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Geotechnical Adaptation to the Vietnamese Coastal and Riverine Erosion in the Context of Climate Change

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ABSTRACT: Climate change related disasters such as erosion along riverine and coastal areas of the Mekong Delta in south and the Red River Delta in north are expected to be exacerbated by land subsidence, sea-level rise (SLR), and magnified typhoons. Adaptation to severe erosion is expected to respond to regional circumstances and the demands of local residents. Based on the expectations outlined above, for soft adaptation, attempts were made to conduct perception surveys of local residents, in addition to field surveys of erosion at riverside and coastal areas using an un-crewed aerial vehicle (UAV). Furthermore, for hard adaptation, a proposal is made to conduct pilot field tests at the coast for reinforcing coastal dykes using the combined technique of locally available materials with cost-saving eco-geosynthetics in addition to application of ICT. This paper explains the possibility of smart adaptation combining soft and hard adaptation to reduce severe coastal and riverine erosion in the Vietnamese deltas.

KEYWORDS: Climate change, Erosion, Adaptation, Geosynthetics, Natural fibers, UAV, Dyke

1. INTRODUCTION

Climate change related disasters along riverside and coastal areas of the Vietnamese deltas and lagoons are caused by land subsidence, sea-level rise (SLR), and magnified typhoons. Sometimes, combinations of two or three such events can induce more extreme damage. This paper explains erosion, which is regarded as a severe natural disaster affecting riverine and coastal areas. Erosion in waterfront areas, exacerbated by land subsidence, sea-level rise (SLR), and magnified typhoons, is divisible into two categories: coastal erosion, whereby sand beaches disappear because of SLR and less soil supplied from upstream; and dyke erosion, by which dykes collapse because of the events described above. Adaptation to severe erosion necessitates the following.

i) Grasping past and present situations and predicting future trends based on information collated through appropriate organizations, scientists, and engineers using reliable forecasting tools.
ii) Eliminating factors influencing severe erosion such as lack of sediments, perhaps using sediments from industry and other resources.
iii) Executing adaptive measures using hardware, software, human resources and command resources while evaluating their suitability to the situation, circumstances, and environments in the objective areas.

2. CURRENT CIRCUMSTANCES OF CLIMATE CHANGE –INDUCED EVENTS AND THEIR ADPTATION IN MEKONG DELTA

2.1 Current situation of climate change-induced events

According to the Natural Disaster Mitigation Partnership, Vietnam mainly suffers natural disasters from floods, storm surges, and typhoons, but to different degrees depending on the regional circumstances. The Mekong Delta is prone to be struck by flooding, which is exacerbated by sea-level rise (SLR) and which very often engenders riverine and coastal erosion. Actually, SLR is observed at almost all measuring locations along the Vietnamese coast. The average SLR was approximately 2.8 mm/yr, on average, during 1978–2006 (Tran Hong Thai, 2011). Using SRES Scenarios in IPCC AR4, MONRE (2009) respectively forecasted 65 cm, 75 cm, and 100 cm, corresponding to scenarios A1, B1, and A1F1.

2. 2 Current situation of erosion in Mekong Delta

Because no overview of the erosional situation exists at the moment in Vietnam, it is possible to present examination of the case of Soc Trang Province, one region in Mekong Delta that is vulnerable to climate change, as depicted in Photo 1. Figure 1 shows the recent conditions of erosion and accretion along the coastal area in the Soc Trang province (Schmit et al., 2013). Generally speaking, coastal areas in lower Mekong Delta suffer erosion over a short period, although they tend to accrete from a long-term geological perspective (Ta et al., 2002). The recent progress of erosion lessens the supply of soil mass from the upper stream caused by such human activities as dam construction and river improvement. This shortage of sediments is expected to trigger riverine and coastal erosion. In southern areas of Vietnam, erosion has become particularly severe in recent years (Duc et al., 2007; 2012).

Photo 1 An example of erosional scene of river bank in the Mekong Delta

2.3 Current situation of adaptation against erosion in Mekong Delta

Through the results of a perception survey administered to the local residents of the three provinces shown in Figure 2 at the Mekong Delta (Tamura et al., 2014), Table 1 presents a summary of the kinds of adaptation used as countermeasures against natural disasters. Table 1 also includes adaptive measures proposed from some levels.

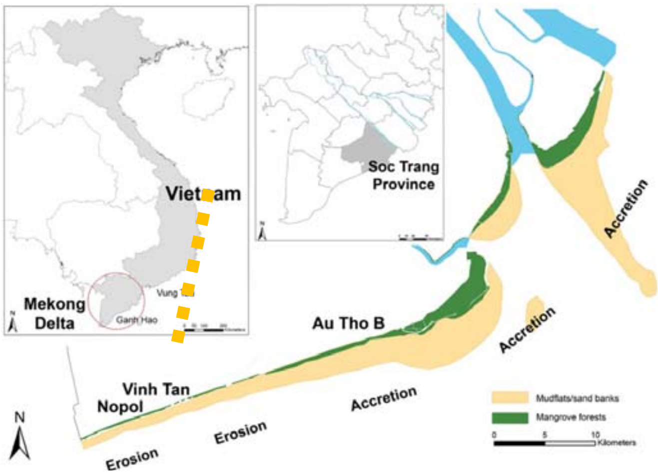


Figure 1 Situation of erosion and accretion in Soc Trang province (from Schmitt et al (2013))

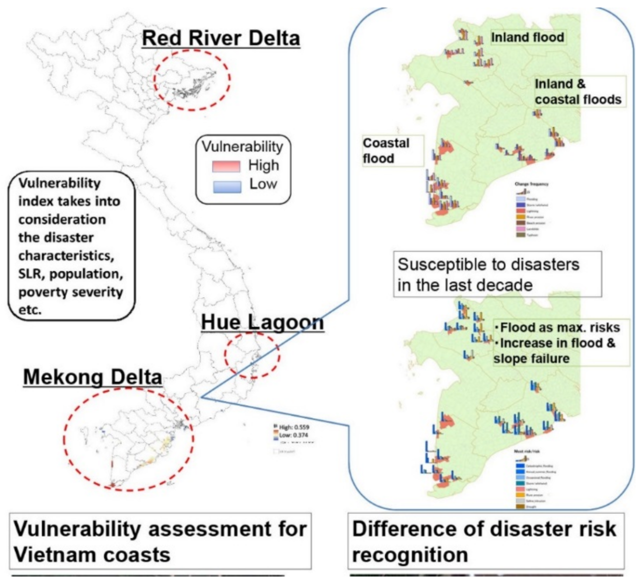


Figure 2 Three provinces with perception surveys

Table 1 Adaptation from levels of residents and local governments

Province	Disaster	Resident-level Adaptation	Governmental Level Adaptation	Adaptation Proposed
An Giang	• Inland or river flood	1)Strengthening and repair of houses 2) Heightening of houses 3)Two-storied houses	• Raised floor houses • Crops highly resilient to flood • Inland flood control technique	1) River dyke improvement mixed with palm fibers and cement 2) Multiple protection combined with proposed reinforcement 3) Monitoring using UAV and sensors
Soc Trang	• Inland or river flood • Coastal storm-surge	1)Strengthening and repair of houses, 2)Heightening of houses 3)Two-storied houses	• Coastal management • Protection of coastal areas • Methodology and technique for maintaining mangroves • Maintenance and control of freshwater	1) River dyke improvement mixed with palm fibers and cement 2) Multiple protection combined with proposed reinforcement 3) Monitoring using UAV and sensors
Ca Mau	• Inland or river flood	1)Strengthening and repair of houses 2)Heightening of houses	• Coastal management & protection • Mangrove preservation • Freshwater supply for regulating excessive use of groundwater • Agriculture and fishery resilient to salt water intrusion	1) Upgrading of combined impact assessment 2) River dyke improvement mixed with palm fibers and cement 3) Multiple protection combined with proposed reinforcement 4) Monitoring using UAV and sensors

Table 1 presents the following.

1) Adaptations common with residents in three provinces are (i) reinforcement or repair of houses and (ii) raising the floors of houses, (iii) whereas other adaptations including selling animals, diversifying income sources, purchasing boats differing among provinces.
2) Few requests and proposals are made for residents to evacuate, such as through early warning using ICT which belong to the software technology in adaptation. This situation must be improved as a further consideration.

3. GEOTECHNICAL ADAPTATION

Generally speaking, no strong attention has been devoted to geo-disasters in the context of climate change. Therefore, no systematic adaption to geo-disasters has been proposed in the context of climate change such as in the IPCC recent report in 2014, which includes only landslide and land subsidence. Very recently, however, Yasuhara (2014) summarized possible geotechnical adaptations as classified into three categories in accordance with the philosophy raised in IPCC AR4 (2007).

The current paper explains some of geotechnical adaptations up as presented in Table 2 and discusses their availability to reduce damage at the coast and riverine in the context of climate change by dividing into hard and soft adaptive measures, respectively.

Table 2 Possible adaptation measures to climate change-triggered natural disasters

Response		General responsive measure	Geotechnical responsive measure
Mitigation		· Geo-engineering -Solar Radiation Management (SRM) -Carbon Dioxide Removal (CDR) · Emission cotrol of CO_2 · Utilization of emission trading · Development of renewable energy	· Underground containment of CO_2 · Development of geo-materials to absorb CO_2 · CO_2 absorption and fixation using thinned woods
Adaptation	Protection	· Control of external forces triggering the impacts of climate change	· Multiple prediction using soil improvement and earth reinforcement techniques
	Accomodation	· Moderate response to climate change by accepting the impacts to some degree	· Construction of highly resilient structures · Early replaciable wall structures if damaged
	Retreat	· Migration from regions undergoing the impacts of climate change	· Monitoring system using ICT or ICRT · Construction of highly robust shelters and refuges using natural and artifical geosynthetics
Synergy of mitigation and adaptation		· Early warning system based on future climate prediction	· Monitoring system using ICT or ICRT · Early warning system using ICT or ICRT · Application of geo-materials to absorb CO_2 for geo-hazard reduction

(ICT: Information and Communication Technology, ICRT: Information, Communication and Robot Technology)

4. HARD ADAPTATION TECHNIQUES

4.1 Adaptation Using Conventional Techniques

Sea dykes, mainly made of soil, were commonly constructed in the 1980s in Vietnam. Their construction techniques are simple and primitive. For that reason, the dykes are easily eroded and severely damaged, particularly in a typhoon. Dykes of such types are still used in some parts of Vietnam. To reinforce the dykes, groins and other conventional techniques are used. On the coast of northern Vietnam, groins are used. There, groins are built of concrete reinforced with 1-m-diameter steel tubes of 10 cm thickness, placed continuously at a depth of 0.5 m under the tidal flat to a height of 1.5 m with sandbags inside. The distance between links is 80 m (Figure 3(a)). Mangrove forest is an effective measure against coastal erosion. A hundred meters of mature mangrove can reduce 0.1 m of wave height. However, such forests cannot be used in areas of severe erosion. Mangrove areas are now being replanted in Hai Dong (Figure 3(b)), where coastal sediments are now accreting.

With investments from PAM and the government from 1998 to the present day, the sea dyke system in this coast has been reinforced intensively. The sea dyke height has been improved by 4.5–5.5 m. Footings were placed at 1.5 m depth. The dyke was reinforced by lines of tripods and covered by polygonal pre-cast concrete of 100 kg mass, even reaching 200 kg on the slope of 1: 2.2–3 (Figure 3(c)). In segments of soil dykes, standby blocks of limestone are disposed nearby for emergency rehabilitation in bad weather conditions (Figure 3(d)). The situation described above is almost identical in the Mekong Delta to that in the northern part of Vietnam.

(a) Revetment and groins

(b) Mangrove plantation

(c) New concrete dike

(d) Standby limestone blocks

Figure 3 Conventional adaptation in Hai Hau coast, Vietnam

4.2 Adaptation Using Advanced Techniques

4.2.1 Application of concrete structures as a rigid structure

Concrete structures of several types have been observed along coastal zones in Vietnam. Figure 4 shows typical scenes of concrete armor blocks placed along the coast. Unfortunately, however, no strong evidence has been presented to support that these structures are available for reducing coastal erosion and thereby for protecting coastal dykes.

(a) Typical placement of concrete armor blocks

(b) Multiple placement of concrete armor blocks

(c) Placement of cellular type of concrete

(d) Placement of cellular type of concrete with crushed stones

Figure 4 Placement of concrete armor units

Different from placement of these typical concrete armor blocks, headland typed concrete structures similar to those presented in Figure 5 have recently been installed to protect the coastal dykes and to maintain sand beaches from erosion. Apparently in Figure 5, erosion has been retarded in the coastal zones with headland-type structures, although other zones have shifted from sediment to eroded zones.

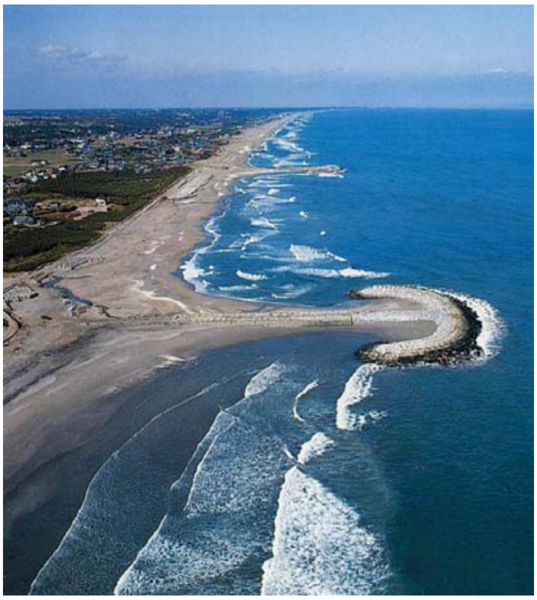


Figure 5 Headland type concrete structures to protect coastal dykes and maintain sand beaches from erosion in Ibaraki, Japan

Therefore, it is necessary to continue to monitor shoreline variation over wide areas in the long span to verify whether this type of concrete structure is available for protecting coastal erosion.

4.2.2 Application of geosynthetics as a flexible structure

Instead of concrete structures in addition to the conventionally used adaptation against climate change-associated natural events, use of geosynthetics was proposed around 1970 and has been adopted in Vietnam for protecting river dykes and coastal levees under severe storm and inundation. A recommendation was made to adopt geosynthetics as adaptation to climate change, as presented in Table 3 (Duc et al., 2012). However, for coastal areas, few case applications are successful for shore protection.

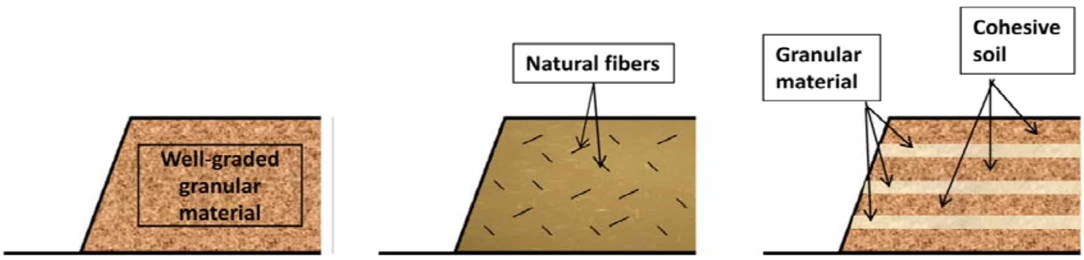
Furthermore, locally available natural geosynthetics are expected to be included in development of adaptive measures. Sato et al. (2013) attempted to combine palm tree fibers with sandy soils to reinforce river dykes, as depicted in Figure 6 (b), together with other possible options in these areas, which is currently under laboratory investigation to ensure its applicability as a promising adaptive measure for this aim.

From a perspective of cost savings, as portrayed in Figure 6 (b), several measures are useful for reinforcement dykes and embankments, including the usage of locally available materials described above. However, adequate compaction is crucially important as a fundamental aspect of geotechnics.

Sandwich structures portrayed in Figure 6 (c) are particularly suitable or construction of dykes using cohesive soils. Therefore, usage of locally available granular materials is expected for formation of sandwich layers above and beneath cohesive soil layers (Yamazaki et al., 2007; Yasuhara et al., 2007; 2011; 2013).

Table 3 Suggested preventive measures against coastal erosion with utilization of geosynthetics (modified from Duc et al. 2012)

Driving factors	Consequences	Required measures	Supporting measures related to the erosion rate			
			< 2 m/y	2–5 m/y	5–10 m/y	> 10 m/y
Typhoon	Increase erosion rate	Raise height of dykes Concrete revetment with geotextile Land-use planning	Mangrove	Groin (geotube) Mangrove	Groin (geotube) Seadyke toe protection with geobag	Groin (geotube) Sea dyke toe protection (geobag) Breakwater (geotube) Internal standby dyke Evacuation
Sea level rise	Instability of sea dykes					
Sediment deficit						



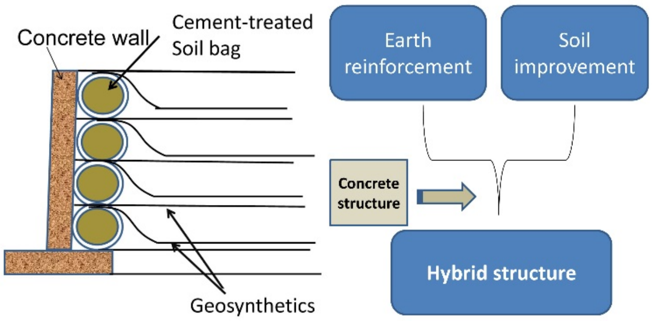
(a) Adequate compaction (b) Combining locally available natural fibers (c) Sandwich-structure using granular materials

Figure 6 Some options for dyke reinforcement

4.2.3 Hybrid earth structures produced with earth reinforcement and soil improvement

Soil bags covered by geosynthetics, as portrayed in Figure 7, are a temporary adaptation. Therefore, construction of such permanent countermeasures as by adopting the concrete facing is necessary as soon as possible after temporary work.

Another necessary issue is construction of countermeasures against inundation caused by combined storm surges and SLR. For the execution of countermeasures, the authors propose reinforcement techniques combining soil bags with geosynthetics also, as presented in Figure 7, which can be regarded as a permanent countermeasure. To upgrade the reinforced sea walls with geosynthetics, other work such as injection of cement mortar into soil bags can be undertaken (Yasuhara et al., 2011). This can be regarded as a "hybrid structure," the concept of which is presented in Table 3 together with improved reinforcement.



(a) Example of hybrid wall structure

(b) Concept of hybrid wall structure

Figure 7 From single to hybrid use of reinforcement and improvement

Table 3 Geotechnical improvement and reinforcement for dykes

Improvement/ Reinforcement	Example of technique	Remarks
Mechanical improvement/ Reinforcement	· Well-graded soils · Well-compacted soils · Inclusion of fiber materials	· Inexpensive · Durable · Locally available material or traditionally used material
Chemical improvement/ Reinforcement	· Mixture of cement, quicklime and adhesive materials	· Attention to contamination
Mechanical-chemical improvement/ Reinforcement	· Admixture of fiber materials with cement · Sandwich-structure using non-woven fabrics with quicklime · Placement of geosynthetics with soils stabilized using cement	· Hybrid · Cost–benefit and analysis

4.2.4 Multiple protection

Actually, 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 and typhoons, examples of which were observed with Typhoon Linda in Vietnam in 1999 and Typhoon Haiyan in Philippines in 2013. As one solution for extremely disastrous events, multiple protection can be proposed as presented in Figure 8, which depicts three combined countermeasures: an off-shore wave-eating facility, near-shore measures (mangrove plantations are popular in many economically developing countries), and a dyke reinforced with locally available techniques and materials. The necessity and requirement of such measures will be increased not only in economically developing countries but also in economically developed countries such as Japan because of endangerment from threats posed by climate change. The roles of respective techniques constituting multiple protections as presented in Figures 8 and 9 are shown in Table 4.

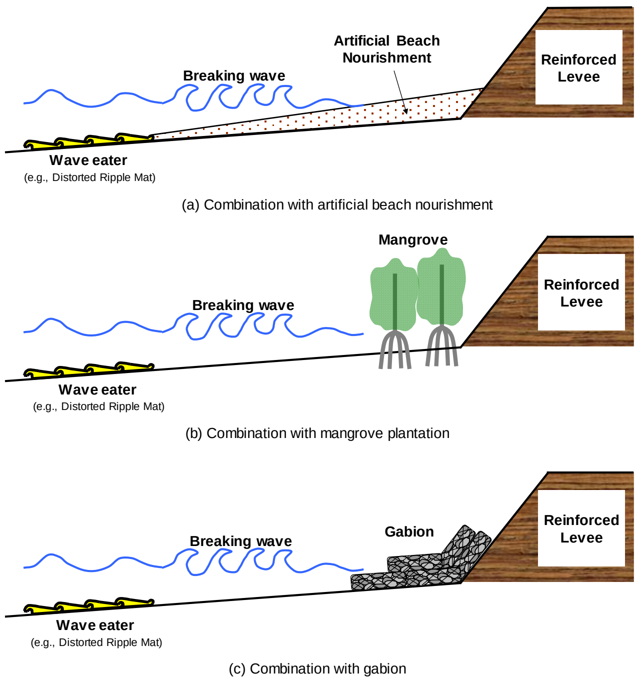


Figure 8 Multiple protection of coasts with levees reinforced using naturally available materials

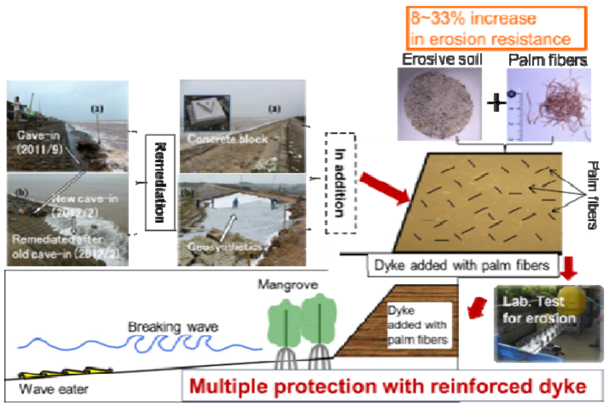


Figure 9 Multiple protective measures used in coastal areas (Sato et al. 2013; Yasuhara et al. 2013)

Table 4 Role of each measure in a multiple adaptive protection

Location	Material or Method	Role
Off-shore	Wave eater	Weaken impacts of waves and currents
Near-shore	Beach nourishment Mangrove plantation Gabion placement	Protection against erosion and scour of dykes
Between sea and human residence/ facilities	Reinforcement or improvement and their combination	Protection of hinterland

5. SOFT ADAPTATION

Because hard adaptation to erosion is insufficient, proper utilization of Information and Communication Technology (ICT) or Information, Communication and Robot Technology (ICRT) should be done as soft adaptation in accordance to situations of the objective areas and requests given by both local governments and residents. To do so successfully, an attempt was made to propose so-called 4S technology in which 4S stands for GIS, GPS, RS, and IC-Sensing (Yasuhara, 201). Figure 10 presents the modified 4S technology including addition of Un-crewed Aerial Vehicle (UAV).

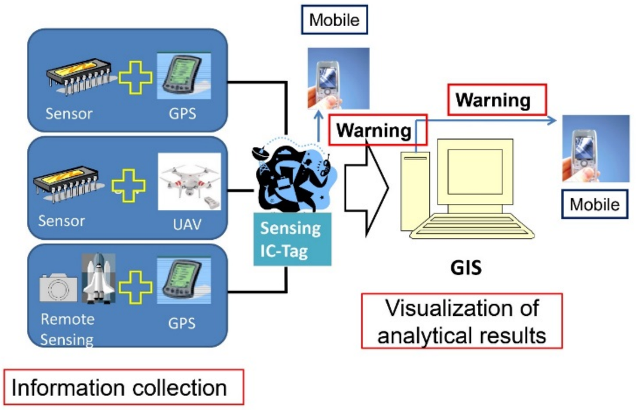


Figure 10 Modified 4S Technology

One example is the use of UAV, attempted to measure the present erosional situation. The UAV shown in Photo 2 is characterized by easy operation and economic and accurate images with a high-resolution camera.

(a) UAV (PHANTOM2) with digital camera

(b) Flying UAV above 80 m in the sky

Photo 2 Un-crewed Aerial Vehicle: UAV

Figure 11 presents three locations near the mouth of the Hau River, a tributary of the Mekong River, in Soc Trang province, where we took aerial photographs and moving pictures in June 2014. Still images were converted from moving pictures and were compared with photographs from Google Earth taken 8 years prior.

Comparison in Photo 3 shows that the shorelines of both locations with 1.73 km distance from each other are retarded by 240 m for location A close to the river mouth and 140 m for location B little away from the river mouth. The difference of erosional retardation of shoreline as shown in Photos 3 and 4 is ascribed to the following.

i) Different incident waves corresponding to geomorphological difference near the coast
ii) Location of coastal dykes
iii) Existence of such coastal structures as breakwater or pier
iv) Properties of bottom sediments, gravel, sand or silt

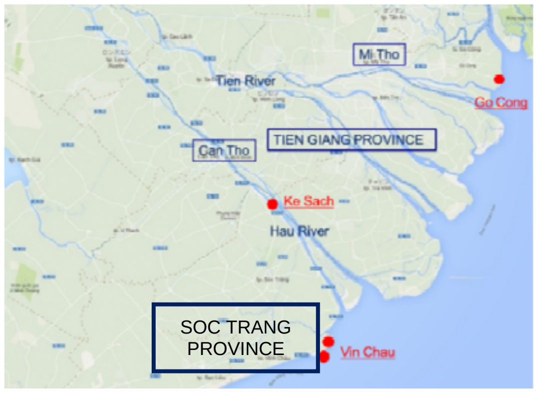


Figure 11 Three locations for investigation using UAV

(a) Location A-near the mouth of the Hau River

(b) Location B away from the mouth of the Hau River

Photo 3 Comparison of UAV picture with Google Earth

Photo 4 Distance between two locations

At the moment, however, no data acquisition has been completed on detailed properties of soils from sea bottoms and dykes without the plastic chart presented in Figure 12, indicating that no significant difference was found between bank soils and undisturbed soils taken from locations near the banks; most are classified into silty clay labeled by [CH]. Therefore, coastal and riverine dykes might be constructed using soils behind the dykes as surplus soils after such construction works as excavation for shrimp yards. Therefore, we suggest that some soil improvement or earth reinforcement techniques be used based on the fundamental principles of geotechnics, of which examples are portrayed in Figure 4 to avoid or retard erosional damage and dyke failure. This is also made sure by Figure 13 which depicts the grain size distribution curves in which there is no significant difference observed between banking and seabed soils.

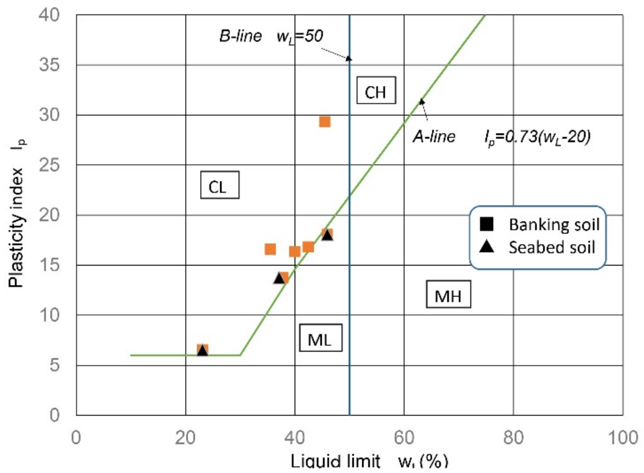


Figure 12 Plasticity chart for soils in Soc Trang Province for banking soils and seabed soils

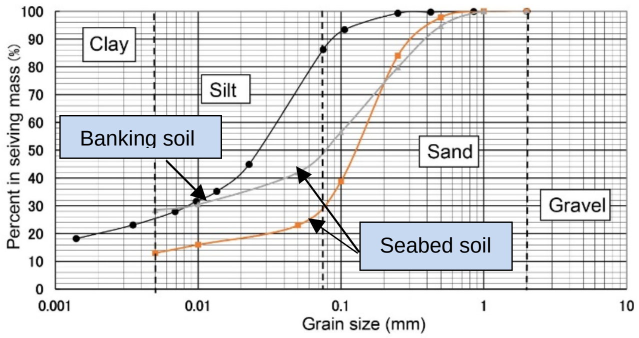


Figure 13 Grain size distribution curves for banking soils and seabed soils

6. SUGGESTED WORK FOR FURTHER DEVELOPMENT

To propose cost-saving techniques that can be adopted to reduce coastal and riverine erosion at the Mekong Delta, a trial of "sand mattress" in combination with "eco-sand bags" has been conducted to protect the eroded section of the river bank at Tiengiang province. A coming project for river bank protection in the Mekong Delta will be built using the "eco-sand bag" solution. Addition of such natural-origin materials as palm fibers and bamboo chips for mixing with the cement can also be recommended for additional development to increase stability of riverine and coastal dykes to climate change. This must be called a "Hybrid Geo-technique" because it combines soil improvement and earth reinforcement. Figure 14 presents an eco-friendly and smart-dyke reinforced with placement sand-mattress and soil bags originally proposed by Water Resources University. The author and other researchers are involved in planning to install IC-sensing tags in the dyke for measurement of acceleration characteristics during change of climate and weather for a long time of period and fly over the dyke for monitoring behavior of the dyke before and after such an event as storm and severe weather.

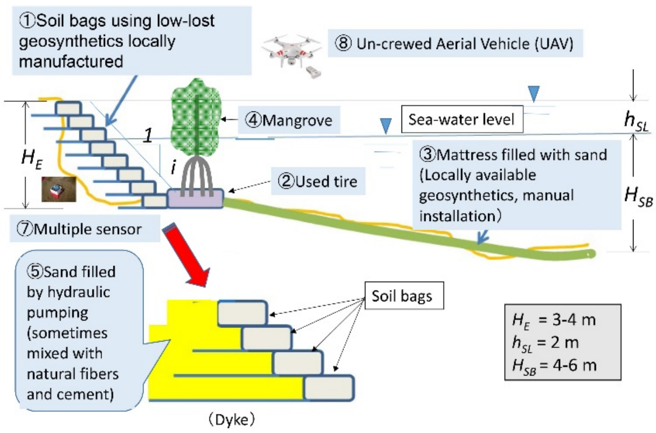


Figure 14 Key sketch for eco-friendly multiple adaptive measure to erosion combined with monitoring system

7. CONCLUSION

The current paper attempts to outline the Vietnamese situation of erosion at riverine and coasts. Among them, Tiengiang province and Soc Trang province in the Mekong Delta were selected as a case study as areas vulnerable to erosion, although Vietnamese coasts have suffered from chronic damage from erosion in the context of climate change and human activities. The following are suggested from fundamental investigations in this study.

i) Hybrid geotechnical adaptation was proposed for reducing riverine and coastal erosion in the context of climate change.
ii) As a hard adaptive measure, a trial of "sand mattress" in combination with "eco-sand bags" has been conducted to protect eroded section of river bank at Tiengiang province. This combined technique is anticipated as a cost-saving adaptive measure that suits the local circumstances.
iii) UAV was selected as a powerful and easily operative tool included in ICRT for monitoring the erosional situation. An attempt was made to measure the present erosional situation. This equipment can enable monitoring of the erosional situation precisely through the high-resolution camera equipped inside.
iv) Combinations of eco-friendly reinforcement techniques as a hard adaptation measure and an easily operated monitoring tool as a soft adaptive measure will help build the smart dyke system, which must be cost-saving and which must respond to the demands of local residents.

8. ACKNOWLEDGMENTS

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