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Spatial distribution of plant root forces in root-permeated soils subject to shear

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ABSTRACT

This paper aims to investigate the spatial distribution of root forces in root-permeated soils that are subject to shear. *In-situ* large shear tests, 1.0 m × 1.0 m × 0.5 m, on plant root systems are carried out. The root system of *Leucaena leucocephala* (Lam.) (white popinac) and *Acacia confusa* (Formosa acacia) are used in this study. The axial forces developed in plant roots in soil that is subject to shear rely on the root location and orientation with respect to the shear direction. The majority of the roots in front of the tree stem, with respect to the shear direction, develop compressive forces during the shearing process, as the root orientation is low. Roots on the side of the tree stem tend to develop tensile forces during the shearing process. Most of the measured root forces at the back of the tree stem with respect to the shear direction are in tensile modes. Post-peak root forces continue to develop with increasing shear displacements. The percentage of the maximum mobilized root force in tensile modes during shear in this study reaches to approximately 68% of its ultimate tensile resistance at a shear displacement of 10–25 cm, whereas most of the instrumented data are less than approximately 45%. The maximum mobilized stress level for roots in front of the tree stem during the shearing process is low with respect to the ultimate tensile resistance of the root, and the maximum mobilized stress level for roots on the side and at the back of the tree stem is moderate. This study provides an in-depth look at the root forces developed in a plant root system subjected to shear.

1. Introduction

The mobilization of root forces within root-permeated soils that are subject to shear contribute significantly to the shear resistance of soil. Currently, there are no reliable methods to estimate the root stress within root-permeated soils that are subject to shear (Wu, 2013). To estimate the increase in shear strength caused by plant roots, existing methods, such as those based on the simple force equilibrium theory (Waldron, 1977; Wu et al., 1979; Gray and Leiser, 1982), typically assume that tensile forces of roots are fully mobilized in root-permeated soils subject to shear. This assumption may be inaccurate because the deformation pattern for each root in the root system may be inconsistent. Some of research indicated that the simple force equilibrium theory overestimated the shear strength increase contributed by plant roots in the soil (Baets et al., 2008; Comino et al., 2010; Docker and Hubble, 2008; Hubble et al., 2010). Additionally, root forces developed in root-permeated soils may be affected by root orientation, root length, root diameter, and the location of the root with respect to the direction of soil movement (Schwarz et al., 2010; Fan, 2012). Root forces developed in plant root systems that are subject to shear show a strong correlation with complex soil–root interactions. Gray and Leiser (1982) proposed a simple equation for estimating the shear strength increment caused by inclined roots in the soil, and root orientations significantly affect the shear resistance provided by roots in the soil. The method for estimating the shear resistance contributed by roots in the soil is simple; however, the drawback to this approach is that all the roots break simultaneously and the shear resistance contributed by each root can be cumulative.

Jewell and Wroth (1987) conducted direct shear laboratory tests on reinforced sands to investigate the effect of reinforcement orientation on the shear strength increment of the soil. Their results showed that the optimal orientation of a single

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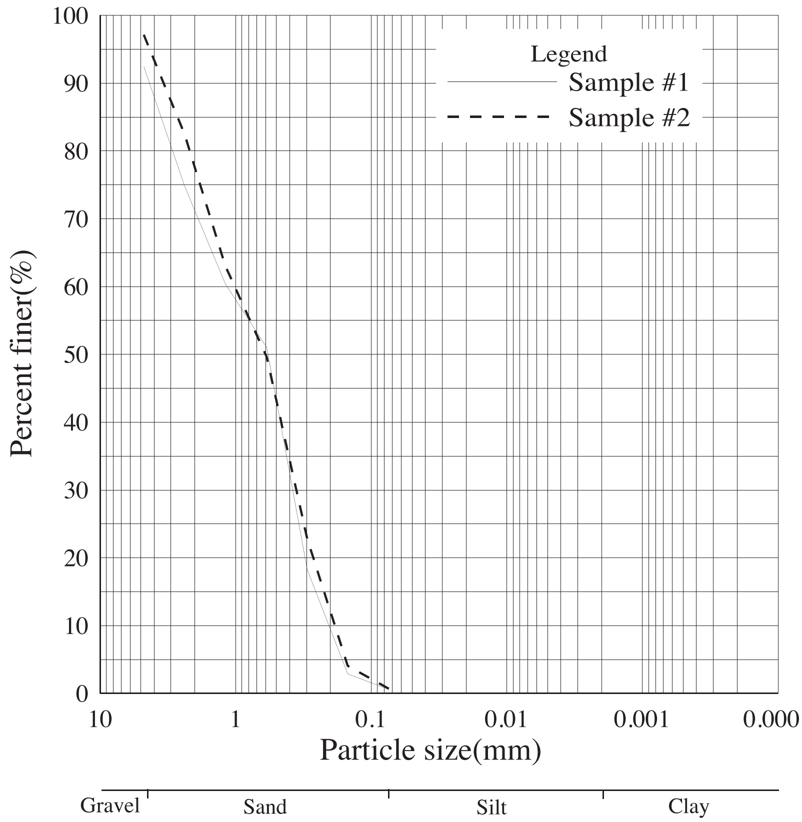

Fig. 1. Soil particle distribution at the test site.

reinforcement to obtain the maximum increase in shear resistance to the soil was approximately 60° opposite of the shear direction. The shear strength increments provided by the reinforcements that were oriented normal and parallel to the shear plane were approximately 70% and nearly zero, respectively, of the maximum increase in shear resistance. Additionally, the reinforcements may be in compressive mode if the orientation (θ) of the reinforcement ranges from 90° to approximately 150°.

Wu et al. (1988) and Wu (2013) proposed an analytical model to estimate the root force and the shear resistance of root-permeated soils. The root segment was simulated as a beam with an elastic-plastic support and as a cable for small and large shear displacements, respectively. Roots can undergo compression during shear if the root orientation at the shear surface is greater than 90° with respect to the shear direction. The failure of the root subjected to compression is caused by buckling in the low confining pressure region. The calculated root force values are substituted into the equation based on the simple force equilibrium theory (Waldron, 1977; Wu et al., 1979) to estimate the shear resistance of the root-permeated soil.

Wu and Waston (1998) performed *in-situ* shear tests on soil blocks with plant roots to investigate the contribution of plant roots to the shear resistance of the soil. Stress conditions in selected roots were measured using a device consisting of metal strips, clamps and strain gauges. The devices were mounted on two lateral roots and three roots growing vertically downward from the main lateral roots at depths of approximately 10–15 cm below the ground surface. The diameters of the selected roots were less than 2 cm. Most of the measured root forces were considerably less than the ultimate tensile force of the corresponding root. The authors

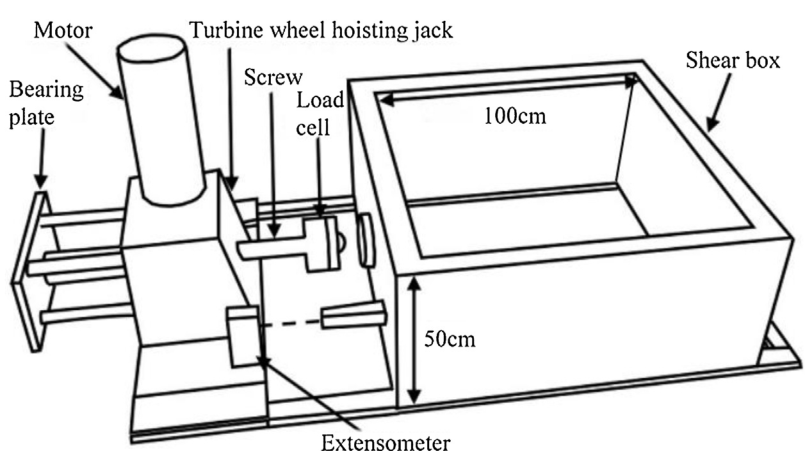

Fig. 2. *In-situ* shear apparatus.