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学 位 論 文 題 名

Study on the morphological behavior of the channel with erodible banks

（河岸侵食性流路の形状挙動に関する研究）

学位論文内容の要旨

The morphology of alluvial rivers is deeply related to the interactions between water flows, the bed forms, and transportation and deposition of sediment particles. Variables affecting alluvial rivers are numerous and interrelated. Riparian vegetation is one of crucial factors to affect alluvial rivers and ecosystem. Vegetation increases flow resistance, reduces the flow velocity, and increases water depth. Vegetation increases bank strength, which leads to decrease the lateral channel changes, reduce the near bank flow velocity, and increase the tractive force. Investigating the behavior of alternate bars taking into consideration of bank strength, which is affected, in turn, by bank vegetation in natural rivers, is of interest in order to design stable channels when straightening rivers or building navigation canals. There have been few studies, however, that have examined this topic.

This research has been conducted to find out morphological behavior of the channel with erodible banks, the major findings are summarized as follows.

In Chapter 2, a model applicable to braided rivers with erodible banks has been presented to estimate to the channel evolution quantitatively. A generalized coordinate system was used for natural shaped boundary because the erosion and deposition occurred laterally, and the channel shapes were transformed into arbitrary shapes. As a numerical scheme, CIP (Cubic Interpolated Pseudo-particle) method was used in the flow field since the method introduced little numerical diffusion. Sediment transport equation in the streamline and the transverse wise, considering the secondary flow, was employed to estimate bed and bank evolution in time. To simulate bank erosion, it was assumed that bank was eroded when gradient of bank in the transverse direction was steeper than the angle of repose because the bed was scoured in the vicinity of the banks induced by secondary flow, leading to channel with natural shaped boundary. At the same time, the amount of bank material beyond the angle of repose was included to the calculation of the bed evolution as sediment supply. However, inner bank and other parts in the channel, which were changed into land, were not included in the range of computation.

The model was verified by experiments on braided channel with erodible banks. The calculation results of the longitudinal change in time for Run-1 and Run-2 were relatively satisfied with the experimental results, although the longitudinal wavelength and thalweg of the bed in the calculation are slightly different from those of the experiment. The channel width was in good agreement between calculation and experiment for Run-1, while the width was underestimated for Run-2 as time increased. The comparison of cross sectional changes between calculation and experiment at 6m from upstream for Run-1 and Run-2, respectively, showed a little difference, because of the poorly treated results of boundary between the dried and wetted parts of the bar in the channel. It is important that this presented model can simulate braided river with unconstrained banks, where previous numerical models have not been applied, although the model has this limitation.

In Chapter 3, flow characteristics and channel evolution to explain vegetation effects on the river were investigated experimentally and numerically. Laboratory experiments were carried out to elucidate the influence of riparian vegetation on the rivers with erodible banks. One run for a braided river without vegetation from initially straight channel and two kinds of runs for the river with vegetation were conducted. For the vegetated river alfalfa seed was introduced to the reproduced channel with erodible bed and banks composed of nearly uniform sandy materials in the laboratory by controlling the density.

As time progressed, lateral erosion of bank in the channel without riparian vegetation increased larger than with the vegetation. The bed eroded deeply and the width narrowed owing to the reinforced bank by vegetation. As vegetation density increased, bank erosion rate was lower because vegetation root reinforced bank materials and the vegetation density increased flow resistance. Some of the alfalfa plants in the bars and banks on the border of main channel, where the vegetation was under the relatively large influence of flow, were prone, acting as retardation of flow. The plants were pulled out when the banks eroded or the bed scoured, and caused log-jams effects at the downstream explained. The developed braided channel without vegetation consists of a network of webbed channels with unconfined width, which is deeply associated with bank erosion. Riparian vegetation makes an crucial role to control the channel shapes and width. The secondary channels in the vegetated zones sustained their shapes without changes. However, the flow capacity in the vegetated-secondary channels may considerably decrease due to the increased roughness by vegetation. The plants were pulled out when the banks eroded or the bed scoured, and caused log-jams effects at the downstream. In the rear of the emergent bars or unevenly vegetated regions near the main stream, log-jams made an important role as a seed of sedimentation, divided flow into both sides, or changed its directions, leading to channel bifurcation.

Chow(1959) recommended values for the Manning's coefficient to account for additional resistance for the energy loss due to grass, bushes or trees, to treat vegetation in open-channels as additional flow resistance to be added to the bed roughness, although the bed roughness and drag force of flow through emergent vegetation must be considered to simulate vegetation effects separately (Tsujimoto 1999, among others).

The numerical model simulates relatively well the scour hole, which is due to the vortex driven by downward flow near the strong banks. The calculation results show the the features of bar migration in the whole areas, while in the experimental channel the features are only shown in the main channel. The longitudinal wavelength and thalweg of the channel in the calculation are a little difference from those in the experiment. The reason is that the numerical model does not predict the drag and diffusion for flow through emergent vegetation, although we are trying to simulate the vegetated channel using a modified Manning's coefficient as a simple method. The adaption of Manning's coefficient for its simplicity can not reflect the feature of flow within the vegetated area and can not reflect the regions of emergent vegetation.

The calculation results shows that the numerical model reflecting the drag of flow through the regions of emergent vegetation simulates better than the model adapting Manning's coefficient for its simplicity. The numerical model slightly over predicted the channel width. This may be due to the poorly treated boundaries near the partially wetting or drying bars and banks, relatively smaller angle of repose as a parameter, the Manning's roughness due to the vegetation in the vegetated regions, the friction factor at the vegetated banks. A more elaborated numerical scheme to treat the boundary and precise parameters are needed for the future. Nevertheless, the simulated results are overall acceptable.

In Chapter 4, 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 model. The lateral rate of channel expansion, bar migration speed, and wavelength in the two kinds of nearly straight channels were studied. In one, the aspect ratio (i.e., ratio of width to depth) was 23.9, and the critical angle of repose, represented bank strength, was 30, 35, or 40 degrees. In the other, the aspect ratio was 35.7, and the critical angle of repose was 25, 30, or 35 degrees.

In the initially straight channel with non-cohesive materials in the bed and banks, migrating alternate bars appear with widening of the channel. These bars give rise to bank erosion at suitable places, and lead to a meandering channel. 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 because of the higher forcing effects between the bars and 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.

学位論文審査の要旨

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（河岸侵食性流路の形状挙動に関する研究）

沖積河川の形状は，水の流れや河床形状および流砂と深く関係しており，多様な因子の相互作用により決定されている．また，自然河川においては河道内の植生は河川の生態系に影響を及ぼす重要な因子の一つであるとともに，流れや流砂にも影響を及ぼすため，河道形状の決定にも大きな影響を与える．すなわち，植生は流れの抵抗増加，流速の減少，水深の増加の原因になるとともに，河岸近傍においては流速の減少，せん断力の減少などを誘発し，河岸そのものの耐侵食強度を増加させる要因にもなる．自然河川において植生の影響を受ける河岸強度を考慮した砂州の挙動を検討することは河川工学上極めて重要である．しかしながら，現在までに河道内の植生の影響をも考慮した河道形状の形成に関する研究は数少ない．本研究は，植生の影響を受ける河岸侵食性河川の平面形状の形成機構を数値計算モデルと室内実験により検討を行ったものである．その主な結果は以下とおりである．

本論文は，全５章で構成されている。

第１章では，序論であり，研究の背景および目的を述べている。

第２章では，河道断面形状の発達過程を定量的に把握するための河岸侵食を考慮した数値計算モデルを提示した．モデルは複列・網状河川にも適用可能なものとした．侵食性河岸を有する河川においては，侵食と堆積が河岸に沿って発生し，平面形状が任意の形状に変化するため，境界適合型の移動一般座標系による基礎式を用いた．流れの計算は数値分散が極めて少ないCIP法を用いて行った．河床の侵食・堆積は二次流を考慮した流砂の連続式を用いた．平面形状の変動計算は，二次流によって河岸付近の河床が洗

掘される場合，河岸の横方向傾斜が水中安息角より急になれば，河岸が侵食され，平面形状を変化させることとした．この時，安息角以上の河岸材料は流砂供給源として河床変動計算に反映させることとした．

計算モデルは網状河川を模擬した実験結果との比較により検証し良好な結果が得られた．

第３章では，河岸侵食性河川における植生の影響を把握するために室内実験と数値計算を行った．植生河川の実験では，河川の植生をアルファルファの栽培によってモデル化した．この結果，植生河川の河岸侵食は植生のない河川より小さくなるが，河床はより低下する傾向がみられた．また，植生の密度が増加すれば流れの抵抗は増加し，下流に log-jam 効果が見られた．

Chow(1959)は開水路の植生によるエネルギー損失に起因する付加抵抗をマンニングの粗度係数を修正した値で表す方法を，また，辻本ら(1999)は植生の影響を流れに対する抗力として計算する方法を提案しておいる．本論文では，両方の方法を使用して数値計算を行った．この結果，マンニングの粗度係数を修正する方法では植生を通過する流れの拡散と抵抗がよく再現できなかったが，植生による流れの抗力を考慮する方法は植生を通過する流れの拡散と抗力がうまく再現可能であることが確かめられた．

第４章では，数値計算方法を用いて河岸の耐侵食強度を考慮した砂州および河道平面形状挙動に関する検討を行った．２種類の直線河川において河岸の耐侵食強度と河幅の拡大率，砂州の移動速度，砂州の波長，砂州高の関係を調査した．計算結果によれば，初期の直線河道から河幅の拡大と交互砂州の移動が始まり，ある程度砂州が発達したところで，河岸侵食が発生し始め，これと同時に砂州の移動は阻害された．河岸の強度との関係で見ると，耐侵食性の高い河岸ほど砂州と河岸の間の強制効果(forcing effect)が弱いため，砂州は独自で発達・移動する傾向が見られた．砂州波高は河幅水深比の増加に従って増加した．また，河岸強度が弱い河道ほど，砂州高が高くなる計算結果を得られ，河幅の拡大に従って，砂州の移動速度は遅く，砂州の波長は短くなるという傾向が明らかになった．このように，交互砂州の発達・移動特性は同じ水理条件下でも河岸の強度によってその特性が大きく異なることが明らかになった．

第５章では，本論文で得られた結果をまとめている．

これを要するに，著者のこれまでの数値計算と室内実験により得られた研究結果は，河川工学に大きく寄与するところがあり，著者は北海道大学博士(工学)の学位を授与される資格があるものと認められる．