学　位　論　文　内　容　の　要　旨
DISSERTATION ABSTRACT

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Experimental and numerical investigations on cantilever failures for cohesive riverbanks
(実験および数値計算による粘着性ひさし状河岸の浸食・崩落に関する研究)

Riverbank failure results in extensive sediment production in an alluvial channel and can cause severe environmental and economic problems such as loss of fertilization in agriculture areas and destruction of infrastructure. However, because a cantilever failure involves a rapid channel widening and delivers a large volume of sediment into a channel, such a failure is a serious issue in a river engineering. Difference types of riverbank failures have been investigated in several previous studies, but these works have limitations in understanding the complex mechanisms of cantilever failure regarding the coupling of fluvial erosion with that failure. Elucidating the underlying mechanism of a cantilever failure by means of experimental works and numerical studies are therefore the challenging tasks for complete understanding of fluvial erosion, cantilever failure, slump block effect and bedload sedimentation along a channel.

Firstly, the simple bank failure model was employed to simulate riverbank failure and bed deformation using a two dimensional depth-averaged model and an equilibrium sediment transport model for homogeneous and heterogeneous grain size conditions. Moreover, the numerical conditions were similar with those used in the previous experimental works of non-cohesive materials. The numerical models under homogeneous and heterogeneous conditions can reproduce the experimental results using an appropriate angle of repose and a suitable transversal grid size. For homogeneous condition, the temporal changes in cross-sectional profile averaged over longitudinal direction were in a relatively good agreement with the experimental results. However, the numerical results of the bed deformation were not satisfactory in heterogeneous condition. The main reason is that the armoring effect was developed to reinforce the top of bank-toe in the experimental results of non-cohesive materials but the simple bank failure model is limited in its ability to simulate the armoring effect.

Next, the cantilever failure mechanisms were investigated by means of small-scale experiments and numerical modeling. In laboratory experiments, three types of cohesive materials with different percentages of silt-clay content were carried out in seven cases by varying the hydraulic conditions. The small-scale experiments showed that fluvial erosion of the lower part of cohesive riverbanks progressively undermines the upper part during the initial stage of a cantilever failure. Tension cracks then develop at the upper surface of the cohesive riverbanks and beam-type failure occurs thereafter. Moreover, the numerical modeling of a cantilever failure implemented by a triple-grid approach within the framework of fluvial erosion and the cantilever's subsequent failure were validated by the small-scale experimental results. The simulated results showed good agreement with the small-scale experimental results in terms of spatial-averaged bank width and water level along cohesive riverbanks. Additionally, the small-scale experimental results were compared to both the failure mechanisms of the cantilever failure model and simple bank failure model. The comparisons showed that the simple bank failure model cannot reproduce the complex mechanism of cantilever failure regarding the limitation of the coupling failure mechanisms.

After that, the previous empirical and analytical equations of the actual shear stress, critical shear stress, erodibility coefficient, and factor of safety of shear-type and beam-type failures were employed to validate the temporal variations of spatially averaged bank width with the existing small-scale experimental works and the U-Tapao

River, Songkhla Province, Thailand. For fluvial erosion, the actual shear stresses of the small-scale experimental works range from 0.68 to 1.23 Pa, whereas those of the U-Tapao River are within the range of 18.51 to 22.52 Pa. Moreover, the critical shear stresses estimated by the percentage of silt-clay content of the small-scale experimental riverbanks are within the range of 0.38 to 0.57 Pa, whereas those of the U-Tapao River range from 9.44 to 12.99 Pa. Additionally, a comparison results of the erodibility coefficient between the previous relationships with the small-scale experimental results and U-Tapao River showed a poor agreement. Therefore, the relationship between the critical shear stress and erodibility coefficient are needed to be measured locally. For overhanging block stability, the results showed that the dominant cantilever failure mechanisms of the experiment and the U-Tapao River are the beam-type and shear-type failure, respectively. Finally, the comparison results of the temporal variations of spatially averaged bank width between the numerical and small-scale experimental results showed the high degree of confidence. Significant errors occurred during the cantilever failure stage because the failure material was dropped into the channel and protected against further fluvial erosion at the bank-toe. Therefore, the slump block effect must be considered in the new numerical modeling.

Finally, to deal with the limitations of the previous small-scale experimental works and numerical model of the process of a cantilever failure with the slump block effect, a series of large-scale experimental works were conducted with the objective to fully understand the complex mechanism of a cantilever failure by considering the geometrical and material scaling, and sidewall correction effect. Additionally, the slump block failures during the progress of a cantilever failure and its decomposition phenomena were discussed in the laboratory experiments. Moreover, a novel coupled numerical model by considering the effect of fluvial erosion, cantilever failure, slump block and bedload sedimentation was developed to simulate the cantilever failure mechanism. The large-scale experimental results expressed that fluvial erosion at the submerged zone generates an overhanging block in the upper part of the cohesive riverbanks. Tension cracks then develop on the upper surface of the cohesive riverbanks and the cantilever failure after that occurs along the tension crack line. The dominant failure mechanism was observed to be beam-type failure, which was clarified by using the acceleration sensors installed inside the cohesive riverbanks. In addition, the large-scale experimental results indicated that cohesive riverbanks with higher silt-clay contents are more susceptible to failure than those with lower silt-clay contents. Moreover, slump blocks were observed on the bed channel in front of the riverbank, where they formed a sediment buffer that reinforced riverbanks and reduced fluvial erosion. The slump block phenomena for the formation and deformation showed a significant effect on the cohesive force of the riverbanks and affected the riverbank geometry. Therefore, a reduction of the silt-clay content leads to smaller slump block dimensions as well as faster decomposition. The relationship between the slump block volumes and their decomposition times in the this large-scale experimental study seems to be almost random, without any identifiable rules governing this phenomena. Furthermore, the numerical model with slump block effect satisfactorily reproduced the fluvial erosion, cantilever failure and riverbank protection by the slump blocks. Additionally, the numerical results showed good agreement with the large-scale experimental results in terms of the spatial-averaged bank width. On the other hand, the numerical results without slump block effects showed the excessive fluvial erosion rate more than the large-scale experimental results. Therefore, the effect of the riverbank protection due to the slump block were clearly demonstrated in this study. In addition, this study can conclude that this numerical model is a powerful tool to analyze and predict the complex mechanism of a cantilever failure with slump blocks.