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Experimental study on native plant root tensile strength for slope stabilization

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Abstract

The use of plants for protection of slopes or river embankments against water and wind erosion is spreading in civil and environmental engineering. Naturalistic approach for slope stabilization has been more and more studied and experimented, and a genuine discipline, that integrates traditional geotechnical engineering methods, has been created: Bioengineering. To evaluate plants roots effect on soil shear strength and slope stability, theoretical and experimental studies about biotechnical and mechanical characteristics are needed, to better understand soil-root interaction mechanism. This work provides indications on mechanical strength parameters of some species of native plant roots. Tensile strength of two Mediterranean species have been analyzed caring out a series of experimental tests. Results indicate that tensile strength of roots is influenced by many factors, among which, the most important are root diameter, its moisture and the location where plants had grown up.

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Keywords: bioengineering; naturalistic engineering; slope stability; root reinforcement; apparent cohesion

1. Introduction

Bioengineering or Naturalistic Engineering is a discipline that uses living plants for erosion control and soil stabilization measures, generally in combination with other stabilization works such as timber piles, earth structures [1] etc. Positive effects of vegetation on slope stability has been noted and documented since Middle Age, but

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techniques using plants for sliding slopes and river embankments stabilization have been described for the first time in Austria, in 1826. Many applications were made especially in Alpine Regions. Vegetation, combined with structural elements, can effectively contribute as a control measure against erosion or certain instability processes, especially shallow ones. In fact, plants plays an active role on slope stability, both on surface, protecting and holding soil particles, and in deeper layers, reducing pore pressure (hydrological effect) and increasing soil shear strength (mechanical effect). The use of vegetation is particularly appropriate in contexts where soil conservation measures are needed to correctly insert the intervention into landscape.

Naturalistic engineering works costs depends on the material purchase and provision, its transportation, and on the realized work maintenance costs. In many cases they are financially advantageous (about 40-90%) with respect to conventional approaches using concrete. Nowadays only a limited number of studies about this topic, requesting an inter-disciplinary approach, both botanic and geotechnical, have been realized, most of them in Central Europe. Moreover, although in international literature experimental data on plant tensile strength can be found, those values must be considered valid only local conditions.

This work provides indications on mechanical strength parameters of native plants roots. In particular tensile strength of native Mediterranean species have been analyzed by means of a series of experimental tests carried out at the Department of Civil Engineering and Architecture of University of Catania. Results indicate that tensile strength of roots is influenced by many factors, among which, root diameter moisture and the location where plants had grown.

2. The role of vegetation in slope stability

Vegetation can improve slope stability both influencing hydrological processes that determine stability conditions and modifying directly the soil mechanical properties. Soil hydrologic balance depends directly on vegetation for its influence on interception, infiltration, evaporation and transpiration. Roots water absorption reduce soil water content. Plants usually have a positive effect on mechanical properties due to reinforcement action, anchoring the shallower soil to the deeper (Fig. 1). Roots density within the soil mass and their tensile strength contribute to improve the capacity of the soil to resist against shear loads. The maximum tensile strength or pullout resistance of roots, together with an assessment of roots size and distribution (Root Area Ratio), can be used to evaluate the appropriate root reinforcement values to be used in the stability analysis of a slope.

Development of the plants root apparatus is controlled by the interaction between genetics and environment. Roots maintain their basic characteristics, that depend on the genotype, but the same species could have deeply different root systems for as regards root density, diameters distribution, extension and depth that can be reached [2,3].

Laboratory data show that tensile strength generally decreases with root diameter: root strengths are lower for large diameters and higher for small diameters [4,5]. Moreover, root tensile strength depends on the biological components of the root: smaller diameter roots have more cellulose than larger diameter roots and therefore are characterized by higher strength [6].

The reliable benefit of apparent cohesion is limited to shallow depths, as root distribution is mainly concentrated within 1m from the ground surface (Fig. 4). The use of an enhanced value of the soil cohesion is appropriate for grass and shrub areas where fine root distribution with depth is consistent and easily defined [7]. Field studies of forested slopes [8] indicate that fine roots, 1 to 20mm in diameter, are the ones that contribute most to soil reinforcement. Grasses, legumes and small shrubs can have a significant reinforcing effect down to depths from 0.75 to 1.5m [9]. Some researchers have attempted to compute the values of apparent cohesion due to the presence of the roots in the ground by designing and developing in situ shear tests for different types of root systems [10,7,11].

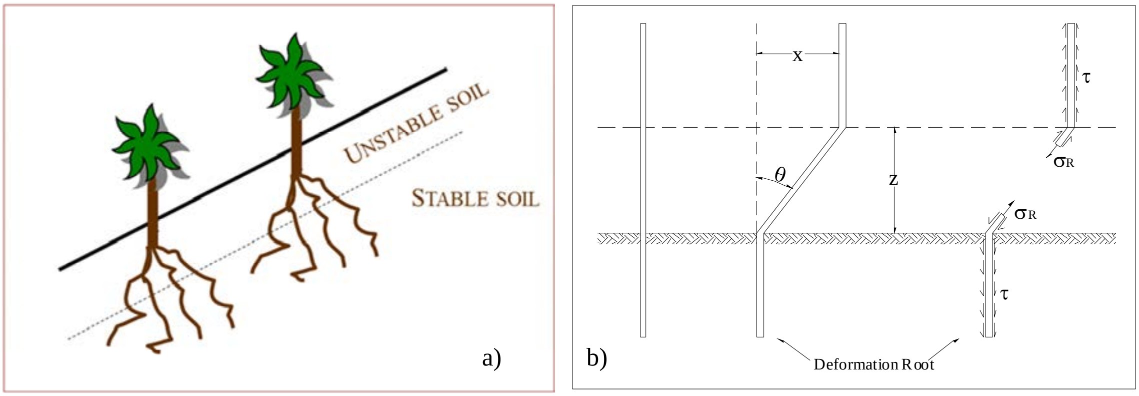

Fig. 1. Stabilizing effect of plant roots (left); anchoring to stable soil (right).

3. The investigated plants roots

Native shrub species such as broom and asparagus were chosen for the experimental investigation. The study was conducted with plants collected in the area of Motta S. Anastasia (Catania), and Mirabella Imbaccari (Catania) in the center of Sicily (Italy), just a few km western of Catania. Those plants grow up spontaneously in the quoted sites and have been transplanted with their root balls. Thirty plants were sampled. Table 1 lists the key features of the examined plants.

Table 1. The investigated plants characteristics.

Botanical name	Asparagus Acutifolius	Spartium Junceum
Family	Liliacee	Leguminous plants
Root depth (m)	0.25-0.65	1
Root apparatus	Espanded and fasciculated	Espanded
Soil characteristics	It adapts to all types of land provided with adequate drainage.	It adapts well on clay ground and stations in arid and poor soil.
Speed of growth	Slow	High
Average tensile strength	3,9 MPa	4,4 Pa

The present study focused on two typical Mediterranean species. Three different type for the experimental investigation have been used. Black asparagus roots, taken on Motta S. Anastasia hills named "asparagus N°1"(Fig. 2), black asparagus roots taken at Mirabella Imbaccari named "asparagus N°2" and "broom" roots taken on Motta S. Anastasia hills. After collection, roots have been cataloged based on the average diameter value. Table 2 shows for each chosen root type, the sample denomination and the corresponding diameter.

The equipment used is a hydraulic testing machine, having a 40 kN maximum load, that was improved by installing a load cell and a transducer for displacement detection. The test system was connected to a computer for digital data acquisition. Measurements for assessing the tensile force value of plants were performed on 30 samples whose diameters ranged from 3.00 to 6.10 mm, including root bark. Tests were performed about two days after removing the root samples from the field. In the present paper only results for Asparagus n. 1 are presented.

The aim of the experimental tests was to determine the tensile strength of the examined roots. Twenty-one samples of roots of "asparagus N°1"were tested. The ends of the roots were clamped using cork and polystyrene. It was also added organic peroxide as an additive (Fig. 3). Moreover, the ends of the roots have been connected with the clamp to driving system.

The data acquisition system, includes displacement transducers load cells and a computerized system, with the associated system software, working with the system controller and associated firmware to control the instrument and data acquisition and registration. Due to the considerable amount of data collected by transducer, a data acquisition system was used. An analog to digital converter digitized the analog signals from the sensors. Digital data were then stored and processed by a computer.

Fig. 2. Asparagus Acutifolius investigated :(a) Foliar apparatus; (b) Root.

Table 2. Root Asparagus Acutifolius N°1 and their diameters.

Sample	$\varnothing_{\textbf{average}}$ (mm) *N°1 Asparagus Acutifolius*
A1	3,80
A3	3,00
B3	4,18
B4	5,40
B5	5,00
B6	4,70
B7	4,80
B8	4,00
B9	3,70
B10	3,90

Sample	$\varnothing_{\textbf{average}}$ (mm) *N°1 Asparagus Acutifolius*
C1	6,10
C2	3,60
C3	4,15
C5	5,80
C6	4,35
C7	5,05
C8	4,15
C9	5,00
C10	4,45
C11	4,40
C13	5,10

Fig. 3. Some samples of clamped tested roots.

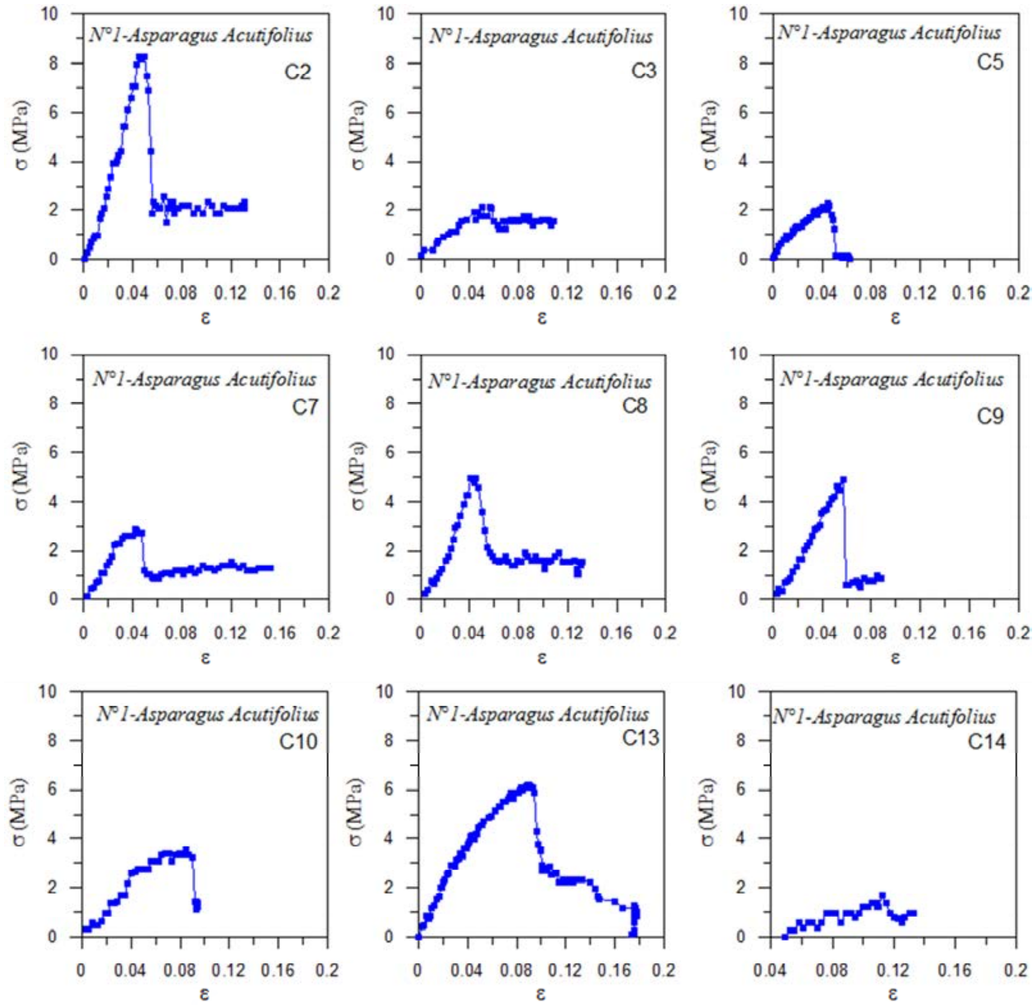

Fig. 4. Typical σ−ε curves for samples of Asparagus Acutifolius N°1.

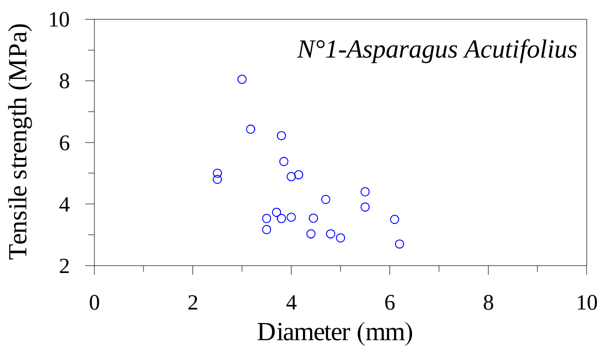

Fig. 5. Tensile strength versus root diameter for Aparagus Acutifolius N. 1.

Stress -strain curves for some samples of Asparagus Acutifolius n. 1, resulting from laboratory tests, are shown in Figure 4. Values of tensile strength ranging from 2.5 to 8 MPa were observed. Figure 5 shows root tensile strength as a function of root diameter. Results indicate that the smaller the diameter, the greater the tensile strength of the root.

4. Conclusions

In recent years, the practice of using natural stabilizing works to increase shear resistance and stiffness of soils has become widespread. Roots role in strengthening soil at the ground surface and the contribution of root tensile strength in improving slope stability is also recognized by geotechnical engineers.

In the present work native species plants roots tensile strength for the center of Sicily has been investigated by laboratory tests. It has been observed that roots tensile strength is affected by various external factors such as flora species, root diameter and environmental conditions. Results of experimental tests indicate that the tensile strength of the root of Asparagus ranges between 2.5 and 8 MPa so it could be successfully utilized for stabilization of shallower slides and erosion control.

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