EROSION MECHANISM OF NGA BAY RIVERBANKS, HO CHI MINH CITY, VIETNAM

Bui Trong Vinh[1] and Nguyen Hai Truong[1]

[1] Department of Geo-Environment, Faculty of Geology and Petroleum Engineering, Ho Chi Minh City University of Technology, Ho Chi Minh City, Vietnam, Tel: +84 913634448, e-mail: btvinh@hcmut.edu.vn

Received Date: December 24, 2012

Abstract

Nga Bay river is a main river navigation channel from East Sea to Sai Gon port. Although Nga Bay riverbanks are covered by dense mangrove trees, those have been eroded severely. Field investigation, GIS and numerical model (MIKE 21) were carried out to determine and analyze the erosion mechanism in this river mouth. The actual erosion rate was determined by erosion investigation stakes was about 10 m/y. These results corresponded with GIS analyses. The main destroyed factors were currents, waves and ship-generated waves. However, mangrove trees were the main protected factors destroyed by local population for economic activities. The numeral results showed that current speed around river mouth area is stronger than critical resistance of riverbank materials and caused severe erosion.

Keywords: Erosion mechanism, Erosion rates, GIS, Nga bay river, Numerical model, Remote sensing, Ship-generated waves, Wind waves

Introduction

The cohesive bank erosion has been studied many years since. Most researchers focused on bank erosion caused by river flows and weathering processes (Thorne C.R., 1982; ASCE., 1998; Simon et al., 2000). Some studies have been carried out to determine the influence of silt-clay content on subaerial erosion process (Couper P., 2003). However, no study has been established to investigate the effects of waves, wave-induced currents, tidal currents, and weathering processes to cohesive bank erosion around river mouth and newly developed coastal zones.

Can Gio mangrove forest is Viet Nam national reservation. Nga Bay river valley plays a very important role because of the forest core zone. This river is also the main navigational channel from East Sea to Sai Gon port. Ship-generated waves and tidal currents caused erosion severely. Along the riverbanks, local resident villages, shrimp ponds, and salt ponds have been reclaimed by destroying the mangrove forest. The erosion mechanisms of the study have not been well understood.

Research Methods

To understand the mechanisms of erosion, three research methods have been carried out. The research area was surveyed to collect soil and water samples, installed investigation stakes and determined factors affected riverbanks. Changes of the riverbanks from 1995 to 2009 were analyzed through remote sensing by GIS methods. Numerical model (MIKE 21) was applied to calculate current velocity and wind-induced wave height affected riverbanks.

Field Investigation

The authors investigated study area and took soil and water samples to determine riverbank materials and salinity of water. Thirty marking erosion pins were installed perpendicularly to the riverbanks (3 pins at each site, 3 m in length to each pin) at ten severe eroded sites along the riverbanks from October 2011 to November 2011 to estimate erosion rates. During the investigation, the impact factors on riverbanks like waves, tides, currents, mangrove forests, salt-ponds and shrimp ponds were also determined.

Figure 1. Study area and sampling sites [Google Earth 2012.5.12]

Remote Sensing and GIS Method

In this study, five images were used as shown in table 1. Mapinfo software was also used to make maps and calculate erosion rates, the change of mangrove forest areas and erosion rate of riverbank.

Table 1. Satellite Images used in the Study Area

	Date	Satellite	Sensor	Resolution m/pixel
1	02/02/1989			
2	02/11/1995			
3	01/02/2001	Landsat 4 – 5	TM	30 x 30
4	12/20/2004			
5	12/18/2009			

Numerical Model

Numerical model (Mike 21) was applied to calculate current speed and maximum wind-induced wave height affected each riverbank, from there we could forecast tendency erosion of each specific riverbank. The governing equations are based on mass preservation and momentum preservation in water level change and inshore current processes [4]

$$\frac{\partial \zeta}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=\frac{\partial d}{\partial t}$$

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{qp}{h}\right)+gh\frac{\partial \zeta}{\partial x}+\frac{gp\sqrt{p^2+q^2}}{C^2.h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial x}\left(h\tau_{xx}\right)-\frac{\partial}{\partial y}\left(h\tau_{xy}\right)\right]-\Omega_q-fVV_x+\frac{h}{\rho_w}\frac{\partial}{\partial x}\rho_a=0$$

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{qp}{h}\right)+gh\frac{\partial \zeta}{\partial y}+\frac{gq\sqrt{p^2+q^2}}{C^2.h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial y}\left(h\tau_{yy}\right)-\frac{\partial}{\partial x}\left(h\tau_{xy}\right)\right]-\Omega_q-fVV_y+\frac{h}{\rho_w}\frac{\partial}{\partial y}\rho_a=0$$

Where:

- h(x, y, t): Water depth (m); d(x, y, t): Change of water depth according to time (m).
- p, q(x, y, t): Density of currents according to x and y direction (m^3).
- C(x, y): Chezy resistance number ($m^{1/2}/s$); g: gravitational acceleration (m/s^2).
- ζ(x, y, t): water surface elevation above datum (m); f(V): frictional index of wind.
- V, V_x, V_y(x, y, t): Wind speed according to x, y direction (m/s); Ω(x, y): Coriollis index (s^{-1});
- p_a(x, y, t): Atmospheric pressure ($kg/m/s^2$); ρ_w: Density of water (kg/m^3);
- τ_{xx}, τ_{xy}, τ_{yy}: radiation shear stress.

Results

The results of field investigation, satellite images analysis, and numerical calculation showed that the erosion mechanisms of Nga Bay riverbanks have been determined as shown in Table 2.

Table 2. The Erosion Mechanisms of Nga Bay Riverbanks

	Source	Erosion mechanisms
1	Nature	Riverbank materials Wave action Tidal regimes and tidal currents Unstable mangrove forests and aquatic animals
2	Human	Salt-ponds and shrimp ponds Navigational Operations

Natural Mechanisms

Riverbank Materials

Soil samples were taken with 60 cm length tubes. Three samples in each tube were analyzed at the top (ND1), middle (ND2) and bottom (ND3). The results indicated that the silt and clay contents are the main materials of riverbanks with over 50%-70%. Therefore, the riverbanks are considered as cohesive banks. These banks have been unstable and easy to be destroyed. Figure 2 shows that erosion and deposition areas of each riverbank section. It is found that erosion areas of the strong-affected riverbank section are larger than in weak-affected riverbank section.

Table 3. Properties of Soil Samples

Tube	Sample	Depth (cm)	Riverbank materials (%)		
			Sand	Silt	Clay
1	ND1	0	8.1	36.6	55.3
	ND2	30	7.3	31.9	60.8
	ND3	60	11.4	33.0	55.6
2	ND1	0	9.5	39.7	50.8
	ND2	30	21.0	33.3	45.7
	ND3	60	6.4	38.1	55.5
3	ND1	0	5.0	22.4	72.6
	ND2	30	17.8	21.5	60.7
	ND3	60	3.7	39.1	57.2
4	ND1	0	13.9	33.5	52.8
	ND2	30	13.6	34.8	51.6
	ND3	60	12.1	35.8	52.1
5	ND1	0	14.6	30.3	55.1
	ND2	30	12.7	31.8	55.5
	ND3	60	3.4	36.0	60.6

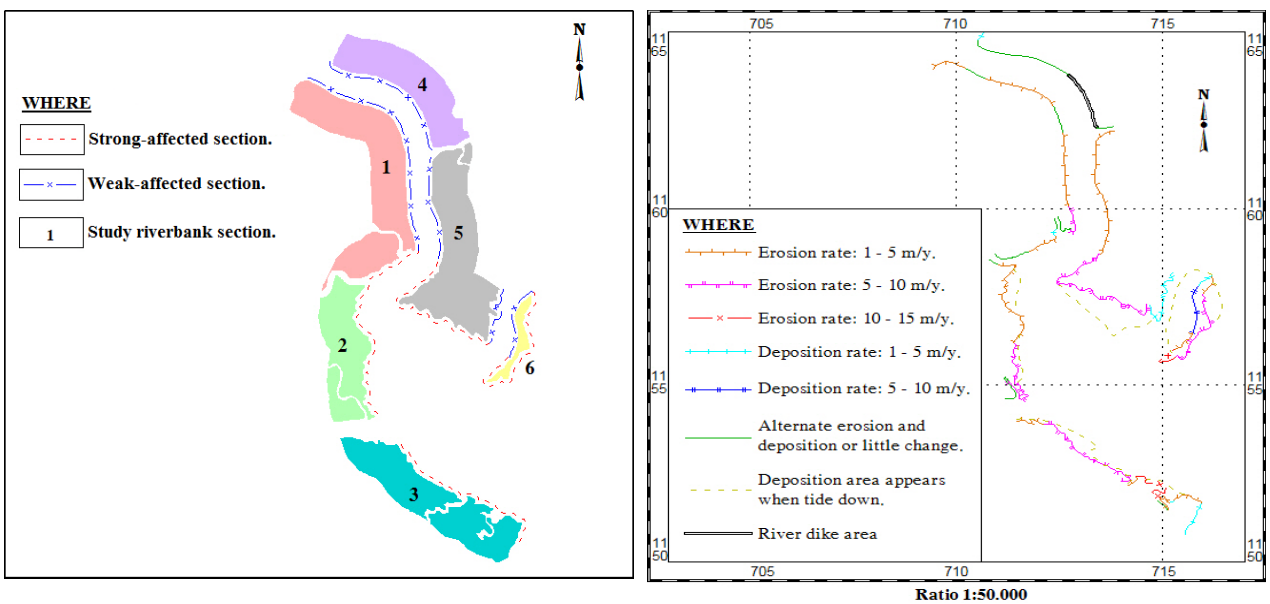


Figure 2. Riverbank erosion and deposition areas

Wave Action

In the study area, effects of waves on riverbanks are strongest in neap tide because the riverbanks totally exposed (Figure 3). Ship-generated waves and wind waves attack riverbanks directly and cause mass erosion (Region A). In spring tide, surface erosion of the riverbanks caused by ship-generated waves and strong currents (Region B).

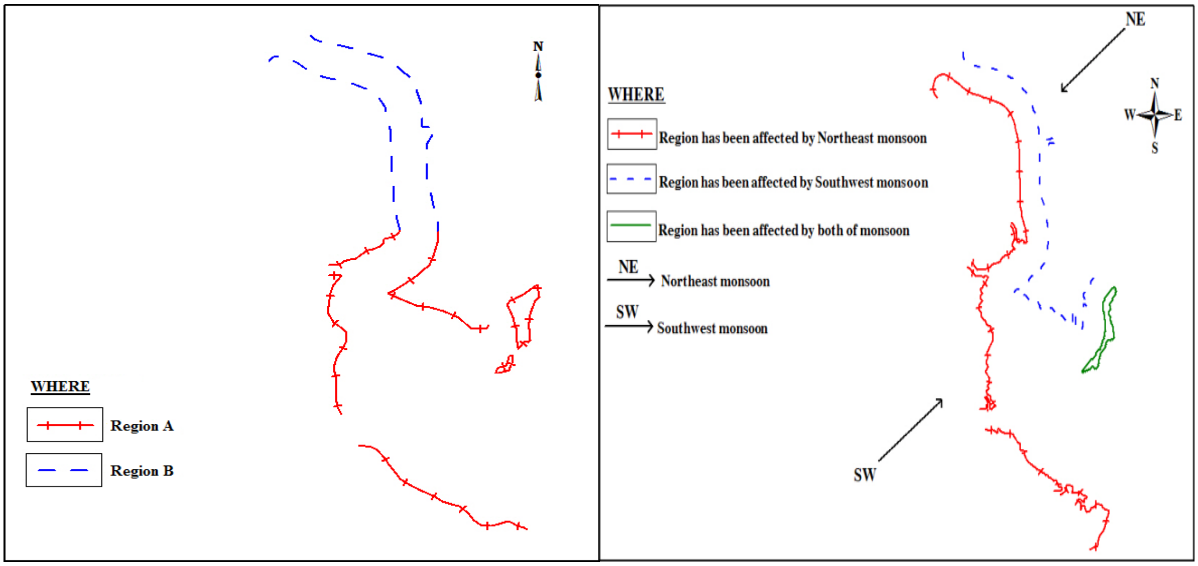


Figure 3. Two main regions affected by waves and monsoon seasons

Tidal Regimes and Tidal Currents

The study area is affected by semi-diurnal tidal regime of East Sea with high amplitude (3.3 - 4.1 m) in the spring tide and low amplitude (0.3 m - 2.2 m) in the neap tide. Therefore the riverbanks are affected continuously in the same day. Figure 4 shows that water level in the northeast monsoon as well as southwest monsoon. Therefore riverbanks are affected continuously in year. The riverbanks of the study area are mainly composed of silt and clay so they have strong shrinkage ability. Therefore, in the neap tide, the banks were exposed and drained. In the spring tide, riverbanks are flooded and expanded. These processes cause riverbanks unstably.

During the period of the high and low tidal level, strong currents will be formed. Figures 5 & 6 show current speed during spring tides and neap tides. In these figures, the maximum speed can reach 80 cm/s. These strong currents can cause riverbank erosion.

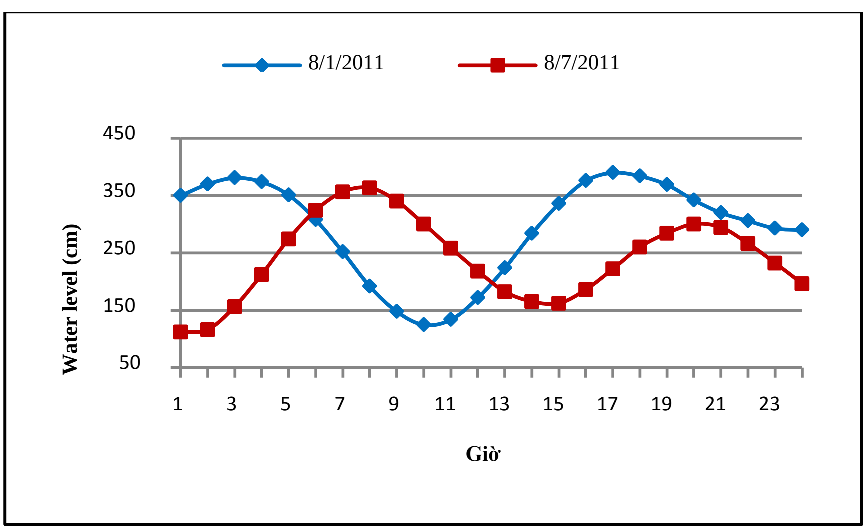


Figure 4. Water level in northeast and southwest monsoon

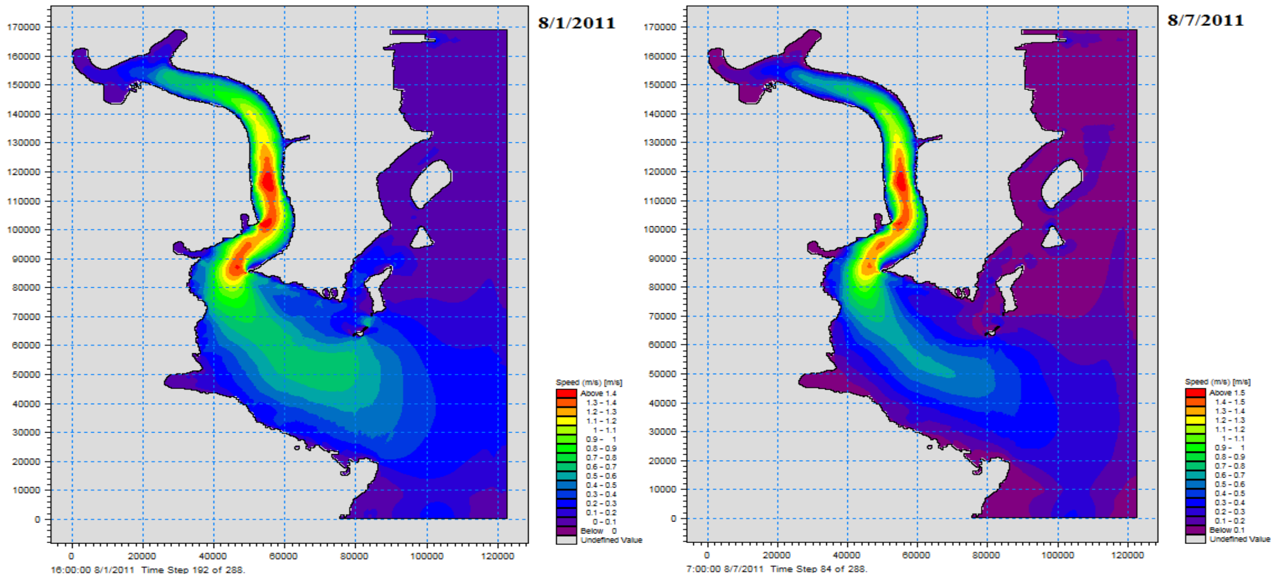


Figure 5. Current speed at highest tides on Jan. 8th, 2011 and on July 8th, 2011

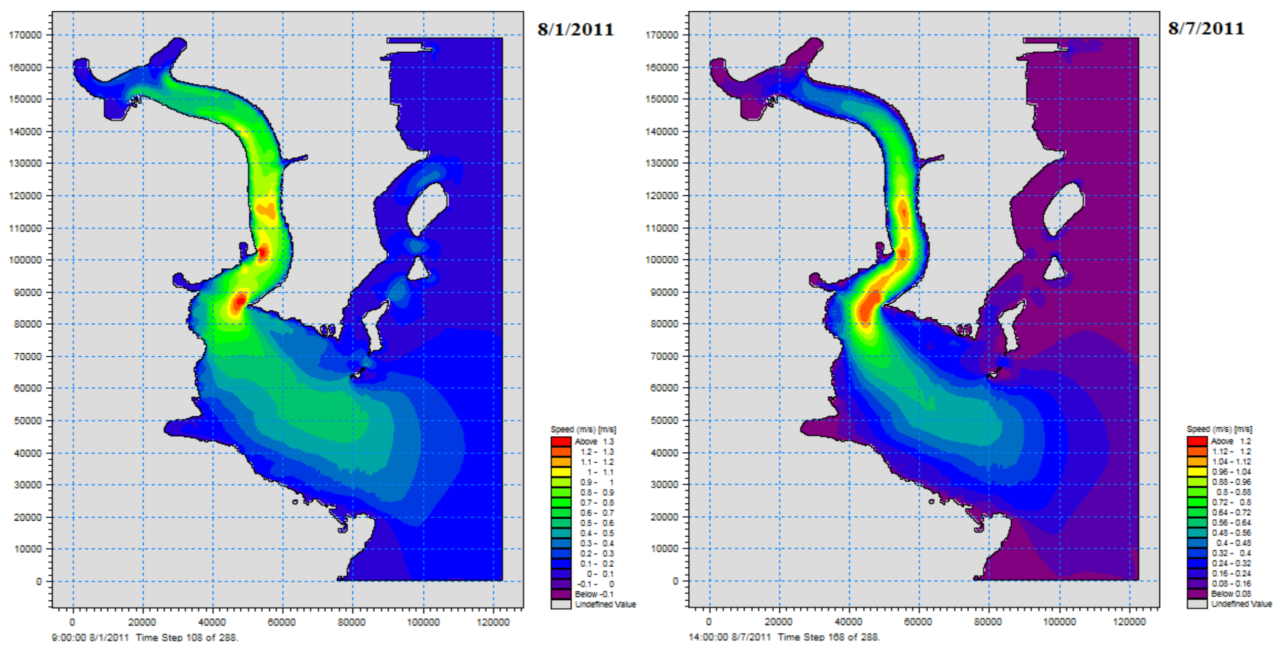


Figure 6. Current speed at lowest tides on Jan. 8th, 2011 and on July 8th, 2011

Unstable Mangrove Forests and Aquatic Animals

Along the riverbanks, mangrove tree fringes are dominated. The species of mangrove trees change from Avicennia, Rhizophora and Nypa Palm. These mangrove trees usually protect land from erosion. However, in the study sites, many mangrove trees have been collapsed because of hydraulic forces (waves, currents), exposed shallow roots to the environments and human factors. On the other hand, there are various aquatic animals such as crabs, shells, fish etc. which burrow and make many holes in the riverbanks. These holes will cause the mangrove trees unstable to waves and currents. Figure 7 shows shallow exposed roots of mangroves with many burrowed holes and weakened riverbanks.

Figure 7. Burrowed holes of aquatic animals and weakened riverbanks

Human Factors

Salt-ponds and Shrimp Ponds

Salt-ponds and shrimp ponds affected mainly mangrove forests because residents destroyed mangrove forests for making salt-ponds and shrimp ponds (Figures 8). Protecting methods have been applied at salt-ponds and shrimp ponds are temporary and unstable (Figure 9). When the mangrove trees are not cut down, the riverbanks are stable because of the role of mangrove forest. When the mangrove trees have been cut down to construct shrimp ponds and salt ponds, the riverbanks are not strong enough to protect land from strong currents and waves. Once the riverbank is destroyed, the location of the riverbank retreats by the width of the pond.

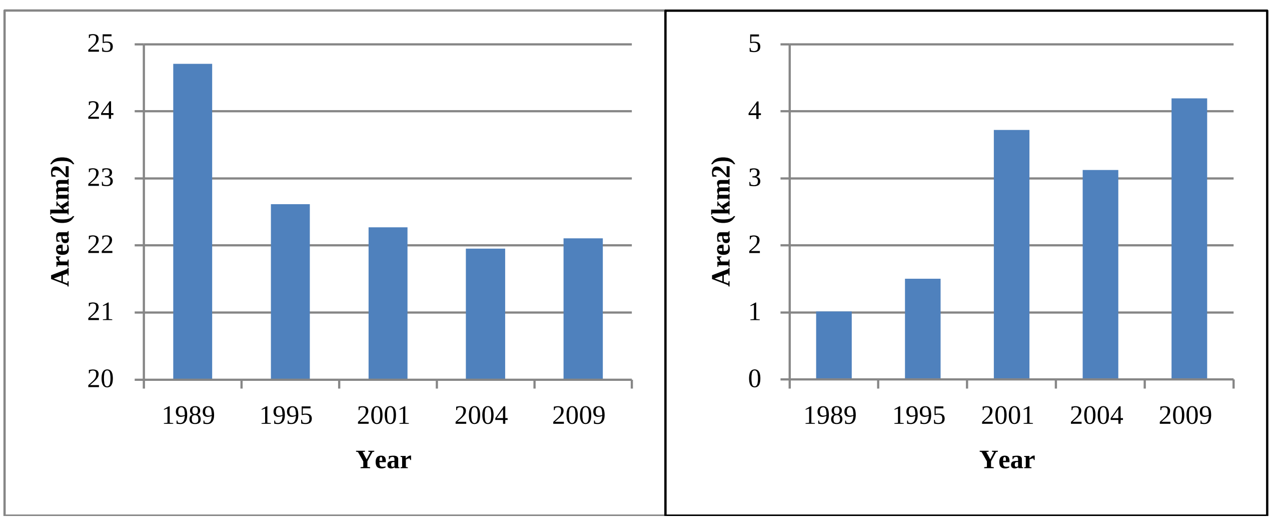
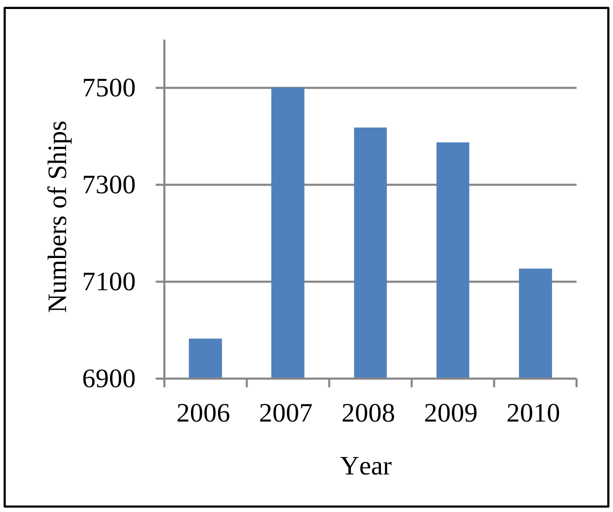


Figure 8. Decreased mangroves (left) and increased salt-ponds and shrimp ponds (right) areas from 1989 to 2009

Figure 10. Unprotected areas (left) and temporary protected by mangrove (right)

Navigational Operations

The study area is main river traffic from East Sea to Sai Gon port for big ships with 30.000 to 70.000 DWT. Besides this is also a channel for high speed ships from Ho Chi Minh City to Vung Tau Province. Therefore, effects of ship-generated waves on the riverbanks have been also investigated. Figure 11 shows the number of ships navigated from 2006 to 2010 and ship-generated waves measured in the study area. From this figure, the highest number appeared in 2007 and decreased in the following years. However, it has been still crowded area. The wave heights in this figure were about 15 cm. However, when high speed and big ships moved close to the riverbanks, wave heights can be more than one meter. The applied shear stresses of these waves cause the riverbank erosion severely.



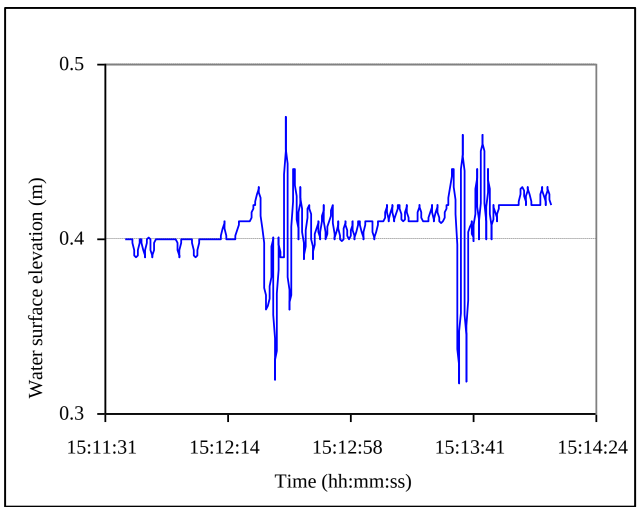


Figure 11. Numbers of Ships in 2006 to 2010 and ship-generated waves in Nga Bay River

Discussions

Along the Nga Bay River, both banks are almost covered with mangrove trees but have been eroded severely with high intense. The erosion rates of some parts are from 2 to 10 m/year. Many factors cause bank erosion, however, hydrodynamic processes are one of the main cause with some other factors such as many holes of aquatic animals and dead roots and leaves of mangrove trees. Gaskin et al. (2003) discovered that mass erosion was the most significant erosion process in undisturbed samples of Champlain Sea clay of the St. Lawrance riverbanks. In some part of the Nga Bay riverbanks, the mass erosion process is also the predominant erosion mechanism.

Bui et. al. (2009) investigated that the critical shear stress of both in situ undisturbed samples and remolded samples depend on the sand-silt-clay contents, moisture contents, salinity, consolidation, and vegetation. The critical shear stresses of the samples are directly proportional to clay contents, salinity, consolidation, and vegetation; and inversely proportional to the moisture contents. These mean that the erosion mechanisms of the bank and bed will be influenced significantly by these factors. Couper (2003) also studied the effect of silt-clay content on the susceptibility of riverbanks to subaerial erosion. The results indicate that riverbanks with high silt-clay contents are the most susceptible to erosion by subaerial processes. Other factors such as dead roots and leaves, holes of aquatic animals play important role in weakening the bank before erosion process occurs.

The calculated tidal currents on cohesive banks showed that some areas have been attacked by wind waves, ship-generated waves, and strong currents. Therefore, it can be judged that the numerical model for predicting effect of strong currents used in this study can apply to the case of relatively strong current.

Conclusions

Field investigation indicated that the erosion processes of Nga Bay riverbanks are being occurred severely with erosion rates of 2 to 10 m/year. Two main erosion mechanisms of Nga Bay riverbanks have been investigated by in situ investigation, satellite images analysis, laboratory experiments and numerical study. The natural mechanisms caused the riverbank erosion are mainly by the nature of cohesive and weak materials, wind waves, tidal currents, and aquatic animals. The human factors are mainly construction works by destroying mangrove trees and navigational operations with high ship-generated waves.

References

[1] Task Committee on Erosion of Cohesive Materials, American Society of Civil Engineers (ASCE), "Erosion of cohesive sediments," *Journal of the Hydraulics Division*, Vol. 94, No. 4, pp. 1017-1050, 1968.

[2] T.V. Bui, I. Deguchi, and M. Arita, "Erosion mechanisms of cohesive bed and bank materials," In: *Proceedings of the Nineteenth (2009) International Offshore and Polar Engineering Conference*, Vol. 3, International Society of Offshore and Polar Engineers,Osaka, Japan, pp. 1305-1312, 2009.

[3] P. Couper, "Effects of silt-clay content on the susceptibility of river banks to subaerial erosion," *Geomorphology*, Vol. 56, No. 1-2, pp. 95-108, 2003.

[4] DHI, *Mike 21.* Retrieved from https://www.mikepoweredbydhi.com/products/mike-21

[5] S.J. Gaskin, J. Pieterse, A.A. Shafie, and S. Lepage, "Erosion of undisturbed clay samples from the banks of the St. Lawrence River," *Canadian Journal of Civil Engineering*, Vol. 30, No. 3, pp. 585-595, 2003.

[6] Institute for Environment and Resources, *Artificial Beach Project in Can Gio Coastal Areas*, Environmental Impact Assessment Report 7/2003, Ho Chi Minh City, Vietnam, 2003.

[7] A. Simon, A. Curini, S.E. Darby, E.J. Langendoen, "Bank and near-bank processes in an incised channel," *Geomorphology*, Vol. 35, No. 3-4, pp. 193-217, 2000.

[8] C.R. Thorne, “Processes and mechanisms of river bank erosion,” In *Gravel-bed rivers: fluvial processes, engineering and management*, R. D. Hey, J. C. Bathurst, and C. R. Thorne, eds.: Wiley and Sons, Chichester, United Kingdom, pp. 227–271, 1982.
[9] V.D. Lomtadze, Geotechnic & Dynamical Geotechnic (Translator: Pham Xuan, Nguyen Thanh, Dang Hong Diep, Pham Manh Ha, Tran Van Hoang), 1982.