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Experimental investigation of the effect of grading characteristics on the liquefaction resistance of various graded sands

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Abstract

The liquefaction susceptibility of various graded fine to medium saturated sands are evaluated by stress controlled cyclic triaxial laboratory tests. Cyclic triaxial tests are performed on reconstituted specimens having global relative density of 60%. In all cyclic triaxial tests; loading pattern is selected as a sinusoidal wave form with 1.0 Hz frequency, and effective consolidation pressure is chosen to be 100 kPa. Liquefaction resistance is defined as the required cyclic stress ratio which caused initial liquefaction in 10 cycles during the cyclic triaxial test. The results are used to draw relationship between grading characteristics (e.g. coefficient of uniformity and coefficient of curvature) and the liquefaction resistance of various graded sands. It is found that a relationship between cyclic resistance and any of the size (i.e. D_{10}, D_{30} or D_{60}) would be more realistic than to build a relation between grading characteristics and the cyclic resistance.

Keywords: Liquefaction resistance; Coefficient of uniformity; Coefficient of curvature; Cyclic triaxial test; Grading characteristics

1. Introduction

Factors affecting cyclic shear strength (liquefaction potential) behavior of sands under repeated loading (e.g. mainly earthquake induced) has been extensively studied. The effect of some of the factors such as relative density, effective confining pressure, applied cyclic stress ratio, sample preparation technique, cyclic loading pattern and frequency, consolidation ratio, degree of saturation, stress history, testing procedure, sample size, and compliance of testing equipment are well understood. On the other hand, the effect of other factors such as the fines content, particle structure, shape and size, membrane penetration and partial drainage are incomplete and requires further research. Furthermore, few studies in the literature have specifically evaluated the effect of particle gradation alone. Some of the findings of the rather limited number of studies in literature are summarized on Table 1. However, in these studies the effect of particle gradation is not isolated from other factors that may affect the resistance to liquefaction.

The objective of the current paper is to present the results of an experimental investigation of the effects of grading characteristics on the liquefaction resistance of reconstituted sand specimens at a relative density of 60%. Factors such as relative density, particle shape, mineralogy, specimen size, method of compaction, effective confining pressure, cyclic loading pattern and frequency, degree of saturation, have been held constant in comparison of the cyclic resistance of sands with different gradation (Yilmaz, 2006).

2. Cyclic triaxial testing

The cyclic resistance of reconstituted sand specimens with different gradation is determined using an electro-hydraulic

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Table 1
Summary of the literature review on the effects of particle gradation on the liquefaction resistance of sands

Findings	Reference
Particle size has much more effect on cyclic resistance with respect to particle shape and particle size distribution curve	Lee and Fitton (1968)
For the same number of cycle (10 cycles), as mean particle size reduces from 1.0 mm to 0.1 mm, magnitude of stress ratio to cause liquefaction decreases	Seed and Peacock (1971)
Fine sand with D_{50} value around 0.08 mm is more susceptible to liquefaction	Seed and Idriss (1971)
Liquefaction is very likely for uniform clean and loose sand	Castro and Poulos (1977)
As particle size increases, the cyclic resistance increases	Finn et al. (1970), Ishihara et al. (1975), Miura et al. (1994)
At lower relative densities gradation has control over liquefaction such that; poorly graded specimens have lesser cyclic resistance with respect to well graded specimens	Vaid et al. (1990)
For clean sands as D_{50} increases, the cyclic resistance increases. Fine sands are more susceptible to liquefaction than coarse sands. For failure as the number of cycle increases, the effect of D_{50} and C_u parameters on cyclic resistance decreases. In case of $D_{50}>0.25$ mm the effect of D_{50} values on the liquefaction resistance is very little. The effect of gradation on cyclic resistance is lesser than the effect of mean particle size	Polito (1999)

cyclic triaxial testing apparatus. The testing procedure used is based on ASTM D 5311.

2.1. Sample size

All specimens are prepared with the diameter of 70 mm and the height of 140 mm using seven layers with a constant thickness of 20 mm each. The resulting height to diameter ratio of 2 is kept constant.

2.2. Initial degree of saturation

It is stated that the higher the initial degree of saturation of the sample the less is the back pressure necessary to achieve the desired final degree of saturation (EM 1110-2-1906, 2006). Moreover, it is mentioned that cyclic resistance is significantly affected by the initial degree of saturation (Ladd, 1977). Therefore, for all samples the initial degree of saturation is fixed as high as 70%. The required amount of dry soil mass and water for each layer of specimens is determined accordingly.

2.3. Sample preparation technique

Effect of sample preparation techniques on undrained cyclic shear strength of soils is large (Silver and Park, 1976; Silver et al., 1976; Ladd, 1977; Yoshimi et al., 1984; Tatsuoka et al., 1986a; Miura et al., 1994; Ishihara, 1996). Wet compaction technique among others has very little random particle distribution and produces local void ratio discrepancy tendency with respect to other reconstituted sample preparation techniques (Ibrahim and Kagawa, 1991).

In order to ensure consistency of density throughout the specimen, the specimens are produced using under compaction technique recommended by Ladd (1978). As each layer is placed, some of the compaction energy will be transmitted to the lower layers. Therefore, not only the layer being placed, but also the layers below it, is likely to be densified. To compensate for this, the layers are placed at an increasing relative density from bottom to top. For example, if an overall relative density of 60% is desired, the seven layers would be placed from bottom to top at relative densities of 57, 58, 59, 60, 61, 62, and 63% respectively.

To be able to prepare cylindrical wet compacted samples, a compaction mould is used in sample preparation. During compaction, a vacuum of about 20 kPa is applied to the membrane inside the compaction mould. Then, each layer is placed one by one after being compacted to the height of 20 mm. A compaction hammer with base diameter of 35 mm is used to apply compaction energy to the each layer.

2.4. Final degree of saturation

After taking necessary measurements, the samples are first saturated by CO_2 at least for 30 min and then by de-aired water. The degree of saturation control is done by means of Skempton's pore pressure parameter B. According to JGS 0541 (2000) and ASTM D 5311-92 (2002) test samples are considered to be fully saturated if B is at least equal or greater than 0.95.

2.5. Consolidation

When samples are fully saturated, they are subjected to consolidation. During consolidation the difference between all-round pressure and back pressure is arranged such that for each specimen the effective consolidation pressure is fixed as 100 kPa.

2.6. Dynamic load

After consolidation process (e.g. measuring the height and volume and calculating corrected area of the each specimen just before the application of dynamic load), the double amplitude of sinusoidal varying dynamic load which is to be exposed is calculated using Eq. (1) (ASTM D 5311-92, 2002). Desired cyclic stress ratio (CSR) is kept constant and ranged from as small as 0.10 to as high as 0.45.

$$P_d = 2 \times \sigma'_{3c} \times \mathrm{CSR} \times A_c \quad (1)$$

Where;

P_d: calculated cyclic load, kN
σ'_{3c}: effective consolidation pressure, kPa