Two-dimensional riverbed variation analysis method focused on bed surface unevenness and mechanism of sediment transport in stony-bed rivers

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In a stony-bed river with a wide range of particle size distribution, large stones act as a strong fluid-resistance element during a flood. Sands and gravels often tend to remain in unevenness of the bed surface formed by large stones of various sizes. A stony-bed river will be in a stable bed condition when the cross sectional form and particle size distributions corresponding to the flow force are established. However, it is difficult to predict riverbed variations in stony-bed rivers by the conventional riverbed variation analysis methods, which do not account for these essential mechanisms resulting from the unevenness of the bed surface. In this study, we developed a new model of two-dimensional riverbed variation by considering the mechanism of riverbed variation and characteristics of bed surface unevenness. We applied the new model to the field experiment results carried out in the Jyoganji River. The model is capable of explaining water surface profiles, discharge hydrographs, bed variations, sediment transport rate, particle size distribution and height of each particle size in stony-bed rivers.

Key words

Stony-bed river, new bed variation analysis model, bed surface unevenness, sediment transport, field experiment, gravel bed river.

I BACKGROUND AND OBJECTIVE OF THE RESEARCH

In a stony bed river with wide range of particle size distribution, stones and gravels are moved violently during flood, readily leading to bed scouring and bank erosion. A model predicting reasonably both two-dimensional flood flow and riverbed variation is required for the channel design and planning in stony-bed rivers [2]. The authors have conducted large scale field experiments in the Jyoganji River to elucidate the mechanism of bed variation in stony-bed rivers [3] [5]. Large stones exert great resistances on the flood flow. Sands and gravels tend to remain in unevenness of the bed surface formed by large stones of various sizes. A stony-bed river will be in a stable condition when the cross sectional form and particle size distributions corresponding to flow force are established.

In this study, we develop a new model of two-dimensional riverbed variation by considering the mechanism of riverbed variation and characteristics of bed surface unevenness. We verify the applicability of the new model with the results of the field experiment carried out in the Jyoganji River in 2009 [5].

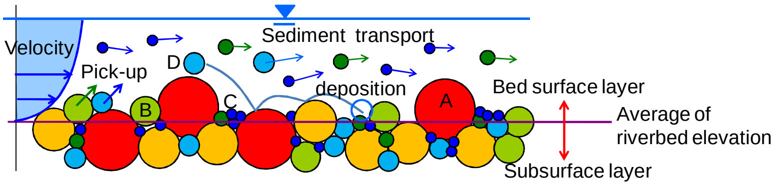


Figure 1 Relationship between bed surface, flow and sediment transport

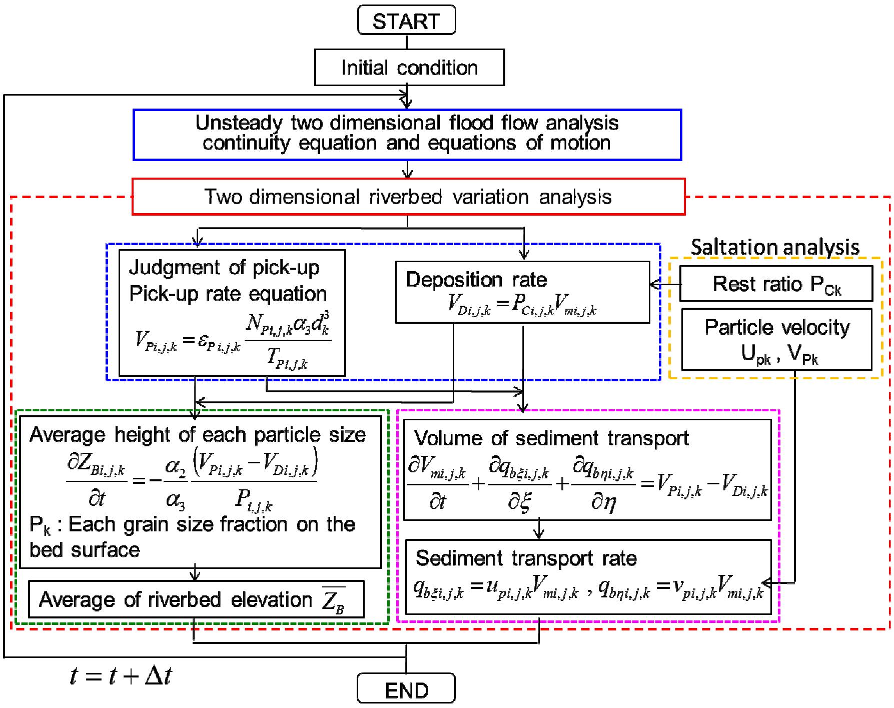


Figure 2 Procedure of the two-dimensional riverbed variation analysis

II TWO-DIMENSIONAL BED VARIATION MODEL IN STONY-BED RIVERS

Figure 1 illustrates sediment transport mechanism resulting from bed surface unevenness in stony-bed rivers. Figure 2 shows an analysis procedure of the new two-dimensional riverbed variation. The bed elevation in the conventional model has been treated as a constant within an analytical grid. In our new model, we calculate the height of each particle size on the bed surface in order to express unevenness of the bed surface. Moreover, we developed the form resistance using d_{90} to consider effects of large stones in the bed surface. The sediment transport model is composed of pick-up rate from the riverbed, deposit rate to the riverbed and particle velocity on the bed. Pick-up rate is calculated by considering the sheltering effect of large stones. Deposit rate is evaluated by using the rest ratio of each particle P_{ck} and the volume of sediment transport V_{mk}. The rest ratio P_{ck} is estimated by saltation analysis which is calculated in consideration of particle size distribution on the bed and bed surface unevenness.

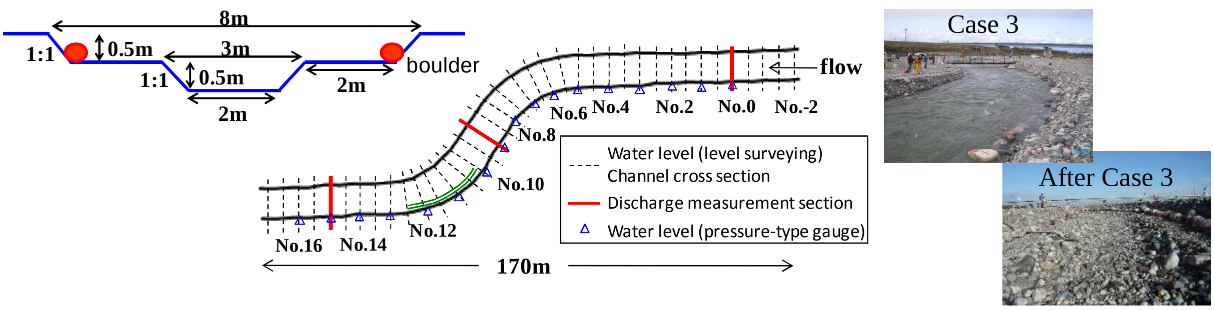


Figure 3 Plan view and initial cross sectional form of the field experimental channel

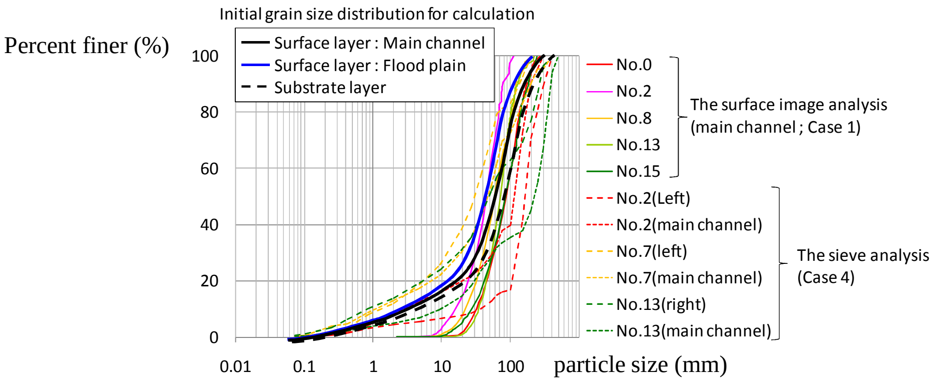


Figure 4 Particle size distribution used for the computation

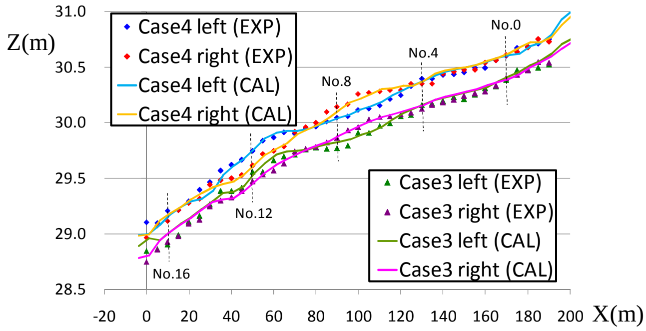


Figure 5 Comparison between observed and calculated water surface profiles

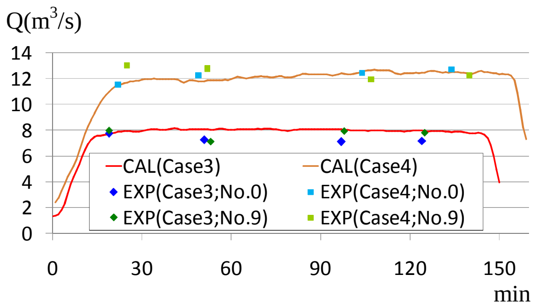


Figure 6 Comparison between observed and calculated discharge hydrographs

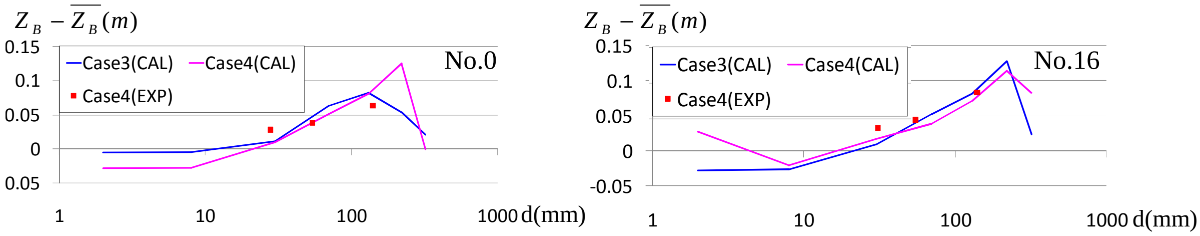


Figure 7 Comparison between the observed and calculated bed elevation of each particle size

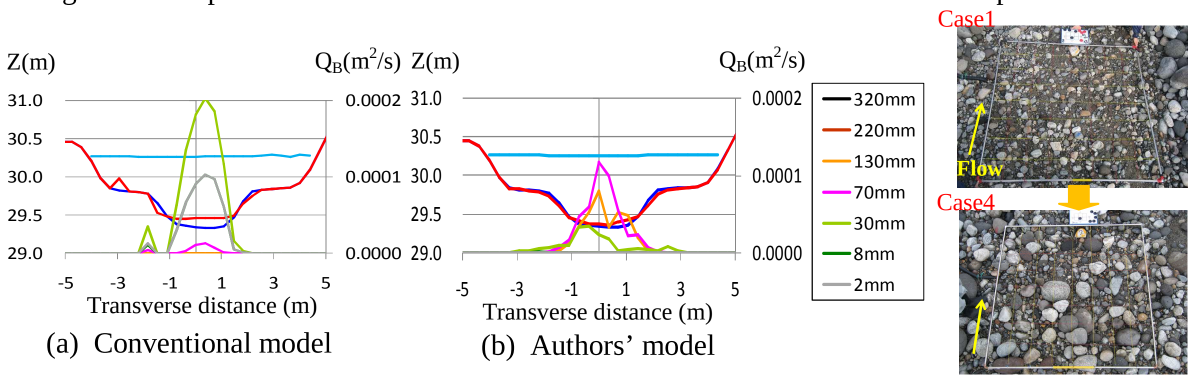
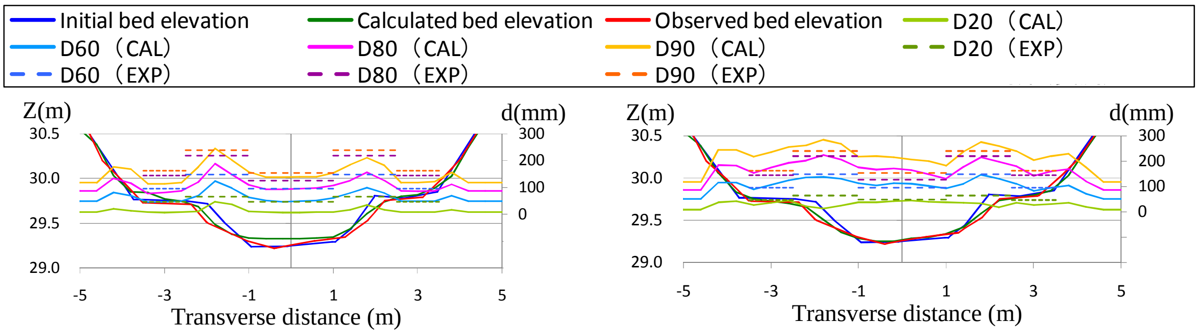


Figure 8 Transverse profiles of sediment discharge for each particle

III APPLICATION TO FIELD EXPERIMENTAL RESULTS

We applied the new model to the results of field experiment conducted in the Jyoganji River [5]. Figure 2 shows a plan view and initial cross-sectional form of the field-experimental channel. The channel is 190m long, 8m wide and 1:130 in bed gradient. The model was validated by the results of case 3 (8m^3/s) and case 4 (12m^3/s). We use the observed water level hydrographs at No.1 and No.15 as the boundary conditions. Figure 4 shows the initial particle size distribution for the calculation. The calculation was made by the division of seven particle sizes (320mm, 220mm, 130mm, 70mm, 30mm, 8mm, 2mm).



(a) Conventional model (b) Authors' model

Figure 9 Cross sectional form and particle size distributions (D20, D60, D80, D90) at No.4 section

Figure 5 shows the observed and calculated water surface profiles. The calculation reproduces well the observed water surface profiles. Figure 6 shows the comparison between observed and calculated discharge hydrographs. These calculated results almost agree with the observed results. Figure 7 shows the comparison of the calculated and observed heights of each particle size. The calculated results nearly reproduce the observed heights of each particle size. Figure 8 shows transverse sediment discharge profiles for each particle size. Which show the comparison between the results of conventional model [1] [4] and new model. In the conventional model, small particle groups are mainly transported. On the other hand, the new model gives the transportation of large gravel and cobble size groups. Actually, groups of large gravel and cobble were transported actively in Case 3 and Case4. Figure 9 shows the comparisons of the cross sectional form and particle size distributions (D_{20}, D_{60}, D_{80}, D_{90}) between the conventional model and new model. The conventional model cannot reproduce the observed particle size distributions on the bed surface. On the other hand, the authors' new model is capable of explaining cross sectional form and particle size distributions. It is demonstrated that bed variation, sediment transport rate, particle size distributions and height of each bed surface particles in stony-bed rivers as well as water surface profiles and discharge hydrographs are explained by the authors' new model.

IV CONCLUSIONS

We developed the new model of two-dimensional riverbed variation considering the sediment transport mechanism related to bed surface unevenness in stony-bed rivers. Water surface profile, height of each particle, bed variation and particle size distribution in stony-bed rivers were reproduced properly by the new model.

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