Hiding effect among sediment particles exposed on surface of riverbed with an extremely wide range of sediment grain sizes

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Introduction

In this study, the experimental investigation was conducted on the sediment transport on riverbed composed of materials with extremely wide range of sediment grain sizes. Such phenomena are seen in river reach just downstream of a dam in Japan. In order to analyze the riverbed deformation process, it is necessary to fully evaluate the hiding effect of cobbles on gravels and sand. The hiding effect means that the tractive force acting on sand decreases as the exposure degree of cobbles increases. Ashida and Fujita (1986) investigated the hiding effect of gravels and proposed a formula to evaluate the sediment discharge of fine sand suspended from the void among gravels.

The riverbed materials are classified into three grain size groups of sediment: L-, M-, and S-particles. L-particles are cobbles that cannot move at all. M-particles are gravels that can move as bedload. S-particles are fine sand or silt that can move as suspended load. We have conducted fundamental experiments on movable bed under the condition that each grain size group is represented by only one grain size (Figure 1), and the relationship of the hiding effect was formulated as follows:

$$\frac{\tau}{\tau_M} = \frac{1}{\alpha^2}\left(\frac{\Delta_M}{D_L}\right)^2 + 1 \qquad (1)$$

in which α is proportional constant (= 0.3) (Sekine and Hiramatsu, 2017) (Figure 2). However, since the grain size distribution is continuous in actual rivers, the experiments in this study were conducted on riverbed with M-particles consisting of several grain sizes. In the static equilibrium, the vertical structure of the riverbed was examined. Based on these results, we investigated whether the results obtained in authors' previous experiments are general.

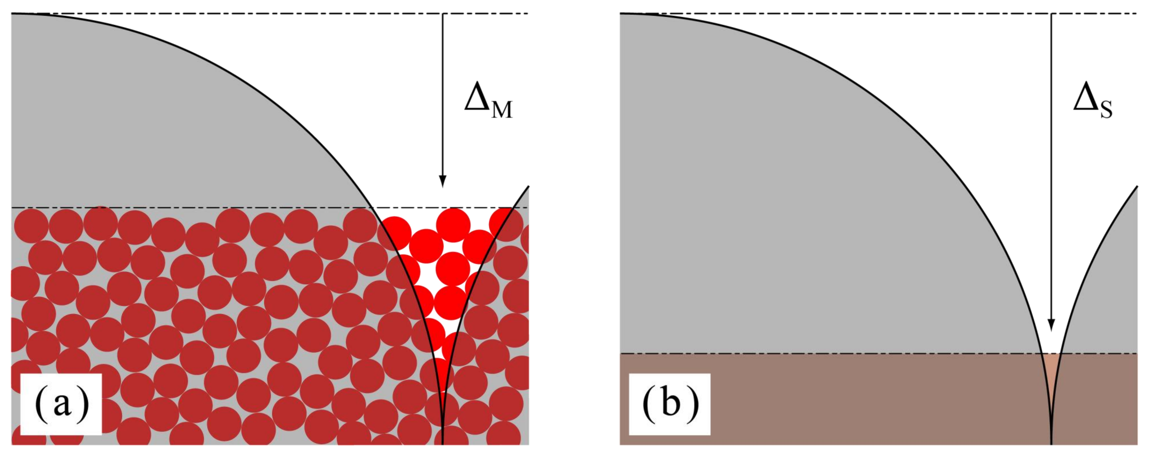

Figure 1. Vertical structure of riverbed in static equilibrium: (a)L-M bed, (b)L-S bed.

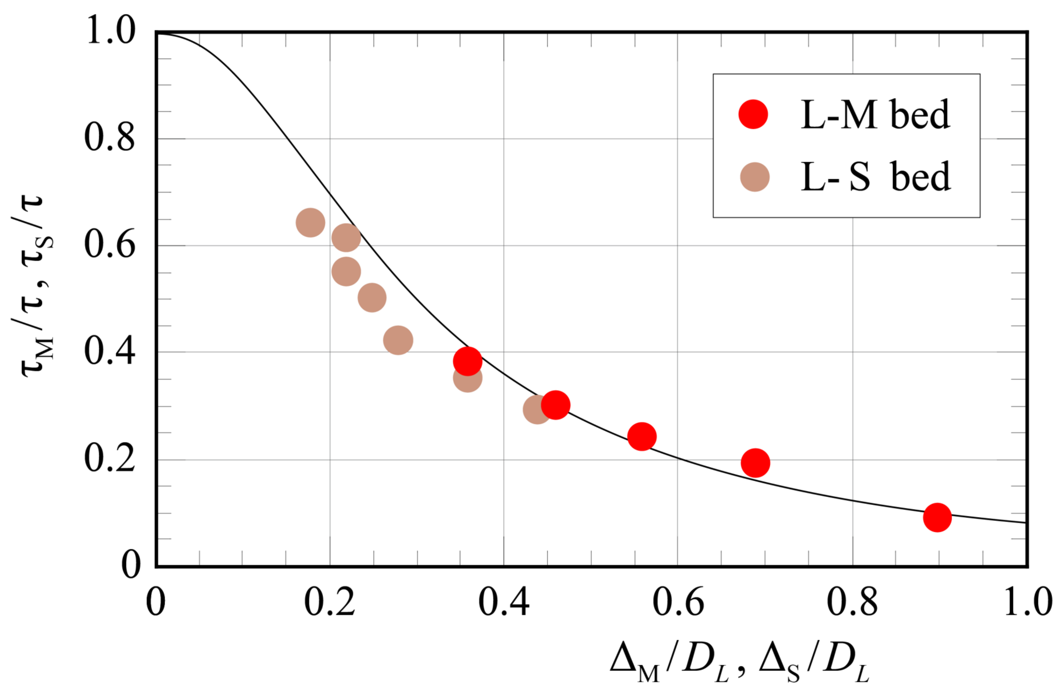

Figure 2. Hiding effect of L-particles

Table 1. Experimental conditions and results: The friction velocity was u^* = 0.058 (m/s).

Case	Mixed ratio of M- and S-particles						Δ_{Ma}/D_L	Δ_{Mb}/D_L	Δ_{Mc}/D_L	Δ_{Md}/D_L	Δ_{Me}/D_L	Δ_S/D_L
	Ma	Mb	Mc	Md	Me	S						
A	0	0	0.50	0	0	0.50	-	-	0.30	-	-	0.37
B	0	0.17	0.17	0.17	0	0.50	-	0.27	0.28	0.29	-	0.34
C	0.10	0.10	0.10	0.10	0.10	0.50	0.28	0.29	0.31	0.33	0.38	0.38

Summary of experiments

Alumina balls with diameter of D_L = 50 (mm) were used for L-particles (specific gravity is 3.98). Glass beads with grain sizes of 5, 4, 3, 2, and 1 mm were used for M-particles (specific gravity is 2.5). These are called Ma-, Mb-, Mc-, Md-, and Me-particles in order of decreasing grain size. These were painted black, yellow, green, red, and blue, respectively. Silica sand with grain size of 0.21 mm was used for S-particles (specific gravity is 2.65). The flume used for the experiments was an open channel with a rectangular cross-section with the total length of 16 m, the width of 0.2 m and the slope of 1/250. The bottom of the reach between 8.5 and 14 m from the upstream end of the channel is 0.05 m lower than that of the other reach, and this lower reach is called 'movable bed reach'. In the initial riverbed M- and S-particles were filled to the top of L-particles in this reach (Table 1).

The experiments were conducted under the condition that flow rate was Q = 15 (L/s), and the discharge was reduced to zero when the riverbed attained the static equilibrium state. Any sediment was not supplied from the upstream end. Under the equilibrium state, no sediment was transport at all, and therefore bed can not change any more. After the bed attained this state, measurement about the vertical structure of the riverbed was conducted. For example, the height of individual particles in the void space among L-particles was measured in the middle reach of the movable bed and in the center of the transverse direction.

Results

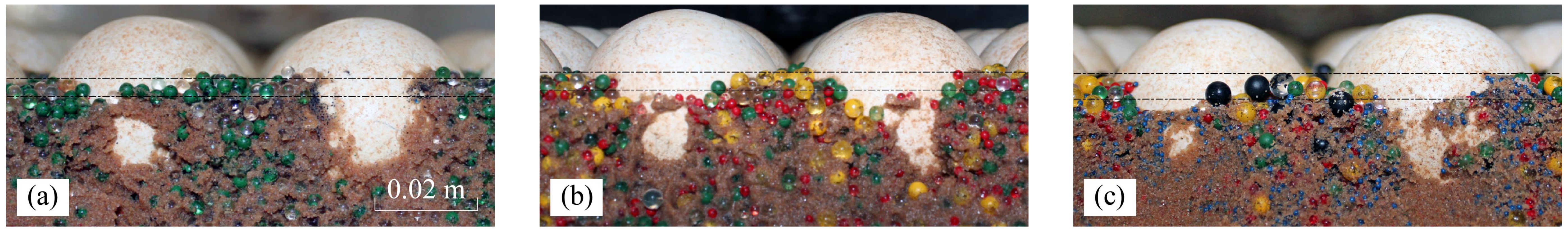

Figure 3. Schematic view of vertical structure of riverbed in static equilibrium: (a) Case A, (b) Case B, (c) Case C.

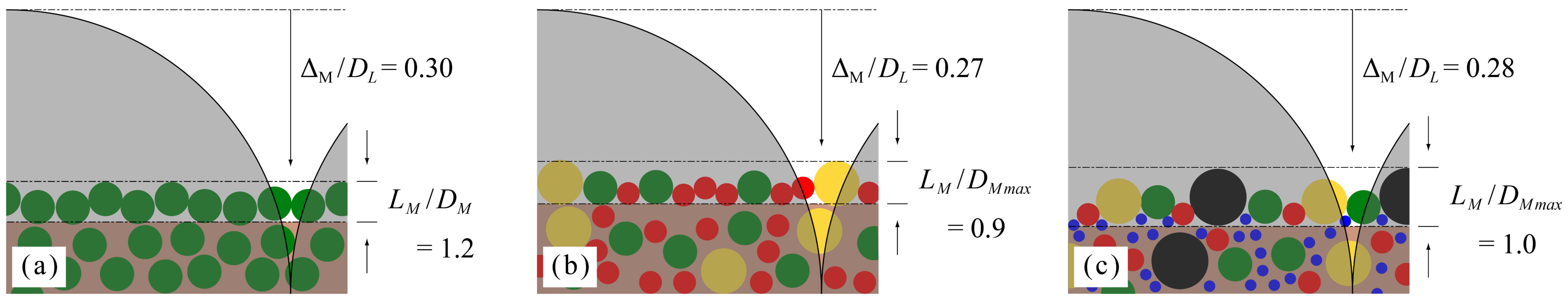

Figure 4. Cross-section of riverbed in static equilibrium: (a) Case A, (b) Case B, (c) Case C

- ✓ A layer consisting of only M-particles was formed in the void space among L-particles in all cases. This layer is called 'M-particle layer' (Figure 3). The maximum grain size of M-particles group is defined as D_{Mmax}. In Cases B and C, L_M / D_{Mmax} were 0.9 and 1.0 (Figure 4). This means that the thickness of M-particle layer was approximately equaled to D_{Mmax}, which was consistent with the previous results (Sekine and Hiramatsu, 2017).
- ✓ Top surface elevation of M-S particles Δ_M becomes almost same (Figure 4). The difference in elevation among each grain size was almost the same as the difference in grain size. In other words, the bottom elevation of each size of M-particles is consistent with the same plain which corresponds to the bottom surface of the M-particle layer.

Conclusion

- ✓ The experiments were conducted in which the riverbed framework is composed of cobbles that cannot move at all.
- ✓ The vertical structure of riverbed under the static equilibrium state was made clear by conducting a series of experiments.
- ✓ In the the void space among L-particles, it was found that M-particle layer was formed. Characteristics of the structure of this layer was also understood quantitatively.
- ✓ The thickness of this M-particle layer is approximately equaled to D_{Mmax}, and the bottom elevation of each size of M-particles in this layer was the same level on averaged.

References

Ashida and Fujita, 1986, *Proceedings of JSCE*.
Sekine and Hiramatsu, 2017, *Gravel-Bed Rivers*.

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