HYDRODYNAMIC MODELING OF MALACCA STRAITS USING EFDC

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A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Civil – Hydraulics and Hydrology)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JANUARY 2013

For three special persons in my life
my father, mother and sister

ACKNOWLEDGEMENT

I would like to express my utmost gratitude and sincere appreciation to my supervisor, Dr. Noor Baharim Hashim for his advice, guidance and support throughout the project's study. Lots of ideas and knowledge contribution from him were increased my understanding and interest related to the study problems.

Special thanks go to Ms. Maznah Ismail, Mrs. Ziba Kazemi and Mr. Khairul Anuar Mohamad who shared a lot of ideas and information regarding my project's study. I also would like to acknowledge the members of panel who gave the constructive comments and suggestions during pre and post-project presentations; Assoc. Prof. Dr. Sobri Harun, Dr. Zainab Mohamed Yusof, Mr. Abu Bakar Fadzil and Mr. Zulkiflee Ibrahim.

Not forgotten to the people from agencies and firm; Mrs. Ezahtulsyahreen Ab. Rahman, Mrs. Rosmani Mohd Yusof and staffs (DOE Malaysia) for providing the data of marine and river water quality, Mr. Ahmad Azri Salleh and staffs (DID Malaysia) for providing the data of river discharges, and to Mr. Kester Scandrett and Dr. Nghiem Tien Lam (Dynamic Solution-International LLC) for sharing their skills in using EFDC_Explorer 7.0, besides Jabatan Perkhidmatan Awam for funding my master's study.

My gratitude also goes to the master's coursemates of Hydraulics and Hydrology batch 2011 – 2012 for their friendship and helps during good and hard time throughout the course's study. Last but not least, I would like to express my deepest gratitude to my family, teachers and friends that gave me strength and encouragement until today's accomplishment. Million thanks to all of you.

ABSTRACT

Straits of Malacca have long been the important trade route linking the Indian Ocean to the South China Sea and Pacific Ocean, also rich with renewable and nonrenewable resources. The rapid economic development and population growth near the coastal areas exposed the coastal and marine resources to the environmental problems. The study focused to the preliminary development of hydrodynamic model of Malacca Straits by applying the Environmental Fluid Dynamics Code (EFDC) 3D public-domain modeling package. Objectives of study are to calibrate, validate and verify the hydrodynamic variables of water level, current velocity and current direction, and to simulate the hydrodynamic circulation processes of waterbodies. Water quality analysis also performed prior study to know the status of waterbodies. The model was set as coarse grid that bounded from Langkawi to Kukup, which refined for hydrodynamic calibration and verification at Batu Pahat coastal area. Optimum bottom roughness height from sensitivity analysis was applied to verify and validate the model. Statistical analysis was used to evaluate the model performance. The optimum bottom roughness heights were found at 0.001 m and 0.004 m at shallow and deeper regions respectively. The model was reasonably good in simulating water levels and current directions, respectively with correlation coefficient of 0.92 and relative RMS error of 22.92%. The wave currents circulate inward from open boundaries during flood caused collision near Port Klang coastal area. The wave currents during ebb caused maximum velocity of 1.47 m/s and maximum bed shear stress of 4.82 N/m^2. Sungai Perak loads out the highest fluxes of DO, BOD, NO_3, and PO_4 constituents whilst Sungai Langat loads out the highest flux of NH_3-N constituent during year 2009.

ABSTRAK

Selat Melaka telah lama menjadi laluan penting perdagangan yang menghubungkan Lautan Hindi dengan Laut China Selatan dan Lautan Pasifik, juga kaya dengan sumber-sumber boleh diperbaharui dan tidak boleh diperbaharui. Pembangunan ekonomi yang pesat dan pertumbuhan penduduk berhampiran kawasan pantai mendedahkan sumber pantai dan marin terhadap masalah alam sekitar. Kajian ini tertumpu kepada pembangunan awal model hidrodinamik Selat Melaka dengan menggunakan Kod Dinamik Bendalir Alam Sekitar (EFDC), iaitu pakej pemodelan 3D domain awam. Objektif kajian adalah untuk menentukur, menvalidasi dan mengesahkan pembolehubah hidrodinamik paras air, halaju arus dan arah arus, dan untuk mensimulasikan proses peredaran hidrodinamik badan air. Analisis kualiti air dilakukan di awal kajian bagi mengetahui status badan air. Model telah dibina sebagai grid kasar yang disempadani dari Langkawi ke Kukup, yang dihaluskan untuk penentukuran dan validasi hidrodinamik di kawasan pantai Batu Pahat. Kekasaran dasar optimum dari analisis sensitiviti telah digunakan untuk menvalidasi dan mengesahkan model. Analisis statistik telah digunakan bagi menilai prestasi model. Kekasaran dasar optimum ditemui pada 0.001 m dan 0.004 m masing-masing di kawasan cetek dan kawasan lebih dalam. Model agak baik dalam simulasi paras air dan arah arus, masing-masing dengan pekali sekaitan 0.92 dan ralat RMS relatif 22.92%. Arus gelombang beredar masuk dari sempadan terbuka semasa air pasang menyebabkan pertembungan berhampiran kawasan pantai Pelabuhan Klang. Arus gelombang semasa air surut menghasilkan halaju maksimum 1.47 m/s dan tegasan ricih dasar maksimum 4.82 N/m2. Sungai Perak mengeluarkan fluks tertinggi bagi konstituen DO, BOD, NO_3, dan PO_4 manakala Sungai Langat mengeluarkan fluks tertinggi bagi konstituen NH_3-N pada tahun 2009.

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LIST OF SYMBOLS

σt	-	Sigma-t
m	-	Mass
t	-	Time
g	-	Gravitational acceleration
v	-	Velocity
ρ	-	Density
F	-	Force
p	-	Pressure
τ	-	Shear stress
z_0^*	-	Bottom roughness height
T	-	Temperature
W	-	Constituent loading
C	-	Concentration
Q	-	Discharge
Pa	-	Pascal

LIST OF ABBREVIATIONS

3D	-	Three dimensional
ACD	-	Admiralty Chart Datum
BOD	-	Biochemical Oxygen Demand
DID	-	Department of Irrigation and Drainage
DO	-	Dissolved Oxygen
DOE	-	Department of Environment
EFDC	-	Environmental Fluid Dynamics Code
EIA	-	Environmental Impact Assessment
EPA	-	Environmental Protection Agency
JUPEM	-	Jabatan Ukur dan Pemetaan Malaysia
LPG	-	Liquid Petroleum Gas
LSD	-	Land Survey Datum
MPN	-	Most Probable Number
MSL	-	Mean Sea Level
NH_3-N	-	Ammoniacal nitrogen
nm	-	Nautical miles
NO_3	-	Nitrate
PO_4	-	Phosphate
ppt	-	Part per thousand
RE	-	Relative Error
RMS	-	Root Mean Square
RRE	-	Relative RMS Error
TLDM	-	Tentera Laut Diraja Malaysia
UNEP	-	United Nations Environment Programme
UTM	-	Universal Transverse Mercator

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The chapter of introduction is written to give some idea to the study of Malacca Straits. The importance of Malacca Straits to the community of coastal areas at both Malaysia and Sumatera, also to the traders from surrounding East Asia is elaborated. The environmental problems of waterbodies that arose which caused by surrounding economic development also discussed. The objectives and scope of study are the main part in this chapter to be highlighted. Besides, the importance of study to the water resources industry also stressed.

The Straits of Malacca have long been an important trade route that linking the Indian Ocean to the South China Sea and Pacific Ocean. In 1993 and 1995, over 100,000 oil and cargo vessels traversed it each year, carrying 3.23 million barrels of crude oil through the Straits each day (Thia-Eng et al., 2000). The rapid industrial development of many East Asian countries has lead to an increase in shipping traffic. The growth of trade and industry along the Straits has led to the development of ports and urban centers. The Straits are also rich in renewable and non-renewable resources, including productive coastal ecosystems, extensive capture fisheries, aquaculture, coastal tourism, mining and valuable natural gas reserves.

South-east Asia is a centre of marine biodiversity and the Malacca Straits are located centrally within it. The Straits are one of the largest estuarine environments in the region, characterized by soft-bottom habitats, fringing coral reefs, seagrass beds and mangrove lining coastlines. Offshore shallow Sunda Shelf support high biodiversity of commercial species include fishes, seaweeds, horseshoe crabs, shrimps, bivalves, gastropods, sea cucumbers and sea urchins (Thia-Eng et al., 2000). The extensive mudflat with rich of organic substances and fine silt particles is important as nursery grounds. The Straits rich with multi-species fish stock, mainly demersal, pelagic finfish, crustaceans and molluscs. Moosa (1988) estimates the area to hold the potential annual stock of 253,000 tones of pelagic fish, 220,000 tones of demersal fish, and 88,400 tones of shrimp. The extensive capture fisheries giving employment to 245,161 fishfolks and around 45% of Malaysian fishers are dependent on the Straits (Thia-Eng et al., 2000).

Seagrass beds are found mostly on the Malaysian side, particularly in Tanjung Tuan at Port Dickson and around Langkawi Island. Japar (1994) reports the largest known Malaysian seagrass bed can be found on Merambong Shoal with length of 1.2 km and width of 80 – 100 m (Thia-Eng et al., 2000). The beds serve as habitats for endangered species of sea cows and green turtles. In many parts of Malaysia and Indonesia, coral reefs become tourist attractions and the marine tourism resorts have been developed based on its existence. The coral reefs also provide physical protection to the coastal and island ecosystems. The white sandy beaches coupled with coral reefs become the main attractions that make coastal tourism a thriving industry in Malacca Straits. MPP-EAS (1998) states of the revenues US$777 million from beach use, about US$221 million comes from diving and snorkeling (Thia-Eng et al., 2000).

The oil fields in Malacca Straits mostly located on the east coast of Sumatera. Around eight million barrels of potentially recoverable oil have been identified from that fields, and offshore oil production from the Malacca Straits amounts to 55,000 barrels per day (Thia-Eng et al., 2000). Arun field in Acheh is a major gas field that produces around 12 trillion cubic feet of LNG annually. Tin ore and bauxite are also

found (Burbridge, 1998) and mined along the Indonesian coast. Urea, kaolin, granite and sand mining were undertaken in places such as Johor and Riau (Thia-Eng et al., 2000).

1.3 Problems of Study

In recent years, the rapid economic development and population growth near the coastal areas affect the resource exploitation. Within Peninsular Malaysia, the population tends to concentrate in major urban cities of Penang, Ipoh, Selangor and Johor Bahru due to the presence of rich natural resources. The coastal economies were mainly agricultural and fisheries sectors have been shifted towards industrials and services. The various activities along the Straits of Malacca exposed the coastal and marine resources to the environmental problems like coastal erosion-sedimentation and water quality degradation.

As of 1985, 1972 km of West Coast Malaysia coastline, includes from Kuala Perlis to Sungai Udang, West Johor and Northern Kuala Selangor coast had been affected by critical erosion (Thia-Eng et al., 2000). The mangrove extraction activities and lands conversion for agricultural purposes were the main factors that increased the rate of shorelines erosion. Thia-Eng et al. (2000) also reports the serious siltation in some river mouths and harbors along the west coast of Malaysia around Port Klang, Kuala Perlis and Kuala Kedah. The natural and human activities such as deforestation, dredging, and land reclamation were resulted the sedimentation problems to the Straits.

In Indonesia, a large area of coral reefs off Asahan district had been dredged, followed by the conversion of mangroves forest to the shrimp ponds. The reefs in Singapore waters also have been stressed due to sedimentation and water quality

deterioration from port and land reclamation activities. Chua et al. (1998) reports the turbid conditions, fluctuating salinity and high sediment load discharges from land also contributes to the problems. The recorded seagrass species of fourteen, eleven and nine from Indonesia, Singapore and Malaysia waters respectively, only seven were remains and this considerable loss was caused by the land reclamation (Thia-Eng et al., 2000).

The Straits of Malacca received the pollutant discharges from both land and sea based sources. High level of biochemical oxygen demand (BOD) usually found near the industries and sewage outfalls, such as in Juru estuary, Chuah at Negeri Sembilan, and Johor Straits (Thia-Eng et al., 2000). Based from the analysis on marine water that sampled by the Department of Environment (DOE) Malaysia from year 2006 to 2010, the result for dissolved oxygen (DO) shows eight out of 34 estuary waters were below than 5.0 mg/L (Figure 1.1), indicates the occurrence of hypoxia. The levels of ammoniacal nitrogen (NH_3-N) above 0.1 mg/L are detect from marine water sample at several locations along the Straits of Malacca (Figure 1.2), indicates by Agency (2001) as the contamination of sewage and industrial waste. From the viewpoint of human health, the significance of ammonia is marked as consequent to the possible presence of pathogenic microorganisms (Agency, 2001).

Heavy metals include cadmium, copper, lead, mercury and nickel primarily from manufacturing sectors were reported by Choo et al. (1994) in coastal waters of Perak and Penang (Thia-Eng et al., 2000). High concentration of lead, nickel and cobalt also reported in waters near petroleum refineries, besides detected metals in bottom sediments that experiencing heavy shipping traffic. An estimated agricultural waste of 218 tones per day from swine farming near the Linggi and Langat rivers were reported by Thia-Eng et al. (2000) in 1989. Lindane, a pesticide residue was also found by Abdullah et al. (1998) in some samples of mussel in West Malaysia marine waters. The coliform levels in most West Coast Malaysia waters exceed the interim water quality standards for recreation (100 MPN/100 ml) (Environment, 1990),

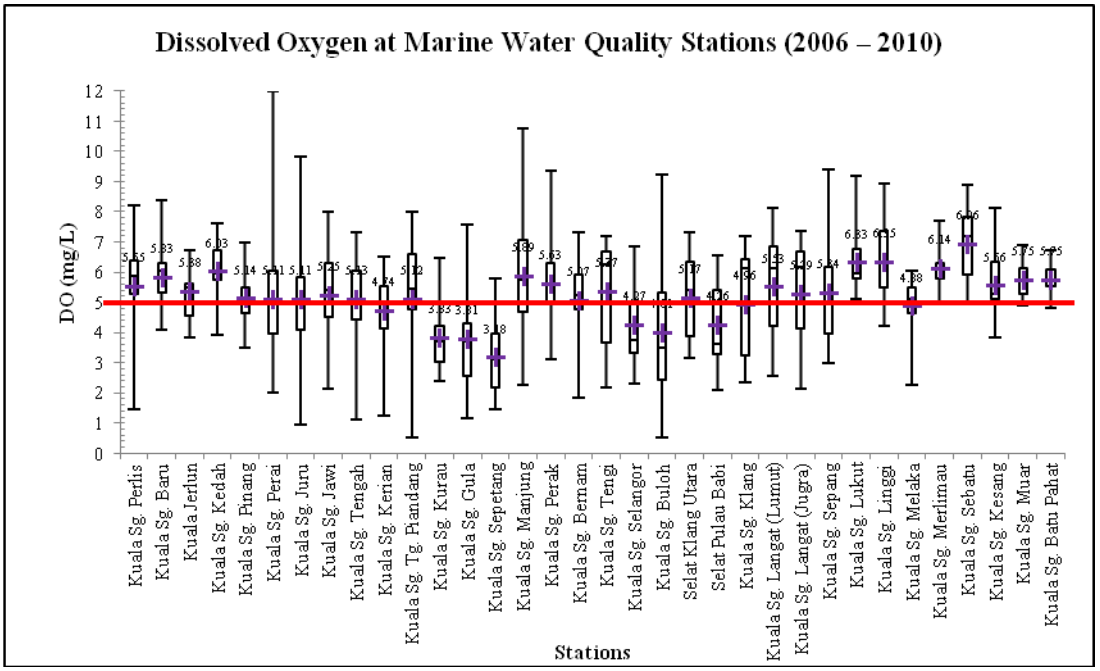

Figure 1.1: Dissolved oxygen levels at 34 marine water quality stations along the Straits of Malacca estuaries from year 2006 to 2010.

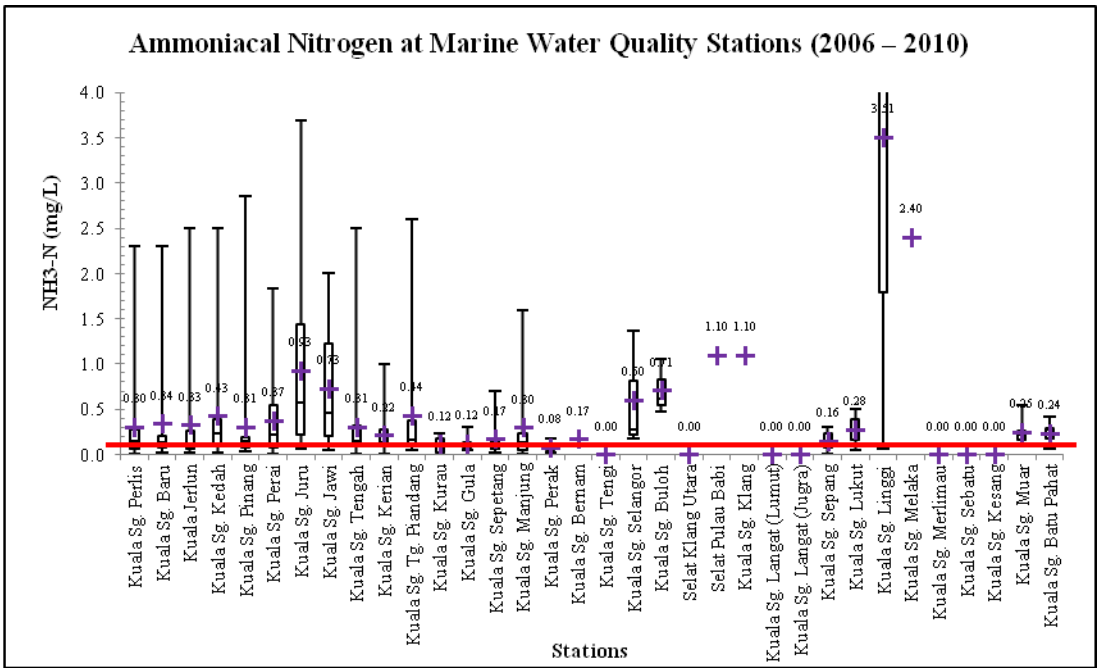

Figure 1.2: Ammoniacal nitrogen levels at 34 marine water quality stations along the Straits of Malacca estuaries from year 2006 to 2010.

which could cause skin diseases and eye irritation, besides cholera and typhoid (Thia-Eng et al., 2000).

Chemical and oil spills are the major sources of pollution to the marine waters that caused serious impact to the ecosystem at inter tidal zone. Tahir (1996) estimates two tones oily waste discharged daily into the Straits, mainly from tanker debalasting besides from small fishing boats operation (Thia-Eng et al., 2000). In Malaysia, tar pollution has exceeded the UNEP standards at Pantai Pasir Panjang, Perak and Pantai Tanjung Rhu, Kedah (Thia-Eng et al., 2000), where tar level reach 10 grams per meter of shoreline (UNEP, 1990). Rusli (2012) reported a collision of an oil tanker with an LPG carrier in 1993 near Sentosa Island results a financial loss of estimated US$ 1.5 million to the hotel business. Hypernutrification in sea waters will lead to the increase of algal blooms and red tides occurrence. The occasional blooms will result the oxygen depletion that caused the fish and shrimp mortality. Inadequate planned of tourism development also caused the impact of erosion, local resident displacement and water pollution from untreated sewage and solid waste (Thia-Eng et al., 2000).

1.4 Objectives of Study

Generally, the objectives of this study focused on the applicability of mathematical modeling to the preliminary development of hydrodynamic model for the Straits of Malacca waterbodies. The specific objectives include:

1. To calibrate, validate and verify the hydrodynamic model variables.
2. To simulate the hydrodynamic flow circulation processes.

In addition to the study listed before, several analyses on water quality also performed to provide additional information on status of Malacca Straits waterbodies. The analyses include:

1. The marine water quality analysis at Malaysia estuaries.
2. The water quality constituents loading quantification from Malaysia rivers.

1.5 Scope of Study

The scope of study concentrates on the preliminary development of hydrodynamic model for the Straits of Malacca waterbodies. The study limits to the following scope of work:

1. Collect the information consists of hydrological and oceanography data include the previous hydrodynamic observation records that relevant to the study area.
2. Use the EFDC model in development of two-dimensional hydrodynamic model on the Straits of Malacca waterbodies.
3. Apply the statistical methods on analysis of results from hydrodynamic model, also on marine water quality data.

1.5 Importance of Study

Based from the development of hydrodynamic model for the Straits of Malacca waterbodies, the study can provide the understanding of hydrodynamic processes on waterbodies along the Straits of Malacca. From the development of hydrodynamic model, it can help in supporting the industries related to maritime especially fisheries, navigation, dredging works, coastal and offshore constructions besides coastal tourism. The development of hydrodynamic model for the Straits of Malacca also being the preliminary works that provide the information to enhance the complex modeling of water quality and eutrophication, sediment transport, and toxic chemical transport and fate processes. The complete models for the Straits of Malacca waterbodies then could be used as the management tools of water resources for the surrounding countries besides prepare for sustainable environment.

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