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Numerical modelling approach for the management of seasonal influenced river channel entrance

Michael T.W. Tay*, S.B. Mitchell, J. Chen, J. Williams

School of Civil Engineering and Surveying, University of Portsmouth, Portland Building, Portland Street, Portsmouth PO1 3AH, UK

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ABSTRACT

The dynamic nature of a river channel entrance is commonly seasonal dependant. This is evidenced in the topography of river channel entrances in East Coast of Borneo which is influenced by both North East (NE) and South West (SW) monsoons on top of surrounding parameters such as waves and tides, sedimentation as well as climate change. Advanced numerical modelling technique is frequently used as a leading approach to investigate the complicated nature of river channel entrance to well represent actual conditions of a designated area. This paper presented a mesoscale numerical modelling method by integrating reductionist and reduced complexity model approach along with local seasonal conditions to well represent river channel entrance problem and propose management measures. The model was established with a set of numerical equilibrium equations and calibrated parameters to reflect the features of regional conditions with the combination of local validated modelling parameters. The model had accurately represented the effects of both NE and SW monsoons in terms of hydraulics and sediment dynamics at the Petagas river channel entrance, as verified by site data and satellite imagery. In addition, the accuracy of the model provides confidence in the implementation of improvement measures at the river channel entrance. The improvement scheme includes a training channel and a breakwater in improving flushing capacity, thus preventing sedimentation and upstream flooding, allowing proper navigation through the river. In conclusion, the accurate investigational result from this numerical model had successfully demonstrated its scientific role in solving dynamic river channel entrance, which can serve as a numerical modelling approach for solving similar river channel entrance problems especially in the East Coast of Borneo with predominant inter-annual seasonal variations.

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1. Introduction

The processes that occur in and around river channel entrances are a vast and very complex subject that has been studied by countless researchers over a long period of time (Pruszak and Szmytkiewicz, 2005; Samaras and Koutitas, 2014). Changes in the morphologies of river channel entrances, known as delta systems, become more pronounced over the last century as a result of sea-level change, changes in fluvial processes, and urbanisation (Zbigniew et al., 2005).

Today, more than three billion people live in the coastal zone (Hinrichsen, 1998). With the increasing influence of human activity along the coastal lines including urbanisation, there has been an increase in surface water runoff, causing an increase in river flow and sediment influx towards river channel entrances. About 80% of people who live in coastal regions are vulnerable to flooding, of whom 38% are located in Asia, mostly in South East Asia (Veerbeek, 2007). Hence, a better understanding of the morphology of river channel entrances is crucial to improve coastal resource planning and management.

The configuration of a river channel entrance strongly depends on the incident of wave energy on the adjacent shoreline (Wright and Coleman, 1972). For that reason, the change in morphology as a function of waves and river discharges should be considered in terms of the formation of a river channel entrance discharge system (Wright and Coleman, 1973). The morphology of a river channel entrance is also affected by tidal currents and waves, in addition to the sources from ocean energy which include various types of currents, storm surge, and climate change causing eustatic rises in sea level (Galloway, 1975; Stanley and Warne, 1994; Wong et al., 2014; Bonaldo et al., 2015). Additionally, most of the major river

* Corresponding author.
E-mail addresses: cve60081@myport.ac.uk, michaeltwtay@gmail.com (M.T.W. Tay).

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channel entrances in Southeast Asia were formed during the Holocene, leading to the mobilisation of large quantities of sediment (Woodroffe et al., 2006).

Previous modelling studies have shown that the prevailing climate of the South China Sea is governed by the North East (NE) and South West (SW) Monsoons, resulting in a local wind speed of around 10–14 m/s (ICZM Task Force, 1998). (Razak et al., 2012; Abdullah, 1992; Husain et al., 1993). The North East Monsoon season lasts from December to March, and the South East Monsoon season lasts from June to October, with the intervening time termed as transition period (Outskirtoutrich.org n.d.). Xue et al. (2012) had proposed a similar directional shift in the coastal current from North East to South West during the monsoon period in the South China Sea. South East Asia, surrounded by South China Sea, also known as wetting region where frequent tropical storms and typhoons occur. (Santini and Paola, 2015).

Most of the river channel entrances of Sabah, Malaysia are known to cause major flooding due to the restriction of water flow, causing backwater effects (Abdullah and Kamal, 2012). Advanced and sophisticated techniques are required to measure and predict the physical changes that occur to the morphologies of the river channel entrances in Sabah, especially Petagas river channel entrance. A numerical model is applied for its cost effectiveness advantage in predicting the outcome of a management system.

Waves plays an important role in sedimentation and coastal morphology much so at the entrance of a river channel (Amoudry, 2008). (Chiang and Hsiao, 2011; Valsamidis et al., 2013). The overall patterns in the month-to-month wave directions are related to the dominant directions of the monsoon winds (Mangor, 2007).

Tides play an important role in circulation. The tidal regime at the site of interest is mixed, mainly diurnal with one tidal cycle per day and $F = 2$ (Lisitzin, 1974), based on a constituent analysis of tidal harmonics by the Kota Kinabalu Port Authority (Malaysian Metrological Department, 2010).

Sedimentation is one of the most common problems affecting the management of a river channel entrance (Jayappa and Narayana, 2009; Mashriqui 2003; Nylen and Ramel, 2011; Robakiewicz, 2010; Nelson et al., 2013). This complex phenomenon occurs throughout Malaysia under hydraulic conditions as the velocities are low, causing sand and silt to be deposited on the river bed (Department of Irrigation and Drainage, Malaysia, 2001). The study of sedimentation dynamic behaviour in relation to temporal pattern need to be carried out with prolonged and reliable data collection (Roy et al., 2012). An understanding of sedimentation requires the proper description of the hydrodynamic processes of tides, river flow, and the morphology of the bed (Department of Irrigation and Drainage, Malaysia, 2001). Using hydrological data obtained from the Petagas River, it has been shown that the incident wave direction during the SW monsoon is the principal factor that affects the morphology of the river channel entrance. Sedimentation at the Petagas channel entrance is known to exacerbate flooding in the Moyong River. According to the local authorities, the navigational conditions of the Petagas river have worsened over the last few years.

The shallow bathymetry of the Petagas river channel entrance had caused more sedimentation due to effect from increased bed friction, which further contributing to flow deceleration and lateral expansion of the river channel entrance (Wright, 1977).

Erosion and sedimentation in river channel entrances can be conducted by means of techniques involving a combination of bed surveys, Acoustic Doppler Current Profiler (ADCP) measurements, and numerical modelling. A good number of such studies were conducted, including those undertaken in the Mekong River Delta in Cambodia, which discharges into the South China Sea (United Nations, 1969; Kocar and Scott, 2012; Xue et al., 2012; Schmitt and Albers, 2014). Numerical modelling was applied in this case to predict the outcomes of different management solutions (Wang et al., 2014; Stark et al., 2016) or even the future shapes of the river channel entrances, due to its cost effectiveness advantages-cheaper and faster than physical modelling.

In recognition of this, a numerical model is proposed in this paper that includes the effects of different monsoon phenomena, in relation to its influence of varying tides and fluvial discharge on river channel entrance dynamics. In addition, the effectiveness of a set of management solution during monsoon periods are analysed, which is the primary focus of this research. The overall objective of this paper is to provide an approach through numerical modelling in solving monsoon influenced river channel entrance problems.

The paper is structured as an approach to numerical modelling where Section 2 describes the overall topography necessary to cover Petagas River channel entrance as well as introducing a set of management solution. Section 3 describes the necessary modelling approach in building a mesoscale model which elaborates on model platform, data utilisation and model setup. Section 4 shows the outcome of the well represented core reduced complexity modelling techniques in terms of wave condition, then the outcome from the calibration of the hydrodynamic model is shown and further describes the effectiveness of the coupled model. The result of proposed management solution aiming at minimising sedimentation behaviour in relation to inter-annual climate variations in the monsoon seasons is also shown in this section and along with it demonstrates the effectiveness of the core model coupled with reductionist model approach. At the final section of the paper, conclusions are drawn, including the importance of numerical modelling in solving future river channel entrance problems and its ability to provide suggestions for policy-makers in managing river channel entrance that is subjected to monsoon influences.

2. Topography of the Petagas river channel entrance

2.1. Overview of existing condition

Located in Sabah, Malaysia (Formerly known as North Borneo), the Petagas river serves as one of the major discharges of the Moyong catchment, which covers an area of 297 km^2 (DID, 2011). With the expansion of the urban centre of Kota Kinabalu into the Moyong floodplain, a transition in terms of land use is ongoing, from rural development and cultivation of rice paddies to intensive urban development, causing immense changes in the characteristics of the rivers located in the Moyong Catchment, especially the Petagas river (DBKK, 2011). Apart from being one of the largest and most important catchments in terms of economic development, the Moyong basin receives a rainfall intensity of up to 400 mm per day, one of the highest in Malaysia (DID, 2011). At its channel entrance, the Petagas river is located immediately to the south of Kota Kinabalu International Airport (KKIA), a major international transport hub. The channel connects and discharges into the South China Sea by a southwest-oriented channel, which is about 50 m wide at this location.

The Petagas river channel entrance is located on the West Coast of Sabah near the town of Potation, a few kilometres to the south of Kota Kinabalu City, Malaysia (Fig. 1). The river discharges fresh water into the South China Sea.

The bathymetry of the river channel entrance is highly variable due to ongoing sedimentation. Fig. 2b demonstrates that continuous reclamation since 1973 has led to a very shallow river channel entrance with a sand bar stretching approximately 200 m southward from the runway reclamation. This reclamation was done for the extension of the airport runway to accommodate bigger aircraft. Fig. 2b also shows the discolouration of the water in the

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