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# Reactivation of Alternate Bars to Increased Sediment Supply

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## ABSTRACT

Alternate bars formed on alluvial channel is confirmed that their wavelength and wave height increase with time, and they often stop transforming and migrating reaching an equilibrium state. In addition, it is reported that increasing sediment supply upstream influences the activity on the alternate bars. We conduct several numerical simulations to investigate the correlation between the sediment supply rate and the bar topographic fluctuations. The conditions of sediment supply were set in previous studies. Based on the present results, alternate bars reformation occurs when the sediment volume increases beyond a particular threshold value. Thus, we can use these results to restore the fluvial morphology by reactivating river bars.

KEY WORDS: sediment supply; configuration; bed topography

## INTRODUCTION

Sediment supply due to erosion and landslides plays a dominant role in the formation of river topography. Moreover, sediment supply is often terminated when a dam or another structure is constructed upstream. In this way, the sediment supply conditions in rivers are modified. Therefore, it is essential to grasp the relation between the sediment supply conditions and the fluctuation of river topography in order to predict river topography accurately.

Over the past few decades, several experiments have been conducted to investigate this relation. Teramoto and Tsujimoto (2004) and Miwa, et al. (2009) investigated the effects of variable discharge and sediment supply conditions on low-watercourse formation in channels with alternate bars. They reported that the low watercourse stabilized when the discharge was small, implying ordinary flow and no sediment supply through the bar topography, which was formed when large discharge and moderate sediment was supplied. On the other hand, Venditti et al. (2012) experimented on the sediment supply termination under constant flow and observed the disappearance of the non-migrating bars. Hence, the response of the non-migrating bars to the sediment supply termination was considerably affected by the changes in both discharge and sediment supply.

Furthermore, the influence of increased sediment supply has also been investigated. Madej et al. (2009) conducted an experiment with several stages of high, moderate, or no sediment supply. They noted a similarity between the results of the experiment and those of their survey in terms of sediment transport and storage. Podolak et al. (2013) investigated the fluctuation of bar topography with increasing sediment supply in terms of specific parameters, such as the bed slope, the spatial variability of the bed height, and the grain size distribution. Both studies reported that new bars were formed over non-migrating bars, when the sediment supply upstream of the channel increased. As non-migrating bars are related to forestation of river channel, which is a problem in Japan's rivers, the reactivation of these bars is important in terms of flood control. Thus, the fundamental characteristics of non-migrating bars reactivation should be explored.

However, it is difficult to distinguish the influence of the different parameters (e.g., the amount, timing, the duration of sediment supply, and the bed topography prior to changing the sediment supply conditions) on reactivation of non-migrating bars. The long-term data on the physical restrictions and the sediment supply are required for an accurate assessment. Moreover, the sediment supply conditions required for the reactivation of the non-migrating bars are unknown. Furthermore, engineering applications demand a quantitative relation between the increasing amount of sediment supply and the bed deformation. In this context, we investigate the behavior of non-migrating bars using the sediment supply amount as the only independent variable. In this study, we conduct a flume experiment wherein a non-migrating bars are reactivated. In addition, we perform a numerical simulation using the same conditions as in the experiment in order to validate our model. Susequently, we perform numerical simulations for different increasing amounts of sediment supply and explore the relation between the increasing amount of sediment supply and the changes in the bar topography.

## EXPERIMENT

### Method

The experiment was conducted in a 10-m-long, 0.3-m-wide, and 1/200 gradient open-channel flume. Sand (average grain size = 0.76 mm) was spread onto the flume bed at a thickness 5.0 cm. A stationary discharge of 1.3 L/s was supplied from the upstream of the flume. The initial combination of the aspect ratio and the shields number was set so that the alternate bar falls inside Kishi and Kuroki's (1984) diagram.

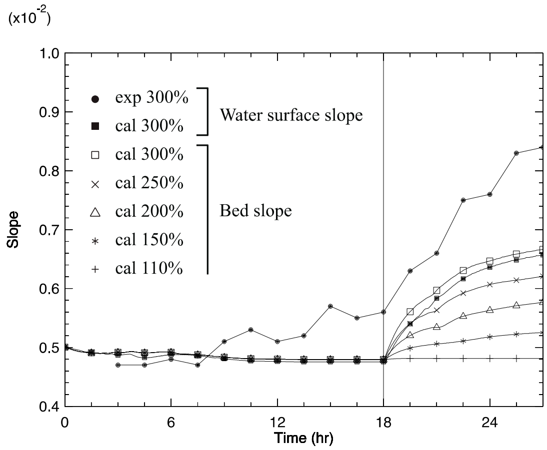


Fig. 1 Transition of the slope

The sediment supply quantity was determined through the following process. A preliminary experiment was conducted before initiating the main experiment to obtain the sediment supply quantity, which generally preserves the initial bed slope (1/200). This quantity was defined as the basic sediment supply amount. Further, each sediment supply amount was presented relative to the basic sediment supply in percentage (e.g., 100% feed). Next, the main experiment was conducted in two stages. In the first stage, 100% feed was supplied, whereas in the second, 300% feed was supplied from the upstream of the flume. Each stage continued until the topography settled down with regard to the occurrence and development of alternate bars. Thus, the duration of the first stage was 18.0 h, and that of the second stage was 9.0 h.

Water surface elevation was measured at several points in the flume, and the mean water surface slope was calculated throughout the flume. The flow was suspended to obtain pictures of the bed topography throughout the flume, and then it was restarted. This procedure was repeated every 1.5 hours until the end of the experiment.

## Results of the Experiment

The bed topography is presented in Fig. 1, and the water surface slope is shown in Fig. 2. During the first stage, alternate bars were formed at 3.0 h (wavelength = 1.7 m). Next, the bars migrated by gradually extending the wavelength. The bars' migrating velocity downstream was faster than upstream, and it gradually decreased. Few differences were observed in the bed topography between 10.5 and 12.0 h. Finally, the bed topography ceased to change after 18.0 h, and the first stage ended.

During the second stage, at 19.5 h, the deposition and erosion was observed at 5.0 – 7.5 m, indicating that the bed topography was destabilized. At 21.0 h, active fluctuation occurred throughout the flume. Subsequently, the irregular bed topography emerged. The bed topography at this time was completely different from that at 18.0 h, indicating that non-migrating bars topography was ed. Subsequently, between 25.5 and 27.0 h, the bed topography in the disturbed state settled down.

## COMPARING THE EXPERIMENT WITH THE SIMULATION

A numerical simulation was conducted under the same conditions as that of the experiment. The boundary condition was periodically applied in order to produce an arbitrary sediment supply. The grid size along the longitudinal and traverse directions was approximately 3 cm. The calculation interval was 1/100 s. We used Nays2DH, which is an iRIC solver for calculating the two-dimensional flow and bed deformation. A comparison at the equilibrium state is preferable in order to grasp the relation between the results of the experiment and numerical simulation. However, it is difficult to define the equilibrium state because too many factors interact, to determine the equilibrium state in terms of single factor. It is estimated that each factor adjusts toward the equilibrium state that influencing them. In fact, Podolak and Wilcock (2013) reported that the factors adjusted to the increased sediment supply over different timescales. In our study, we suppose that each factors' adjustment is completed when it stops fluctuation respond to sediment supply. Thus, we examine the amount of time required that slope and bed topography adjust in the experiment and the simulation.

### First Stage (100% Feed)

The bar wavelength at 18.0 h was approximately 2.5 m in the simulation. However, it was 3.3 m in experiment. The bed slope at the same time decreased to 1/209 in the simulation, whereas it increased to 1/179 in the experiment. The topography adjusted between 10.5 and 12.0 h in the experiment. Conversely, it adjusted between 7.5 and 9.0 h in the simulation. The adjustment of the slope completed after 18.0 h in the experiment and after 15.0 h in the simulation.

### Second Stage (300% Feed)

When the sediment supply was changed to 300% feed in the experiment, new migrating bars were formed over the non-migrating bars, and a similar phenomenon was observed in the simulation. The bar wavelength at 27.0 h was approximately 2.5 m in both cases. The water surface slope at 27.0 h was 1/152 in the simulation and 1/119 in the experiment. The bed topography adjusted between 24.0 and 25.5 h in the simulation, and between 25.5 and 27.0 h in the experiment. The slope nearly adjusted at the end of the simulation (27.0 h), contrary to the experimental observations, although an increasing trend was still observed.

### Validity of Numerical Simulation

The bar wavelength at the end time was generally the same in both stages. The slope at the end of the experiment was larger than that observed at the end of the simulation. In the experiment, changes in the bar topography were observed for a longer duration than in the simulation. Characteristics that slope adjustment follows after bed topography adjustment is agrees between experiment and calculation. The validity of the numerical simulation when sediment supply was increased is verified by confirming repeatability which non-migrating bars reactivated.

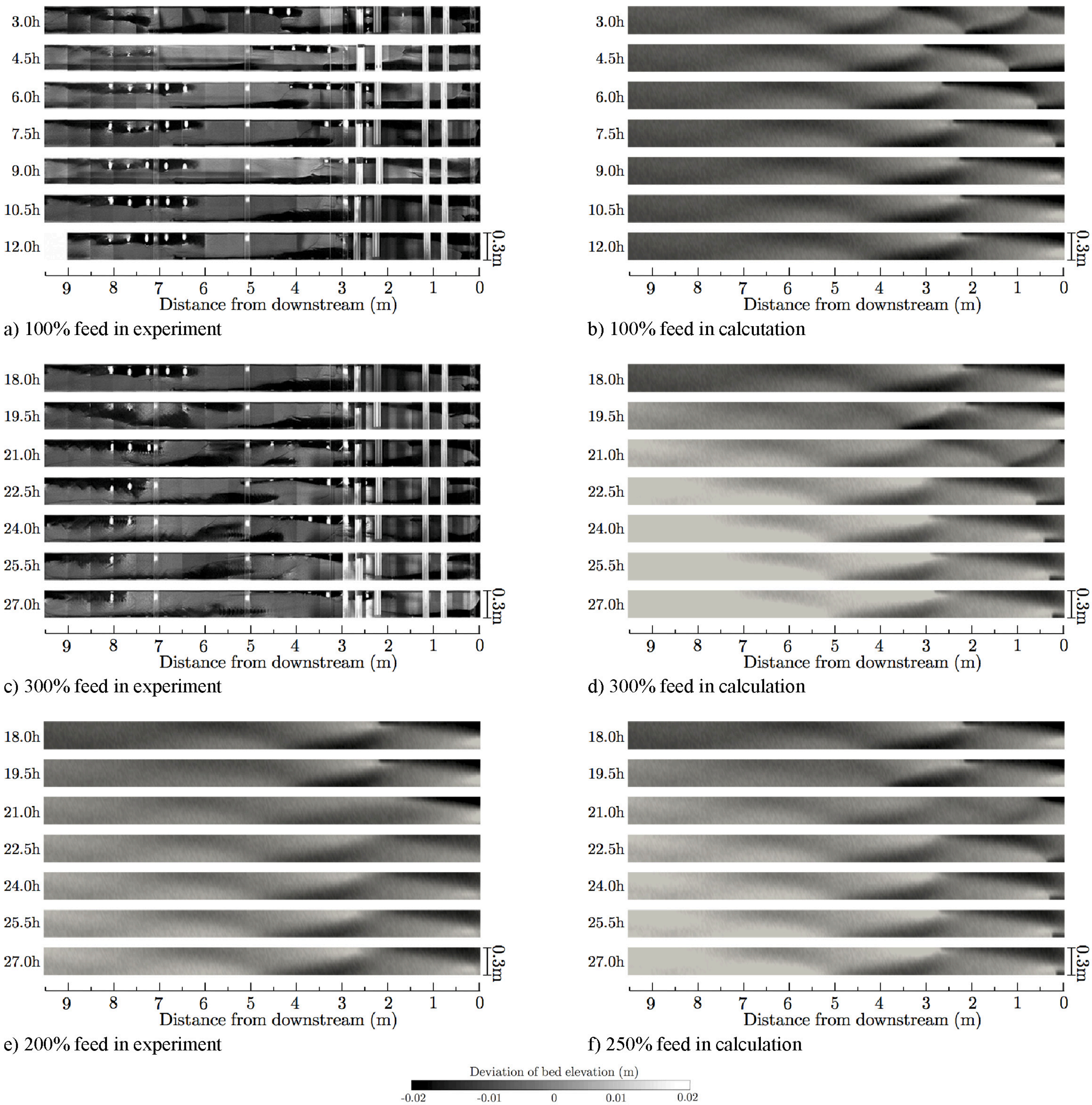


Fig. 2 Transition of the deviation of bed elevation

## INFLUENCE OF INCREASING AMOUNT OF SEDIMENT SUPPLY

We compare the differences in the bar response to the variable increasing amounts of sediment supply (100%, 150%, 200%, 250%, and 300%) using the validated numerical simulation.

### Bed Slope

The bed slope is shown in Fig. 2. The adjustment at 110% feed is completed in 19.5 h. At more than 150% feed, the adjustment seems to nearly complete at the end time (27.0h). As the increasing rate rises, the bed slope becomes larger at the end time.

### Integrated Time Deviation of Bed Elevation

In this study, we defined the integrated time deviation ($D_{Ti}$) index to quantify the degree of bed topography reactivation. We integrate deviation of the bed elevation from the time (18.0 h) when the sediment supply started increasing toward the end of the simulation (27.0 h) (Eq. 1). Here i, j is grid number in the direction of longitudinal and traverse directions, respectively, $t_0$ is the start time, $t_{end}$ is the end time, $\Delta t$ is the computation time interval, and z is the bed elevation. $D_{Ti}$ is a suitable index for indicating the degree of bar topography reactivation because erosion and deposition actively occur as this value increases. The $D_{Ti}$ value for each increasing amount is shown in Fig. 3. In the 110% and 150% feed, $D_{Ti}$ has small values throughout the flume, and there is nearly no difference between them. The value in the 200% feed is larger than that in the 150% feed throughout the flume. In more than 200% feed, as the increasing rate rises, the $D_{Ti}$ value increases throughout the flume.

$$D_{Ti}(i,j)=\sum_{t=t_0+\Delta t}^{t_{end}}\left|z(t,i,j)-z(t-\Delta t,i,j)\right| \quad (1)$$

In more than 200% feed, $D_{Ti}$ fluctuates in a traverse direction to the midstream and downstream, and the value is larger in both sides of the riverbank than in the center of the stream. It is estimated that intense deposition and erosion consecutively occurred in both sides as the bars migrated. Similarly, the value was larger downstream than upstream because the undulation was larger downstream than upstream. The midstream, the value was the lowest because the bar undulation was not as large as downstream, and the bed elevation did not increase as it did upstream.

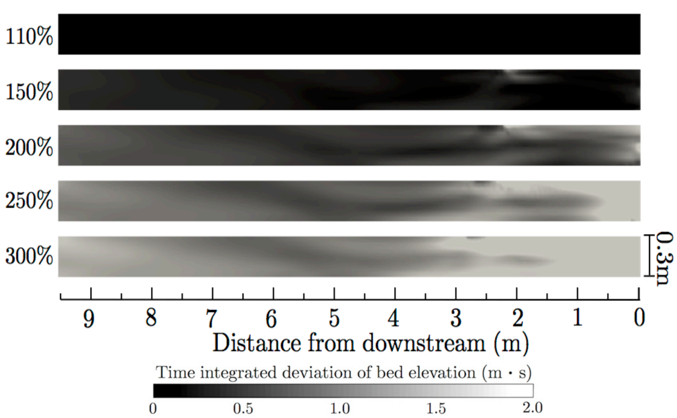


Fig.3 Time integrated deviation of bed elevation

### Bed Topography

The bed topography when the reactivation occurred is presented in Fig. 1. It adjusted between 21.0 and 22.5 h in the 200% feed. Additionally, the adjustment finished between 22.5 and 24.0 h in the 250% feed and between 24.0 and 25.5 h in the 300% feed. The results show that the adjustment of the bed topography lasts longer with increasing sediment supply.

## CONCLUSIONS

Using numerical simulation, we grasped the relation between the increasing amount of sediment supply and the fluctuation of bar topography. Consequently, it appears that the degree of reactivation significantly differs with increasing sediment supply. In these flume and flow conditions, the reactivation significantly occurs in more than 200% feed; However, it does not occur in less than 150% feed. Thus, the reactivation requires an increasing amount of sediment supply beyond a particular threshold value.

Furthermore, the bed topography and slope change with increasing sediment supply over different timescales. We hypothesized that many factors besides topography and slope (e.g., the spatial distribution of bed elevation or sediment transport) also adjust toward the equilibrium state affecting each other. It is necessary to explore several factors including varying sediment supply and the relation between them in order to entirely understand this phenomenon because the adjustment can be correlated with both bar stabilization and its reactivation.

The results of this study will be useful in the restoration of fluvial morphology through the reactivation of non-migrating bars.

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