Indexed in
Scopus Compendex and Geobase Elsevier,
Geo-Ref Information Services-USA, List B of Scientific
Journals, Poland, Directory of Research Journals

International Journal
of Earth Sciences
and Engineering

www.cafetinnova.org

ISSN 0974-5904, Volume 09, No. 06

December2016,P.P.2688-2694

Detached Segmented Submerged Breakwater Made of Geosynthetic Tubes for Kadalur Periyakuppam Coast, Tamilnadu: A Sustainable Shoreline Management Solution

A S KIRAN, PRINCE PRAKASH JEBAKUMAR, VIJAYA RAVICHANDRAN AND TAVVA ABHISHEK
National Institute of Ocean Technology (NIOT), Chennai-600100, Tamil Nadu, India
***Email:** kiran@niot.res.in*

Abstract: Erosion and accretion are two major issues in shoreline management resulting from natural phenomena and/or manmade coastal interventions. Human interventions with the coastlines such as construction of breakwaters, seawalls, groins etc. are likely to transfer the problem to the adjacent shoreline. Impacts of installation of shore protection measures in one location may not be limited to the project site alone but may extend to a larger coastal stretch on both sides of the project site. Environmental concerns rising out of such issues have led to use of detached segmented submerged breakwaters. In recent times, geosystems such as geosynthetic bags, geosynthetic tubes and geosynthetic containers are increasingly used in the creation of offshore breakwaters. Kadalur Periyakuppam (KPK) is a cluster of three fishing villages, near Kalpakkam in Tamil Nadu. The shoreline at KPK is prone to erosion and the situation gets aggravated during cyclones resulting in large scale loss of beachfront. The sediment transport rates at KPK are estimated using Delft 3D software and analyzed using DETRAN. The studies indicate that long-shore transport is predominant throughout the year and onshore-offshore transport is dominant during monsoon and cyclones. At KPK, the offshore transport during cyclones is the major cause of erosion. Any obstruction to the long-shore transport may result in wide spread erosion to the north of the project site. Therefore a detached breakwater has been proposed as an alternative solution. Offshore breakwaters shall intercept the high energy waves thereby reducing the wave attack on the coast. The breakwater is proposed to be laid using geosynthetic tubes. When an alien material like geosynthetics is introduced to the natural sandy coastal area, it is observed to create ecological changes in the vicinity. In order to study the impact of manmade structures in the coast, a pilot study has been carried out to assess the faunal assemblage on a similar artificial submerged geosynthetic reef present in 6m water depths off Kovalam. The effect of the organisms on the strength of the geosynthetics has been assessed by testing geosynthetic bags deployed at wave breaking areas and also those exposed to direct sunlight. Preliminary studies indicate a positive effect on geosynthetics.

***Keywords:** shoreline erosion; coastal morphology; geosynthetic tubes; epibiota*

1. Introduction

Erosion of shoreline is a major threat to coastal population. Majority of the world's coastline are undergoing erosion [6]. Erosion/accretion can occur naturally due to prevailing wave climate, water levels, currents, littoral transport etc. Human interventions with the coastlines such as construction of shore connected breakwaters, seawalls, groins etc. are likely to lead to large-scale erosion / accretion. Impacts of installation of shore protection measures in one location may not be limited to the project site alone but may extend to a larger coastal stretch on both sides of the project site. Detailed studies are required for identifying a suitable shore protection measure based on the site conditions and long term data. National Institute of Ocean Technology (NIOT) has carried out extensive field and numerical studies and proposed the solution of a detached breakwater at 4 m water depth [13].

This paper discusses a sustainable shoreline management measure, which is capable of protecting the coast as well as supporting the biotic diversity by mimicking natural coastal ecosystem.

1.1 Background

Kadalur periyakuppam comprising of three fishing villages is located 70 km south of Chennai (between 12°26'57"N and 12°26'14.2"N). It has Palar River on its north and a creek along its south (Figure 1). The state fisheries department has constructed a number of Fish landing centers along the coast. KPK shoreline undergoes erosion and accretion during monsoon and non-monsoon respectively. The erosion gets aggravated during cyclones. In the recent years, Thane (2011), Nilam (2012), Madi (2013) and Hudhud (2014) has affected the east coast of India and has affected the shoreline of KPK resulting in loss of beach in front of the fish landing centre structures. The erosion causes scour below the fisheries structures and beach loss (Figure 2).

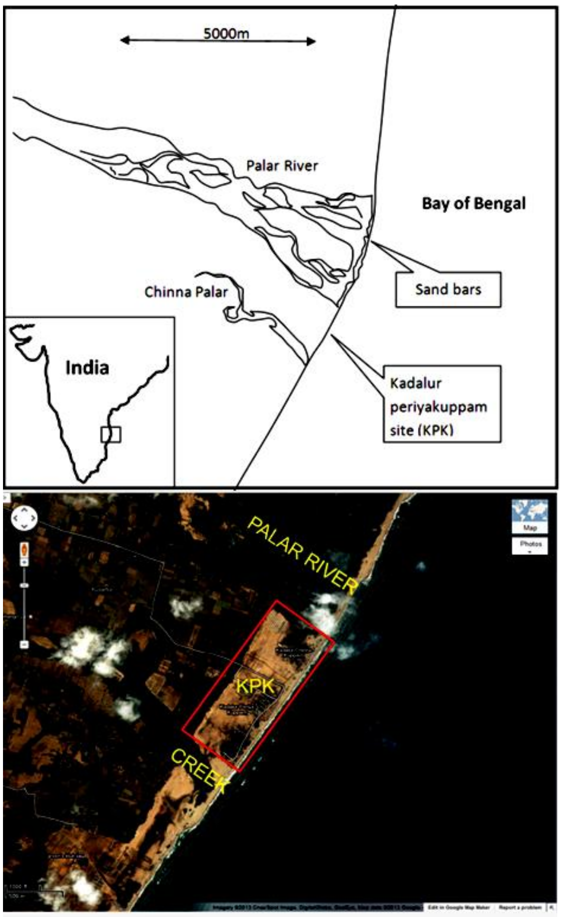

Figure 1. *Location of KPK*

1.2. Detached Submerged breakwater

The shore protection measure has been designed so as to stabilize the coastline in the long-term and protect the shoreline from the effects of storms. It should not transfer the erosion to adjacent coastline or cause any changes. Agencies like USACE have conducted long term studies and found that conventional shore protection measures like groins, shore connected breakwater, seawalls etc. blocks the long-shore sediment transport resulting in erosion on the down-drift side. A shore parallel detached breakwater on the other hand intercepts very less long-shore transport and is likely to perform well for coastal environments [14]. The main advantages of this shore parallel detached segmented submerged breakwater made of geosynthetic tubes are:

- The structure can be designed to offer sufficient protection against hydraulic loading at an acceptable risk
- Impacts are confined to the local environment as wave breaking is transferred to the offshore breakwater location resulting in negligible environmental / ecological damage to the shoreline.
- The interference to the alongshore sediment transport is less compared to shore connected structures.
- It is possible to construct the structure with local materials using local labour and without heavy machineries.
- In the case of any adverse impact on the shoreline, the structure made of geosynthetic tubes can be easily removed which is impossible in the case of conventional hard structures.
- The gaps between breakwater segments help in the accumulation of more sediment behind it and also allow the free movement of fishermen boats.
- Creation of a tranquil environment for biological activity to thrive on the leeward side

Figure 2. *Present condition of buildings at KPK*

Hydrodynamic model studies have been carried out for various breakwater configurations by varying the water depths, segment lengths and gaps and the configuration offering the best result has been adopted. The length of each segment is 200 m with a gap of 60 m between adjacent segments [8]. The stability of the filled geosynthetic tube units, of the breakwater, is checked against sliding and overturning due to high wave action using various methods available in the literature [7].

1.3. Ecological impact of shore protection measures

Until the last decade there was limited research on the harboring of epibiota on man-made coastal defense structures [12,2] including studies on shore-parallel, Low Crested Structures [1,3]. Presently, installation of coastal protection structures is on the rise along the Indian coast. Physical impacts on the adjacent shorelines due to the presence of these structures are being studied. It is inevitable for these structures to create ecological changes also in the vicinity due to the introduction of materials alien to that environment. Studies have been carried out to assess the faunal assemblage on an artificial submerged reef made of geosynthetic tubes present in 6m water depths off Kovalam beach, Kerala, India.

2. Morphological changes of KPK coast due to waves

Sediment transport occurs because of waves, currents or their combined effects. Currents may be driven by tide, wind or wave. Waves have a major role in sediment transport. It stirs up the sediment from the sea bed. Waves create steady current motions such as long-shore currents, undertow and mass transport velocities which transports the sand. In the present study only the effect of wave is considered. Wave data for the study area are based on NIOT wave model/ NIOT wave Atlas [10].

2.1. Numerical model

Using Delft 3D package, a study on the sediment transport processes at Kadalur Periyakuppam has been carried out. Delft-3D flow module is coupled with wave module to compute the morphological response of the coast. The FLOW module is a hydrodynamic and transport simulation program which calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing [4]. For a given bottom topography, wind field, water level, bathymetry and current field, the wave module of DELFT 3D simulates wave propagation, generation by wind, non-linear wave-wave interactions and dissipation [5]. By coupling the WAVE and FLOW modules online at regular intervals, it generates the effects of waves on the flow and provides flow boundary conditions for the wave transformation. Using advection-diffusion equation, sediment transport under combined waves and currents is computed. The morphological changes over a long time can be simulated with a factor called MORFAC. It is a user defined morphological acceleration factor that gives morphological change for a period equal to MORFAC times the simulation time of the model run. [4].

The model consists of two domains as shown in Figure 3. An inner domain, with finer grid (15m*20m), is nested in outer domain, having coarser grids (70m*180m). The bathymetry input to the model is based on bathymetry survey carried out by NIOT near the KPK village area. The Palar river mouth has not been considered in the model as it remains mostly closed throughout the year. Water level boundary condition is applied using astronomical constituents along Eastern boundary while Neumann conditions (alongshore water level gradient) are applied along North and south boundaries. Spatially varying sediment size (D50 value) is given as input based on grain size distribution of grab samples collected from the area. Cyclone data is taken from Indian Meteorological Department (IMD) and Joint Typhoon Warning Center (JTWC) websites.

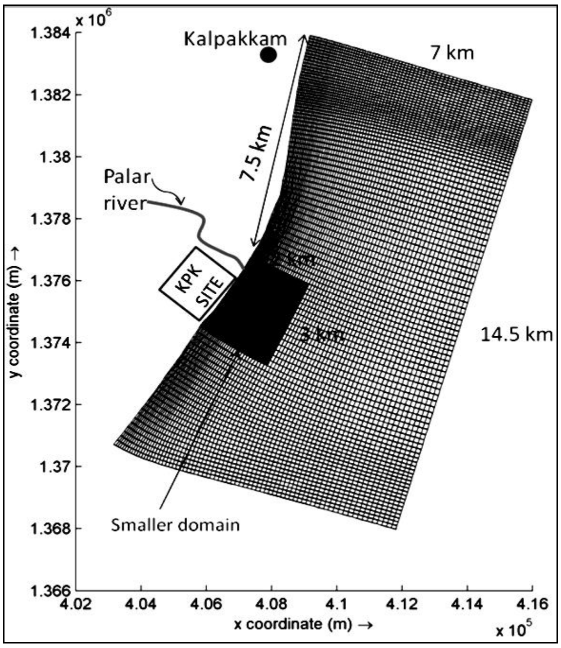

Figure 3. Domain Area showing outer and inner grid

2.2. Shoreline change during cyclones

The existing site conditions are modelled during Nilam cyclone. The model is calibrated using the morphological response of the coast measured during cyclone by NIOT through RTK (real time kinematic) survey over a stretch of 300 m. The model results are shown in Figure 4. Model is validated by using the data collected during Madi cyclone. The results of the model run are shown in Figure 5. From Figure 4 and Figure 5, it is clear that the shoreline is undergoing erosion during cyclones. The depth contours are shifting towards the land indicating loss of beach.

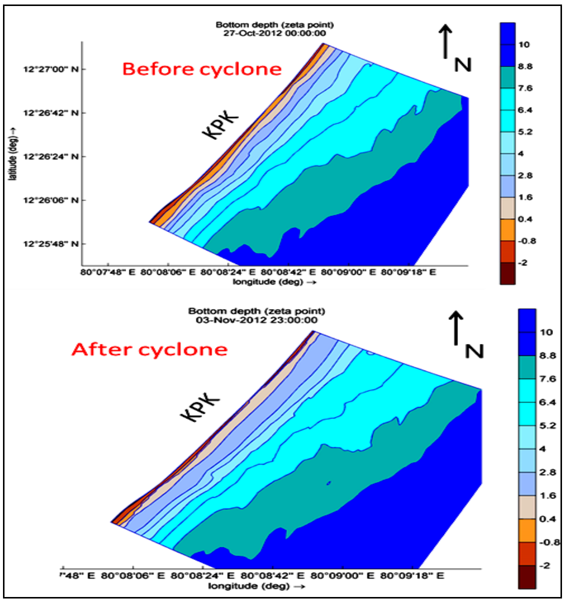

Figure 4. Variation in bathymetry during cyclone Nilam

The sediment transport processes are studied using DETRAN tool by providing the Delft 3D output as input to it. DETRAN is a package developed by Deltares for estimating the cross-shore and along-shore sediment transport. A typical output of DETRAN is shown in Figure 6. The sediment transport rates during Nilam cyclone across cross shore transects are given in Table 1. The quantity of sand lost through shore parallel transect towards offshore at 0.3 m water depth is around 64000 m^3. Also the cross shore profile before and after the Nilam cyclone as shown in Figure 7 shows that the sediment from beach is transported to 2 to 4 m water depths. It is observed from Figure 7 that the 0 m contour shifted by approximately 15 m during the cyclone. This is also observed in the field. The quantity of alongshore transport is comparatively smaller than the offshore transport during cyclones.

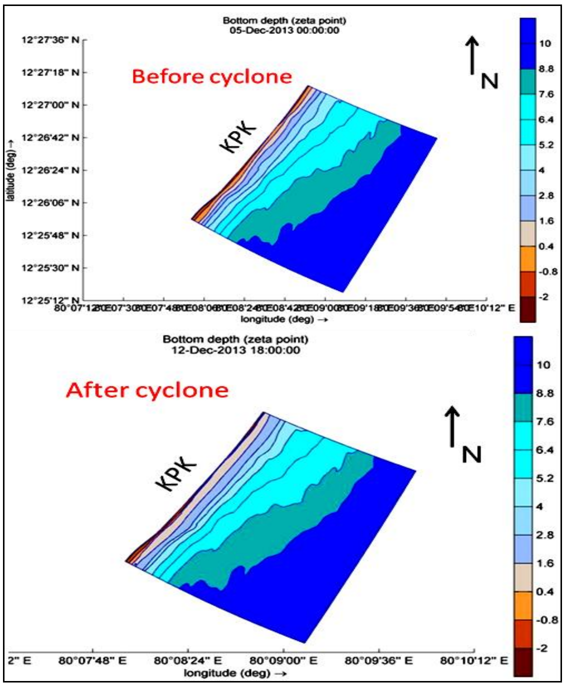

Figure 5. *Variation in bathymetry during cyclone Madi*

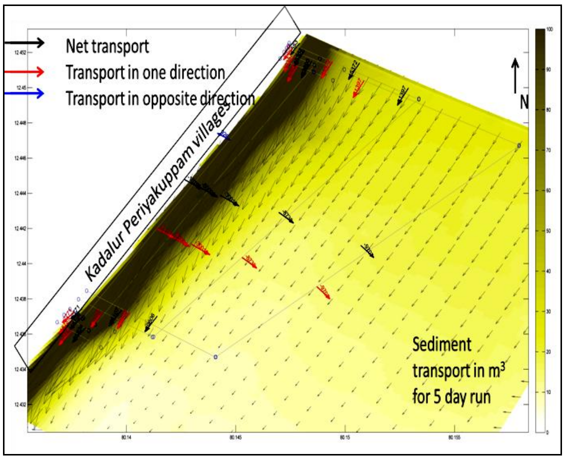

Figure 6. *Typical DETRAN output*

Table 1. *Cross shore sediment transport quantity (transects parallel to coast) in m^3*

Water depth along the transects	Towards shore	Towards offshore	Net	Gross
8 m	1137	-9927	-8790	11064
6 m	2355	-6728	-4373	9083
4 m	4873	-24594	-19721	29467
2 m	3857	-106150	-102293	110007
0.3 m	6628	-70513	-63885	77141

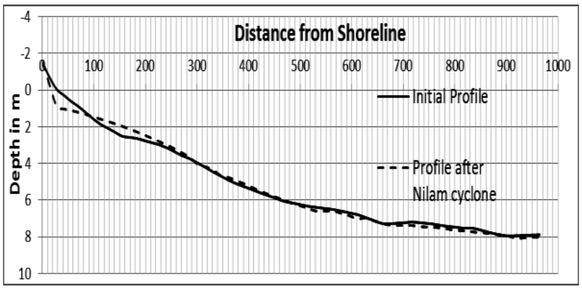

Figure 7. *Cross shore profile at KPK before and after Nilam cyclone model run*

2.3. Annual sediment transport

Using the same calibrated model, the annual sediment transport pattern at KPK is studied by running the simulation for one year. The gross alongshore transport of KPK is approximately 0.6 x 10^6 m^3. The monthly variation in sediment transport is shown in Figure 8.

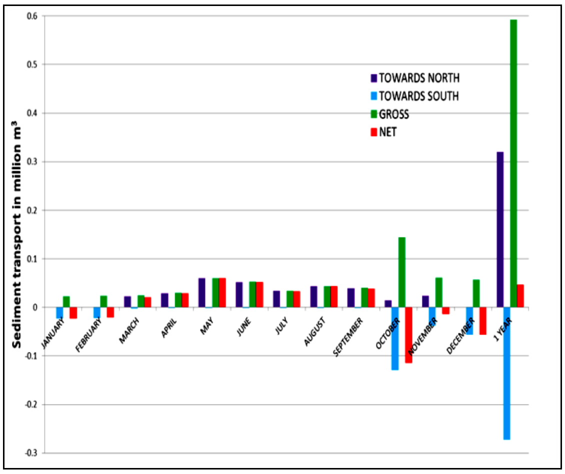

Figure 8. *Monthly variation in sediment transport*

In Figure 8, it can be observed that net transport is towards north from March to September and is towards south from October to February. The net annual transport is towards north. The higher sediment transport rate during the month of October is due to the occurrence of cyclone during the year considered.

From the studies it is observed that the alongshore transport is predominant at the site throughout the year. But during cyclones, the beach loss occurs due to cross shore transport. Taking into consideration of both these results, it is ideal to provide a shore protection measure like detached shore parallel breakwater with negligible interference to longshore transport but prevents the loss of sand in cross shore direction.

3. Ecological impact of Geosynthetic tubes

In order to study the impact of manmade structures on the ecology, a study has been carried out to assess the faunal assemblage on natural substrate and on the artificial submerged reef present in 6m water depths off Kovalam [9]. The estimation of organism on the geosynthetic tube was carried out by taking underwater photographs by SCUBA diving. The variation in biological growth with varying substrates has also been assessed.

3.1. Results of ecological studies

Studies undertaken on epibenthic assemblages on submerged sand-filled geosynthetic tubes at Kovalam coast are similar to faunal assemblages found on nearby coastal natural rocky substrate. Intertidal biodiversity of 20 species, including 3 sea weeds, 1 coelententerate, 7 molluscs, 3 annelids, 1 alpheid shrimp, 1 sponge, 1 echinoderm and 3 arthropods on the geotube as well as the rocky shore of Kovalam coast, are identified during the study. Similar faunal diversity was recorded along the rocky shore and sea wall at Vizhinjam port at Kovalam coast [11].

Comparison of species diversity of the two substrates showed that the geosynthetic tubes at Kovalam were colonized by 13 species of epibiota, while the rocky shore supported 18 species. Hence, it is evident that these geosynthetic tubes simulate an artificial reef environment and provide shelter for diverse biota and also acts as feeding ground to the commercially important lobsters and demersal fishes complimenting the artisanal fishery. Traversing of fish schools along the geosynthetic tubes was also recorded by the divers.

4. Impact of marine growth on strength of Geosynthetic tubes

In order to study the effect of marine growth on the strength of geosynthetic tubes, 50 geosynthetic bags filled with sand have been deployed in 1 m water depths inside the break waters of Ennore fishing harbor. Testing is undertaken on bags taken out every month to assess the faunal recruitment and strength of geosynthetic material. The faunal density was assessed by quadrate method (Table 2). The strength of geosynthetic material has been tested using universal testing machine as per ASTM D4595 for wide width tensile strength. Machine direction and cross machine direction samples are tested.

Table 2. *Epibiota assemblage on the tested geosynthetic bags & its biodiversity*

SI.NO	Type of Epibiota	April - 2015	May - 2015	June - 2015	July - 2015	August - 2015	September - 2015
1	*Ulva sp.*	-	+	-	+	+	-
2	*Chaetomorpha sp*	-	-	-	+	-	-
3	*Didemnum vexillum*	-	-	-	-	+	-
4	*Lissoclinum fragile*	-	+	+	+	+	-
5	*Transparent ascidian*	+	+	+	+	+	-
6	*Herdmania momus Savigny*	-	-	-	-	-	-
7	*Loimia sp.*	-	-	-	-	-	-
8	*Hydroides elegans*	+	+	+	+	+	+
9	*Bugula neritina*	-	+	+	+	+	-
10	*Gammarus sp*	-	+	+	-	+	-
11	*Anthopleura nigrescens*	-	-	+	-	-	-
12	*Anachis fauroti*	-	-	-	-	+	-
13	*Trochus sp.*	-	-	+	-	-	-
14	*Anadara sp.*	-	-	-	-	-	-
15	*Perna virdis*	-	-	+	+	+	-
16	*Crassostrea cucullata*	+	-	-	-	-	-
17	*Donax faba*	-	-	+	-	-	-
18	Lobster	+	+	+	+	+	-
19	Crab	+	+	+	+	-	-
20	Hermit crab	+	+	+	+	+	+
21	*Comanthus sp.*	-	-	-	-	-	-
22	*Chaetopterus sp.*	+	+	-	+	+	-
23	*Cirratulus africanus*	+	+	+	+	-	-
24	*Harmothoe dictyophora*	+	+	+	+	+	-
25	*Marphysa sp.*	+	+	+	+	+	-

26	*Nereis sp.*	+	+	+	+	+	+
27	*Platynereis sp.*	+	+	+	+	-	-
28	*Prionospio cirrifera*	+	+	+	-	-	-
29	*Terebellides stroemi*	+	+	+	+	+	+
30	*Sabellida sp.*	+	+	+	+	+	+

* + present & – absent

From the results of first four months, it is observed that the geosynthetic material recorded a breaking force of 29.07kN/m populated by epibiota with population density of 349 nos./m^2 and 29.96kN/m for population density of 521nos./m^2 . The original material wide width tensile strength is 27kN/m. It infers an increase in the tensile strength of geosynthetic bags colonized by biota. However, more testing is required to arrive at a final conclusion.

In addition to the increase in tensile strength, the epibiotic faunal assemblage prevents the UV exposure on the geosynthetic tube leading to increase in the life span of the coastal protection structure. Thus the geosynthetic tube enhances the coastal biodiversity which in turn increases its life period.

5. Conclusions

It is essential to design shore protection measures taking in to consideration its long term effect on adjacent shorelines and ecology. The conventional shore protection measures are known to either transfer the erosion to adjacent areas or aggravate the problem if installed without conducting proper site specific studies. For the KPK site, it is observed by sediment transport studies carried out during cyclones that the loss of beach occurs due to cross shore transport of sand towards offshore, while annual sediment transport studies at the location shows that there is significant amount of alongshore transport. Any shore protection structure (like groin) constructed obstructing this sediment movement is likely to cause erosion in the down-drift area. Based on these long term observations and numerical modeling studies, a shore parallel detached submerged segmented breakwater to protect the coast has been proposed. The gap between the segments helps the fishermen to venture into the ocean from their villages and also dissipates some of the pressure buildup due to storm waves. Studies carried out on the faunal assemblage on geosynthetic tubes at Kovalam indicates that artificial substrate like geosynthetic tube leaves a positive impact on nature and can be considered as sustainable shoreline management measure. The epibota identified on the geosynthetic substrate is similar to that on the adjacent rocky coast and are not invasive species indicating that there is no ecological damage due to introduction of geosynthetics. This epibiotic faunal assemblage reduces the amount of UV exposure on to the exposed geosynthetic tube leading to increase in the life span of the coastal protection structure. Preliminary studies indicate that the strength of the material is slightly enhanced by marine growth. A detached breakwater made of geosynthetic tubes is capable of protecting the coast as well as supporting the biotic diversity thereby providing an environmentally sustainable shoreline management option.

6. Acknowledgements

The study has been carried out by NIOT under the project 'Sustainable shoreline management' funded by the Ministry of Earth Sciences. The authors are thankful to Director, NIOT for granting approval for publication. The support and suggestions with respect to modeling inputs and data collection provided by Dr. K.M. Sivakholundu and Dr. B.K. Jena is highly appreciated. Wave data has been provided by colleagues K. Jossia Joseph and K. Prabhu. Significant contributions to the fieldwork provided by T. Venkaiah, T. Lokesh and J.A. Rajan are gratefully acknowledged.

References

[1] Bacchiocchi, F., and Airoldi, L, “Distribution and dynamics of epibiota on coastal defence works hard-bottom structures for coastal protection”, *Estuarine Coastal and Shelf Science*. 56, 1157–1166., 2003.

[2] Chapman, M.G, “Paucity of mobile species on constructed seawalls: effects of urbanization on biodiversity”, *Marine Ecology Progress Series*, 264, 2003.

[3] Davis, J.L.D., Levin, L.A., and Walther, S.M, “Artificial armored shorelines: sites for open-coast species in a southern California bay”, *Marine Biology*, 140(6), 1249–1262, 2002.

[4] Deltares, Simulation of multi-dimensional hydrodynamic flow and transport phenomena, including sediments – *User Manual*. Version 3.15, rev. 18392, Deltares, Delft, the Netherlands, 2011.

[5] Deltares, Simulation of short-crested waves with SWAN – *User Manual*. Version 3.04, rev. 15779, Deltares, Delft, the Netherlands, 2011.

[6] Ding, Y., and Wang, S.Y.W, “Development and validation of integrated coastal process models for simulating hydrodynamics and morphological processes”, *proceedings us-china workshop on advanced computational modelling in hydroscience & engineering,Oxford, Mississippi, USA, 2005*.

[7] Kiran A.S., Vijaya R., and Sivakholundu K. M , “Stability analysis and design of offshore submerged breakwater constructed using sand filled geosynthetic tubes”, *International Conference on Asian and Pacific Coasts (APAC*

2015), Procedia Engineering, Volume 116, 2015, Pages 310–319, 2015.

[8] Kiran, A.S., Vijaya, R., and Avula, A.K , “Design of an environmental friendly shore protection measure for kadalur periakuppam , Tamil Nadu using hydrodynamic model studies”, *Proceedings of 5thIndian National conference on Harbor and Ocean Engineering (INCHOE), February 5-7, 2014.*

[9] Prince P J., Vijaya R., and Nandhagopal G, “Preliminary Studies on Nature of Epibiota Assemblage on Low Crested Coastal Protection Structures”, *Proceedings of 5thIndian National conference on Harbour and Ocean Engineering (INCHOE), February 5-7, 2014*.

[10] Rajesh, P.R., Jossia, J.K. and Rajat, R.C, “Modeling of wave characteristics in North Indian ocean”, *Proceedings of International Conference in Ocean Engineering, IIT Madras,2009.*

[11] Ravinesh, R, and Bijukumar, A, “Comparison of intertidal biodiversity associated with natural rocky shore and sea wall: A case study from the Kerala coast, India”, *Indian journal of marine sciences*, 42(2), 223-235, 2013.

[12] Russell, G, “The algal vegetation of coastal defences: a case study from NW England”, *Botanical Journal of Scotland*, 52(1), 31– 42, 2002.

[13] Sivakholundu, K.M., Vijaya, R., Kiran, A.S., and Abhishek, T, “Short term morphological evolution of sandy beach and possible mitigation: A case study off Kadalur Periyakuppam”, *Proceedings of 5thIndian National conference on Harbor and Ocean Engineering (INCHOE), 2014.*

[14] United States Army Corps of Engineers (USACE), Washington DC, U.S. Functional Design of Breakwaters for Shore Protection: Empirical Methods, CERC-90-15, 1990.