A novel approach using sustainable structures in preventing coastal erosion and forming sandy beach in Vietnam

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Abstract. A new solution using ultra-high performance concrete (UHPC) sheet piles was a hard wall structure combined with gabion groyne dams for the purpose of shore protection, sand accretion, and tourist beach creation was proposed in this study. The proposed approach was then applied to meet the both shore protection and sandy beach generation requirements of private Rung Duong resort project in Ba Ria-Vung Tau, Vietnam. The UHPC sheet piles reinforced by fiber reinforcement polymer (FRP) installed in form of a vertical wall were designed and constructed for the shore protection purpose. Together with the later built gabion groyne dam system, the combined structure brought a very good coastal protection effect. As a result observed from Rung Duong resort, the shoreline was pushed back out very far from the resort, while sandy beaches in front of the resort were formed and expanded widely.

1. Introduction
Coastal areas around the world have been facing many serious problems related to coastal erosion [1]. Erosion is occurring very rapidly due to climate change that causes global warming, leading to inundation and increasing the risk of floods in large waves along the coast [2-4]. The problem of coastal erosion is becoming more and more serious because the coasts are becoming more ideal places to concentrate the population and develop production activities such as industry, transportation, tourism, etc. [5]. As reported by Adger et al. [6], nearly 20% of the world's population reside less than 25 km from the coast and 40% of the world's population (2818 million) live within less than 100 km from the coasts, or about 25% of the total surface of the world. Since 1950, the world coast has experienced rapid growth with an average annual urbanization of 2.6% [7]. During the same period, the number of coastal cities increased more than 4.5 times from 472 in 1950 to 2129 in 2015. It is estimated that nearly 30% of houses are within 200 m along low coasts can be seriously affected by erosion in the next 50 years.

According to a report of Ministry of Natural Resources and Environment of Vietnam, coastal and island erosion in Vietnam is taking place very complicatedly. According to incomplete statistics, all coastal provinces and cities currently have an average erosion of 15-30 meters/year [8]. Survey data in 14 central coastal provinces show that the current state of erosion is taking place seriously with increasing scale and intensity. In addition, Vietnam is considered to be one of the few countries that
most affected by sea level rise due to climate change. Vietnam has 28 provinces and cities located in coastal areas with a growing marine economy. The population of coastal areas is densely concentrated, with an expected increase to 19-30 millions by 2021. Sea level rise will increase the amount of extreme water, leading to waves hitting the coast and transmitting more wave energy to the shoreline. Observational data at the naval stations along the coast of Vietnam show that the average water level rise is about 3mm/year. Over the past 50 years, at the Hon Dau customs station, the water level has risen about 20cm. Monitoring data of Ca Mau Water Resources Department also shows that the following year tidal peaks are higher than the previous year with relatively large amplitude [8].

One of the prerequisites for developing sustainable coastal areas on a national, regional, or local scale is zoning and having an optimal strategy for coastal erosion management [9]. The coastal management strategies have become an issue with great international concern as reported in IPCC CZMS [10]. However, history shows that the most commonly used general strategy in the world is to control and minimize island coast erosion by using hard coastal structures [11], or technical solutions to reduce wave energy before landing [12]. Vietnam’s coastal protection and erosion management strategy are also in the same trend. This paper presents the common hard structural solutions being applied to shore protection in Vietnam, thereby proposing a new solution using ultra-high performance concrete (UHPC) sheet pile wall as a hard wall structure combined with gabion groin dam for the purpose of shore protection, sand accretion, as well as tourist beach creation. The approach that was successfully applied to a resort project in Ba Ria-Vung Tau brought very good coastal protection effect.

2. A novel approach using hard structures for coastal erosion and beach protection in Vietnam

2.1. Current situation of using hard structures for coastal protection in Vietnam
Due to the different characteristics of the sea and natural conditions, the current status of using hard structures for coastal protection in Vietnam is differentiated by regions. In the Northern region, the common used hard structures are seawall and revetment. The seawall can be in different types such as vertical or concave shapes with various materials including concrete, stones, and gabions. The revetments are usually built with interlocking blocks (IB) of natural stones, concrete, and gabions. The revetments are usually built with interlocking blocks (IB) of natural stones, concrete, and gabions. Recently, some of them have been strengthened by additional installing wave-break pile system. Figures 1-3 show typical solutions of hard structures for coastal protection in the North of Vietnam.

![Figure 1. Concrete seawall in Do Son, Hai Phong.](image1)

![Figure 2. Revetment with concrete interlocking blocks in Lach Giang, Nam Dinh.](image2)

![Figure 3. Revetment with concrete IB combined with wave-break piles in Nam Dinh.](image3)

Previously, with the main purpose of coastal protection, coastal areas in the Central region were often defended by constructing sea walls or embankments with similar structural types built in the Northern region, as instanced in figures 4 and 5. However, the harmonious climate and beautiful beaches in the central region have created a great attraction to the tourists, resulting in change of the coastal management strategy in recent years. In order to both protect the shores and create landscapes
as well as travel beaches, besides the soft wall solutions using geotextiles bags or tubes (figures 6 and 7), vertical hard wall solutions using reinforced concrete piles (RCP) or pre-stressed reinforced concrete sheet piles (PRCSP) are widely used. Figures 8 and 9 present typical hard structural solutions used in the Central region of Vietnam.

The South of Vietnam is an area consists of many rivers, canals, swamps, and especially surrounding beaches. While riverbank protection measures are quite fragmented, the main solution applied in coastal protection is vertical walls due to deep sea with large waves. The common used vertical walls used in the Southern region are RCP or PRCSP, as illustrated in figures 10-11.
It can be seen that the soft structures solution using geotextiles bags or tubes for tourist beaches is relatively effective in terms of shore protection, construction time and cost, but the fact shows that geotextile is often damaged quickly by the time, especially it is difficult to ensure the durability through big storms. Figure 12 shows an example of geotextile bags failure after a storm in Hoi An, Quang Nam. In addition to soft structures solutions, the hard structures solutions used in Vietnam mainly include seawall, revetment, and vertical hard wall using reinforced concrete piles (RCP) or pre-stressed reinforced concrete sheet piles (PRCSP). These types of structures have significant advantages but there are also disadvantages that make them impossible to apply to real projects. The advantages and disadvantages of the solutions can be summarized as follows:

**Seawall and revetment:** These structure types show several advantages such as making use of local materials, good dissipation of wave energy, less reflective waves especially when the slope is highly rough, solid overall stability, suitable for most soil types, and simple construction technologies. However, main disadvantages of these structures types that cause their inefficient usage in certain cases are unable to take advantage of the sea space outside, time consuming construction, and especially high costs.

**RCP and PRCSP:** These solutions show many advantages, but in parallel with the outstanding features of high bearing capacity and tightness, the disadvantages of high costs, complex manufacturing methods, the high possibility of being affected by environmental erosion, less flexible in construction, and not reusable of these piles types make the ability in applying these solutions to many certain projects infeasible. Moreover, PCP and PRCSP systems alone are also faced the risk of being destroyed by large waves, as exampled in figure 13, meaning that these solutions should come along with another approach to bring more efficient in both shore protection and beach creation.

![Figure 12. Geotextile bags damaged during a big storm in Hoi An, Quang Nam.](image1)

![Figure 13. PRCSP damaged after a storm in Ganh Hao, Bac Lieu.](image2)

**2.2. Novel approach using UHPC sheet pile wall combined with gabion groyne dams**

As aforementioned, many of the above structure protection solutions are still widely used in Vietnam, but the associated disadvantages restrict their application to specific projects such as the private resorts. This kind of projects usually has not too large investment capital but requires the solution meet the requirements of coastal protection and landscapes as well as beaches creation in front of the sea. Considering that reality demand, the approach using UHPC (with Fiber Reinforced Polymer (FRP) as reinforcement) sheet piles for shore protection requirement combined with gabion groyne dams for sand accretion as well as tourist beach creation requirement was proposed.

While the effectiveness of using gabion groyne dams in sand accumulation and yards creation has been reported in many previous studies [1-7], the UHPC sheet pile with FRP structure has shown many advantages such as much higher tensile and bending capacities than normal concrete ($R_t = 18-20$ MPa is very suitable for bending problems when mounted and subjected to soil pressure), very high compressive strength ($R_c = 100-120$ MPa is very suitable pile pressing problem) [13], light weight due to the much thinner structure when compared to reinforced concrete piles with same bearing capacity,
overcoming the phenomenon of corroded piles when exposed to aggressive environments, reducing the amount of material use, and reducing the transportation and construction costs compared to concrete piles solution. The usage of UHPC contributes to the environmental improvement by reducing a large amount of fly ash from thermal power plants [14-17]. The structures using UHPC and FRP have also shown the efficiency in many coastal construction and infrastructure projects in Vietnam [18-23]. Table 1 shows the preliminary correlation of bearing capacity, durability, weight, cost, environmental impact, and construction method of UHPC piles to other pile types.

Table 1. Comparison between different pile types.

| Pile type                  | Bearing capacity | Durability | Weight       | Cost (100% for the highest steel sheet pile) | Being affected by environmental erosion | Construction method                        |
|----------------------------|------------------|------------|--------------|---------------------------------------------|----------------------------------------|------------------------------------------|
| Melaleuca, bamboo, and wood| Very low         | Temporary  | Light        | Low                                         | Easy to get rot and termites           | Handicraft                               |
|                            |                  | bearing    |              |                                             |                                        |                                          |
| Concrete                   | Low              |           | Heavy        | Quite low (40%)                             | Aging over time due to brittleness and  | Closing, driving, and vibration          |
| (Larsen)                   | Very good        | Very high  | Quite heavy  | Very high (100%)                            | Easy to get rust, corrosion. Do not    | Closing, driving, and vibration          |
|                            |                  |            |              |                                             | use in submerged or saline environments|                                          |
| Pre-stressed               | Good             | High       | Very heavy   | High (80%)                                  | Reinforced steel are easy to get rust, | Closing, driving, and vibration          |
| Reinforced concrete        |                  |            |              |                                             | corrosion. Do not use in submerged or  |                                          |
|                            |                  |            |              |                                             | saline environments                    |                                          |
| Composite plastic sheet    | Low              | Low        | Light        | Quite low (50-60%)                           | Aging over time due to brittleness and  | Closing, driving, and vibration          |
|                            |                  |            |              |                                             | damage                                 |                                          |
| UHPC with FRP              | Very good        | Very high  | Fairly light | Fairly low (60-70%)                          | Durable in submerged and saline        | Closing, driving, and vibration          |
|                            |                  |            |              |                                             | environments, not aging over time      |                                          |

The outstanding advantages of the hard structure using UHPC piles compared to other pile solutions can be seen from table 1 and the successful application to the following project has shown the positive effect of this solution in shore protection, sand accretion, as well as tourist beach creation.

3. Practical application for Rung Duong resort in Ba Ria-Vung Tau
Rung Duong Resort is located in Tan Phuoc hamlet, Phuoc Tinh commune, Long Dien district, Ba Ria Vung Tau province. Long Dien district borders Dat Do district to the east, Vung Tau city to the west, Ba Ria city to the northwest, and the East Sea to the south, as shown in figure 14. The project required
a solution that meets two main requirements: (i) the entire resort is protected by hard structure; and (ii) sandy beaches can be deposited to form a bathing area for tourists. The first requirement was met by constructing an 300 m - embankment using UHPC sheet plies, while the second one was satisfied by installing an gabion groyne dam system. Figure 15 displays the positioning of the embankment with the starting point (A) coordinates of 10°24'12.55" N, 107°11'29.06" E and the ending point (B) coordinates of 10°24'15.73" N, 107°11'42.43" E. The natural conditions as input data and the design of UHPC sheet pipes as output data of the solution are detailed below.

![Figure 14. Location of Rung Duong resort.](image)

![Figure 15. Positioning of the embankment.](image)

### 3.1. Natural conditions
The natural conditions of investigated area are similar to the those of the southern delta region. In order to save space, some natural features are highlighted as follows: this area has relatively flat terrain and locates near the funnel-shaped estuary; the dynamic correlation is wave-tide-river; in meteorology, the solar radiation is about 130 Kcal/cm²/ year; There are two distinct seasons including dry season (from Nov. to Apr.) and rainy season (from May to Oct.) with the average annual rainfall of 200-300 mm; the average air temperature is about 26.7°C and the total number of sunny hours in the year is larger than 2700 h; the wind follows the season with the North – East wind in rainy season and South - West wind in dry season and the average wind speed about 2.5-4.2 m/s; the semi-diurnal tide goes up and down twice with large amplitude (4.0-4.5m as can be seen in figures 16 and 17) according to documents collected from 1982 to 2007; the wave is influenced by two dominant wave fields including the North-East monsoon and South-East monsoon wave fields, so the wave characteristics change according to the season. These characteristics of natural conditions are referenced from the previously reported document [24].

![Figure 16. Tide-free (8/2011).](image)

![Figure 17. Tide (3/2014).](image)

### 3.2. Design of UHPC sheet pile
The design of UHPC pile structure to protect the shore and keep the land was constructed as follows:
- The total route length was 300 m.
- FRP-reinforced UHPC sheet pile wall had FRP-reinforced concrete top beam and an anchor system. UHPC material had compressive and tensile strength of 120MPa and 20 MPa, respectively. The concrete beam made by concrete grade of B20 according to TVCN 5574:2012 [25] had cross-section of 400 x 400 mm and reinforces with 4 FRP bars of $\phi = 20$ mm in diameter.

- UHPC pile had a cross-section of 200 x 500 mm with the details of FRP reinforcements shown in figure 18 and a length of 8 m. The pile buried depth was 6 m from the ground level.

- The anchor system consisted of B20 concrete anchor blocks with the size of 1000 x 1000 x 1500 mm using FRP reinforcement of $\phi = 10$ mm in diameter. The UHPC piles connected to concrete anchor blocks through anchor FRP bars of $\phi = 20$ mm in diameter and 5.85 m in length. The spacing between concrete anchor blocks was 4 m, as illustrated in figure 19, whereas the details of connection between UHPC piles and anchor system are shown in figure 20.

![Figure 18. Details of UHPC with FRP.](image)

![Figure 19. Plan layout of UHPC pile and anchor system.](image)

![Figure 20. Cross section layout of UHPC pile and anchor system.](image)

The bearing capacity as well as the stability of the UHPC sheet piles with the anchor system under different load cases (wave load, soil pressure, axial load during pile driving) and combinations according to Vietnamese standards [25] were carefully calculated and checked to ensure the requirements for the structures. Figures 21-24 show some calculation results of the structure.

![Figure 21. UHPC pile calculation model.](image)

![Figure 22. Water pressure load (daN/m).](image)

![Figure 23. Moment diagram (daN.m).](image)

![Figure 24. Shear force diagram (daN).](image)
4. Results
Figures 25 and 26 show some pictures of the construction and installation of UHPC sheet piles.

**Figure 25.** Some stages during pile installation.  
**Figure 26.** UHPC pile driving.

Figures 27 and 28 show the view from the sea of the UHPC pile wall after being built during high tide (not the highest tide) and low tide, respectively.

**Figure 27.** UHPC pile wall during high tide.  
**Figure 28.** UHPC pile wall during low tide.

**Figure 29.** Gabion dam during construction.  
**Figure 30.** Gabion dam after construction.
Once the UHPC hard wall to protect the shore was built, the gabion groyne dam system was constructed for the purpose of sand accretion and yards creation. Figures 29 and 30 show the picture of the gabion dam during construction process and after finishing of construction, respectively. Figures 31 and 32 show the pictures of the sand beach in front of the resort immediately after the time that gabion dam system had been completed built (Aug. 2018) and at the latest survey time (Oct. 2019).

5. Discussions
The UHPC pile wall after being constructed had shown the efficiency in preventing waves and protecting the inner shore of the resort. However, since the UHPC pile wall was ended halfway on the sea, as can be seen in figure 26, due to the inability to cross the project boundary, the efficiency of the UHPC wall in sand sedimentation was not too good. Indeed, the level of the sand outside the wall and in front of the sea was much lower than the top level of the UHPC wall for long time from June 2017 to August 2018. These timelines correspond to the time when the UHPC pile wall was just completed (figure 28) to the time when the gabion dam was built (figure 31), respectively. The low level of the sand as well as the inefficiency of the UHPC pile wall in sand sedimentation led to the unable formation of a tourist beach.

It is clearly observed from figures 31 and 32 that after completing the construction of the gabion dam system for more than a year (from August 2018 to October 2019), the sand accretion was increased significantly and the beach in front of the resort has been formed. At our last survey time on October 2019, the sandy beach was clearly formed and the sand elevation was close to the top of the UHPC pile wall. Furthermore, the images from satellites showed that long sandy beaches along the coast with dozens of meters in width have been formed after the gabion dam system had been built. In figure 33, which captures the shoreline in front of the resort on August 2017 when the UHPC pile wall had been constructed, the sandy beach in front of the resort is observed to be very narrow. Whereas, the shoreline is seen from figure 34 to be far away from the resort and the sandy beach are also very wide. These observations indicate that the approach using UHPC sheet piles together with the gabion dams brings significant efficiency in shore protection, sand accretion, and tourist beach creation. The efficiency of the proposed approach is now still being examined by using the modern structural health monitoring technologies [26, 27], which shall be discussed soon in further study.

Figure 31. View from the sea on Aug. 2018
Figure 32. View from the resort on Oct. 2019.

Figure 33. Image from satellite on August 2017.
Figure 34. Image from satellite on October 2019.
6. Conclusions
In this work, the common hard structural solutions being applied to shore protection in Vietnam were presented, thereby a novel approach using ultra-high performance concrete (UHPC) sheet pile wall as a hard wall structure combined with gabion groyne dams for the purpose of shore protection, sand accretion, as well as tourist beach creation was proposed. The approach was successfully applied to a resort project in Ba Ria-Vung Tau and brought a very good coastal protection effect. As a result of the novel approach applied to Rung Duong resort, the shoreline in front of the resort was pushed back out very far from the resort and sandy beaches in front of the resort were formed and expanded widely.

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