ABSTRACT

DEM Study of Critical State in Binary Granular Soils and a Unified Constitutive Model for Clean and Silty Sands

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Earthquake-induced cyclic shear stresses may lead to a remarkable loss of shear strength, accumulation of pore water pressure, and permanent large amplitude deformations in granular soils. The technical term *liquefaction* is commonly attributed to the family of phenomena named above. Liquefaction of clean sands has been studied extensively in the laboratory, and in past, it used to be believed that the presence of non-plastic fines in coarse granular soils definitely eventuates in strengthening the soil structure against liquefaction. Nevertheless, Yamamuro and Lade [1] revealed that the majority of the catastrophic liquefaction case histories have occurred in natural and man-made silty sand alluvia. Surprisingly, the latest experimental studies have pointed out that the silty sands are very prone to flow liquefaction instability under both monotonic and cyclic shear loading scenarios. In this subject, adding non-plastic fines up to a transitional threshold within the range of 30 to 40% by weight of the total solid phase leads to a gradual decrease in both shear strength and tendency towards dilation. More recent experimental studies have reported the gradual downward relocation of the Critical State Line (CSL) with fines content in void ratio vs. mean principal effective stress (i.e., e vs. p) plane for fines contents lower than the threshold value [2, 3]. Downward relocation of the CSL within the context of the critical state soil mechanics can explain the continuing decrease in shear strength and the tendency towards the contraction observed in silty sands.

Recently, Discrete Element Method (DEM) has received considerable attention as a state-of-the-art versatile tool to study the macro- as well as micro-mechanical behavior of granular media. Herein, the drained behavior of coarse granular samples over a wide range of void ratio and confining stress values is simulated using DEM. It is shown that all samples approach towards an asymptotic ultimate state at which soil deforms continuously without any further changes in shear stress, mean principal effective stress, and volumetric strain, a certain state known as the *critical state* in soil mechanics. Consequently, samples with 2.5, 5.0, 7.5, 10, 15, and 30% by total weight of homogeneously distributed fines are made. Diameter of particles in the coarse phase is five times greater than that of the fines phase. At least, ten numerical simulations are performed for each fines content. In the shear stress vs. mean principal effective (i.e., q vs. p) plane, it is observed that the slope of CSL is not affected by the fines content indicating that the slope of CSL in the q vs. p plane is mainly influenced by the particles shape, Figure 1(a). In an opposite fashion, it is observed that CSL in the e vs. p plane relocates remarkably with the increase of fines content, Figure 1(b).

To explain the downward relocation of CSL in the e vs. p plane, Thevanayagam et al. [3] concluded that fine particles fill the voids between coarse particles and reduce the void ratio; however, they do not participate actively in soil load carrying microstructure. As a direct outcome, the conventional void ratio expressed in term of voids between all particles may not be considered as a legitimate index of compactness in sand with varying fines content. Thevanayagam et al. [3] suggested that the concept of *intergranular void ratio*, e*, in terms of the voids between active particles in the load carrying structure must be used instead of the conventional void ratio in silty sands:

$$e^* = \frac{e + (1-b)FC}{1-(1-b)FC} \quad (1)$$

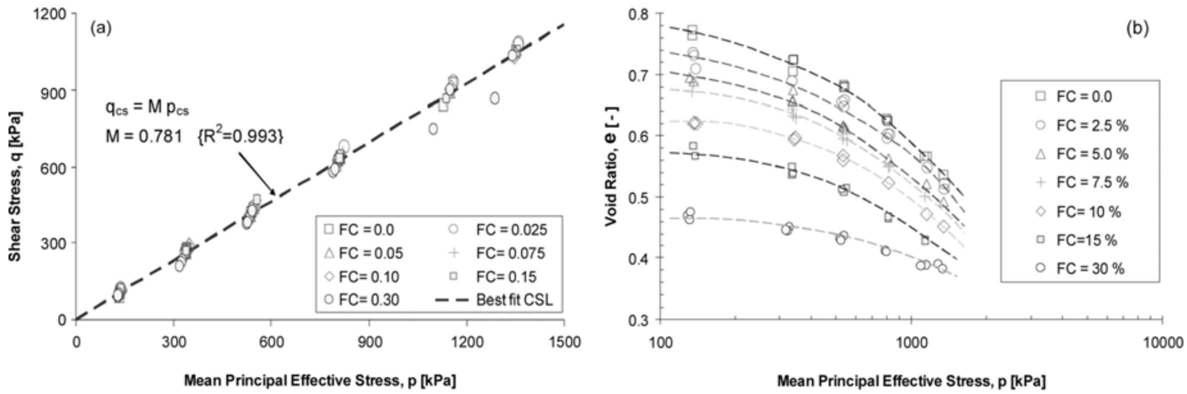

Figure 1. DEM study on the impact of fines content on critical state line in: (a) q vs. p plane; (b) e vs. p plan.

where FC is fines content and $b \in [0, 1]$ is fines participation factor. For b=0, fine particles act as filler without any participation in loading the bearing structure. On the other hand, fine particles contribute as actively as coarse particles when b=1.

Golchin and Lashkari [4] and Lashkari and Golchin [5] suggested a critical state compatible bounding surface plasticity model for clean sands with the following distinctive features: Elastic strains are obtained from a Gibbs free energy function to guarantee the conservation of elastic energy in any arbitrary closed loop. Proper constitutive equations enable the model to consider elastic-plastic coupling in medium-large shear strains. As a direct consequence, the model can take into account the impact of shear stress-induced anisotropy on the elastic ingredients of the model. In this study, constitutive equations of the model of Golchin and Lashkari [4] and Lashkari and Golchin [5] is modified in such a way that intergranular void ratio is used instead of the conventional void ratio. This modification enables the model to consider the relocation of CSL in the e vs. p plane with evolving fines content. It is shown that the model can reasonably simulate the mechanical behavior of clean and silty sands with varying fines content using a single set of parameters, Figure (2).

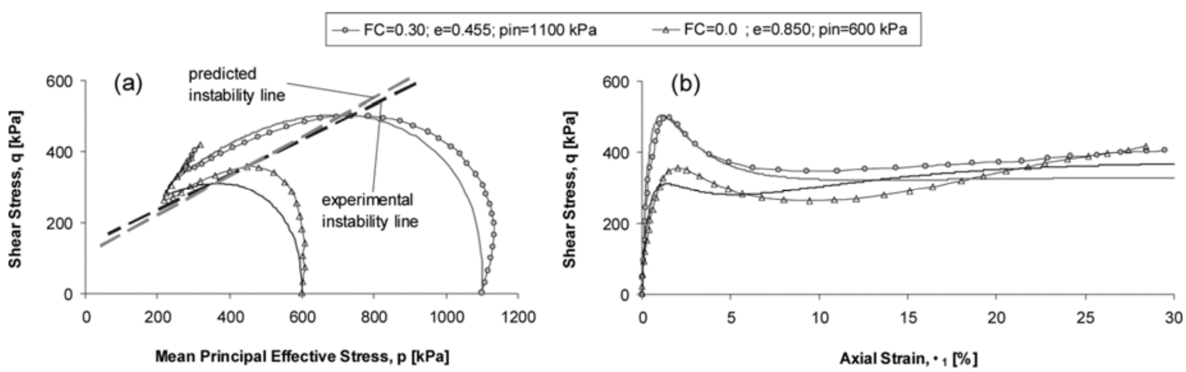

Figure 2. Simulation of the mechanical behavior of a clean (FC=0) and silty sand (FC=0.30) by the unified constitutive model using a single set of parameters in: (a) shear stress versus mean principal effective stress plane; (b) shear stress versus axial strain plane

ABSTRACT

Keywords: Silty Sand; Intergranular Void Ratio; Critical State; State Paramater; Bounding Surface Plasticity; Liquefaction.

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