UNIVERSITI PUTRA MALAYSIA

FLOW CHARACTERISTICS AND SEDIMENT TRANSPORT IN A CHANNEL WITH EMERGENT FLEXIBLE VEGETATION

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By

AMIR MONTAKHAB

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

To

My Father and Mother…

Abstract of the thesis presented to the senate of Universiti Putra Malaysia in fulfillment of the requirements for the Degree of Doctor of Philosophy

FLOW CHARACTERISTICS AND SEDIMENT TRANSPORT IN A CHANNEL WITH EMERGENT FLEXIBLE VEGETATION

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May 2012

Chairman : Badronnisa bt. Yusuf, PhD

Faculty : Engineering

The effect of vegetation on open channel hydraulics is evident through the magnitudes, the profiles of the flow depth and the velocity, which relate to the plant characteristics. A number of vegetation characteristics affect the flow. Among these parameters, vegetation density is the key factor that contributes to the flow behavior and resistance in the vegetated channel. However, in current research practices, vegetation density only covers the number of vegetation and not the other physical characteristics. In reality, natural aquatic vegetation is herbaceous in nature and diverse in characteristics, so the determination of vegetation density in terms of number may be very difficult. For a solution, vegetation porosity which is

based on the vegetation volume is suggested. Thus, this study aims at acquiring a practical method for porosity measurement, and applying it to the study of the effect of emergent flexible vegetation to velocity distribution, turbulence characteristics and sediment transport in continuous and discontinuous distributions of vegetation in a channel.

This study consists of three main parts. In the first part of the study, several porosity measurement methods based on vegetation frontal area (two-dimensional) and vegetation volume (three-dimensional) were applied to estimate the porosity of vegetation (*Lepironia articulata*) in a laboratory flume for various flows and vegetation characteristics. The aim is to explore several methods, and hence, to suggest a method that is practical and accurate for vegetation porosity estimation, as well as to derive the relationships between porosity, velocity and flow depth. Velocity measurements using Acoustic Doppler Velocimeter (ADV) were made at different spatial locations along the flume, and the effects of varying incident flow rates (0.16–0.32ms^{-1}) and vegetation porosity (88-96%) were investigated. The volumetric method for porosity measurement, which considers the fraction of the actual volume of the vegetation to the volume of water, is considered as more practical and accurate than the other methods. It was found that by assuming the vegetation as cylindrical in shape and considering only the frontal area of the most upstream vegetation, the porosity could be underestimated in average by 14%. However, the digital image analysis gave porosity difference of only 5%.

From the laboratory data, correlations between the mean velocity, water depth and vegetation porosity were established. It was observed that by reducing the vegetation porosity by 8% would results in the velocity being reduced between 35% and 60% depending on the flow rate.

The second part of the study explores the effect of porosity of vegetation patches on the velocity distribution and turbulent characteristics of flows that encounter them. It was observed that the flow encountering a single patch formed a turbulent wake at the downstream of vegetation, which then intensified the Reynolds stress and increased turbulence and sediment transport rate. Within this wake, the Reynolds stress increased downstream initially, reached the maximum and then decayed. The location of the maximum point of Reynolds stress was observed to be dependent on the vegetation porosity and flow rates. When the second patch was positioned within the region where the Reynolds stress was maximum, the Reynolds stress was decreased between 50% and 25% depending on vegetation porosity and flow rate. The patches revealed great performance in reducing the Reynolds stress at lower velocity and lower porosity. To sum up this part, flow and turbulence characteristics depend on the vegetation porosity and the distance between patches.

In the final part of the study, sediment transport through continuous and patch vegetations was studied at different porosities and flow conditions. Water samples were collected from several locations along the channel,

and the total suspended solid (TSS) test was applied for sediment trapping measurement. The results showed that porosity, location of patches and flow rate had a significant effect on the sediment transport. In addition, it was observed that the sediment transport in the vegetation channel was reduced up to 70% depending on the porosity value. The vegetation in patches could increase trapping sediment up to 90%. The results suggest that the patchy vegetation system is more efficient in reducing the Reynolds stress as well as sediment transport compared to continuous distribution. Finally, it can be concluded that porosity is an important component and it significantly affects velocity, turbulence and sediment transport in a vegetated channel.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

CIRI ALIRAN DAN PENGANGKUTAN ENAPAN DI DALAM SALURAN DENGAN TUMBUHAN MUNCUL BOLEH LENTUR

Oleh

AMIR MONTAKHAB

Mai 2012

Pengerusi : Badronnisa bt. Yusuf, PhD

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Kesan tumbuhan ke atas hidraulik saluran terbuka dapat dibuktikan melalui magnitud, profil kedalaman saliran dan halaju, yang berkait dengan ciri-ciri tumbuhan. Beberapa ciri tumbuhan yang mempengaruhi aliran adalah seperti; bentuk dan struktur stem dan daun, kelenturan stem, ketumpatan (atau keliangan) dan agihan tumbuhan. Daripada kesemua parameter tersebut, ketumpatan tumbuhan merupakan faktor utama yang mempengaruhi kelakuan dan rintangan aliran di dalam saluran bertumbuhan. Walau bagaimanapun, dalam praktis kajian semasa, ketumpatan tumbuhan hanya mengambil kira bilangan tumbuhan dan bukannya ciri fizikal yang lain.. Secara realiti, tumbuhan semulajadi aquatik

adalah jenis *herbaceous* dan terdapat dalam pelbagai ciri, maka penentuan ketumpatan tumbuhan dalam terma bilangan adalah tidak mudah. Sebagai penyelesaian, keliangan tumbuhan berdasarkan isipadu tumbuhan dicadangkan. Oleh itu, tujuan kajian ini adalah untuk memperoleh kaedah yang praktikal untuk menentukan keliangan, dan mengaplikasikannya dalam kajian kesan tumbuhan muncul dan boleh lentur kepada halaju, ciri turbulen dan pengangkutan sedimen agihan di dalam saluran dengan agihan tumbuhan berterusan dan tak berterusan (tompok).

Kajian ini merangkumi tiga bahagian utama. Bahagian pertama, beberapa kaedah penentuan keliangan yang bergantung pada luas hadapan (dua-dimensi) tumbuhan dan isipadu (tiga-dimensi) tumbuhan digunakan untuk mengira keliangan tumbuhan (*Lepironia articulata)* di dalam saluran di makmal dengan aliran dan ciri tumbuhan yang berbeza. Analisis imej digital adalah antara kaedah yang digunakan untuk mengira keliangan. Tujuannya adalah untuk mengkaji beberapa kaedah, dan untuk mencadangkan satu kaedah yang praktikal dan tepat untuk mengukur keliangan tumbuhan dan juga untuk menerbitkan hubung kait antara keliangan, halaju dan kedalaman aliran. Pengukuran halaju menggunakan Acoustic Doppler Velocimeter (ADV) dilakukan pada lokasi spatial di sepanjang saluran, dan kesan kadar aliran (0.16–0.32ms^{-1}) dan keliangan tumbuhan (88-96%) yang berbeza dikaji. Kaedah isipadu untuk menyukat keliangan yang mengambil kira pecahan isipadu sebenar tumbuhan kepada isipadu air, didapati lebih praktikal dan tepat berbanding kaedah lain. Dengan mengandaikan tumbuhan dalam bentuk silinder dan hanya mengambil kira luas hadapan tumbuhan di paling hulu, keliangan boleh terkurang anggaran secara purata sebanyak 14%. Walau bagaimanapun, dengan kaedah imej digital perbezaan keliangan hanya 5%. Daripada data makmal, korelasi antara halaju purata, ketinggian air dan keliangan tumbuhan dihasilkan. Pengurangan liang tumbuhan sebanyak 8% boleh mengurangkan halaju diantara 35% dan60%, bergantung pada kadar aliran.

Bahagian kedua kajian ini mengkaji kesan keliangan pada tompok tumbuhan terhadap agihan halaju dan ciri-ciri turbulen. Dari permerhatian didapati, aliran yang mengaliri satu tompok tumbuhan membentuk keracak turbulen di hilir tumbuhan, yang kemudiannya meningkatkan tekanan Reynolds dan turbulen dan kadar pemindahan sedimen. Dalam keracak ini, pada permulaan, tekanan Reynolds meningkat di hilir mencapai tahap maksimum dan kemudian berkurangan. Didapati lokasi tekanan Reynolds maksimum bergantung pada keliangan tumbuhan dan kadar alir. Apabila tompok kedua ditempatkan di lokasi berlakunya tekanan Reynolds maksimum, tegangan Reynolds tersebut menurun dalam julat di antara 50% dan 25% bergantung kepada keliangan tumbuhan dan kadar alir. Tompok tumbuhan didapati lebih efektif dalam mengurangkan tekanan Reynolds pada halaju dan keliangan yang lebih rendah. Sebagai kesimpulan untuk kajian kedua ini, ciri aliran dan turbulen bergantung pada keliangan tumbuhan dan jarak antara tompok tumbuhan..

Pada bahagian terakhir kajian ini, pengangkutan sedimen melalui tumbuhan dengan agihan berterusan dan tompok dikaji pada keliangan dan aliran yang berbeza. Sampel air diambil dari beberapa bahagian di dalam saluran dan ujian jumlah pepejal terampai (TSS) dilakukan bagi menentukan kepekatan sedimen terampai. Hasil kajian menunjukkan keliangan, lokasi tompok dan kadar alir memberi impak yang penting terhadap pemindahan sedimen. Selain itu, didapati bahawa pengangkutan sedimen berkurangan sehingga 70% bergantung kepada nilai keliangan. Tompok tumbuhan boleh meningkatkan jumlah sedimen yang terperangkap sebanyak 90%. Hasil ini menunjukkan agihan tumbuhan bertompok adalah lebih berkesan bagi mengurangkan tekanan Reynolds dan juga pengangkutan sedimen berbanding dengan agihan tumbuhan berterusan. Secara kesuluruhan, adalah dirumuskan bahawa keliangan adalah komponen penting dan ia sangat mempengaruhi halaju, turbulen dan pengangkutan sedimen dalam saluran tumbuhan.

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I certify that a Thesis Examination Committee has met on **.........................** to conduct the final examination of Amir Montakhab on his thesis entitled "FLOW CHARACTERISTICS AND SEDIMENT TRANSPORT IN A DRAINAGE WITH EMERGENT FLEXIBLE VEGETATION" in accordance with Universities and University Colleges Acts 1971 and the Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institutions.

AMIR MONTAKHAB

Date: 22 may 2012

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