PULL-OUT RESISTANCE OF 3 DIFFERENT PLANT SPECIES AND THEIR APPLICATION IN SLOPE STABILIZATION WORKS

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ABSTRACT

Understanding of the pull-out resistance of a plant is useful in our assessment of its ability to sustain environmental stress and forces such as wind, landslide, mass movement and soil creeping.

In this study, pull-out strength of some Shrubs, Grasses and Tree ferns was assessed on different stem sizes. Plots of pull-out capacity against displacement in **S**hrubs (*Atriplex halimus*) and Tree ferns (A*sparagus species*) show similar trend, in which only single peak value can be seen. Overall results imply both plants show promising great reinforcing properties due to their superior pull-out resistance than the grasses. These species acquire the maximum strength of pull-out resistance from mainly the lateral roots. At the final stage of pulling out, the irregular sounds of the root snapping were heard just before the plant was uprooted from the soil, which could be a warning of a failing reinforced soil system.

When moisture content was increased, it was observed that the pull-out resistance force decreased drastically. At moisture content averagely 50%, most slopes could be at the brink of collapse as the root reinforcing mechanism is severely compromised, regardless of the type of roots present.

The fabricated equipment has served its intended function and pull-out test had been performed successfully. All species tested give similar trend in the pull-out resistance and displacement relationship, where only one peak value is observed.

Thus, the study suggests that Shrubs and Tree ferns are the best choice for slope stabilization work as they exhibit outstanding root mechanical properties.

KEYWORDS: Pull-out resistance, moisture content.

INTRODUCTION

For many years man has realized the potential of vegetation in controlling surface erosion. Shrubs and grasses help deter erosion on slopes by serving as a blanket against wind and rainwater impact and as a sieve removing soil particles from surface water runoff. Though man has for some time used vegetation to protect the earth's surface against the elements, our concern has only recently focused on the contribution of vegetation in deterring mass movement.

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Past experience shows that slopes under vegetation are more resistant against mass movements and water erosion. However, vegetation cover can be very limited in semi-arid environments and is often damaged by surface fire, overgrazing, drought or flooding. Even following vegetation removal, an increase in water erosion phenomena or shallow mass movements usually appears after a lag period attributed to the time required for roots of the removed vegetation to decay. The effects of roots in protecting the soil from being eroded can therefore not be neglected (Gray and Sotir, 1996).

Roots affect properties of the soil, such as infiltration rate, aggregate stability, moisture content, shear strength and organic matter content, all of which control soil erosion rates to various degrees. One of the important mechanical characteristics of roots is that they are strong in tension. Soils, on the other hand, are strong in compression and weak in tension. A combined effect of soil and roots results in a reinforced soil. When shearing the soil, roots mobilize their tensile strength whereby shear stresses that develop in the soil matrix are transferred to the soil fibres via interface friction along the root length or via the tensile resistance of the roots. The magnitude of root reinforcement depends on morphological characteristics of the root system (e.g. root distribution with depth, root distribution over different root diameter classes), root tensile strengths, root tensile modulus values, the interface friction between roots and the soil and the orientation of roots to the principal direction of strain (Greenway, 1987).

Landslides are a common form of erosion in a steep hill (Ekanayake & Phillips, 1999). Widespread shallow translational landslides (soil slips or debris flows) have been associated with severe storms, and with the removal of indigenous forest and conversion to grassland or pastoral farming. Comprehensive surveys and analyses of landslides after a high-intensity rainstorm have shown that few landslides take place in forested regions as compared to bear slopes (Ekanayake and Phillips, 1999; Ekanayake *et al*., 1997; Marden and Rowan, 1993). Vegetation is able to provide stability to such slopes due to a variety of physical processes. Most commonly, vegetation is applied for surface erosion control, as in the use of turf grass for protection of slopes and swales against the action of rain, wind and frost. Natural plant communities are also understood to play a significant role in the stability of many slopes, riverbanks and shorelines where deeper-seated instability problems, waves or concentrated flow create larger engineering challenges. Various designers have incorporated the geotechnical as well as ecological benefits of vegetation into water resource and slope stabilization projects, with comprehensive documentation dating back to the early part of the 20th century (Schiectl and Stern, 1997). Schiectl and Stern (1997) provide an excellent review of design objectives and typical treatments for waterways bioengineering projects. Greenway (1987) reviews geomorphic factors influencing bioengineering design and discusses mechanisms and analysis tools related to reinforcement of soil by roots with a focus on slope and embankment sites.

Specific attention is paid to the soil's resistance to root displacement and the effect of root's pull-out resistance to the normal load on the shear surface. By measuring the forces in a single root, as this root is displaced, we might better understand the forces involved in root reinforcement and be able to develop a database of plants that can be used in slope stabilization exhibiting outstanding root mechanical properties.

1. SITE DESCRIPTION AND SAMPLING

The assessment of the root pull-out strength of the species was done by means of laboratory tests. Root sampling of 3 different plant species, each plant species comprising of 4-5 individual samples, took place in the Sasumua Water Treatment Backslope, situated in Njambini Division, Nyandarua District of Central Province in Kenya. Soil at this site comprises of fine grained gravels. Selection was random, and roots species having root penetration into soil of more than 0.2 m were excavated. These roots were grasses, shrubs and small trees.

After excavation, the roots were stored in plastic bags to preserve their moisture contents. The roots were taken to the Department of Civil and Construction Engineering Geotechnical Laboratory and kept in a cold room to conserve them. Also 2 m^3 of soil was excavated and transported to the laboratory to conduct the laboratory pull-out testing.

2. THE TESTING FACILITY AND METHODS

The apparatus was specially designed and fabricated for this project (Figure 1).

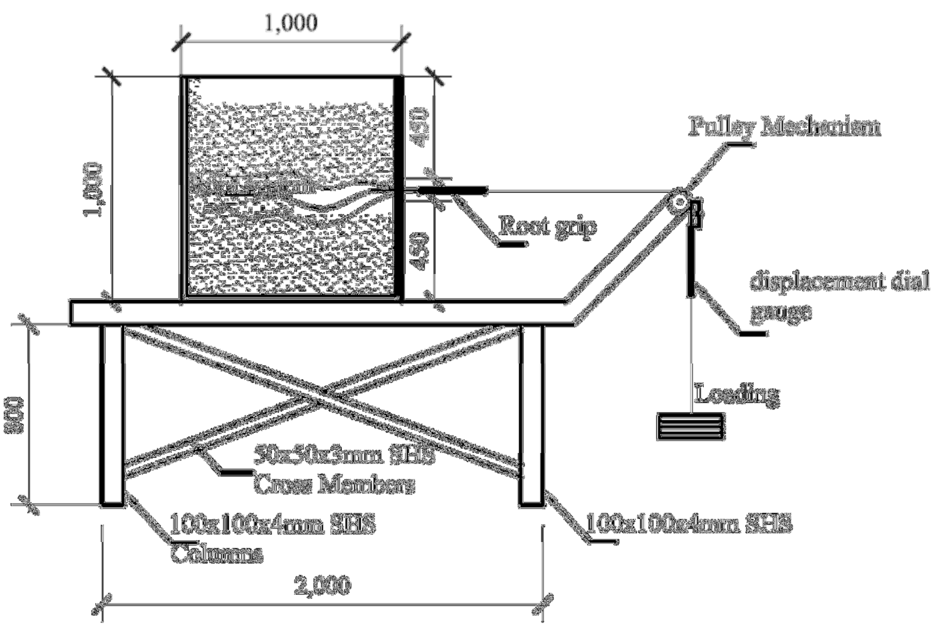

Figure 1. The Pull-out test Apparatus

The main features of the apparatus are:

1. A box, measuring 1m × 1m × 1m to be filled with soil material from the site under investigation, where roots are embedded for pull-out.

2. A pulley mechanism, with loading cap to apply a horizontal pull-out force on the root. The wire-rope to be inelastic and to accommodate large pull-out forces of up to 100 N, which is the estimated maximum pull-out force for small-rooted vegetation.

3. A steel table, where the box is fixed high enough to allow the pulley movement to take place during the pull-out displacement.

4. Loading weights, measuring 1Kg each.

The sample to be tested was clamped between two grips. To ensure that no slippage occurred during each pull-out test, the root crown was gripped using a specially designed wedge and barrel system capable of gripping thicker roots.

Soils were remoulded into the box after knowing the weight required to fill the box. When remoulding reached halfway the box, the root was embedded, and carefully soil was filled around it, rammed around it while avoiding hitting the root. Soil was filled to the entire box. After clamping the roots into wedge grips, the pulley mechanism was mounted, and the loading started at 1Kg weight intervals. Displacement was recorded for every added weight until root sudden pull-out failure took place. This test was repeated for different root configurations for all the plant species. The force just before failure was recorded for each root system.

In another set-up, moisture contents of soil samples were varied, and the maximum pull-out resistance was determined.

3. RESULTS AND ANALYSIS

3.1. PULL-OUT RESISTANCE AGAINST DISPLACEMENT

3.1.1. SHRUBS: SALTBUSH (*ATRIPLEX HALIMUS*)

The maximum stem diameter ranged between 17.55 mm and 31.55 mm. The pull-out resistance force increases drastically at the early stage of the test, i.e., at a small displacement, less than 25.0 mm (Figure 2). Subsequently, the gradient decreases gradually and the pull-out resistance begins to drop after reaching the maximum value at about 0.9 kN. At the final stage, the irregular sounds of the root snapping were heard just before the plant was uprooted from the soil.

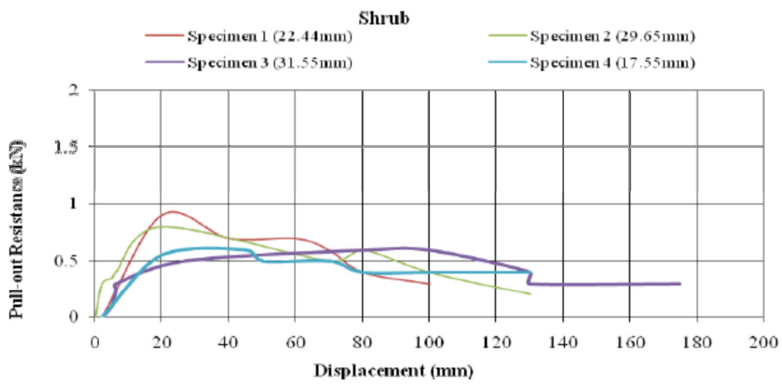

Figure 2. Plots of pull-out resistance against displacement for Saltbush (*Atriplex halimus*)

3.1.2. SWITCH GRASS (*PANICUM VIRGATUM*)

The stem diameters of the tested samples ranged from 9.50 mm to 15.70 mm. The lateral roots spread not more than 15 mm from the primary root and the depth was up to 38.5 cm. The gradient decreases gradually and the pull-out resistance begins to drop after reaching the maximum value at about 0.5 kN. At the final stage, the irregular sounds of the root snapping were heard just before the plant was uprooted from the soil. This observation indicates that the tap root plays a major role in providing the maximum pull-out resistance to this type of plant.

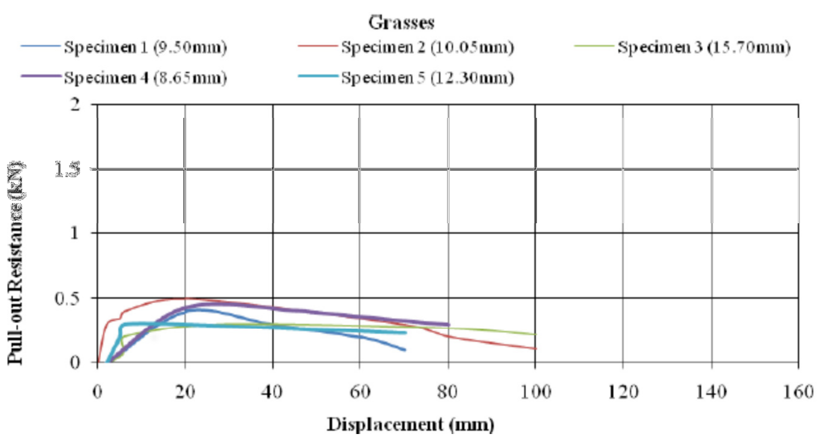

Figure 3. Plots of pull-out resistance against displacement for Switch grass (*Panicum virgatum*)

3.1.3. TREE FERNS (*ASPARAGUS SPECIES*)

The stem diameter ranged between 10.50 mm and 30.50 mm. The roots spread not more than 32 mm from the primary root. Similar to the previous species, *Asparagus species* exhibits gradual increase in the pull-out resistance against displacement. The lateral and fibrous roots of the plant contribute most of the pull-out resistance force to the plant. The value of the maximum pull-out resistance for *Asparagus species* ranged from 0.6 to 0.9 kN. The displacement increases as the resistance increases and drops drastically at a certain point due to breaking or dislodging of most of the lateral roots, i.e., when the plant was completely uprooted.

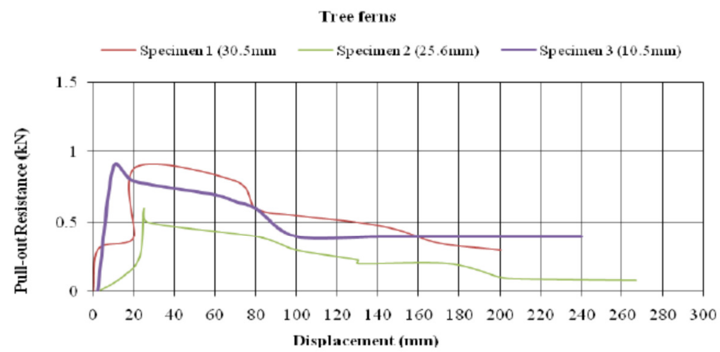

Figure 4. Plots of pull-out resistance against displacement for Tree ferns (*Asparagus species*)

3.2. PULL-OUT RESISTANCE AGAINST MOISTURE CONTENT

In another set-up, moisture contents of soil samples were varied, and the maximum pull-out resistance was determined for shrubs, grasses and trees. Figure 5 demonstrates the relationship between pull-out resistance and moisture content of soil.

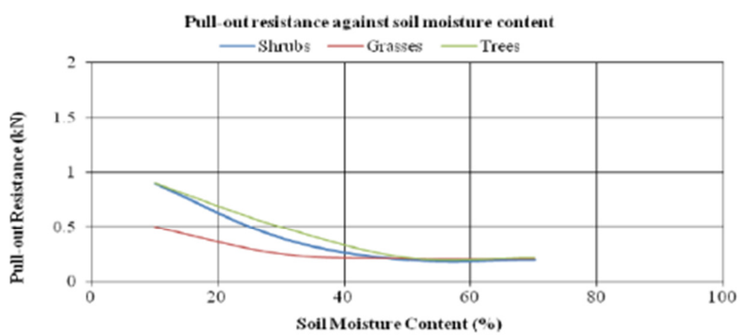

Figure 5. Plots of pull-out resistance against soil moisture content

The pull-out resistance force decreased drastically as moisture content was increased. It was observed that at moisture content averagely 50%, most slopes could be at the brink of collapse as the root reinforcing mechanism is severely compromised, regardless of the type of plant roots present.

CONCLUSIONS

Understanding of the pull-out resistance of a plant is useful in our assessment of the ability of a plant to sustain environmental stress and forces such as wind, landslide, mass movement and soil creeping. Overall results imply that both shrubs and tree ferns show promising great reinforcing properties due to their superior pull-out resistance than the grasses. They both show similar trend in which only single peak value can be seen. These species acquire the maximum strength of pull-out resistance from mainly the lateral roots.

The fabricated equipment has served its intended function and pull-out test had been performed successfully. All species tested give similar trend in the pull-out resistance and displacement relationship, where only one peak value is observed.

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