NUMERICAL EXPERIMENTS ON THE BEHAVIOR OF BARS CONSIDERING THE BANK STRENGTH

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It is of interest to investigate how the behavior of alternate bars leads to channel development by taking bank strength into consideration, which is affected, in turn, by bank vegetation in natural rivers, in order to design stable channels when straightening rivers or building navigation canals. This study examined the behavior of alternate bars in a channel with erodile banks numerically, by considering the bank strength, which is influenced by bank vegetation in natural rivers. The lateral widening rate of the channel, bar migration speed, and wavelength were studied numerically when the channel remained nearly straight. The bars migrated more slowly as the aspect ratio increased. In a channel with strong banks, the bars migrated with speed, and the dimensionless bar was higher. Our numerical experiments showed that the behavior of bars differed with bank strength under the same hydraulic conditions.

Key Words: *Alternate bars, Bar migration, Wavelength, Bank erosion, bank strength.*

1 INTRODUCTION

The behavior of alternate bar plays an important role in channel evolution. A bar affects the bottom in a straight channel, leading to erosion of the side banks, which is one of the crucial factors determining flood damage in urbanized area (Ikeda, 1984).

In the process of channel development, bars emerge under certain hydraulic conditions (e.g., bed material size, slope, width, and flow depth, etc.) as the channel widens from an initially straight channel, with an erodible bed and banks made of non-cohesive materials. This results in local bank erosion, which depends on the migration of bars, and can lead to a meandering or braiding channel (Ashimore, 1982, 1991; Fujita and Muramoto, 1982). Seminara and Tubino (1989) explained the process theoretically. They showed that bar migration speed was influenced by lateral expansion of the channel, which tended to slow bar migration and increase bar wavelength. Several numerical models have been developed to simulate meandering river with erodible banks (Shimizu et al., 1996; Darby and Throne, 1996; Nagata et al., 2000). Furthermore, Shimizu (2002) developed numerical models to simulate the process of channel development from an initially straight channel with erodible banks.

Vegetation along natural rivers plays an essential role in channel development, and better understanding of its influence is of great importance in hydraulic and environmental engineering. Based on field observations, Andrew (1984), Hey and Thorne (1986), and Huang and Nanson (1997) explained that very dense vegetation increases the channel depth and the flow resistance, and decreases channel width. Hickin (1984) found that vegetation density, type, age, and health affected channel processes and morphology via flow resistance, bank strength, and the formation and breaching of logjams.

In a theoretical work, Ikeda and Izumi (1990) explained how bank vegetation reduced the bed shear stress, increasing bank strength and water depth, while decreasing the channel width. Moreover, the effect of roots on bank erodibility and lateral migration channels has been investigated by Smith (1976), Andrews (1984), Hickin (1984), Millar and Qucik (1993), Huang and Nanson (1997), and Jang et al. (2003), who showed that densely vegetated banks were associated with a lower lateral widening rate than were poorly vegetated banks.

It is of interest to investigate how the behavior of alternate bars leads to channel development by taking bank strength into consideration, which is affected, in turn, by bank vegetation in natural rivers, in order to design stable channels when straightening rivers or building navigation canals. There have been few studies, however, that have examined this topic.

The lateral widening rate of the channel, bar migration speed, and wavelength in the two kinds of channels were studied, taking the bank strengths into consideration when the channel was kept nearly straight.

2 NUMERICAL METHOD

The governing equations, *i.e.,* the continuity and momentum equations, for water flow are transformed from the Cartesian coordinate system to a moving boundary fitted coordinate system due to the deformation of side banks, explained in Shimizu (2002) in detail. As a numerical scheme, a CIP method, which solves boundary problems while introducing little numerical diffusion, was used in the advection term, and the central difference method was used in non-advection term in the staggered grid systme.

To calculate sediment transport, Ashida and Michiue (1972)'s formular was used.

To simulate channel widening, when the riverebed near the banks is scoured, and the cross-sectional gradient of the bank slope becomes steeper than the submerged angle of repose (θ_c), it is assumed that any sediment beyond the submerged angle of repose is instantly eroded to the point of this submerged angle of repose (Hasegawa, 1984).

When the computational range is enlarged, for example, due to erosion of the banks, (1) a new central line of the channel, passing through the center of new bank lines, is set. (2) Along this new center line, new cross-sections perpendicular to this line are set at equal intervals as the initial condition in the η direction. (3) Each corss-section is divided into grid numbers in the ξ direction. Consequently, new computational meshes are formed, and all the computational data are transformed from the old to the new computational grid. While transforming the data between grids involves a linear transformation based on geometric location. These calculations are done at an infinitesimal time interval ($\Delta\tau$) and are continued up to the disignated time.

The flow velocities at the inlet and outlet boundaries are set to the same value for each grid square, and the data for the two grid squares with adjacent inlet and outlet boundaries are shared as a periodic boundary condition. At sidewalls, the slip condition is used to calculate the stream wise flow velocity, while no slip condition is used for the transverse flow velocity.

3 FEATURES OF ALTERNATE BARS

To understand the features of alternate bars, which are an influential factor leading to channel development, it is important to consider bank strength, because the morphological behavior of natural rivers is affected by vegetation, which increases the stability of side banks. However, there has been little in the way of research that has examined this.

We investigated the lateral widening rate of the channel, bar migration speed, and the wavelength of a channel with erodible banks, taking bank strengths into consideration , when the channel was kept nearly straight. In addition, our numerical results are compared with those of Fujita and Muramoto (1982); their results depicted the processes of channel evolution well, although they did not considering side bank strength. The definition for alternate bar in a channel with erodible banks is depicted in Figure 1.

The lateral widenging rate of a channel is dependent on the stability of side banks. For practical purposes, we defined several dimensionless parameters, namely, dimensionless channel width, w , dimensionless bar

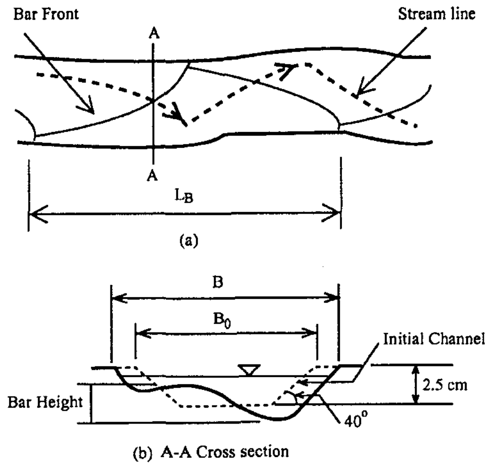


Fig. 1 Sketch used to define an alternate bar with erodible banks

migration speed, S , dimensionless bar wavelength, L , and dimensionless bar height, H , and discuss the width to depth ratio ($\beta = B/D$).

$$w = B/B_o, S = S_B/u_{*o}, L = L_B/B, H = H_B/D \quad (1)$$

where B = averaged channel width, B_o = initial channel width, S_B = averaged bar migration speed, u_{*o} = friction velocity ($=\sqrt{gH_oi}$), g = gravitational acceleration, H_o = initial water depth, and i = slope of the initial bed. The bar height, H_B , is defined as the difference between the maximum aggradated bed level and the minimum scour hole depth from the initial bed level.

The mean diameter of sediment particles is 1.25 *mm*, and the hydraulic conditions for numerical experiments in this study is summarized in Table 1.

Table 1 Hydraulic Conditions

Run	Wid.(Bo) (*cm*)	Dis. (*L/s*)	Wid./Dep.	Angle of repose (*Deg.*)
1	26	0.93	23.9	30
				35
				40
2	36	1.5	35.7	25
				30
				35

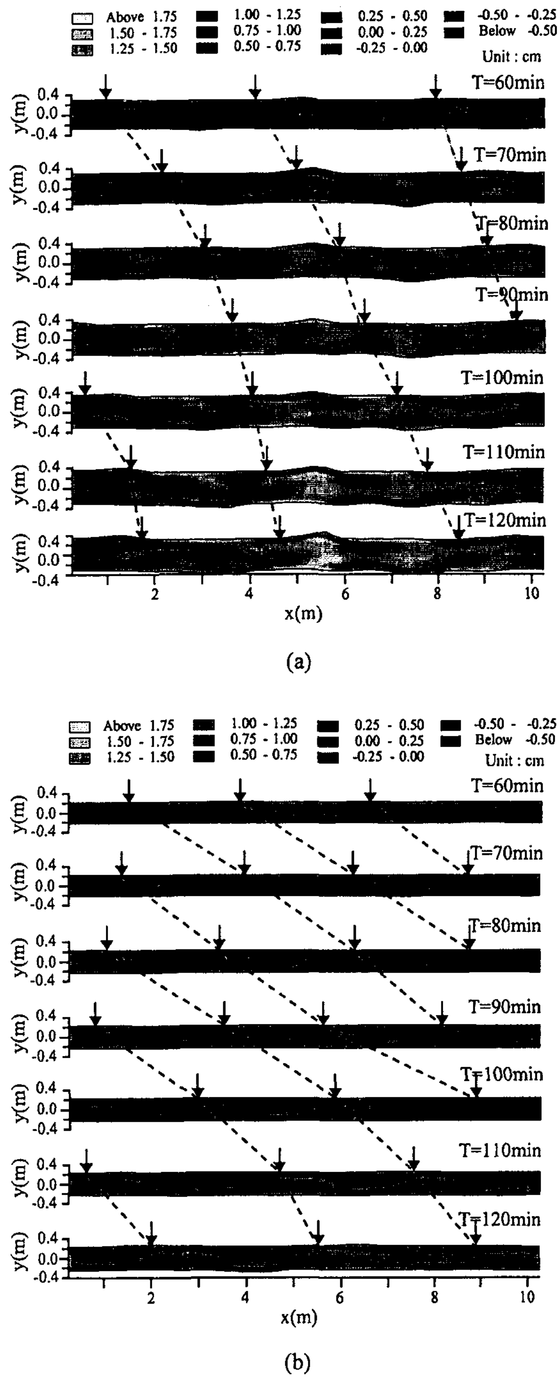


Fig. 2 Bar migration in the channel with the angle of repose : (a) 25 deg.; (b) 35 deg. for Run-2, respectively. The arrow symbol indicates the bar front in the left bank, and dashed line indicates the bar migration along the bank with time. Flow is left to right.

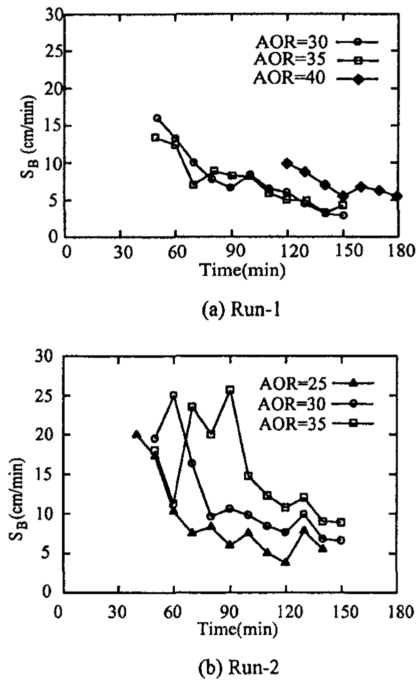


Fig. 3 Plot of the bar migration speed versus bank strength. AOR stands for the critical angle of repose.

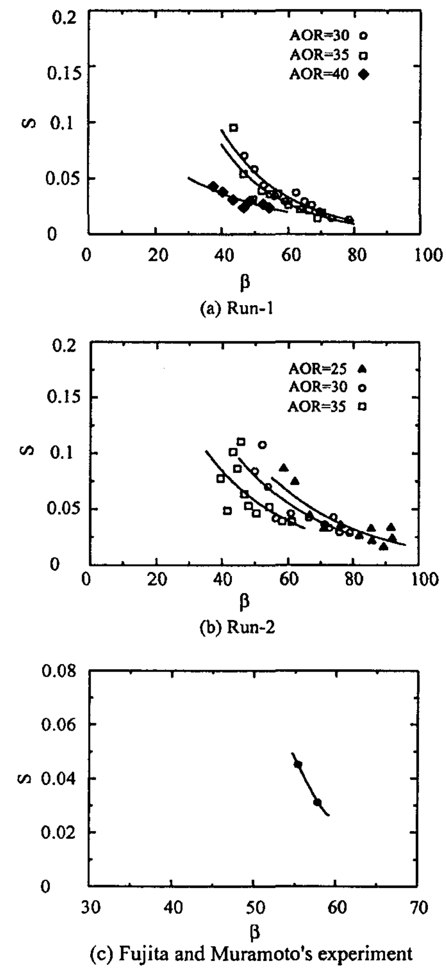


Fig. 4 Plot of dimensionless bar migration speed versus the aspect ratio.

3.1 Bar migration

Figure 2 plots the bar migration in the channel versus the angle of repose. The bars in the channel with stronger banks migrated further than did those in channels with weaker banks in the same period of time, indicating that the bar migration speed is greater in the channel with stronger banks.

The migration speed of alternate bars is plotted against time in Figure 3. The bar migration speed decreased with increasing time. Moreover, the bars migrated faster in the channel with stronger banks because of the weaker forcing effects between the migrating alternate bars and the side banks, and larger bed shear stress due to deeper water depth and less channel widening than those with weaker banks.

Bertoldi et al. (2002) elucidated the forcing effects induced by channel perturbations in laboratory experiments that considered two different regimes, each of which were dependent on the value of the ratio of bar migration speed to the rate of lateral bank erosion. With relatively low ratios, the channel experienced strong forcing effects, which halted alternate bar migration, induced by the non-uniform plane form; with relatively large values, the forcing effects were weaker.

Seminara and Tubino (1989) explained the process of channel development from an initially straight channel, with erodible bed and banks composed of nearly homogeneous sand materials theoretically. Channel widening leads to a decrease in bar migration, which affects the increase in bar wavelength.

The dimensionless bar migration speed is plotted against the aspect ratio in Figure 4. As the aspect ratio increased, the dimensionless bar migration speed decreased. Fujita and Muramoto (1982) obtained a similar result experimentally. Figure 4 shows that the bar migration speed decreases with the aspect ratio. Bar migration is influenced by bank strength. Perhaps the forcing effects between the alternate bars and the side banks are weaker with stronger banks. This is in good agreement with the theoretical prediction of Seminara and Tubino (1989).

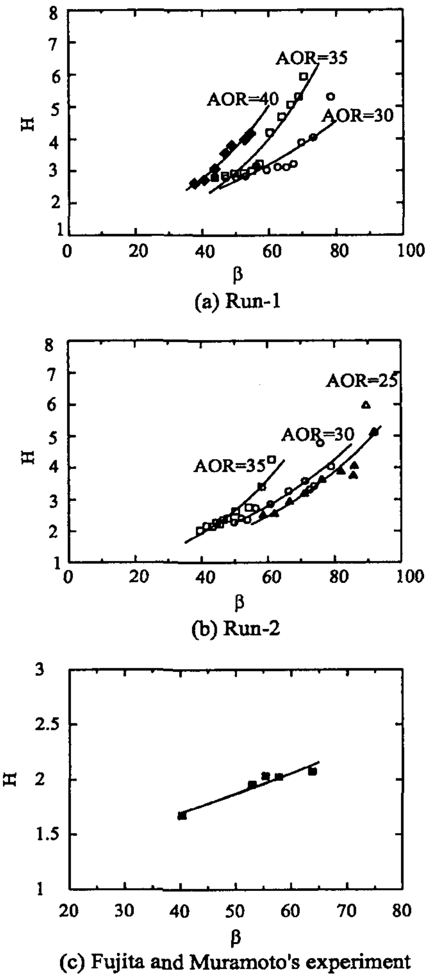


Fig. 5 Plot of dimensionless bar height versus the aspect ratio.

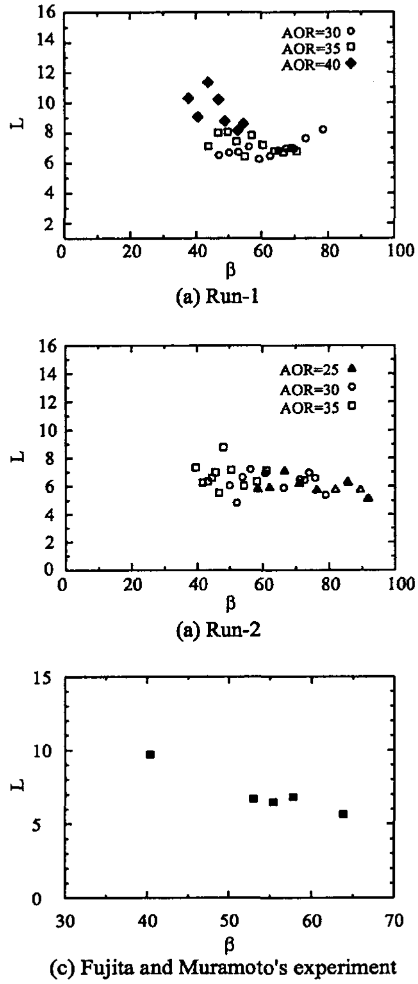


Fig. 6 Plot of dimensionless wave length versus the aspect ratio.

3.2 Bar height

As the aspect ratio increased, the dimensionless bar height increased as shown in Figure 5. This was seen in the experimental results of Fujita and Muramoto (1982). The same dimensionless bar height, in a channel with weaker banks, occurs in a wider channel than it does in a channel with stronger banks.

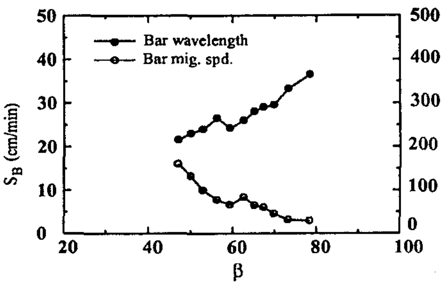
3.3 Bar wavelength

The dimensionless wavelength is plotted against the aspect ratio in Figure 6. As the channel widens, the effect of the dimensionless wavelength is less clear than are the effects of bar migration speed and bar height.

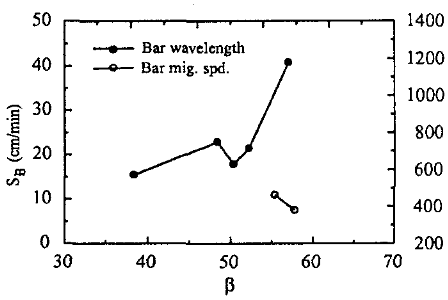
As the aspect ratio increased, the bar migration speed decreased, and bar wavelength increased, as shown in Figure 7. These characteristics are also shown in Fujita and Muramoto (1982). Moreover, Seminara and Tubino (1989) proved this relationship between bar wavelength and bar migration theoretically. The average bar migration speed upstream was the same or lower that downstream. On the countary, the average wavelength upstream was the same or longer than that downstream. The reasons are probably that the hydraulic features upstream are affected by those downstream because periodic boundary conditions up and downstream were employed numerically.

4 CONCLUSIONS

We investigated the behavior of alternate bars, which lead to channel development, taking bank strength into consideration, which is affected, in turn, by bank vegetation in natural rivers, using a numerical



(a) Run-1(Angle of Repoese = 30 deg.)



(b) Fujita and Muramoto's experiment

Fig. 7 Plot of the bar migration speed and wavelength versus the aspect ratio.

model.

The bar migration speed decreased with time, and the migration was influenced by the bank strength. The bar migrated more slowly as the aspect ratio increased, perhaps because the forcing effects between the alternate bars and the side banks are weaker with stronger banks. Bar height increased with the aspect ratio. The dimensionless bar height in the channel with stronger banks was lager because the channel widening was less than it was with weaker banks. The dimensionless bar height in channel with weaker banks was larger in a wider channel than it was with stronger banks .

As the channel widened, the effect of the dimensionless wavelength was less clear than the effects of bar migration speed and bar height. Channel widening leads to a decrease in bar migration, which affects the increase in the bar wavelength. Our numerical experiments showed that the process of channel widening increased the bar wavelength, and decreased the bar migration speed, as shown in Seminara and Tubino (1989), and that the behavior of alternate bars differed with bank strength under the same hydraulic conditions. For the future, quantitative investigations are needed experimentally and theoretically.

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