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Studying shoreline change by using LITPACK mathematical model (case study in Cat Hai Island, Hai Phong City, Vietnam)

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Abstract. Nowadays, there are many methods to study shoreline change in coastal engineering. Among them, mathematical methods are considered as effective ones that have been used for a long time. LITPACK is a numerical model in MIKE software package, developed by Danish Hydraulic Institute (DHI), for simulating non-cohesive sediment transport in wave and currents, littoral drift, coastline evolution and profile development along quasi-uniform beaches. In this paper, the authors apply the model for studying shoreline change in Cat Hai Island, Hai Phong City. Cat Hai is a famous island with dense population working with various coastal - tradition works locating at the centre of Hai Phong, where coastal line is changing with high speed and complicated cycles. Based on the analysis of hydrodynamic-lithologic conditions in this area, a coast protected structure system has been proposed, consisting of revetments, groynes, submerged breakwaters and emerged breakwaters. Results derived from LITPACK model show that they are reliable enough and suitable for use as remedial protecting measures.

Keywords: LITPACK model; Hydrodynamic-lithologic; Simulating, Along time; Shoreline change.

1. Introduction of LITPACK Numerical Model

1.1. Model of LITPACK

LITPACK, developed by DHI, Water and Environment, is a software package for simulating non-cohesive sediment transport in wave and currents, littoral drift, coastline evolution and profile development along quasi-uniform beaches [1].

The main modules of the LITPACK are as the followings: Non-cohesive sediment transport (LIST); Long-shore current and littoral drift (LITDRIFT); Coastline evolution (LITLINE); Cross-shore profile evolution (LITPROF) and Sedimentation in trenches (LITTREN).

1.2. The LITLINE module

LITLINE calculates the coastline position based on input of the wave climate as a time series data. The model is based on one-line theory, in which the cross-shore profile is assumed to remain unchanged during erosion / accretion. Thus, the coastal morphology is solely described by the coastline position (cross-shore direction) and the coastal profile at a given long-shore position. LITLINE is applied in research on shoreline changes due to natural

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conditions, protected constructions and research on shoreline recovering measures by artificial beach nourishment.

The application of LITLINE is underpinned by the equation of the continuity for sediment volumes *Q(x)* [1]:

$$\frac{\partial y_c(x)}{\partial t} = -\frac{1}{h_{act}(x)}\frac{\partial Q(x)}{\partial x} + \frac{Q_{sou}(x)}{h_{act}(x)\Delta x} \qquad (1)$$

in which, $y_c(x)$ is the coastline position; t is time; $Q(x)$ shows the alongshore sediment transport expressed in volume; x is long-shore position; $h_{act}(x)$ – height of the active cross-shore profiles; Δx is long-shore discretization step; $Q_{sou}(x)$ source/sink term expressed in volume.

$h_{act}(x)$ and $Q_{sou}(x)$ are calculated based on user specifications, in which $Q(x)$ derived from the table of sediment transport rate in surf zone. From an initial coastline position $y_{init}(x)$, the evolution in time is determined by solving the above equation.

Solution

The continuity equation for sediment volumes is solved using an implicit Crank-Nicholson scheme, giving the development of the coastline position in time. It can be solved as follows:

The general transported trend in long-shore direction sketched in Fig. 1 and 2, in which Q_i denotes the transport rate between x_i and x_{i+1}, while dQ_i denotes the change in the transport rate with respect to change in coastline orientation (for values of θ close to the local orientation θ_0).

$$dQ(x) = \frac{dQ}{d\theta}(x, \theta_0) \qquad (2)$$

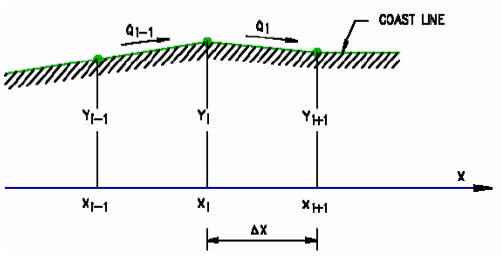


Fig. 1. Long-shore discretization.

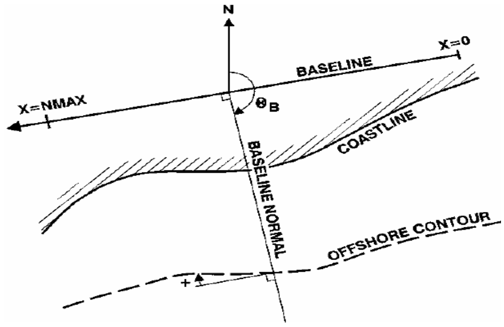


Fig. 2. Definition of base line orientation.

A subscript *t* denotes (known) values of the present time step, while *t+1* denotes (unknown) values of the next time step. Transport rates corresponding to time step *t+1* are estimated through:

Based on a Crank-Nicholson scheme [5], the continuity equation in Eq. 1 can be written as:

$$a_i y_{i-1,t+1} + b_i y_{i,t+1} + c_i y_{i+1,t+1} = d_i \qquad (3)$$

where:

$$a_i = (1-\alpha)dQ_{i-1}$$

$$c_i = (1-\alpha)dQ_i$$

$$b_i = \frac{\Delta x^2.h}{\Delta t} - a_i - c_i$$

$$d_i = a_i y_{i-1,t} + b_i y_{i,t} + c_i y_{i+1,t} - \Delta x(Q_{i,t} - Q_{i-1,t} - QS_i)$$

a_i, b_i, c_i, d_i can be found for the present time step, and with two boundaries (*Q* and coordinate of each point at *t-1*), the system of equation for all long-shore positions can be solved by Gauss-elimination.

The parameter α is Crank-Nicholson factor; it determines how implicit of the solution scheme is: a value of 0 gives a fully implicit solution, and a value of 1 gives a fully explicit solution.

Input data for the module comprise topography conditions including position of the coastline, the dune properties, offshore contours and the appearance of the cross-shore profile along the beach, the roughness coefficient of the bed. These parameters are specified basing on a coordinate system in which *x*-axis is baseline quasi-parallel to the initial coastline, and *y* is perpendicular to *x* and oriented sea (Fig. 2).

Other input data for LITINE are: sediment characteristics (mean diameter of sediment d_{50}, geometrical spreading); hydrologic conditions, (that is medium sea level consisting of storm surge and tide); wave conditions (wave field depicted into 2D wave table, consisting of parameter of wave height, wave directions and periods), this table is edited to LINLINE input data through sub-program of LINCONV. Current conditions: beside the wave-induced current automatically calculated, other factors are also mentioned and directly entered into the program with currents parameters such as speed, direction and other parameters of structure conditions (number, position, apparent dimensions and factors for active dimensions of coastal structures such as: groynes, jetties, revetments, breakwater). Results are the output data of the model shown in graphic and tabular forms, consisting of:

- Coastline position in time series (m);
- Depth of the topographic bed (m);
- Sediment transport rate (m^3/day);
- Accumulation of sediment transport rate (m^3);
- Sediment transport rate unit (m^3/m).

2. LITPACK application for Cat Hai Island, Hai Phong City

2.1. Location of the study area

Located between Cat Ba Island and Do Son Peninsula with coordinates $20^0$47'20''N - $20^0$50'12''N and $106^0$40'36''E - $106^0$54'05''E, Cat Hai is an island with area of more than 25 km^2 and is about 24 km far from Hai Phong center in the east - southeast direction. The island is located in Bach Dang Estuary. It has boundary with Quang Ninh Province in the north, to be separated with Phu Long - Cat Ba Island by Huyen Inlet 1.5 km of width in the east. The island borders with Gulf of Tonkin in the south and Hai Phong shipping channel in the west.

2.2. The current status of Cat Hai shoreline

Cat Hai Island is a place where erosion is happening with highest speed comparing with other places of Hai Phong coastal line. At present, the island has been strongly eroded so that the coastal line was pushed back at high speed from 5 to 6 meters per year in average. Especially at Van Chan, erosion speed reached 25 meters per year. In contrast, sedimentation occurred at Hoang Chau - Ben Goi section from 1938 to 1991, but that area has eroded again. Due to the erosion risk at the place, creating a plan for dam and other coast protected construction system is the study's purpose. Erosion process in recent years can be observed clearly by comparing Landsat images taken in 1999, 2002 and 2003.

According to dynamic shape and characteristic of the LITINE model, the case study shoreline is 6200 m long (from Hoang Chau to Got), it is divided into 5 segments (Fig. 3):

- Segment of Center Island (Gia Loc - Cai Vo segment) is 4325 m long, characterized by surface eroding and lowering process, which is caused by action of South and South-East breaking wave in the South-West monsoon leading to erosion and push back coastline.

- The second segment (Hoang Chau segment), 500 m, is characterized by erosion process because of long-shore tidal currents.

- The third segment (shoreline of Got - Hang Day inlet), 425 m, is characterized by erosion process because of tidal current impact.

- The fourth segment (shoreline of Nam Trieu Inlet), about 400m long, is characterized by very light erosion. Tidal and wind-generated currents cause sedimentation occasionally.

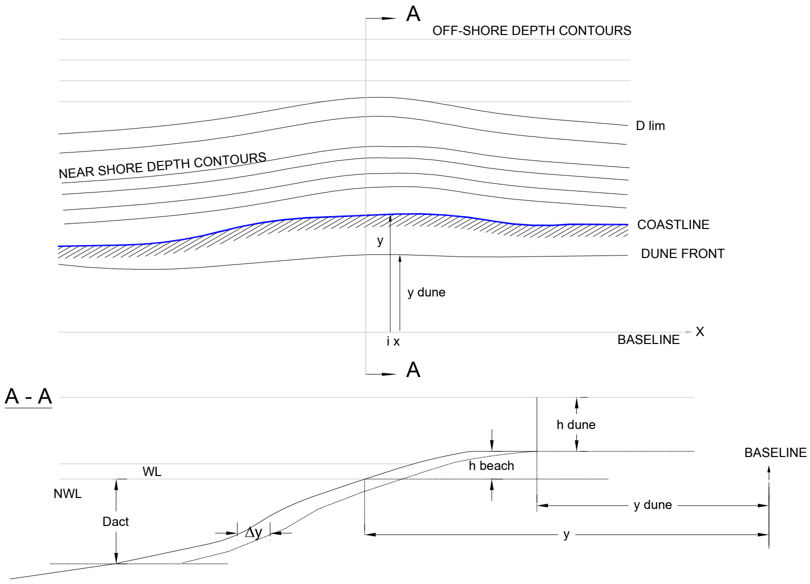
- The fifth segment, Lach Huyen Inlet with 350 m long, is characterized by slight erosion and sediment deposition. In this area tidal currents are dominated. The submerged side of Cat Hai Island is calculated for a under water sand bar, which elongates about 4000 m long coastline of average 100 m wide, and gentle slope.

2.3. Orientation coast protected construction

This paper does not mention detailed description in design and structure of coast protected construction system. We focused on consideration of natural and social conditions, especially in lithology and hydrology dynamic conditions in order to design a suitable and effective protecting construction system. Then, we used numerical LITPACK model to evaluate its technological effectiveness as a case study.

Protection objectives

Based on shoreline changes, the needs of socio-economic development and Cat Hai Island's master plan, designing and arranging protected constructions in Cat Hai coastline should



Note:
+ θ_B : clockwise angle with normal to baseline and the north direction, ;
+ y_{dune} : dune position;
+ h_{beach} : height of the active beach;
+ h_{dune} : height of dune;
+ Offshore contours: contours of offshore depth;
+ D_{act} : active depth.

Fig. 3. Definition of components in coastline description.

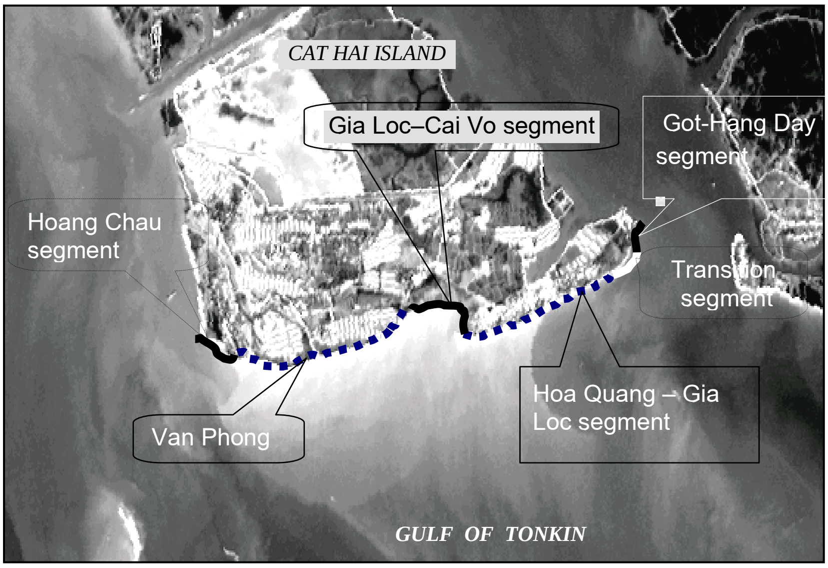


Fig. 4. Current status of the case study on the SPOT 4 image.

achieve following functions: (1) Prevent tidal flood and sea water passing dyke into residential area; (2) Prevent carrying sediments of alongshore current out of conservation area; (3) Minimize wave height before breaking and carrying sand out of coastal zone; (4) Build an aesthetic and stable shoreline. Additionally, it is necessary to build a street surrounding island to meet the transport and economic development needs of island's residents [2].

General instructions for protecting constructions in the study area

Solutions such as mangrove growing are not applicable because of erosion conditions and environmental conditions are unsuitable. Artificial beach nourishment also cannot be used because waves and currents will carry those materials to shipping channel of Hai Phong Port and make siltation. Besides, building groynes will not be effective if missing breakwater because groynes prevent only sand. They do not have effect on reduction of wave dynamic; they can even raise the height of waves. However, one of the most important objectives is the need to reduce wave dynamic. According to the regulations for designing sea dyke, it is not supposed to build too high. In this case, breakwater is the good solution to restrict the height of dyke.

Having a high and stable dyke system that can prevent seawater surge in high tide is necessary to avoid salt penetrate. Total length of sea dyke parts is 6200 m.

Main factor causing erosion along Cat Hai shoreline is the south and southeast storm wind-induced wave, thus the privileged requirement of construction reinforcing measures is to build the breakwater parallel with the shoreline and perpendicular to wave propagation. Its responsibility is cutting waves to minimize the wave height and energy before breaking. It is estimated that breakwater can minimize approximately 50% of wave height. During the second and the sixth storm in 2005, strong waves passed over, eroded the top and inside of dyke, destroyed outside structure and almost of construction system because of inexistence of the breakwaters.

In order to protect coastal zone and avoid substance to be carried toward to both sides of island that causes shallow surface, it is necessary to build sand-prevented construction systems perpendicular to shoreline, which are groynes. Constructions in this area have to fulfill dimension and structure stability requirements. We should not use the natural materials with unsuitable size or loss weight structures. It requires the resistant structures to confront wave attack and dyke, revetment base scour.

2.4. Master arrangement of construction system

About construction of the system, it can be cleared with some main description as follows:

- Dyke system: develop and build some new bare dyke segments based on present dyke segments to make a complete dyke system and to use as a street around the island.
- Breakwater system is built with curved shape. Its location and size are guided by government with detail: the longest distance between the breakwater and dyke is 160 m long and height is 1 to 1.5 times higher than the wavelength. The breakwater length is 1.5 to 3 times the distance between the dyke and breakwater, as a result, the length of designed breakwater is 200 m. Submerged breakwater is located alternately with emerged breakwater to reduce the height of wave attack, prevent erosion dyke as well as to create advantage conditions for transportation sediments between inside and outside of conservation area.
- Groynes combining dyke and breakwater are responsible for preventing sand. The distance among groynes is 2 to 3 times longer than the length of each groyne.
- The structures connect breakwater with revetment combines two tips of dyke (from T shaped-breakwater construction to dyke) into

an advantage, stable line system.

2.5. Calculate changes of shoreline after having protected constructions by using LITPACK model

After arranging shoreline protected constructions system, modeling study shoreline is implemented by using LITPACK model to simulate, calculate and forecast the change orientation. Input data consists of wave height, wind speed, sea water level, sediments and other input parameters.

Topographical data: Location of shoreline, shape of cross-shore profiles, direction of contours in deep water area according to topographical data in 2002 with 5820 m long of island shoreline; angle between its normal and north is 173^0.

Wave data: Based on the frequency of wave height and wave period (Table 1).

Other parameters: the values of other parameters are [5]:

- Roughness: 0.012;
- Geometrical spreading ($\sqrt{d84/d16}$): 0.748;
- Mean grain diameter d_{50}: 0.1mm;
- Fall velocity: 0.06m/s;
- Time of calculation: 12 months.

Besides, it is necessary to put other data when having protected constructions such as types of construction (including revetments, groynes, emerged breakwaters and submerged breakwaters); number of construction types (revetments, groynes, emerged breakwaters and T-shape structures, submerged breakwaters, and jetties); coordinate depicting location of each construction type such as apparent length, useful length, distance from structure to shoreline,...

2.6. Modeling the calculated area

The mathematical model is applied into an area of 5820 m in length (from Hoang Chau to Got) and 1200 m in width (from shoreline to sea) with grid step of 10 m parallel (583 points) and 10 m perpendicular to the shoreline (120 points). Time of simulation is 12 months, from January to December of a year, and the step is 60 hours. Input data for the model consist of number calculated cross-shore profile, location of points, roughness of seabed, diameter of seabed substances, geometrical spreading.

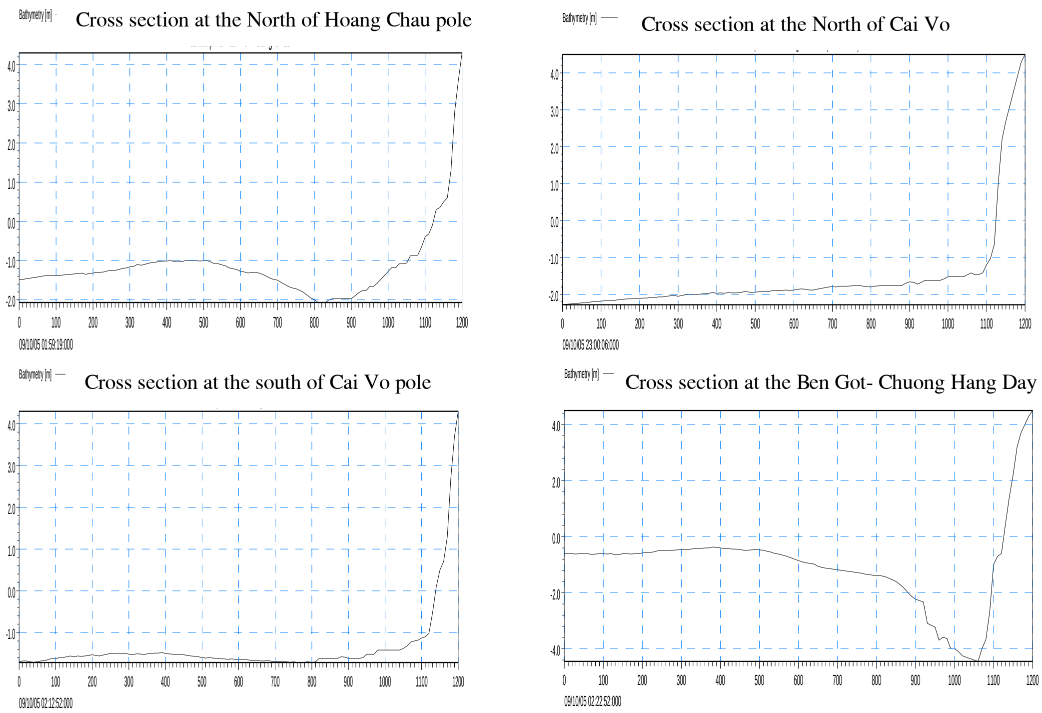
2.7. Procedure of calculation

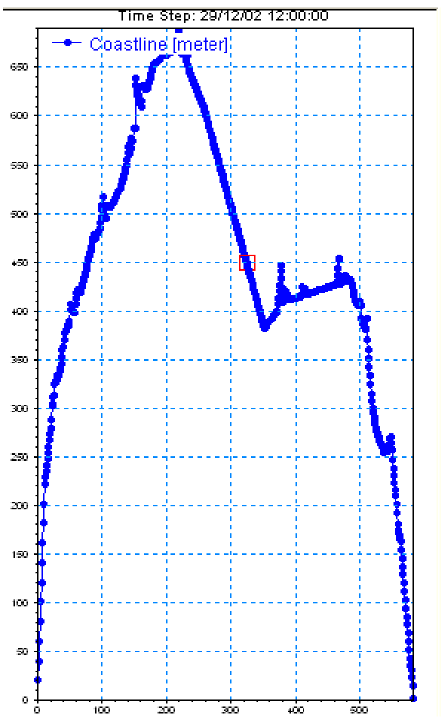
The calculation process has been done in the following steps:

- Input topographical parameters and other related conditions (shoreline, cross-shore profiles,...).
- Input annually monitored table of wave frequency and convert it into input wave data by using LITCONV module [3].
- Convert input sediment data by using LITTABL module.

Table 1. Wave height and wave period during year [4].

	Month	1	2	3	4	5	6	7	8	9	10	11	12
	Direction	S	E-SE	E	S-SE	S-SE	SE	S	E	E	E	S	E-NE
Waves period T (s)	Wave height (m)												
	0.0-1.0								7.7	7.7			
	1.0-2.0												
	2.0-3.0	9.1	7.6	7.5	9.3						6.8	6.7	7.1
	3.0-4.0					9.3							
	4.0-5.0						8.2						
	5.0-6.0							11					





	Time	1	2	3	4	5
118	23/10/02 00:00:00	20.1818	40.3636	60.5455	80.7273	100.
119	25/10/02 12:00:00	20.1818	40.3636	60.5455	80.7273	100.
120	28/10/02 00:00:00	20.1818	40.3636	60.5455	80.7273	100.
121	30/10/02 12:00:00	20.1818	40.3636	60.5455	80.7273	100.
122	02/11/02 00:00:00	20.1818	40.3636	60.5455	80.7273	100.
123	04/11/02 12:00:00	20.1818	40.3636	60.5455	80.7273	100.
124	07/11/02 00:00:00	20.1818	40.3636	60.5455	80.7273	100.
125	09/11/02 12:00:00	20.1818	40.3636	60.5455	80.7273	100.
126	12/11/02 00:00:00	20.1818	40.3636	60.5455	80.7273	100.
127	14/11/02 12:00:00	20.1818	40.3636	60.5455	80.7273	100.
128	17/11/02 00:00:00	20.1818	40.3636	60.5455	80.7273	100.
129	19/11/02 12:00:00	20.1818	40.3636	60.5455	80.7273	100.
130	22/11/02 00:00:00	20.1818	40.3636	60.5455	80.7273	100.
131	24/11/02 12:00:00	20.1818	40.3636	60.5455	80.7273	100.
132	27/11/02 00:00:00	20.1818	40.3636	60.5455	80.7273	100.
133	29/11/02 12:00:00	20.1818	40.3636	60.5455	80.7273	100.
134	02/12/02 00:00:00	20.1818	40.3636	60.5455	80.7273	100.
135	04/12/02 12:00:00	20.1818	40.3636	60.5455	80.7273	100.
136	07/12/02 00:00:00	20.1818	40.3636	60.5455	80.7273	100.
137	09/12/02 12:00:00	20.1818	40.3636	60.5455	80.7273	100.
138	12/12/02 00:00:00	20.1818	40.3636	60.5455	80.7273	100.
139	14/12/02 12:00:00	20.1818	40.3636	60.5455	80.7273	100.
140	17/12/02 00:00:00	20.1818	40.3636	60.5455	80.7273	100.
141	19/12/02 12:00:00	20.1818	40.3636	60.5455	80.7273	100.
142	22/12/02 00:00:00	20.1818	40.3636	60.5455	80.7273	100.
143	24/12/02 12:00:00	20.1818	40.3636	60.5455	80.7273	100.
144	27/12/02 00:00:00	20.1818	40.3636	60.5455	80.7273	100.
145	29/12/02 12:00:00	20.1818	40.3636	60.5455	80.7273	100.

Fig. 5. Illustration of graphic and tabular results.

- Run LITPACK and enter other parameters.
- Export results into graphs and animated images by PLOT COMPOSER in MIKE Zero package.

2.8. Results and discussion

After entering and calibrating input data, LITPACK will automatically calculate and print out the results. Products are simulated by detail numerical tables and graph due to changing time. With tabular results, one can observe directly on numerical table and shoreline graph, and then easily realize that the shoreline change process will occur more positively than natural change process. Depositing sediments occurs strongly at the root of groynes and at segments without groynes (Fig. 5). Graphic results (active length of groynes) are calculated from revetment to breakwater and the distance between baseline and breakwater is called *apparent length*.

The result shows that: after 6 months, deposition sediments occur at the bottom of groynes, especially in Got, Hoa Quang, Hoang Chau groynes. However, erosion occurs at the gap of western Hoang Chau and the outside area of dyke.

For longer time, after 12 months, shoreline will become more stable and deposition will occur at most of coastal zone, strongest at bottom of Hoa Quang, Van Phong, Hoang Chau groynes. In other sides, erosion process will continuously happen at segments among Western Hoang Chau groynes (this area is out of dyke and apart from old alluvial) and stop when reaching revetment and being alternated by a strongly alluvium development.

According to these results, Hoang Chau has the most stable deposited rate of 27 m over the area; other segments slowly widens to the sea from 2 to 15 m. Particularly in Hoa Quang groynes, deposited rate is 47 m per year but this alluvial segment is not large and stable.

In planning, evolution of the dynamic process can be illustrated that: after arranging construction, changes of Cat Hai Island shoreline are quite reasonable with lithology-dynamic rule of this area. In fact, waves erode coastal zone and sediments are carried by long-shore currents to Nam Trieu in the west, which cause siltation of Hai Phong shipping channel. Sediment is carried to Got and Huyen Inlet in the north. After arranging sand and wave-prevented construction, sediment carried to the west is trapped at Hoang Chau groynes with stable cumulative rate at the highest rate of 27 m per year. Meanwhile, stable alluvium rate at other areas is lower; the lowest rate in Gia Loc - Cai Vo is only from 2 to 5 m per year where sediment carried from the north into Huyen Inlet is trapped at groynes in Hoa Quang and Got areas.

3. Conclusions

Arrangement shoreline protected construction system in Cat Hai is mainly based on the analysis of hydrodynamic-lithologic conditions, meteorological, economic, social conditions and master plan of the island.

The LITPACK model can be successfully applied for simulating, calculating and forecasting orientation of coastal line changes due to erosion and sedimentation process.

According to the simulated and calculated results, the selected protected construction system, which includes revetments, T-shape sand prevented constructions, emerged and submerged breakwaters, is the most suitable and reasonable counter measures for Cat Hai shoreline stabilization.

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