Enhancement of coastal protection under the context of climate change: A case study of Hai Hau coast, Vietnam

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Abstract

Climate change and global warming have led to severe typhoons and sea level rise (SLR) which may threat the stability of coastal structures. However, countermeasures to enhance coastal protection against SLR and severe typhoons have not appropriately considered in Vietnam. This paper focused on the enhancement of coastal protection in Hai Hau district – the most serious erosion coast in the North Vietnam. Erosion in Hai Hau coast has occurred continuously since the beginning of 20th century with average retreat rates of 10-15 m/y. The maximum rates reached to 40-50 m/y in some segments. Sea level is considered to rise about 2 mm/y on average in Vietnam. The number and intensity of tropical cyclones have a complicated change with a tendency of much more severe in recent years (2004-2013). Each year the accelerated rate of erosion due to SLR is 0.1-0.3 m/y in the Hai Hau coast. SLR also causes larger wave pressure on the seadikes making them more unstable in typhoons and storm surges. In the projected scenarios of SLR, erosion rates and scouring of dikes trough in Hai Hau coast were predicted to increase sharply in the next few decades. Besides, typhoons induce wave overtopping cause severe erosion of inner slopes of sea dikes and lead to dike broken. Countermeasures to enhance coastal protection of Hai Hau district focus on using local available materials, ecological engineering and geosynthetics measures. As a conclusion of the paper, to cope with future threats induced by climate change, solutions of multiple protections in Hai Hau coast were proposed which include conventional structures (i.e. dike, revetment, groins, mangrove) together with geotubes as submerged breakwaters and vetiver grass.

Keywords: Erosion coast, sea level rise, typhoon, geosynthetics, ecological engineering, coastal protection

1. Introduction

According to the fifth report of IPCC, average temperature of the global increased 0.89^{0}C in the period of 1901-2012 and about 0.72^{0}C over the period of 1951-2012. From 1993 to 2010, the rate of SLR was very high at 3.2 mm/year. The SLR would also raise the ground water level (GWL), thereby, engendering infrastructural instability along the coastal zones (Yasuhara et al. 2007)

Many coasts around the world have suffered erosion as a significant hazard in the region such as in Bangladesh, China, and the Southeast Asia. The increase of erosion rate due to SLR can reach to 0.14–0.31 m/y in the coast of the Red River delta, Vietnam (Duc et al. 2012). Coastal disasters in Vietnam impact on human settlements and infrastructure, which has become severe in terms of magnitude, frequency, and volatility (Takagi et al., 2013). There were some types of structures designed in order to protect coastline. Chu et al. (2009) classified river and coastal structures according to materials used, including conventional methods and relatively new ones. The most three traditional types are earth-fill dike, masonry and concrete, and steel sheetpiles or bored piles. In the past decade methods using geotextile or geosynthetic materials and prefabricated concrete segment have been considered and innovated.

Due to lack of investment, the current coastal dikes still have to suffer overtopping seawater. In such case, vetiver grass is a suitable application for protection of inner coastal dike slope. The vetiver hedgerows reduce soil loss on a slope by 62–86 % in comparison to the case without vetiver hedgerow (Donjadee and Tingsanchali 2013). Vetiver can also be used in combination with other traditional engineering solutions (Truong 1998; Truong et al. 2008).

Mangrove forest is another measure against coastal erosion, which has been applied in the coast of Hai Hau. A hundred meters of mature mangrove can reduce 0.1 m of wave height (Mazda et al. 1997 and Quartel et al. 2007).

Application geotube is now popular worldwide with its advantages such as easiness, cost-effectiveness, rapidity of installation and durability (Koffler et al. 2008). Recently, owing to the high cost of rubble mound coastal structures, the application of geotube technology has become a serious consideration (Shin and Oh 2007). They work as an efficient and environmentally friendly solution to protect shoreline from erosion (Sheehana and Harrington 2012).

Hai Hau is a district in coastal zone of Nam Dinh province that has been formed by deposition process of the Red River delta system. The Hai Hau coast includes 7 communes such as Hai Loc, Hai Dong, Hai Ly, Hai Chinh, Hai Trieu, Hai Hoa, and Hai Thinh. The shoreline is a straight line directing from Northern East to Southern West in a distance of about 27 km (Fig. 1). The slope is 1:40 in near the shore, and it is from 1: 350 to 1: 200 at the depth of over than 1 m. The slope decrease as the sea water depth increases. The shoreline is covered by fine sand with the thickness of 0.5 - 2m. That sandy layer is thinner seaward. The tidal amplitude is 2.5–3 m. Waves have main directions of East, Northeast in winter and East, Southeast in summer. The average height of waves is 0.7 - 1.3m and reach to 3.2 m in storms.

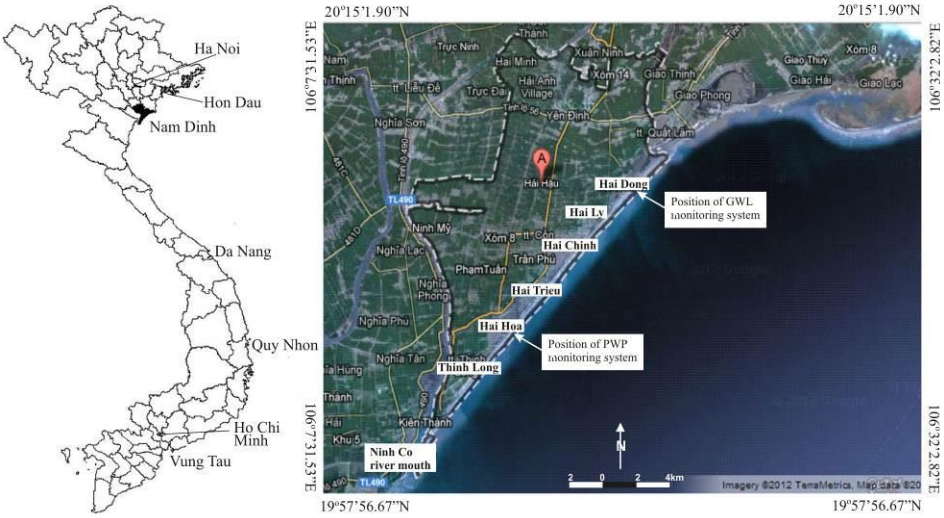

Fig. 1 Location of the Hai Hau coast

2. Coastal erosion and the protection in Hai Hau

The erosion in Hau Hau coast occurred from 1905, having close relation to the Ha Lan river mouth. The shoreline in Giao Long and Giao Phong was deposited between period of 1905 and 1930 with speed of deposition reaching 200 m/year in some segments. Nevertheless, during the period from 1965 to 1985 the shoreline was eroded. The Ba Lat mouth then gradually became the main river mouth in Hau Hau coast. After 1980s, the erosion was prone to decrease because the shoreline was protected by the sea dike system. In the period between 1985 and 1995, the erosion intensity was more 1.5 times higher than the period of 1965-1985. Specifically, at hai Chinh – Hai Hoa segment the erosion speed was 15-20 m/year. Recently, the shoreline in Hai Thinh commune is being the most eroded segment in Hai Hau coast with the average speed of 400 m/year.

Fig. 2 Land loss due to erosion in Hai Ly

Fig. 3 Broken seadyke in Hai Hau

In the 1980s, sea dike in Hai Hau coast was simply embanked by available soils which is easily eroded by wave and storm surge in typhoons. To reinforce the dike some conventional solutions were used like T-groins, mangrove forest and tripods (Fig. 4). The sea dike system in Hai Hau district was intensively reinforced with the height of the dike extending to + 4.5-5.5m, the foot of dike placing at 1.5m depth and concrete revetment covering outer slope.

a) T-groin

b) Mangrove plantation

c) Tripods

d) Concrete revetment

Fig. 4 Conventional measures in Hai Hau coast

3. Recognition of Climate Change in Vietnam

According to the MONRE (2009), the annual average temperature in Vietnam became higher about 0.5 – 0.7^{0}C from 1985 to 2007. The annual average temperature in the period of 1961-2000 was higher than that of the period of 1931-1960.

Basing on data of 4 stations: Hon Dau (Quang Ninh province), Da Nang and Quy Nhon (Centre part) and Vung Tau (South of Vietnam), the relative sea level rise in Vietnam was 1.9 mm/year from 1960 to 2000 (Hanh & Furukawa, 2007). According to data taken from two stations Hon Dau and another one at Hai Hau coast, Thuy NN (1995) showed that the SLR was 2.24 mm/y in Vietnam from 1950s to 1990s.

It is clear that the number of typhoons landing Vietnam coast rapidly increased from 2005 up to now. Especially, the number of typhoons was 14, 13 and 19 in 2008, 2009 and 2013 respectively. In the period of 1961-2004, the number indicated an unclear relation to climate change but complicated (Fig. 5). Therefore, the number and intensity of typhoons attacking Vietnam coast would be unpredictable in the future.

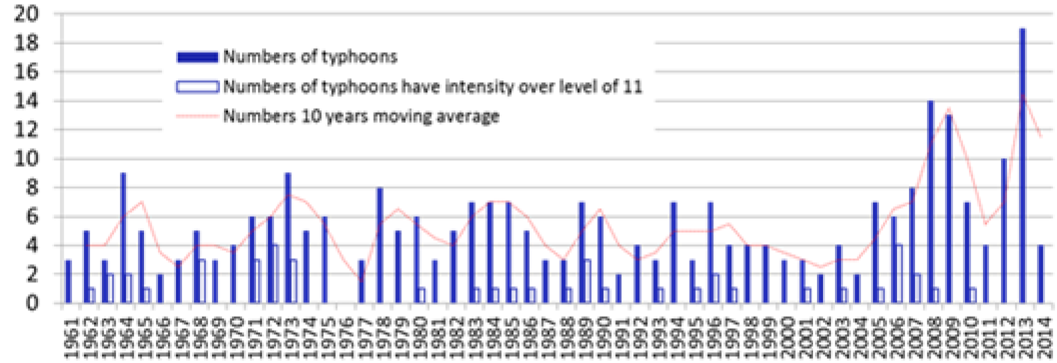

Fig. 5 Number of typhoons attacked Vietnam coast (1961-2014)

4. Impacts of Climate Change

4.1 Increase of erosion

Using the formula of Bruun (1962), accelerated rate of erosion due to SLR in Hai Hau coast was estimated.

$$R_{\infty} = 0{,}001S\,\frac{L_*}{h_* + B} \tag{1}$$

in which: S - SLR (mm/y); R∞ - the accelerated rate of erosion due to SLR (m/y); L* and (h*+B) are the width and vertical extent of the active cross-shore profile.

Duc et al. (2012) showed that the accelerated rate can reach to 0.17-0.25 m/y along the coast of Hai Hau, and as raw estimation SLR can cause 10-50% of the exceeding rate during the periods 1985-1995 and 1995-1999.

4.2 Scour

The physical model of Barnett and Wang (1988) was used to estimate the rate of beach lowering in Hai Hau.

$$\Delta h = 100\Delta Y \times b / l \tag{2}$$

Where: Δh – Rate of beach lowering (cm/y), ΔY - Erosion rate (m/y), l - Width of beach from shoreline to the depth of mean sea level (m), and b - Height of berm (m).

Recently, the beach lowering rate is very serious in Thinh Long town with the value is 156 cm/year. Meanwhile, the figure for Hai Ly, Hai Chinh, Hai Trieu, and Hai Hoa is at high rate with 15-25cm/year.

5. Impacts of extreme weather events

5.1 Typhoon-induced erosion

The retreat distance caused by extreme wave heights can be estimated by the formula of Kriebel and Dean (1993). Hai Hau coast experienced the erosion rate of about 100 m in a severe typhoon in 1999 at Nghia Phuc coast (Duc et al. 2007). The erosion rate can reach to 7.1 m when the wave height is 4.25 m high and the duration is 2.4 hours. As a consequence of climate change leading to stronger variability of frequency and intensity of typhoons in the Vietnamese coast, the extreme erosion rates can be more often and severe in the future.

5.2. Wave overtopping and soil erosion

To estimate amount of overtopping water under extreme condition being combination of storm surge and highest tide level in Hai Hau coast, the formula of van der Meer and Janssen (1995) was used, which is as follows:

$$\frac{q}{\sqrt{gH_s^3}} = \frac{0.06}{\sqrt{\tan\alpha}}\gamma_b \xi_{op} \exp\left(-4.7\frac{R_c}{H_s}\frac{1}{\xi_{op}\gamma_b\gamma_f\gamma_\beta\gamma_v}\right) \tag{3}$$

In which: $\xi_{op} = \dfrac{\tan\alpha}{\sqrt{S_{op}}}$ and $S_{op} = \dfrac{2\pi H_s}{gT^2}$

q: average overtopping rate (m^3/s per m width); g: 9.81 ms^{-2} is acceleration due to gravity; Hs: significant wave height (m); α: average slope angle; γ_b: reduction factor for a berm; ξ_{op}: breaker parameter; R_c: crest freeboard (m); γ_f: reduction factor for slope roughness; γ_β: reduction factor for oblique wave attack and γ_v: reduction factor due to a vertical wall on a slope; S_{op}: Wave steepness; T: period of wave (s);

Data acquired from the Damrey typhoon in 2005 were used in the equation (3). The input parameters are H_s = 3.2 m; T = 5.7 s; γ_b = 1; γ_f = 0.9; γ_β = 1; γ_υ = 0.65 (Fig. 6). The results shown average overtopping rate were illustrated in table 1.

Velocity of water flow on surface of inner slope is calculated by Chezy's equation as:

$$v = C\sqrt{Ri} \tag{4}$$

In which, Chezy coefficient (C) was determined by Manning's equation:

$$C = \frac{1}{n}R^{1/6} \tag{5}$$

$$R = \frac{bh}{b + 2h} \tag{6}$$

Where:

v: mean flow velocity (m/s); C: Chezy coefficient; R: hydraulic radius; i: slope of channel bed; n: roughness coefficient (Pierre, 2012); b: width of flow (m); h: depth of flow (m).

Materials used to build coastal dike in Hau Hau coast are mostly clayey sand with low compaction. Based on empirical relations between water velocity and erosion rate for various types of soils (Fig. 7) of Briaud (2008), erosion rates at the inner slope of the Hai Hau dikes during a typhoon are shown in table 1.

Erosion is very severe at Hai Hoa, Hai Trieu, Hai Chinh, and Hai Ly, especially in Hai Trieu where inner slope was bare soils and no vertical concrete wall to prevent wave running up. It shows a good match with the fact of the Damrey typhoon, when coastal dikes in Hai Hoa, Hai Trieu, and Thinh Long were broken. After the typhoon, coastal dike in Thinh Long was rebuilt and the current one has much higher resistance to overtopping-induced erosion.

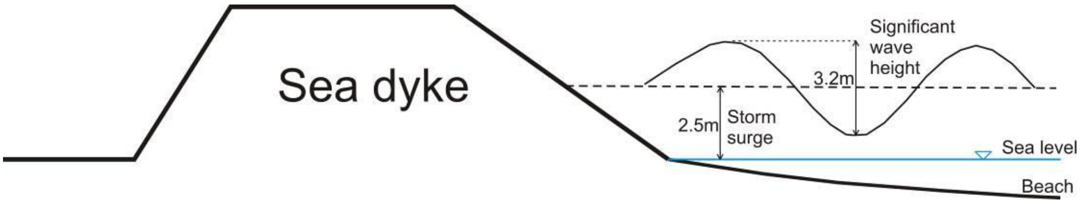

Fig. 6 Input data of storm surge and wave in Damrey typhoon

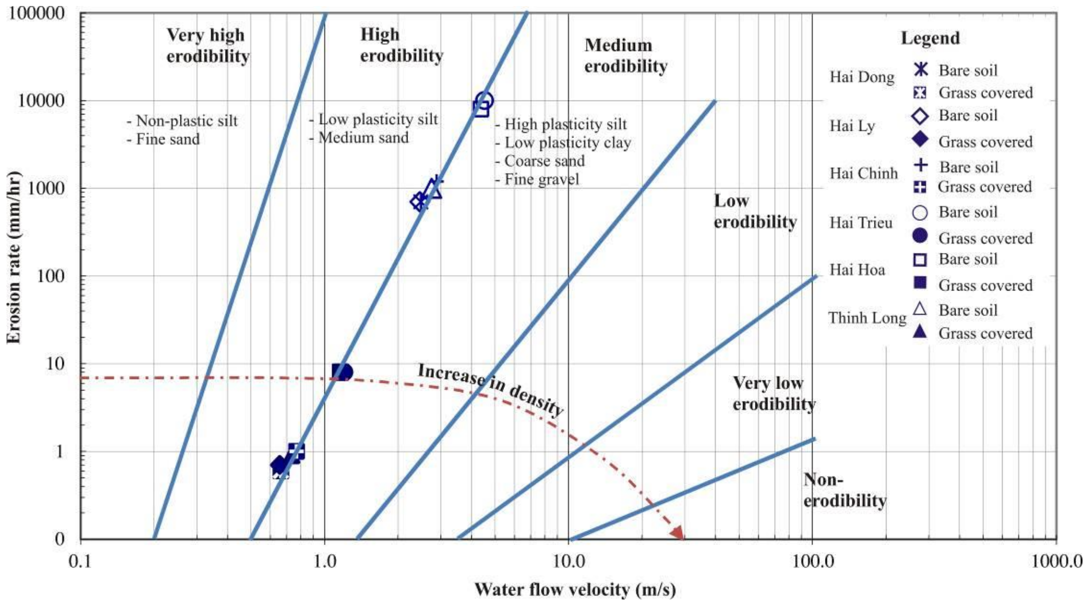

Fig. 7 Estimation of erosion rate in soils at inner slope of coastal dike in Hai Hau coast (Original chart referred from Briaud 2008)

Table 1 Erosion rates caused by wave overtopping during typhoon at dike inner slopes

Section	Outer slope (deg.)	Crest freeboard Rc (m)	Length of inner slope (m)	Inner slope (deg.)	Overtop-ping flow (l/s per m)	Water flow velocity (m/s)		Erosion rate (cm/hr)	
						Bare soil	Grass covered	Bare soil	Grass covered
Hai Dong	14	1.80	5.2	25	81	2.48	0.66	70	Very low
Hai Ly	14	1.60	7.5	25	115	2.46	0.66	70	Very low
Hai Chinh	13	1.35	7.0	25	137	2.88	0.77	120	Very low
Hai Trieu	14	1.40	5.0	33	164	4.53	1.21	1000	Very low
Hai Hoa	15	1.60	4.2	27	150	4.40	1.17	800	Very low
Thinh Long	14	1.60	7.2	30	115	2.75	0.73	100	Very low

6. Geotechnical monitoring for Climate Change adaptation

6.1. Ground water level (GWL) monitoring system

In order to monitor GWL under the dike, a monitoring system was installed in Hai Dong commune. The data taken from the system will be connected to tide level in the area. The system includes two sensors to be assembled in two boreholes which are 10 and 12m in depth. Being combined with tide level data in the study area, the data shows relationship between fluctuation of the tide level and GWL was presented in Fig. 8. Generally, every fluctuation in tide level triggers corresponding fluctuation in GWL in a linear relation. Corresponding with the amplitude of tide oscillation from 0.047 to 1.70m height, the GWL fluctuates between -1.54 and -0.313m. Therefore, elevation difference of GWL and tide level in the monitored period changes from 1.59 to 2.01m. Considerably, the data gotten by the sensor 1 is always higher than sensor 2 which vaies from 8.7 to 39.7cm. The difference may be come from two reasons: Firstly, the sensor 1 was installed closer to the shoreline than the sensor 2; Secondly, layer 3 (clay soil) is located at higher elevation at position to install the sensor 2 so that it leads to a hysteresis in changing of GWL.

Due to this relationship, GWL can be interpolated. It is forecasted that the ground under sea dike will be saturated when seawater level reaches to 2.5m high.

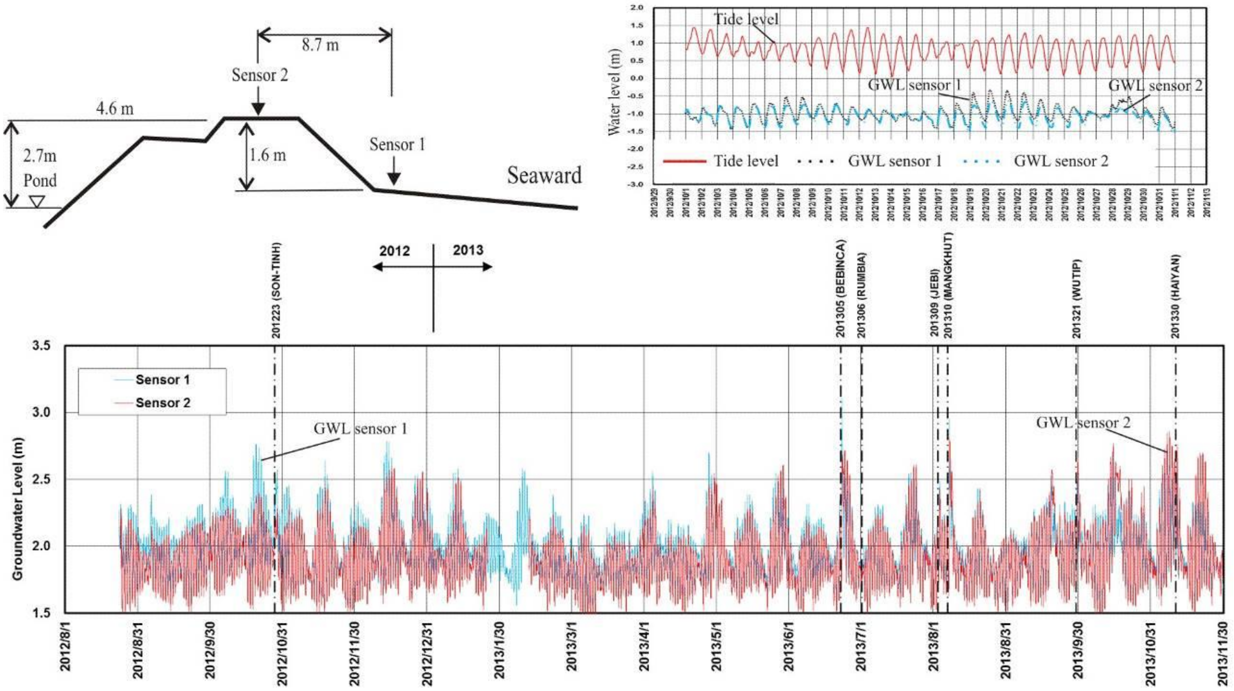

Fig. 8 Groundwater level monitoring system in Hai Dong commune

6.2. Pore water pressure (PWP) monitoring system

Calculations to determine PWP under the ground through data of GWL are somewhat incorrect because of concerned factors like tide, wave and stratum. Therefore, in order to have a precise insight into variety in PWP in the dike body and ground, a PWP monitoring system was installed in the area (Fig. 9).

Equipment used for the system is provided by Slope Indicator. Sensors are Vibrating Wire (VW) type possessing a high accuracy in range of pressure from 0.7 Bar to 35 Bar. Totally, 7 piezometers were installed in and under the sea dike.

The piezometers are located at different depth and isolated from each other to establish a net of multi-level PWP inside and under the dike.

PWP at the same depth but different positions inside and under the dike are different. PWP in the same borehole but different levels are also different. The deeper piezometers are located the higher PWP value they show. North-east monsoon strongly impacts on changes in PWP, inducing higher PWP even in lower tide level conditions.

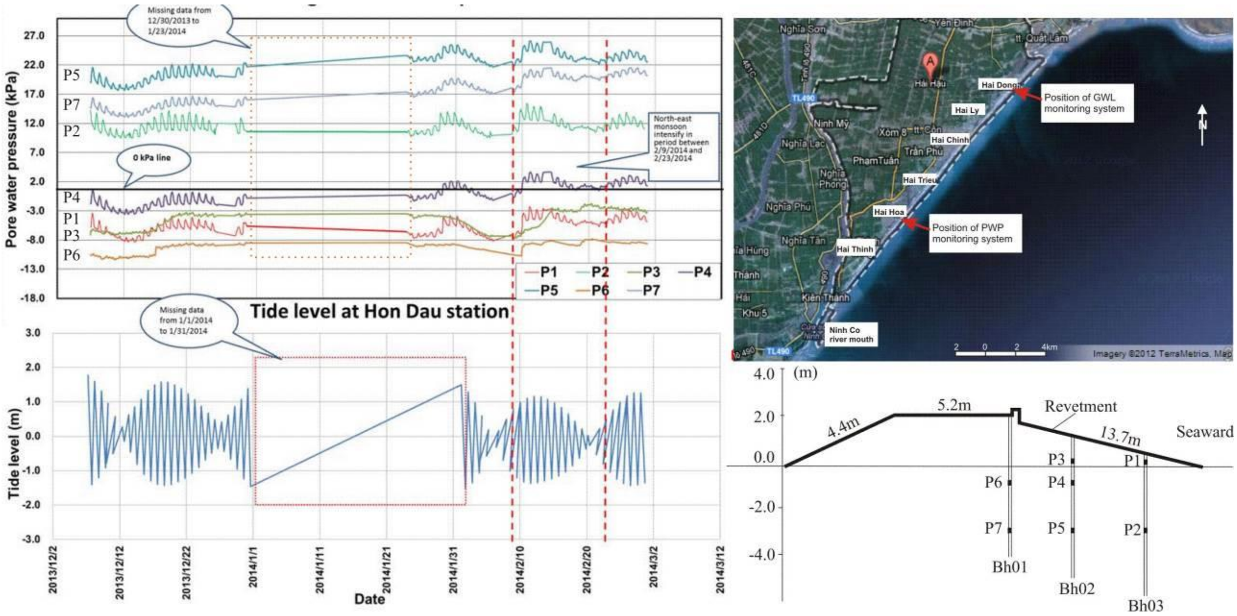

Fig. 9 Relationship between tide level and change in PWP in Hai Hoa

7. Geotechnical measures for climate change adaptation

The use of only a single countermeasure such as the dyke reinforcement described above is insufficient for long-term protection, particularly against severe weather conditions following storm surges or typhoons. As one solution to extremely disastrous events, multiple protection can be proposed as shown in Fig. 10, which depicts three combined countermeasures: an off-shore wave-eating facility, near-shore measures (mangrove plantation is popular in the developing countries), and a dike reinforced with vetiver grass and locally available techniques and materials.

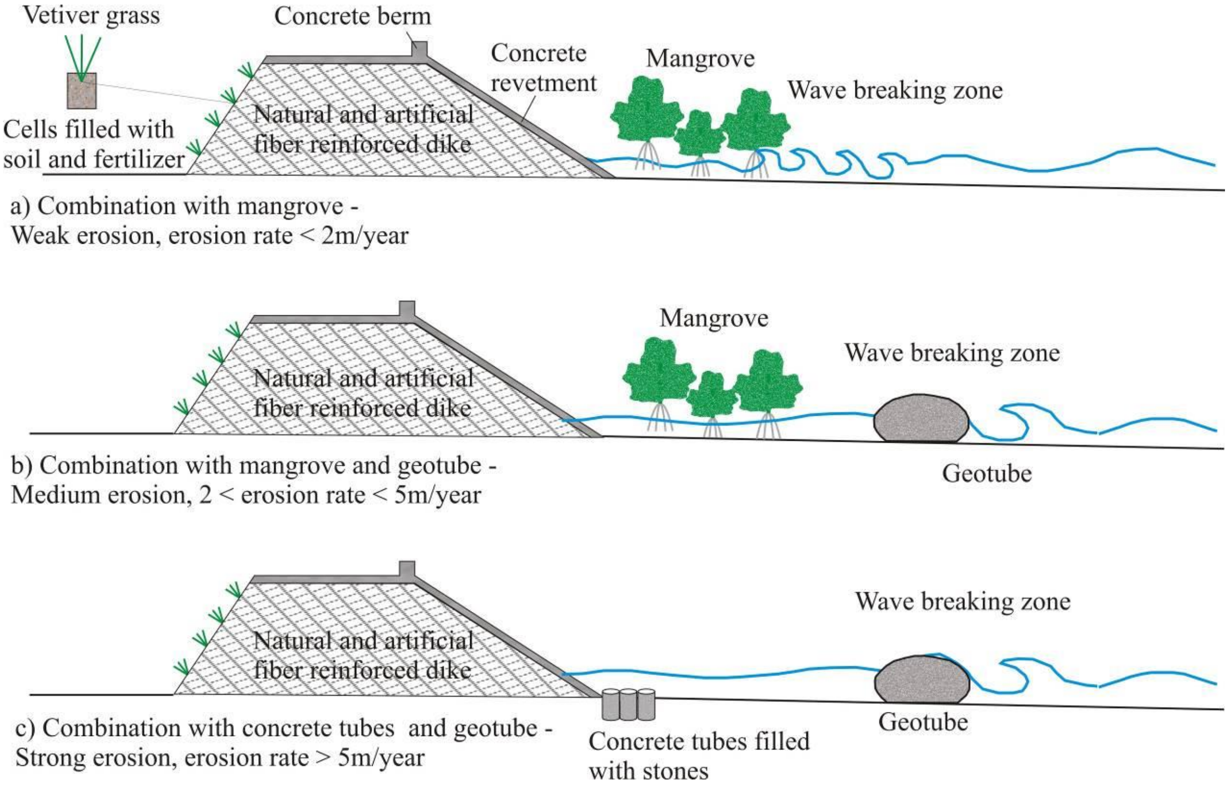

Fig. 10 Multiple protection and adaptation to climate change of coasts with different severity of erosion

8. Conclusions

Hai Hau coast has been undergoing severe erosion. In the context of climate change, SLR, typhoons and storm surge accelerated coastal erosion, beach lowering, scour and inner slope erosion that directly threat human settlements along the coastline. In Hai hau coast, two monitoring systems of PWP and GWL were installed to understand climate change impacts on seadyke stability. The results conclude that a multi-protection measure against climate change with the combination of conventional methods (dike, revetment, T-groins), geosynthetic material (geotube) and ecological engineering solutions (vetiver grass, mangrove forest) are effective for Hai Hau coast to adapt to climate change.

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