Chapter 55
Application of Geotextiles for Protection Against Coastal Erosion

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Abstract Protection of the coast against erosion is an important component of coastland management. Waves, littoral drift, storm surges and sea-level rise coupled with anthropogenic activities near-shore such as dredging are the main causes of coastal erosion. Geotextiles (GTs) made from thermoplastics (synthetic) belong to the group of planar textile fabrics used usually in or on the soil to improve its engineering performance. Synthetic geotextiles have been in use to protect coasts for the last 5/6 decades effectively in developed countries. The USP of synthetic geotextiles is its long-term durability, high tensile strength and felicity in making customized fabric and economy. For geotextiles to perform efficiently, they must satisfy site-specific mechanical, hydraulic and durability requirements. The long-term behavior of geotextiles against mechanical stresses in a site-specific hydraulic environment can be pre-assessed in the laboratory. Synthetic geotextiles singly may not, however, protect a coast subject to severe erosion for which offshore structural intervention in addition to robust on-coast geotextile protection may be necessary. Innovative forms of geotextiles such as geo-tubes/geo-containers are also used in appropriate cases in place of simple geotextile fabrics. Eco-concordance of polymer-based geotextiles is not, however, without question. It is worth exploring if mangroves can be nurtured along coasts concurrently with synthetic GTs to protect coastland against erosion. Mangroves with their stilt roots can hold coastal soil, can induce accretion of silt over coasts when silt-laden seawater passes through their root system and can attenuate wave impact.

Keywords Coastal erosion · Coastal protection · Geosynthetics · Geotextiles · Mangroves · Soil stability

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55.1 Introduction

55.1.1 Coastal Erosion and Its Causes

Protection of the coast against erosion is an important component of coastland management. Man has been trying to protect the coast since ages against ravages caused by sea-borne erosive forces with the help of available natural resources. Attempts to protect the coast by using natural implements in the past, however, did not sustain as such measures were more instinctive in nature and empirical than scientific. On top of it, processes of erosion in sea-coast and the behavior of coastal soil against such erosive forces of nature were not precisely known in the past. Waves driven by wind and propelled by the movement of ships veering past the coast, the orientation of oceanic currents—principally littoral (along-shore) currents, and occasional storm surges resulting from tectonic disturbances such as tsunami are palpable causes behind erosion in the coast. Sea-level fluctuation due to diurnal/semi-diurnal tides caused as a result of global warming disquiets coastal equilibrium. The development of high pore-water pressure within coastal soil also affects coast-soil stability.

Oceanic environment being highly dynamic warrants careful observation over a sufficient period of time for identification and estimation of the erosive forces responsible for coastal erosion at a particular site. On coasts verdant with aquatic vegetation such as mangroves, the problem of erosion is markedly less. Besides attenuation of wave impact, root-webs of mangroves facilitate part of sea-borne sediment to accrete over shore when silt-laden brackish water flows through them, largely compensating soil loss caused as a result of erosion. Additionally, anthropogenic interventions may affect coastal stability. Offshore structures help re-orient wave and current behavior of the coast. Deepened sea-bed profile caused by dredging near-shore could also affect the impact of waves and current on the coast.

55.1.2 Remediation of Coastal Erosion by Use of Geotextiles

Over the years man has gained precise knowledge about the nature and intensity of sea-borne erosive forces and the behavior of varying kinds of coastal soil against them. It now stands established that the best approach to control coastal erosion should be two-pronged-first, to adopt measures to lessen the effects of such erosive forces on the coast by structural interventions and secondly, to devise contrivances for retention of coastal materials in place and to dissipate pore-water pressure developed within coastal soil that could disquiet its stability. The development and application of geotextiles address these dual objectives.

In this paper, an attempt has been made to present the basic design approach underlying use of geotextiles in combating coastal erosion without going into engineering design intricacies considering the fact that the target readership comprises mostly agricultural scientists/researchers and fiber technologists.

55.2 Geotextiles

Geotextiles are basically breathable fabrics made of either artificial fibers or natural fibers. This discussion is confined to artificial geotextiles made from thermoplastics such as polyamide, polyester, polyethylene, polypropylene, commonly known as 'synthetic geotextiles' or 'geosynthetics' in view of the fact that natural geotextiles made usually of jute or coir fibers degrade quickly especially when exposed more so in saline ambience and are far less durable than their synthetic counterpart in general. Moreover, most of the natural fibers are too coarse to make fabrics that conform to the precise design pore size (AOS, i.e., apparent opening size) and strength. In this paper, the term 'geotextiles' has been used to denote polymer-based synthetic geotextiles only.

It needs mention that any geotextile fabric, natural or polymeric, has three constructional variants, viz., woven, non-woven, and open-weaved (knitted). Woven geotextiles are the strongest and most durable of the three variants. Considering the intensity of erosive forces (also called loads) in the coast, woven geotextiles are invariably used as a protective cover over eroded/erosion-prone coast.

Three criteria are critical in the design of geotextiles. These are durability, tensile strength and the desired pore size. The principal functions of a geotextile are separation, filtration, drainage and reinforcement. Fabric-permeability is a critical criterion in the design of a site-specific geotextile for the proper performance of filtration function.

Filtration is the most important function of geotextiles. This implies that the fabric is supposed to retain coastal materials in place on the one hand and on the other has to facilitate dissipation of pore-water pressure generated within the coastal soil under protection. Prima facie, the aforesaid two functions, may appear to be in contrast in as much as retention of coastal materials calls for smaller fabric pore size in keeping with an average grain size diameter of coastal soil whereas pore-water dissipation requires bigger fabric-openings for release of excess pore-water pressure from coastal soil. Rigorous research in the field has led to the development of valid test-procedures to satisfy both the criteria with optimized porometric features of geotextile fabric in relation to the average grain size diameter of coast-soil particles and estimated pore-water pressure, besides conforming to the criterion of strength and allied properties.

Woven geotextiles possess higher abrasive, puncture and tearing resistance and tensile strength than the non-woven type. Non-woven type, however, being more permeable than the woven variant possesses higher filtration efficiency. It is for this reason, sometimes, both types are used in conjunction in cases where both strength and more efficient filtering capability of a geotextile are simultaneously required.

Basically, geotextiles are used in or on the soil to improve its engineering performance. Improved engineering performance implies enhanced capacity of soil to remain stable under the impact of different kinds of pre-estimated imposed loads. Fundamentally, the role of geotextiles is that of a change agent that helps in building up 'effective stress' in the soil to be protected. Effective stress is a condition of the soil that maximizes its resistivity against the impact of loads. Simply stated, it is a factor of compactness of soil particles that can be attained by ensuring adequate filtration. Proper filtration removes inter-particulate voids between soil particles, thus making it compact with soil particles touching each other and thus generating effective stress within the soil mass.

To ensure efficient performance by a geotextile, in-situ mechanical, hydraulic and durability criteria must be known and addressed (Van Zanten 1986). The long-term behavior of geotextiles against mechanical stresses in a site-specific hydraulic environment is pre-assessed in the laboratory.

However, it should be noted that geotextiles singly may not always protect a coast subjected to severe erosion. In moderate cases of coastal erosion, the fabric is overlain by revetment (also called 'riprap' or 'armor') made of stone boulders/concrete blocks to withstand the initial impact of the imposed forces such as current and waves and to prevent washing away of coast-soil and resist uplift caused by seepage flow. Stones of high specific gravity and individual weight are recommended for constructing revetments. In extremely severe cases, protective structures such as offshore breakwaters and spurs may have to be built for repulsion of currents away from the coast or for diverting current to a safer direction. Geotextiles are sometimes put to use in such structures appropriately for strengthening them.

Two mechanical criteria for geotextile fabric overlain by riprap deserve consideration (Lawson 1992). These are mass per unit area and trapezoidal tear resistance. ASTM standards exist for these two criteria. For hydraulic criteria, the orientation of flow and wave activity at the site is to be considered. In the event where varying hydraulic flow patterns are to be encountered, selection of a geotextile should be done on a conservative basis keeping higher tolerance limits for deciding its specification. The fundamental design principle is that the geotextile should be able to resist the maximum estimated imposed loads including chemical and biological loads during its design service life. In other words, the strength of the chosen geotextile should remain higher than the estimated occurring loads. Additionally, care must be taken to ensure that the geotextile does not turn out to be a plane of sliding.

To pre-estimate, the occurring loads, the oceanic environment at the site should be assessed properly. Data on waves and currents, especially wave heights, current orientation and its celerity, sea-level fluctuations vis-à-vis mutating ground-water level over a period of time, sub-soil characteristics such as plasticity, cohesiveness, permeability, angle of internal friction and grain size diameter, must be considered by the designer. On top of these, at sites where ship movements induce considerable waves, data on ship traffic, ship velocity and ship size may be necessary. The specifications of geotextiles to be used for coastal protection should be selected taking into account its strength, durability and filtration efficiency against occurring loads. Understandably, the design of geotextiles in a dynamic coastal environment demands specialized engineering knowledge and experience.

Selection of anappropriate geotextile product for a specific application should be matched by strict quality control over the manufacture of the recommended geotextile in the factory as well as work execution at the site. For coastal application, comparatively heavy types of geotextiles with high tensile strength and adequate resistance against puncture and abrasion are usually recommended. As already indicated, in cases where woven geotextiles do not singly meet the filtration requirements, the non-woven variety of appropriate specifications should be used in conjunction with its woven counterpart.

Apart from the design criteria stated above, two other probable pos-application conditions of geotextile fabric that deserve attention are 'clogging' and 'blocking'. Clogging is caused by extraneous deposits within the fabric-thickness, while blocking is blockade caused by the accumulation of extraneous particles on the fabric surface. Clogging and blocking of any woven geotextile fabric understandably affect filtration efficiency. Susceptibility of a woven geotextile to clogging and blocking can be predicted by conducting gradient ratio test (ASTM D 5101)/hydraulic conductivity ratio test (ASTM D 5567) prior to application.

As indicated, the use of geotextiles in tackling coastal erosion is not always confined to their use singly as fabric with only revetment (riprap) overlying it for preventing their displacement against various erosive agents and seepage uplifts. Various innovative forms of geotextiles have been developed over the years that can be put to use effectively to control severe coastal erosion if the situation so demands.

55.3 Innovative Forms of Geotextiles

Several innovative forms of geotextiles have since been developed beyond its conventional form as fabric. Mention may be made of sand-filled geo-tubes, geotextile containers, poly-felts (multi-layered filters), rope-gabions, etc., as tools against severe erosion. In cases where the use of geotextile as the fabric is not considered sufficient, these innovative variants are sometimes used considering the extent of the severity of coastal erosion. Geo-tubes filled with suitable granular materials are used as scour apron on sea-bed and as ingredients for constructing dykes/spurs. Geo-tubes are sometimes filled by pumping dredge-spoils directly from a dredging site if it is close to the coast. Large-volume geo-containers are sometimes used as components of offshore structures in cases of severe coastal erosion. Precise placement of geo-tubes/geo-containers on the coast or for building offshore constructions calls for support of appropriate constructional facilitators. For the construction of some types of offshore structures, geo-bags containing suitable granular materials are stacked in convenient geometric shapes by placing them one above the other as is done in the case of stacking of cement/grain-filled bags. In India, such innovative forms of geotextiles have been sparingly used so far. Details of such innovative variants and their specific applications have been avoided for the space-limitation of this paper.

55.4 First Trial with Geotextiles

The first physical trial with geotextiles was undertaken in the Netherlands in the 1950s to protect the coast against massive erosive forces of the North Sea. This gigantic project was a concerted effort of hydraulic engineers, researchers, fabric engineers and construction experts of the country. The success of this application led other developed countries to try the product. In fact, global interest in geotextiles ensued after the success of the trial leading to increased activity in research, innovation and application of geotextiles in various fields of civil engineering where soil poses problems.

The use of geotextile mattresses on riverbed in the Hugli estuary opposite Haldia for construction of a 2.8 km long massive guide-wall at the northern tip of Nayachar island (opposite Haldia docks) was successfully carried out by the Kolkata Port Trust with technical support from the Dutch Government for the first time in the country in the late 1980s. The mobile riverbed was found destabilizing the massive wall being built over it, and the geotextile mattresses were used to stabilize it (Sanyal 1991a).

55.5 Eco-Compatibility of Geotextiles

Geosynthetics, however, do not possess full-proof eco-concordance which has led to increasing adoption of natural geotextiles (usually made of jute and coir) in areas calling for less severe technical requirements. Questions have been raised by environmentalists about the behavior of polymeric-derivatives staying within or on soil for years. Doubts remain to be cleared convincingly so far.

55.6 Mangroves and Coastal Erosion

Mangroves deserve consideration by experts for coastal protection in the context of environmental preservation. The ability of mangroves to protect coastland stands substantiated by studies. It is worth exploring if mangroves can be nurtured along coasts concurrently with geotextiles to protect coastland against erosion. Mangroves with their stilt (knee) roots can hold coastal soil and at the same time can induce accretion of silt over coasts when silt-laden seawater passes through their rootsystem. Mangroves can attenuate wave impact to a good degree. There are about 64 varieties of mangroves with varying degrees of salt tolerance and growth rate. It is advisable to consult agriculture experts to decide on the choice of the right type of mangrove species for a particular site (Sanyal 1991b).

Mangroves thrive in coastal swamps and inter-tidal brackish water zones, especially along sea-coasts and estuarine reaches where the coast is alternated by wetting during tides and drying during ebbs at a regular periodicity. The plant has special characteristics inherent in them to sustain and grow in such an environment. There are other factors that determine the expanse of a mangrove forest such as inter-tidal reach, soil substrata, extent of salinity of soil and water and period of inundation. It has been noticed in initial studies that mangroves can dissipate wave energy by about 40%.

55.7 Conjunctive Use of Geotextiles and Mangroves

It is worthwhile to explore if mangroves can be grown on the coasts in association with geotextiles. The bio-engineering approach could compensate to a good extent the eco-discordance caused by geotextiles. To ensure conjunctive use of mangroves and geotextiles, perforations may be made in the geotextile fabric to plant mangrove-saplings through them following a pattern and spacing that will allow uninhibited growth of each plant. The resultant effect of the combination demands careful in-situ study and subsequent refinement of the plantation technique. The author advocates a physical trial and study with these two anti-erosion tools, one natural (mangroves) and the other artificial (geotextiles) under the close technical surveillance of a competent research outfit.

55.8 Conclusions

Till such time a fully eco-compatible solution is found, and geotextiles with their variants remain to be the only plausible answer to the problem of coastal erosion. Despite questions about doubtful eco-concordance of geotextiles, their effectiveness in addressing geotechnical problems of various natures and degree stands established beyond question due to validation by physical applications, intensive study and continuing research. Besides, the aspect of the economy and easy availability cannot also be ignored. Conjunctive use of geosynthetics and mangroves, if successful in controlling coastal erosion, will dispel reservations about the man-made product's eco-incompatibility and promote its wider acceptability.

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