density, μ : dynamic viscosity, g_i : gravitational acceleration, v_i : SGS turbulent viscosity, C_S : Smagorinsky constant (0.173), Δ : calculation grid size. Physical property ϕ (density ρ , dynamic viscosity μ) and averaged velocity u_i are calculated as volumeaveraged values and mass-averaged values, respectively, as follows:

$$\phi = \alpha \phi_s + (1 - \alpha) \phi_f, \ \phi_f = f \phi_l + (1 - f) \phi_g \tag{6}$$

$$u_i = \left\{ \alpha \rho_s u_{si} + (1 - \alpha) \rho_f u_{fi} \right\} / \rho \tag{7}$$

where *f*: fluid volume fraction in fluid calculation cell, α : solid volume fraction in fluid calculation cell, suffix *l*, *s* and *g* denote liquid phase, solid phase and gas phase, respectively. u_f is fluid velocity and u_s is solid velocity. Continuity equation and momentum equation are solved by the SMAC scheme with staggered grid.

2.2 Evaluation of solid rigidity in fluid calculation

Solid rigidity is evaluated by simulating particle motion as rigid body and setting average density ρ and average velocity u_i with eq. (6) and eq. (7). Solid velocity u_{si} in eq. (7) is calculated equation below:

$$u_s = \dot{r}_G + \omega \times r_f \tag{8}$$

where \dot{r}_{G} : translational velocity vector of particle gravity center, ω : angular velocity vector of particle, r_{f} : position vector from gravity center to the evaluation point of u_{s} . The solid volume fractions in fluid calculation cell α in eq. (6) and eq. (7) are calculated by splitting a fluid calculation cell into sub-cells and counting the number of sub-cells included in gravel particle (Fig. 3).



Fluid calculation cell

Figure 3. Evaluation of particles volume with sub-cell.



Figure 4. Cells image for calculation of rigid body properties.

2.3 Evaluation of water surface variation

Water surface variation is evaluated with continuity equation of fluid volume fraction *f* based on the VOF method (Hirt and Nichols, 1981).

$$\frac{\partial f}{\partial t} + \frac{\partial f u_i}{\partial x_i} = 0 \tag{9}$$

Gas motion is not calculated to reduce calculation time and fluid motion is calculated under pressure zero condition at the water surface as boundary condition.

2.4 Modeling of various shape particles

Various particles in shape and size are made compactly by the combination of several small spheres to detect contact and collision points between particles as seen in Figure 1. It is difficult to calculate shapes of lapped part of spheres geometrically, therefore, evaluation of rigid body properties such as mass, gravity center and tensor of momentum inertia become major issues. We calculate rigid body properties of particles by using sufficiently small cells for calculation of rigid body properties and numerical integration in consideration of volumes and points of cells included in particles (Fig. 4). The rigid body properties of particles are not changed in motion, therefore they have only to be calculated just once at the beginning of the simulation.

2.5 *Governing equation of particle motion in streams*

Particle motions are simulated by momentum equations and angular momentum equations as rigid bodies:

$$M\ddot{\mathbf{r}}_G = M\mathbf{g} + \mathbf{F}_f + \mathbf{F}_c \tag{10}$$

$$\dot{\boldsymbol{\omega}}_{r} = \mathbf{I}_{r}^{-1} \left\{ \mathbf{R}^{-1} \left(\mathbf{N}_{f} + \mathbf{N}_{c} \right) - \boldsymbol{\omega}_{r} \times \mathbf{I}_{r} \boldsymbol{\omega}_{r} \right\}$$
(11)

where bold face letters indicate vector tensor and matrix, M: mass of particle, \mathbf{r}_{c} : gravity center point, g: gravitational acceleration, F: forces acting on particles surfaces, N: torques acting on particles, $\boldsymbol{\omega}$: angular velocity, **R**: transformation matrix from the local coordinate system to the global coordinate system, and I: tensor of momentum inertia. Suffix f, c: fluid force and contact force, respectively, suffix r:components in local coordinate systems of each particle. Dot notations over letters denote time derivatives. In calculation of angular momentum equations, at first, next time step angular velocities of local coordinate system $\boldsymbol{\omega}_r$ are solved with eq. (7), next, angular velocities of global coordinate system $\boldsymbol{\omega}$ are calculated with transformation matrices **R**. Next time step transformation matrices **R** are set in consideration of the rotation in time step Δt with the angular velocities $\boldsymbol{\omega}$. Next time step small sphere positions are set with next time step transformation matrices **R** and small sphere positions in local coordinate system. In these coordinate transformation between global coordinate system and local coordinate system, quaternion is used instead of transformation matrix **R** (Ushijima et al. 2008).

2.6 Evaluation of fluid force

Fluid forces acting on a particle is evaluated with integrating forces acting on a particle in the multiphase flow (Ushijima et al. 2008):

$$F_{f,i} = \int_{\Omega_s} \left\{ -\frac{\partial P}{\partial x_i} + \rho \frac{\partial}{\partial x_j} \left\{ 2\left(\nu + \nu_t\right) S_{ij} \right\} \right\} d\Omega \quad (12)$$
$$N_{f,i} = \int_{\Omega_s} \mathcal{E}_{ijk} r_{f,j} \left\{ -\frac{\partial P}{\partial x_k} + \rho \frac{\partial}{\partial x_l} \left\{ 2\left(\nu + \nu_t\right) S_{kl} \right\} \right\} d\Omega \quad (13)$$

where $F_{j,i}$, *i* component of fluid force, $N_{j,i}$, *i* component of torque caused by fluid force, $r_{j,i}$; position vector from the gravity center of the particle to the fluid calculation cells, Ω_s ; an area occupied by a particle and ε_{ijk} Levi-Civita symbol.



Contact detection and calculation of contact forces are conducted with each small sphere composing particles



Figure 5. Evaluation of contact forces.

2.7 Evaluation of contact force

Contact forces acting between particles are calculated by the contact detection of each small sphere composing a particle (Fig. 5). Contact forces and torques acting on gravity centers of particles are calculated by the summation of the contact forces calculated concerning each small sphere:

$$F_c = \sum F_{cp,n} N_c = \sum r_{cp,n} \times F_{cp,n}$$
(14)

where, F_c , N_c : contact force and torque acting on the gravity center of a particle, $F_{cp,n}$: contact force acting on each sphere, $r_{cp,n}$: position vector from the particle gravity center to the contact point.

Contact forces between particles are calculated by the Distinct Elements Method (Cundall and Strack, 1979) and the spring constants k and coefficients of dashpot c are calculated by equations (15)–(17) (Gotoh, 2004):

$$k_{n} = \left\{ \frac{4}{9} \left(\frac{r_{1}r_{2}}{r_{1} + r_{2}} \right) \left(\frac{E}{1 - pos^{2}} \right)^{2} e_{n} \right\}^{\frac{1}{3}}$$
(15)

$$s_0 = \frac{k_s}{k_n} = \frac{1}{2(1+pos)}$$
(16)

$$c_n = 2h \sqrt{\frac{m_1 m_2}{m_1 + m_2}} k_n, \ c_s = c_n \sqrt{s_0}$$
(17)

where suffix *n* and *s*: a component of direction from center of spheres to the contact point and orthogonal two directions on the tangential plane, respectively, r_1 , r_2 : radii of contacting two spheres m_1 , m_2 : mass of contacting spheres.

3 NUMERICAL EXPERIMENT ON MOVABLE GRAVEL BED WITH VARIOUS SHAPE AND SIZE

3.1 *The out line of numerical movable bed channel and experimental condition*

Figure 6 shows the shape of the numerical channel with movable bed and definition of coordinate axes used for numerical analysis. The shape of the



Figure 6. Shape of the numerical movable bed channel and definition of coordinate axes.



Figure 7. Grain size distributions.

numerical channel with 15 m long 1 m wide and 1:20 bed gradient was designed by considering flow condition entraining gravel particles and length of bed waves and computational load. Four different shapes of particles are prepared which are composed of 8–10 small spheres as shown in Figure 1. Five sizes of particles (40 mm, 50 mm, 70 mm, 90 mm, 120 mm) are prepared by varying small spheres sizes composing particles. The diameters of the various shape particle are given as the diameter of spheres with the same volume. Particles are packed in to the channel by varying the supplying rate to fit the particle size distribution in Figure 7. In this paper we define large particles as larger than 90 mm and small particles as smaller than 70 mm. The discharge of $0.5 \text{ m}^3/\text{s}$ is given at the upstream end of the channel, and zero pressure condition is given at the downstream end. The number of particles discharging out the end of the channel are supplied simultaneously at the upstream point in x = 1-2 m section. The numerical analysis of the movable bed was started at the same time as the start of discharging water, and we defined the time of numerical experiment start as water discharge at the downstream end becomes almost constant, and the numerical experiment was conducted in 70 s. Hereinafter experimental time is defined as the time from experiment start. The parameters used in the simulation are shown in Table 1.

3.2 The result of the numerical experiment

3.2.1 The outline of the variation of the flow condition, bed condition and sediment transport discharge

Figure 8 shows the time variation of longitudinal bed levels and water surface profiles averaged in

Table 1. Parameters used in the simulation.

$\Delta x, \Delta y, \Delta z$: Fluid calculation cell size	$\begin{array}{l} 0.01 \ (m) \\ 5.0 \times 10^{-4} \ (s) \\ 1,000 \ (kg/m^3) \\ 2,650 \ (kg/m^3) \\ 8.9 \times 10^{-4} \ (Pa \cdot s) \\ 8.9 \times 10^{-4} \ (Pa \cdot s) \end{array}$	$\Delta t'$: Time step for DEM calclation	$5.0 \times 10^{-6} (s)$
Δt : Time Step for fluid calculation		<i>E</i> : elastic modulus	$5.0 \times 10^{10} (Pa)$
ρ_w : Density of water		<i>pos</i> : Poisson's ratio	0.33 (-)
ρ_s : Density of gravel		<i>h</i> : Coefficient of dashpot	0.11 (-)
μ_w : Dynamic viscosity of water		Number of gravel particles	$33 \times 10^{3} (-)$
μ_c : Dynamic viscosity of gravel		Number of small spheres	$301 \times 10^{3} (-)$
μ_s : Dynamic viscosity of gravel	$8.9 \times 10^{-4} (\text{Pa} \cdot \text{s})$	Number of small spheres composing gravel particles	$301 \times 10^{3} (-)$



Figure 8. Longitudinal profiles of averaged water levels and bed levels.



Figure 9. Space and time variation of bed surface.

lateral direction. The values are averaged for two seconds. After 70 s from experiment start, average depth is 0.23 m, average velocity is 2.17 m/s and Froude number is 1.45. The flow is supercritical flow and water surfaces vary in the same phase as the bed wave. Figure 9 shows numerical computation results of the bed surface. Bed level and distribution of particles diameter on the bed surface are shown in Figure 10. In Figure 9 and Figure 10, the bed condition before the experiment is also shown for the reference. Regarding the bed profiles shown in Figure 8, bed degradation occurs from the downstream end, and it propagates toward upstream and bed surface wave comes to be seen. Relatively high positions are seen at x = 4 m, 7 m, 9 m and 13 m points in Figure 8. At those points large particles form clusters and particles sorting occurs on the bed surface. Figure 11 shows sediment discharge rate of each particle size measured at the downstream end, and Figure 12 shows the number of flowing out particles from downstream end per unit time. The sediment discharge rates shown in Figure 11 vary in short time although total transport rate of each particle is almost



Figure 10. Bed level and particle diameters distributions on the bed surface.



Figure 11. Sediment discharge rates.



Figure 12. Number of flowing out particles.

stable. Sediment discharge rate of large particles is larger while flowing out numbers of small particles are larger in Figure 12, therefore it was recognized that small particles are also moving well as large particles. In this experiment, aggradations occur at supplying section x = 1-2 m and x = 4-5 m, and degradations in the downstream of x = 5 m point, and bed is not in equilibrium condition. However sediment discharge rate is almost stable and bed level is also stable in downstream of x = 5 m point, while particles overall sizes are moving. Therefore it is considered that this result of numerical movable bed experiment is worthy to investigate movement and arrangement of gravel particles against streams and mechanism of particle motions.



Figure 13. Snap shot view of the flow vectors near the bed surface (t = 45 s right side of the channel).



Figure 14. Vertical distribution of flow and particles *x*-direction velocities.

3.2.2 *Factor of increasing transport rate of large particles*

The factors of large amount of the sediment discharge of large particles, larger than 90 mm, are investigated. Figure 13 shows vectors of streams near the bed surface, and Figure 14 shows the vertical distributions of time averaged flow velocities in the x-direction at the center of the channel. The velocities are averaged over 0.15 m lateral range which is about the largest particle size. Figure 14 also shows time averaged velocities of particles passing the section. As seen in Figure 13 and Figure 14, fluid velocities decrease considerably from upper position to the lower position within the scale of larger particles scale and is about 2.0 m/s at the upper position of large particles while at the lower position of the large particles where small particles are arranged, fluid velocity decreases greatly and is smaller than 0.5 m/s. The large particles located relatively high position received large velocities, therefore sediment transport rate of large particles become great.

3.2.3 *The process of large particles cluster formation*

We investigate the factors of large particles cluster formation on the bed surface shown in Figure 9 and Figure 10. Figure 15 shows trajectories of each size particles from t = 42.5 s to t = 47.5 s. In addition to the figures of the x-y planer trajectories, bed level is also shown on the background. The trajectories of small particles, smaller than 70 mm, in x-y plane take deep water passage beside projecting beds, while large particles, larger than 90 mm, move over projecting beds formed at center of the channel around x = 8.5 m point and right side and left side of the channel around x = 13 m point. It is because gravity centers of rolling large particles are high position. Therefore large particles receive upward force due to collision with projecting beds at lower part than gravity center of particles, and small particles cannot move over projecting beds

but come to take detours because gravity center of small particles are low position on the bed surface. In this manner, large particles move over projecting beds more easily than small particles and received large fluid velocity, therefore large particles are not able to stop easily on flat bed. Large particles can stop at projecting beds as high as large particles size, therefore it is considered that large particles tend to form clusters. Deeper water passages are formed beside large particles clusters of the bed surface and small particles come to move deeper water passages beside large particles cluster. In this manner, particles on the bed surface are divided into large particles clusters and other particle groups. This results in the particle sorting of the bed surface.

3.2.4 *Hydrodynamic forces acting on the bed surface*

To investigate how particles resist against streams, we convert the hydrodynamic forces acting on particles to the forces acting on unit x-y plane area, evaluating hydrodynamic forces as the stress, and investigate the relationship between converted stress, uneven bed surface shape, and sizes of particles on the bed surface. Figure 16 shows longitudinal profile of bed level in upper figure, longitudinal profiles of stress acting on particles in middle figure, and longitudinal profiles of mean



Figure 15. Trajectories of particles (t = 42.5 s - 47.5 s).



Figure 16. Longitudinal profiles of water level, bed level, hydrodynamic forces acting on particles, mean diameter of particles on the bed surface (t = 45 s).

particle sizes on the bed surface in lower figure. The stress acting on particles from streams are evaluated with eq. (18) by integrating x-direction hydrodynamic forces from channel bottom to the top of the moving particles and dividing the area of x-y integrating area to evaluate forces acting on per unit bed surface area.

$$=\frac{\int \int \int \alpha \left\{-\frac{\partial P}{\partial x_{1}} + \rho \frac{\partial}{\partial x_{j}} \left\{2(\nu + \nu_{t})S_{1j}\right\}\right\} dxdydz}{\int \int dxdy}$$
(18)

Integrating range in lateral direction is from y = -0.15 m to y = 0.15 m and longitudinal integrating distance is 0.01 m as fluid calculation cells sizes. Mean particles sizes in lower figure indicate the averaged value of 0.15 m squared area on the bed surface evaluated as area-averaged diameter of particles seen on the bed surface. From Figure 16, it was demonstrated that resisting forces against

streams were acting at the projecting beds formed by large particles clusters.

3.2.5 *The effect of particles shapes on starting and stopping of their motion*

We investigate how particles behave when particles start to move and stop. To investigate the behavior of particles, we define the eigenvector corresponding to the largest value of principal moment of inertia as short axis, and eigenvector corresponding to the shortest value as long axis. A short axis and a long axis defined in this manner are orthogonal. A long axis is the easiest axis to rotate among principal axes. Short axis is the hardest axis to rotate, and indicates almost the same direction as normal vector of the most flat plane of particles. Long axes and short axes of the particles are shown in Figure 17. Figure 18 shows time variations of averaged particles velocities in x-direction, and contact forces and hydrodynamic forces acting on particles nondimensionalized by x-direction gravity force, and angles between a long axis and x-axis and angles between short axis and z-axis, the time of the data was selected concerning the starting and



Figure 17. Conditions of long axis and short axis of particles on the bed surface.



Figure 18. Time variation of the particles velocities, hydrodynamic forces, contact forces and particles direction concerning starting and stopping motion.

stopping of particles motion, and all the values are evaluated by averaging individual particles motion. In this figure, red lines in upper figures show particles velocities and starting of the particles motion is shown as a time detaching from zero, and stopping of the motion is a time corresponding to zero. The time zero is selected at the time when a particle begins to move and comes to a stop. In the figure of starting motion of large particles, it is seen that, at the starting motion of large particles, the angle between long axis and x-axis are becoming larger. According to the variation, it is revealed that static large particles incline long axes toward downward, and at the beginning of the motion, they change the direction of long axes to roll downward easily. The angle between short axes and z-axis also become larger, thus static large particles point flat plane toward up direction, and at the starting, they change the directions of flat plane. Accordingly projected area is increasing, and therefore hydrodynamic forces shown in upper figure is increasing together with the variation of direction of particles. This kind of characteristics of the time variation of the motion are shown in the figure of small particles, however, characteristics of the time variation is not seen so clearly. This is because that, at the lower part of the bed surface where small particles rest on, stream direction changes largely due to arrangement of the static large particles and small particles rest in a gap of large particles, therefore, small particles starting and stopping motions are affected by the irregular shape of gap. Concerning the stopping of large particles, time variations of long axes and short axes show the opposite variations, long axis inclines to the x-direction and short axis to the z-direction then it was revealed that particles end up the motion by inclining their flat planes in the upward direction. Characteristic variations are that the large particles motion are stopped by receiving negative x-direction contact forces and accordingly hydrodynamic forces acting on the particles are increasing a little, on the other hand, hydrodynamic forces acting on small particles are decreasing after the stop of small particles motions. The reason of the differences is considered that small particles can stop at small velocity regions behind stationary large particles, while large particles stand high positions and receive large hydrodynamic forces and therefore cannot stop easily but do by the collision and support of surrounding large particles.

4 CONCLUSION

This paper developed a numerical movable bed channel composed of particles with various shapes and sizes and predicted the three-dimensional particles motions and forces acting on streams from particles which are difficult to measure in gravel-bed rivers. The results of the numerical experiment draw following principal conclusions.

- 1. From the investigation of detailed particles motion data, the motion mechanism of each size particles in streams and resistant mechanism of different sizes and shapes particles in streams were demonstrated.
- 2. Large particles start to move with inclining the flat plane direction from upward direction to another direction, accordingly hydrodynamic forces are increasing, and inclining the long axis from downward to another direction to roll easily. Small particles indicate similar time variation although the trend of the variation is not so clearly than large particles, because small particles are affected by irregular shapes of gaps formed by surrounding static large particles and streams around small particles are disturbed and assume various direction due to surrounding large particles.
- 3. Rolling and saltating large particles move high position of the bed surface and receive large flow velocity, therefore large particles cannot stop easily. Large particles stop by collision with surrounding large particles and tend to form large particles clusters. Small particles move deeper water passage beside clusters therefore particle sorting occurs at the bed surface. The formation of large particles clusters has an important role to stabilize gravel-bed surface resisting against large hydrodynamic forces of flows.

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