Impact of sea embankment works in Cat Hai Island-district (Hai Phong city, Vietnam) on hydrodynamic fields and sediment transport

Tu Tran Anh[1,*], Tien Pham Van[2], T. Vu-Huu[3]

[1]Institute of Marine Environment and Resources (IMER-VAST), Haiphong City 18000, Vietnam

[2]Institute of Energy, Ministry of Industry and Trade, Vietnam

[3]Faculty of Civil Engineering, Vietnam Maritime University, 484 Lach Tray Str., Hai Phong, Vietnam

*Corresponding authors: tuta@imer.vast.vn

Abstract. Coastal contruction works have a certain impact on hydrodynamic fields. The MIKE 21/3 model is used as a tool to simulate the scenarios before and after the construction work (area of 752 ha in Cat Hai district, Hai Phong city). The simu-lation results show that: after the construction, there is no impact leading to the change of the water level regime in the study area; The flow direction changes quite a lot after the construction, especially in the east of the calculating area. Due to the narrowing the water area outside Lach Huyen estuary, the flow in both spring and ebb tides are markedly increased in magnitude as well as in spatial; Among the three modelled rivers - Lach Huyen, Cam and Lach Tray rivers - the sediment from Lach Huyen and Cam rivers is the most direct and strongest influenced. In the case of construction, there is not much difference between the dry and the rainy season scenarios. However, it is necessary to pay attention to rein-forcing the cape area with embankments, underground breakwaters, etc. to ensure the stability of the area under the impact of extreme conditions such as storms and strong monsoons.

Keywords: Sea embankment, current, wave, sediment, dry season, rainy season.

1 Introduction

The sea-encroachment activities to expand the area are important for the socio-economic development of the locality and the country [11]. Dinh Vu - Cat Hai economic zone, one of two economic zones in the North of Vietnam, was established in January 2008. This economic zone was established to develop the maritime economy with a focus on seaport services, includng the work/project "Investment in construction and business of infrastructure of Xuan Cau non-tariff industrial zone", an area of 752 hectares in Cat Hai town, Cat Hai district, Hai Phong city.

The construction and operation of the above works will have certain impacts on the natural conditions and environment of the area: hydrodynamic regime, sediment transport [6, 7, 8, 9]. This work presents the research and calculate results the effects of the construction on the flow regime and sediment tránportation in the area for the scenarios (dry season; rainy season, before and after the construction. Corresponding to these scenarios, the sediment transport at the boundary of the leveling area is also simulated. In this work, the MIKE 21/3 model is used as a calculation tool.

2 Data and Methodology

2.1 Data

In this paper, we used the following data:
- Topographic data of the seabed and estuary area measured by the Vietnam Navy Command;
- River profile data and riverbed topography provided by Red River Survey Federation;
- Topographic data of the study area is extracted from maps at scale 1:10,000; 1:25,000 provided by the Department of Surveying and Mapping.
- Wind data is analyzed from a series of wind monitoring data at Hon Dau station from 1975 to 2016
- Offshore wave data at the open boundaries of the grid are extracted from the reanalyzed wave data source of the European Center for Medium-Range Meteorological Forecasting from 1982 to 2016, with the spatial resolution of 1/8 degree longitude, time step 3 hours.

2.2 Methodology

This paper used hydrodynamic model MIKE 21/3 FM to simulate wave propagation from the offshore deep water area to the nearshore area.. The detailed wave propaga-

tion model will provide simulation results of wave field and bottom stress for hydraulic (FM) and mud and sand transport (MT, ST) models in correction and process variability transport of sand [1, 2, 3, 4]

3 Results

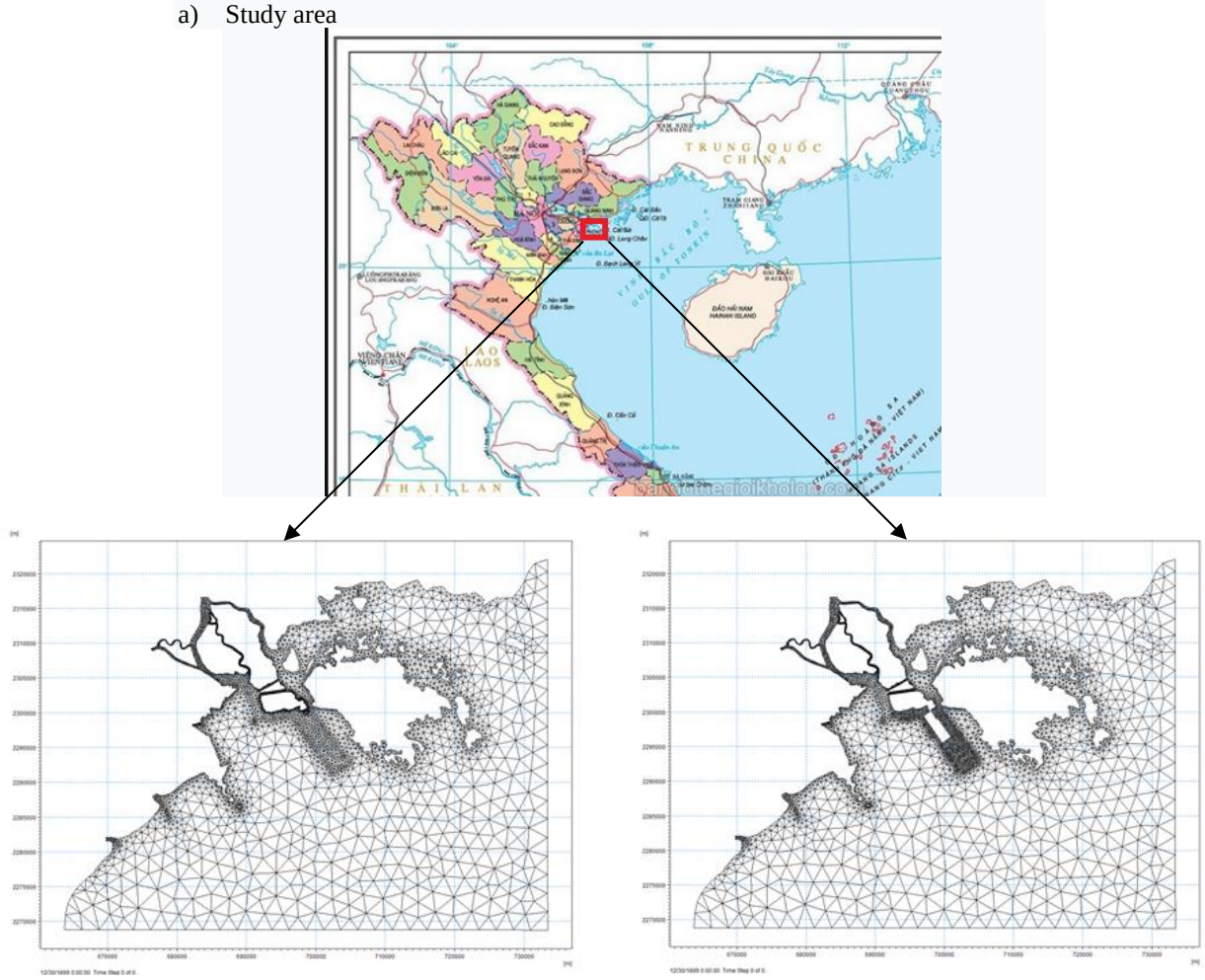
- ***Set up input conditions for the model***

In this study, the models Mike 11, Mike 21 SW, Mike 3 HD FM, Mike MT are used to calculate wave fluctuations, flow and sediment transport. Mike model 11 calculates the discharge boundary for hydrodynamic regime and sediment transport. The Mike 21 SW model dynamically connects to the flow computational model (Mike 3 HD FM) to consider the wave and flow interaction. It also dynamically connects to the sediment transport model (Mike MT) where the transport process is mainly due to wave flow cause by the gradient of the wave radiation stress field in the collapse wave region.

+ Set up the computing domain and grids

The computing domain in this study is set up in detail for the construction area with an unstructured net including 5873 mesh nodes with the current domain and 5429 grids with the planning domain. The length of the minimum mesh edge is 100 m (project area, estuary, canal and coastal area) the largest is about 5 km (offshore area).

a) Study area



b) Current domain

c) Planning domain

Figure 1. Map of scope and coputing domain of study area

+ Application of integrated model to calculate estuary boundary

The integrated model of Mike 11 and Mike 21 HD FM is used in the calculation of the river-sea hydrodynamic regime. The model was calibrated and validated according to measured a data at hydrological stations in 2006 and 2007. Then, the model was applied to calculate the discharge boudary for the Mike 3 HD FM model and calculates the variation of flow and sediment transport process for Mike MT model in case of before and after constructions. The calculating results of discharge boudary at the mouths of Da Bach, Cam, Lach Tray, Van Uc and Thai Binh rivers are shown in the figure below.

+ Data on suspended sediment concentration at river mouth boundary

Average daily suspended sediment concentration data were gathered at 5 hydrological stations in March and August 2015, specifically as follows: Do Nghi boundary (Da Bach river), Cua Cam boundary (Cam river), Kien An boundary (Lach Tray River), Van Uc mouth boundary (Van Uc river) and Thai Binh mouth boundary (Thai Binh river).

• ***Results on hydrodynamic simulation***

+ Calibration and validation results

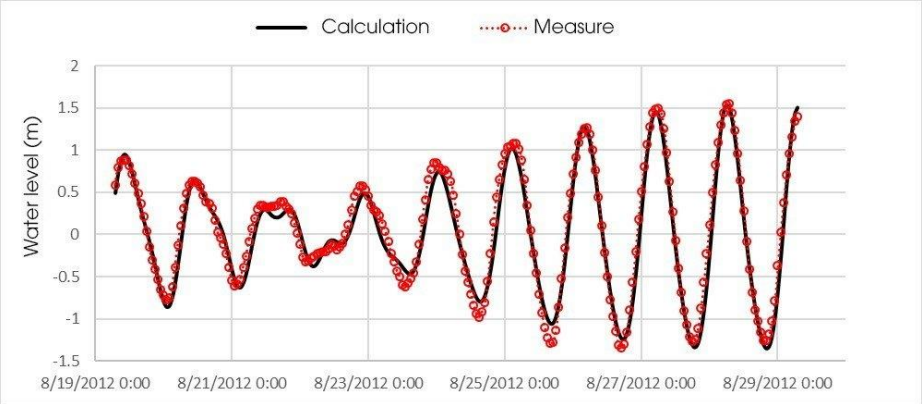


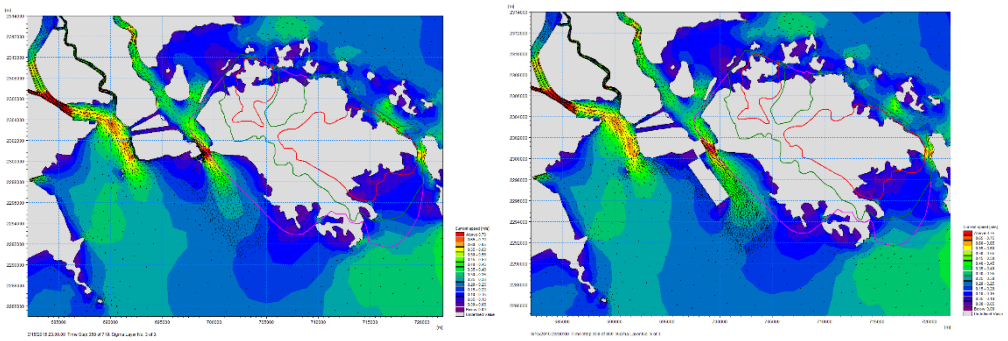
Figure 2. Comparison between modeled and measured of water levels at Hon Dau station

The modeled and mesured results for flow velocity is quite consistent in tidal phase, but big difference in value. The correlation of modeled and measured data of flow at two stations Do Son and Hoang Chau ranges from 0.46 to 0.76, the smallest at the bottom layer of Hoang Chau station, the largest at the middle layer of Do Son station. The modeled results of wave and wave height is quite close to the measured data but the wave cycle is low compared to the measured data. In general, the modeled results of water level and flow velocity are quite good, the error is acceptable (Figure 2).

+ Flow in dry season

Before the construction (KB01): the flow in the area in the dry season has the following characteristics: at the end of the high tide phase and at high tide, the flow velocity is quite small, the influence of the river mass is very limited, so the sea water penetrates deeper into the estuaries. The time of phase transition between high tide and low tide is quite small, about 2 hours. Also because the amount of river mass is small, the stopping time at low water time is shorter, the flow quickly changes from stopping to flowing. The simulation results of the flow during the high tide phase in the dry season show a

deeper influence of sea water masses into the mainland, especially in the area of Lach Tray estuary and the southwest of Dinh Vu island.
At the low tide time, the flow velocity in the coastal area of Hai Phong is quite small - about 0.1 to 0.2 m/s and strongly dispersed in the direction of flow. Also because the amont of water mass of rivers is small, the stopping time at low tide time is shorter, the flow quickly changes from stopping to flowing. The flow velocity at Bach Dang river is of 0.7-0.8 m/s and gradually decreases to Dinh Vu with a velocity of 0.2-0.4 m/s. In the northeast of the study area, due to the small amount of water brought from Quang Ninh and the low discharge from the Chanh River, the flow velocity in the dry season is only 0.1-0.2 cm/s.



(a) (b)

Figure 3. Surface flow-in dry season: (a)-before construction and (b)- after construction

The simulation results of the flow during the high tide phase in the dry season show that the influence of sea water masses deeper into the mainland, especially in the area of Bach Dang estuary. The flow direction in the area outside the estu-aries is quite uniform and direct towards the inside of the rivers. However, it only flows to to Dinh Vu area with a speed of 0.2-0.3 m/s, goes deeper, the flow is influenced by Bach Dang river with a speed of 0.5-0.7 m/s.
With the shape of the shoreline, in the dry season, the movement of water masses in the study area is toward more south and southwest of Do Son peninsula. Although the water discharge from the river in the dry season decreases sharply, the strengthening of the northeast wind makes this trend in the dry season decrease evidently.
After the construction (KB02): the flow in the dry season has the following character-istics: there is no much difference in the flow velocity between the surface, middle and bottom layers. However, there is a clear difference in flow before and after the con-struction. The construction has narrowed the scope of drainage from the mainland to the sea throught Lach Huyen estuary, so the flow velocity here increased significantly.

+ Flow in the rainy season
Before the construction (KB03): in the rainy season due to the big flow of river water during the high tide phase, the velocity of the flow from the sea towards the estuaries is small. In this tidal phase, the flow direction is mainly south - southeast with velocity

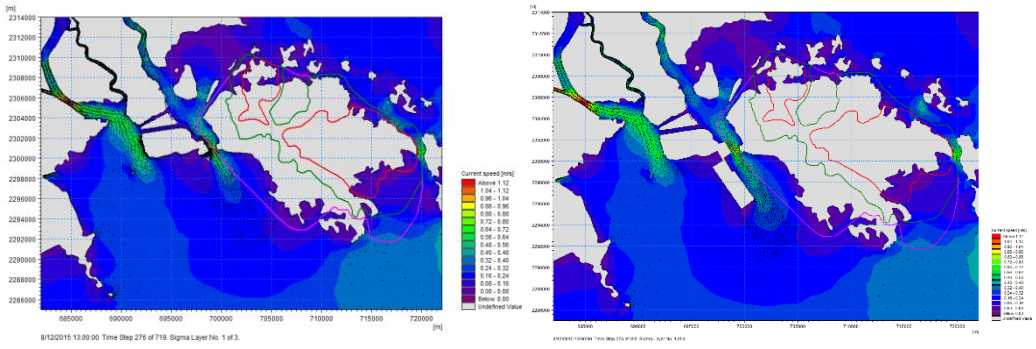
value varying from 0.2-0.7m/s. In the area of Cam-Bach Dang estuary, where the water flow is the biggest among rivers of the coastal area of Hai Phong, there is almost no reverse flow from the sea.

During the high tide, the flow direction in the coastal area of Hai Phong is strongly dispersed with relatively small velocity values, especially in the water area between Hon Dau, Cat Ba and Cat Hai. Also in the Cam-Bach Dang estuary, because the river flow is still quite strong while the water level is highest, the flow at that time is quite high and outward direction (south, southeast and southwest). The combination of river flow and tidal flow is clearly shown in the ebb tide phase, creating a combined flow with a relatively large velocity compared to other tidal phases. The flow direction in this case is toward direction of the river to the sea, and is mainly southeast, southwest and south. The flow velocity value varies in the range from 0.2 - 0.8m/s. In some places due to narrow channel such as Lach Huyen estuary, Nam Trieu estuary... the flow velocity can reach values above 1.0m/s.

During the low tide, the river water mass is strong toward to the sea, however due to the limitation of river water flow, the flow towards to the sea only exists in the range of about 10 - 20 km from the shore to the outside. At that time, the flow in the Bach Dang river area was very high, varying from 0.9 to 1.4 m/s.

The calculation results show the shift trend of water masses to the south and southwest of the Do Son peninsula in different changes of the tidal phase (except for the high tide phase). The cause of this phenomenon may be due to the compaction of water masses while the exchange of water in the north is very lim-ited causing by the relatively shallow terrain in the northeast.

After the construction (KB04): the flow velocity in the rainy season decrease from the surface layer to the bottom. However, there is a clear difference in flow before and after the construction. The construction has narrowed the scope of drainage from the mainland to the sea throught Lach Huyen estuary, so the velocity here increased significantly. In particular, the flow velocity in zone 7 (Figure 5.22) suddenly increased, because the construction created a rather narrow channel.



(a) (b)

Figure 4. Bottom flow-in rainy season: (a)- before construction and (b)- after construction

- ***Results of wave simulation***

The wave in the study area before construction: wave height varying from 10 - 75 cm in the dry season and and from 10 - 60 cm in the rainy season. There is no much difference in wave height before and after the construction.

• Results of sediment trasport simulation

+ In dry season

Before the construction (KB01): the sediment transportation is closely relat-ed to hydrodynamic regime and sediment supply sources. In the dry season, due to the strong decrease in the supply source of sediment from the estuaries, at the time of high tide, the sediment transportation flow is very limited to the coastal area compared to the rainy season. Only a small area of water outside the Nam Trieu estuary has a relatively high sediment concentration (from 40-120mg/l) and the rest of the areas have a small sediment concentration.

In the ebb tide phase, the suspended sediments from the mainland have favorable conditions to disperse outward. The waters with relatively high sediments suspended concentration (about 50-110mg/l) are also concentrated near to the Nam Trieu and Lach Tray estuaries. Due to the influence of the hydrodynamic regime and the main influence of the northeast winds, the suspended sediment flows mainly to the southwest after leaving the estuaries with a very small scope compared to the rainy season.

The ebb tide period is the time the sediment transport flow from mainland is likely to have the greatest effect on the coastal zone. However, as in the low tide phase, suspended sediment can only have a very limited effect just outside the estuaries. The suspended sediment concentration in water at the northern coastal areas of Do Son peninsula, the coast of Cat Hai and Cat Ba in this case also low.

In the dry season, the mechanism of transportation and change of suspended sediment (SS) in the coastal estuary of the study area in the case of high tide is similar to that in the rainy season. However, the decrease of suspended sediment and water mass from rivers makes the influence of sea water masses with low suspended sediment concentration become stronger, the waters with low suspended sediment concentration go deeper into river beds, especially rivers with low water mass such as Lach Tray.

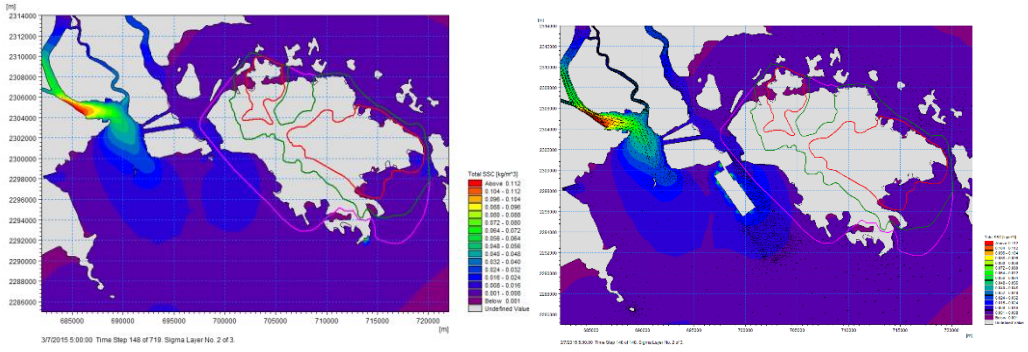
In the southwest area of Cat Ba island, the SS concentration in this area is quite small with values fluctuating below 10mg/l. This can be explained because this is a place less affected by sedimentary sources from the mainland compared to the rest of the calculation domain and the SS value is also stable in both seasons

In the southern and southwestern areas of Cat Hai island, due to its location clos-er to the estuaries of the northern Do Son peninsula, the SS concentration in the water decreases gradually from those estuaries to this area, and it fluctuates be-tween 5 to 30mg/l. The variation of SS concentration with time strongly depends on water level fluctuations and it represents the role of sediment flows from the mainland. The value of SS concentration usually peaks at low water and decreas-es gradually with rising tide until the concentration is minimized at high tide. The variation of SS concentration is also stronger on high tide days.

On the last calculation date, SS concentration is range of 40 - 45 mg/l in the southern area of Cat Hai Island, and from 25 to 30 mg/l in the Cat Ba area (aquaculture areas, beaches). These calculation results are similar to some previous publications [5, 10, 12, 13, 14, 15, 16, 17].

After the construction (KB02): the picture of SS scope is narrower compared to the before construction. The value of SS concentration in the Cam river mouth area is the largest compared to that in the whole study area. In the area around the construction soles, with the assumed initial condition to be leakage at the boundary of the construction is 50 mg/l of SS, the SS concentration value varies in the range of 40-80 mg/l. The volume of water with sediment concentration value less than 40 mg/l does not exceed the embankment tip of the outermost construction on the sea side.

- On the last calculation date, SS concentration is range of 30 - 55 mg/l in the southern area of Cat Hai Island, and from 25 to 30 mg/l in the Cat Ba area (aquaculture areas, beaches).



(a) (b)

Figure 5. Dispersion of SS in the middle layer- in dry season: (a)- before construction and (b)- after construction

+ In the rainy season

Before the construction (KB03): The characteristics of transportation and variation of SS in the dry season were similar to those in the rainy season. However, to the decrease in fresh water flow and the changes in wind direction have created specific differences in SS characteristics in the study area in the dry season. In the rainy season, the SS conconcentration in the rivers is greater than 100 mg/l. Cam river area has higher SS content than other rivers. With these characteristics, the SS simulation results in the rainy season show the waters with high SS concentration mainly occur in the Nam Trieu and Cam river estuaries with the influence of sedimentary sources from the upstream. Due to the influence of the flow, the distribution and fluctuations of suspended sediments in the coastal estuaries of the study area mainly follow the fluctuating of the tidal water level.

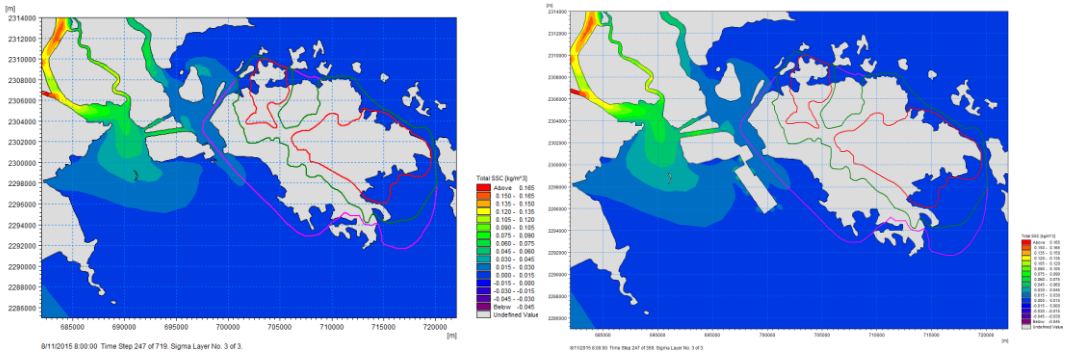
- During the high tide phase, the flow direction is from the sea to the estuaries, so the water area with high suspended sediment content is gradually pushed towards the mainland. In the coastal areas of the study area, during this time, the suspended sediment concentration in water is small, demonstrating the strong intrusion of sea water masses into the coastal area during this tidal phase.
- The intrusion of sea water masses is strongest at the time of high tide. During this tidal phase, the transportation of suspended sediment continues as the trend of the rising tide phase. Dispersion of suspended sediments from rivers to the coastal areas is the most

limited and only concentrated close to the estuaries. Meanwhile, the remaining areas are affected by sea water masses with relatively small suspended sediment content (< 30mg/l).

- Dispersion of suspended sediment from the mainland to the outside of the coastal estuary is clearly shown in the ebb tide phase. Under the influence of the flow in this tidal phase, the suspended sediment not only moves outward, but also tends to move more south-southwest in the direction of river water masses.
- During the low tide, river water masses as well as suspended sediments from the mainland have the strongest conditions to move outward, especially towards Nam Trieu estuary. The suspended sediments with high concentration also occurs in some other areas such as in the southern coast of Cat Hai island and in the northern coast of Do Son peninsula. Although this is the best time that the sediment flow has favorable conditions to expand to the sea compared to other tidal phases, the influence range of suspended sediments from the mainland in normal weather is only concentrated in Nam Trieu estuary area, in southwest of Cat Hai island, and in northern coastal area of Do Son peninsula.

After the construction (KB04): The variation of SS with time: in the southwest area of Cat Ba island, the fluctuation of SS concentration over time shows this area is not affected by sedimentary sources from the mainland. The concentration of suspended sediment in this area is less than 60mg/l. With a small SS concen-tration and less impacted from the estuary, the SS in this area is quite stable over time. However, during the high tide days (water level greater than 2.5m) of the spring tide period, peaks of suspended sediment concentration were observed at low tide, showing a tiny influence from the estuaries and rivers; In the southern and southwestern areas of Cat Hai island, due to its location closer to the estuar-ies of the northern Do Son peninsula, the suspended sediment content in the wa-ter decreases gradually from those estuaries until this area and fluctuates in about 15 - 60mg/l. The temporal variation of the SS strongly depends on the water level fluctuations and it represents the role of sedimentary flows from the mainland. SS values usually peak at low tide and gradually decrease at high tide until the con-centration is minimized near times of high tide. The variation of suspended sedi-ment concentration is also larger on high tide days.

- On the last calculation date, the concentration of suspended sediment in water in the west coast of the study area was found in the range of 150 mg/l (from the mouth of the Cam-Bach Dang river to the Do Son peninsula). In Cat Ba area (aquaculture areas, beaches) the value of SS is about 40 mg/l. Because the big river water mass from the mainland in the rainy season is much larger than that in the dry season, the spatial scope of suspended sediment in the water mass higher than 100 mg/l and pass over Hon Dau island. At the construction soles, the value of suspended sediment between is 60 – 100 mg/l in the surface layer and is of 30 -50 mg/l in the middle/bottom layer with significant difference.



(a) (b)

Figure 6. Transportation of surface suspended sediment - in dry season: (a)- before construction and (b)- after construction

4 Conclusions

From the calculation results of the numerical model, some conclusions can be made as follows:

- For the water level: after the construction, there is no impact leading to the change of the water level in the study area;

- For the flow: the flow in this area is mainly influenced by the tidal current, the river current, the wind current, and the topography of the area. The flow velocity in the high tide phase is smaller than that in the ebb tide phase. The flow direction changes a lot after the construction, especially in the east of the calculation domain. The remarkable note is the intensification of flow in the canal area created by the construction and Cat Ba island. Because the construction narrows the water area outside Lach Huyen estuary, the flow in both ebb and phases was markablely increased in both magnitude and scope.

- For the suspended sediment transportation: among 3 caculated rivers included Lach Huyen River, Cam River and Lach Tray River, the suspended sediment in Lach Huyen and Cam rivers is the most direct and strong influenced. After the construction works: there is not much difference of SS between the rainy season and rainy season. However, it is necessary to pay attention to reinforcing the cape area with embankments, underground breakwaters, etc. to ensure the stabil-ity of the construction under the impact of extreme conditions such as storms and strong monsoons.

References

1. DHI 2011, MIKE 21 & MIKE 3 Flow Model FM Hydrodynamic and Transport Module Scientific Documentation.
2. DHI 2011, MIKE 21 & MIKE 3 Flow Model FM Mud Transport Module Scientific Documentation.
3. DHI 2011, MIKE 21 & MIKE 3 Flow Model FM Sand Transport Module Scientific Documentation.

4. DHI 2011, MIKE 21 & MIKE 3 Flow Model FM ECO Lab / Oil Spill Module User Guide.
5. Lefebvre J.P., Ouillon S., Vu Duy Vinh, Arfi R., Panche J.Y., Mari X., Chu Van Thuoc, Torreton J.P., 2012. Seasonal variability of cohesive sediment aggregation in the Bach Dang-Cam Estuary, Haiphong (Vietnam), Geo-Marine Letters, 32 (2), 103-121.
6. Tran Duc Thanh, 1991. Determining causes and proposing solutions to prevent coastal erosion of Cat Hai island from the point of view of dynamic geology. Project of Hai Phong city.
7. Tran Duc Thanh, 1992. Investigate and survey the accretion level to assess the feasibility of building Ngoc Hai fishing wharf. Project of Hai Phong city level.
8. Tran Duc Thanh, 2000. Research on prediction and prevention of coastal erosion in the North of Vietnam from Quang Ninh to Thanh Hoa (period 1999-2000). National project, code KHCN.5A.
9. Tran Duc Thanh, Vu Duy Vinh, Dang Hoai Nhon, Bui Van Vuong, 2019. Solutions for stabilizing lagoon mouths in Central Vietnam. Journal of Marine Science and Technology, Volume 19, No. 1; pages 1-13.
10. Pham Huy Tien, 2005. Prediction of erosion-accumulation phenomena in coastal and estuarial areas and proposing of solutions to prevent them. Summary report of National project, code: KC.09-05; 297 pages
11. Du Van Toan, 2016. “Sea encroachment and their impacts on coastal ecological environment in the world and in Vietnam”. Environmental Magazine.
12. Tran Anh Tu, 2012. Evaluation of suspended sediments in the coastal estuary area of Hai Phong. Master thesis. Archived at the Institute of Marine Environment and Resources.
13. Dinh Van Uu, 2013. “Hydrodynamic and environmental characteristics in the Bach Dang estuary area”. VNU Science Journal, Natural Science and Technology 29, No. 1S (2013). p 196-200.
14. Vu Duy Vinh, 2012. Study of suspended sediment transport characteristics in Hai Phong coastal area by Delft3D model. Master thesis. Archived at the Hanoi-University of Science, Vietnam National University Hanoi.
15. Vu Duy Vinh, 2015. Applying numerical model to assess role of mangrove forest in wave attenuation in Hai Phong coastal area. Journal of Marine Science and Technology, Volume 15, No 1 (2015): 67-76.
16. Vinh, V.D.; Uu, D.V. The influence of wind and oceanographic factors on characteristics of suspended sediment transport in Bach Dang estuary. J. Mar. Sci. Technol., 2013, 3, 216–226
17. Duy Vinh, V.; Ouillon, S.; Van Uu, D. Estuarine Turbidity Maxima and Variations of Aggregate Parameters in the Cam-Nam Trieu Estuary, North Vietnam, in Early Wet Season. Water 2018, 10, 68.