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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　Uddin MD. Jahir

学　位　論　文　題　名

Fluvial bar instability with bank erosion
(側岸侵食を伴う河道砂州の不安定性)

Linear stability analysis of fluvial sand bars involving bank erosion is performed with the use of the shallow-water equations, the Exner equation, and the bank erosion equation newly proposed in this study. For performing linear stability analysis, it is considered flow in channels with erodible banks and beds. This study assumed that the length scales of bar formation and bank erosion in the streamwise direction are on the same order of magnitude in the range of linear stability analysis. In this study, the quasi-steady assumption has been employed in which time scale of flow variation is sufficiently short compared with that of topographical variations of bed and banks, and therefore, the flow can be assumed to achieve equilibrium state immediately and the time derivative terms in the flow equations can be dropped.

This study employs simple assumptions of bank erosion processes that the location of banks are shifted over time with the average channel width kept constant but the local channel width itself can change in space and time. In addition to the boundary condition of flow, additional boundary conditions of sediment continuity at the banks are imposed for the solution of all the equations. It is assumed that the river bed and banks are composed of gravel and bank erosion takes place due to increases in the bed shear stress in the vicinity of banks. If the bed shear stress at the junction between the laterally sloped bank region and the horizontally flat central bed region increases, sediment on the bank region starts to move. Once sediment starts to move on the bank region, sediment is removed from the bank because it is pulled in the lateral direction by the gravity. This results in bank erosion. It is assumed, therefore, that the bank erosion speed depends on how large the bed shear stress at the junction is compared with some critical bed shear stress.

The shallow water equations are analyzed with perturbation techniques. The resulting perturbation equation is solved by the boundary conditions with the use of the spectral collocation method with the Chebyshev polynomials. The analysis provides the growth rate of perturbation as a function of the wavenumber, the aspect ratio, and the bank erodibility. Instability diagram is obtained from this numerical solution, and find the contours of the maximum growth rate corresponding to multiple bars with a variety of modes (lateral wavenumbers) as well as single alternate bars. The awkward shapes of contours are also found in the diagram which is caused by the superposition of a number of contours of single alternate bars and multiple bars with different modes. It is found that the flat bed becomes unstable in a wider range of wavenumber with increasing the value of bank erosion coefficient γ. This implies that the bed instability is intensified by bank erosion.

Analytical solutions are also obtained by the use of asymptotic expansions around the state of no bank erosion (the bank erosion coefficient γ equals 0) in order to clarify the effect of bank erosion on the instability of sand bars with different lateral wavenumbers. Because γ is a bank erosion coefficient, the problem reduces to the original bar instability problem at the lowest order of γ. The bank erosion coefficient γ has been evaluated from field data (ranges 4.27×10^{-5} to 4.39×10^{-2}) and experimental data (0.5).

From the analytical solution, instability diagram is obtained, and found that bank erosion stabilizes the bed in the ranges of small wavenumbers, and of large wavenumbers and aspect ratios. It was found from the analysis that the tendency of expanded unstable region is remarkable especially in the case of single alternate bars. The expansion of unstable region in the direction of increasing wavenumbers means that the wavelength of bars decreases. The implication is that excessive sediment supplied due to bank erosion causes the increase of bed instability, and the resulting decrease in the bar wavelength. It is also found that if the value of γ is smaller than 0.04, the effect of bank erosion is negligible at least in the instability diagram.

From the instability diagram, the discontinuous changes of neutral curves in the ranges of large aspect ratios and wavenumbers have been found. It is also found that the discontinuity is not observed in the case of large Froude numbers. From these results, it is suspected that the term at $O(\gamma)$ becomes too large for the expansion to be valid. The analytical solution is assumed to be applicable only in the ranges of relatively small aspect ratios and wavenumbers, and large Froude numbers.

The analytical solution and numerical solution have been compared, and found from the instability diagram that the envelope of all the neutral curves of analytical solution agrees well with the neutral curve of numerical solution in the range of large wavenumbers. It is found, however, the agreement is not good in the range of small wavenumbers.

The bed topography obtained from the present analysis has been compared with that obtained in the Watanabe's experiments (2015). The similar pattern of bed topography has been found from the comparisons. The wavelength of bars predicted by the present analysis has also been compared with field data. Only field data of meandering is selected with significant bars. The prediction obtained in the present analysis agrees better with the field data than that obtained in the analysis of meandering performed by Ikeda et al. (1981). This implies that the some cases of meandering can possibly be explained by the present theory of the bar instability with bank erosion. The present analysis is also tested with the use of experimental data obtained by Watanabe, Crosato and Hasegawa. A reasonable agreement can be seen between the prediction and the experimental data.