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Influence of coefficient of uniformity and base sand gradation on static liquefaction of loose sands with silt

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ABSTRACT

When occurred on site static or flow type liquefaction could result in catastrophic consequences due to its sudden occurrence with large strains. Presented here is an experimental study based on monotonic undrained triaxial compression tests conducted on three clean sands and their mixtures with three different non-plastic silts at three different fines contents ($\leq$25%). The results demonstrate that base sand gradation has significant influence on the static liquefaction potential of clean and silty sands. It was observed that clean sands become more liquefiable as their mean grain size got smaller and/or they became more uniform. However, it was found that the order of liquefaction resistance of the same base sands were reversed when they were mixed with silt (i.e. resulting silty sands become more liquefiable as the mean grain size of base sand got larger and/or base sand became relatively well graded). Possible reason for such a reversed behavior was hypothesized and then experimentally justified with extra tests. It was also found that the influence of base sand gradation on static liquefaction of loose specimens was most significant at low fines content (e.g. 5%) and almost erased at relatively high fines contents (e.g. 25%). In the last part of the study, the relationship between the normalized peak deviator stress (q_{peak}/σ'_{3c}) and coefficient of uniformity (CU) is discussed. It was shown that unlike clean sands, for which liquefaction potential decreases with increasing CU, the liquefaction potential of sand-silt mixtures reconstituted in the laboratory increases with increasing coefficient of uniformity (i.e. technically as they became more well graded). Two equations were proposed to represent the discussed relationship between q_{peak}/σ'_{3c} and CU; one for stable and temporarily liquefied specimens, the other for liquefied specimens. Finally, the applicability of these equations to other types of silty sands in literature was shown.

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1. Introduction

Liquefaction of sandy soils is still among the most popular, yet challenging research areas of geotechnical engineering. Many people in civil engineering practice often subconsciously link the word "liquefaction" with a source of dynamic loading such as earthquakes. Even though liquefaction in the form of cyclic mobility is an important aspect, liquefaction can occur under static loading conditions as well, which is called static liquefaction. Static liquefaction is a form of flow type liquefaction and when occurred on site, could be quite catastrophic as it occurs in a sudden manner accompanied by large displacements. Even though liquefaction in the form of cyclic mobility could occur in a wider range of soil and site conditions, consequences of static liquefaction are generally more severe [21]. Lade and Yamamuro [25] presented a summary of twenty cases, in which submarine slopes, earth dams, various types of fills and embankments were subjected to static liquefaction. These static liquefaction cases revealed that the predominant soil type was generally silty sands.

Several factors including fines content (FC) [35,24,29], confining stress [40,46] and deposition method [15,48,7] were shown to influence the static liquefaction or undrained behavior of sands through laboratory research. Among the mentioned factors, influence of FC is perhaps the most intriguing and at the same time the most studied one.

The complexity of the liquefaction problem is not limited to the effect of above mentioned factors only. Grain size distribution had also attracted attention for its possible influence on the shear strength of sands. Koerner [19] performed drained triaxial

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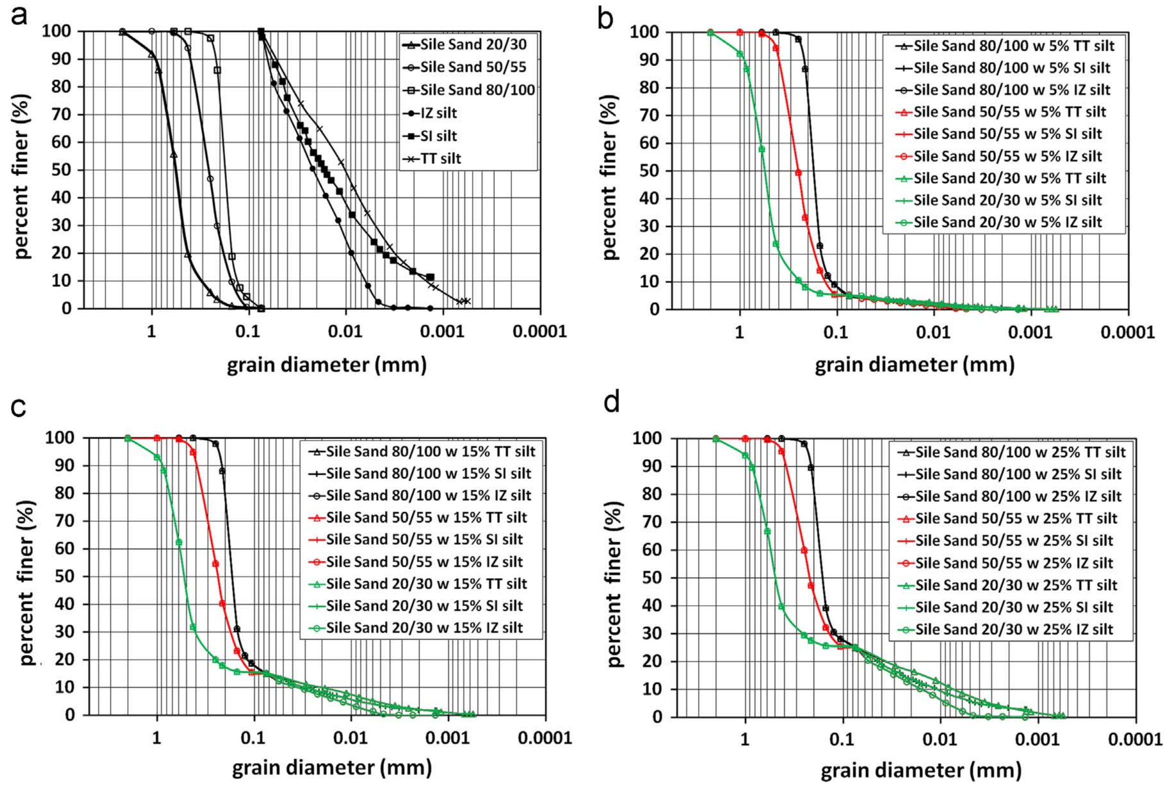

Fig. 1. Grain size distribution curves for the (a) base soils (clean sands and non-plastic silts), (b) different silty sands with 5% FC, (c) different silty sands with 15% FC, and (d) different silty sands with 25% FC, used in the experimental program.

compression tests on clean quartz sand in both saturated and dry states to look at the influence of gradation on the internal friction angle. He found that varying the coefficient of uniformity (CU) had negligible effect on the value of the effective friction angle for quartz sands at a given relative density. Kuerbis et al. [22] compared two different gradations of clean Brenda mine tailings sand, and concluded that undrained triaxial compression behavior is similar for both well graded and uniform versions of Brenda mine tailings sands. In a later study, Pitman et al. [35] added clean 70/140 silica sand to clean Ottawa sand in order to change the sand gradation. Similar to Kuerbis et al. [22], Pitman et al. [35] also concluded that monotonic undrained triaxial compression behavior of various samples prepared at similar initial void ratios are not influenced by the gradation of the sand (i.e. uniform or relatively well graded).

Some researchers on the other hand have reported that grain size distribution could be important for the undrained response of sands. Kokusho et al. [20] performed both monotonic and cyclic undrained triaxial tests on clean river sand of different gradations. Accordingly, influence of sand gradation had negligible effect on cyclic liquefaction resistance at a given relative density. However, static liquefaction resistance increased as the river sand became well graded (i.e. the coefficient of uniformity increased) at a given relative density. Kokusho et al. [20] also reported that effective stress internal friction angles (ϕ‘) of the sands have increased with increasing CU. Igwe et al. [16] conducted stress controlled undrained ring shear tests on clean industrial quartz sand with different gradations. Similar to Kokusho et al. [20], Igwe et al. [16] also concluded that as the sand gradation is changed so that the coefficient of uniformity is increased, its static liquefaction resistance is also increased at a given relative density.

So far, the vast majority of the previous literature focused on the possible influence of gradation on the liquefaction behavior of clean sands. However, it seems that conclusions regarding the influence of grain size distribution on static liquefaction behavior of clean sands are somewhat conflicting. Furthermore, when silty sands are of interest, the number of previous studies investigating the influence of gradation is very limited. Belkhatir et al. [6] conducted undrained triaxial compression tests on mixtures of Chlef sand and silt, and stated that peak undrained strengths decreased linearly with increasing CU of the mixtures due to increased fines content up to 50% for the specimens prepared at the same relative density. Maleki et al. [27] run undrained triaxial compression tests on different gradations of Shooshab sand mixed with 15% silt, and observed that as the sand matrix became smaller, undrianed shear strength of specimens increased when prepared at the same void ratio. Monkul [28] performed drained direct shear tests on mixtures of two base sands and two non-plastic silts, and observed that drained shear strengths of mixtures were not significantly influenced by either the gradations of base sand or silt or the value of fines content ($\leq 25\%$). However, the amount of volumetric contraction was found to be influenced by the gradation of specimens.

As could be seen from the mentioned studies, grain size distribution plays a considerable role on the stress-strain behavior and shear strength of sands. The goal of this study is to investigate how the gradation of the base sand matrix and some characteristics of the overall gradation (e.g. coefficient of uniformity, gap gradation) influence the static liquefaction potential of loose clean sands and loose sands mixed with different contents and types of non-plastic silts (i.e. $FC \leq 25\%$).

2. Soils tested

Three clean sands were obtained from a sand quarry in Şile region at the city of Istanbul. These sands, which have the same geologic origin but different gradations, are named Sile Sand 20/

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