UNIVERSITI PUTRA MALAYSIA

MODELLING HYDRO-MORPHO DYNAMICS OF RIVER JUNCTIONS UNDER THE IMPACT OF UNSUBMERGED VANES

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By

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Faculty : Engineering

Controlling the flow and river bed morphology in the confluence and branching junctions are important in rivers training and navigation works. The flow in a river junction is highly complex, due to rapid changes associated with flow dynamics, sediment transport, and geomorphology. Erosion and deposition zones are considered as the main critical features that appear at the river junction and causing many problems such as increasing the possibility of flood risks at the river confluence, on the other hand, a shortcoming of the inflow discharge at the river branching which effects different water supply projects. In this study, two cases have been selected owing to their suffering from hydro-morpho dynamics issues. The first case is a confluence of Kurau and Ara rivers located at tropical region Perak, Malaysia, while the second case is a branching of Tigris river located at temperate region Missan, Iraq. The aim of this study is to control the hydro-morpho dynamics features at the junction of a confluence and branching rivers. Measured and acquired data were used to investigate the scour hole that usually formed in the erosion zone and bar formed in the deposition zone. The data of the confluence junction was acquired while for the branching junction was measured. Garmin echoMap 50s device was used to measure the bathymetry survey, while Son Tek River Surveyor device M9 was used to collect discharge, velocity distribution, and cross-section geometry. In addition, Van Veen Grab sampler was used to collect bed material sampling of the Tigris branching junction. The results of data collection for the confluence of Kurau and Ara rivers show that the velocity was ranged between 0.8 and 1.1 m/s at the location of the maximum scour zone and between 0.1 and 0.3 m/s at the location of deposition zone, while for the branching of the Tigris river the velocity was around 0.5 m/s at the location of the scour zone and 0.1 m/s at the deposition zone. A 2D numerical model of Mflow_02 solver was used to build, calibrate and validate the numerical models using field data to simulate the selected river junctions before simulating various arrangements of unsubmerged vanes as control structures. This solver was able to calculate two-dimensional plane unsteady flow, river bed morphology and sediment transport by unstructured meshes of finite element method. The error of the model output was found to be less than 20% in both cases. The simulations with different arrangements of unsubmerged vanes were proposed as control structures to mitigate scouring and deposition zones that usually occurred at natural river junctions. The results revealed that the most effective size and location of unsubmerged vanes mainly depend on their performance in deposition and scouring zones. For both cases, simulation results show that a single unsubmerged vane can successfully control the scouring and deposition zones. In the confluence junction, the third scenario of installing a single unsubmerged vane with 10 m length at an angle of 30° gave the best solution for diminishing the maximum scour zone and minimizing the deposition zone. In branching junction, the results of the fourth scenario by introducing a single unsubmerged vane with 50 m length, placed perpendicular to the flow direction of the main branching river, show that the deposition zone was reduced to 82% when compared with the simulation without vane. In summary, this study addresses the applicability of using the 2D numerical model in complex riverine system for predicting hydro-morpho-dynamics changes in junctions with and without vanes as training structures. The significance of this study is attributed to the simulation of various scenarios for controlling scour and deposition zones by using unsubmerged vanes and recommended the best solution that provides minimum scouring and deposition zones and thus may enhance river flow dynamics.

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

PEMODELAN HIDRO-MORFODINAMIK PERSIMPANGAN SUNGAI DI BAWAH IMPAK STRUKTUR BILAH TIDAK TENGGELAM

Oleh

HYDAR LAFTA ALI

Julai 2019

Pengerusi : Profesor Madya Badronnisa Binti Yusuf, PhD
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Pengawalan aliran dan morfologi dasar sungai dalam pertemuan dan persimpangan cabang adalah penting dalam pengawalan sungai dan kerja pelayaran. Aliran di perismpangan sungai adalah sangat kompleks, disebabkan oleh perubahan pantas yang berkaitan dengan dinamik aliran, pengangkutan sedimen, dan geomorfologi. Zon hakisan dan pengenapan dianggap sebagai ciri kritikal utama yang terdapat di persimpangan sungai dan menyebabkan banyak masalah seperti meningkatkan risiko banjir di persimpangan sungai, sebaliknya, kelemahan aliran masuk di cabang sungai yang mana memberi kesan terhadap projek bekalan air yang berbeza. Dalam kajian ini, dua kes telah dipilih yang mana kes-kes ini mengalami masalah hidro-morfo dinamik. Kes pertama adalah pertemuan Sungai Kurau dan Sungai Ara yang terletak di rantau tropika Perak, Malaysia, manakala kes kedua adalah cabang Sungai Tigris yang terletak di rantau sederhana Missan, Iraq.

Tujuan kajian ini adalah untuk mengawal ciri-ciri hidro-morfo dinamik di persimpangan pertemuan dan cabang sungai. Data yang diukur dan diperolehi telah digunakan untuk menyiasat lubang keruk yang biasanya terbentuk di zon hakisan dan beting yang terbentuk di zon pengendapan. Data persimpangan pertemuan telah diperoleh manakala data untuk persimpangan cabang telah diukur. Peranti Gechin echoMap 50s telah digunakan untuk mengukur ukur batimetri, sementara alat Pengukur Sungai Son Tek M9 telah digunakan untuk mencerap kadar alir, pengagihan halaju, dan geometri keratan rentas. Selain itu, pensampel Van Veen Grab telah digunakan untuk mengumpul sampel bahan dasar sungai di persimpangan cabang Tigris.

Hasil pengumpulan data untuk pertemuan Sungai Kurau dan Sungai Ara menunjukkan bahawa halaju adalah antara 0.8 dan 1.1 m/s di lokasi zon keruk maksimum dan antara

0.1 dan 0.3 m/s di lokasi zon pengendapan, sementara untuk cabang Sungai Tigris halaju adalah sekitar 0.5 m/s di lokasi zon keruk dan 0.1 m/ di zon pengendapan.

Model 2D berangka Mflow_02 solver telah digunakan untuk membina, menentukur dan mengesahkan model berangka dengan menggunakan data lapangan untuk mensimulasikan persimpangan sungai yang dipilih sebelum mensimulasikan pelbagai bentuk susunan struktur bilah sebagai struktur kawalan. Model ini dapat mengira aliran tidak stabil satah dua dimensi, morfologi dasar sungai dan pengangkutan sedimen oleh jejaring tidak terstruktur menggunakan kaedah unsur terhingga.

Ralat hasil model didapati kurang daripada 20% bagi kedua-dua kes. Simulasi dengan susunan struktur bilah tidak tenggelam yang berbeza telah dicadangkan sebagai struktur kawalan untuk mengurangkan zon kerukan dan pemendapan yang biasanya terjadi di persimpangan sungai semulajadi. Hasilnya menunjukkan bahawa saiz dan lokasi yang paling berkesan bagi struktur bilah tunggal tidak tenggelam adalah bergantung kepada prestasi stuktur bilah di zon pengendapan dan hakisan. Bagi kedua-dua kes, keputusan simulasi menunjukkan bahawa struktur bilah tunggal tidak tenggelam berjaya mengawal zon pengerukan dan pengendapan. Di pertemuan persimpangan, senario ketiga dengan memasang struktur bilah tunggal tidak tenggelam dengan panjang 10 m pada sudut 30 ° memberikan penyelesaian yang terbaik untuk mengurangkan zon keruk maksimum dan zon pengendapan. Pada persimpangan cabang, hasil keputusan bagi senario keempat dengan memperkenalkan struktur bilah tunggal tidak tenggelam dengan panjang 50 m yang diletakkan berserenjang dengan arah aliran cabang utama sungai, menunjukkan bahawa zon pengendapan telah dikurangkan kepada 82% jika dibandingkan dengan simulasi tanpa struktur bilah.

Kesimpulannya, kajian ini membahas kebolehupayaan penggunaan model berangka 2D bagi sistem sungai yang kompleks untuk meramal perubahan hidro-morfo dinamik di persimpangan dengan dan tanpa menggunakan struktur bilah sebagai struktur kawalan. Kepentingan kajian ini adalah dikaitkan dengan simulasi pelbagai senario untuk mengawal zon keruk dan zon pengendapan dengan menggunakan struktur bilah tidak tenggelam dan mengesyorkan penyelesaian terbaik yang dapat menyediakan zon pengendapan dan kerukan minimum dan seterusnya meningkatkan dinamik aliran sungai.

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Declaration by graduate student

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

DEM	Digital Elevation Model
Mr	Momentum Flux Ratio
CFD	Computational Fluid Dynamics
MAD	Mean Absolute Deviation
MSE	Mean Square Error
RMSE	Root Mean Square Error
MAPE	Mean Absolute Percentage Error
a.m.s.l	Above Mean Sea Level

CHAPTER 1

INTRODUCTION

1.1 General

The flow in river junctions whether confluence or branching in irrigation and drainage systems are essential components, referring to the fluvial systems which produce a complex hydro-morpho dynamic environment (Al Omari et al., 2018; Riley et al., 2014). There are two important aspects associated with the flow in river junctions, and these are erosion and deposition zones. Erosion zone is a morphological process that usually occurs at the beds and outer banks of confluence and branching rivers and known as scouring hole, while the deposition zone usually occurs at the inner banks (opposite to the location of erosion) and recognized as points bars or islands caused by sediment deposition. The scour hole zone is a region formed in the bed sediment erosion and considered as one of the major morphological features of channel junction (Guillén-Ludeña et al., 2016; Alomari et al., 2018). The scour hole is associated with sediment transport caused by the increased flow turbulence and velocity intensities, which led to creating secondary vortexes. These vortexes play a significant role in changing the bed morphology at the junctions (Herrero et al., 2015; Leite Ribeiro et al., 2012; Rhoads et al., 2009). In contrast, the deposition can be recognized explicitly in the separation zone created under low pressure and flow recirculation. The separation zone at channel junctions exerts a direct influence on the flow dynamics and also morphological features (Birjukova et al., 2014; Thanh et al., 2010; Best and Rhoads, 2008; Ramamurthy et al., 2007). The separation zone has a direct effect on loss of capacity in irrigation channels or threatens mechanical elements of power plants water circuits.

The size and location of the scour hole and the separation zone mainly depend on the junction angle and discharge ratio (Goudarzizadeh et al., 2010; Rhoads et al.,2009; Best., 1988; Best and Reid., 1984). In which the recent experimental work shows that the minimum scour hole and separation zone occurred at a 30˚ of junction angle (Alomari et al., 2018). Early studies have been focused on hydrodynamics features with rigid boundaries means that their experimental works were without sediment transport and movable bed (Taylor,1944; Grace and Priest, 1958). This approach still received attention for a vast explanation with different parameters and geometry forms (Ramamurthy et al., 2007; Mignot et al., 2013; Seyedian et al., 2014; Herrero et al., 2016). Also, there are studies under the natural conditions to assess the flow with the morphological process (Szupiany et al., 2009; Riley et al., 2014; Casas, 2013; Redolfi et al., 2016; Yuill et al., 2016). There are many examples of natural river junctions that suffering from hydro-morpho dynamic issues, and one of the published examples is the confluence of Wahei and Xianjiapu rivers in southwest China. This confluence is exposed to flooding due to the sedimentation issue that reduces the capacity of the main river (Wang et al., 2016).

Another published example is the branching channel of the Ohio River that supply water to the electric power project. The flow in this case clearly shows the effect of the sediment deposition that create a sand bar at the entrance of the branching channel, which reduce the water supply to a side project (Neary et al., 1999).

Flooding and sedimentation that recognized at the channels junctions may founded at many other locations worldwide, and as a summary from the related studies show that the topic is important due to having relevance to real life problems. More investigations are required to mitigate and control the problems that occurred in channel junctions.

1.2 Problem Statement

River junctions such as branching and confluence are usually exist in a natural river system. Scouring and deposition are the main natural processes that usually occur at river junctions. The above processes are considered as complex hydro-morphological dynamics phenomenon that occurs due to rapid changes in the mechanism of water and sediment flow. The erosion and deposition at the river junctions are considered as critical issues (Alomari et al., 2018; Moradinejad et al., 2017; Best, 1988; Mosley, 1976). The scouring and deposition zones located in river junctions are continuously reduce the hydraulic capacity of rivers. The main consequences of the scouring and deposition are restriction in navigation, flooding and the effect on safety of structures constructed near river banks.

On the other hand, the dimensions, arrangement and inclination angle of the rehabilitation structures that can be used to control the deposition and scouring zones at the river junctions were proposed by Odgaard and Wang (1991); Mirzaei et al. (2014); Wuppukondur and Chandra (2017a; b) and others. But there were lack of studies on the best effective dimensions, arrangement and inclination angle. Alternatively, rehabilitation works can be used, but these works are costly since dredging equipment should be used to remove and maintain sediment accumulation repeatedly from time to time. Thus, managing hydro-morpho dynamic at the channel junction is still considered as challenging (Kalathil et al., 2018; Wuppukondur and Chandra, 2017a).

The related studies were mainly parametric type for predicting, characterization and simulation of scouring and deposition zones. Only few studies on controlling and managing these morphological features were focused on using submerged vanes in different strategies (Odgaard and Wang, 1991; Neill et al., 1997; Michell et al., 2006; Beygipoor et al., 2013; Wuppukondur and Chandra, 2017a; b). Disadvantages of using submerged vanes are limited to discharge ratio, producing non-uniform of velocity distribution due to its numbers (Barkdoll et al., 1999), and affect the navigation in rivers.

The hydraulic performance of the rehabilitation structures depends mainly on its location, angles, dimensions, and morphological conditions (Karmaker and Dutta, 2016; USACE, 2012). For this reason, no specific criteria are used for designing an obstacle in a river system. Thus, in this study, unsubmerged vanes were used as a control structure in the confluence and branching junctions. Physical or numerical simulation was required to optimize the design of the unsubmerged vane. However, using physical models entails several limitations, such as high cost, steady flow (hydraulic similarity), and scale effect. By contrast, numerical models are low-cost and can be used efficiently for unsteady mobile bed conditions.

1.3 Objectives

The purpose of this research work was to study hydro-morpho dynamics of confluence and branching rivers with the consideration of introducing different arrangements of unsubmerged vanes at suitable location of these river junctions in order to minimize erosion and deposition zones. While the specific objectives are:

1. To characterize the features of hydro-morpho dynamics in confluence and branching rivers using data obtained from the field measurements
2. To simulate the hydro-morpho dynamics patterns at the confluence and branching rivers using the 2D Mflow_02 solver
3. To determine the best location, dimension, and inclination angle of the unsubmerged vanes to mitigate the erosion and deposition zones.

1.4 Scope and Limitation of the Study

The scope of the present study covers the examination of the hydro-morpho dynamics of river junctions based on field measurments and numerical simulation under various flow conditions with and without control structures, while the limitations of the study are

1. Two real cases of river junctions were numerically examined, and these cases include a river confluence at the tropical region and under uncontrolled flow condition (confluence of Kurau and Ara rivers, Perak, Malaysia) and a branching river at the temperate region and under controlled flow condition (branching of Tigris river at Missan, Iraq).
2. The confluence between Kurau and Ara rivers are with an angle of 135°, range of discharges between 9 to 43 m^3/s and average median particle diameter (d_{50}) of 1.1 mm (Sirdari 2013; DID 2009; Teo et al., 2017)
3. The branching of the Tigris river is with an angle of 50°. The field data was measured during high and low flow seasons. The discharges were found to be 247.239 m^3/s and 119.298 m^3/s for high and low seasons respectively, and average median particle of bed material (d_{50}) was 0.055 mm
4. Available DEM data were used for mapping the scouring and deposition zones at river junctions

5. A 2D numerical solver of Mflow_02 for both hydrodynamics and morphology simulation was used in this study. The solver is limited to three equations for calculating sediment transport, and these equations are Meyer-Peter and Müller formula (1948), Ashida and Michiue formula (1972) and Engelund-Hansen formula (1974).
6. Also, the solver is limited to three methods for calculating the turbulence field (flow with large and small eddies) and these methods are zero-equation model, k-ε model, and direct input kinematic eddy viscosity
7. For accurate simulation, fine unstructured grids consisted of 6136 nodes were created to cover the area of the river confluence, and 4511 nodes to cover the area of branching river
8. The calibration of the solver is conducted by adjusting nodes number, time step, turbulence model, and Manning roughness. The nodes number, time step, and turbulence model are determined by trial and error while the initial Manning roughness is recommended by Sirdari (2013) and Teo et al. (2017) for the case of a river confluence and by the Ministry of Water Resources, Iraq and Ali (2016) for the branching river case.
9. The geometry, location, and angle of the vanes were arbitrarily selected and used in the numerical investigation

1.5 The significance of the study

A 2D of hydro-morpho dynamic model was used to simulate two different river junctions which include uncontrolled river confluence at a tropical region and controlled river branching at a temperate region. A combined field measurement and acquired data were used in the model calibration and validation before simulating the hydro-morpho dynamic at the selected river junctions with and without control structures. The simulation included various scenarios for controlling scour and deposition zones at the river junctions. The scenarios also included introducing vanes with different arrangements for minimizing scouring and deposition zones and enhancing river flow regime. The most significant solution which gives minimum scouring and deposition zones was included in the simulations of this study.

1.6 Thesis Layout

The thesis was composed of five chapters. Chapter One, presents a general description of the flow in river junctions with the main critical features that found in river junctions, the problem statement, the objectives of the study, the scope and limitations and the significance of the study.

In Chapter Two, relevant literatures of hydro-morpho dynamics features and sediment transport at the confluence and branching rivers are reviewed extensively. This chapter reviews recent works done in laboratories, field sites, and numerical simulations. Finally, a summary of the literature review including research gap was cleared and listed.

Chapter Three illustrates the methodology of this study, starting with the explanation of the selected case studies, which includes the demonstration of fieldwork and data acquisition for the first case, the confluence of Kurau and Ara rivers and the second case, the branching of the Tigris River. The data of water discharge, bed material samples, and calculations of the critical velocity of sediment inception motion are displayed. Model background, structure, characteristics and the governing equations are also illustrated. Model implementation and boundary conditions for the selected river junctions as well as the simulation procedures without and with vanes were explained, and then four statistical error indices were explained to assess the accuracy of the model prediction.

Chapter Four displays the results of the study, which characterized the main features for the confluence and branching cases based on the field measurements. Models calibration, validation and simulation results of different scenarios were presented as figures, tables and discussed based on each objective of the study individually. Finally, Chapter Five presents a conclusion and novelty of the study, as well as recommendations for future studies.

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He started his PhD research in Water Resources Engineering, Faculty of Engineering. Universiti Putra Malaysia in September, 2016 and the result of this research is reported in this thesis.

LIST OF PUBLICATIONS

Hydar L. Ali, Badronnisa Yusuf, Thamer Ahamed Mohammed, Mohd Shahrizal Ab Razak, Yasuyuki Shimizu, Balqis Mohamed Rehan. (2019). Improving the Hydro-Morpho Dynamics of A River Confluence by Using Vanes. *Resources*, 8(1), 9. indexed in ISI and Q1 in Scopus, open access

Hydar L. Ali, Badronnisa Yusuf, Thamer Ahamed Mohammed, Yasuyuki Shimizu, Mohd Shahrizal Ab Razak, Balqis Mohamed Rehan. (2019). Assessment of Vanes Effectiveness in Controlling Erosion and Deposition Zones at a River Confluence using a 2D mode. International Journal of Integrated Engineering, 11(2), indexed in Scopus and ISI, open access

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