Hydrodynamic Analysis in Porong Estuary to Preserve Each Environmental Physical Condition

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1. Introduction

On May 29, 2006, hot mudflows emerged in Sidoarjo regency. Today, more than eight years later, there is no sign that this natural phenomenon will cease in the near future. Initially the volume of mud spewing from the burst center was very high: an estimated 100,000 m^3 per day in 2006-2007, reaching 180,000 m^3 per day in December 2006. It subsequently reduced to an estimated 75,000 m^3 per day by July 2009, 50,000 m^3 per day in September 2011, and 25,000 m^3 per day in November 2012[1)]. According to the regulations issued by the government, the mud must be channeled into the Porong River and settled into the Porong Estuary or the sea (see Figure 1). Therefore, it is important to conduct more focused study on hydrodynamics in the Porong Estuary as the end of the materials' settlement that flowed into the Porong River. This study conducted a hydrodynamics analysis in the Porong Estuary using the RMA2 computer program in the Surface water Modeling System (SMS). Velocities in this research area are compared with field data in order to examine the similarities. In addition, the results based on the sampling analysis (physical and chemical analyses) are discussed in this paper.

Figure 1 Study location

2. Methodology

This research uses the RMA2 computer program included in the SMS package. Generally, this program solves the depth-integrated equations of fluid mass and momentum conservation in two horizontal directions[2)]. The forms of equations are:

$$h\frac{\partial u}{\partial t} hu\frac{\partial u}{\partial x} hv\frac{\partial u}{\partial y} - \frac{h}{\rho}\left[E_{xx}\frac{\partial^2 u}{\partial x^2} + E_{xy}\frac{\partial^2 u}{\partial y^2}\right] + gh\left[\frac{\partial a}{\partial x} + \frac{\partial h}{\partial x}\right] + \frac{gun^2}{\left(1.486h^{\frac{1}{6}}\right)^2}(u^2+v^2)^2 - \xi {V_a}^2 cos\psi - 2hv\omega sin\Phi = 0 \quad (1)$$

$$h\frac{\partial v}{\partial t} hu\frac{\partial v}{\partial x} hv\frac{\partial v}{\partial y} - \frac{h}{\rho}\left[E_{xx}\frac{\partial^2 v}{\partial x^2} + E_{xy}\frac{\partial^2 v}{\partial y^2}\right] + gh\left[\frac{\partial a}{\partial x} + \frac{\partial h}{\partial x}\right] + \frac{gvn^2}{\left(1.486h^{\frac{1}{6}}\right)^2}(u^2+v^2)^2 - \xi {V_a}^2 sin\psi - 2hv\omega sin\Phi = 0 \quad (2)$$

$$\frac{\partial h}{\partial t} + h\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) + u\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y} = 0 \quad (3)$$

where h is water depth; u and v are velocities in the Cartesian directions, x, y, and t are Cartesian coordinates and time; ρ is the density of the fluids; E is the Eddy viscosity coefficient; g is acceleration due to gravity; a is the elevation of the bottom; n is Manning's roughness n-value; *1.486* is conversion rate from SI (metric) to non-SI units; ξ is the empirical coefficient for wind shear; V_a is wind speed; ψ is wind direction; ω is the rate of the earth's angular rotation; and Φ is local latitude.

In the physical and chemical analyses, three samples were used in this research; one of the samples was taken from the source of the hot mudflow and two were from the Porong Estuary, taken at coordinates 7° 34' 30.0" S, 112° 52' 10.6" E (sample A) and 7° 33' 54.3" S, 112° 52' 20.6" E (sample B).

The aims of the physical analysis are to obtain soil classification gradations of coarse aggregate and fine aggregate through the use of a sieve analysis (coarse aggregate) and hydrometer analysis (fine aggregate) whereas the chemical analysis was conducted using Scanning Electron Microscopy (SEM) FEI, Type: Inspect-S50. This equipment has the ability to test or look at the structure of the sample's surface with a magnification of up to 1,000,000 times. This equipment has two operating modes: high vacuum (for conductive samples) and low vacuum (for non-conductive samples). In addition, the tool is equipped with EDAX, which can be used to test the content of the element on the surface structure of visible material. The content of the elements to be tested ranged from beryllium to uranium. The distribution of elements in the material can be detected in the form of surface area, line, and mapping.

3. Data and Analysis

Several parameters are required before conducting a simulation in RMA2 namely, bathymetric data in order to generate mesh and discharges data as inflows in the upstream and the tidal data to examine the water surface elevation in the boundary condition. Bathymetric data were taken in 2010 whereas discharge inflows are from the Porong River and Kedunglarangan River during the wet season and 15 days of tidal data. The numerical region and field observation points are depicted in Figure 2.

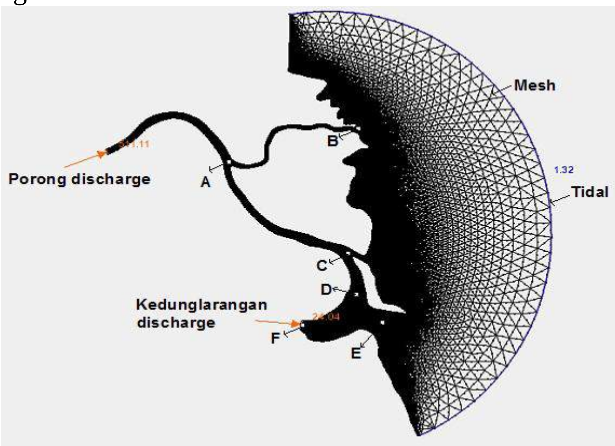

Figure 2 RMA2 input data and observation points

Based on the numerical simulation results, the velocity values at observation points C (0.58 m/s), D (0.32 m/s), E (0.24 m/s), and F (0.07 m/s) are similar to those from the field velocities data, Indicating that the values are plotted within the range of minimum and maximum velocities: C (0.4-0.6 m/s), D (0.3-0.6 m/s), E (0.15-0.3 m/s), and F (0.05-0.2 m/s). Although the observation at point A is close to the maximum value, it is quite different from observation point B, which has a large value in the maximum field velocity data range (see Figure 3) because at observation point B the direction of velocity is different. Thus, it can be assumed that the difference stemmed from the effect of rainfall as the measurement was taken during the wet season.

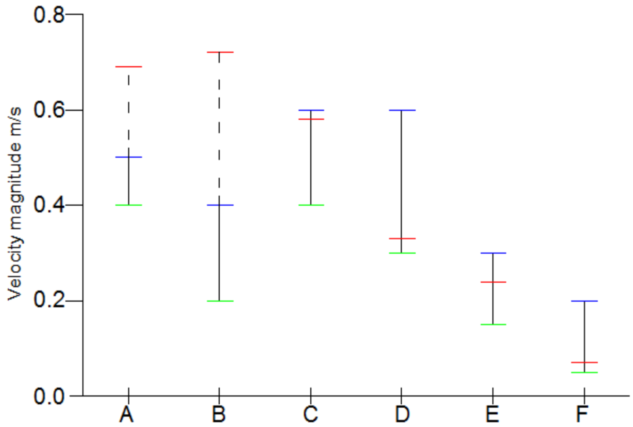

Figure 3 Comparison of velocity magnitude between simulation and field data

The flow velocities are relatively large and expected to be able to transport the sediment to the estuary. Therefore, it is necessary to analyze the source of sediment flowing into the Porong Estuary. Sediment in the Porong Estuary can be derived from the mudflow, land erosion, or the sea itself.

In this research, two samples of sediment were taken from the Porong Estuary and the results were compared with the sample from the mud source. Two kinds of sampling analysis, physical (sieve and hydrometer analysis) and chemical using SEM, were utilized. The results are shown in Tables 1 and 2.

Table 1 Physical analysis

	Sample A		Sample B		Mud sample	
Material	Silt	15.54%	Silt	15.57%	Silt	13.24%
	Clay	84.46%	Clay	84.43%	Clay	86.76%

Based on the results, samples A, B, and C are similarly composed of silt (more than 13%) and clay (more than 84%) materials, demonstrating that the sediment in the Porong Estuary is similar to the sediment from the mud source.

In order to get more accurate results, the sample was also tested using a SEM analysis, whose results are shown in Table 2.

Tabel 2 SEM analysis

Element	Sample A		Sample B		Mud sample	
	Wt%	At%	Wt%	At%	Wt%	At%
CK	8.64	14.07	8.40	14.57	0.00	0.00
OK	47.60	58.18	36.21	47.12	10.21	17.25
NaK	1.60	1.36	10.82	9.80	31.36	36.87
MgK	1.52	1.22	0.91	0.78	0.00	0.00
AlK	11.29	8.18	7.89	6.09	3.31	3.31
SiK	18.17	12.65	11.80	8.74	5.23	5.04
MoL	0.88	0.18	0.00	0.00	0.00	0.00
ClK	0.81	0.45	10.74	6.31	44.19	33.69
KK	0.94	0.47	0.46	0.25	0.33	0.23
CaK	1.50	0.73	4.59	2.39	0.73	0.49
TiK	0.63	0.26	0.34	0.15	0.31	0.18
FeK	6.41	2.25	4.60	1.71	2.01	0.98
SK	0.00	0.00	3.23	2.10	0.00	0.00

The SEM result indicates that samples A and B as well as the mud sample contain clay and silt minerals. Each sample included a wealth of oxygen (O) and silicone (Si) whether measured as a weight percentage (Wt%) or atomic percentage (At%), as well as many elements, such as aluminum (Al), calcium (Ca), sodium (Na), potassium (K), demonstrating the existence of minerals.

4. Conclusion

This research concludes that the velocities at the observation points have the ability to transport mud from the Porong River to its estuary, as evident from the similarity of velocities in terms of both the numerical results and field data. The results of the physical and chemical analyses also demonstrated that the sediment from the Porong Estuary has the same characteristics as the mudflow source.

References

1. Sisinggih, Dian, “Evaluasi Kondisi dan Fungsi Muara Porong dalam Sistem Pengaliran Lumpur ke Laut” October 2013, UB, Malang (*in Indonesian*)
2. Donnell, Barbara P., Letter, Joseph V., McAnally, W. H., and others, “Users Guide for RMA2 Version 4.5,” [20 Jan] 2006, [http://chl.wes.army.mil/software/tabs/docs.htp]