学　位　論　文　内　容　の　要　旨

博士の専攻分野の名称　　博士（工学）　　氏名　Sanchez Kristine Domogoy

学　位　論　文　題　名

Meandering-like river channel evolution due to the formation of fluvial bars
(砂州の形成によって発生する蛇行状流路変動)

Depending upon the fluid flow and sediment transport conditions, a variety of structures can develop on the riverbed whenever perturbations are induced. These include ripples, dunes, antidunes and alternate bars. Among these, alternate bars are megascale bedforms that arise upon the order of the channel width and sediment size. Alternate bars can cause riverbanks to erode, where it is thought that bar formation can trigger incipient meandering. While alternate bars are formed due to bed instability, meandering is formed due to bank instability.

This study aims to perform linear stability analysis of the formation of sand bars on the riverbed with the use of a new bank erosion model. The process-based bank erosion model states that the time variation of bank junction is proportional to the lateral sediment transport rate at the junction between the bed and bank regions, which is evaluated by the lateral sediment transport rate in the bank region and the time variation of the bed elevation at the junction. Furthermore, the model used in the study accounts for the variability of the parameters that influence the formation of bars, and to clarify the effect of bank erosion into the analysis by determining its effect on bar wavelength.

The St. Venant shallow water equations are used as governing equations and the process-based bank erosion model is derived to its simple form following the assumptions of the study. In addition, a parameter, ϵ, is introduced in order to provide a protection that inhibits bank erosion, such as slump block armouring or the presence of vegetation. From linear stability analysis, the solutions of banks that are in-phase are obtained for the case of bar instability with and without bank erosion. The growth rates of perturbation are solved using ϵ - expansion to consider the effect of the slump block armouring or the presence of vegetation. The Chebyshev polynomials are also employed for numerical solution. If the growth rate is positive, the base state is unstable and it is considered that bars theoretically form; otherwise, the flat bed is stable and no bars grow.

The results from linear stability analysis are presented in three cases. Firstly, the parameters such as Froude number, Shields number and bed friction coefficient are varied. Secondly, the aspect ratio and the parameter that inhibits bank erosion ϵ are varied. Thirdly, the phases at the banks and the spatial distribution of the perturbed variables are presented. In the first case, the growth rates of perturbation are plotted in the dimensionless wavenumber - aspect ratio plane, or the k-β plane. It is found that when the Froude number is increased, the unstable region shifts to a range of smaller wavenumbers or the wavelength increases. Also, when the bed friction coefficient is increased, the values of the growth rates are amplified. In a similar way, when the aspect ratio is increased from $\beta = 10$ to 40, the growth rates are amplified. Meanwhile, when the Shields number is increased, the effect of bank erosion is minimized; at Shields number equal to 0.06, the effect of bank erosion is relevant.

For the second case, the growth rates are plotted against k, and β is varied from 10 to 20. The parameter that inhibits bank erosion, ϵ, is also varied from 0 to 1. As a general observation, it is found that the contours shift to a range of smaller wavenumbers and the maximum growth rates are damped when ϵ is increased. On the other hand, for $\beta = 10$ and 20, the phase diagrams and the spatial distribution diagrams reveal that the perturbation variable for the streamwise flow velocity is out-of-phase with the perturbation variable for the lateral flow velocity, while the perturbation variable for the flow depth is out-of-phase with the perturbation variable for the bed elevation. The phase diagrams also show that the perturbation progresses in the downstream direction in a periodic manner, and that left bank and the right bank perturbations are in-phase with each other, confirming that the solution is for in-phase banks.

In order to validate the theoretical results, a comparison is performed for the calculated wavelength values with wavelength values obtained from experimental studies on bar formation. The dominant wavenumber corresponding to the maximum growth rate of perturbation as obtained from stability analysis is selected as the representative wavelength for actual comparison of bar wavelength. It is found that the calculated wavelength values generally underestimate the observed wavelength values. In addition, the experimental data obtained for both erodible and non-erodible banks are plotted in the instability diagram generated for bar instability with and without bank erosion, respectively. It is revealed that the experimental data fall within the stable region. It is suggested that the aspect ratio be increased to a value higher than the critical aspect ratio obtained from the analysis.

The study concludes that the aspect ratio, Froude number, Shields number, bank slopes and roughness coefficient are the parameters that influence the formation of bars. It is found that bars are more likely to develop at low aspect ratios when the bed friction coefficient is increased. The study also reveals that the Froude number and the parameter ϵ that inhibits bank erosion influence the solution for bar instability by increasing the wavelength of the bars, while increasing the aspect ratio and the bank slopes causes the maximum growth rates of perturbation to be amplified. Since the theoretical result can provide a rough estimate of the actual values of bar wavelength, a comparison of the theoretical and experimental results is performed. It is revealed that the observed wavelength is twice as large as the calculated wavelength values. The predicted results from the analysis generally underestimate the results of the experiment. It is possible that in the scheme of linear stability analysis, the instability process first selects the wavenumber and then enhances the growth rates of the bars; hence, bar formation in the stability analysis is slow.