Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

The use of cellular confinement systems for erosion control in sandy soils

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ABSTRACT: Hydrological processes cause soil erosion on sloping land ranging from sheet erosion to rill erosion to gully erosion. These forms of erosion are made worse by the impact of high energy raindrops on bare soils. Seepage causes changes in porewater pressure leading to strength reduction and ultimately causing slip failure. Permeability also has a strong impact on soil stability with well drained soils being more stable than impermeable soils. The large number of systems available in Australia to tackle these problems includes biodegradable mats and meshes and slowly degradable geotextile mats and meshes. Several researchers in the past have attempted to rate products using performance indexes with little success. The majority of these products offer short-term solutions rather then long term, as they ultimately break down exposing the vegetation to the hydrological forces. These soils also have poor nutrient contents and cannot sustain the vegetation and revert back to bare soils. Finally, vegetation cannot tolerate submergence or root water logging for more than a few days and dies exposing the soil again to the hydrological forces. The use of cellular confinement systems can provide a long term solution by stabilising the soil, resulting in increased shear strength, intercepting the flow of surface water, introducing surface reinforcement, and reducing the instability of soils. This paper presents results of rainfall simulation experiments performed to analyse the effectiveness of a cellular confinement system under different conditions on exposed sandy soil. Measurements were made for surface runoff, water infiltration and sediment loss resulting from various rainfall intensities and slopes. These results suggest that the cellular confinement system is an effective method for preventing slumping.

1 INTRODUCTION

Erosion is a naturally occurring process that transports soil by water and wind, and is a vital part of the rock weathering cycle. The natural landscape around us is the result of millions of years of weathering and erosion**.** Millions of dollars around the world is being spent on conservation measures and research in an effort to reduce erosion and conserve soil. Benefits include improved drinking water quality, reduced damage to the drainage networks and reduced transportation of silts by waterways.

Since it can be difficult to generate vegetation in the arid climate prevalent across much of Australia, an influx of products have come to the marketplace including:

- various forms of jute mats and meshes
- straw and wood fibre encapsulated by plastic netting
- coconut fibre mats
- non woven geotextiles
- nylon fibre mats encapsulated by UV netting
- three dimensional multi layered polyethylene netting
- three dimensional geomatrix monofilaments fused at their intersections
- cellular confinement mats.

The majority of these products offer short-term solutions rather than long term, as they degrade fairly rapidly and expose any vegetative growth to hydrological forces. In addition, Australian soils typically have poor nutrient contents, and therefore cannot sustain the vegetation, reverting back to bare soils. Cellular confinement systems or geocell are not subject to these limitations as they do not degrade rapidly. This paper describes experiments carried out using rainfall simulation to investigate the effectiveness of a cellular confinement system used in Australia at stopping soil erosion. General outcomes of a series of experiments are presented.

2 WATER EROSION

The main factors involved in the process of water erosion are:

2.1 *Rain characteristics*

The impact of raindrops on a bare soil surface, or on thin sheets of water covering the soil, throws soil particles into the air. On a sloping site, more than half of the splashed soil usually lands down slope of the point of impact. Lighter materials such as very fine sand, silt and clay can be easily removed, while greater raindrop energy or runoff might be required to remove the larger sand and gravel particles.

Increase in raindrop size and intensity greatly increases the raindrop's ability to move soil. This potential for causing erosion is called the erosivity of rainfall. In Australia, the highest values of erosivity occur in the tropical north of Queensland, where they happen to coincide with the steep lands of the Great Dividing Range.

2.2 *Sheet erosion*

Sheet erosion is the removal of soil in thin layers from sloping land. The loose soil or soil dislodged by raindrop impact is rolled along or carried in suspension by the flowing water. Runoff can occur whenever there is excess water on a slope that cannot be absorbed into the soil or trapped on the surface. The amount of runoff can be increased if infiltration (penetration of water into the soil) is reduced due to soil compaction, crusting or freezing, the effects of fire (Robichaud, 2000) and when the soil had been previously saturated.

2.3 *Soil erodibility*

Soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of soil. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Sand, sandy loam and loam textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils.

2.4 *Site topography*

The steeper the slope, the greater the soil loss due to erosion. Soil erosion also increases as the slope length increases due to the greater accumulation of runoff. It is for this reason that slopes are terraced to reduce runoff.

2.5 *Site cover*

Soil erosion potential is increased if the soil has no or very little vegetation cover. Plant and residue cover protects the soil from raindrop impact and splash, tends to slow down the movement of surface runoff and allows excess surface water to infiltrate. The majority of erosion products try to imitate this function.

3 RAINFALL RUNOFF SIMULATION

Rainfall simulation has been used extensively to determine the effects of rainfall on the environment. Examples include the effects of:

- soil erosion (Riley *et al* (1999), Torri *et al* (1999), Poulenard, J *et al* (2001))
- agricultural runoff (Sadeghi and Isensee (2001), Nunez-Delgado *et al* (2001))
- chemical movements (Thompson *et al*, 2001), (Carey *et al*, 2002)

Future plans for rainfall simulation by one of the authors of this paper (P.Hackney) include using simulation to determine refraction of microwave radio signals in storms and also movement of human pathogens from leaking septic systems.

For this project a rainfall simulator was designed and built, based on the work of Loch *et al* (2001). In summary, the simulator was constructed with 3 downward pointing nozzles (H22 and H7 size, supplied by Hawkesbury Irrigation, Windsor, New South Wales, Australia). These nozzles each had individual pressure gauges on them, allowing the water pressure for each nozzle to be varied. In addition it was necessary to modify each of the nozzles to get the required rainfall rate and uniformity coefficient. This was done by slightly enlarging or reducing in size the opening of the nozzles.

The nozzles were swept backwards and forward over the area being studied by use of a 12V motor, with the speed of sweep 3.0 seconds (out and return) and angle of sweep being 118 degrees.

The rainfall simulator was designed so that it could be either used in the field or attached to a frame, upon which an artificial plot area could be placed. For these experiments the frame (and rainfall simulator) could be tilted to any angle up to 50 degrees by using a fork lift (see Figure 1). The artificial plot area could be moved within the frame to make sure it intercepted the water being generated by the rainfall simulator nozzles.

Figure 1 Rainfall simulator, sample tray and frame

A water and sediment collection system was designed to take surface runoff, infiltrated water and sediment from the artificial plot area "test bed".

3.1 *Material Properties*

The cellular confinement cell tested was manufactured from 1.25mm punched HDPE containing 2% carbon black having opened aperture dimensions of 205x240mm, supplied by Geofabrics Australia (refer Figure 2).

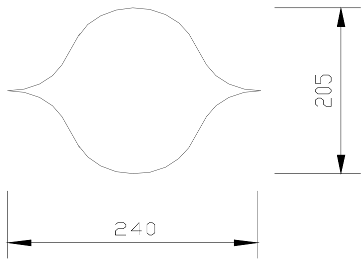
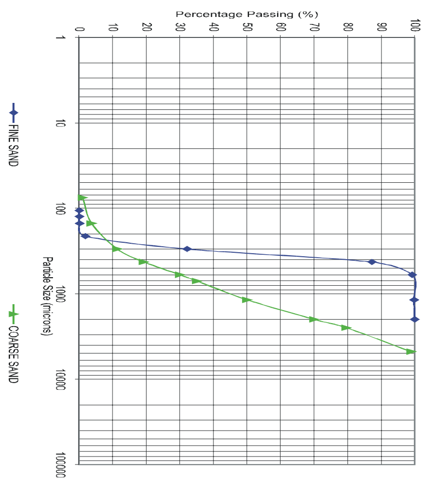


Figure 2 Cellular Confinement Cell aperture dimensions

Two types of soils were used, a coarse grained sand and a fine grained sand (see Figure 3). Both of the soils are highly erodible at slope angles greater than 20^0 and high rainfall intensities.

Figure 3 Particle size distributions, coarse and fine sand



The soils were contained within a test bed, dimensions 800mm wide, 1600mm long, 100mm depth (see Figure 4). The surface of the soil was 2.3m from the bottom of the rainfall simulator nozzles.

Figure 4 Test bed

The test bed either had an impermeable base (polyethylene plastic) or a permeable base (non-woven needle punched geotextile, 150g per square meter) to simulate the cellular confinement system being placed on a permeable or impermeable base in the field. Before each test the soil was saturated with water whilst horizontal and then lifted to the angle being investigated. The soil was saturated to simulate the situation in a saturated soil on a hill slope, just before more heavy rain arrives – a "worst case" scenario.

3.2 *Slopes*

Tests on three slopes 1.5:1 (33 degrees); 1.25:1 (38 degrees) and 1:1 (45 degrees) were carried out. These angles were chosen because these slopes are typical of those found in road cuttings and mountainous areas. In addition most soils are naturally unstable at these slope angles and would fail without artificial stabilisation.

3.3 *Rainfall Intensities*

Three rainfall intensities were investigated - 50mm/hr, 125mm/hr and 200mm/hr. Calibration of the rainfall across the plot area was carried out by use of nine raingauges located in and around the plot area

The uniformity coefficient was calculated using Christiansen's formula (Christiansen, 1942) where, x_i is the rainfall depth at gauge and $\bar{x}$ is the average rainfall at that particular intensity at that particular slope for n number of rain gauges.

$$UC = 1 - \frac{\sum_i^n | x_i - \bar{x} |}{n\bar{x}}$$

The uniformity coefficient ranged between 78 and 92% for various angles and rainfall intensities, the average of 86% indicated that the rainfall intensity and depth were reasonably uniformly spread over the test area.

3.4 *Infiltration Rates*

Two conditions were investigated:

- soil represented by a free draining path (i.e. allow water to pass through a porous bed)
- soil with an impermeable bed

3.5 *Experimental Program*

The experimental program is listed in Table 1. Parameters measured during the program included:

- rainfall duration and intensity.
- runoff and infiltration rates.
- runoff water quality (total suspended solids).
- time to slope failure

Table 1 Rainfall Runoff Simulation Program

Soil Condition	Slope (degrees)	Rainfall Intensity (mm/hr)
Coarse sand (permeable base) using perforated geocell of 100mm depth	33°	50
		125
		200
	38°	50
		125
		200
	45°	50
		125
		200
Coarse sand (impermeable base) using perforated geocell of 100mm depth	33°	50
		125
		200
	38°	50
		125
		200
	45°	50
		125
		200
Fine sand (permeable base) using perforated geocell of 100mm depth	33°	50
		125
		200
	38°	50
		125
		200
	45°	50
		125
		200
Fine sand (impermeable base) using perforated geocell of 100mm depth	33°	50
		125
		200
	38°	50
		125
		200
	45°	50
		125
		200

4 RESULTS

4.1 *Without a cellular confinement system*

When tests were run using coarse or fine sand with a permeable or impermeable base to the testing tray, but no cellular confinement system, then the sand slumped before the minimum test angle of 33 degrees was reached. No further tests were carried out without the cellular confinement system being present.

4.2 *With a cellular confinement system – Permeable base*

When tests were run using the permeable base for the testing tray no slumping of the coarse or fine sand within was observed and no overland flow of water was seen under any of the experimental conditions investigated (Figure 5). The following results refer to water that infiltrated through the permeable base of the test bed.

Figure 5 Unslumped sand in test bed tray

4.2.1 *Permeable base, coarse sand*
For a fixed slope angle the greater the rainfall intensity the quicker the infiltration through the test bed, and also the greater the peak flow, as is shown in Figure 6 for the 45 degree angle experiment. The same pattern was seen for all three angles of the test bed

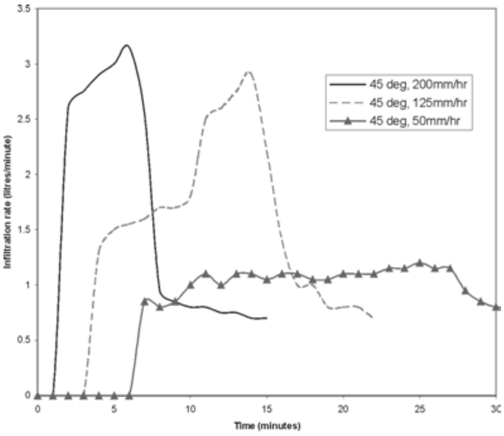


Figure 6 Graph of 45degree constant angle, coarse sand, variable rainfall

4.2.2 *Permeable base, fine sand*
For a fixed slope the greater the rainfall intensity the quicker the first infiltration through the test bed, and also the greater the peak flow, as is shown in Figure 7 for the 45 degree angle experiment.This relationship between peak flow and rainfall intensity is also seen at 38 and 33 degrees, however the trend for higher rainfall intensity causing quicker first infiltration is less evident in the 38 degree experiment, and has completely disappeared for the 33 degree experiment (see Figure 8).

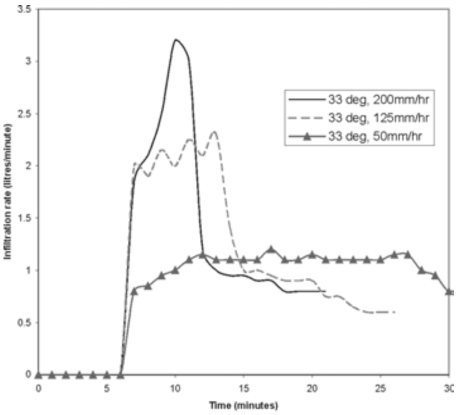


Figure 7 Graph of 45 degree constant angle, fine sand, variable rainfall

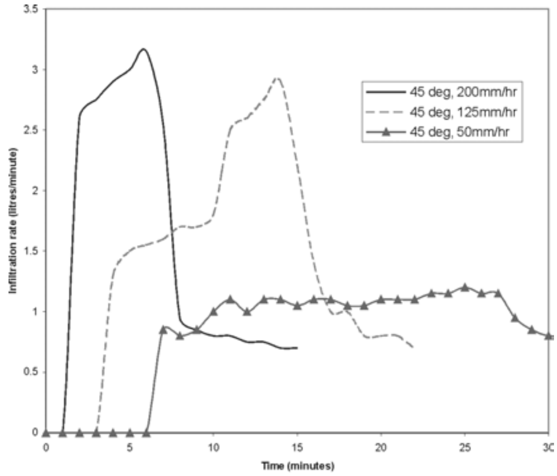


Figure 8 Graph of 33 degree constant angle, fine sand, variable rainfall

4.3 *With a cellular confinement system – Impermeable base*

With the impermeable base slumping did occur at various times and at varying amounts, depending on the sand type, angle of slope and rainfall intensity. Slumping was observed to occur firstly at the bottom of the slope, followed by progressive failure higher and higher up the slope (Figure 9).

Figure 9 Slumped sand in test bed tray (impermeable base)

The initial slumping appeared to be due to ponding of water at the bottom wall of the test bed, which prevented water flowing out of the test bed under gravity (see Figure 10).

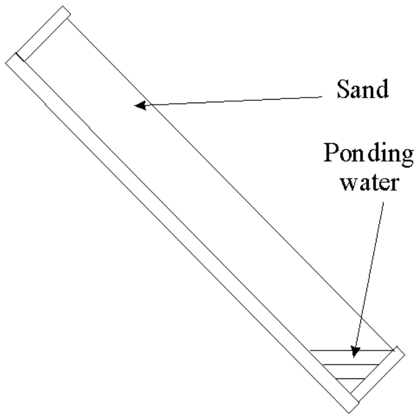


Figure 10 Ponding at bottom of test bed

This ponding of water is similar to that seen at the bottom of a natural slope where it meets an impermeable barrier.
Tables 2 and 3 summarise the results found for the tests with an impermeable base in the test tray.

Table 2. Coarse sand, impermeable base in test tray

Slope Angle (deg)	Rainfall intensity, (mm/hr)	Time of slump, bottom of slope (seconds)	Time of slump, middle of slope (seconds)
33	50	92	No slumping
33	125	60	210
33	200	50	85
38	50	101	No slumping
38	125	60	480
38	200	12	48
45	50	140	No slumping
45	125	100	330
45	200	8	51

Table 3. Fine sand, impermeable base in test tray

Slope Angle (deg)	Rainfall intensity, (mm/hr)	Time of slump, bottom of slope (seconds)	Time of slump, middle of slope (seconds)
33	50	No slumping	No slumping
33	125	90	160
33	200	50	127
38	50	120	No slumping
38	125	60	350
38	200	30	140
45	50	60	360
45	125	60	420
45	200	38	195

The results in these tables show that the time of slumping at the bottom of the slope for both fine and coarse sand is directly related to the amount of rain falling on the slope – the more rain the more rapid the slope failure. These results are consistent with the hypothesis that ponding at the bottom of the tray is causing slope failure.

5 GENERAL DISCUSIONS AND CONCLUSIONS

The results presented in this paper suggest two main conclusions.

- Well drained sandy soils incorporating a cellular confinement system or geocell are stable at very high rainfall intensities and slopes of 45 degrees or less.
- Poorly drained sandy soil incorporating a cellular confinement system will eventually slump, depending on the slope angle and rainfall intensity, but at a much later time than a slope without a cellular confinement system. This can be avoided by the use of flat drainage directly under the cellular confinement system (refer to figure 11)

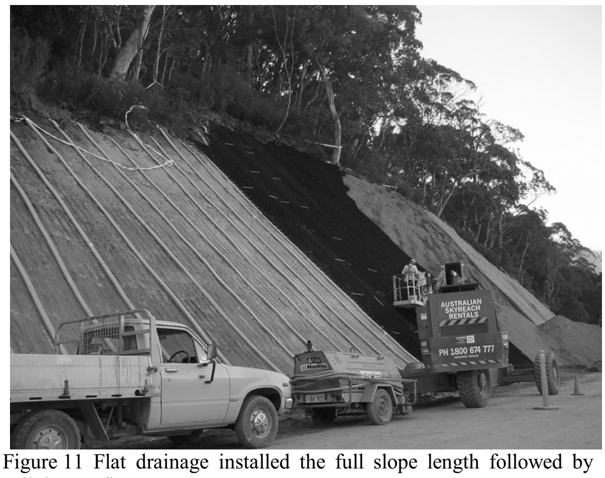


Figure 11 Flat drainage installed the full slope length followed by cellular confinement.

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