MODELING OF OIL SPILLS IN THE GANH-RAI GULF FOR THE PLAN OF COASTAL ENVIRONMENTAL MANAGEMENT

Le Song Giang*, Huynh Thi Minh Hang**

(*) Department of Fluid Mechanics - University of Technology- VNU-HCMC

(**) Institute for Environment & Resources - VNU-HCMC.

ABSTRACT

Lying on the transport waterway, Ganh-rai gulf is often faced with the risk of oil spill hazard. It is necessary to have a tool to predict the areas that can be affected by spilled oil when it is poured out into the environment, from which they can decide where are the priority to be protected as well as to set up the plan of shore cleaning.

This paper presented a two-dimension model that can simulate the drifting and the fate of spilled oil in the water. The model will be useful for the contingency plan, as well as for the estimating the economics lost caused by spilled oil. The result of research is verified and adjusted by comparing with the past oil spill hazards in Ganh-rai gulf in recent years.

INTRODUCTION

According to the environmental sensitivity categories for the shoreline from Mui ne to Tien river in response to oilspilled hazard (Hang &Vinh- 2002), Ganh-rai gulf is placed in the extreme sensitivity by the natural and man - made factors as follows:

Natural factors:

- Well-sheltered shoreline.
- The cost type is tidal flat located on the river mouth formed by fined materials on which mangrove forest is widespread.
- The richness of marine resources

Man-made factors:

- The concentration of petroleum activity both onshore and offshore (Fig.1).
- The activity of many commercial seaport and fluvial port (Saigon, Dong Nai, Thi vai...)
- The diversity of economic activities that run over whole year.

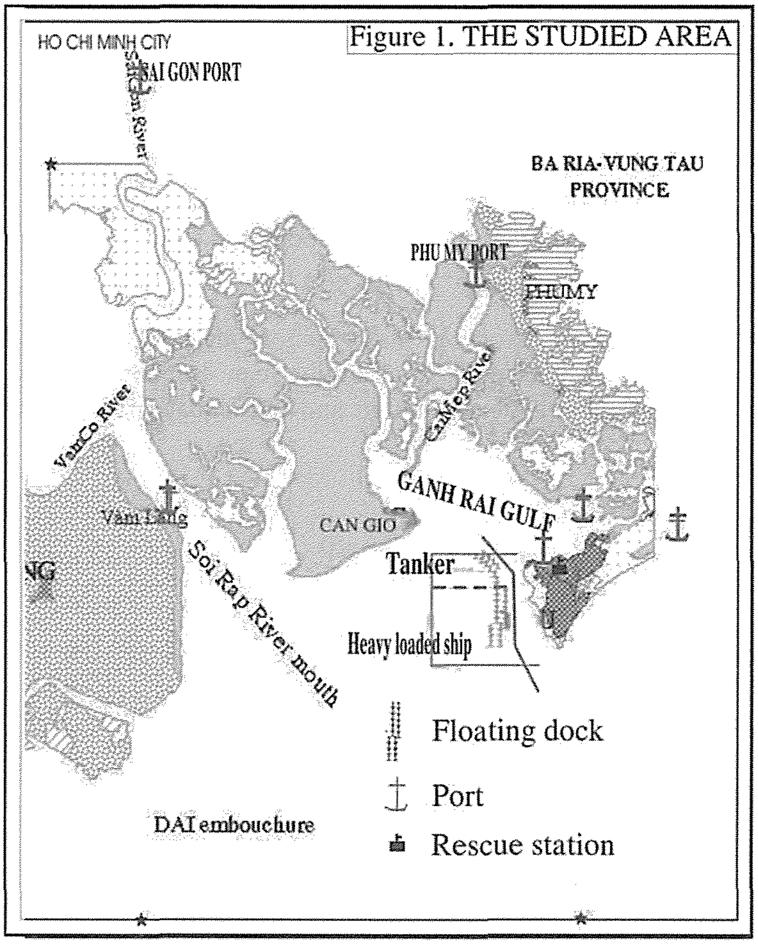

Fig.1.The concentration of petroleum activity both onshore and offshore

As the consequence of the fact the risk of oilspilled hazard of the area, caused by transportation, is quite high. An oilspill, when it happens, will cause a long-term damage not only for economical situation but also for ecosystem. Therefore in the oilspill response contingency plan, a tool that can predict the affected areas from spilled oil when it is poured out is very necessary for the decision-maker decide, not only for the response operation but also for the lost evaluation an for planning the monitoring of environmental rehabilitate.
The fate of spilled oil can be summarized as followings:

- Drifting
- Weathering:
- Evaporation and photo-oxidization (on the surface of the oil slick).
- Dissolution, emulsification and dispersion, at the lower part of the slick. All of them will bring the spilled oil into water column.
- Sedimentation: it will drop the spilled oil on the bottom of the sea floor.
- Biodegrading.

Aiming to contribute a resolution for such the task, the oil spill simulation module is built in basing upon the natural features of Ganh-rai gulf with the different oil types. The oil spill module is verified by the two real oil-spills in the area. The module will address in the simulation the drifting of an oil slick in the three layers of the water column: the surface layer (for drifting), suspended layer (0.2 - 5.0 meter under the surface) for the water-oil emulsion and the bottom ones.

MODEL DESCRIPTION

After entering in water, the evolution of spilled oil is governed by number of mechanism such as: spreading by the gravity, inertia, viscous and surface tension forces; transportation by current and wind; and transformation by physico-chemical processes. In order to simulate this evolution, a model has been developed. It combines two modules: hydrodynamic and oil spill transport. The description of these modules is conducted below.

Hydrodynamic Module

Water circulation is one of major factors affecting the oil transport. For shallow water, the two-dimensional velocity distribution can be obtained by solving the set of equations including equation of continuum and two equations of momentum. These equations can be written:

C:

$$\frac{\partial \eta}{\partial t} + \frac{\partial Uh}{\partial x} + \frac{\partial Vh}{\partial y} = 0 \qquad (1)$$

Mx:

$$\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} + V\frac{\partial U}{\partial y} + g\frac{\partial \eta}{\partial x} + F_x + M_x = 0 \qquad (2)$$

My:

$$\frac{\partial V}{\partial t} + U\frac{\partial V}{\partial x} + V\frac{\partial V}{\partial y} + g\frac{\partial \eta}{\partial y} + F_y + M_y = 0 \qquad (3)$$

Where U and V - two components of depth-averaged velocity; η - free surface level; M_x and M_y - the terms describing the sub-grid mixing processes; F_x and F_y - two components of external forces evaluated by formula:

$$F_x = fr\frac{\sqrt{U^2 + V^2}U}{h} - \frac{\tau_{wx}}{\rho h} - fV \qquad (4a)$$

$$F_y = fr\frac{\sqrt{U^2+V^2}V}{h} - \frac{\tau_{wy}}{\rho h} + fU \quad (4b)$$

h - water depth; fr - friction coefficient at the bottom; f - Coriolis parameter; τ_{wx} and τ_{wy} - two components of wind stress on free surface.

The equations (1) - (3) are solved by finite differential method using the ADI schema of Ponce and Yabusaki [1]. A rectangular staggered grid is used. During the tidal period, shoreline is changed noticeably so the grid can be changed with the tide.

Oil Spill Transport Module

There are number of transport and fate models for oil spill [2]. The simple ones can only compute the trajectory of oil slick on the water surface. But the most advanced models can compute the vertical distribution of the oil phases concentration. In this model, the bulk concentration of oil is computed in three layers: surface; suspended; and bed sediment. The transport equations of oil concentration in each layer can be written:

The surface layer:

$$\frac{\partial C_s}{\partial t} + \frac{\partial}{\partial x}(U_s C_s) + \frac{\partial}{\partial y}(V_s C_s) = \frac{\partial}{\partial x}\left(D\frac{\partial C_s}{\partial x}\right) + \frac{\partial}{\partial y}\left(D\frac{\partial C_s}{\partial y}\right) + \alpha V_b C_v$$

$$- S_E C_a - \gamma C_s + M_s(x,y) - D_s(x,y) \quad (5)$$

The suspended layer:

$$\frac{\partial (C_v h)}{\partial t} + \frac{\partial}{\partial x}(UC_v h) + \frac{\partial}{\partial y}(VC_s h) = \frac{\partial}{\partial x}\left(hD\frac{\partial C_v}{\partial x}\right) + \frac{\partial}{\partial y}\left(hD\frac{\partial C_v}{\partial y}\right)$$

$$-(\alpha V_b + \beta + hk_0)C_v + \gamma C_s + V_r C_b \quad (6)$$

The sediment layer:

$$\frac{\partial C_b}{\partial t} = \frac{\beta}{a} C_v - \left(\frac{V_r}{a} + k_a\right) C_b \quad (7)$$

Where: C_s and C_a - volumetric and area oil concentration in the surface layer per unit surface area; C_v - depth-averaged volumetric concentration of oil in the suspended layer; C_b - volumetric oil concentration in the bed sediment; U_s and V_s - components of surface drift velocity; D - diffusion coefficient; α - coefficient representing probability of deposition of an oil droplet reaching the water surface; V_b - the buoyant velocity of suspended oil droplet; S_E - rate of evaporation; γ - coefficient defining the rate at which the surface oil is dispersed and dissolved into the water column; M_s - effect due to mechanical spreading; D_s - effect due to shoreline deposition; β - coefficient defining the rate at which the suspended oil is deposit on the bed; k_0 - aerobic biodegradation rate coefficient; V_r - the sediment resuspension velocity; k_a - anaerobic biodegradation rate coefficient; a - the thickness of contaminated sediment layer.

The surface drift velocity is combined from 1.1 times of the depth-averaged water velocity and 0.03 times of wind speed. Model parameters have been estimated from established relationships and models [3-5].

The equations (5) and (6) are solved by finite volume method using ADI schema [6], while the equation (7) is integrated analytically by assuming C_v constant at each time step.

Oil Spill Simulation in the Ganh-Rai Gulf

As the entrance of the important waterway to the important fluvial ports of main-point economic zone of South Vietnam, Ganh-rai gulf is faced with the risk of oil spill hazard as mentioned above. Several oil tanker accidents occurred here in 1993, 2001 and 2003.The oil spill simulation is applied on the two recent oil spills as the two case studies.

The oil spill on 7 Sept 2001, at 1:20AM: The accident happened at the buoy G13; 900m^3 of DO were poured in the water

The oil spill on 20 March 2003, at 11:00AM. The accident-ejected 600m^3 of FO in the water at buoy G8

The computational domain is a rectangle of the size 39 × 24km. Fig.2 shows the sea bathymetry. It is covered by a regular grid with the resolution of 100 × 100m. In earlier work [7], the hydrodynamic model has been calibrated for this domain using the field data of Prof. Nguyen Sinh Huy and not repeated here.

THE ACCIDENT ON 7 SEPT 2001

At the time of accident, there was SW wind of 7m/s speed. The figures, from 3 to 5, present the movement of oil slick in three layers. A star marks initial position of oil slick. Arrows also present the velocity field. At the beginning, the oil slick moved to the north and at about 4:00AM it reached to the mouth of Thi vai river. After that, due to tidal current, it turned back to the sea and attached Vung Tau beaches at 8:00AM. At about 11:00AM all Vung Tau beaches are affected by spilled oil of which the strongest ones was the Thuy van beach.

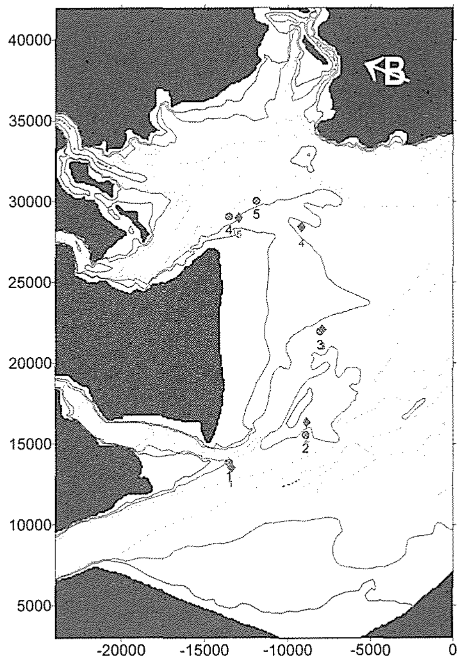

Fig.2. The sea bathymetry

THE ACCIDENT ON 20 MARCH 2003

At the time of accident, wind direction was eastward and its speed is about 5.6m/s. As same as previous case, the movement of spilled oil can be also observed in Fig.6 to Fig.8. About 6 hours after the accident, the spilled oil reached to the Can-Gio cape (at 5:00PM). Then, it turned to offshore and came back to Can-Gio beaches at 1:00AM next day. At 5:00AM the spilled oil affected on the mouth of Dong-Tranh and Soai-Rap River.

CONCLUSIONS

As the fate of spilled oil depends on the natural features (especially current, topography of sea floor, wind) and depends upon the oil 's component. Therefore the modeling software that simulates the movement and the change of spilled oil must be fitted with all of theses factors. The oil spill module is applied on the oil of DO and FO. It simulates the fate of theses oil in the two accidents happened in the two typical seasons of the area. The result of the experience is rather closed to the real situation. The primary result proves that oil spill module can be used in the contingency plan for the oil spill response in Ganh-rai Gulf. It can be the useful tool for decision maker in emergency case and it is also the necessary tool for the environmental manager for the monitoring of the environment recovery after the hazard.

ACKNOWLEGDMENT

The paper belongs to the research on "***Building the sensitivity index system for the shoreline from Mui Ne to Tien River***".

The Authors would like to extend the sincere thanks to the Committee on Earth Sciences - the Natural Sciences Programme of Ministry of Sciences and Technology, who supports for the research.

References

1. Huynh Thi Minh Hang & Bui Trong Vinh. "Sensitivity Grading for shoreline in response to oilspill and environmental management". Journal of the Science of Earth, No 24/2002.
2. Huynh Thi Minh Hang. " Environmental Geology". Text book, 2001 Vietnam National University printing house
3. *Ponce, V.M. and S.B. Yabusaki (1981).* Modeling Circulation in Depth - Averaged Flow, *J. of Hydraulics Division, ASCE, Vol. 107, No. HY11, pp. 1501 - 1518.A.C.*
4. Spaulding, M.L., Howlett, E., Anderson, E. and Jayko, K. (1992). *Oil Spill Software with a Sell Approach*, Sea Technology, pp. 33-40.
5. Steinberg, L.J., Reckhow, K.H. and Wolpert R.L. (1997). *Characterization of Parameters in Mechanistic Models: A Case Study of a PCB Fate and Transport Model*, Ecological Modelling, Vol. 97, pp. 35-46.
6. Stolzenbach, K.D., Madsen, O.S., Adams, E.E., Pollack, A.M. and Cooper, C.K. (1977). *A Review and Evaluation of Basic Techniques for Predicting the Behavior of Surface Oil Slick*, Report No. 222, Ralph M. Parsons Laboratory For Water Resources and Hydrodynamics, Department of Civil Engineering, MIT, USA.
7. Yapa, P.D., Shen, H.T. and Angammana, K. (1994), *Modelling Oil Spills in a River-Lake System*, J. Marine System, Elsevier, pp. 453-471
8. Le Song Giang and Pham Thi Mong Thu, (2003). *Numerical Study of Sediment Transport in Can-Gio Sea*, 2003's Annual Science Conference on Fluid Mechanics, Da-Nang, July 2003. (in Vietnamese)