Ecological Engineering 36 (2010) 19–26

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Triaxial compression test of soil–root composites to evaluate influence of roots on soil shear strength

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A R T I C L E   I N F O

Article history:
Received 15 March 2009
Received in revised form 6 August 2009
Accepted 14 September 2009

Keywords:
Robinia pseudoacacia
Ecological engineering
Soil–root composite
Triaxial compression test
Shear strength

A B S T R A C T

In order to evaluate influences of roots on soil shear strength, a triaxial compression test was carried out to study the shear strength of plain soil samples and composites comprised of roots of *Robinia pseucdoacacia* and soil from the Loess Plateau in Northwest China. Roots were distributed in soil in three forms: vertical, horizontal, and vertical–horizontal (cross). All samples were tested under two different soil water contents. Test results showed that roots have more impacts on the soil cohesion than the friction angle. The presence of roots in soil substantially increased the soil shear strength. Among three root distribution forms, the reinforcing effect of vertical–horizontal (cross) root distribution was the most effective. Increase in soil water content directly induced a decline in soil cohesion of all test samples and resulted in a decrease in shear strength for both plain soil samples and soil–root composites. It was concluded that the triaxial compression test can be effectively used to study influences of roots on soil shear strength.

1. Introduction

It has been widely recognized and accepted that plant roots can improve soil shear strength (e.g. Waldron and Dakessian, 1981; Abe and Ziemer, 1991; Zhou et al., 1997; Operstein and Frydman, 2000; Campbell and Hawkins, 2003) and stabilize slopes of surface soil (Ziemer, 1981; Marden et al., 1991; Ekanayake et al., 1997; Nilaweera and Nutalaya, 1999). Such functions turn vegetation into an effective ecological engineering tool to achieve harmony between humans and nature. At present, evaluation of the reinforcing effect of roots is mainly focused on comparisons of the shear resistance of soil with and without roots. Since the slope stability is highly dependent on the shear strength of soil, an increase in soil shear strength can effectively improve slope stability (Burroughs and Thomas, 1977; Wu et al., 1979; Coutts, 1983, 1987; Gray, 1995; Coutts et al., 1999; Watson et al., 1999; Davoudi et al., 2004; Pollen, 2007). It is especially necessary to study how to increase soil shear strength.

Many empirical models have been developed to predict soil shear strength to save time and labor from direct measurement. Those models include the multiple regression model by Hirata in 1990, the hyperbolic model by Miao and Yin in 1999, the Fredlund model by Fredlund in 1996, the linear regression analysis model and non-linear regression analysis model by Goktepe et al. in 2008, etc. However, differences in physical properties of different soils may result in big changes of soil shear strength, and applications of empirical models may have some limitations.

To quantify the contribution of roots to soil shear strength, several shear tests have been used for measurement of soil shear strength. Day (1993) conducted a direct shear test and concluded that the shear strength of soil with roots is greater than that of soil without. Wu and Watson (1998), Zhang et al. (2006), and Deng et al. (2007) carried out *in situ* direct shear tests on plain soil and soil–root systems and their results demonstrated that the shear strength of plain soil is distinctly lower than that of soil–root systems. Campbell and Hawkins (2003) used a direct shear test in laboratory to show soil permeated with roots of paper birch and lodgepole pine can significantly increase soil shear strength, although the degree of increased shear strength is different for different types of soil. Similar results have also been reported by Ali and Osman (2007) in a direct shear test on four types of soil–root systems, and Fan and Su (2008) in *in situ* direct shear tests on soil with roots of Prickly Sesban. In summary, plant roots make important contributions to an increase in soil shear strength.

Modified direct shear tests have been widely adopted *in situ* or in laboratory studies on the influence of roots on soil shear strength. However, the research on using a triaxial compression test to study the same topic is relatively new. The application of a

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0925-8574/$ – see front matter
doi:10.1016/j.ecoleng.2009.09.005

triaxial compression test for the study of reinforcing material in soil was first used in civil engineering-related fields. Schlosser and Long (1974) used a triaxial compression test to study sand reinforced by metal strips in 1974. They suggested that metal strips could be helpful in increasing the shear strength of sand. Gray and Al-Refeai (1986) reported that the shear strength of reinforced earth could be determined by the tensile strength of reinforcing materials in his research on shear strength of fiber-reinforced soil using a triaxial compression test. Moreover, a large number of triaxial compression tests were carried out to study effects of geotextile reinforcement on the mechanical behavior of earth materials (Futaki et al., 1990; Athanasopoulos, 1993; Al-Omari et al., 1995; Krishnaswamy and Isaac, 1995; Ashmany and Bourdeau, 1988; Haeri et al., 2000). These reports discussed effects of shear strength of reinforced earth materials from different angles by using different sizes of samples, types and arrangements of reinforcing materials, types of earth materials, etc. and offered important advice for the design of reinforced systems. Liu et al. (2006) were among the first to use a triaxial compression test to study shear strength of forest roots–loess composites. In their consolidated undrained (CU) triaxial compression tests, the relationship between shear strength and stress was studied and factors that affect shear strength of roots–loess composites were also discussed. This paper studies, using a consolidated-drained (CD) triaxial compression test, the shear strength of composites comprised of representative loess from the Loess Plateau in Northwest China and roots of *Robinia pseucdoacacia* dominating in reforestation of the plateau. This study also tests impacts of soil water contents on shear strength of loess and roots–loess composites. The triaxial compression test is expected to be applied in future study of soil reinforcement by roots.

2. Materials and methods

2.1. Tests apparatus

Triaxial Compression tests were conducted with a KTG Automatic Triaxial Compression System (Beijing Huakan Technology Co. Ltd., China) in the Soil Mechanics laboratory at the College of Architectural Engineering, North China University of Technology. The system, similar to ELE Triaxial System (ELE International, UK) and Material Test System (MTS Systems Corporation, USA), is one of strain-controlled triaxial apparatus. It consists of four main components (Fig. 1): (1) a triaxial chamber for testing specimens of a diameter of 39.1 mm; (2) a testing machine with a capacity of cell pressure up to 2000 kPa and a range of strain rates between 0.002 and 2.000 mm/min; (3) a data control system; and (4) a cell pressure burette. The data control system is used to generate cell pressure and back pressure for the triaxial testing and to monitor changes in water level inside the cell pressure burette, which can be converted into the volume change of specimen. Signals from the data control system are collected and conditioned by the data acquisition system (5). All data will be transferred to the personal computer (6) and communicated with software HKKTG.

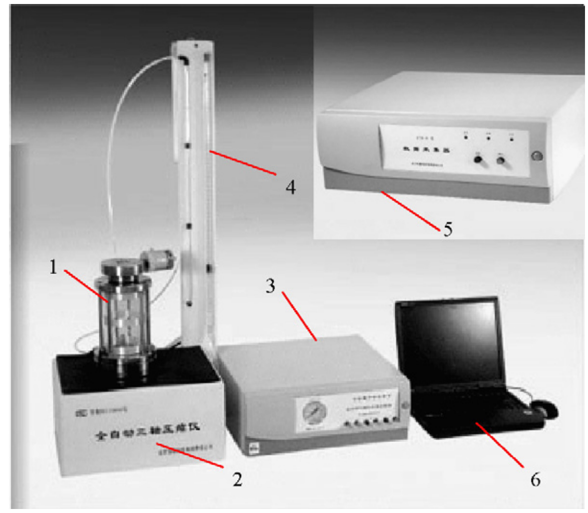

Fig. 1. Diagram of KTG Automatic Triaxial Compression System.

2.2. Sample preparation

Loess soil and roots of *R. pseucdoacacia* were both sampled from field at the Tianshui Soil and Water Conservation Experimental Station (1350–1500 m altitude, 34°36′N, 105°42′E) of the Yellow

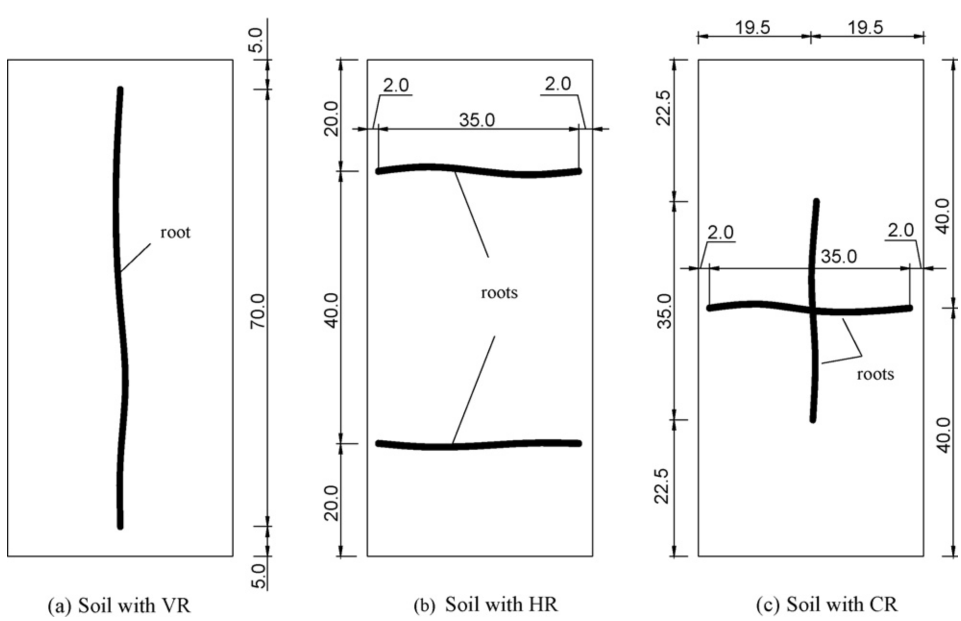

Fig. 2. (a–c) Schematic diagram of three types of soil–root composite (mm).