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Influence of the percentage of sand on the behavior of gap-graded cohesionless soils

Ndriamihaja Livah Andrianatrehina [a], Hanène Souli [a,*], Joël Rech [a], Jean-Jacques Fry [b], Jean-Marie Fleureau [c], Saïd Taibi [d]

[a] *Université de Lyon, École nationale d'ingénieurs de Saint-Étienne (ENI Saint-Étienne), Laboratoire de tribologie et dynamique des systèmes, CNRS UMR 5513, 58, rue Jean-Parot, 42023 Saint-Étienne cedex, France*
[b] *Électricité de France, Centre d'ingéniérie hydraulique, 73073 Le Bourget-du-Lac cedex, France*
[c] *Laboratoire de mécanique des sols, structures et matériaux, CNRS UMR 8579, École centrale Paris, Grande voie des Vignes, 92295 Châtenay-Malabry, France*
[d] *Laboratoire "Ondes et milieux complexes", CNRS UMR 6294, Université du Havre, rue Philippe-Lebon, 76600 Le Havre, France*

A R T I C L E I N F O

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A B S T R A C T

In this work, the effect of the fine content on the undrained mechanical behavior of a granular material is studied. Consolidated undrained triaxial tests were carried out on sand and gravel mixtures. The intact sample contains 30% of sand. In order to simulate suffusion in the sample, degradation consisted in reducing the fines amount to 20, 10 and 5%.
The undrained peak strength and the dilative phase amplitude decrease when the fine content decreases, with the highest values for the intact sample and the lowest values for the sample with 5% fines. On the other hand, the contractive phase progressively increases with the fine content. The degraded samples present a higher internal friction angles than the intact one.

1. Introduction

The detachment and transport of the finest elements of a soil under the effect of water flow in a porous medium is called internal erosion or suffusion. The effect of this phenomenon on the mechanical properties on soils is complex and has received little attention until recently.

Several authors analyzed in detail the phenomena occurring in a sample subjected to suffusion. Chang and Zhang [1] carried out downward flow tests on a granular sample and highlighted the existence of several "critical" suffusion hydraulic gradients: (i) the "initiation" gradient (around 1) corresponding to the first movement of fines, (ii) the "skeleton deformation" gradient (around 2), and (iii) the "failure" gradient (around 7). They showed that these critical gradients depended on the stress state. Ke and Takahashi [2] performed upward flow tests from which they also derived several critical gradients, much lower than in the case of downward flow. They showed that, whatever the value of the initial fine content, the final fine content was more or less the same at the end of the suffusion tests. They evidenced the fact that, from a certain hydraulic gradient, suffusion occurred in the shape of "sand volcanos", and not uniformly in the surface of the sample. This

* Corresponding author.
E-mail addresses: milivah@yahoo.fr (N.L. Andrianatrehina), hanene.souli@enise.fr (H. Souli), jean-jacques.fry@edf.fr (J.-J. Fry), jean-marie.fleureau@ecp.fr (J.-M. Fleureau), Said.Taibi@univ-lehavre.fr (S. Taibi).

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observation was confirmed by the measurements of Sail et al. [3], who observed the formation of a blowout, first at the surface, then progressing downward after one hour under a gradient of 5. Apart from the effect of stress, Bendahmane et al. [4] and Marot et al. [5] showed that suffusion also depended on several factors, e.g. the angularity and initial density of the particles. Ouyang and Takahashi [6] related the effect of the fine content to the fabric of the soil subjected to erosion. The conclusion of these tests is that it is difficult to study directly the behavior of a sample subjected to suffusion as this sample will present heterogeneity of the grain size distribution, both vertically and horizontally.

In other studies, the authors tried to study the effect of suffusion on the mechanical properties of a soil, either by subjecting a sample to a suffusion test before the mechanical tests, or by preparing homogeneous samples supposed to represent the material after the suffusion tests. Ke and Takahashi [7] performed CPT tests on samples with the same initial relative densities, different initial fine contents, and more or less the same fine content after the suffusion tests, to assess their strength. They measured a slight increase in cone-tip strength when the initial fine content decreased. Chang et al. [8] showed a slight decrease in peak friction angle during suffusion when the loss of fines increased. Zhao et al. [9] carried out compression, CD and CU triaxial tests, as well as microstructure observations, on binary mixtures of grains with the same initial void ratio. They observed that the sample with a fine content approximately equal to 30% (corresponding to the filling of the pores of the coarse particles by the fines) presented the highest isotropic compressibility, a contracting behavior on triaxial path, and the smallest strength. On the contrary, the sample with a fine content lower than 30% was the less compressible, highly dilative and with the highest strength. The sample with a fine content higher than 30% featured an intermediate behavior. However, in these tests, the void ratio was kept constant and, as the fine content changed, it means that the maximum and minimum void ratios also changed, as well as the relative density of the samples.

Dash et al. [10] show that the mechanical properties of granular soils primarily depend on relative density. The behavior of soils is also depending on the grain size distribution curves of the materials as shown by Liu et al. [11], the angularity and shape of the grains, etc. It is important to mention that the angularity and the shape of the grains play an important role in the suffusion as demonstrated by Kovac [12] and Marot et al. [13].

Some works studied the effect of suffusion on the mechanical behavior of samples by means of numerical models. Scholtès et al. [14], Hicher [15], and Muir Wood et al. [16] simulated the suffusion process by a progressive reduction of the fine content. Scholtès et al. [14] and Hicher et al. [15] used a multiscale model to describe the change in the mechanical properties of a soil subjected to consolidated drained (CD) triaxial tests. They showed that degradation of the granular samples led to a decrease in the strength of the material. The authors related this behavior to the more organized structure of the samples. Moreover, degradation of the samples changed gradually their behavior from dilative to contractive. Muir Wood et al. [16], using DEM analysis, showed that degradation of samples resulted in the rising of the critical state line in the compression plan.

In this article, the interest is focused on the study of the evolution of the mechanical behavior of the samples when the fine content is gradually decreased. The experimental study was carried out on gap-graded granular materials. Consolidated undrained (CU) triaxial tests were performed on samples with different fine percentages and the same initial relative density, under two values of confining stress. This approach does not represent the suffusion phenomenon, which is much more complex, as shown before. However, it is a simplified way to assess how the behavior of the samples evolves when the fine content gradually changes in the process before the fines are totally eliminated. The samples were obtained by mixing a gravel ($2 < d < 16$ mm) and a sand ($0.1 < d < 0.315$ mm). These mixtures were chosen because coarse soils are not frequently studied in the literature and because they correspond to materials that can be found in some dikes or dams. In this work, degradation was simulated by reducing the amount of fines from 30% in the intact material to 20, 10 and 5% in the degraded ones. The effect of degradation was studied by following the evolution of the stress deviator and pore-water pressure during CU triaxial tests.

2. Material and experimental methods

2.1. Samples preparation

The test materials were made from an alluvial deposit coming from the Rhône River in France. The grain size distribution curves (Fig. 1) show that there is no fraction smaller than 100 μm. The grains are in their majority sub-angular. The materials were obtained by mixing two granular fractions, a coarse fraction made of gravel ($2 < d < 16$ mm) and a fine fraction made of sand ($0.1 < d < 0.315$ mm). For these materials, the transition fine content (TFC), i.e. the percentage of fines corresponding to the filling of the voids of the gravel by the sand (Skempton and Brogan [17]), is given by the following expression (Andrianatrehina et al. [18]):

$$TFC = \frac{e_c}{1 = e_c + e_f} = 30\% \qquad (1)$$

where e_c is the intergranular void ratio, i.e. the void ratio of the coarse grains, independently of the fines contained in the voids, and e_f is the interfine void ratio, the void ratio of the fines independently of the coarse grains. This formula, is similar to that proposed by several authors (Dash et al. [10]; Emdadul Karim and Jahangir Alam [19]; and Chang et al. [5]) to characterize the fine content corresponding to the change from "sand-dominated" behavior to "gravel-dominated" behavior.

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