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Effects of gravel content on shear resistance of gravelly soils

Wen-Jong Chang [*,1], Thitibhorn Phantachang [1]

Department of Civil Engineering, National Cheng Kung University, 1 University Road, Tainan 70101, Taiwan

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ABSTRACT

Shallow landslides in colluvium, which generally consists of wide particle gradation in a loose state, occur in steep-slope terrains. To perform stability analyses, shear strength parameters that represent soil constituents, in-situ stress state, and shearing mode are needed. This experimental study investigates the effects of gravel content on the shearing characteristics of gravelly soils based on the intergrain state concept. A series of drained simple shear tests was performed on reconstituted specimens of gap- and well-graded sands with various gravel content levels. The results reveal that: (1) the shear strength of gravelly soils depends on the packing condition of dominant particles, with the intergrain granular void ratio being a more representative parameter for the soil packing condition than the global void ratio; (2) the drained shear strength of loose, gravelly sand is dominated by sand matrix properties, with the inclusion of gravel content reducing the strength by no more than 20% compared to that of pure sand; (3) the strength parameters of sand-like gravelly soils can be estimated from the sand matrix with proper reduction.

1. Introduction

Colluvium is a heterogeneous and incoherent mass of soil material and/or rock fragments moved downhill by gravity and rain, and typically in an unconsolidated, loose state with low shear strength. Slope failures in colluvium triggered by rainfall or earthquakes have been reported in the literature (e.g., Carro et al., 2003; Shakoor and Smithmyer, 2005; Chang et al., 2005; Schulz, 2007). Depending on the composition of materials and degree of coherence, colluvium can be categorized as rock or soil mass, the latter of which is more vulnerable to slope failure. This study focuses on sand-like colluvium, which is composed of a matrix of sand particles mixed with rock fragments or gravel. The incoherence of sand-like colluvium allows deposits to be treated as granular materials. Fig. 1 shows the cutting slope of the colluvium deposit in central Taiwan described in Chang et al. (2005). The oversized particles are dispersed in the soil matrix, which mainly consists of sand.

Due to the presence of oversized gravel particles, block sampling and large-scale testing apparatus are required to determine the shear strength parameters of colluvial deposits. Limited by the sampling methods and testing apparatus, laboratory testing on soils with oversized particles is a challenging task. In addition, the effects of particle size on colluvium or rockfill are difficult to evaluate and could be site-dependent. Indirect approaches such as back analyses, empirical correlations, and parametric studies have thus been employed to determine the shear strength parameters of colluvium. However, the uncertainties embedded in these techniques are difficult to evaluate. Therefore, a simple but rational approach for evaluating the strength parameters of sand-like colluvium for stability analyses is attractive for practical engineering applications.

This experimental study investigates the effects of gravel content (GC) on the shearing characteristics of gravelly soils based on the intergrain state concept. A systematic study is performed on reconstituted specimens of both gap- and well-graded sands with various GC levels, subjected to drained, simple shear condition, which represents the stress state and shearing conditions along a sliding surface. A practical procedure is proposed for evaluating the strength parameters of sand-like colluvium.

2. Literature review

2.1. Shear strength of gravelly soils

Soils with gravel particles are generally called gravelly soils, which include colluvium, rockfill, and tailings. Based on in-situ investigations, Fleming and Johnson (1994) and Iannacchione and Vallejo (2000) found that colluvium contained approximately 10% to 50% rock fragments. Laboratory tests on gravelly soils have been performed on these materials. To facilitate laboratory testing, four common methods have been proposed to redcue the maximum particle size of specimens, namely (1) the scalping technique (Zeller and Wulliman, 1957), (2) the

* Corresponding author.
E-mail addresses: wjchang@mail.ncku.edu.tw (W.-J. Chang), rockmass@gmail.com (T. Phantachang).
[1] Department of Civil Engineering, National Cheng Kung University, Tainan 70101, Taiwan.

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Fig. 1. Cutting slope of typical colluvium in Taiwan.

parallel gradation technique (Lowe, 1964), (3) the generation of a quadratic grain-size distribution curve (Fumagalli, 1969), and (4) the replacement technique (Frost, 1973).

Holtz (1961) performed triaxial tests on scalped, reconstituted gravelly clay and concluded that the friction angle increases as the GC increases and that the strength increment is related to clayey soils. Marachi et al. (1972) used the parallel gradation technique to prepare remolded gravelly sands and concluded that the frictional angle decreases as the maximum particle size increases and that the major factors affecting the stress–strain curve are the oversized particle shape and the gradation curve. Fannin et al. (2005) conduct direct shear tests on both a field block sample and matrix materials and concluded that under low vertical stress (5 to 20 kPa), the residual friction angles of the mixtures and the matrix materials are similar and that the residual strength is mainly affected by soil composition, particle shape, and gradation. Fragaszy et al. (1992) conducted drained triaxial tests on a soil matrix mixed with oversized particles and showed that the oversized particles floating in the fine matrix had an insignificant influence on soil shear strength and deformation characteristics.

Recent studies related to shearing behavior of gravelly soil mixtures were carried out by Vallejo and Mawby (2000); Varadarajan et al. (2003); Kokusho et al. (2004); Simoni and Houlsby (2006), and Anantanasakul et al. (2012). These studies were conducted based on the global void ratio framework. Studies of the effects of fines content on liquefaction characteristics revealed that the engineering properties of mixed soils, such as clayey and silty sands, depend on the packing condition of dominant (or matrix) particles, which is represented by the intergranular void ratio. Experimental investigations on liquefaction characteristics of mixed soils based on the intergrain state framework were conducted by Thevanayagam and Martin (2002); Naeini and Baziar (2004), and Chang and Hong (2008).

Kokusho et al. (2004) performed cyclic triaxial tests on reconstituted gravelly soil specimens and concluded that the undrained cyclic strength of such soils is mainly dependent on relative density rather than particle gradation. Chang et al. (2014) studied the liquefaction characteristics of gap-graded gravelly soils based on the intergrain state concept and categorized gap-graded, sand-gravel mixtures as sand-like, gravel-like, and in-transition soils, each of which showed different liquefaction characteristics. Based on these studies on gravelly soils subjected to cyclic loading, the monotonic responses of gravelly soils can be studied based on the intergrain state concept and the effects of GC can be quantitatively described.

So far, no systematic studies have been conducted to evaluate the effects of GC in the soil matrix while considering the packing state of matrix particles. The main objective of this paper is to investigate the effects of GC on the shearing characteristics of gravelly soils such as colluvium, tailings, and rockfill by performing consolidated, drained simple shear tests. The concepts of binary packing and intergrain state are applied to simplify the particle packing system. Moreover, systematic experiments of gap- and well-graded sand matrices with various GC levels were performed to evaluate the applicability of these concepts to shearing characteristics such as shear stress–strain curves, volumetric strain variations, and drained shear strengths at various shear strain levels.

2.2. Intergrain state concept

The intergrain state concept, which considers the microstructure of particle packing, has been used to describe the engineering properties of mixed soils, such as the strength of sandy gravels (Fragaszy et al., 1992), undrained shear strength of silty sands (Georgiannou et al., 1990), and liquefaction resistance of silty sands (Kuerbis et al., 1988). The packing conditions and void distributions in natural soils are complicated because of large variations in particle size and deposition conditions. To simplify the packing conditions of mixed soils, binary packing models have been proposed. The three major assumptions in an idealized binary packing model are as follows: (1) only two distinct particle sizes are considered, (2) the ratio of coarse to fine particle diameters is large (no less than 20), and (3) the packing of coarse particles is not affected by fine particles, and vice versa. Loose colluvium with oversized particles floating in the granular matrix satisfies most of these assumptions.

Because void distribution is one of the major factors affecting the shearing behavior of granular soils at intermediate to large strain levels, various void parameters inferred from idealized binary packing models have been proposed, as shown in Fig. 2. The void ratio (e), defined as the volumetric ratio between voids and the volume of all solid particles, is used as an overall packing index for soils (Fig. 2(a)). Skeleton void ratios are used to describe the idealized packing conditions of the dominant particle fraction. For soils with distinct coarse and fine particles, the