Comparison of Erosion Control Methods in Steep Slopes

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Introduction

Steep soil slopes that have no vegetation or have a poor cover are rapidly eroded when rainfall occurs. This situation may also occur in cut sections of highways, or downstream of culverts because of flow concentration at the conduits´ outlet. Protection at the outlet may be riprap, gabions, cellular confinement systems, biotechnology, soil cement or others, depending on materials availability. Peru is a very diverse country, with climates ranging from hyper arid in the Pacific Coast to very humid rain forests in the Amazon Jungle.

In some areas of Peru, rocks suitable for erosion control are not available, such as the lower Amazon jungle or some valleys in the Andes. The use of riprap for erosion control becomes prohibitive because of the high costs of material that has to be brought from distant areas. In humid areas, vegetation offers protection against flows occurring naturally. However, cross drainage structures at low points collect water from gutters so that discharges are higher than those produced by Nature. Therefore, it is necessary to determine in which cases culvert discharges are allowed to flow directly into natural terrain and when reinforcement is needed. Native vegetation is preferable for use in erosion control. However imported species that have adapted well to the country and have not produced adverse results to the environment may be used.

Studies have been carried out in the United States and other countries to protect the soil against erosion using vegetation or biotechnology (Gray and Sotir, 1996). Studies by Temple (1984, 1987) have been conducted to explore the use of vegetation in the downstream slope of dams as protection against erosion by overtopping. Controlling the erosion has become a subject of research and design oriented publications have been printed in recent years. (Escobar, 2003), Lachar (1999). Although publications from FHWA include erosion control measures downstream of culverts using riprap and gabions, little information have been found on the use of vegetation or biotechnology measures downstream of cross drainage structures. This paper presents a preliminary experimental study conducted to explore the use of vegetation for erosion control. Copyrighted erosion control measures such as Geoweb ® and Mac Mat® have been tested in an independent study for its potential use in Peru in the situations describe above.

Experimental Facilities and Equipment

Tests were conducted at the National Hydraulics Laboratory (LNH, acronym in Spanish) located at the Universidad Nacional de Ingeniería (UNI) in Lima, Peru. Water was supplied from an 80 m^3 (2825 cu ft) sump located underneath the Main Building of the Laboratory. A centrifugal pump with a maximum capacity of 6 m (19.7 ft) and 200 L/s (7.06 cfs) was used to deliver water to a 27 m^3 rectangular tank, whose water surface is located 5.8 m above ground level. Water was conveyed by a 355.6 mm (14") pipe to the upstream end of the experimental module where a tank with a 90º triangular weir had been placed. Water level was measured with a Neyrpic hook gage. Downstream of the weir, a stilling basin delivered flow to a chute, which, in turn delivered water to another stilling well. Several rows of hollow bricks were used to straighten the flow upstream of the slopes. Slide gates control the flow to two boxes where soil had been placed at a 50 % slope (2 Horizontal: 1 Vertical). The use of two boxes allowed testing of two different erosion control measures. This experimental module was basically a modification of an existing testing facility used for jet scour experiments. Downstream of the slopes, a sediment basin was built. This sediment basin was connected with a return channel that conveyed water back to the sump. Figure 1 shows the setup for the experiments. A slide cart carrying a point gage was used to survey the slope's topography. Dimensions are given in millimeters.

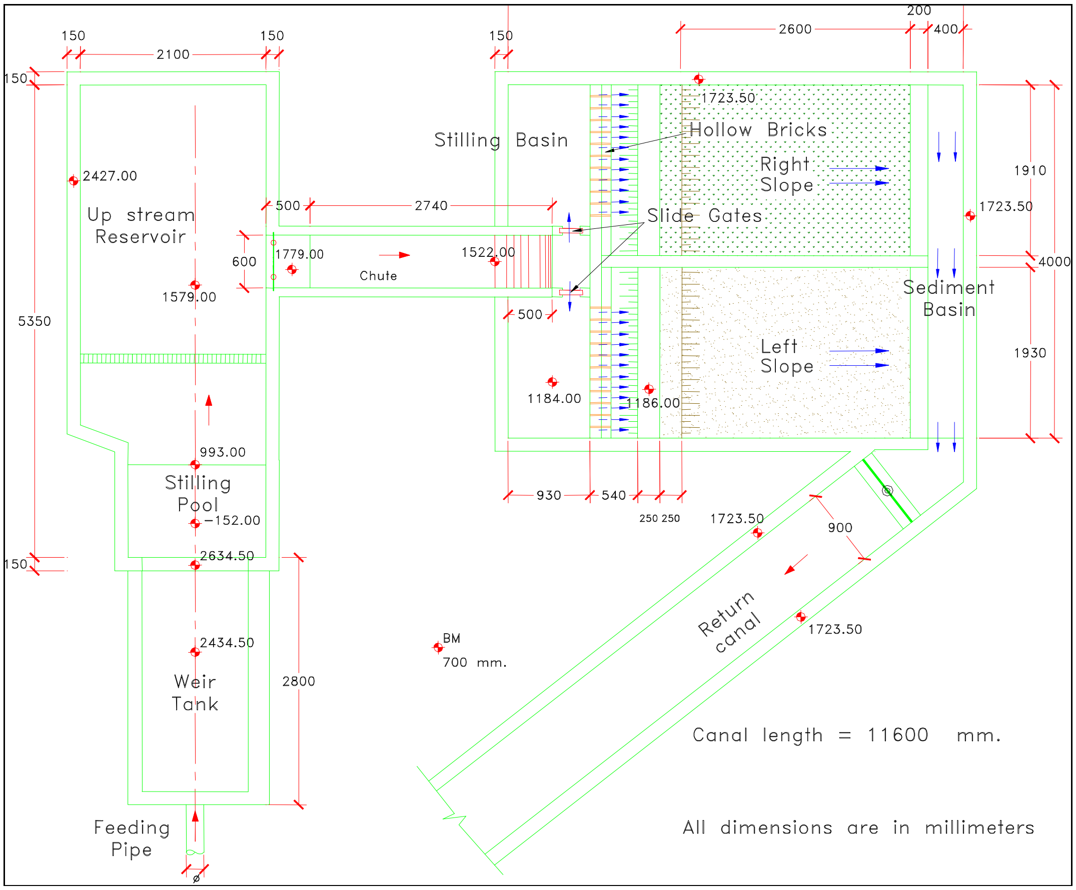

Figure 1. Plan of experimental module.

General procedure

Pumps were ignited to deliver water to a 27 m^3 (953 cu ft) rectangular tank located approximately 5.8 m (19.03 ft) above ground level. Water was conveyed by 356 mm (14”) internal diameter pipe (feeding pipe in Figure 1) to the experimental module. Discharge was measured at the weir tank. The target discharge was attained during filling of the experimental facility and was maintained until the tests finished. A 3” valve was used for fine adjustment of the discharges.

In the first stage and second stage tests, conducted by the first author, experiments had a 10 minute duration to compare erosion produced at bare soils with erosion occurring in soils protected with vegetation or reinforced with other erosion control measures.

In the third stage, conducted by the second author, tests had a 60 minute duration. Erosion was measured a 10, 30 and 60 minutes. A 100 mm x 150 mm grid was used to measure erosion with a point gage set above the slopes. Velocity was measured used potassium permanganatum diluted in water and a Sony camera with a Hi 8 format that allowed to measure times between the release of the trace at the upstream end of the slopes and the arrival at the downstream end.

Description of setup of tests conducted at the experimental module

This section describes the setup of the three stages of this experimental program. A brief description of the setup and the results follows. Tables 1 and 2 shows a summary of observations of the behavior of bare soil and the protective covers against erosion caused by runoff. Table 3 shows the depth of scour reached in the different tests. In all tests the surface was wetted by spraying water. Special care was taken for not causing erosion before the tests started.

First stage

In the first stage, experiments were conducted with bare soil, Tanzania grass (Pannicum Maximum Jacq. Cv. Tanzania) or with a combination of Tanzania grass and an erosion control system. All tests lasted 10 minutes to allow comparison with the bare soil tests.

Bare Soil tests

A low plasticity silty clay (classified as CL-ML, using SUCS system) soil brought from Carabayllo, a nearby district, was placed at a 50 % slope. Discharge was adjusted until target was attained. Unit discharges ranging from 0.5 L/s/m were enough to produce rilling. Severe rilling was produced at a unit discharge of 1.5 L/s/m. The soil eroded rapidly, showing deep rills and gullies at unit discharges nearing 3 L/s/m.

Second Stage

Tanzania Grass Tests

Tanzania grass, a species that is well suited for use in humid environments, was seeded in the CL-ML soil. Tests were conducted after a 20 day waiting period. Stem density was 2 814 stems/m^2. When only Tanzania grass was used, the soil did not show major signs of scour with unit discharges higher than 7.5 L/s/m (0.08 ft^2/s). Losses of grass and some soil took place at 20 L/s/m (0.22 ft^2/s), approximately.

Tanzania Grass with Cellular confinement cells Tests

In this tests series Tanzania grass was seeded inside Geoweb® cells. Stem density was 4 056 stems/m^2, the highest stem density obtained in the first test stage. It is believed that cell configuration allows for conservation of humidity while allowing good drainage, favoring a greater stem density. Losses of grass were observed at one cell due to bad geoweb placement at 15 L/s/m (0.16 ft^2/s). Losses were observed in the center of the cells at 27.5 L/s/m (0.296 ft^2/s).

Tanzania Grass with three dimensional filament mat Tests

Mac Mat® was used in conjunction with Tanzania Grass vegetation cover. Stem density was 2962 stems/m^2. This value is very close to the Tanzania Grass Test. Scour was observed around the stem bottoms at 27.5 L/s/m (0.296 ft^2/s).

Third stage

Quicuyo or Kikuyo (*Pennisetum Clandestinum*) is a species that grows well at very high altitudes (up to 3 800 m or 12 300 feet above sea level) in semi arid environments, such as the ones found in the Peruvian Andean valleys. It is native of Central and Eastern Africa, but its use is widespread in South America. This species was grown outside the experimental facility and transplanted into the experimental module in the cellular confinement cells tests. Because the plants were grown outside the experimental facility and then transplanted into the module, Geoweb® was the only erosion control system used. These tests had a net duration of 60 minutes, although erosion measurements were taken at 10´ for comparison with the Tanzania Grass test

Kikuyo Grass Tests

Kikuyo was brought from Puno, in SE Peru where it grows at average temperatures ranging from -2º C to 21º C (28.4 to 69.8 ºF). Stem density was 878 stems/m^2 (81.38 stems/sq ft). Kikuyo was transplanted in grass mats, so that joints formed a weak point after a considerable period of testing time. Micro rilling was observed at a 10 L/s/m (0.11 ft^2/s) after a 30 minute testing period. Micro scour occurred around the stems at 20 L/s/m (0.22 ft^2/s), being more noticeable at 27.5 L/s/m (0.296 ft^2/s) after 30 minutes of testing. Gullies formed at 35 L/s/m (0.38 ft^2/s) when time reached the 30 minute mark. Eventually, a grass mat was flipped over by the end of the 35 L/s/m test as shown in Figure 2.

Figure 2. Failure at a 35 L/s/m unit discharge using grass mats of Pennisetum Clandestinum.

Kikuyo Grass with Cellular confinement Cells Tests

Kikuyo was originally grown outside the testing module and transplanted into the Geoweb® cellular confinement system. Stem density was 896 stems/m^2 (83.2 stems/sq ft), which is slightly greater than the density obtained with the grass only. Small holes were observed by the end of the 27.5 L/s/m (0.296 ft^2/s) tests. Roots

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were exposed by the end of the test in which a discharge of 35 L/s/m (0.38 ft^2/s) was applied.

Table 1. Summary of observations during erosion control tests. Part 1.

		Stage 1	Stage 2			Stage 3	
		Observations during erosion control tests					
Unit discharge (l/s/m)	Test Duration (min)	Bare CL-ML soil	Tanzania Grass	Geoweb with Tanzania	Mac Mat with Tanzania	Kikuyo Grass	Geoweb with Kikuyo Grass
Stem Density (stems/m2)		0	2814	4056	2962	878	896
0.5	10'	Rill Erosion					
1.0	10'	Rill Erosion	Minimum losses	Minimum losses	Minimum losses		
2.0	10'	Severe Rill Erosion	Minimum losses	Minimum losses	Minimum losses		
3.0	10'	Very Severe Rill Erosion	Micro rilling	Minimum losses	Minimum losses		
5.0	10'		Micro rilling			Minimum loss of surface organic material	Minimum loss of surface organic material
	30'					Minimum loss of surface organic material	Minimum loss of surface organic material
	60'					Total loss of surface organic material	Total loss of surface organic material
7.5	10'		Very small losses due to sheet erosion and turbulence at the bottom of the stem	Minimum losses	Micro rilling		
10.0	10'					Micro Rilling	Micro Rilling
	30'					Micro Rilling	Micro Rilling
	60'					Very small losses due to sheet erosion and turbulence at the stem bottoms	Very small losses due to sheet erosion. Low turbulence at the cells walls.

Table 2. Summary of observations during erosion control tests. Part 2.

		Stage 1	Stage 2			Stage 3	
		Observations during erosion control tests					
Unit discharge (l/s/m)	Test Duration (min)	Bare CL-ML soil	Tanzania Grass	Geoweb with Tanzania	Mac Mat with Tanzania	Kikuyo Grass	Geoweb with Kikuyo Grass
	10'			Losses due to bad Geoweb installation	Very small losses due to laminar erosion and turbulence at the stem bottoms	Very small losses due to laminar erosion and turbulence at the stem bottoms	Very small losses due to laminar. Low turbulence at the cells walls.
15.0	30'						
	60'						
	10'		Losses of grass and soil due to high shear stresses. Local scour in affected zones			Small losses due to laminar erosion and turbulence at the stem bottoms	Slosses due to the formation of small holes at the slope bottom
20.0	30'					Micro scour at individual stems	Micro scour at individual stems
	60'					Idem.	Idem.
	10'			Important losses due to bad geoweb placement. Small losses of grass in the center of the cells.	Very small losses due to sheet erosion and turbulence at the stem bottoms.	Scour at individual stems	Scour at individual stems
27.5	30'					Grass in the central area starts weaking	Scour in the upper layer of soil near the cell walls
	60'					Small gullies in the grass mats joints	Scour in the upper layer of soil near the cell walls
	10´					Visible gullies in the grass mat joints	Small holes due to scour are observed
35.0	30´					Grass mat turned over	Roots are exposed. No losses of roots or stems
	60´						Roots are exposed. No losses of roots or stems

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Table 3. Average depth of scour recorded during erosion tests.

		Stage 1	Stage 2			Stage 3	
		Average erosion (mm)					
Unit discharge (l/s/m)	Test Duration (min)	Bare CL-ML soil	Tanzania Grass	Geoweb with Tanzania	Mac Mat with Tanzania	Kikuyo Grass	Geoweb with Kikuyo
0.5	10'	32					
1.0	10'	50	0	0	0		
2.0	10'	80	1	0.4	0.8		
3.0	10'	160	2.6	0.8	1.6		
5.0	10'		3.6			2.4	3.5
	30'					2.6	3.8
	60'					5.9	4.2
7.5	10'		4	1.4	1.6		
10.0	10'					2.3	3.3
	30'					1.8	2.5
	60'					1.2	1.7
15.0	10'			2.2	2.4	1.2	2.2
	30'					1.6	3.3
	60'					0.9	2.2
20.0	10'		6.8			0.7	1.7
	30'					1.3	1.9
	60'					1.7	3.3
27.5	10'			4.1	4.8	2.4	1.8
	30'					2.1	2.1
	60'					3.1	3.9
35.0	10´					1.7	1.7
	30´					2.4	1.4
	60´					**Failure was recorded**	1.6

Bare soil tests showed that a CL-ML soil is very weak against runoff at steep slopes. The use of Tanzania grass significantly reduced the average erosion in the second stage tests. The use of biotechnological measures in conjunction with Tanzania grass showed better results than the use of Tanzania grass alone.

In the third stage, Kikuyo grass was used as a vegetated cover. In this case, the species was transplanted to the testing slope. This fact affects the tests because contact area between grass mats becomes a source of failure when shear stresses increase. Furthermore, the contact between the Geoweb® wall cells also becomes a potential failure surface. It is expected that interweaving of roots will take place when roots grow with time. In the Third stage tests, scour remains similar for tests

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with cellular confinement cells and Kikuyo grass and with Kikuyo grass only, although soil does not fail when Geoweb® is applied.

Preliminary results and recommendations

When grass mats are transplanted into a slope, contact areas between mats become potential sources of failure.

Biotechnological erosion control methods significantly improved the resistance of the cover to scour, especially when the species was seeded (not transplanted). Unit discharges up to 25 L/s/m were tested using the Tanzania grass and no major signs of erosion were observed.

It was noticed that the stem density was increased to approximately 4000 stems/m^2 when Geoweb® was used to hold Tanzania grass. When Tanzania grass or Mac Mat® and Tanzania grass was used, the density was approximately 2900 stems/m^2. Cellular confinement systems may encourage higher stem densities.

Further tests should be conducted using a uniform time frame. Test time should be set to 60 minutes.

Erosion control techniques must be thoroughly tested to use the results for engineering design. In addition, vegetation species are not always well adapted to all environments, so that different vegetation species must be tested in a country that has different habitats.

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