

# Sustainable Hard and Soft Measures for Coastal Protection



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**Abstract** The coastal regions across the globe are more densely populated; this effect could be endorsed to urban development including the infrastructure for ports, inland waterways, trade and commerce, tourism, fisheries, hub for power plants, etc. Owing to the growing population demands many residential, industrial and commercial units have been constructed in the close vicinity/proximity of the shoreline. The developmental activities across the shore mandate the construction of facilities that promote industrial growth such as fishing harbours, ports, jetties, training walls, quays and wharfs as well as facilities for tourism development such as surfing friendly seabed slopes, added beach width for recreational activities and establishment of beach resorts, quays and wharfs. Predominant coastal hazards such as coastal flooding, coastal erosion, sea level rise, storm surge and seawater inundation are common threats to sensitive coastal communities. Alongside the prevailing natural causes of melting glaciers due to global warming and sea level rise, extreme events such as storms and cyclones; man-made artificial structures in the near shore regions/in between shallow and intermediate water depths can potentially destabilize the shoreline and lead to excessive coastal erosion if not addressed carefully. This paper details the vast experience gained in the field of coastal protection measures along the coastline of India.

**Keywords** Coastal erosion · Sustainable coastal protection · Hard engineering measures · Soft engineering measures

## 1 Introduction

The coastal stretches are highly dynamic in nature which is attributed to varying forces exerted upon them due to waves, tides, currents, suspended and bed load sediments, etc. In addition, the seasonal variations also bring about cyclones, storm

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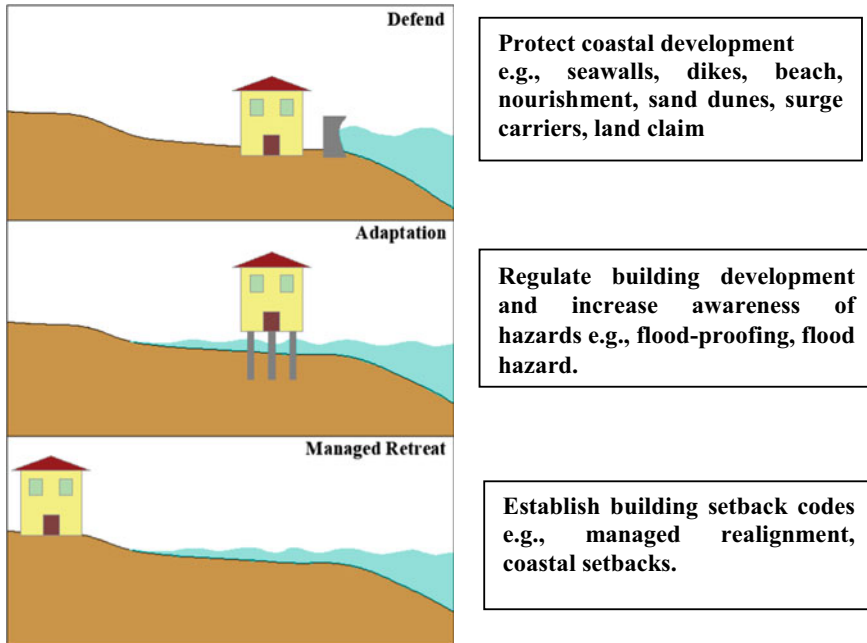
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surges, depressions, tsunami and tidal bores. The varying combination of the aforesaid forces tends to disrupt the equilibrium of the coastline. All the coastal stretches are not subjected to extreme forces, some of the stretches are naturally sheltered in a bay-like area where the regular impact of waves, tides and currents are relatively less and are typically exempted from any form of coastal hazard whereas, a significant stretch of the Indian coastline is exposed to the extreme wave climate leading to coastal erosion.

The artificial or man-made causes for coastal erosion are the construction of conventional coastal structures such as breakwaters, jetties, fishing harbours, ports to promote trade and fisheries. This can be either long-term or short-term effect on the coastline adjacent to these structures which lead to shoreline oscillation due to the interception of the long-shore littoral drift currents within the surf zone which redistributes the sediment supply on the downdrift side causing erosion and loss of beach width termed as erosion. The confluence of rivers and oceans may also contribute to erosion on its downdrift side, whereas, on the updrift of the structures or river mouths are characterized by beaches or sand bar formation, which also possess challenges in maintaining the river mouth connected to the Sea. Natural causes also play a crucial role in aggravating coastal hazards, the seasonal storms and cyclones significantly increase the near shore water depths resulting in seawater flooding and erosion. Extreme events such as the tsunami result in huge damage to life and property, wreck the existing coastal infrastructure, causes extensive coastal erosion during run-down, etc.

To regulate and stabilize the coastline, shore protection measures are in place to win back the lost sediments due to erosion. In most of the scenarios, where a short-term effect in loss of sediments, the “do nothing” approach would naturally restore equilibrium. If the causes resulting in coastal erosion are adverse, to protect, to accommodate, or to retreat approaches (Fig. 1) can be attempted. This paper would discuss a few case studies on the coastal protection aspects.

The Coastal Regulation Zone (CRZ) notification was issued in February 1991 to regulate the activities in the coastal area by the Ministry of Environment and Forests (MoEF), Govt of India, which states that, “the coastal land up to 500 m from the High Tide Line (HTL) and a stage of 100 m along banks of creeks, lagoons, estuaries, backwater and rivers subject to tidal fluctuations, is called the CRZ”. The CRZ’s includes only the inter-tidal zone and land part of the coastal area and does not include the ocean part. Most of the planned protection measures are located within the CRZ’s and sometimes probing into the ocean, since they are in a highly sensitive zone utmost care and attention to detail for the design is given by planners, engineers and Govt. agencies prior to implementation of coastal protection measures. All the existing options are explored to present an ecological and economically effective solution to redress the coastal erosion.



**Fig. 1** Basic approaches to handle coastal erosion

## 2 Why Is Coastal Protection Necessary?

The Indian sub-continent has a vast area of about 3.287 million km<sup>2</sup> with a coastline length of about 7500 km (including mainland and island) which is ranking only next to China in terms of the extent of the population affected due to climate change, subsidence and socio-economic reasons as pointed out by Nicholls et al. [8] that is projected in Fig. 2. It is easier to adapt the “do nothing” approach and choose the “retreat” option and relocate the near coast settlements further landward. Although, it is a simpler plan it is not economically viable to relocate the densely populated coastal stretches. The coastal metropolitan cities are a hub for all kinds of trade related activities, major nuclear and thermal power plants are located near the ocean for ease in the disposal of contaminant water and wastes, fisheries and salt mining are amongst the important coastal industries. Moreover, many culturally significant ancient structures are built along the shore with immense tourism potential which cannot be sacrificed to the sea. The proper planning, design, execution and maintenance of coastal protection measures could be economically as well as ecologically viable.

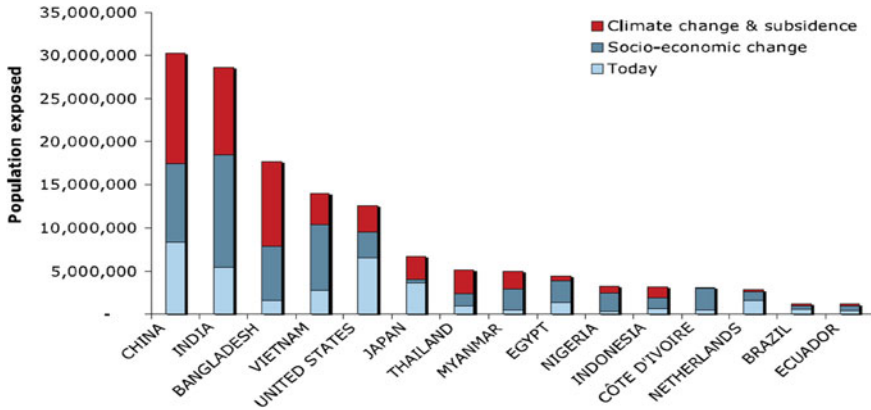


Fig. 2 Ranking of countries affected by climate change [8]

### 3 Preliminary Studies

The primary step is to identify the causes for erosion, whether it is temporary or persistent. This can be identified through field studies or satellite imaging. Secondly, a detailed field study and data collection regarding the nature of the coast, soil properties, sediment concentration, physical features, bathymetry, tide cycles, wave climate and frequency of extreme events need to be assessed. Lastly, the socio-economic factors including the aesthetic appeal of the coast, safety evaluation, public convenience, etc. need to be worked out, alternative temporary and more economic options are to be investigated and modelled with the aid of numerical or physical model studies in the laboratories. In the event of a long coast, for instance, that of the entire maritime state, a preliminary survey followed by identification of vulnerable stretches and evolving with conceptual designs need to be prepared. From the conceptual designs, detailed design needs to be done with the recent shoreline positions and bathymetry. If the necessary funds are available to execute the planned coastal protection measure, it can be commissioned under suitable weather conditions to arrive at optimum results. As the different seasons (South West, North East and Non-monsoon) dictate the direction the sediment transport or littoral currents, the construction sequence must be planned ahead. This is crucial at a locations where the groin field is planned as a coastal protection measure.

## 4 Coastal Protection Measures

### 4.1 General

The shore protection measures adopted can either be classical methods such as construction of groin field, seawall, revetments, or novel methods such as employing vegetation cover, geo-synthetic materials, beach nourishment or dune stabilization. The choice of adopting an established shore protection measure for a specific field problem needs to be done after scrutinizing the local field conditions and ensuring that the proposed measure is sustainable up to or beyond its design life. The coastal protection measures, in general, as projected in Fig. 3 is broadly classified as hard measures (groins, seawalls, offshore detached breakwaters) and soft measures (Artificial Beach Nourishment, Bio-Shields/Vegetation, dune stabilization, application of geo-synthetics). Erstwhile a combination of both can also be implemented.

The **hard** measures are conventional methods of coastal protection that consist of gravity type structures usually made up of rubble mound or precast concrete units. Implementing these measures yield immediate results, yet they are expensive,

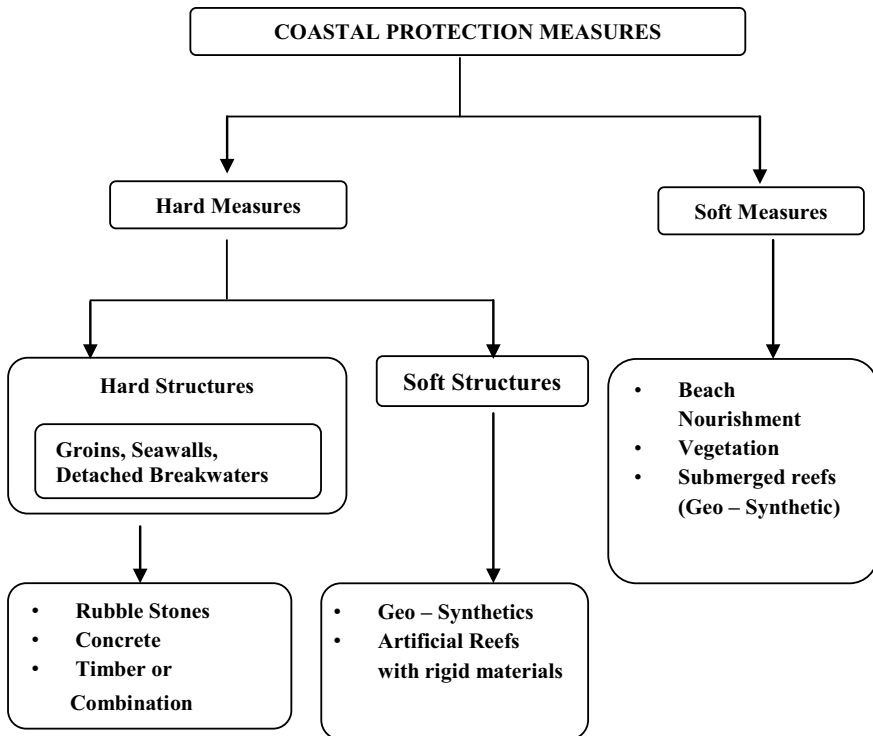


Fig. 3 Broad classification of coastal protection measures

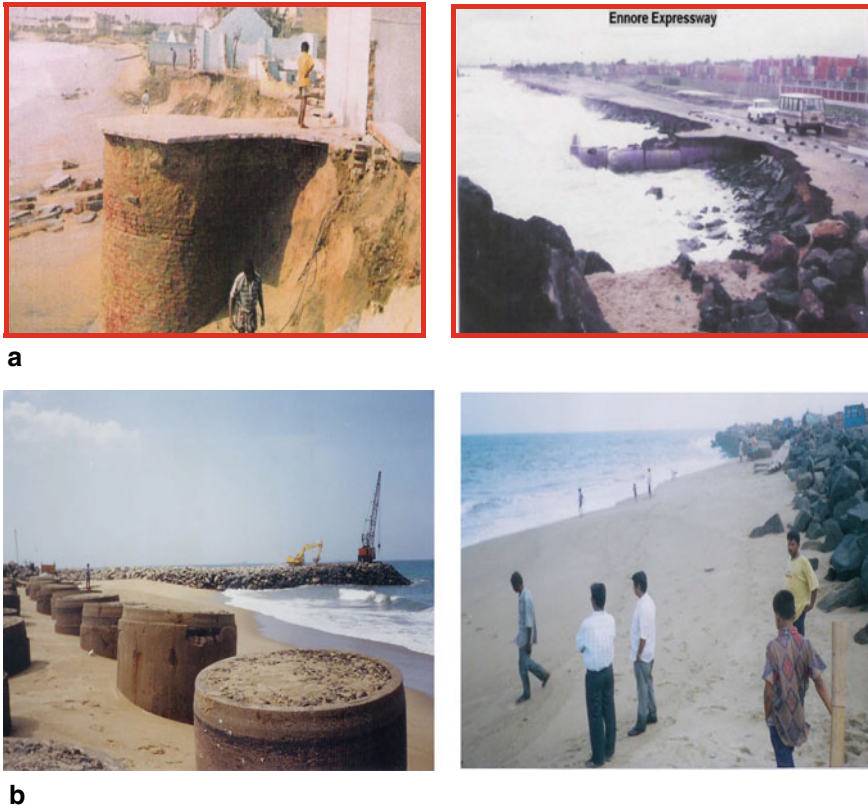
unaesthetic, leave behind an ecological footprint and sometimes difficult to construct, however, its effects might be adverse if not properly planned and executed and are irreversible. However, they are a well established and the most reliable method to attain shoreline stability within a short possible time span. A few examples of successful implementation and performance of hard engineering measures are discussed in brief in the following sections. Adopting natural rocks for the armour layers for the different hard measures, has in fact resulted in its depletion forcing precast concrete blocks. Several types of concrete armour blocks (such as tetrapods, accropodes, dolos, x-blocks, etc.) are available which can be laid as single or double layers, the details of which are discussed in the coastal Engineering Manual [3]. Chandramohan et al. [2] modified the stem length of the DOLOS, termed it as KOLOS that was adopted for the breakwaters of the port at Krishnapatnam, Andhra Pradesh, India.

The **soft** engineering measures form the other contrast spectrum of coastal protection techniques, which leaves behind a minimum or almost no ecological footprint. In comparison with the hard structures, the shoreline response to these measures is rather a slow process. The popular soft engineering measures are artificial beach nourishment, dune stabilization and vegetal cover protection. These methods require a higher degree of expertise for planning and execution in the field. The recent developments in the application of geo-synthetics in coastal engineering problems can be termed as soft engineering structures. Pilarczyk [12] and Koerner [6] have discussed in detail the application and design guidelines of geo-synthetic materials across various civil, hydraulic and coastal engineering perspectives. Although geo-textile was employed for road construction in South Carolina, it was Recio and Oumeraci [13, 14] who pointed out the usefulness of the application geo-synthetic materials for marine works. The conventional structures such as seawalls, submerged breakwaters, reefs, etc. can be entirely or partially made from geo-synthetic materials. This is a viable option for remote locations where the transport of heavy boulders and concrete is difficult.

## ***4.2 Hard Engineering Measures***

### **Groin Field**

Groins are shore connected structures extending from the shore and probing into the ocean up to or beyond the surf zone width and influence the local morpho-dynamics of the coasts by altering the sediment distribution and trapping sediments between groins. They can be designed in varying shapes and lengths depending on the site of implementation. The coastal city of Chennai houses the world's second-longest beach the Marina beach immediately south of its major port (initial breakwaters of the port was constructed in 1881), which intercepts the long shore sediment transport resulted in accretion on the updrift side (south of the breakwaters) and erosion on its downdrift side, i.e., on the north of the breakwaters. The images of the eroded north Chennai coastline are projected in Fig. 4a. This effect is attributed to the predominant



**Fig. 4** **a** Eroded stretches of North Chennai coastline (before 2004). **b** Accreted stretches of North Chennai coastline (after 2004)

net littoral transport rate directed towards the north. Several temporary measures to protect the coast failed miserably since the coast experiences an annual northerly net long shore sediment transport to an extent of 0.8 million  $\text{m}^3$ . A proposal was made by Sundar et al. [18] to construct 10 number of transitional groins north of Chennai port (from  $13^\circ 08' 48.36'' \text{ N}$ ,  $80^\circ 18' 50.10'' \text{ E}$  to  $13^\circ 10' 47.80'' \text{ N}$ ,  $80^\circ 19' 18.87'' \text{ E}$ ) to resolve the five decades long erosion problem. This protection measure was observed to be effective in restoring the lost beach width (Fig. 4b) which performed satisfactorily well even during the Indian Ocean Tsunami as reported in the post-tsunami survey of Tamilnadu coast by Sundar [19]. A detailed study by Sanjeevi and Jayaprakash [15] reported that about 94,465  $\text{m}^2$  of land has been gained in the Royapuram area and 35,660  $\text{m}^2$  in Ramakrishna Nagar area and on an average, 68,757  $\text{m}^2$  of land has been regained between 2004 and 2011, post the implementation of the groin field. An aerial photograph of the shoreline in mid-2020 is projected in Fig. 5, which highlights the success of the groin field, 16 years after implementation. About 25 stretches of the Kerala coast experiencing perennial erosion were protected

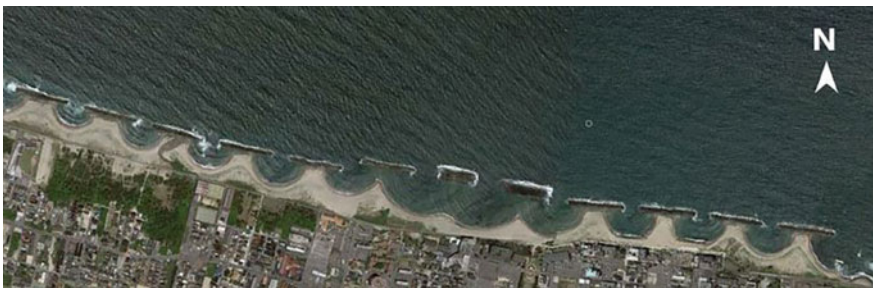


**Fig. 5** Aerial view of North Chennai coastline (May 2020)

by well-planned groin fields through comprehensive scientific methods of evaluation, which has yielded positive results of winning back the lost beaches as detailed by Sundar and Sannasiraj [23]. The above examples prove the effectiveness of groin fields as a coastal protection measure.

**Offshore Detached Breakwaters**

As the name suggests these structures are non-shore connected and lies in the offshore parallel to the coast, their function is similar to that of the arms of the extended breakwaters. The incident wave energy is diffracted by these structures and result in the formation of a calm lee side which are zones of lesser energy dissipation, thereby facilitating the formation of coastal features such as salient and tombolo. The details of the design and specifics are discussed by Sundar and Sannasiraj [24]. A case study is presented by Fujiwara et al. [4] where a series of 12 detached breakwaters protect the Kaike coast in Japan against excessive erosion as shown in Fig. 6.



**Fig. 6** Aerial view of beach formation (2003) along Kaike coast [4]



Although the effectiveness of offshore detached breakwaters to combat coastal erosion is proven through various literature, this measure has not been popular in the Indian waters, since it is both cost and labour-intensive measure, which requires heavy machinery, skilled labours, barges, etc. for successful commissioning. It is recommended that coupling detached breakwaters with wave energy conversion devices, such as an oscillating water column [11], which would make the project undertaking more economically viable. Integrating an Oscillating water column (OWC) in a detached breakwater as a coastal protection measure, a study initiated by Ashlin et al. [1] has claimed with thrice the width of the OWC spacing within one of the detached breakwaters exhibited a better performance to an extent of extracting about 2.2 times of the incident wave power. This could be an option in particular for the Islands.

### Seawalls

A seawall is usually constructed along the coast and its purpose is to protect the coast by mitigating erosion and flooding. They are usually constructed when the original beach width of the shore is less and if the seaward bed slope is very steep. The seawall structure does not alter the local morpho-dynamics whereas it stabilizes the existing condition by preventing additional damage to the coasts. These structures can be composed of rubble mounds, concrete units, gabions, or plain concrete walls. They can also be of vertical, sloped, or curved surfaces.

It is evident that the conventional sloping face seawalls composed of rubble mounds units require repetitive repair and rehabilitation works at constant intervals as reported by Sundar and Murali [20].

The Shankumukam coast ( $8^{\circ} 28' 49.2''$ ;  $76^{\circ} 54' 37.7''$ ) in Thiruvananthapuram district is a densely populated region and its shoreline extends to about 4 km, up to the mouth of Veli estuary which is a virgin beach. The rate of erosion is found to be severe during the months of June to August (South-West Monsoon season) as shown in Fig. 7. To combat the seasonal erosion problem construction of a seawall was proposed by the Kerala Irrigation Department as shown in Fig. 8a, with a wide base of 21 m. Sundar and Murali [20] proposed an alternative solution as shown in Fig. 8b with a base width of only 8 m, which makes some part of the beach available during non-monsoon seasons and during peak monsoon season and the designed seawall would perform satisfactorily. The seawall cross section construction along a 6 km stretch of the coast north of Chennai harbour (see Fig. 8c) as discussed by Sundar et al. [18] has withstood the forces due to the great Indian Ocean tsunami of 2004. A comprehensive assessment of the coastal protection measures implemented as a response to the tsunami of 2004 is reported by Sundar et al. [22].



Fig. 7 A view of Shankumukam coast during south-west monsoon

### 4.3 Soft Engineering Measures

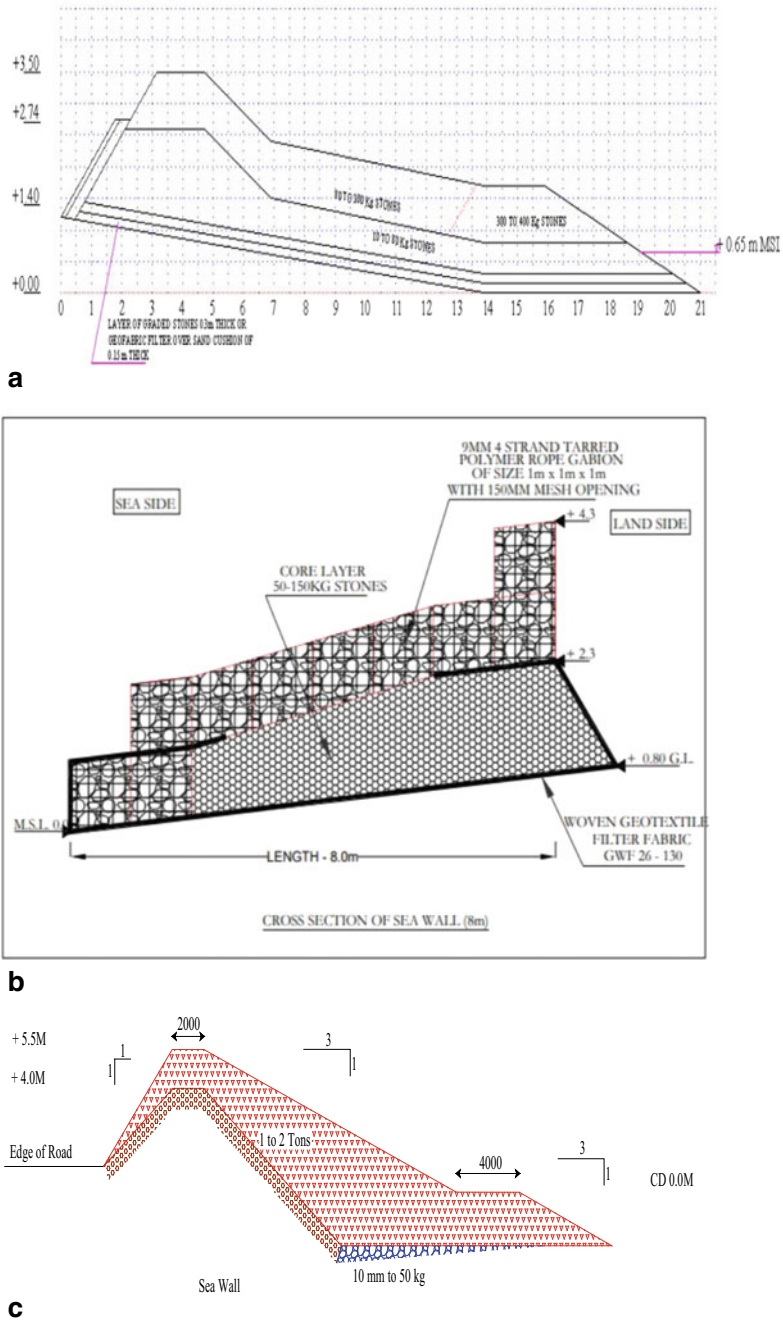
#### Artificial Reefs

Reefs are natural coral formations on the seabed surface which would actively dissipate incident wave energy approaching the coast by facilitating gradual dissipation and even pre-mature wave breaking. The coral formation promotes the coastal ecosystem by supporting algae and vegetal growth over its surface in addition to supporting fish culture. Since it is difficult to plant corals in desired locations, coral like artificial concrete units is used to serve a similar purpose across desired locations. These concrete units can be precast or cast in-situ and positioned offshore over the seabed at desired lengths and intervals to protect the proximate shoreline.

**Vaan island, Tamilnadu:** Artificial concrete units (in cross section and plan) as shown in Fig. 9 were used to protect the coast of Vaan island ( $8^{\circ} 50' 17''$  N and  $78^{\circ} 12' 37''$  E), in the Tuticorin district off south-east Indian coast. In a period of over four decades the land area of the island was reduced by approximately 85% [5]. From field investigations, Patterson et al. [10] reported that these reefs within six months of installation exhibited remarkable recovery of beach width along the northern side of the island.

#### Geo-synthetic Seawall

In line with the newly adopted materials and techniques in coastal protection, an innovation cross-section of a seawall comprising different geo-synthetic units such



**Fig. 8** a Seawall cross section at Shankumukam (Proposal 1). b Seawall cross section at Shankumukam (Proposal 2). c Seawall cross section at North of Chennai harbour [18]

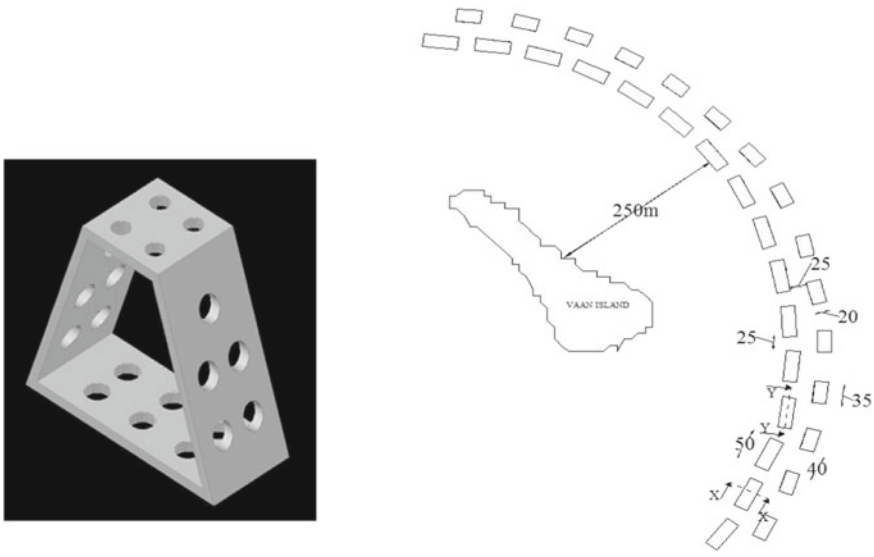


Fig. 9 Cross section and plan of artificial reefs in Vaan island

as geo-synthetic reinforced soil retaining wall (GRW/ barrier force system), geo-bags (small bags and mega bags), geo-cells, geo-grids, and geo-textiles (woven and non-woven) was proposed as shown in Fig. 10. This serves the purpose similar to that of a conventional seawall, without employing rubble stones or concrete units. The

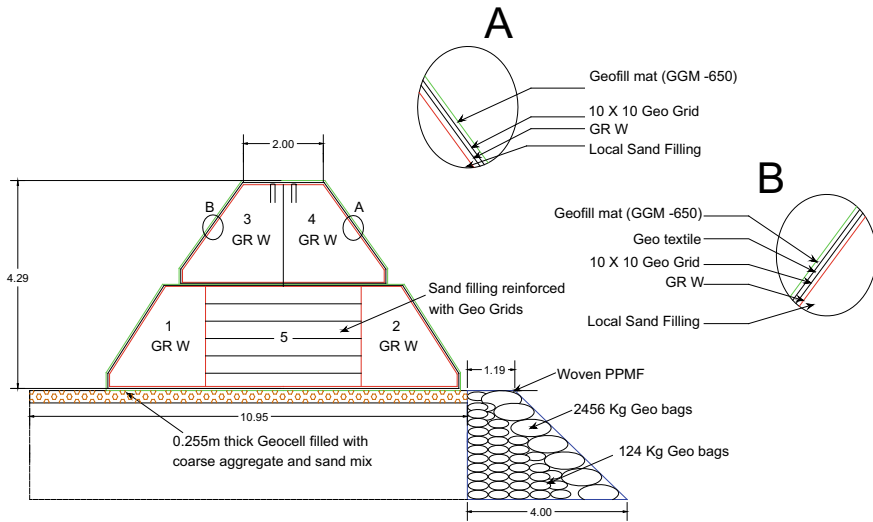


Fig. 10 Geo-synthetic seawall cross section

geo-synthetic seawall was tested for hydro-dynamic stability through physical model studies and geotechnical stability through an analytical model study by Sukanya et al. [17]. Later, this section was implemented along the Pallana beach ( $19^{\circ} 17' 55.19''$  N and  $76^{\circ} 23' 18.55''$  E), located in Allepey district of Kerala along the South-west Indian coastline, as a pilot plant extending to about 100 ft in length parallel to the coast. The structure performs satisfactorily well and prevents coastal flooding during monsoon season. The image of the seawall in the field soon after construction in 2015 and later in 2019 is projected in Fig. 11.

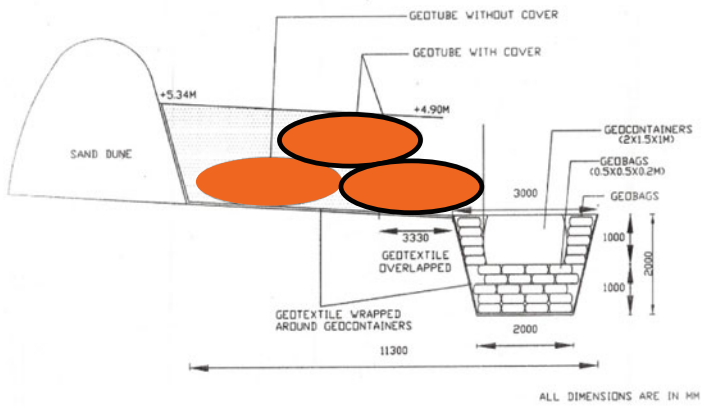
Application of Geo-synthetic products like geo bags, geo-containers and geo-tubes to perennial erosion (Fig. 12a) along the Digha beach, Shankarapur, West Bengal was designed and implemented along the coast, the cross section of which is shown in Fig. 12b. The details are reported by Sundar et al. [21]. The protection measure was quite effective as can be seen in Fig. 12c. Unfortunately, due human interference and damages to the geo-tubes lead to its failure around 2011, thus questioning its sustainability.



**Fig. 11** A view of geo-synthetic seawall along Pallana, Kerala



a

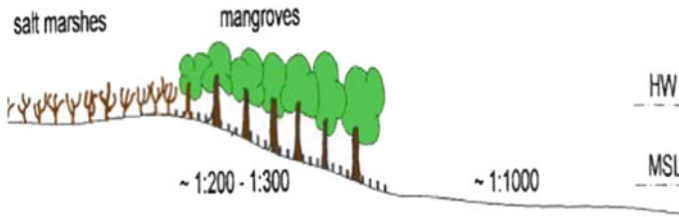


b



c

Fig. 12 a Status of the Digha coast in 2007. b Cross section of protection for Digha. c The effectiveness of the Seawall in Digha after construction



**Fig. 13** Vegetation roots prevent scour [16]

### Artificial Beach Nourishment

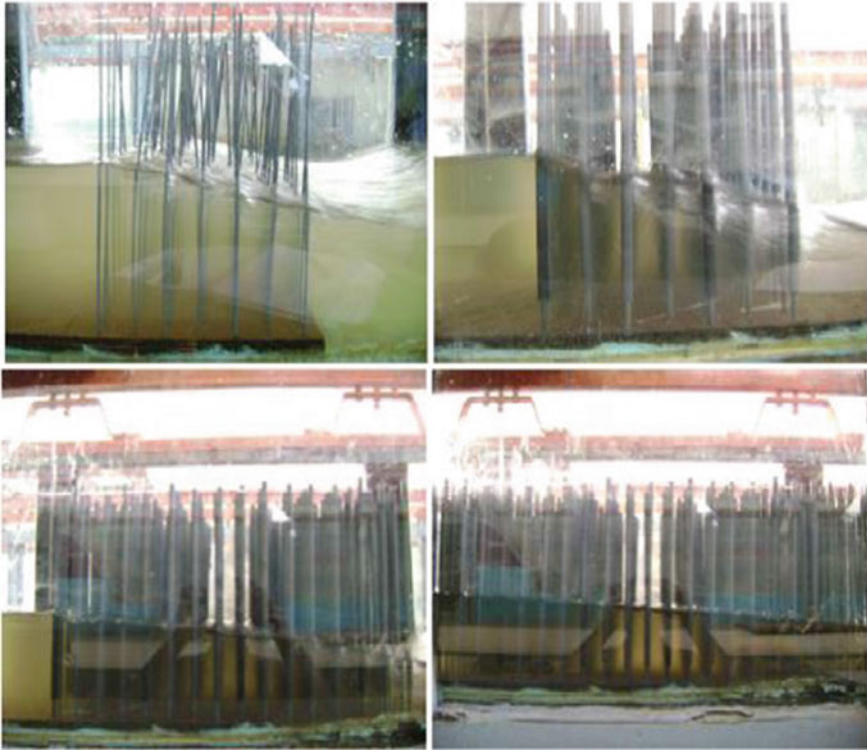
The process of transferring the sediments from the updrift side to the downdrift side by means of slurry pumps at regularly defined intervals to stabilize the beach is known as artificial beach nourishment. The initial cost for procuring and installing high-capacity slurry pumps are high. The allied operation, maintenance and repair costs for such facility is also expensive. This approach is suitable for locations where the updrift accreted coast and downdrift eroded coast are in close proximity, making it easier for the transfer of sediments. A pilot study on the sand by-passing along the Puducherry coast as discussed by Neelamani and Sundaravadevelu [7] was an attempt that initially yielded fruitful results but could not sustain due to several reasons, the main issue being related to the pump capacity and problems in handling.

### Vegetation Cover

It is a common observation that the regions of dense mangrove forests along the coast experience minimum or no erosion even during extreme coastal hazards. The root system of the mangroves holds back the sediments and prevents it from getting washed away due to long-shore and/or cross-shore currents, seawater inundation and run-down. Coastal vegetation also influences the resistance against sliding. The roots clearly armour the soil, see Fig. 13 from Schiereck [16]. Noarayan et al. [9] conducted a comprehensive laboratory study on the hydraulic resistance characteristics of a flexible plantation in a laboratory. The view of the laboratory set-up for varying vegetation thickness and spacing is seen in Fig. 14. A relative rigidity parameter for the vegetal growth is proposed in correlation with the friction factor. It was concluded that for ideal flow conditions the incident wave energy can be reduced by up to 90% by means of vegetation cover.

## 5 Conclusions

A comprehensive review of the hard and soft measures implemented as coast protection measure along the Indian coast has been discussed in this paper. The salient conclusions drawn are



**Fig. 14** Typical view of the varying thickness of vegetation tested in the laboratory [9]

The **hard measures**, viz., groin fields along North Chennai harbour have solved a five-decade-old problem. About 30 stretches along the Kerala coast proved to be effective over the past decade has proved its efficiency in protecting the eroding coast. The re-designed Seawalls have proved to be effective. Both the above protection measures have also withstood the forces induced by the tsunami of 2004. Detached offshore breakwaters integrated with wave energy convertor like the Oscillating water column device could be a viable solution for Island an aspect that needs detailed investigations. The depletion of natural rocks leads to dependency on concrete blocks necessitating the exploration of new types of efficient and cost-effective concrete blocks like KOLOS.

The **soft measures** adopted have exhibited mixed responses. Artificial beach nourishment poses problems related to pump capacity, its maintenance and availability of continuous supply of sand. The plantation although eco-friendly can be adopted only as a long-term protection measure. The application of geo-synthetic products adopted has raised concerns on its sustainability particularly the emerging type exposed to sunlight as UV rays poses a challenge. The other problem is human vandalism. Execution and Maintenance of such products need further investigation as skilled labour/simple technology is needed for filling geo-tubes.



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