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Large-scale studies on soil erosion control of slopes in Asian weathering conditions using geosynthetics

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ABSTRACT: Large-scale testing facilities were constructed to investigate the severity and rate of soil erosion and to evaluate the performance of different soil erosion control geosynthetics. The investigation provided useful and practical information on the erodibility of the soil commonly found or used in Asia and proposed effective soil erosion control from both performance and cost point of view. Under Asian weathering conditions, perforated geotextile provided more than 95% reduction in soil erosion and offered significant cost savings compared to conventional 3-D geosynthetic mats.

1 INTRODUCTION

Soil erosion is a common phenomenon in region of high annual rainfall intensity like Asia particularly in the south east. Often the aftermath is disastrous with loss of lives, land and properties. Studies on the erodibility of soils have been carried out and data collected. However, effective measure of soil erosion prevention is still lacking particularly in newly constructed cut slopes. Commonly used and economical technique is closed grass turfing. But such technique is influenced by maintenance and weathering conditions. Hot climatic conditions exceeding 35°C resulting in dead grass and therefore does not provide effective soil erosion protection. Even in the advent of geosynthetics, very little erosion control projects were monitored for performance or evaluated for cost effectiveness. Geosynthetic materials manufactured for erosion applications are often intended to provide short term but immediate erosion control, while allowing vegetation growth later to take over the permanent role of erosion protection. The short term or temporary solution is what most contractors considered not justified for a material cost more than 10 times higher than conventional closed turfing. Therefore there is a need to balance performance and cost. At a testing facility in Malaysia, large-scale slopes were constructed and investigated to address the above problems and to provide a balanced performance versus cost solution for geosynthetics used in surface soil erosion protection.

2 TEST SETUP

Four large-scale slopes (also known as cells) were constructed at a controlled testing facility to allow reliable monitoring and investigation of soil erosion and its method of prevention. In order to simulate most typical cut slopes constructed along the major roads in the region, these slopes were constructed 3m high, about 50° inclination, using residual (laterite) soil as backfill. Apart from a common type of soil used or found in the region, laterite was also chosen due to its high erodibility. Studies have shown that this soil had an erodibility factor, K about 0.003 t.h/m^2.kN (Roslan & Tew, 1998) of the Universal Soil Loss Equation (USLE) (Hudson, 1981). The grading of the backfill soil consisted gravel 0-25%, sand 45-60%, silt 12-21% and clay 25-37%. This soil was considered high risked erosion soil according to the textural classification of soil.

The slope was well compacted and internally reinforced with nonwoven geotextiles placed in horizontal position to ensure stability of the slope. Construction of the slope was by overfilling beyond the outer edge of the geotextile reinforcement and later trimmed to obtain an approximately 300mm of soil at the surface of the slope which was not reinforced by geotextiles. This part of the soil (300mm) was subjected to erosion. At the toe of each slope, collection drain was constructed. Eroded soil and rainwater were collected in the drains and consequently, the rainwater was allowed to drain via the weep hole fitted in the drains with a geotextile filter. The eroded soils remained in the drains were collected, dried and measured in the laboratory to determine the amount of soil eroded (Hosoyamada & Roslan, 1991). Figure 1 shows the test setup experimental cells.

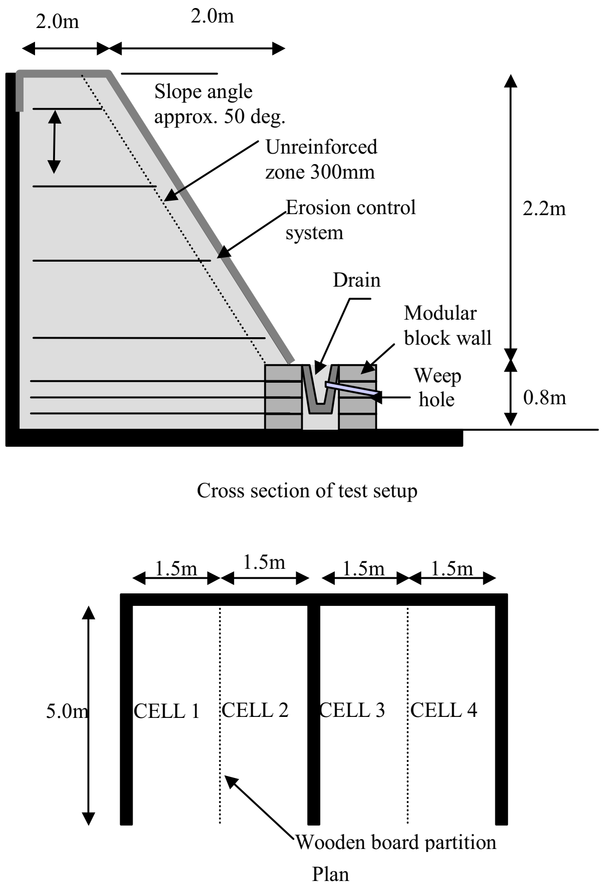

Figure 1. Large-scale experimental test setup

3 TEST SERIES

Four series of tests were conducted. In each series, four cells were monitored simultaneously and different types of soil erosion control geosynthetics were used as shown in Figure 1.

Each series of test was monitored for approximately 2 to 3 months until after natural vegetation growth had established on the slope (Figure 2). Daily rainfalls were recorded and compared with other rainfall monitoring stations to established similar trends.

Figure 1. Test cells with and without erosion control geosynthetics.

Figure 2. Test cells after more than 2 months.

Table 1 shows the series of tests that were conducted and the erosion control geosynthetics used. In test series 1 and 2, similar configuration of cells were used to verify repeatability and accuracy of test results.

Table 1. Configuration of test series.

Test Series	Cell 1	Cell 2	Cell 3	Cell 4
1	Bare slope (control)	Turfing + perforated geotextile	Hydroseed only	Hydroseed + perforated geotextile
2	Configuration same as test series 1 (for repeatability & accuracy test)			
3	Bare slope (control)	Hydroseed + paddy straw mat	Hydroseed + coconut fiber mat	Hydroseed + perforated geotextile
4	Bare slope (control)	Hydroseed + coconut fiber mat	Hydroseed + 3-D PE mesh with grids	Hydroseed + 3-D PE mesh

The prepared slopes were firstly hydroseeded and geosynthetics, where required, were placed over the slopes and secured in position using wire pins. For cell with spot turfing and perforated geotextile, the slope was not hydroseeded. Perforated geotextile was laid directly on the prepared slope and grass turfing was placed over the geotextile and pegged to the slope.

Figure 3 shows one of the erosion control geosynthetics, the perforated geotextile.

4 TEST RESULTS

The amount of soil loss measured in the bare slope is used to determine the soil erodibility factor, K of the Universal Soil Loss Equation. The K value calculated was 0.0023 which was in close agreement to that provided by Roslan & Tew (1998). Since the same soil is used in the whole test, this soil factor is the same for all cells and is subsequently used to determine the cover management factor, C of the USLE for other cells with geosynthetics. Thus the value C is the ratio for the amount of soil loss of the cells with geosynthetics to the bare slope (C=1). The lower C factor, the better the cell coverage and more effective erosion protection system.

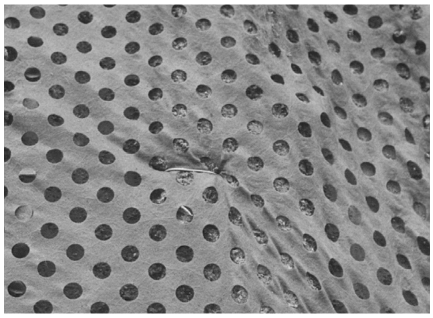

Figure 3. The light weight perforated geotextile, one of the erosion control geosynthetics used in the tests.

The C factors of all the cells protected with geosynthetics are given in Table 2. The C factor of cell with hydroseeding and perforated geotextile was consistent in all the three tests indicating high reliability measurements in the tests (Table 3). Similar trend can also be observed in other test cells except for the cell with coconut fiber mat. In one of those tests, surface soil slippage was observed underneath the erosion mat.

Table 2. C factors for all cells with erosion control geosynthetics.

Geosynthetic used	No of tests	Average C factor
Turfing + perforated geotextile	2	0.0682
Hydroseed only	2	0.0642
Hydroseed + perforated geotextile	3	0.0053
Hydroseed + coconut fiber mat	2	0.1695
Hydroseed + paddy straw mat	1	0.0177
Hydroseed + 3-D PE mesh with grid	1	0.0454
Hydroseed + 3-D PE mesh	1	0.0031

Table 3. Repeatability test for cells with hydroseed and perforated geotextile.

Geosynthetics used	No of tests	Cell reference	C factor
Hydroseed + perforated geotextile	3	1-4	0.0053
		2-4	0.0058
		3-4	0.0048

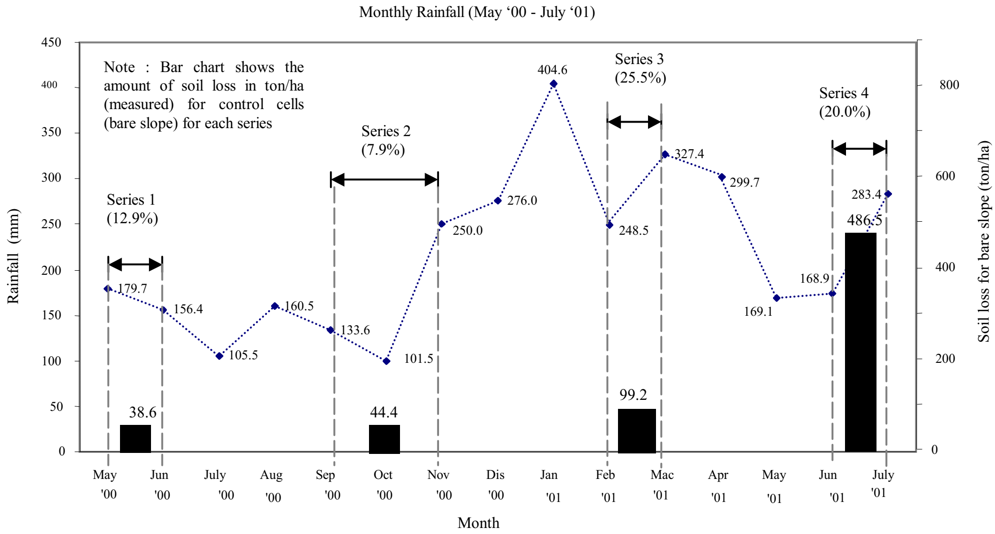

Figure 4. Monthly rainfall, period where test series were conducted and soil loss of bare slope in ton/ha.

5 DISCUSSIONS AND ANALYSIS

Figure 4 shows the monthly rainfall and the period the tests series were conducted. The amount of soil loss for bare slope is given in bar chart. It can be noted that tests series 1 and 2 were conducted during the low rainfall intensity and frequency period compared to tests series 3 and 4. Figures in parentheses showed the erosivity of daily rainfall defined as the ratio of numbers of daily rainfall event exceeding 20mm to the numbers of days within the respective period of measurements.

The annual rainfall recorded was about 2500mm and for the respective period of measurements, the amount of soil loss for bare slope varies from 38 to more than 450 ton/ha. Minor and major rill soil erosion was observed on the soil surface throughout the test series significantly indicated a moderate to high degree of soil erodibility corresponding to soil classification of clayey sand.

From the test results in Table 2, it was observed that the lowest C factor was that of cell with hydroseed and 3-D PE mesh. The opened 3-D mesh provided good coverage to prevent soil erosion.

Cells with hydroseed and coconut fiber mat recorded the highest average C factor. This was due to soil slippage underneath the erosion control mat. It was observed that the thick and dense coconut fiber mat absorbed water during the rainfall season. The saturated coconut fiber mat soaked the soil surface causing soil slippage near the surface. The situation was improved when the soil was well compacted. These tests were conducted in series 3 and 4 where heavy intensity and higher frequency of rainfall was recorded.

For cells with spot grass turfing and perforated geotextile, it was observed the grass turfing obstructed surface runoff and diverted water to flow in between the grass creating a definite flow path. These tests were in series 1 and 2 where rainfall frequency and intensity was low. The grass dried and did not grow or spread to cover the entire slope surface. Instantaneous soil erosion control was provided mainly by the perforated geotextile. Soil erosion occurred through the holes of the perforated geotextile.

Cells with hydroseeding only were also tested during the low rainfall frequency and intensity period of series 1 and 2. The seeds grew well on the slope and within two weeks sufficient grass coverage was already established for soil erosion protection. This method was greatly influenced by weathering conditions. High rainfall intensity would wash the seeds away and rendered no vegetation growth on the slope for soil erosion protection.

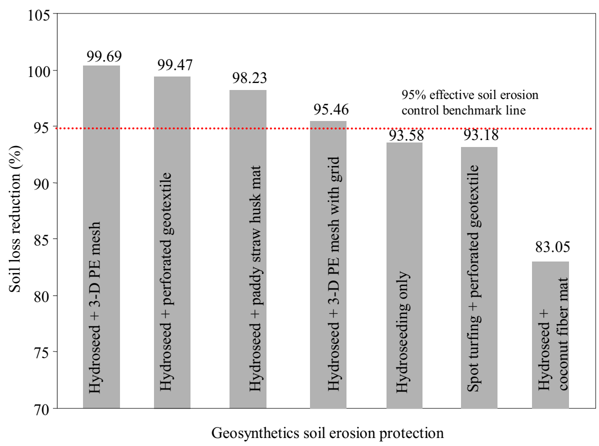

Figure 5. Percentage of soil loss reduction using different geosynthetics soil erosion protection.

The performance of all the geosynthetics erosion protection methods is shown in Figure 5. If 95% soil loss reduction is taken as the benchmark for acceptance of soil erosion control, it can be noted that the 3-D PE mesh geosynthetics, perforated geotextile and paddy straw husk mat provide effective immediate soil erosion protection and allow vegetation growth for long term erosion protection.

Table 4 shows that ratio of estimated soil loss of perforated geotextile, paddy straw husk mat and the 3-D PE mesh with grid, based on the C factors obtained, against the 3-D PE mesh. It can be noted that the 3-D PE mesh and perforated geotextile performed equally well. Although the soil loss of perforated geotextile is 1.7 times more than that of 3-D PE mesh, the economic factor of these geosynthetics needs to be taken into consideration to provide an optimum performance versus cost solution.

Table 4. Ratio of estimated soil loss against 3-D PE mesh

Perforated geotextile	1.7
Paddy straw husk mat	5.7
3-D PE mesh + grid	14.6

6 ECONOMIC EVALUATION

For illustration purpose, assume an annual soil loss of 1000 tonne per hectare of land area. This would yield an approximate soil loss of 5.3 and 3.1 tonne using perforated geotextile and 3-D PE mesh respectively as shown in Table 5. The soil loss using these geosynthetics can be considered negligible compared to that without any geosynthetic erosion protection. However, the cost of using the 3-D PE mesh geosynthetic can be more than 10 times compared to perforated geotextile. For this reason, perforated geotextile provides an optimum performance versus cost solution compared to the 3-D PE mesh geosynthetic.

Table 5. Economic evaluation of erosion protection geosynthetics in relation to performance

	Soil loss/ annum/hectare (tonne)	Cost of geosynthetic/ha*
Bare slope	1000 **	none
Perforated geotextile	5.3***	unit price
3-D PE mesh	3.1***	14 x unit price

* Estimated based on current information in Asia
** Assumed value for illustration purpose
*** Soil loss of bare slope x C factor

7 SUMMARY AND CONCLUSIONS

Large-scale slopes have been constructed at a controlled testing facility to allow reliable monitoring and investigation of soil erosion and its method of prevention under Asian weathering conditions.

Different soil erosion control geosynthetics or systems were used and the amount of soil loss using these systems were compared against bare slope. Rainfall data were collected throughout the period of the investigation.

An annual rainfall of about 2500mm was recorded. The amount of soil loss for bare slope varies from 38 to more than 450 ton/ha during the period of low and high intensity and frequency of rainfall respectively.

The amount of soil loss was not directly proportional to the amount of rainfall recorded but depended on the erosivity of daily rainfall and the erodibility of the soil to withstand rain impact. Soil erodibility was also influenced by construction compaction.

The performance of soil erosion control system using spot turfing and hydoseeding alone was influenced by weathering conditions. While the former required much rain to encourage vegetation growth, the latter, on the contrary, would perform better with little rain to avoid the seeds being washed away. Under these circumstances, a perforated geotextile is recommended together with these systems either for immediate soil erosion control or to prevent the seeds from being washed away.

The best performance of soil erosion protection were provided by both the 3-D PE mesh and the perforated geotextile with hydroseed. More than 95% soil loss reduction was achieved using these systems. However, for optimum performance versus cost solution, perforated geotextile with hydroseed system provided more than 10 times cost savings compared to the 3-D mesh system.

8 REFERENCES

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