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Prediction of suspended fine-sediment concentration and siltation at Kapar coastal region in Malaysia

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Abstract

Field studies of fine-sediment transport were carried out at Kapar coastal region, on the west coast of Malaysia Peninsula, during 1999 and 2000, in particular, near the Kapar power station construction where serious siltation was found. The work was aimed at the development of predictive models of suspended sediment concentration (SSC) and sedimentation rate in the vicinity of the Kapar power station construction. This paper reports the model development and its prediction of siltation in this particular region. A new approach is proposed to predicting sediment deposition rate (siltation) from a time derivative of the suspended sediment concentration, i.e. the erosion ($dC/dt>0$) or deposition ($dC/dt<0$) rates combined with the average depth from the bed through which the particles settle during deposition. The prediction of siltation rate is compared with the experimental survey result from 1985 to 1992 and a good agreement is achieved.

1 Introduction

Fine cohesive sediments are important mainly in two types of problems, siltation of engineering constructions such as harbours and channels; and environmental mixing and dispersion of contaminants that often contain heavy metals and pesticides as a result of their cohesive nature. Both require an understanding of physical processes relating to their transport, deposition, and resuspension (erosion), followed by parameterisation of those processes in predictive models that can be used for practical engineering and environmental applications.

Field studies of fine-sediment transport were carried out at Kapar coastal region, on the west coast of Malaysia Peninsula, during 1999 and 2000, in particular, near the Kapar power station construction where serious siltation was found. Several experimental observation stations were established to measure near-bed tidal currents, suspended sediment concentration, water temperature, salinity and tidal elevation. The measured resuspension (erosion) and deposition of suspended sediment at tidal frequencies have clearly indicated the correlation between the near-bed current velocity and suspended sediment concentration (see Fig. 1). The above experimental work is aimed at the development of predictive models for studying suspended fine-sediment concentrations and sedimentation rate in the vicinity of the Kapar power station construction.

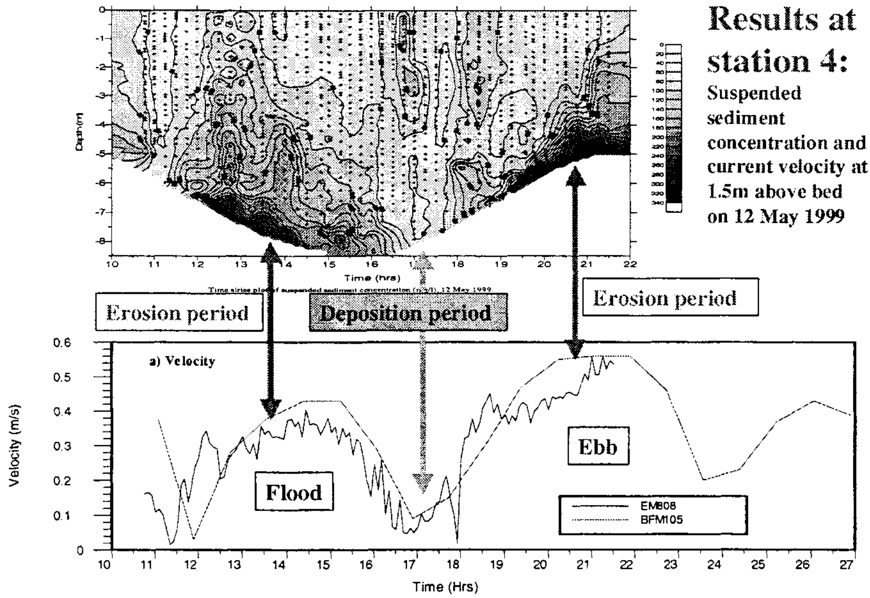

Figure 1 Experimental results of resuspension and deposition of suspended fine-sediment concentration varied with near-bed current velocity

Commonly, the predictive models for resuspension and deposition of suspended fine-sediments are controlled by a number of parameters including the critical resuspension velocity (V_{cr}), critical deposition velocity (V_{cd}), an erodibility constant (E_{exp} determined by experiments), current velocity near the bed (V_{nb}) and particle settling velocity (w_s). Both the erosion and deposition models are functions of near-bed current velocity that can be derived from the current meter data by assuming the dominant tidal frequency to be M_2. In this study, a new approach is applied to determining the erosion or deposition rate from a time derivative of the suspended sediment concentration, i.e. the erosion ($dC/dt>0$) or deposition ($dC/dt<0$) rate. The correlation between the suspended sediment concentration and the near-bed current velocity is obtained from the field data. When the deposition rate is combined with an average depth from the bed, h_s, through which the particles settle during deposition and is integrated with time in a period, the sediment deposition rate (siltation) can be calculated. Predictions of near-bed velocity, suspended sediment concentration, and siltation rate are compared with experimental data.

2 Field Studies

The study area, Kapar, is located on the west coast of Malaysia Peninsula in the State of Selangor, about 15 km north of Port Kelang. Its coastal area faces the straits of Malacca which experience a mild marine environment as result of the sheltering effect of Sumatra Island. The study area is located within the North Kelang Straits, in 15 m water depth and 3 km from shore. The seaward side of the study area is exposed to the busy shipping channel of North Kelang Straits, the main access to Port Kelang at the south. The shipping channel is dredged to 13.5 m depth. Very fast current reaching a maximum of 1.3 m/s was observed in the channel. Bounded on the east is an area of mud flats, which is exposed at low tides. Behind this mud flat is mangrove forest which is part of a typical environment of the muddy Peninsula west coast.

Series of tidal currents, CTD and suspended sediment concentration measurements were carried out between May 1999 – April 2000, covering both spring and neap tidal cycles. Several measurement stations were established along the road bridge (jetty) and at off shore south of the jetty (Figure 2). Station 1 was located at the end of the jetty in 15 m water depth closest to the navigation channel. Station 2 was close to the circulating water intake pump house, while station 3 was located on the inter-tidal mud flat. The road bridge stations allowed easy communication between the stations, therefore the neap and spring tide measurement could be carried out for the same tidal cycle. At the offshore stations, the spring and neap tide measurements were carried out individually and not in the same tidal cycle.

At these stations, current velocities were measured using impeller type current meter model 108 and 105 made by Valeport Ltd, U.K., as well as by Electromagnetic Current meter model 808 also manufactured by Valeport Ltd, U.K. Currents were recorded at 1.5 m above seabed every 10 minutes interval. Similarly, vertical profiles of salinity, temperature and suspended sediment concentration were obtained using an Applied Microsystem Limited STD-12 CTD. This CTD was fitted with an OBS sensor (D & A Instrument OBS-3) which has a better response to high suspended sediment concentration in the study area. The CTD-OBS casts were made at 20 minutes interval for the whole tidal cycles.

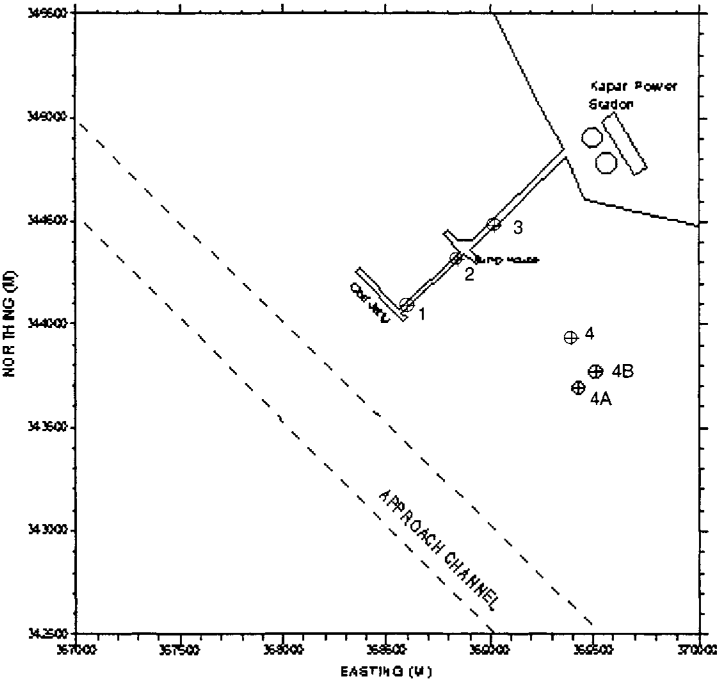

Figure 2. Location of measurement stations

The time-series plots of the observed velocity (at 1.5 m from bed) and suspended sediment concentration (at 0.5 m from bed) at station 2 (Pump house) during spring and neap tidal cycles are shown in Figure 3. During spring tide, the maximum concentration reached at early stage of each flood and ebb period. Concentration then gradually reduced to a minimum until another sharp increase due to the increase of flow velocity that causes new bed layer to be removed and brought into suspension. During neap tide, the concentration is much less with a maximum concentration of only about a quarter of those found during the spring. Less erosion observed during the neap tide may form a consolidation layer of net deposition from spring tides, causing siltation problem in this region, particularly, around the pumphouse. Similarly, high suspension sediment concentration reaching 1400 mg/l near the bottom was observed at Station 4B during spring tide. During neap tide, the suspended sediment concentration is much less than that during spring tide, ranging from 10 – 200 mg/l in the water column. This is because the near-bed current velocity during neap tide is much smaller than that during spring tide.

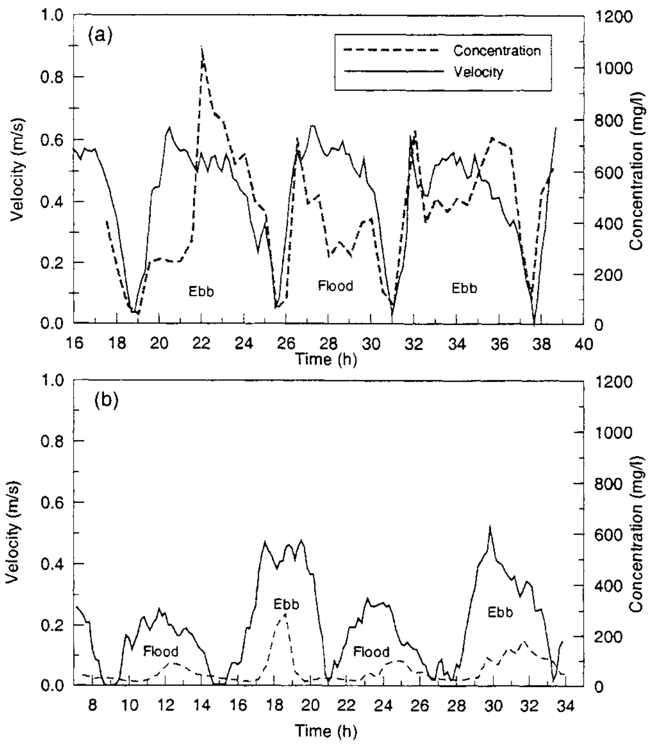

Figure 3. Observed velocity (at 1.5 m from bed) and suspended sediment concentration (at 0.5 m from bed) at station 2 (Pump house) during (a) spring and (b) neap tidal cycles.

3 Model Description

In most of numerical models (e.g. Wolanski, [1], Cromey, et al., [2]), both the erosion and deposition rates are modelled as a function of near-bed current velocity that can be derived from the current meter data by assuming the dominant tidal frequency to be M_2. Thus, the water level (tidal height) can be approximated by

$$S = a + b \sin(ct + d) \tag{1}$$

where S is the tidal height; t is the time; and a, b, c and d are model constants determined from field data. Then the near-bed current velocity is parameterised by

$$V = f_v \frac{dS}{dt} \tag{2}$$

where f_v is a model parameter to be determined from measurements at different locations. For example, due to the flow modification by industrial constructions, the near-bed current velocity in the pump house (see Figure 3) is considerably different from that away from the construction (see Figure 1).

A correlation between suspended sediment concentration, C and near-bed current velocity, V is then obtained by the following relationship

$$C = A\exp(V^m) \tag{3}$$

where A = 140.422 and m = 3.2307 are regression coefficients from experimental data. In this paper, the sediment erosion rate, E_r and deposition rate, D_e are estimated from

$$E_r = \frac{dC}{dt} > 0 \qquad \text{and} \qquad D_e = \frac{dC}{dt} < 0 \tag{4}$$

Thus the average net sedimentation rate during a time period $T = (t_2 - t_1)$ can be calculated by

$$H_s = -\frac{1}{T}\int_{t_1}^{t_2} \frac{dC}{dt}\frac{h}{\rho_s}dt \tag{5}$$

where ρ_s is sediment density, and h is the average depth through which particles settle during deposition. From a previous sediment sampling and analytical study (Hassan, 1992), *h*=0.315m was found in the area. The maximum siltation rate is estimated from the deposition rate only, i.e. without including erosion rate.

4 Results

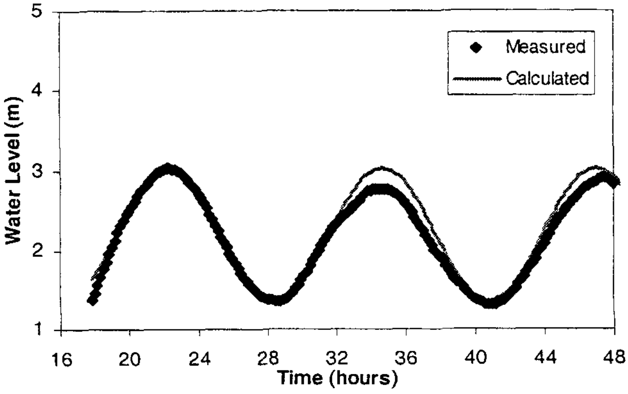

Figure 4. Comparison of calculated with measured water level.

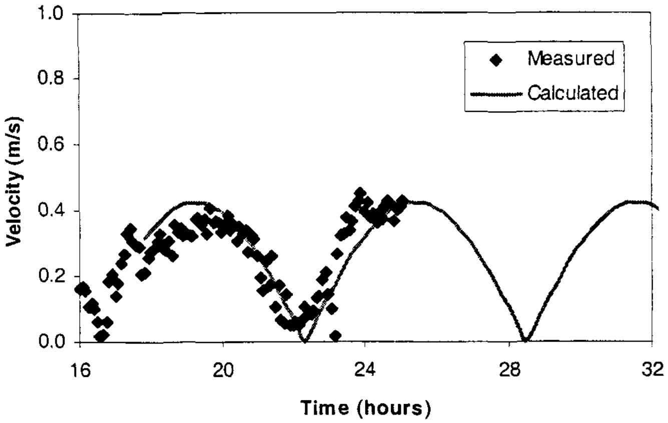

Figure 5. Comparison of calculated with measured near-bed velocity.

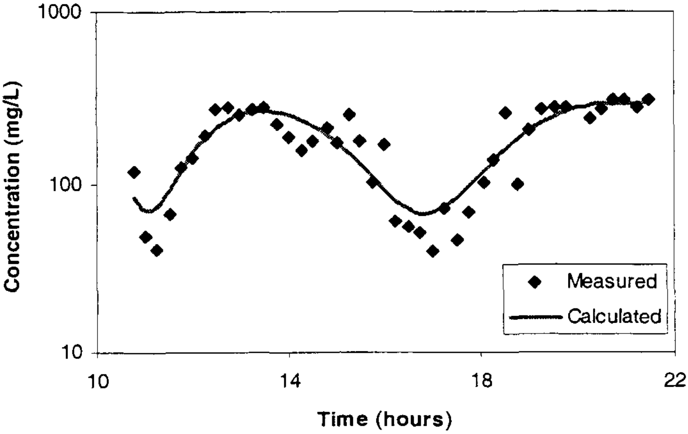

Figure 6. Comparison of predicted with measured sediment concentration.

Verification of the proposed models was carried out by comparing prediction with experimental data. First, we compared water level calculated using the tidal model with one of measured data at Station 4 in May of 1999 as shown in Figure 4. Then the calculated near-bed velocity was compared with experimental data (Figure 5). It can be seen that all predictions are in good agreement with measured values. Figure 6 shows comparison of predicted suspend sediment concentration according to the calculated near-bed velocity with measured data as a function of time. It can be seen that the present numerical predictions are in good agreement with measurements.

Figure 7 shows an analytical relationship between the near-bed velocity derived from the measured water level and the predicted erosion (dC/dt>0) or deposition (dC/dt<0) rates. It is interesting to note that the erosion rate increases up to a maximum value at the half of the peak velocity and then decreases to a minimum value at the maximum velocity. When the current velocity decreases from the maximum, the deposition process occurs until the current velocity starts increasing again after slack water.

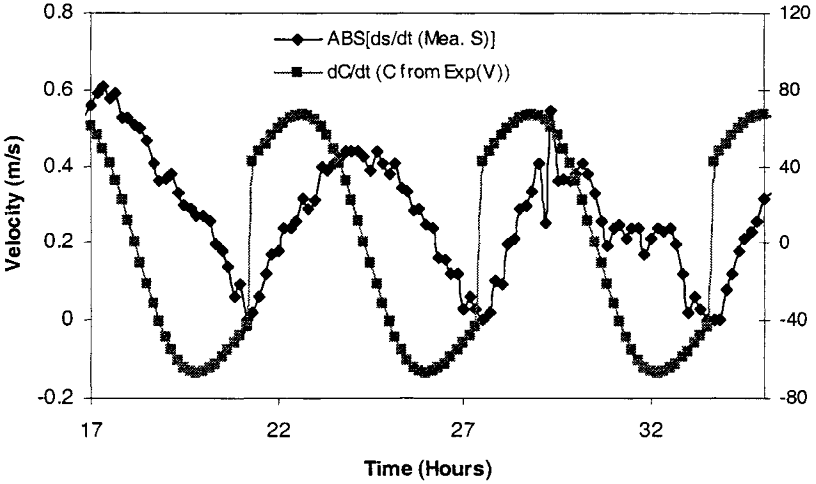

Figure 7. Relationship between velocity and erosion (dC/dt > 0) or deposition rate (dC/dt < 0).

The information needed for the prediction of siltation rate includes maximum and minimum water level and their corresponding times, sediment density, and the average depth through which particles settle during deposition. As example, predictions coving spring and neap tides at different seasons (March and September) were performed. A summary of input data and predicted results is presented in Table 1.

It is found from the above calculations that there exist significant differences of siltation rate between different tidal periods (spring and neap tides), and between different seasons (March and September). For example, in September, the maximum deposition rate in spring tide (1.962 m/year) is considerably higher than that in neap tide (0.079 m/year). In neap tide, the maximum deposition rate in March (0.508 m/year) is much higher than that in September (0.079 m/year). This information might be of importance for engineering dredging and environmental management in this area.

Table 1

Date	Time (Hours)	Water level	Net siltation rate (m/year)	Max. siltation rate (m/year)
17 March 1999 Spring tide	5.90	4.9	0.306	0.981
	12.30	0.60		
9 March 1999 Neap tide	9.00	4.40	0.154	0.508
	15.16	1.40		
18 Sept 1999 Spring tide	18.99	5.50	0.632	1.962
	12.95	0.40		
11 Sept 1999 Neap tide	10.75	3.50	0.025	0.079
	17.18	2.50		

It should be noted that this yearly siltation rate presented in Table 1 was based on the assumption that the whole year period is in the same condition, i.e. the same seasonal and tidal conditions. Therefore, it should be averaged with different tidal periods and seasons to obtain an average siltation rate for a long period such as a month or year. By averaging the above calculations, it is found that the net yearly siltation rate is 0.279 m/year and the maximum rate 0.882 m/year. When comparing these predicted results with the measured data which were about 0.25 m/year of net deposition rate and 0.86 m/year of maximum deposition rate obtained from the period of 1985 to 1992 (Hassan [3]), we find they are in very good agreement.

5 Conclusion

Siltation of fine cohesive sediments has caused serious engineering problem by requiring significant dredging costs and environmental problem of contaminants that often contain heavy metals and pesticides as a result of their cohesive nature. Predictive models that can be used for practical engineering and environmental applications are needed. Field studies near the Kapar power station construction where serious siltation was found, were carried during 1999 and 2000. The experimental data were used for the development of predictive models of suspended sediment concentration and sedimentation rate in the vicinity of the Kapar power station construction. A new approach was applied to predicting sediment deposition rate (siltation) based on a time derivative of the suspended sediment concentration, i.e. the erosion ($dC/dt>0$) or deposition ($dC/dt<0$) rates. One of the main control parameter in predicting siltation rate using this approach is the average depth from the bed through which the particles settle during deposition. This parameter was determined from experimental sampling and analytical analysis. The prediction of siltation rate was compared with the experimental survey result from 1985 to 1992 and a good agreement is achieved.

Acknowledgment

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