Geotextiles and Geomembranes 29 (2011) 402–414

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

Geotextile bag revetments for large rivers in Bangladesh

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ARTICLE INFO

Article history:
Received 4 January 2010
Accepted 11 November 2010
Available online 8 January 2011

Keywords:
Sand-filled geotextile bags
Geotextile bag revetments
Riverbank protection
River training works

ABSTRACT

Since the late 1990s, riverbank revetments constructed of sand-filled geotextile bags (geotextile bags) have been developed in Bangladesh in response to the lack of traditional erosion-protection materials, particularly rock. After independence in 1971 and the related loss of access to quarries, rock was replaced by concrete cubes, but those are expensive and slow to manufacture. Geotextile bags on the other hand, first used as emergency measures during the second half of the 1990s, can be filled with local sand and therefore provide the opportunity to respond quickly to dynamic river changes.

Geotextile bags also provide the potential for substantial cost reduction, due to the use of locally available resources. The use of the abundant local sand reduces transport distance and cost, while local labor is used for filling, transporting, and dumping of the 75–250 kg bags. Driven by the need for longer protection, the idea of using geotextile bags for permanent riverbank protection emerged in 2001. Eight years of experience have enabled systematic placement of geotextile bag protection along about 12 km of major riverbanks at a unit cost of around USD 2 M per km. By comparison, concrete-block revetments cost around USD 5 M per km. In addition, there are strong indications that geotextile bags perform better than concrete blocks as underwater protection, largely due to their inherent filter properties and better launching behavior when the toe of the protected underwater slope is under-scoured.

This article reports the outcome of the last eight years of development work under the ADB-supported Jamuna-Meghna River Erosion Mitigation Project (ADB, 2002), implemented by the Bangladesh Water Development Board. Besides substituting geotextile bags for concrete blocks as protective elements, the project involved development of a comprehensive planning system to improve the overall reliability and sustainability of riverbank protection works.

1. Introduction

1.1. Background

Bangladesh is one of the most densely populated countries of the world (more than 1000 persons per km^2), with few natural resources. At the same time it is one of the most disaster-prone areas with an average of about 6 major disasters annually. The country is largely situated on the fertile delta of four great rivers: Ganges, Brahmaputra, Padma and Meghna. These rivers flow through alluvial plains built up over million of years from sediments mainly derived from the unstable southern slopes of the Himalaya. The rivers are characterized by (i) very high discharges, in the order of 100,000 m^3/s in severe floods, (ii) local flow velocities exceeding 4 m/s at exposed points, (iii) deep scouring, locally exceeding 70 m in depth, (iv) great lateral instability with bank erosion rates in some places exceeding 1 km per year, and (v) an absence of rock sources for riverbank stabilization.

In this environment riverbank protection was attempted over a long period, with only limited success. A major impediment was the high cost of concrete blocks. This often limited the length of the protective works to a few hundred meters, while erosion problems commonly affect lengths of several km. In 1999 riverbank erosion became critical alongside two large irrigation projects: one situated on the right or west bank of the lower Brahmaputra (called Jamuna in Bangladesh), and the other on the left or east bank at the confluence of the Upper Meghna with the Padma – which carries the combined flow of the Brahmaputra and Ganges (ADB, 2002). In terms of average annual discharge the Brahmaputra is classified as the fifth largest river of the world, while the Padma is the third largest, only surpassed by the Congo and Amazon (Schumm and Winckley, 1994).

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doi:10.1016/j.geotexmem.2010.12.003

Table 1
Properties of geotextiles used for bags.

Properties	Test standard	Test values
Opening size O_{90}[b]	EN ISO 12956	≥0.06 and ≤0.08 mm
Mass per unit area	BS EN 965	≥400 g/m^2
CBR puncture resistance	EN ISO 12236	≥4000 N
Tensile strength (machine direction or MD and cross machine direction or CMD)[a]	EN ISO 10319	≥20.0 kN/m
Elongation at maximum force (MD)	EN ISO 10319	≥60% and ≤100%
Elongation at maximum force (CMD)	EN ISO 10319	≥40% and ≤100%
Permeability, (velocity index for a head loss of 50 mm − $v_{H50)}$	EN ISO 11058	≥2 * 10^{-3} m/s
Abrasion	Following RPG of BAW, Germany, O_{90} according to EN ISO 12956 and thickness according to BS EN 9641	After test: tensile strength ≥ 75% of specified tensile strength, thickness ≥ 75% of original value, O_{90} ≤ 0.09[b] mm
UV resistance	ASTM D4355[c]	≥70% of original tensile strength before exposure

[a] In case of non-isotropic material ≥ 14 kN/m for machine direction.
[b] Based on experienced variations of test results, values should not vary more than 0.01 mm from the specified values in this table.
[c] The same requirements apply in case the ISO test is used.

1.2. Geotextile bag revetment and adaptive management

At both project sites mentioned above, concrete-block protection was not economically feasible for the protection of what was largely agricultural land. Nevertheless, relatively high investments in the areas and the high population density called for an initiative to develop more cost-effective solutions. The backbone of the new development is the use of sand-filled geotextile bags, which had been used locally for emergency protection since the mid 1990s. Based on such experience with 250 kg bags, a feasibility study recommended the use of graded geotextile bags weighing between 11 and 126 kg, which were dumped in 2002 as a launching heap along the water line of eroding riverbanks. This concept assumed that once erosion undercut the heap, the different sizes of bags would launch down the underwater slope and protect it from further erosion.

The first systematic underwater investigations raised doubts about the thickness of the cover layer achieved after launching, and consequently about the long-term reliability of the coverage. Consequently, a modified "adaptive" concept was developed, based on phased planning and implementation. This concept provides the necessary flexibility to respond in an adaptive manner to the largely unpredictable river behavior. Core principles include:

Fig. 1. A geotextile bag from the wave zone at the Bahadurabad test site on the Jamuna River. The bond between the fibers is destroyed and the bag is open. The bag was placed in early 1997, and the photo was taken in early 2005.

(i) *Erosion prediction during the dry season* to support prioritizing and budgeting for riverbank protection after the following flood season, and to initiate emergency measures at priority sites before the flood season.
(ii) *Extensive river surveys during the flood season* to identify the current channel geometry and enable prediction of the main channel locations and points of erosional attack during the following dry season.
(iii) *Phased implementation of bank protection over several years* starting with (a) optional immediate protection before the flood season, if there is an emergency situation, followed by (b) installation of main protection during the next dry season, and (c) later placement of adaptive protection to extend the existing work to deeper levels if river attack continues. Adaptive protection, which in this phased concept is a fundamental requisite for long-term stability, differs from traditional approaches where the initial design was expected to serve for a long time with only minor maintenance.
(iv) *Monitoring on a regular basis* to provide the information required for deciding on maintenance and adaptive protection.
(v) *Placement of strategic stockpiles* of geotextile bags near the riverbank, to support emergency work and reduce response times.

The main design and construction phase of the Project from 2003 to 2006 built on experience with emergency works in 2001–2002. This continued experience with geotextile bags, and associated improved understanding about failure mechanisms of riverbank protection, led to publication of updated "Guidelines for Riverbank Protection" in 2008, supported by the Bangladesh University of Engineering and Technology (BUET). By the end of

Table 2
Geotextile bag dimensions.

Weight of bag	Empty bag size [mm]	Area of empty bag	Area of fully filled bag[a]	Volume of fully filled bag[b]	Number of bags per m^3
126 kg	1030 × 700	0.72 m^2	0.54 m^2	0.0700 m^3	14.3
78 kg	830 × 600	0.50 m^2	0.37 m^2	0.0433 m^3	23.1

[a] The area of a fully filled bag is about 75% of the area of an empty bag.
[b] The volume is calculated assuming that 1 m^3 of sand weights 1800 kg after consolidation under water. This translates into 32% voids. For comparison the loose sand fill weighs 1500 kg/m^3 and has 43% voids, but it gets denser after consolidation or compaction under water. These computations do not account for water molecules sticking to the sand grains, which adds to the weight when weighed in air.