International Symposium and Short Course on Soil/Ground Improvement and Geosynthetics in Waste Containment Structures, 2003, AIT, Thailand

GEOSYNTHETICS FOR EROSION CONTROL AND PRESERVATION OF ENVIRONMENT

by

D.T. Bergado, Professor of Geotechnical Engineering, School of Civil
Engineering, Asian Institute of Technology, Bangkok, Thailand

S. Soralump, Department of Civil Engineering
Kasetsart University, Bangkok, Thailand

Introduction

Soil erosion can wreck havoc not only on civil engineering structures (Fig. 1) but also in natural surroundings (Fig. 2) from the mountainous terrain down to the coastal areas whenever there is contact between soil and water. Various schemes of river bank erosion protection have been recommended to stabilize sections of the river bank slope where soil erosion has reached dangerous levels which threaten the safety of the people living and using the road along the Mekong River. The UN through the UNDP and Mekong Secretariat has instituted a Mekong River basin-wide protection program in the Greater Mekong Subregion (GMS) and recommended pilot bank protection projects as indicated in Fig. 3 (Bergado et al, 1994). However, such engineered schemes can also fail if not done properly as demonstrated in Fig. 4.

Severe slope failure and soil erosion occurred during the 1997 rainy season in about 100 m stretch near the vicinity of KM 190+215 in Namkading to Savannakhet Road. This road (Route 13) is part of the main north-south arterial highway in the country of the People's Democratic Republic of Laos connecting Cambodia in the south to China in the north. The site location is indicated by an arrow in Fig. 5 and is situated along the bend of the Namkading River, near its junction with the Mekong River.

Geosynthetics

The term *geosynthetics* come from the word *geo* which refers to earth and *synthetics* which means human-made products (Koerner, 1997). The materials used to manufacture geosynthetics are almost entirely from the plastics industry i.e. primarily polymers although fiberglass, rubber, steel, and natural materials are sometimes used. The different types of geosynthetics include geotextiles, geogrids, geonets, geomembranes, geopiers and geocomposites. The word *polymer* comes from the Greek *poly* meaning "many" and *meros* meaning "parts" (Koerner, 1997). Thus, a polymeric material consists of many parts joined together to make the whole. Each part or unit is called the monomer. There are only few synthetic polymers that make up the vast majority of geosynthetic materials (Table 1). Polyethelene and polypropylene are the most common.

A geotextile is a permeable geosynthetic made of textile materials. In manufacturing geotextiles, elements such as fibers or yarns are combined into planar textile structures (Holtz et al, 1997). The fibers can be continuous filaments which are very long thin strands of a polymer or staple fibers, which are short filaments, typically 20 to 150 mm long. The vast majority of geotextiles are either woven or nonwoven. Woven geotextiles are made by weaving process similar to textile clothing (Fig. 6). Nonwoven textile manufacture is a high-tech process in which a synthetic polymer fibers or filaments are continuously extruded and spun, blown or otherwise laid onto a moving belt (Fig. 7). Then, the mass of filaments are either needle-punched, in which the filaments are mechanically entangled by a bed of needles or heat bonded, in which the fibers are welded together by heat and/or pressure at their points of contact in the nonwoven mass.

Geosynthetics have 6 primary functions, namely: filtration, drainage, separation, reinforcement, fluid barrier, and protection. Geotextiles are used as filters to prevent soils from migrating into riprap and other armor materials, while maintaining water flow, in coastal and stream bank protection systems to prevent soil erosion. Geotextiles or geocomposites can be used as drainage media by allowing water to drain from or through soils of low permeability. Geotextiles are used as separators to prevent road base materials from penetrating into the underlying soft subgrade and maintain the design thickness and roadway integrity. Geotextiles and geogrids can also be used as reinforcement to add tensile strength to a soil matrix and thereby providing a more competent structural material. In addition to the primary function, geosynthetics usually perform one or more secondary functions. A listing of common applications according to primary and secondary functions is presented in Table 2.

Slope Failure and Soil Erosion

After just one rainy season, severe slope failure and soil erosion occurred at about 100 m stretch near the vicinity of KM 190+215 of Namkading to Savannakhet Road in Laos. The failure site is located at the bend of the Namkading River near its junction with the Mekong River. The extent of the slope failure and soil erosion is shown in plan view in Fig. 8. The panoramic view of the failure site is given in Fig. 9. The stratigraphy in the slope failure area can be deduced from Fig. 9.

The uppermost layer consists of lateritic soil fill with layered compaction. This layer constitute the subgrade of the asphaltic road pavement. This soil is classified as clayey sand with field density of 1.6 g/cc. The field compaction is 90% of the standard Proctor compaction. Underlying the well-compacted layer is the sandy gravel fill with large boulders. This layer is both frictional and permeable. There was no indication of layered compaction. Below the gravelly fill, a clayey to silty residual soil layer is situated. This soil is similar to the uppermost residual soil exposed at the cut slopes in the other side of the road and may constitute the original surface soil deposit at the site prior to the road construction. Being fine-grained, this soil is highly susceptible to erosion when in contact with river water during the rainy season. There was also some indications of underground seepage and toe erosion of the slope. Furthermore, the remnants of the asphaltic road pavement were observed to be tilting in the direction down the slope towards the river. This is an indication that the slope failure was not rotational failure but mainly caused by the erosion of the erodible soil layer at the toe which, consequently, undermined the upper portion of the slope.

Site Investigation

Preliminary and quick explorations were done using the dynamic cone penetration tests with boreholes 1 and 2 at the bottom of the slope (Fig. 10) and boreholes 3 and 4 at the top of the slope near the shoulders of the asphaltic road surface (Fig. 11). At the top of the slope, the lateritic clayey sand layer with layered compaction was confirmed to be 2.0 m thick. Thus, the layered compaction was only done near the top immediately below the asphaltic pavement. At the bottom of the slope, a weak deposit of silty sand was found to be 2 to 3 m thick. This layer may have been deposited by the receding floodwaters of the river. The presence of the underlying hard layer were confirmed to constitute the foundation level of the erosion protection scheme.

Two boreholes were done, one each at the top and bottom of the slope failure area. Wash boring technique was employed together with standard penetration tests (SPT) down to 15.0 m depth from the top of the slope. The borehole at the bottom of the slope were drilled down to 6.0 m depth. The SPT blowcounts established the soil strength parameters for the subsequent slope stability analysis. Index properties of the soil samples were also obtained for soil classification.

Remedial Measures for Erosion Control and Slope Stabilization

The recommended remedial measure is shown in Fig. 12. In this scheme, gabions (1.0 m x 1.0 m) and mattresses (0.30 m thick) were used for erosion protection. Furthermore, geotextile filter and geotextile reinforcement ensured stability during saturation in the rainy season and sudden drawdown conditions. Nonwoven, needle-punched (TS-700) geotextiles, served as filter separator, drains and reinforcements. Geotextiles were also specified along the existing intact slope to prevent any internal erosion due to underground seepage from the underlying layers. The base of the gabions were set at Elev. 143 to the firm foundation layer. Further details of the erosion protection and remedial measure are shown in Fig. 13.

Large permeability of the geotextile filter is desired but at the same time soil particles should be minimized from passing into the filter. The basic requirement of the permeability criteria is that the geotextile filter must remain more permeable than the adjacent soil (Holtz et al, 1997) such that:

$$K_{geotextile} > K_{soil} \tag{1}$$

For applications in critical projects, Holtz et al (1997) suggested that the permeability of the geotextile should be at least 10 times greater than the corresponding permeability of the soil.

A geotextile clogs if soil particles are trapped within the fabric structure. Clogging can reduce the permeability of the geotextile. Current geotextile-soil retention criteria are generally based on the relationships developed between an indicative pore size for geotextile and grain size of the soil such as the recommendations of Bergado et al (1996) as follows:

$$O_{95} \leq 3\ D_{85} \tag{2}$$

and

$$O_{15} \geq 2 \text{ to } 3\ D_{15} \tag{3}$$

where:

O_{95} = 95% opening size of geotextile filter
O_{15} = 15% opening size of geotextile filter
D_{15} = diameter of the 15% particle size
D_{85} = diameter of the 85% particle size

A summary of filtration criteria is given in Table 3.

For geotextile strength in both separation and reinforcement applications, the formulation of the allowable values takes the following form (Koerner, 1997).

$$T_{allow} = T_{ult}\left(\frac{1}{RF_{ID}\ x\ RF_{CR}\ x\ RF_{CD}\ x\ RF_{BD}}\right) \tag{4}$$

where:

T_{allow} = allowable tensile strength
T_{ult} = ultimate tensile strength
RF_{ID} = reduction factor for installation damage
RF_{CR} = reduction factor for creep
RF_{CD} = reduction factor for chemical degradation
RF_{BD} = reduction factor for biological degradation
IIRF = value of cumulative reduction factors

Typical values for reduction factors are given in Table 4.

Slope Stability Analyses

The slope stability analysis assumed a worse case scenario of sudden drawdown. Since the site is near the Mekong River, the records of water levels during flood season from 1965 to 1988 in the Mekong River were used. The maximum dropping rates were 0.96 m, 2.81 m, and 3.89 corresponding to the periods of 1 day, 5 days, and 10 days, respectively. Thus, a sudden drawdown of 3.50 m in 10 days was assumed in the stability analyses.

The stability analyses were carried out using STABL6 computer program. Several possible failure modes such as block sliding through possible weak planes, interval failure of the gabion wall, and overall circular failure of the river bank slope were analyzed. The following properties of the compacted backfill soil consisting of clean sands were used:

a) Effective residual internal friction angle, ϕ, of 35 degrees.
b) Coefficient of permeability at 95% standard Proctor compaction of 10^{-2} mm/s.

Typical examples of the slope stability analyses are demonstrated in Figs. 14 and 15. The values of the factor of safety were sufficient.

Implementation of Remedial Measures

The remedial measures were implemented before the rainy and flood season of 1998. Figures 16a,b shows the construction of the erosion protection scheme. The nonwoven, needle-punched (TS-700) geotextiles were used as filter, separator, drain, and reinforcements.

The completed erosion protection scheme are shown in both upstream and downstream views in Figs. 17a,b. The photos were taken during high water level in the Namkading River during the rainy season in 1998. At present, the erosion control and remedial measure structure is functioning very well.

Conclusions

The use of geosynthetics for erosion control and preservation of the environment has been demonstrated in a case study. Severe slope failure and soil erosion occurred adjacent to the banks of Namkading River in the vicinity of KM 190+215 in Namkading to Savannakhet Road which is part of Route 13, the main north-south road artery of Laos. The site is located near the junction of Namkading River to Mekong River. The remedial measure includes a combination of gabions, mattresses and geotextiles. The nonwoven, needle-punched geotextiles served as filter, drainage, separation, and reinforcement. The results of the slope stability analyses showed quite stable slope even when sudden drawdown was assumed as most critical condition. The remedial measure has been implemented and is functioning very well. Specifications for the filtration criteria, permeability, and allowable strength of the geotextiles have also been recommended.

References

Bergado, D.T., Alfaro, M.C. and Chan, E.H.C. (1992), Filtration and Drainage Characteristics of Vertical Drain, Proc. of Symposium on International Lowland Technology, Institute of Lowland Technology, Saga, Japan, pp. 181-188.

Bergado, D.T., Long, P.V. and Dezeure, J. (1994), Mekong River Bank Slope Protection at Thadeau and Muangwa Ventiane, Laos, Proc. Intl. Conf. on Landslides, Slope Stability and the Safety of Structures, Kuala Lumpur, Malaysia, pp. 45-50.

Calhoun, C.C. (1972), Development of Design Criteria and Acceptance Specifications for Plastic Cloth, U.S. Army Corps of Engineers, Waterways Experiment Station, MS, Technical Report S: pp. 6-55.

Carroll, R.G., Jr. (1983), Geotextiles Filter Criteria, Transportation Research Record (916), pp. 46-53.

Chen, R.H. and Chen, C.N. (1986), Permeability Characteristics of Prefabricated Vertical Drains, Proc. 3rd International Conference on Geotextiles, Vienna, Austria, pp. 46-53.

Christopher, B.R. and Holtz, R.D. (1985), Geotextile Engineering Manual, Report FHWA-TS-86/203.

Holtz, R.D. and Christopher, B.R. (1987), Characteristics of Prefabricated Drains for Accelerating Consolidation, Proc. 9th European Conference on Soil Mechanics and Foundation Engineering, Dublin, A.A. Balkema, Vol. 2, pp. 903-906.

Holtz, R.D., Christopher, B.R. and Berg, R.R. (1997), Geosynthetic Engineering, BiTech Publishers Ltd., Canada.

Koerner, R.M. (1997), Designing with Geosynthetics, Fourth Edition, Prentice Hall Inc., New Jersey, U.S.A.

Ogink, H.J.M. (1975), Investigations on the Hydraulic Characteristics of Synthetic Fabrics, Delft Hydraulics Laboratory, Publication No. 146, Delft, The Netherlands.

Rankilor, P.R. (1981), Membranes in Ground Engineering, John Wiley, Chichester, U.K.

Sweetland, D.B. (1977), The Performance of Non-woven Fabrics as Drainage Screens in Subdrains, MSc. Thesis, University of Strathclyde, Glasgow, U.K.