Vietnam Journal of Mechanics, VAST, Vol. 29, No. 3 (2007), pp. 415–426
Special Issue Dedicated to the Memory of Prof. Nguyen Van Dao

PRELIMINARY RESULTS OF THE STUDY ON THE REASONS OF THE HAI HAU EROSION PHENOMENON

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Abstract. Overall the evolution process of the Red River Delta based on the maps and historical data resulted in a fact that before the 20^{th} century all the Nam Dinh coast line was attributed to accumulation. Then started the erosion process at Xuan Thuy district and from the period of 1935 – 1965 the most severe erosion was contributed in the stretch from Ha Lan to Hai Trieu, 1965 – 1990 in Hai Chinh – Hai Hoa, 1990 – 2005 in the middle part of Hai Chinh – Hai Thinh (Hai Hau district). The adjoining stretches were suffered from not severe erosion. At the same time, the Ba Lat mouth is advanced to the sea and to the North and South direction by the time with a very high rate.

The first task of the mathematical modeling of coastal line evolution of Hai Hau is to evaluate this important historical marked periods e. g. to model the coastal line at the periods before 1900, 1935 – 1965; 1965 – 1990; 1990 – 2005. The tasks is very complicated and time and working labors consuming.

In the paper, the primarily results of the above mentioned simulations (as waves, currents, sediments transports and bottom – coastal lines evolution) has been shown. Based on the obtained results, there is a strong correlation between the protrusion magnitude and the southward moving of the erosion areas.

1. COASTLINE EROSION AT HAI HAU BEACH

The length of the erosion stretch at Hai Hau district ranks the second after the Ganh Hao stretch which is located in Ca Mau province, north east of Ca Mau cap. The 30 km of Hai Hau beach has suffered from erosion at least from the beginning of the last century. The coast has been eroded at a rate of 10 – 15 m/year during the last half century. At present two sea dyke system have been constructed to protect the coast. Some descriptions of the eroded stretch are below:

+ The shore line has NE-SW orientation (coincided with the main predominant north-east monsoon wave direction). Theoretically the N, NNE, NE wind direction (from land to sea) can not generate waves. But in reality there are quite high wave fields with NE wind direction. This situation can not be simulated by the monochromatic wave theory, but by the spectral method.

+ The erosion rate for Hai Hau beach is not unique. At present the most severe erosion takes place at Hai Ly – Hai Trieu communes,

+ The bottom slope is rather gentle (<0.008) as a results of repeated shore line retreats (more gentler than classical equilibrium profiles).

+ A small Red river tributary named Vop - Ha-Lan mouth had been closed since 1955.

+ Present eroded rate is approximately 10m/year (with the present of sea dyke system). It takes 20-30 year for one sea-dyke system retreat.

+ There is a strong correlation between the seaward advance of Ba Lat mouth and the position of the severest erosion. With the Ba Lat mouth seawards development and formation of underwater sand bars the strongest erosion area moves southward. Based on the historical data, four periods of coastline evolution in Hai Hau district have been divided as:

* 1912-1935: the coast began to be eroded from the nearest south of Ba Lat mouth to Hai Dong commune;

* 1935-1965: the strongest erosion area occurred at the coast from Hai Dong to Hai Trieu communes;

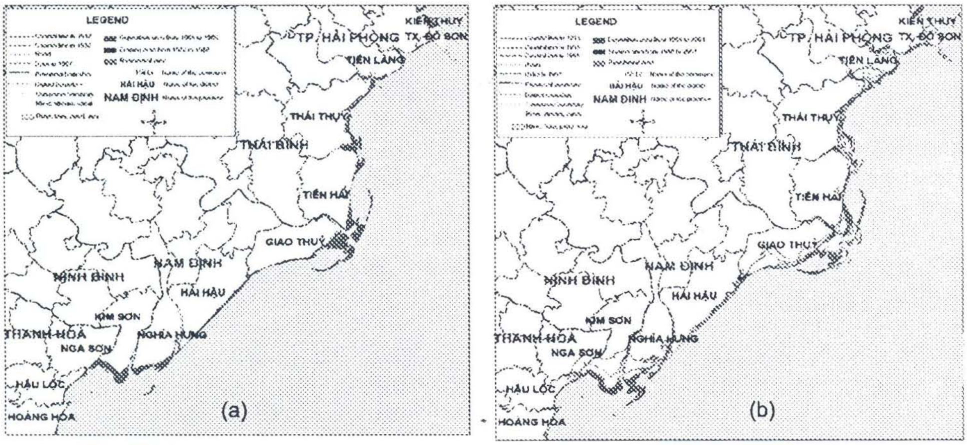

Fig. 1. RRD's coastline evolution during 1965-1989 (a) and 1989-2001 (b)

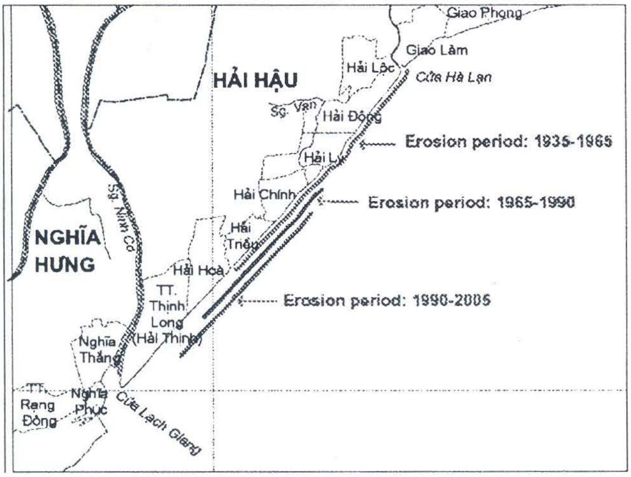

Fig. 2. The southward moving of the severest erosion areas in Hai Hau beach

* 1965-1990: the strongest erosion area occurred at the coast from Hai Chinh to Hai Hoa communes;

* 1990-2005: the strongest erosion area occurred at the coast at the coast from Hai Chinh commune to Thinh Long town (Hai Thinh commune)

There are some hypothesizes of the main mechanism causing the shore line retreat in the area but all of them are designated to wave activities. One of the important theoretical point of the authors is the correlation between the seaward advance of the Ba Lat mouth and the position of the severest erosion in Hai Hau beach. The southward moving of the severest erosion areas are mapped in the figure 2. It was found out that, with the Ba Lat mouth seawards development and formation of underwater sand bars the strongest erosion area moves southward. This hypothesis will serve as the most important criteria for the explanation of reason of the Hai Hau present state of erosion and for the proposed coastline protection measures at the beach.

2. PRIMARILY EXPLAINATION OF THE COASTLINE EVOLUTION

Sediment transport plays an important role in many aspects of coastal, estuarine engineering. Waves, tidal currents and wave-induced currents are the main forcing of the sediment transport. The sediment transport is responsible for the morphological changes and the shoreline evolution in the coastal zone. However, the understanding of the mechanism responsible for these phenomena is still not clear. Numerical modeling is one of useful tools for the evaluation of the hydrodynamic parameters such as the wave height, the currents, the sediment transport, the bottom level change and shoreline evolution for the design of shore protection and environment problems.

In order to simulate the evolution of Nam Dinh coast, in the present study, a 2-D numerical model has been developed to simulate the sediment transport, the bottom level change and the coastline evolution under the action of waves. The model includes a total load module which is based on the approach of Watanabe (1988), the advection-diffusion model which is used to simulate the sediment transport from the river mouths and the morphology and shoreline change modules.

The tidal current, the wind-induced current, the wave-induced currents and the waves parameters are supplied as inputs. Tidal and wind drift currents are obtained by using a 2-D hydrodynamic model based on resolving the full shallow-water equations by a finite differences method developed by Manh and Yanagi (2003). The wave parameters, the most important sea parameters, influencing coastal processes, are obtained by using the wave model STWAVE (Hung et al. 2006). These matters are not presented here.

2.1. Modeling of the Sediment Transport Rate due to Current (in the presence of wave)

The formula of sediment transport rate $q_c\,(\mathrm{m}^2.\mathrm{s}^{-1})$ due to current (in the presence of wave) proposed by Watanabe (1988) is used:

$$q_c = A_c\left(\frac{(\tau_{b,cw}-\tau_{cr})\left|\vec{V}\right|}{\rho g}\right) \tag{2.1}$$

The sediment transport rate in x and y direction are as follows:

$$q_{cx} = A_c\left(\frac{(\tau_{b,cw}-\tau_{cr})\,U}{\rho g}\right); \qquad q_{cy} = A_c\left(\frac{(\tau_{b,cw}-\tau_{cr})\,V}{\rho g}\right) \tag{2.2}$$

where A_c is a non dimensional empirical coefficient; $\left|\vec{V}\right|$ is the absolute velocity; ρ is the fluid density; g is the gravity acceleration; U, V are the components of flow velocity in the x and y directions respectively; $\tau_{b,cw}$ is the bed shear stress due to waves and currents, and assumed to be form as linear superposition of the respective wave and current components (Van Rijn, 1989):

$$\tau_{b,cw} = \tau_{b,\delta} + \tau_{b,w}, \tag{2.3}$$

$\tau_{b,\delta}$ is the bed shear stress due to current (modified by wave motion):

$$\tau_{b,\delta} = \alpha\tau_{b,c}, \tag{2.4}$$

where α is a factor related to the influence of the waves on the bed shear stress. $\tau_{b,c}$ is the bed shear stress due to current alone.$\tau_{b,w}$ is the bed shear stress due to waves defined by Van Rijn (1989).

τ_{cr} is the critical bed shear stress for incipient motion, determined from the Shield curve for oscillatory flow:

$$\tau_{cr} = (s-1)\rho g d\psi_{cr}, \tag{2.5}$$

where d is the diameter of sediment particle; s is the specific gravity; ψ_{cr} is the critical Shields parameter.

2.2. Modeling of the Sediment Transport Rate due to Wave

The sediment transport rate due to wave q_w (m^2/s) in the direction of wave propagation:

$$q_w = F_D \frac{A_w\left(\tau_{b,cw} - \tau_{cr}\right)\hat{u}_b}{\rho g}, \tag{2.6}$$

$$A_w = \frac{B_w w_s}{(1-\lambda)(s-1)\sqrt{(s-1)gd}}\sqrt{\frac{f_w}{2}}. \tag{2.7}$$

The sediment transport rate in x and y direction are as follows:

$$q_{wx} = F_D \frac{A_w\left(\tau_{b,cw} - \tau_{cr}\right)\hat{u}_b\cos\theta}{\rho g}; \qquad q_{wy} = F_D \frac{A_w\left(\tau_{b,cw} - \tau_{cr}\right)\hat{u}_b\sin\theta}{\rho g} \tag{2.8}$$

where B_w is a non dimensional coefficient; λ is the void ratio of sediment; w_s is the fall velocity, estimated by approximate formula of Van Rijn (1993):

$$W_s = \frac{10\nu}{d}\left[\left(\frac{0.01\,(s-1)\,gd^3}{\nu^2}+1\right)^{0.5} - 1\right], \tag{2.9}$$

where θ is the wave angle with respect to the x direction; ν is the kinematic viscosity coefficient of water (10^{-6} m^2.s^{-1}); F_D is the transport direction function defined by Watanabe (1988).

2.3. Sediment Transport Rate due to combined Waves and Currents

Sediment transport rate due to combined waves and currents is assumed to be the sum of the transport rate vectors due to waves and the transport rate vectors due to currents:

$$\vec{q} = \vec{q}_c + \vec{q}_w. \tag{2.10}$$

2.4. Advection-Diffusion Modeling

The advection-diffusion model is used to simulate the suspended sediment transport from the Ba Lat river mouth taking into account the sediment exchange between the water and the bed. The governing equation is as follows:

$$\frac{\partial(CH)}{\partial t} + \frac{\partial}{\partial x}\left(CQ_x - K_x H\frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(CQ_y - K_y H\frac{\partial C}{\partial y}\right) = F_{\text{bed}}, \tag{2.11}$$

where C is the turbidity, K_x, K_y are the coefficients of the horizontal diffusion. In the general case, $F_{\text{bed}} = F_e - F_d$ is the sediment fluxes exchanged between the water and the bed. F_{bed} is either erosion or deposit fluxes, depending on the relationship between bed shear stress and bed materials.

There does not exist a lot of deposit formulations for fine-sediment transport. The most frequently used one is proposed by Einstein-Krone (Krone, 1962):

$$F_d = W_s C\left(1 - \frac{\tau_{b,c}}{\tau_{cd}}\right), \tag{2.12}$$

where F_d is the deposition rate, τ_{cd} is the critical stress for deposition. τ_{cd} depends on the turbidity and the currents near the bed.

The bed erosion is already included in the formulation of Watanabe (1988), so when modeling the advection, the diffusion of suspended sediment, only the deposition of the sediment from river mouths is taken into account, i.e. the erosion flux F_e is set to zero.

2.5. Bed Level Change

The conservation of the sediment mass is expressed by:

$$\frac{\partial h}{\partial t} = \frac{1}{1-\lambda}\left[\frac{\partial}{\partial x}\left(q_x - \varepsilon_s\left|q_x\right|\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(q_y - \varepsilon_s\left|q_y\right|\frac{\partial h}{\partial y}\right) + F_{bed}\right], \tag{2.13}$$

where ε_s is an empirical coefficient, dealing with the effect of the bed slop; h is the water depth.

2.6. Shoreline Change

Based on the one-line theory, the equation governing shoreline change is as follows (Hanson and Kraus, 1989):

$$\frac{\partial y}{\partial t} + \frac{1}{D_B + D_C}\left(\frac{\partial q}{\partial x} - Q\right) = 0, \tag{2.14}$$

where y is the shoreline position; D_B is the berm elevation; D_C is the depth of closure; q is the longshore transport rate, Q is the line source or sink of sediment.

2.7. Adaptation of the model to the Nam Dinh coast zone

For this application, the study area is the nearshore zone of Nam Dinh province. It covers the lower part of the Ba Lat river mouth, extends alongshore over 60km from the Diem Dien mouth southwards to the Lach Giang mouth and as far as 25km offshore (figure 1). Bathymetric data of the area were digitalised from maps 1/25000 and 1/100000 made by Vietnam People's Navy, published in 2000 and 1984, respectively.

Simulation Conditions

For the advection-diffusion model, a concentration of 10 mg.l^{-1} is imposed for the whole area as the initial condition. At the open boundaries, the suspended sediment at the river mouth in ebb tide is imposed at $1.0 g.l^{-1}$ corresponding to a mean river discharge of 4500 $m^3.s^{-1}$ for the wet season and $0.2 g.l^{-1}$ corresponding to a mean river discharge of 1500 $m^3.s^{-1}$ for the dry season (Van Maren et Hoekstra, 2004).

Following the approach of Van Maren et Hoekstra (2004), the yearly morphological changes are calculated by simulating half a spring-neap cycle for each wave conditions, and multiply this with a morphological factor which is defined from the frequency of occurrence of each wave class. Summation of the resulting morphological computations yields the yearly morphological change. In this work, calculations are done with two wave classes with the highest frequencies of occurrence, corresponding to NE and SE winds. The duration of simulation for each wave class and the other statistic data in table 1 are given by Hung *et al* (2006).

Table 1. Different Cases of Simulations*

Computation scenarios	Wave heigh t, m	Wave Period d, s	Wave Dir. deg.	P [%]	Mean river discharge, $m^3.s^{-1}$	Duration of simulation, days	Wind velocity/Dir, $m.s^{-1}$/deg.
Case 1	0.81	3.95	180.02	31.36	4500	57.23 (wet season)	4.5/135 (SE)
Case 2	1.04	3.87	80.12	37.57	1500	68.56 (dry season)	6.0/45 (NE)

*Directions of waves and winds are referred to Meteorological (Zero from North)

Sedimentological Parameters adopted for Simulations

The principle sedimentological parameters are taken as follows:

- The median grain diameter $D_{50}=90\mu m$;
- The void ratio $\lambda=0.4$;
- The sediment density $\rho_s=2650$ $kg.m^{-3}$;
- Non-dimensional coefficient for wave $B_w=3$;
- Non-dimensional coefficient for current $A_c=1$;
- Critical value for direction of transport rate $\prod_c=1$;
- Effective bed slop coefficient $\varepsilon_s=1$.
- The horizontal eddy diffusivity for suspended sediment $K_x = K_y=10$ $m^2.s^{-1}$.

The critical bed stress for deposition τ_{cd} depends on the suspended sediment concentration and flows near the bottom. It is obtained from experiments in channel, in laboratories with sediments of some estuaries, but there is no results concerning the fluid mud of BaLat. For reference, some values of τ_{cd} are shown hereafter. Krone (1962) used $\tau_{cd}=$ 0.06 $N.m^{-2}$ for mud beds in the Bay of San-Francisco with an initial concentration of sediments less than 0.3 gl^{-1}. Mehta (1986) obtained the τ_{cd} is equal to 0.15 $N.m^{-2}$ for kaolin beds, to 0.10 $N.m^{-2}$ for mud beds in the Bay of San-Francisco and to 0.08 $N.m^{-2}$ for mud beds in Maracaibo (Venezuela). Base on those values and the critical stress value obtained from calculations, the critical stress for deposition τ_{cd} is chosen at 0.1 $N.m^{-2}$.

2.8. Results and discussions

Calculated Net Sediment Transport

The long-shore and cross-shore sediment transports are taken into account in the model. In general, the numerical results (fig. 3) show that the long-shore sediment transport is dominant and considerable within as far as some hundreds of meters offshore. Further offshore, the net sediment transport rates decrease sharply.

In the NE wind the net sediment is mainly transported southwards along the shore. Also, in the SE wind, the net sediment is mainly transported northwards along the shore. The maximum net sediment transport rates reach as much as $0.1\text{kg.m}^{-1}.\text{s}^{-1}$.

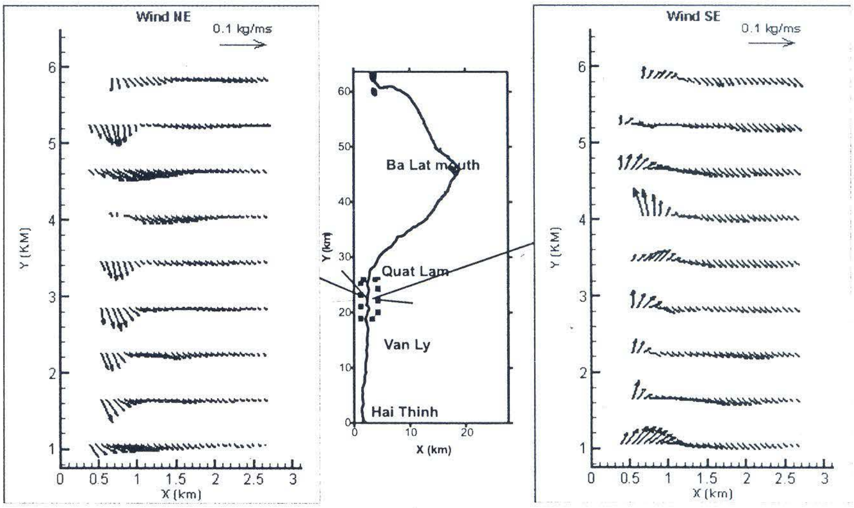

Fig. 3. Calculated net sediment transport rates in the NE (left) and SE (right) winds

Calculated Bed Level Change

- Accretion Caused by the Suspended Sediment from the River Mouth

Fig. 4 shows the calculated bottom change caused by the sediment deposition from the Ba Lat river mouth in the NE and SE winds. The sediment from the river mouth is transported by the currents and causes the bed accretion. The numerical results show that the accretion mainly takes place at the north and south areas of the river mouth, where the sand spits are formed. At the very main course of the river mouth, larger river flow does not support the bed accretion. Those are in agreement with the observations.

Because of the longer duration and the more intense of the NE wind speed compared to the SE wind, in the NE wind the sediment from the river mouth is transported further alongshore, as far as Quat Lam area. The accretion rate in the NE wind is minor. In the NE wind, the maximum rate of bed accretion is 0.1-0.2 m whereas in the SE wind, this value is up to 1m. That is caused by the larger suspended concentration, from the Ba Lat mouth in the wet season, supplied to the bed.

- Bed Level Change Caused by the Wave Action

Figure 5 shows the calculated bottom change in the NE and SE wind seasons. In the figure, the area filled with dot symbols is in accretion and the area filled with cross symbols is in erosion. In general, we observe that the area in accretion are larger than the area in erosion and the erosion tends to take place closely to the shore. However, the rate of accretion is minor, under 0.1-0.2m. The rate of erosion in the NE wind is more intense

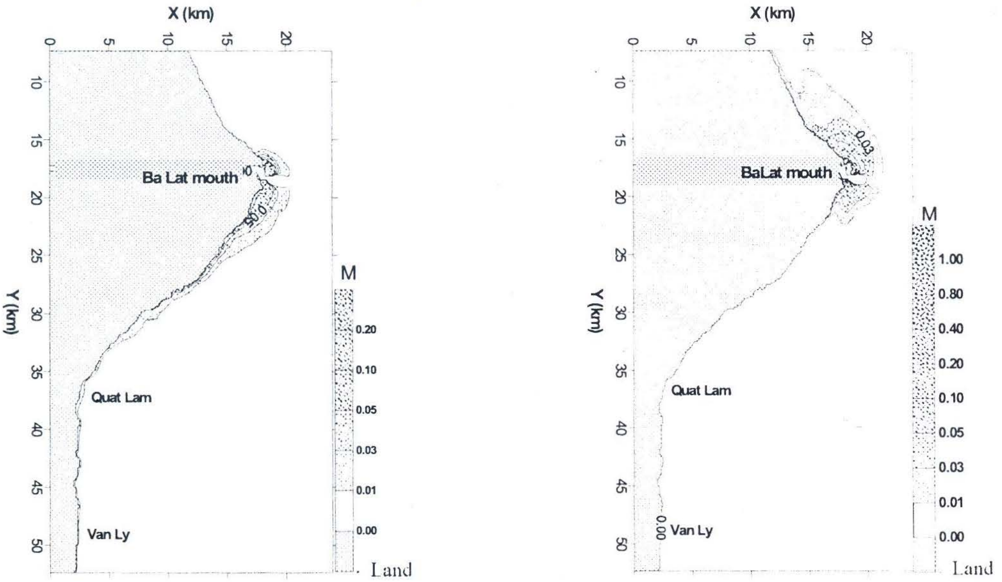

Fig. 4. Calculated bottom elevation differences caused by the sediment deposition from the river mouth in the NE wind (left) and SE wind seasons (right)

than that in the SE wind. Close to the shore, the rate of erosion can reach up to 1m in the NE winds and as much as 0.4m in the SE wind.

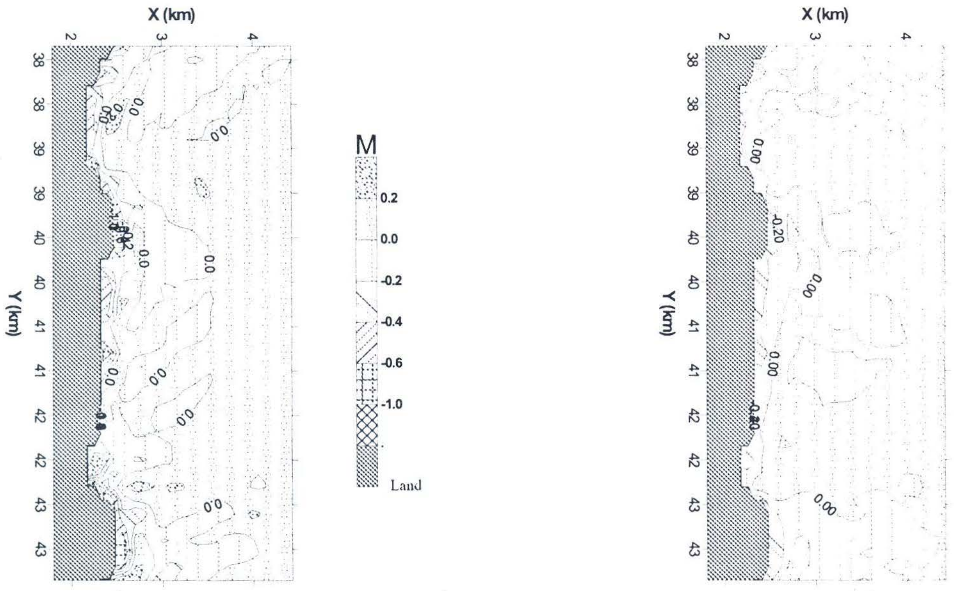

Fig. 5. Calculated bottom elevation differences caused by the wave action and current in the NE wind (left) and SE wind (right) seasons in Van Ly area

For a clearer showing of the tendency of bed erosion/accretion, figure 6 is made. This figure shows the calculated bottom elevation differences of three profiles in the NE wind season in Van Ly area. In this figure, the minus value of the bottom elevation difference indicates the erosion and the positive value shows the accretion. Due to the sediment transport is considerable within some hundreds of meters offshore, the bed change mainly takes place in this area. In the NE wind, near the shore bed erosion rate can reach up to 1m, further offshore there is a tendency of bed accretion or erosion with a minor rate. Over 2 km offshore, the wave action nearly does not cause any considerable effects on the bed level.

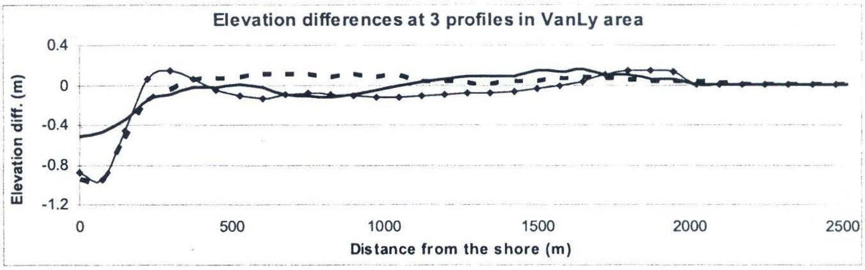

Fig. 6. Calculated bottom elevation differences of some profiles in the NE wind season in Van Ly area

Calculated Shoreline Evolution

Figures 6 shows the calculated shore line evolution with the effects of waves, tide currents, wind-induced currents in 2001 and 1912 in the NE and SE wind seasons. In this figure, in order to see more clearly the shoreline evolution after modeling, the coordinates of the shoreline are reduced to 50 times, and the coordinates differences between the shorelines before and after simulation are kept the same. For the calibration step, the calculations are done in order to obtain that the shore line erosion rate of the year 2001 is as much as 8-10m per year as observation. Then, the calculations are done with the shore line of the year 1912 for the SE wind season. The calculated results show that the shoreline of the whole interest area does not change much in the SE wind season compared to that in the NE wind (figure 7). In the NE wind, the shore line of the year 2001 is eroded at the south part, from Quat Lam to Hai Thinh, whereas there is a clear tendency of shoreline erosion at the Quat Lam area in 1912. What responsible for this phenomenon should be the convex shape of the shoreline. The land area at the Ba Lat mouth is convex and it plays a role as a groin.

It is worth to mention that this shoreline evolution has been calculated for NE and SE monsoons 2001 only (not for other wind directions also) and for NE monsoon 1912 only. The effect of calculated accumulation from the Ba Lat mouth is not added over there and various matters still waiting for the further study. So in comparison with the figure 2 the part from Hai Chinh to Ha Lan river mouth is not the severe erosion part.

3. CONCLUSIONS

- A 2-D numerical model of the sediment transport, the bottom level change and the coastline evolution under the action of waves and currents has been developed to simulate the coastal erosion in Nam Dinh province, of which the total load model is based on the approach of Watanabe (1988), the advection-diffusion model is used to simulate the

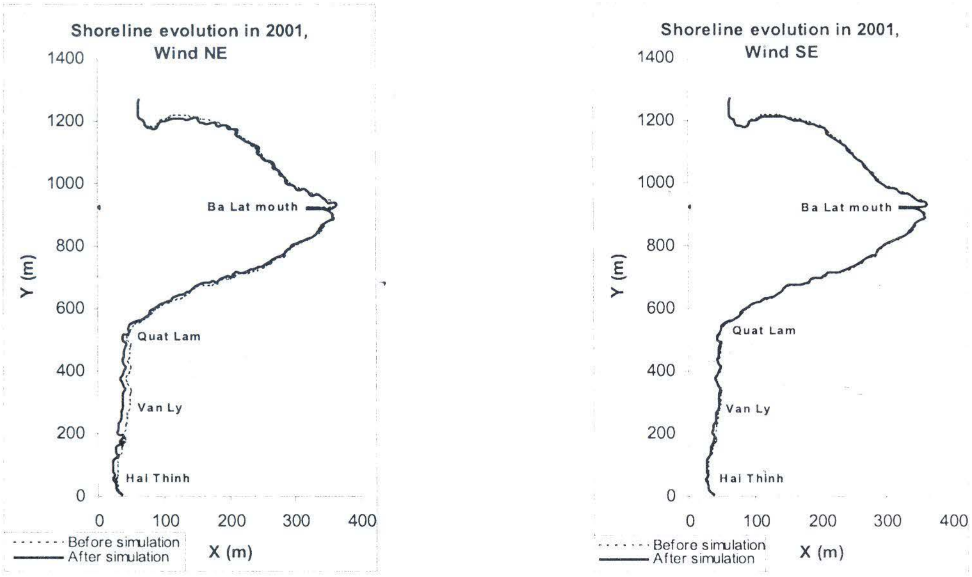

Fig. 7. Calculated shoreline evolutions in the NE wind (left) and in the SE wind (right) seasons in 2001

sediment transport from the Ba Lat river mouth taking into account the sediment exchange between the water and the bed, and the shoreline evolution is based on the one-line theory.

- The long-shore and cross-shore sediment transports are taken into account in the model. The dominance of the long-shore sediment transport is shown with the model. The net sediment transport is considerable within as far as some hundreds of meters offshore. The maximum net sediment transport rates reach as much as $0.1\ \mathrm{kg.m^{-1}.s^{-1}}$.
- The NE wind season contribution in sediment transport and coast evolution is much greater than the SE wind season contribution.
- In reality the Ba Lat mouth plays a role of a groin. The more seaward and southward its development this role is more clearly.

Preliminarily results of coastal evolution in 2001 and 1912 show a good qualitative agreement with the observation.

- The obtained preliminarily results have weaks points they could be caused by:

* Not considering the other wind directions,

* Not including the water and sediment discharge of the other river mouths – Ha Lan, Ninh Co and Day.

* Not considering the effect of Hoa Binh electric plant lake in the upper basin of the Red River.

* Not considering the effects of man activities dykes buiding.

Acknowledgements. This work was mainly supported by the project VS/RDE/03 "*The evolution and sustainable management in the coastal areas of Vietnam*" which is provided at the Center for Marine Environment Survey, Research, and Consultation, Institute of Mechanics (2003-2007).

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Received June 20, 2007.

CÁC KẾT QUẢ NGHIÊN CỨU SƠ BỘ VỀ NGUYÊN NHÂN HIỆN TƯỢNG XÓI LỞ BỜ BIỂN HẢI HẬU

Tổng quan về sự tiến triển đường bờ châu thổ sông Hồng dựa vào các bản đồ và số liệu lịch sử đã chỉ ra rằng: Trước thế kỷ 20 toàn bộ bờ biển Nam Định chỉ có bồi lắng. Sau đó bắt đầu thời kỳ xói lở khu vực huyện Xuân Thuỷ và từ 1935 - 1965 xói lở tập trung mạnh nhất ở đoạn cửa Hà Lạn - Hải Triều, 1965 - 1990 ở Hải Chính Hải Hoà, 1990 - 2005 ở giữa xã Hải Chính - Hải Thịnh. Đồng thời ta cũng thấy rõ ràng cửa Ba Lạt ngày càng lồi ra (về phía biển và phía bắc - nam) với cường độ rất mạnh.

Nhiệm vụ của mô hình hoá toán học quá trình biến đổi đường bờ Hải Hậu trước hết là phải mô phỏng lại được các mốc quan trọng đó tức là đường bờ xói với các mốc trước 1900, 1935 - 1965; 1965 - 1990; 1990 - 2005. Đây là nhiệm vụ phức tạp đòi hỏi nhiều công sức, thời gian.

Bài này trình bày một số kết quả ban đầu của việc mô phỏng đó (sóng, dòng chảy, vận chuyển bùn cát và biến động bờ đáy biển). Kết quả nghiên cứu cho thấy mối tương quan rất mạnh giữa vùng đất lồi ra ở cửa Ba Lạt và chuyển dịch về phía nam của vùng xói lở.