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Coastal Geosynthetics Protection — an environmental appraisal

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Abstract

Currently, coastal erosion has became so serious an environmental issue that needs immediate address for formulating long-term remedial measurements. Geosynthetics, both as stabilisation measures like revetments and external measures like breakwaters are used as counter measures in the coastal erosion protection system. The geosynthetics protection is also proved to be an ideal method for beach-restoration. The objective of this study is to review the different methods of geosynthetics protections for the coastal areas and to evaluate their environmental significances. Some of the common geosynthetic applications are geotextile, geonets, geogrids, geomats, geotubes, geobags, gabions and concrete filled mattresses, etc. In India, though there is limited use of geosynthetics, yet it has a great potential towards coastal zone management. Indigenous methods like earth-works have short-term benefit and concrete structures cause direct and indirect environmental pollution, On the other hand, geosynthetics are essentially long-term solutions and space saving, cost-saving, eco-friendly, safety, pollution free, along with other significances. Throughout the world, according to the projection trend, the demand of geosynthetics increases continuously. In the coastal areas of India, which is the habitat of a large share of the total population geosynthetics are especially useful to combat the problems of tropical cyclone, coastal erosion and land scarcity.

Introduction

There are two types of synthetic products: natural synthetics like jute, ramie, etc. and artificial synthetic polymers like polyethylene. Nowadays, environmental engineers feel to use geosynthetics structures in abundance as a long remedial measurement replacing indigenous methods and concrete structures to mitigate natural hazards like coastal erosion, coastal depression, flooding, coastal landslides, etc. As mentioned by Small and Nicholls (2003) that 23% of the world's population lives both within 100 km distance from the sea and less than 100 m above the mean sea level on the coasts and population density in the coastal regions is about three times higher than the global average. In other words, nearly three quarters of the world population lives on the sea-coasts and it is also found to be true in India also. The *vulnerable coastal place* is marked as the place which is prone to erosion from unaltered natural processes and undesirable man-induced phenomena.

Coastal erosion is a highly sensitive contemporary environmental issue under the banner of global environmental issues and their protection. Sand mining, destruction of natural vegetation, and different engineering works for the new establishments of sea resorts, ports, industries, fish-landing centres, construction of roads and railways, etc. along the coastline are noteworthy human impacts for the initiation and development of such an issue. Therefore, it can be said that this type of environmental issue is associated with several factors from geologic, geomorphic, marine, climatic, sedimentary, vegetative and anthropogenic origin. In the tropical coastal environmental system, coastal erosion at the time of tropical cyclones seems to be an unavoidable important phenomenon. In India, as Khullar (2006) remarked that there is eight percent of the total land surface, particularly on the Eastern and Gujarat coast, vulnerable to the tropical cyclones. Coasts, about 45 percent of the world, are under such vulnerability (Kale and Gupta 2001). According to International Geographical Union and Coastal Commission for International Survey of Coastal Zones, 70% of the sandy beaches of the world are prone to erode (Biswas

1989). According to Bose (1989), (on) all over the coastal areas, in any plan for management the main consideration is to protect life and property of the local and other people from the natural disaster. Different types of coastal structures based on different specific methods, traditional or contemporary engineering, are constructed to protect the coastal lands from severe erosion, but, sometimes, there is again a need for some of the remedial measurements to protect these coastal structures. Proper engineering construction can make the beneficiaries survive and its maintenance is important for the same purpose of its construction (Sahu 2008). In this context, study of various methods of coastal protection and their environmental significance are important for the coastal planning and management purposes. It is a world-wide experience that coastal erosion cannot be prevented.

To protect coast from erosion artificial modern technology-based geosynthetic coastal structures are spreading all over the world, particularly in the developed countries. It is observed that between developed and developing countries and also between different academicians a debate continues on the acceptability of geosynthetic systems from the environmental perspective. However, there is a growing interest both in developed and also in developing countries for installing low cost coastal protections as the initial total cost of defence works and their maintenance continues to rise. The shortage of natural rock in certain geographical regions can also be a reason for looking to other materials and systems (Pilarczyk 2003; 2008). This paper only focuses on what ways coastal erosion can be prevented using advanced technologies and their Environmental Performance Assessment (EPA). It also does not include engineering descriptions rather it presents the significance of geosynthetic applications on the coasts from the geographical perspective. The objective of this paper is to review different methods of geosynthetics protection and their environmental significances.

Geosynthetic Applications and Coastal Structures

Geosynthetic systems are found to be used in the environmental protection purposes and for infrastructure (Fig. -1). These have immense significance in the coastal belts for coast protection with other types of uses like land reclamation, hill slope protection and flood control within environmental protection works as well. The main reasons behind coastal erosional problem are hostile hydraulic forces generating from sea waves and currents, tides, and also from storm surges. Throughout the world, various artificial coastal structures are effectively engaged to reduce and also to solve the problem of erosion on sandy beaches. They have direct and indirect protection system to the coast through reducing the hydraulic load on the beach. In some places coastal structures and their remedial measurements worked as a unit. The function of these coastal structures, forming a sub-system within the broad coastal environmental system, depends on various elements of the coastal environmental system such as coastal surface condition, slope, geologic, climatic, drainage, hydraulic, and marine characteristics (Sahu 2008).

According to Matthews (2001), maximum common protective works on a coast are: *hard engineering structures* like break waters, sea walls, dykes, levees or embankments, groynes and jetties, and *engineering procedures* like beach nourishment and dune stabilisation. Low crested and submerged structures as detached breakwaters and artificial reefs are becoming very common coastal protection measures (Pilarczyk, 2003). In Japan, these highly expensive broad-crested submerged breakwaters are found to be used, but they have different limitations during storm surges and also in tidal environment. Thus and therefore, in the way of searching the alternative methods and systems, geosynthetic applications came for use. Geosynthetics are used as engineering structures for beach protection and nourishment and they are not properly hard engineering structures. Sometimes, they are used as protective measurements to protect coastal hard engineering structures.

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Nature and Types of Geosynthetics

The term *geosynthetic* is derived from the two words: *geo* means geo-technical related earth materials like soil, sand, rock, etc. and the term *synthetic* refers to the synthetics of natural and/or polymeric materials (Holtz 2001). Generally, it means to the artificial polymers used with naturally available earth materials. According to the American Society for Testing and Materials (ASTM) Committee (Holtz 2001), geosynthetic is 'a planar product manufactured from polymeric material used with soil, rock, earth, etc as an integral part of a man-made project, structure, or system.'

Within the geosynthetic systems, high-strength synthetic fabrics and sand or mortar, etc. are used for filling up the synthetic nets or bags as well. The geosynthetics are synthetic products, thin, flexible and sheet like materials made of polyethylene (PE), polypropylene (PP), polyvinylchloride (PVC) and polyester (PET) and also ethylene copolymer bitumen (ECB) and chlorinated polyethylene (CPE) (Agrawal 2011). Polyethylenes have a very simple structure composed of long **chains of carbon atoms with two hydrogen atoms attached to each carbon atom. Due** to their non-polar nature, polyethylenes are resistant to chemicals and they also have very low permeability to liquids and gases and are almost insoluble at the temperature below 60°C. High density polyethylene (HDPE) and low density polyethylene (LDPE) are used in geosynthetic applications like geonets, geogrids, etc. Geotextiles are made of knitted or stitch-bonded fibers or yarns.

Geosynthetic systems have four forms: sheet like mattresses, tubular long structure or geotube, submarine structure with a very large sized geotextile bag or geocontainer and bags of a small volume or geobag (Koffler et al. 2008). In general, they are viewed in three forms (Fig. -2). Planner structure and three dimensional structures are very common and the other is geocomposite form. Popular geosynthetic varieties have net like structure (Fig. -3a), tube-like shape (Fig. -3b) and bag form (Fig. -3c). Geotextiles are common standard textile manufacturing applications. They are flexible and porous continuous sheets. They are of *woven* and *non-woven* types. Geogrids are grid like systems. They have a uniformly distributed array of gaps between their longitudinal and transverse lines. These gaps allow direct contact between soil particles on either side of the sheet. Geonets look like fishing nets. They are open grid-like applications intersecting at a constant acute angle. Besides, there are geocomposite structures like geotextile-geonet; geotextile-geogrid; geonet-geomembrane, etc. Three dimensional geosynthetic structures are geocell, geomattresses, geobag, geotube, etc. Besides, there are jute-based biodegradable geosynthetics of natural origin also. In geocells strips of polymeric sheet are joined together forming relatively thick interconnected cells filled with sands. Geomattresses are deep geocell layers when 0.5 m to one m wide strips of geogrids have been linked together with vertical polymeric rods. Geobags are the geosynthetic bags made of natural or synthetic fibers filled with local available materials like sands. In 1970, there were only five to six types of geosynthetic applications, but, at present, throughout the world, there are more than 600 types of geosynthetic applications (Holtz 2001).

Coastal Geosynthetic Applications

In general, geosynthetics have six primary functions: filtration, drainage, separation, reinforcement, fluid barrier, and protection (Holtz 2001). Geosynthetics are used as counter measures to control beach erosion and also for beach nourishment purposes. They protect the coast from sea-erosion. Fig. -4 (a & b) depicts the area of geosynthetic applications for their installation and use. One group of civil and environmental engineers considered geosynthetic protection as an ideal method for the beach-restoration project. According to the Department of Ocean Engineering, IIT, Madras, geosynthetic products like geotubes and geobags are the new coastal protective measurements in India replacing indigenous methods of earth works. The woven geosynthetics of polypropylene are used for the confinement of soils using local soil into a geosynthetic cover. To control the problem of sea coastal erosion and further better coastal management, the function of geosynthetic measures depends on the place specificity including geological, geomorphological and hydrological aspects of a particular problem area on the coast, coastal climate and the marine processes. Geomattresses are used for slope and bed protection works. Geobags are suitable for the protection of beach slopes, cliffs and concrete walls - particularly their toe - but they are used mainly to construct groynes, hanging beaches and offshore breakwaters as well. The geotubes are mainly advised for the construction of groynes, perched beaches and offshore breakwaters. They are also used as coastal embankments for reclamation purposes. Geocontainers also have the same type of applicability with geotubes.

World and India Review

Today, considering the use and application of geosynthetics, there is a profound dichotomy between developed and developing countries. Geosynthetics are used in the developed countries like U.K., U.S.A., Australia, etc., even in China also, for building and also for protecting coastal embankments, dykes, sea walls, offshore breakwaters and revetments in common. In the 17th century, the Dutch first employed small sand-filled containers to protect coast from erosion effects (Harris and Sample 2009).

In 1950, modern geosynthetic coastal protection methods for the first time had been adopted in Holland. Thereafter, in the developed countries, since 1980, for the construction of sea-front embankments, sea-dykes, seawalls, offshore breakwaters and revetments, geosynthetics have been being used in common. During the 1960s, only woven geotextiles were used to control erosion. But, in the 1970s, both woven and nonwoven geotextiles were adopted in protection and land management applications. In India, it is only found to construct groynes in the coastal areas due to their low construction cost. Here with other Asian countries like Japan, Korea, China, Taiwan, Vietnam, Thailand, Singapore, and Malaysia following the pioneering developed countries like Netherlands, U.K., U.S.A., Canada, Australia, and Russia, coastal geosynthetic protection system has become popular. Geotextiles have also been used for protection works in Bangladesh.

In India, at present, though there is limited use of geosynthetics yet there is greater opportunity in respect to the coastal zone management. According to the projection trend the demand of geosynthetics increases around 5.3% annually throughout the world. Presently, the annual consumption of geosynthetics is close to 1000 million square meters, whose market value is probably close to US$1500 million (Holtz 2001). In China, the geosynthetics reinforcement has been widely adopted for the purposes of engineering management and it yields great benefit to the society and economy. In India its consumption level is very low, less than 1.5% of the global production. In the U.S.A., use of geosynthetics to control coastal erosion is mandatory and there consumption of geosynthetics is highest as well.

Environmental Significances and Performance

In general, geosynthetics are mainly used for reinforcement and protection purposes in the coastal areas. Different coastal structures are found to be used on coasts from the traditional brick or stone structure or concrete structure to more contemporary systems as geotextile, geobag and others. In the discourse of environmental engineering, traditional methods like earth-works have short-term benefit and concrete structures cause direct and indirect environmental pollution, whereas, geosynthetics have several physical and socio-economic significances. The organic material like jute tends to shrink and swell under field conditions and it is extremely flammable (Theisen 1992). In the environmentally fragile areas of high latitudes, geobags have positive significance in comparison with classical armour rock solution from the environmental perspective, particularly from the transport environmental impact perspective (Artières et al. 2010).

Geosynthetics can take any form in accordance with the functional requirements of the coastal areas particularly for beach nourishments and also to increase life time of the coastal hard engineering structures through protecting them. As they are thin and flexible, and sheet-like materials, (therefore,) they are remarkably significant for coastal erosion protection and control. Geosynthetics are space saving. Physically they take negligible area in comparison with the concrete wall structure made of rocks or cementing blocks. In the densely populated coastal areas and also in the beach tourist spots in India space for protection works is inadequate and there geosynthetics are much applicable. Geosynthetics have myriad hollows and these hollow parts of geosynthetics allow free movement of air, water and sand particles from one side to another of the sheet, which is environmentally significant for sustainable use. Geogrids are used for base protection of seawalls and they have foundation reinforcement applications. Woven polypropylene geotextile tubes are used as low-crested submerged structures to weak sea-waves before to reach shore line. Geosynthetics are essentially long-term solutions for nearly 50 to 100 years life time in many cases and space saving, cost-saving, eco-friendly, safety, pollution free, along with other significances.

Palmeira et al. (2008) mentioned the advantages of the use of geosynthetics from the environmental perspective for Asia. Manufacturing of geosynthetic products leads to less carbon-di-oxide emission than the construction of conventional types of retaining walls (Palmeira et al. 2008). Geosynthetic applications save beach materials from the toe to upper section of an erosion-prone coast and thus minimises the rate of coastal erosion. It is observed that 0.4 mm. thick plastic filter cloth could replace up to a metre of soil (Theisen 1992). Geosynthetics provide protection against ecological disasters like flooding and cyclone confining minimum cost. These structures can survive a coast during the severe storm conditions with a wave range of 2.5 to five metres (Yalciner 2006). They are considered as ideal for the beach-restoration system. Economically, this system is saviour as it takes minimum transportation cost since its weight is very low than the materials used for concrete embankments and it requires negligible installation charges with minimum maintenance cost for a long time employing much skilled labours and saved natural environmental system using large amount of natural resources like sand, soil, rock, and other materials.

According to Werth, Haselsteiner and Steinbacher (2011), application of geosynthetic methods is economically benefitted. The use of geotextile in many cases reduces the thickness of granular filter layer and therefore the associated costs, thereby it is considered as cost effective (Islam 1999). In many cases, geosynthetic applications significantly increase the safety factor and improve the performance of a coastal structure and reduce the costs in comparison with conventional design and construction alternates (Holtz 2001). For the geosynthetics the CBR ratio is estimated as ≤ 3.5. It is experienced that the use of sand-filled geotubes as a core of the coastal structures can reduce effectively the estimated cost (Pilarczyk 2003). In the coastal environmental system, geotubes artificially prevent movement of sands over beaches from the landward section and therefore the shore line retreats at a higher rate. When geosynthetic mounds are covered by sands with natural vegetation then they are considered as a natural dune.

Geosynthetic applications are environmentally significant in the sandy beaches where there is shortage of large sized natural rocks. It is also significant at places where large vehicles cannot carry heavy cementing blocks and other weighted things .There, in those places geosynthetics have been transported easily. It can be installed on any type of coastal surface. For a safe and secure coastal environmental system geosynthetics are cost-effective in the long run. It is calculated that geosynthetics cover only less than five percent to the total project cost. Dinesh Kumer, Josanto and Sankaranarayanan (1993) opined that though it is low cost and cheap method of coastal protection but in India its proper implementation is expensive. In India, environmental consciousness among people is not enough to establish sustainable development applications on coasts. Since population grows very sharply and land scarcity progressively increases, to meet the stringent environmental regulations geosynthetics are environmentally significant. Geosynthetics reduced wave energy to the required level on beaches through their wave breaking processes and thus maintain the dynamic balance in the coastal environmental system.

Environmental Problems

As geosynthetics have high resistance to chemical and biological attack therefore there is no problem for their reinforcement and use in the coastal areas. However, if, there are industries on coasts and from those there is a chance of chemical environmental pollution in the coastal areas, it may finally lead to change the chemical compatibility of the polymers within geosynthetics. Use of geosynthetics depends on chemical property of the underlying soil. Geosynthetics work properly when there is a strong base of high strength soil or rock support. Based on the nature and type of coastal erosional problem for a particular place it is important to install proper designed geosynthetic application. From the engineering perspective, therefore, significance of geosynthetic applications is general as well as systematically related throughout the world but when any question is raised in relation to a particular case of a place then arises the necessity for a regional as well as an idiographic study in search of solutions. Environmental engineers, civil engineers, and others remarked on the significance of geosynthetic applications based on their laboratory and few field applications. It is true that throughout the world significance of geosynthetic applications for a long time has not yet been tested. Gibeaut et al. (2002; 2003) remarked that the geotubes can only be used as a temporary measurement to defeat coastal erosion. In front of the geotubes at a beach tourist spot the sub-environment of the beaches has been disturbed enough as beaches are becoming narrower and the tourists' use of the beach may be diminished.

Conclusion

Throughout the world, it is rigorously witnessed, that in the coastal areas, due to unaltered natural processes and undesirable human impact, the coastal environmental stability is affected and thus, coastal erosion became very serious. Nowadays, it is considered as a high alarming environmental issue to the governments of all problem-faceted countries, which immediately needs more attention to establish long-term remedial measurements like geosynthetic applications. At present, developed countries use geosynthetic products and systems on coasts for beach nourishment and erosion protection purposes and side by side it is also important for the less-developed and developing countries as well. The impact of Geosynthetic applications (impact) and environmental significance on place and society are acceptable .Therefore they need much more low-cost models for the less developed and developing countries. With the fast growing technological achievements use of geosynthetics cannot be passed side out for a long time. They have various environmental significances in their favour for installation but at the same time proper installation is important to get ultimate benefit from them. Spatially, geosynthetics have relationships with their surroundings, therefore, for a better coastal plan and management aiming to protect coastal habitat, economy and society geosynthetics are the alternates apart from concrete and traditional methods.

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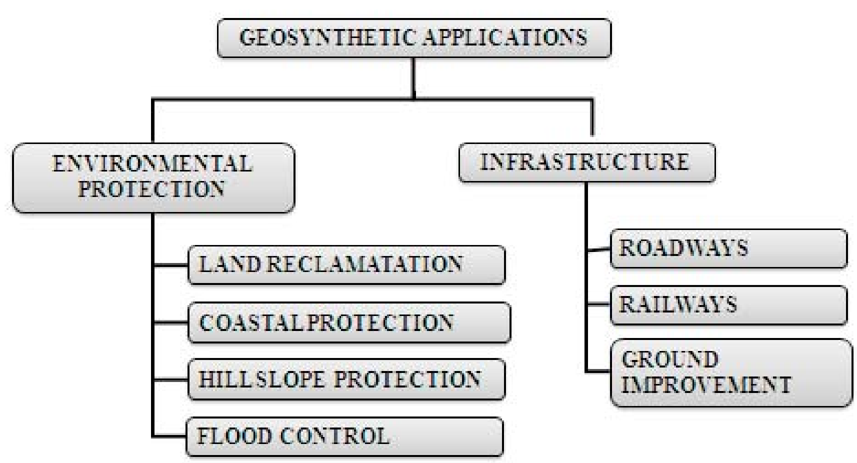

Fig.1: Geosynthetics Application Areas

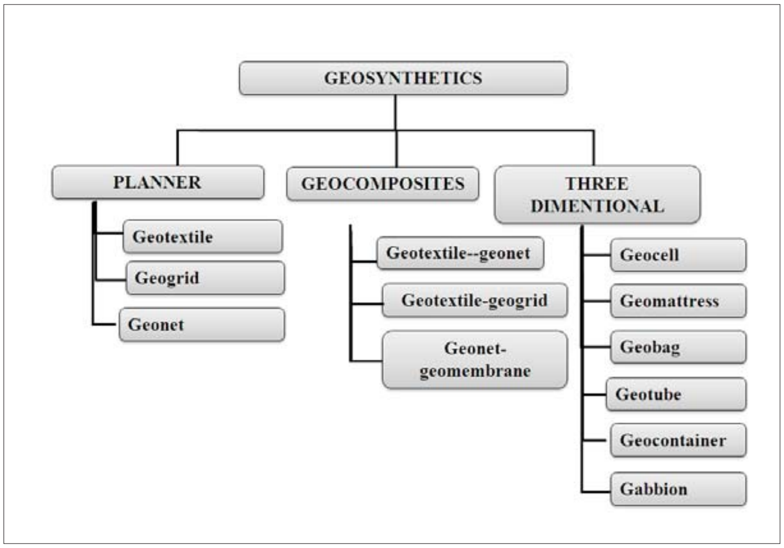

Fig. 2: Types of Geosynthetics

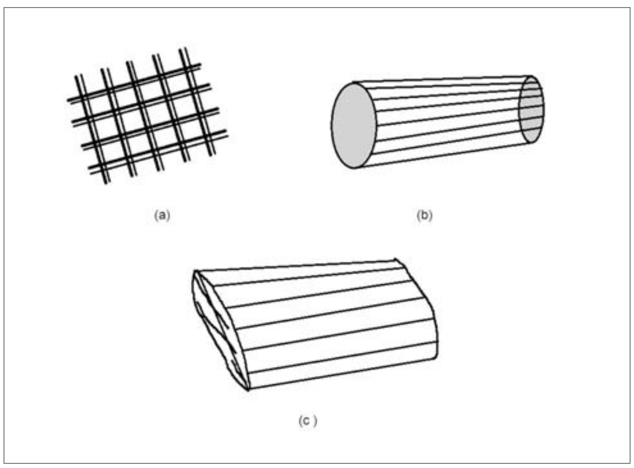

Fig. 3: Common Shapes of Geosynthetics (a) net, (b) tube and (c) bag

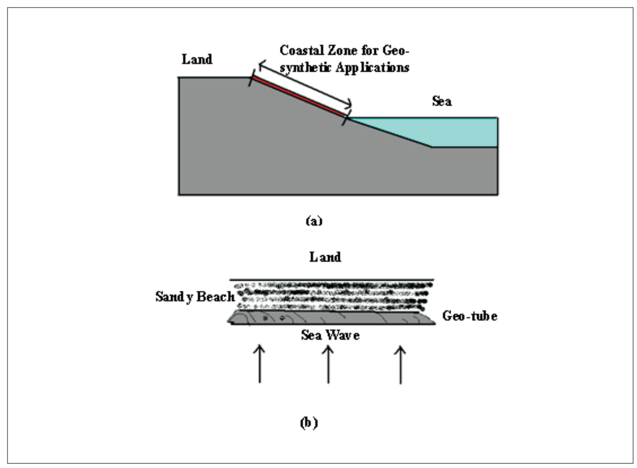

Fig. 4: Location of Coastal Applications

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