Conference Paper, Published Version

Bidorn, Butsawan; Thamsiriroj, Thanasit; Chanyotha, Sere

Characteristics of Coastal and Estuarine Sediment in the Upper Gulf of Thailand

CHARACTERISTICS OF COASTAL AND ESTUARINE SEDIMENT IN THE UPPER GULF OF THAILAND

Butsawan Bidorn[1], Thanasit Thamsiriroj[2], Seree Chanyotha[3]

ABSTRACT

Oceanographic parameters consisting of wind and wave characteristics, coastal water level and current and sediment characteristics play an important role in coastal erosion processes. However, they are very complex and area specific. Therefore, an empirical approach to develop the relationships of these parameters to erosion obtained from oceanographic surveys is normally used. This study aims to develop relationships of oceanographic characteristics to sediment transport rates in the Chao Phraya estuary during the North East (dry) monsoon. Field surveys were carried out in the coastal area near the Chao Phraya River mouth, Upper Gulf of Thailand. Two observation stations were set up in the surf zone, 1.0 km and 2.5 km across the shore. Measurements included sediment transport rate, wind speed and direction, wave height, wave period, wave direction, water current and water level. All sampling was performed on an hourly basis. Results suggested that the magnitude of parameters including wave height, water current, wind speed and sediment concentration were within the low range during the North East Monsoon. From a regression analysis of parameters concerned, it was shown that current speeds yields the highest correlation to the sediment transport rate, followed by significant wave height and water level gradient, respectively. An analysis by linear multiple regression showed that up to 72-82% of the variance in suspended sediment transport rates in the study area can be predicted from current velocities, significant wave heights and water level gradients.

1. INTRODUCTION

Coastal erosion and sedimentation processes have long been of interest to coastal engineers. Applications include coastal protection, land reclamation, channel dredging and water quality management. In Thailand, coastal land loss due to erosion has been severe for the past decades, and Vongvisetsomjai (1990) found that the land loss rate in some areas was as high as 25 m annually. The extreme rates here may be a consequence of land subsidence as well as well as sea level rise. Shoreline changes processes are influenced by hydrographic and oceanographic characteristics, mainly comprising wind and wave characteristics, near shore currents, tide flows, and sediment

[1] Ph.D. student, Department of Earth, Ocean and Atmospheric Sciences, Florida State University, Tallahassee, Florida, 32306, USA (bb11x@my.fsu.edu)
[2] Researcher, Department of Water Resources Engineering, Chulalongkorn University, Bangkok, 10330,THAILAND (thanasit.tham@gmail.com)
[3] Assistance Professor, Department of Water Resources Engineering, Chulalongkorn University, Bangkok, 10330,THAILAND (seree.c@chula.ac.th)

transport. However, interactions among those parameters are highly complicated, particularly in an estuary area.

In coastal protection works, sediment transport rate is one of the most important variables in shoreline reformation assessment. Unfortunately, historical data and field study involving sediment transport rates in the Chao Phraya estuary are presently unavailable or inadequate. Consequently, most shoreline change studies in coastal protection works in this region used sediment transport data obtained from numerical models using wind and wave data (Wichaimekphat *et al.*, 2006 and Ekphisutsuntorn *et al.*, 2010). In addition, the Chao Phraya estuary is a muddy and tidal flat coast, so sediment processes in this area are expected to be complicated. According to the studies by Bidorn and Vatthananukij (2010) and Bidorn *et al.* (2011) wave characteristics in the Upper Gulf of Thailand cannot be characterized by wind data in the region. Therefore, sediment transport calculated from wind and wave data using generalized sediment transport formulae might not be suitable for estimating the sediment movement in this area.

The study area (Fig. 1), in general, is a muddy coast with a mild bottom slope (about 1:1,500 in average). During the North East monsoon period (November-February), wave heights are mostly in moderate condition (0.0-0.5 m), and tidal ranges are between 1.5-2.5 meter with a weak current speed.

This study aims at developing the relationships among sediment transport rates and the other oceanographic parameters from field data observed and collected in the coastal area nearby the Chao Phraya estuary during the North East monsoon period. The results from this study can be used for estimating the sediment transport rate in this area for coastal protection and other studies in the Chao Phraya estuary area.

2. FIELD MEASUREMENTS

We carried out field surveys for collecting wind speed and associated direction, wave height, wave period, wave direction, water current, water level and suspended sediment concentrations within the coastal area near the Chao Phraya River mouth from 3:00pm on November 5 to 3:00pm on November 6, 2011. Two observation stations were established in the surf zone at approximated distances from the shoreline of 1.0 km (Sta.1) and 2.5 km (Sta.2) respectively (Fig. 2).

For wind observations, YOUNG wind tracker model 0620 and KENEX wind monitor-AQ model 05305 were installed at Station-2 platform about 6 meters from seabed to measure 15-minute wind speeds and associated directions.

Wave characteristics including wave height and wave period at Sta.1 were continuously measured using an Ultrasonic Wave Height Meter and were recorded by HP Data Logger with 50 Hz frequency. At Sta.2, a NORTEK Acoustic Wave and Current Profiler (AWAC) was deployed on the seabed 3 meters depth in average. Wave characteristics including significant wave height, mean waver period and mean wave direction were estimated using AWAC-AST software for 30 minute intervals. The Ultrasonic Wave Height Meter and AWAC were used for measuring water level at Sta.1 and Sta.2, respectively.

Hourly current speed and direction at Sta.1 were measured by OGAWA Electromagnetic Current Meter model TK-145. Current data was observed from the surface to the bottom at 0.5 meter intervals. Meanwhile, 10-minute current profiles at Sta.2 were measured and recorded by AWAC.

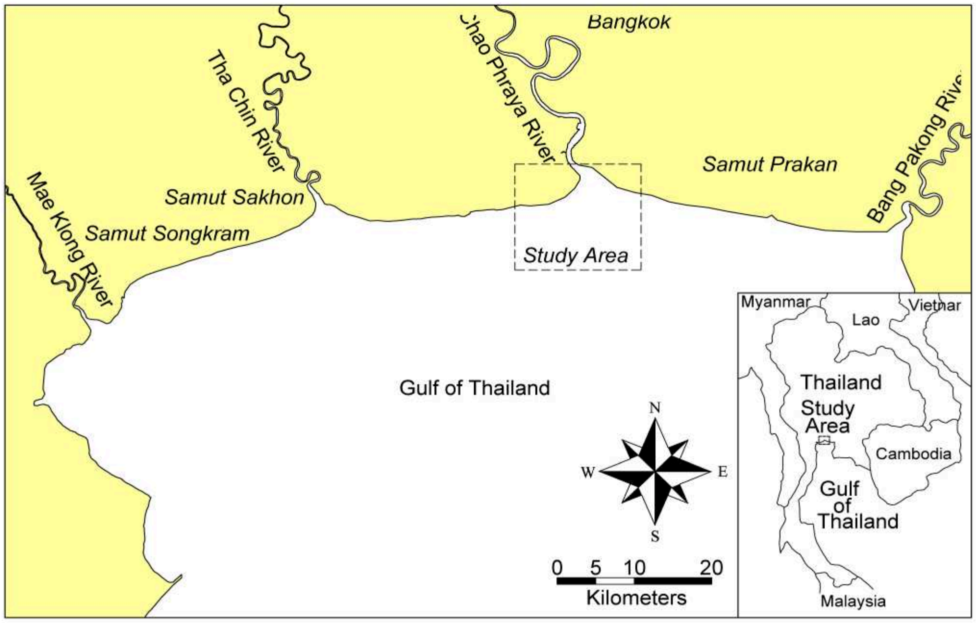


Figure 1 Study area.

The measurement of suspended sediment loads at Sta.1 and Sta.2 were performed using 4-direction suspended load samplers designed and fabricated to enable a simultaneous collection of onshore-offshore and longshore sediment samples at three different water depths. The sampling was done on an hourly basis. Samples were filtered onto pre-weighed filters at the laboratory soon after the samples were collected. All of the field observation equipment used for this study is shown in Figure 3.

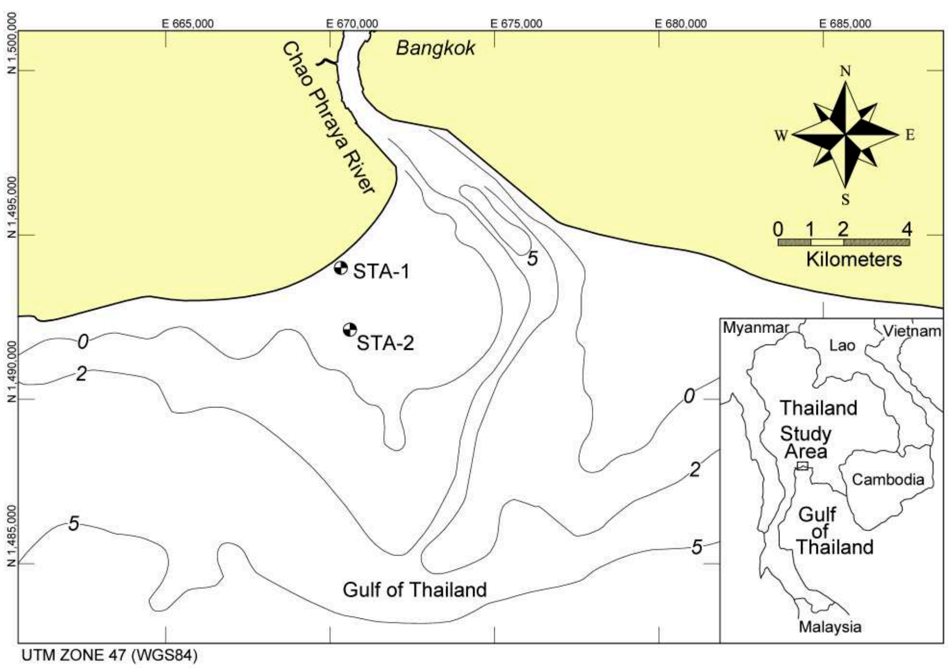
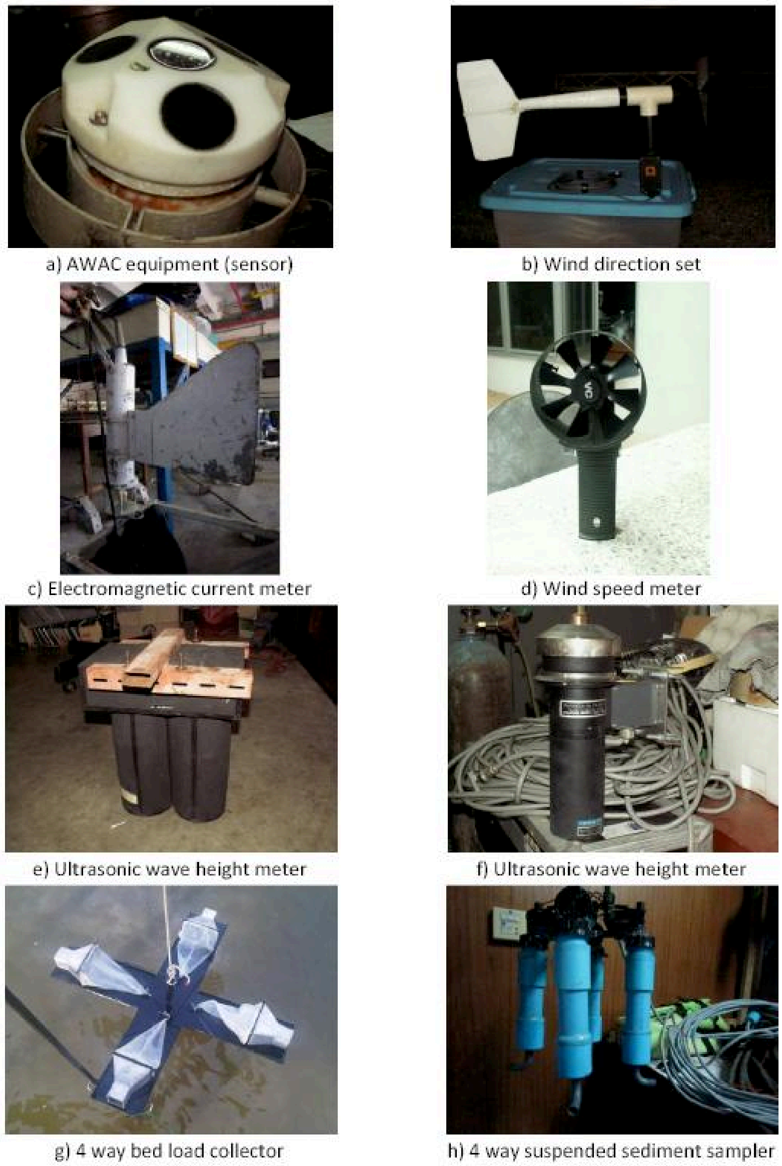


Figure 2 Observation stations.



a) AWAC equipment (sensor)
b) Wind direction set
c) Electromagnetic current meter
d) Wind speed meter
e) Ultrasonic wave height meter
f) Ultrasonic wave height meter
g) 4 way bed load collector
h) 4 way suspended sediment sampler

Figure 3 Field observation equipment.

3. RESULTS

A summary of the field observation data are shown in Table 1. Some of the details of the observed oceanographic characteristics are discussed below.

3.1 Tides

The field observations were carried out on November 5-6, 2012 when the tidal type was neap (Fig. 4), and the tides at Sta.1 and Sta.2 were mixed with a more-or-less symmetrical rise and fall (Fig. 5a) with the rising and falling time of approximately 6 hours. The tidal ranges at Sta.1 and Sta.2 were 1.51 m and 1.34 m, respectively. The maximum water depth at Sta. 1 was 3.08 m, while the measured water depth at Sta.2 was 3.07m. However, the water level pattern at Sta.1 and Sta.2 was very similar.

Table 1 Field observation data summary.

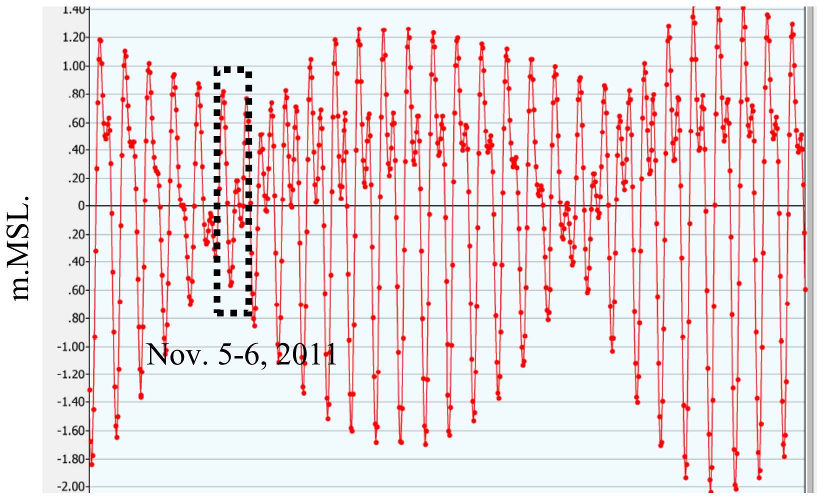
Observation parameters	**Sta.1**		**Sta.2**	
	range	**average**	**range**	**average**
1. Water depth (m.)	1.58-3.09		1.73-3.07	
2. Tidal range (m.)	1.51		1.34	
3. Wind speed , U_{10}(m/s)	0.04-4.67	2.45	n/a	n/a
4. Wind direction	N,S	N	n/a	n/a
5. Significant wave height (m.)	0.04-0.12	0.06	0.04-0.13	0.09
6. Mean wave period (sec.)	1.10-3.78	1.75	1.02-3.78	2.76
7. Mean wave direction (deg.)	n/a	n/a	N-ENE	ENE
8.Current speed during flood tide				
- at 0.9 m. above seabed (m/s)	0.11-0.24	0.15	0.07-0.23	0.15
- at 1.4 m. above seabed (m/s)	0.19-0.2	0.20	0.04-0.31	0.15
- at 1.9 m. above seabed (m/s)	n/a	n/a	0.11-0.28	0.18
- at 2.4 m. above seabed (m/s)	n/a	n/a	0.12-0.38	0.26
9.Current speed during ebb tide				
- at 0.9 m. above seabed (m/s)	0.01-0.15	0.06	0.02-0.14	0.06
- at 1.4 m. above seabed (m/s)	n/a	n/a	0.07-0.31	0.21
- at 1.9 m. above seabed (m/s)	n/a	n/a	0.33-0.50	0.40
- at 2.4 m. above seabed (m/s)	n/a	n/a	n/a	n/a
10.Current direction during flood tide				
- at 0.9 m. above seabed (m/s)	N-E	NE	N-ENE	NE
- at 1.4 m. above seabed (m/s)	N	N	NNW-E	NNE
- at 1.9 m. above seabed (m/s)	n/a	n/a	WSW-NNW	WNW
- at 2.4 m. above seabed (m/s)	n/a	n/a	W-SSW	WSW
11.Current direction during ebb tide				
- at 0.9 m. above seabed (m/s)	ESE-SSW	S	N-S	SE
- at 1.4 m. above seabed (m/s)	n/a	n/a	SW-SE	SSW
- at 1.9 m. above seabed (m/s)	n/a	n/a	SW-S	SW
- at 2.4 m. above seabed (m/s)	n/a	n/a	n/a	n/a
12. Sediment concentration				
- at 0.5 m. above seabed (mg/l)	48.8-60.0	60.6	45.3-172.0	72.6
- at 1.5 m. above seabed (mg/l)	31.3-60.3	48.5	24.0-70.0	46.1
- at 2.5 m. above seabed (mg/l)	24.8-31.5	28.0	24.8-28.5	26.8

3.2 Winds and Waves

Even though the observations were undertaken in November, when the weather in this region is typically dominated by the NE monsoon, the predominant winds in the study area were weak and came from the South (Fig. 5b). Only during a short period, 2:00pm-4:00pm on November 6, 2011, did the wind direction reverse to the North. The wind speeds at 10 meter above mean sea level (U_{10}) ranged from 0.04-4.67 m/s, with an average wind speed of 2.45 m/s.

From recorded wave data, the wave characteristics at both stations were ripples and wavelets with significant wave heights (H_s) of 0.02-0.13 m. The average significant wave height for Sta.1 and Sta.2 were 0.06 m and 0.09 m, respectively. For both stations, the mean wave periods were between 1.02 to 3.78 seconds. However, because of the limitations of the ultrasonic wave height meter, the wave directions at Sta.1 were not measured. Therefore, wave directions from Sta.2 were used to represent wave directions in the study area. Figure 5(c) depicts wave vectors for Sta.2, and it was found that the predominant wave direction came from the South with average wave direction of ENE.

From wave characteristics comparison between Sta.1 and Sta.2 at the same sampling time, it was found that the wave height at Sta.1 was smaller than Sta.2. Meanwhile, the wave periods at Sta.1 roughly corresponded to those at Sta.2. Figures 5(b) and 5(c) show the significant discrepancy between the direction of wind and wave in the study area.



Source: http://tiwrm.haii.or.th/DATA/REPORT/php/sealevel

Figure 4 Tidal characteristic during observation period.

3.3 Currents

For current characteristics in the study area, the measured current speeds (C) and directions (C_{dir}) were influenced by tide. During flood tide, current speeds near the bottom (0.9 m above seabed, $C_{0.9m}$) at Sta.1 and Sta.2 were between 0.07 to 0.24 m/s with the similar average velocity of 0.15 m/s. However, current speeds at 1.4 m above the sea bottom ($C_{1.4m}$) at Sta.1 and Sta.2 were slightly higher than $C_{0.9m}$: at Sta. 1; the magnitudes of current speeds were 0.19-0.20 m/s with average current velocities of 0.20 m/s. At Sta.2 the current speeds were 0.04-0.31 m/s, and the average speed was 0.15 m/s. The currents for 1.4 m above seabed at Sta.1 were directed to N, while the current directions at Sta.2 varied between NNW to E with the average current direction of NNE. Unfortunately, the current data at level 1.9 m ($C_{1.9m}$) and 2.4 m ($C_{2.4m}$) at Sta. 1 could not be measured. For Sta.2, the current speeds at 1.9 m were 0.11-0.28 m/s, and the average speed was 0.18 m/s. The current directions at this level were WSW-NNW, and the mean direction was WNW. At 2.4 m above sea bottom of Sta.2, where only a few current data was measured during high tide, the current speeds were between 0.12-0.38 m/s, and the directions varied from W to SSW.

During ebb tide, current speeds at 0.9 m above seabed ($C_{0.9m}$) were lower than currents at the same level during flood tide. The current velocities at both stations at this level were 0.01-0.15 m/s, and the current direction varied between N and S with an average direction of SE. At shallower levels, current speeds during ebb tide were stronger than current speed during flood tide at the identical level. Unfortunately, the water levels at Sta.1 were lower than the current meter position during ebb tide, so current characteristics at Sta.1 could not be measured at that time. At Sta.2, the mean velocities at 1.4 m and 1.9 m depths above bottom were 0.21 m/s and 0.40 m/s, respectively. From our observational data, it was found that current directions in shallower levels typically headed to SW-SE.

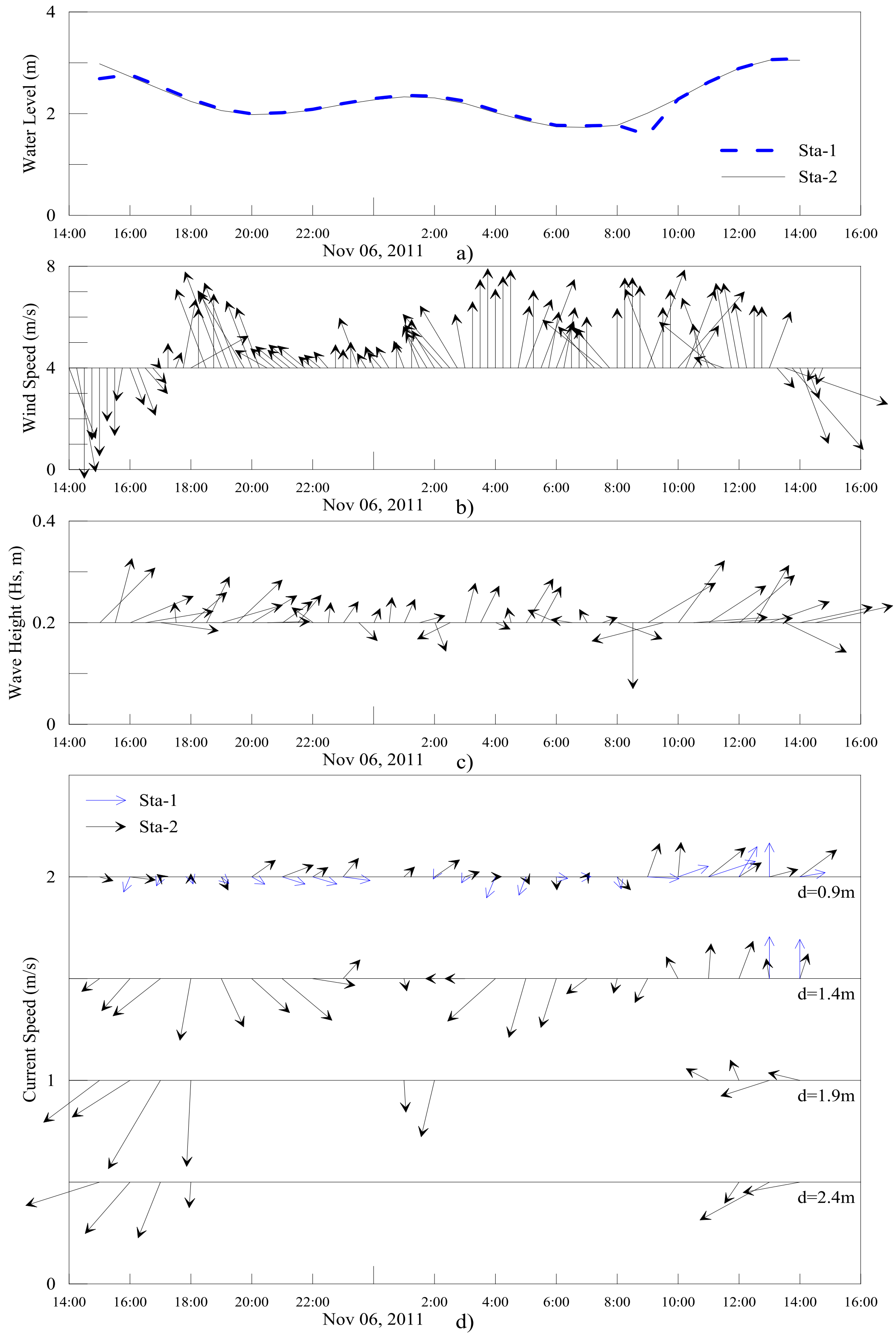


Figure 5 Oceanographic data records at Sta.1 and Sta.2, November 5-6, 2012.

3.4 Suspended sediment concentrations

From sediment concentration sampling data, it was found that suspended sediment concentration at Sta.1 and Sta.2 were not significantly different. At deeper levels (0.5 m above seabed) at Sta.1 and Sta.2, the suspended sediment concentrations were higher than in the shallower levels. At Sta. 1, the average suspended sediment concentration at 0.5 m, 1.5 m and 2.5m were 60.6 mg/l, 48.5 mg/l and 28.0 mg/l, respectively. The concentration of suspended sediment at Sta.2 coincided with the suspended sediment at Sta.1 at the same level. At 0.5 m, 1.5 m and 2.5 m from seabed at Sta.2, the average suspended sediment concentrations were 72.6 mg/l, 46.1 mg/l and 26.8 mg/l, respectively.

4. SEDIMENTATION ANALYSIS

4.1 Sediment transport rate and wind

The relationship between sediment transport rate (SS) at Sta.1 and Sta.2 and wind speed at ten meters above sea level (U_{10}) shows that the wind speeds were poorly correlated with suspended sediment movement rates for Sta.1 (Fig. 6a). Similarly, we see that wind speeds in the study area were insignificantly associated with suspended sediment movement rates at Sta.2. Thus, it appears that wind speed plays an unimportant role in suspended sediment transport in the study area during weak wind conditions.

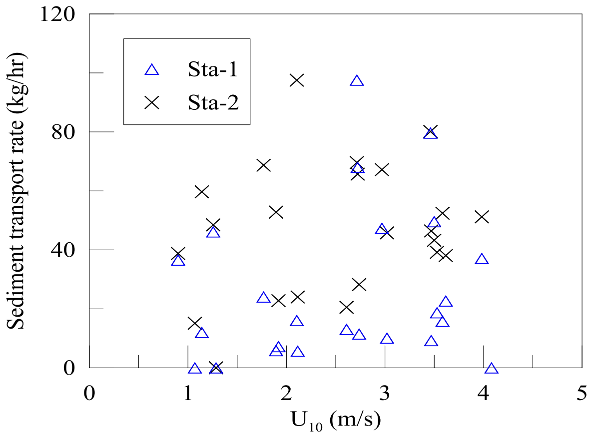
4.2 Sediment transport rate and waves

A regression of sediment transport rates against significant wave heights at Sta.1 shows that sediment movement rates increased rather rapidly when wave heights were higher (Fig. 6b). An exponential equation gave the best fit for the correlation between the two parameters at Sta.1 (R^2=0.24). At Sta.2, the data shows a fair correlation between wave heights and sediment transport rates with an exponential best fit of R^2=0.35.

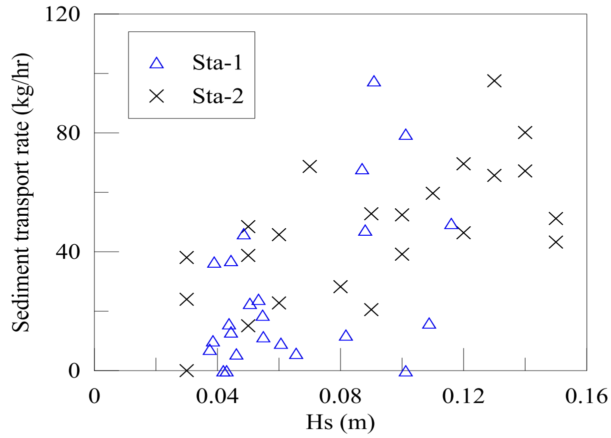
Theoretically, wave direction is one of the important factors that influences sediment transport in the surf zone. However, the plots of sediment transport rates at Sta.2 versus wave directions, θ (Fig. 6c) show an insignificant relationship between suspended sediment transport rates and wave directions. So wave directions during moderate wave conditions might not affect the rate of sediment movement in the study area.

4.3 Sediment transport rate and currents

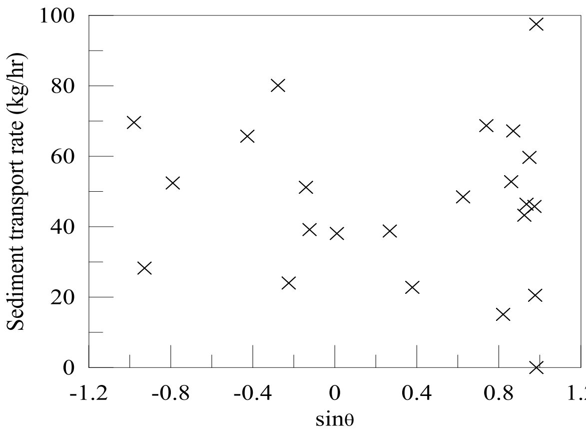
The plots of the suspended sediment transport rate versus currents at each level of sampling are shown in Figures 7 (a) to (d). At 0.9 m above seabed, the relationship between sediment transport rates and current speeds at Sta.1 and Sta.2 can be approximated by exponential equations with R^2 of 0.81 and 0.16, respectively. That means sediment transport rate at Sta.1 primarily depended on the current speeds near the seabed. On the other hand, current speeds near the sea bottom plays a minor role on sediment transport at Sta.2. At level of 1.4 m, 1.9 m and 2.4 m above sea bed, the relationship between suspended sediment rates of movement at Sta.2 could be best fitted with a power equation with R^2 of 0.36, 0.0001 and 0.31, respectively. This indicates that the sediment transport rates at Sta.2 are influenced by higher level current speeds. However, the plot of depth average current speeds at Sta.2 versus sediment transport rate (Fig. 6d) shows a good correlation between both parameters, and their relationship can be fitted using a power equation with R^2 of 0.62.



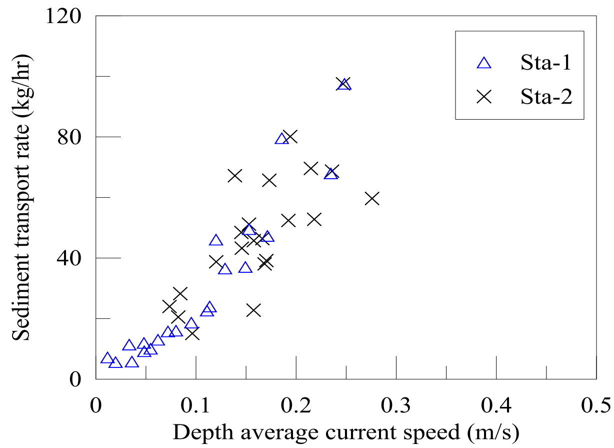
a)



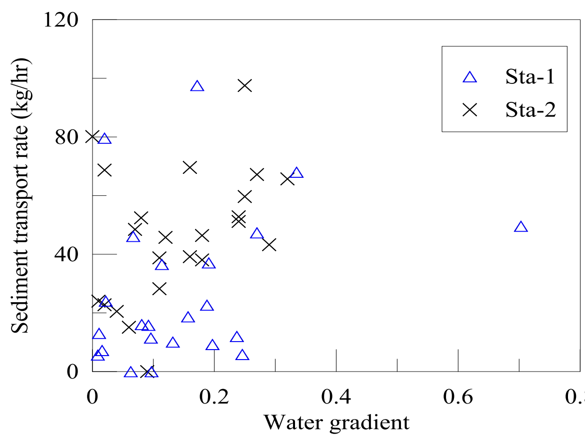
b)



c)



d)



(e)

Figure 6 Relationship between sediment transport rates and wind, wave and water level characteristics.

4.4 Sediment transport rate and water level gradients

It was found that the relationship between suspended sediment transport rates and water level gradients (Fig. 6e) that a power equation can best represent the correlation between both parameters at Sta.2 with a fair correlation (R^2=0.32). However, the plot shows an insignificant association between sediment transport rates and water level gradients at Sta.1 (R^2=0.06).

4.5 Multiple regression analysis

Regarding the data analysis as mentioned above, it was found that the depth average current speed (C_{ave}) for Sta.1 yielded the highest correlation to the suspended transport rates (SS) with R^2 of 0.81, and followed by the significant wave height (H_s) with R^2= 0.24. Other parameters such as water level gradient (WL_{grad}), wind speed (U_{10}), wind and wave direction yielded low correlations to the sediment transport rate at Sta.1. For Sta.2, the depth-average current speed also gave the highest correlation to sediment transport rate (R^2=0.62), and the second highest correlation to sediment transport rates at this station was significant wave height with R^2 of 0.56. Water level gradient was the third high correlation to sediment transport at Sta.2 with R^2 of 0.32. Similarly, wind speed, wind and wave direction yielded low correlations to the sediment transport rate at Sta.2.

Based on these results, the suspended sediment transport rates at Sta.1 could be estimated from depth average current velocities alone. However, the significant wave heights and water level gradient will still have some impacts. By engaging significant wave heights and water level gradients into multiple regressions analysis, the goodness of fit increase about 1%. Up to 82% of variance in the measured suspended sediment movement rates at Sta. 1 can be estimated knowing the depth-average current speed, the significant wave height and water level gradient at the site. The final regression equation for Sta.1 is given as:

$$\ln SS = 1.046 C_{ave} + 2.647 Hs - 0.143 \mathrm{WL}_{\mathrm{grad}} + 5.151 \tag{1}$$

where SS is suspended sediment transportation rate (kg/h), C_{ave} is depth-average current velocity (m/s), H_s is significant wave height (m) and WL_{grad} is water level gradient (m/h). The goodness of fit is given by R^2 = 0.82.

For Sta.2, the average current speeds, significant wave heights and water level gradients all play important roles for sediment processes. From multiple regressions analysis, up to 72% of the variance in suspended sediment transport rates at Sta.2 can be predicted from those parameters above. The final regression equation for Sta.2 is as follows:

$$\ln SS = 0.857 C_{ave} + 3.899 Hs - 0.110 \mathrm{WL}_{\mathrm{grad}} + 5.011 \tag{2}$$

where the abbreviations are as shown above.

As mentioned above, the sediment transport rates in the surf zone of the Chao Phraya estuary during the NE monsoon were primarily characterized by current velocities, which were induced by tide and wave heights. Wind data and wave directions play unimportant roles on sediment transport rate, so using wave characteristics which are estimated from wind data may result in incorrect estimates for sediment transport rates in this region.

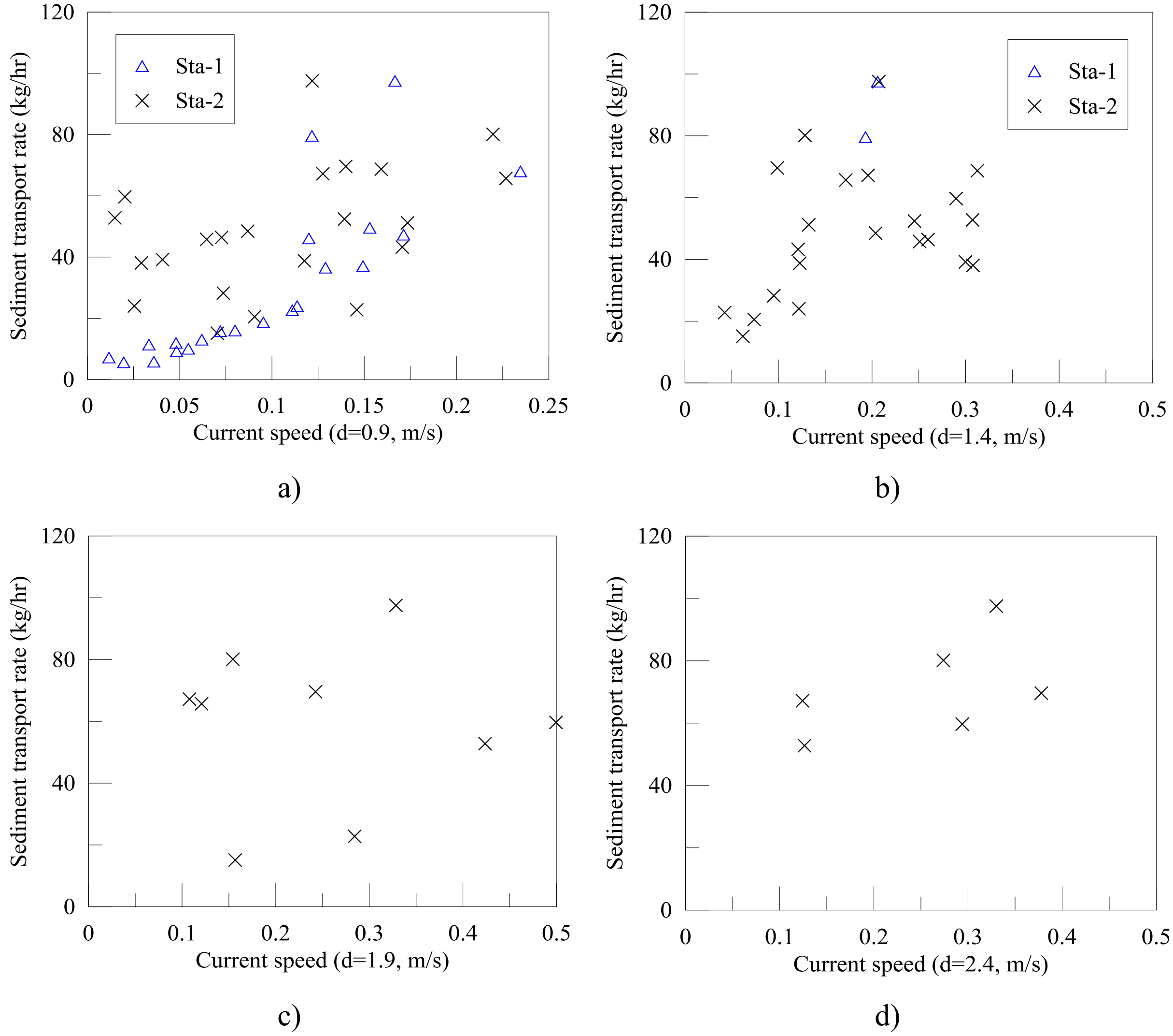


Figure 7 Relationship between sediment transport rates and current velocities at the association level.

5. CONCLUSIONS

This study focused on characterization of suspended sediment transport rates in Chao Phraya estuary during a one-day period in the dry season. Since historical oceanographic records and sediment data in study area are unavailable, we carried out field observation for measuring wind characteristics, water levels, current patterns, and wave characteristics in the surf zone of Chao Phraya Estuary during neap tide on November 5-6, 2011. Based on 24 hours continuous measurement at two observation platforms (1.5 km and 2.5 km away from the shoreline), it was found that the tidal currents were weak with magnitudes of 0.04-0.38 m/s for flood tide, and 0.01-0.50 m/s during ebb tide. In addition, currents were approximately directed North during flood tide and were directed South during ebb tide. Wave characteristics in the study area were calm with significant wave heights less than 0.13 m, and wave direction mostly headed North. It was also found that predominant wave directions did not correspond with wind directions. Even though the observation was made during the North East monsoon, the wind was weak and came from the South. For suspended sediment, the concentrations of sediment at both stations were low (less than 70 mg/l), and the concentrations near the bottom were higher than the sediment concentrations near water surface.

Regression analyses were carried out to determine the factors that control the suspended sediment transport rate in the coastal zone of Chao Phraya estuary. Wind speeds, wave heights, wave directions, current speeds, water level gradients were employed as independent parameters. The regressions show that the sediment transport rates in the study area were the highest correlated with depth-average current velocities. Significant wave height and water level gradients are the next most important parameters, respectively. Wind characteristics and wave directions play insignificant roles in suspended sediment movement in this area.

By using multiple regression, suspended sediment transport rates in the Chao Phraya Estuary can be estimated based on current speed, significant wave height and water level gradient with a good correlation to measured data (R^2 is 0.72-0.82). However, the results from this study can be applied only for periods of calm or moderate sea conditions that prevailed during these measurements.

ACKNOWLEDGEMENTS

This study was partially supported by the Water Resources Department, Chulalongkorn University and the Science and Technology Research Partnership for Sustainable Development, JST-JICA, Japan.

REFERENCES

Bidorn B., and Vathananukij V. (2010), Discrepancy of Overland Wind and Overwater Wind, Journal of Research in Engineering Technology, Publication of Kasetsart University, Vol.7, No.3, pp.65-70.

Bidorn B., Chanyotha S., Sirapojanakul S. and Mama V. (2011) "Wind wave prediction in Northwest Upper Gulf of Thailand, The first EIT International Conference on Water Resources Engineering, August 17th-18th, Pethcaburi,Thailand. pp. 78-83.

Vongvisessomjai, S. (1990) "Coastal erosion", Coastal Erosion in the Gulf of Thailand, pp. 144–164.

Wichaimekphat, W., Supharatid, S. and Tingsanchali, T. (2008) "A Study of Bang Khun Thien Coastal Erosion and Protection", Vietnam -Japan Estuary Workshop 2006, August 22nd -24th, Hanoi, Vietnam, pp.134-139.

Ekphisutsuntorn, P., Wongwises P., Chinarasri C., Hamphries U. and Vongvisessomjai S. (2010) "Numerical Modeling of Erosion for Muddy Coast at Bangkhuntien Shoreline, Thailand", International Journal of Civil and Environmental Engineering, Vol. 2, No.4, pp. 230-240.