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Influence of matric suction on geotextile reinforcement-marginal soil interface strength

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ABSTRACT

This paper presents descriptions and results of multi-scale pullout and interface shear tests on a woven polypropylene (PP) geotextile reinforcement material in a marginal quality soil. A main objective of these tests was to develop a moisture reduction factor (MRF) for the pullout resistance equation in the currently available design guidelines. The tests were carried out at different overburden pressure and gravimetric water content (GWC) values. The differences in the soil-geotextile interface strength among the cases with different GWC values were used to determine the corresponding MRF values. Results of the study indicate that the reinforcement interface strength and pullout resistance could decrease significantly as a result of the loss in the matric suction (e.g. by 42% between the cases of 2% dry and 2% wet of the soil optimum moisture content). It is concluded that wetting of the soil-geotextile interface during construction or service life of a reinforced soil structure can measurably reduce the interface strength and pullout resistance of the geotextile reinforcement which needs to be accounted for in design. Results of the study will be also useful to estimate the difference in the pullout capacity of geotextile reinforcement in a marginal soil when placed at different GWC values during construction. The methodology described in the paper could be used to expand the database of MRF results to include a wider range of soil types and geotextile reinforcement for practical applications.

1. Introduction

Transportation agencies worldwide are faced with the persistent problem of landslides and slope failures along highways, railroads and other transportation-related infrastructure. Repairs and maintenance work due to these failures are extremely costly. In Oklahoma, many of these failures occur in the eastern and central parts of the state due to higher topography and poor soil type (Hatami et al., 2010a,b, 2011). A recent example of these failures is a landslide on the US Route 62 in Chickasha, Oklahoma (Fig. 1).

An ideal solution for the construction or repair of highway slopes and embankments is to use coarse-grained, free-draining soils to stabilize these structures as recommended by design guidelines and specifications for Reinforced Soil Slopes (RSS) and Mechanically Stabilized Earth (MSE) structures in North America (e.g. Elias et al., 2001; Berg et al., 2009). However, coarse-grained soils are not commonly available in many parts of the world. Consequently, the fill material and transportation costs can be prohibitive depending on the location of the borrow source for the high-quality soil.

One possible solution in such cases is to use locally available soils as construction materials because they would require significantly less material transportation, fuel consumption and generated pollution as compared to using high-quality offsite soils. It has been estimated that fuel costs could constitute as much as 20% of the total transportation costs of high-quality soils (Ou et al., 1982).

However, locally available soils for the construction of reinforced slopes in many parts of the world are of marginal quality (e.g. soils with more than 15% fines). Geosynthetic reinforcement is a well-established and cost effective technology for the construction and repair of slopes and embankments (e.g. Berg et al., 2009). For instance, it has been reported that reinforcing marginal soils could help reduce the cost of fill material by as much as 60% (Keller, 1995). However, proper drainage and adequate soil-reinforcement interface strength are essential elements for reinforced soil structures built with marginal soils in order to provide safe and satisfactory performance during their service life. Mechanical response of marginal soils and that of their interface with geosynthetic reinforcement are complex and may include strain softening, excessive deformation and loss of strength as a result of wetting (Zheng et al., 2013). Loss of

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Fig. 1. Failed slope of a highway embankment in Chickasha, OK. Note: the height and inclination angle of the slope are $\approx$12 m and 17°, respectively.

strength due to increase in the GWC can be especially crucial at the soil-reinforcement interface because depending on the type of geosynthetic employed (e.g. geotextiles) this interface can act as a potential slip plane. This can be understood by noting the fact that interface friction coefficient values are typically less than unity for many types of geotextiles (e.g. Koerner, 2005).

Moreover, failure of reinforced earthen structures that are built with marginal soils and lack a proper drainage system may simply occur in the form of significant wetting-induced deformations as opposed to complete collapse. As a result, there have been documented cases of serviceability problems and failures of these structures related to the use of marginal soils without adequate care in their design and/or construction (e.g. Zornberg and Mitchell, 1994; Mitchell and Zornberg, 1995; Christopher et al., 1998; Koerner et al., 2005; Sandri, 2005).

Hamid and Miller (2009) studied the shearing behavior of an unsaturated low-plasticity fine-grained soil using a modified direct shear test apparatus in which the matric suction of the soil specimen was controlled. Their results showed that the matric suction contributed to the peak shear strength of unsaturated interfaces but did not significantly influence their post-peak shear strength. However, variations of the net normal stress affected both the peak and post-peak shear strength values.

Liu et al. (2009) carried out a series of direct shear tests to study the interface shear strength of geogrids and geotextile embedded in sand and gravel. The test results showed that the shear strength of the soil-geotextile interface was 0.7 and 0.85 of the soil shear strength for Ottawa sand and gravel, respectively. Results also indicated that the shear strength of soil-geogrid interfaces was generally higher than that of soil-geotextile interfaces. The soil-geogrid interface shear strength was found to vary between 0.89 and 1.01 of the soil shear strength for the types of geogrids tested.

Anubhav (2010) conducted a series of direct shear tests to examine the shear stress-displacement behavior of sand-geotextile interfaces. The results indicated that the peak shear strength of the interface between the sand and a coarse-textured geotextile was significantly higher (i.e. up to 35%) than that for the interface between the sand and a fine-textured geotextile. The results also showed that the shear displacement at peak shear strength increased with overburden pressure.

In this study, it is postulated that adequate internal drainage capacity exists in the reinforced soil structure to prevent the development of positive pore water pressure in the soil. However, seasonal variations of the moisture content due to precipitation or subsurface water infiltration could still result in significant changes in matric suction during the service life of the structure in the absence of a proper global drainage system in the structure, or if for instance, the existing drainage system is compromised as a result of excessive clogging. A conservative design approach for slopes and embankments is to assume that the embankment soil is fully saturated. However, this is not an ideal design approach for the following reasons: the soil properties from tests carried out on fully saturated soil samples (i.e. dry unit weight, cohesion and friction angle) do not realistically represent actual field conditions. This is because the soil is never placed and compacted in a fully saturated condition during construction. In addition, since the magnitudes of hydraulic conductivity in fine-grained unsaturated soils are extremely low, it is usually unlikely that a significant portion of the slope would ever become saturated even under extreme rainfall conditions. However, in addition to hydraulic conductivity, the degree of saturation in unsaturated soils also depends on the hydraulic gradient which could be significant due to matric suction. Furthermore, saturated soil samples in the laboratory cannot be compacted to the specified relative compaction (e.g. 95% of maximum dry unit weight) to represent field conditions. Therefore, their measured properties would underestimate the corresponding field values. As a result, an embankment design using saturated soil properties will be neither optimized nor realistic.

The focus of this paper is on pullout capacity of geotextile reinforcement in marginal soils which is an important design consideration in internal stability of reinforced soil structures. Based on the above discussion, since RSS are typically constructed with the soil compacted at or the vicinity of the optimum (gravimetric) moisture content (OMC = GWC_{opt}), the mechanical properties of the soil for the design of RSS need to be determined in the laboratory at the corresponding GWC values. Therefore, a primary objective of the study is to quantify the magnitude of reduction in the pullout capacity of geotextile reinforcement as a result of loss of matric suction in the unsaturated marginal soil due to wetting. This can lead to excessive deformations and even failure of the reinforced soil structure. However, the influence of the soil GWC on the reinforcement pullout capacity and the resulting factors of safety against failure is not explicitly accounted for in the current design guidelines and provisions. In this study, a moisture reduction factor (MRF), denoted by $\mu(\omega)$, is proposed to account for the pullout resistance of geotextile reinforcement in the design of reinforced soil structures with marginal soils. The MRF value is a function of the soil GWC value (and hence of the soil suction), which makes the predicated value of the pullout resistance more accurate and reliable for design purposes.

It should be noted that due to the very low hydraulic conductivity of unsaturated marginal soils, measuring the change in the pullout resistance of a significant size soil-geotextile specimen in drained conditions (e.g. conforming to the ASTM D6706 test protocol) is extremely time consuming. Therefore, in this study the marginal soil in the pullout tests described in this paper were placed at prescribed GWC values ranging from OMC-2% to OMC+2% to determine the corresponding MRF values. Consequently, the MRF values in this study do not exactly represent the reduction in the reinforcement pullout capacity as a result of wetting of a soil mass compacted at an initial GWC and unit weight. However, they provide some quantitative data that could be used to estimate the magnitude of such reduction for design purposes. Furthermore, these results are more directly applicable to determine the expected pullout capacity of the reinforcement in the marginal soil if placed at any GWC value within the range between OMC-2% and OMC+2%.

2. Theory

2.1. Reinforcement pullout capacity in reinforced soil structures

For internal stability, the pullout resistance per unit width (P_r) of the reinforcement in reinforced soil structures is determined using Eq. (1). It is defined as the maximum tensile load required to