博士（工 学） ブーンヤアルンネ スラジェート

学 位 論 文 題 名

Computation of Turbulence and Bed Morphology in Meandering Rivers

（蛇行河川における乱流と河床形態の数値計算に関する研究）

学位論文内容の要旨

Most of the job of a river is done through its channel. The day-to-day task of handling discharge, the year-to-year task of eroding, transporting, and depositing sediment, and the long-term adjustments toward some equilibrium are all dependent on processes that occur within or immediately adjacent to a river's main channel. In common, a typical characteristic of river is wandering and have a meandering shape because of instability of the alternate-bar type in straight channels finally developed fluvial meandering. The meander grows by the process that the river shift their positions across the valley bottom by depositing sediment on the convex bends while simultaneously eroding the on the concave banks of the meander bends. Therefore, from the straight channel with a preferable hydraulic condition, bars were formed and became convex bends. At the same time concave bends were also generated on the other side of bars. After some years, meander shape became clearer and vegetations emerged on the permanent dry bars then flood plains. Therefore, the morphological process of meander development is one of the great concerns of hydraulic engineers. Besides, considering flow itself, the meander has a characteristic of strong turbulence. The curvature of the meander makes the processes different from straight channel by centrifugal or helical forces resulting in the different momentum exchanges in transverse direction. This turbulence flow is therefore significant for modeling of bed morphology. In the terms of the concentration of pollution transport, the capability of flushing is impeded by the meander as well. Hence, the transport or movement of pollution in the meandering rivers required a reliable turbulent model and curvature effect required to be included.

For much of this century hydraulic engineers have been measuring and analyzing river channels in order to tie them in some predictable way. Therefore, the turbulence, morphology and behavior of channel have long been considered a sensitive indicator of the "state" of any river as well as a record of processes acting within a watershed. This knowledge is essential to hydraulic engineer because his responsibility is to help others to live with nature or survive from river disasters and secure the human welfares in a sustainable and harmonic way. With today's advances in computer technology, hydraulic engineers explore the river processes and problems by using computer-based solutions. This involves building computer models of the river flow, turbulence, morphology, and etc. These models are then used to understand the complex interaction between flow turbulence and bed response. Although it is difficult nearly impossible to predict the precise extent of the change, the nature of change can be estimated qualitatively. Therefore this work will explore in qualitative prediction of interaction between river morphology and turbulence, with an emphasis on the applicability of existing mathematical models and tools numerically.

Taking above statement into account and what can be done today, basic objectives of this study are a) to employ the modeling and numerical approaches in order to simulate the flow and turbulent motions in meandering channels for their practical applicability and b) to recognize the bed morphological processes lead to forming a meandering channel. The additional objective is c) also to investigate the performance of turbulent model (temporal and spatial) for predicting the bed morphology with existing of structure (local scour). Therefore, the depth-averaged two-dimensional models were used to compute the turbulent

flow in a meandering channel. Firstly the attempt was done on the shear mixing layer on various turbulent models. Secondly the simulation was performed on the meandering channel with groynes generated turbulence by recirculation. The "Boundary-Fitted Coordinates" was employed throughout the study to transform continuity and movement equations from physical to general coordinates in order to compute the flow in meander and to couple the curvature effect. The numerical model was based on the finite different method using a staggered grid with the CIP method for purely advection scheme. The mean flow field was compared against the experiment and showed a good agreement. With the assumption of coexisting of horizontal (generated from horizontal velocity gradient) and vertical (originated from the bottom) turbulences taken into account, the depth-averaged k-ε model for turbulent closure was chosen. For model verification, the turbulent characteristic from experiment was used to verify the accuracy of selected turbulent model. The turbulences are well predicted by the k-ε model. In comparison, if modeled only by vertical turbulence (0-equation), the eddy viscosity was found to be underestimated. Additionally, the concentration transport was simulated to see its movement and exchange processes in groyne fields.

Since the flows and turbulence are satisfactory predicted by our model, an extension on bed morphology simulation was also performed. As the meandering shape originates from instability of the alternate bars in straight channels, the straight channel case was initially selected for the simulation. It was found that the model could predict the bed forms for the straight channel with unsteady inflow well. Additionally the bed morphology of alluvial meandering channels based on the experimental series of sign-generated function conduct at CERI Hokkaido was calculated and detailed findings are discussed. Finally, the bed morphology of local scour simulation was done to investigate the performance of turbulent model (temporal and spatial) for predicting the bed morphology with existing of structure with comparison with experimental data. .

学位論文審査の要旨

主　査　　教　授　　清　水　康　行
副　査　　教　授　　長谷川　和　義
副　査　　教　授　　山　下　俊　彦

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（蛇行河川における乱流と河床形態の数値計算に関する研究）

現在においても、河川の洪水災害は自然災害の中でも最も深刻な問題の一つである。中でも大量の土砂輸送を伴う土砂災害は、一瞬にして尊い人命や財産が奪われるなど、時には極めて甚大な被害となる場合も多く、そのメカニズムの解明や対策が急がれている。一見、突発的に発生するかのように見えるこれらの異常な土砂災害、即ち、河岸侵食や大量の土砂堆積なども10年～100年という長い目でみると、河川そのものが持つ砂州の形成や蛇行といった特性の一部である。通常、河川が蛇行するのは流れと土砂の持つ不安定性に起因する交互砂州起源の河岸侵食によるものと、河岸自体の不安定性に起因する蛇行現象が挙げられる。本論文の目的はこれらの河川蛇行現象のモデル化に向けた基礎的研究であるが、何れの場合もこれらの現象を河川の流れ自体が持つ不安定性、およびそれと流砂現象の相互作用に対する理解が不可欠となる。

本論文の主題は大きく２つに分けられる。１つは扱う流れの乱流モデルの選択であり、もう一つは流砂・河床変動モデルの選択である。これらについて本論文では下記のような構成で検討を行っている。

第１章は序論であり研究の背景，目的および範囲を述べている。

第２章は過去の研究の紹介であり、本論文の研究内容に関連するこれまでの研究成果の報告および問題点の指摘を行っている。

第３章は河川の蛇行現象に関する特性の定性的な検討を行っている。

第４章は以降の章で検討に用いられる数値モデルの基礎式、座標変換、乱流の扱い方、流砂量式、差分計算の方法などに関する記述を行っている。

第５章は研究対象として模型実験の紹介を行っている。対象は水制を有する移動床蛇行実験、非定常流量ハイドログラフを用いた砂州の形成に関する移動床実験、各種の蛇行波長、振幅、川幅・水深比の組み合わせによる移動床蛇行水路実験である。

第6章は解析および検討結果と考察である。解析は、(1)水平せん断不安定による流れの混合現象、(2)水路横断構造物（水制）による水平剥離現象と混合現象、(3)移動床蛇行水路の河床変動の再現計算、となっている。これらの解析を通じて、既往の乱流モデルによる結果の比較や新たなモデルの提案も行っている。

第7章では本研究で得られた新しい知見をまとめ、その有用性や限界などについて考察が行われており、最後に今後の研究課題についても言及されている。

これを要するに、著者のこれまでに得られた蛇行河川における乱流と河床形態の数値計算に関する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る。