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Coastal erosion and mitigation methods – Global state of art

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Coastal erosion is assuming large proportions these days. Global climate change coupled with local attributes is eroding the coasts of the world in alarming proportions. Most of the conventional protection methods are hard, short lived, expensive and not eco-friendly. Trend in coastal erosion mitigation and protection has been shifting these days towards soft but novel, eco-friendly methods. Pro-active methods are being developed and used which are eco-friendly, construction-friendly, cheaper and which also reasonably address the root cause of the problem without much 'side effects'. Many non-traditional ways to armor, stabilize or restore beaches, including the use of patented precast concrete units, geotextile sand-filled bags, green belts, bio-engineering, sand fencing, beach-face dewatering systems, integrated costal protection methods are being used. Retreat from the coast is also thought about, in many circles. Present study consists the global coastal erosion scenario and also some of the state of the art soft and pro-active erosion mitigation methods.

[**Keywords**: Coastal erosion, Beach erosion, Geotextiles, Green belt, Artificial reef, Sand fencing, Soft and hard options]

Introduction

The world is witnessing a spate of disasters due to global climate change and consequent sea level rise. IPCC Fourth Assessment Report: Climate Change 2007[1] states that sea level is projected to rise between the present (1980–1999) and the end of this century (2090–2099) by 0.35 m (0.23 m to 0.47 m) for the A1B scenario. Scientific Committee on Antarctic Research[2] (SCAR) reports that sea levels are likely to rise by as much as 1.4 m by the end of this century. In the United States, sea level has been rising 2.0-3.0 mm/year along most of the Atlantic and Gulf coasts[3]. Sea level rise prediction is high for the western Japan, particularly at about 17 cm/century in western Kyushu[4]. The sea level rise along the Indian coast from 1993 to 2003 was about 3.1 mm a year[5]. At the time of authoring this paper, Copenhagen meeting is sizzling with the problem of the climate change, sea level rise and measures required to be adopted immediately by nations to mitigate this. Obviously, one of the fallouts of the climate change is increasing global coastal erosion and loss of valuable coastal land. Along with land valuable vegetation, buildings and housing units are also being damaged. It is quite well noticed that about 70% of the coastline of the world is eroding[6]. In India, which has a long coastline of about 7500 km including our Islands, 23% of the coast is eroding (Source: saarc-sdmc.nic.in/pdf/ coastel.pdf). In addition to sea level rise, there are a number of reasons for the erosion menace that we are witnessing today. A large number of developmental activities like construction of ports and fisheries harbors, destruction of mangroves, beach mining, unlimited river bed mining, tsunami induced sea bed disturbances, destruction of sea grass bed, coral reef mining, changing wave height and direction due to climate change, damming of rivers etc., are some of the causes for the shrinking of our coasts.

Materials and Methods

Global coastal erosion scenario

As mentioned earlier, a good chunk of coastlines of the world are severely eroding. Every coastal country and almost every coastal state, has had it's share of critically eroding shorelines. USA, Canada, Thailand, India, Nigeria, China, Sri Lanka, Japan, United Kingdom, Germany and so on, all these nations are tormented by the problem. The rates of erosion however, differ with the countries. For example in USA, the rate of erosion varies from 0.3 m to 0.6 m/year and approximately 86% of U.S. East Coast barrier beaches (excluding evolving spit areas) have experienced erosion during the past 100 years. Bilan[7] reported that the erosion rate in the northern part of Jiangsu province in China is serious and as high as 85 m/year; in Hangzhou bay the rate is 40 m/year, while in Tianjin it is 16–56 m/year. Nigeria looses

Fig. 1— Part of the Isles Dernieres in central Louisiana before and after passage of Hurricane Andrew in August 1992 (Source: http://pubs.usgs.gov/fs/hurricane-impacts).

Fig. 2— Morris island light house on land during W.W. II, in Southern California, USA, now inside Sea (Source: http://www.savethelight.org/gallery200705to200706.html#stayhere)

Fig. 3— Severe erosion at Maravanthe beach in Karnataka state of India, threatening NH-17[12].

land at the rate of 25-30 m/annum. The erosion rates along the Niger delta coast in Nigeria varies, 18-24 m annually at Ugborodo/Escravos station, 10-14 m annually at Opobo and 20-24 m annually at Bonny station[8]. Over the past 15 years, some beaches on Trinidad and Tobago have reported annual erosion rates of 2-4 m, which is primarily attributed to rising sea levels[9].

Shoreline retreat of 2.7 m/year has been reported in Mauritius and the coasts of some islands in Fiji have retreated by more than 30 m in the past 70 years. In the specific case of Viti Levu and Taveuni in Fiji, beach erosion has been attributed to a combination of human-induced causes (including loss of the mangrove fringe and other natural protection) and elevated sea level, which has been rising at a rate of approximately 1-1.5 mm/year since. 1960[10]. Coastal erosion has wiped out dozens of homes and left nearly 200 inhabitants homeless in Buchanan, the second largest city in Liberia. The causes for erosion are unregulated sand mining, and extraction of breakwaters, which some residents use for construction purposes[11].

The images in Figure 1 show part of the Isles Dernieres in central Louisiana before and after sustained winds in excess of 135 miles/hour accompanied Hurricane Andrew, as it passed across the western end of the barrier islands. The photograph on the left was taken in July 1992 before Hurricane Andrew, photograph on the right was taken several days after the passage of Hurricane Andrew in August 1992 (Source: http://pubs.usgs.gov/fs/hurricane-impacts). The destruction of the coast is obviously seen in the Figure.

Figure 2 shows Morris Island lighthouse initially on land during World War II in Southern California, subsequently inside sea due to heavy erosion. Severe coastal erosion at Maravanthe in Karnataka state of India, where National Highway NH-17 also is threatened by the huge monsoon waves is shown in Figure 3. Subsequently, the shoreline here was strengthened by a seawall.

In New Zealand, in the Queen Charlotte Sound, it is reported that the wake waves formed by the ships and ferry boats plying from ports along the coast, cause erosion of the nearby coast. Figures 4(a) and 4(b) below show the sad demise of a sea stack at Nye Beach, Newport, Oregon, USA from 1890 to 1990 (over a period of 100 years) due to coastal erosion.

Figure 5(a) shows a magnificent chalk headland on the south coast of England, in Sussex. The cliff there is the highest chalk sea cliff in sea in Britain, rising to 162 m above MSL, eroded by sea waves. Figure 5(b) portrays the cliff erosion in Massachusetts, USA. The light house inside the sea and the houses on the cliff may be clearly seen.

Skyrocketing coastal erosion occurred in Alaska between 2002 and 2007 along a 64 km stretch of the Beaufort Sea. The surge of erosion, averaging more than double the historical rates, is threatening coastal towns and destroying Alaskan cultural relics (Source : http://www.eurekalert.org/pub_releases/2009-02/agu-erd021809.php). In Nigeria, Africa it is feared that 80% of coastline is at risk of being swept away by the surging waves of Atlantic Ocean, because of its low elevation (Source: http://findarticles.com/p/articles/mi_m1594/is_2_13/ai_83667620/). Rates of erosion in Atlantic Canada can reach up to 10 m/year, but are generally less than one m/year. Historical records show the loss of entire islands along the coast of Nova Scotia (Source: http://gsc.nrcan.gc.ca/coast/facts_e. php#fast).

In Bangla Desh, erosion in Sandwip Island in Ganges delta has assumed serious proportions. From 1913-1988 i.e. in 75 years, the Sandwip Island has been reduced to about 50% of its original size. Erosion was about 200 m/year between 1913 and 1963, and about 350 m/year between 1963 and 1984 (Source: http://en.wikibooks.org/wiki/IB_Geography). The causes of erosion were attributed to wave action due to strong southwest monsoon, high astronomical tides, storm surges in the Bay of Bengal (BOB), and refraction of waves due to a canyon in BOB. Louisiana State in USA, is losing coastal land at the rate of one acre for every 24 minutes, according to U.S. Army Corps of Engineers (USACE). If this is not arrested, some 800,000 acres of land is reported to be lost in next about 40 years and Louisiana shoreline is expected to recede by about 33 miles. A US Federal

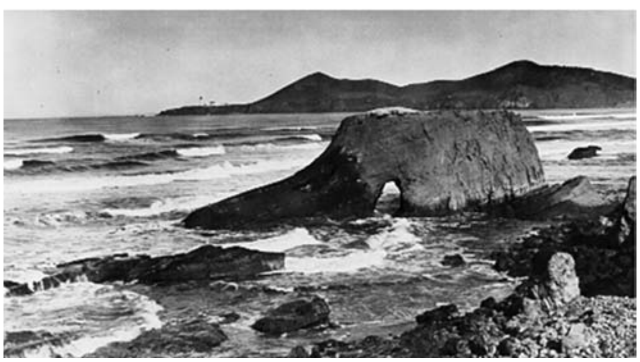

Fig. 4(a) — Sea stack at Nye Beach, Newport, Oregon, USA in 1890 (Source: http://walrus.wr.usgs.gov/pubinfo/jump.html).

Fig. 4(b) — Almost vanished sea stack at Nye Beach, Newport, Oregon, USA in 1990 (Source: http://walrus.wr.usgs.gov/pubinfo/jump.html).

Fig. 5(a) — Cliff erosion in UK (Source: http://en.wikipedia.org/wiki/Beachy_Head).

Emergency Management Agency (FEMA) report of year 2000, states that in next 60 years, 25% of homes and other structures with-in 150 m of shoreline and the shores of Great Lakes would fall victim to erosion.

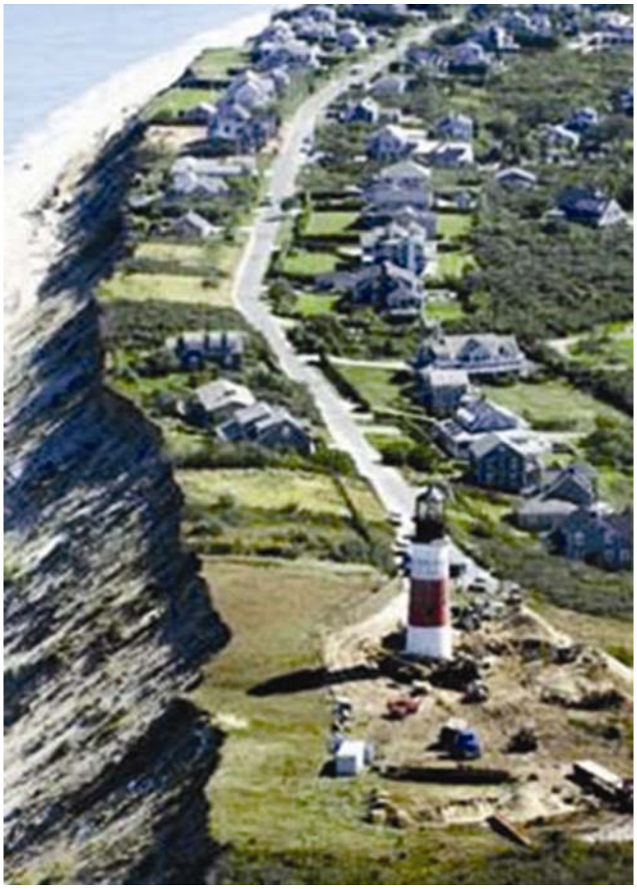

Fig. 5(b) — Cliff erosion, Massachusetts, USA[13]

Japan loses 160 ha of land every year by erosion. If the situation doesn't change, Japan will be loosing 2400 ha after 10 years, and 4800 ha after 25 years (http://www.natureinterface.com/e/ni02/P030-033/). In Do Son - Ba Lat coastal section of Viet Nam, erosion occurs in a very complicated manner with different trends in three periods as follows: Period 1930-1965: erosion occurred over a length of 46.4 km, with average rate of 7 m/year; Period 1965 - 1990: erosion occurred over a length of 59 km, with average rate of 8.1 m/year; Period 1990 to 2005: erosion occurred over a length of 23.7 km, with average rate of 11 m/year[14].

Results and Discussion

Mitigation of Erosion

The mitigation of coastal erosion is a difficult task since a number of parameters and processes are involved in the same. There are a number of mitigation methods both hard and soft, available for mitigating erosion. Hard options are expensive, not eco-friendly and usually massive in size. For example, seawalls, bulkheads, revetments, groins, jetties etc. They are normally made of materials like rubble mound, concrete, etc. Most of the hard options, for example seawalls, have been found to be interfering with local wave hydrodynamics and sediment movement, cause up-drift accretion, down-drift erosion, harm to swimmers, divers, and to marine life. Initially they save the upland at the cost of beaches which is termed 'beach erosion'. After the beaches are lost, upland also would vanish into sea, which is called 'coastal erosion'. Figure 6 clearly distinguishes between beach and coastal erosion[15].

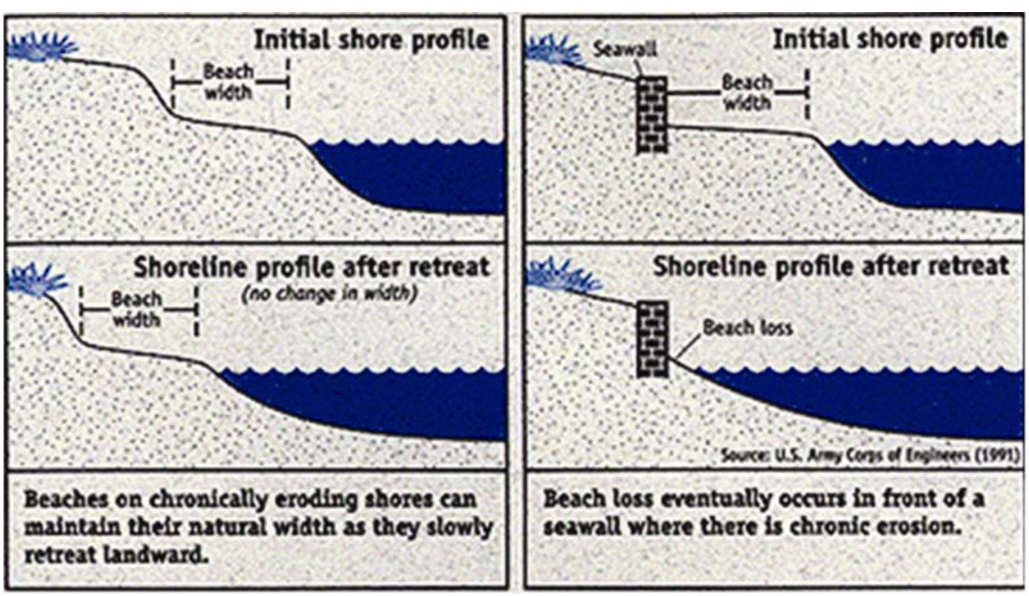

Fig. 6— Coastal erosion vs beach erosion (Source: http://www. soest.hawaii.edu/SEAGRANT/CEaBLiH.html).

In contrast, soft options are usually not expensive, not massive in size, and mostly eco-friendly. These are options like sand bypassing, dune rehabilitation, dune vegetation, beach face dewatering, sand fencing, green belts, Biorock®, geotubes, geotextile sand containers etc., which are being used extensively these days in place of hard options. There are also pro-active methods such as flood proofing, setback limits, zoning, relocation, abandoning, demolition, do nothing etc., which are used similar to soft options.

Of late, the trend in coastal erosion mitigation and protection around the globe has been shifting towards soft and pro-active methods. Newer concepts are emerging and up-to-date methods, technologies are being developed, which are reasonably eco-friendly, construction-friendly, cheaper and also address the root cause of the problem without much 'side effects'. These new technologies often involve non-traditional materials or shapes. They include the use of geotextiles, bio-engineering, geotubes, green belts, artificial reefs of sand filled polythene bags or concrete reef balls, artificial coral reefs and oyster reefs made of bamboo or steel rebars, integrated coastal protection systems etc. These methods are being used now extensively all over the world to mitigate coastal erosion.

Green Belts

Green belts are a series of trees in a number of rows to protect the coast from onslaught of waves. One may remember Picchavaram in Tamil Nadu, which was protected and saved by mangroves along the coast during the Asian tsunami of 2004. A 'Green belt' development project has been taken up by Karnataka state in India, up to 250 m from the sand zone, launched on 7.12.09 at a cost of Rs. 19.81 Crores, spread over 5 years. It is promoted by Department of Forest and Environment and Western Ghats Task Force. Local people and members of the Village Forest Committees and Biodiversity Management Committees will be involved in the project (Source: http://www.deccanherald.com/content/40048/green-belt-protect-coastline.html). In a Green belt, saplings are divided normally in to fruit trees, timber trees, commercial trees, flowering trees and avenue trees. Green belt creations as well as their restoration have been used in Sri Lanka to arrest erosion and tsunami effects. Figure 7 shows Pandunas being planted to develop a protective Green belt along a typical Sri Lankan Coast. However in some cases, villagers living near the restored coastal habitats and officers of the relevant government agencies of Sri Lanka, indicated that although a large number of restoration works have been implemented since January 2005 in the Matara Coastal stretch, most of them failed due to lack of maintenance[16].

Artificial Reefs

Coral reefs are home to over 25% of all marine life and are among the world's most fragile and endangered ecosystems. Coral reefs in 93 of the 109 countries containing them have been damaged or destroyed by human activities. In addition, human impacts may have directly or indirectly caused the death of 5-10% of the world's living reefs, and if the pace of destruction is not slowed down, another 60% could be lost in the next 20-40 years (Source:http://www.marinebiology.org/coralreefs.htm). Coral reefs dissipate the wave energy by wave breaking and hence protect our coasts. Wherever corals reefs have been damaged for reasons like-pollution, dynamite use for fish catching, rising sea water temperature etc., artificial submerged reefs of practically any material may be used to recreate the coral reef colonies.

Artificial submerged reefs of sand filled polythene bags or of patented concrete reef balls are being used today in extensively. Artificial reefs are man-made structures of anything-from sunken cars/ships/concrete blocks/sandbags etc., that attract marine life and also attenuate the sea waves. These reefs augment the

Fig. 7— Pandanus planting program in inter tidal zone for a green belt in Sri Lanka[15]

amount of sea life such as fish, algae, barnacles, corals, oysters etc., and also cause shoreline to accrete. The Reef Ball Foundation is a publicly supported non-profit international environmental NGO working to rehabilitate marine reefs. Reef ball foundations has placed Reef Balls™ in more than 59 countries, have executed more than 3500 projects and deployed over 1/2 million reef balls the world-over (Source: http://www.reefball.org/). Figures 8(a) and 8(b) show typical concrete reef ball used for artificial reefs, and wide beach formation by reef balls in Dominican Republic of Caribbean region respectively. Reef balls also help in recreational snorkeling and diving opportunities.

The Global Coral Reef Alliance (GCRA) uses the method of mineral accretion, or the Biorock® process, owned by Biorock® Inc., and licensed to GCRA. This technology has been successfully applied to fish and shellfish mariculture, as well as to growing limestone breakwaters to protect islands and coastal areas from erosion and rising sea levels. Coral reefs built with the Biorock process are now growing in Maldives, Seychelles, Thailand, Indonesia, Papua New Guinea, Mexico and Panama (http://www.globalcoral.org/). In USA, the artificial reef programs are run for the benefit of recreational sports fishing, SCUBA diving, commercial fishing, waste disposal, environmental mitigation etc. The materials used are mostly waste, including concrete, rock, construction rubble, scrap tires, cars, railway carriages, ships, army tanks etc. Malaysia and the Philippines have used waste tires to build many of their artificial reefs. The central Visayan Islands of the Philippines have known to use 1600 pyramid bamboo modules. Figure 9 shows the

(a) (b)

Fig. 8(a) — Typical concrete reef ball used for artificial reefs. 8(b). Beach before and after placing three rows of concrete submerged artificial reef breakwater in Dominican Republic (Source: http://www.reefball.org/).

Fig. 9— Tetrahedral design of tyres used in artificial reef in Poole Bay, Dorset, UK (Courtesy of Dr. K.J. Collins; Source: HR Wallingford, UK).

Tetrahedral design of tyres used in artificial reef in Poole Bay, Dorset, UK and Figure 10 depicts a pyramidal bamboo module used in an artificial reef in Philippines.

In Australia, reefs have been built from materials such as tires and redundant ships. These reefs are used primarily as a focus for recreational angling and SCUBA diving. In Taiwan, many fishing vessels which were made obsolete by government policy to reduce the size of the fishing fleet, were sunk to provide new habitats (http://www.sbg.ac.at/ipk/ avstudio/pierofun/ ar/reef.htm). Figures 11 and 12 show the use of rebars and concrete blocks for artificial reef development.

Geotextiles

In Sri Lanka and Australia sand filled non-woven geotextile containers, also called 'soft rock structures', good against abrasion, and having high UV resistance, of 100-250 cu.m size, stable in 8-10 m high waves have been used. Figure 13 shows Terrafix soft rock geotextile sand container. Typically, it could be a 20 m long and 4.8 m wide geotextile sand bag, depending upon site conditions and design parameters. The range of application for these products is extensive and covers areas such as scour protection, groynes, berms, artificial reefs and containment of hazardous materials[17].

Many a times sand containers are used in variants like 'sand sausages' or as 'geotubes', composed of geotextile tubes filled with sand and typically they could be 1 to 2.5 m in diameter. Geotubes have been used in Goa in India recently Figure 14(a). However, it is reported that the 140 m stretch of the geotube at candolim beach has been punctured by floating debris, resulting in further erosion of the devastated beach (Source: http://www.

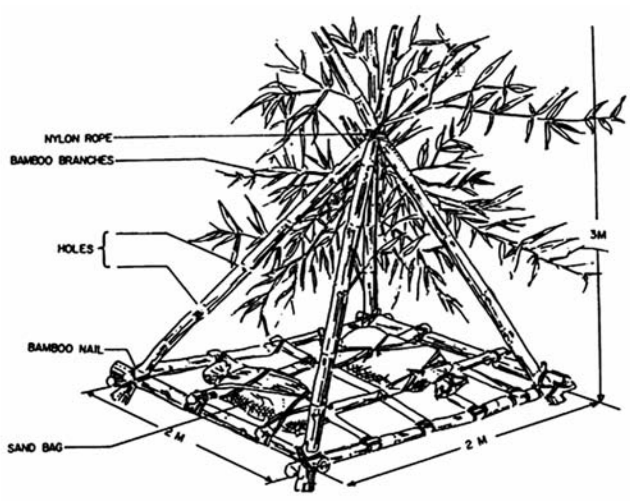

Fig. 10— Pyramidal bamboo module used in an artificial reef for coral reef development in Philippines (Source: http://www.apfic.org/Archive/symposia/1990/15.pdf).

Fig. 11— Rebars used for coral reef development (Source: Wolf Hilbertz/www.globalcoral.org).

Fig. 12— Artificial reef develoment using concrete blocks (Source: http://en.wikipedia.org/wiki/Artificial_reef).

villagetinto.in/news/ candolim-shore-devastated-geo-tubes- fail, assessed on 04.04.2010).

In Germany, the historical house “Kliffende” on the Island of Sylt, which was only 5.40 m away from the edge of the cliff, has been defended with geotextile sand cushions. Figure 14(b). The geotextile structure survived storm surges with a still water level at 2.5 m above normal and severe wave action which could reach more than 5.0 m. (Source:http://www.coastalmanagement.com.au/papers/GeoEng00.pdf).

Zoning

Definition of flood proofing: Any structural/non-structural change in design, construction or alteration of a building in order to reduce the damage caused by flooding or flood related factors such as storm surges, large waves, and erosion is considered as ‘flood proofing’ alternative. A storm surge elevation at 1% exceedence level (100-year recurrence interval) plus waves is used to arrive at risk and insurance rates for individual properties located on the flood maps. Insurance rates for buildings are much lower for structures elevated above the 100 year flood level and are a requirement, for all new construction in the coastal, high-hazard zone in US. In effect, these regulations become flood-plain zoning laws applicable to individual property owners and have resulted in a reduction in government expenditures for insurance claims and disaster assistance benefits in US[18].

Setback Limits

This method adapts to limit any construction close to the shoreline. The land-use planning and construction siting is probably the most effective way of reducing coastal hazards caused by storms, in particular on eroding coasts. The instrument to be used is the Coastal Regulation Zone (CRZ) notification to regulate the various construction practices. Through CRZ, the administration can provide funds to states to help solve the coastal hazard problem. In US, many states have developed coastal construction setback lines and zones that consider and use historic erosion rates at each of the sites. Obviously, the widths and definitions may vary from state to state[19].

Retreat

Retreat usually is the final adaptation option. It includes acts such as relocation, abandonment and also the demolition of the structures situated along the coastal zone. In some of the cases retreat could possibly be the only option left. Nevertheless, all constraints such as economic, environmental, social, legal etc., need to be properly evaluated before the

Fig. 13— Terrafix soft rock geotextile sand container (Source: http://www.globalsynthetics.com.au/files/introduction_coastal.pdf).

Fig. 14(a) — Geotube used at a beach in Goa (Source: http://www.goablog.org/posts/coastal-erosion-threatens-goas-idyllic-beaches/).

Fig. 14(b) — Defended cliff area with geotextile sand cushions on the Island of Sylt, Germany (Source: http://www.coastalmanagement.com.au/papers/GeoEng00.pdf).

option is adopted and implemented. In USA, Brighton Beach Hotel in Coney Island, New York, which is a large beach-front hotel, was lifted onto freight cars to relocate it elsewhere. Similarly, relocation of the Cape Hatteras Lighthouse was completed by the National Park Service (NPS), U.S. Department of Commerce recently. The original lighthouse built in 1803, was replaced in 1870 by the present structure, which is probably the tallest (61 m) in the US. When built in 1870, it was approximately 490 m from the shoreline. By 1935, this distance diminished to about 30 m.

It is reported that in India too, people are weighing the option of retreat from the coast in order to save the beaches and human life. However, it is also feared that once retreated from coast, the coast may be used for beach sand mining, tourism and industrial lobbies to move in, unless strict meassures are taken to prevent this. Moreover, this method may be adopted only after considering and weighing all other options available, as it is bound to induce socio-economic stresses in the peope affected. As is well known, the Government of Hawaii depends heavily on the tourism industry for its revenue needs. It is buying selected coastal land from private owners for the natural erosion to take place and to keep the beaches intact for tourism and recreation (Source: http://www.state.hi.us/dlnr/exhibits/clp/CoastalErosion3.html).

Sand Fencing

When dunes are destroyed by man, disease of beach grass, animal overgrazing etc., re-construction of dunes is possible by this technique, i.e. by driving wooden pickets to about 2 m height, parallel to shoreline at the end of the natural dune line. The porosity of fences could be 50% and the fence fills in about a year, if good wind is available. Fencing may be raised for another 2 m if required after filling once. This method has been used effectively in US, UK etc, to reconctruct the damaged dunes. See Figure 15 for a typical sand fencing used in US. However, the method needs more time for dune rehabilitation as sand accumulation along the fence is a slow process and depends on the wind velocity, beach slope etc. Hence, it may not be adopted where emergency measures are required to restore the beach.

Fig. 15— Sand fencing on an US beach (Source: http://www.gulfmex.org/crp/7004/fence.jpg).

Conclusions

The recent trends in coastal erosion mitigation is shifting towards soft, innovative, and pro-active methods, since the hard methods have their own repurcussions on coastal land and beaches such as down-drift erosion, high cost, poor aesthetics etc. Hard structures such as seawalls and revetments, stop erosion of coastal lands, but refocus the erosion onto the beach. A number of soft methods are available now for erosion mitigation and are being used popularly all over the world. They are very eco-friendly, cheap and construction-friendly too. They may be necessarily adopted on a larger scale in the future erosion mitigation projects, and choice of the particular solution depending upon the local hydrodynamics and site conditions.

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