LIQUEFACTION RESISTANCE OF UNSATURATED INAGI SAND

The University of Tokyo Student Member ○Hailong Wang
The University of Tokyo Member Junichi Koseki

1. INTRODUCTION

Liquefaction tests of unsaturated soil has been conducted by many researchers because large amount of geotechnical projects, e.g. slope protection, river levee, embankment etc. were related to unsaturated soil, and the effect of degree of saturation of soil on liquefaction resistance has not been fully understood. Yoshimi et al. (1989) attempted to relate liquefaction resistance of unsaturated sand to degree of saturation and B-value; Huang et al. (1999) and Ishihara et al. (2001) attempted to relate it with wave propagation velocity and B-value; Yasuda et al. (1999) conducted unsaturated liquefaction tests on a sandy gravel; Goto et al. (2002) studied the impact of cyclic stress history on liquefaction resistance of unsaturated sand and currently, Okamura et al (2006) made efforts on relating liquefaction resistance of unsaturated sand to theoretical maximum volume stain of the material. Most of these studies mentioned above, however, focused on materials with high degree of saturation (e.g. Sr>80%) and small amount of fine content (e.g. FC<5%). Thus, the liquefaction resistance of clayey sand with relatively low degree of saturation needs to be studied.

In this study, triaxial liquefaction tests of medium dense Inagi sand with degree of saturation at about 70% were conducted. For comparison purpose, fully saturated liquefaction tests under similar conditions were also conducted.

2. TEST PROCEDURE

2.1 Test Material

Inagi sand passing through 2mm sieve was used in this study. This material consists of 70.5% sand, 18.2% silt and 11.3% clay, classified as SF material according to JGS0051. Its specific gravity is 2.656, and the maximum and minimum dry densities are 1.39g/cm^3 and 1.00 g/cm^3, respectively.

2.3 Triaxial test

A small scale triaxial apparatus for specimen of 50 mm in diameter and 100 mm in height was employed in this study. An air pressure controlled double cylinder was equipped to supply sinusoidal shear stress with frequency of 0.1Hz. For the saturated test, volume change of specimen during consolidation was estimated from the amount of water drained out and the effective stress was recorded by a HCDPT (High Capacity Differential Pressure Transducer). For the unsaturated test, the membrane filter technique (Nishimura et al., 2012) was applied to triaxial apparatus instead of traditional ceramic disc. A special pedestal which can fix the membrane filter tightly and form a flat surface (Fevrier, et al 2010) was installed. A thin tube was connected to the top cap at one end and to a PAP (Pore Air Pressure) transducer at the other end. In order to lessen the effect of extra air, the connection tube was kept as short as possible and a thinner steel tube was further installed into it. A hydrophobic filter was glued at the surface of the top cap to keep pore water from entering into the pore air pressure measurement system. The PWP (Pore Water Pressure) was measured by a pressure transducer connected with pedestal.

A steel mould with an inner diameter of about 50mm was used to make specimens outside the triaxial apparatus for both saturated and unsaturated tests. The specimen was moulded by pouring test material with initial water content of around 22% into the mould at one time and statically compressing from two side of the mould simultaneously. The relative density (Dr) of specimens ranged from 64% to 72% at the end of consolidation.

For the saturated test, the specimen was first saturated by double vacuum method for around 15 hours according to JGS 0520. Specimens with B-value ≧0.96 were thought to be fully saturated. Then the specimen was consolidated under an effective confining pressure (σ_0') of 60kPa for about 2 hours. After consolidation, the vertical cyclic loading was applied while keeping confining pressure (σ_0) constant.

For the unsaturated test, some extra water was added from the top of the specimen to achieve the target degree of saturation at about 70% after consolidation. Then the specimen was sealed in the mould for about 15 hours for uniformity of water distribution. After mounting the specimen on pedestal and components installation of the apparatus, the specimen was consolidated by a net normal stress (σ_0-u_a) of 60kPa under drained-exhaust condition for about 2 hours. After consolidation, the vertical cyclic loading was applied under fully undrained condition while keeping confining pressure (σ_0) constant.

3 TEST RESULTS

Fig.1 and Fig.2 show the typical time histories of measured data during cyclic loading in the saturated and unsaturated tests, respectively. Similar with pore water pressure in the saturated test, pore water pressure and pore air pressure increased gradually under cyclic loading in the unsaturated test. Suction value remained positive until the specimen was close to liquefied state. Notice that in the time history of the unsaturated test, the axial strain first biased to extension side, and as pore water pressure and pore air pressure increased further, it accumulated on the compression side gradually; while this was not very apparent in the saturated test. This may be caused by the change of mean stress(p)

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Contact address: Room Ce202, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan, Tel: +81-3-5452-6422

during cyclic loading.

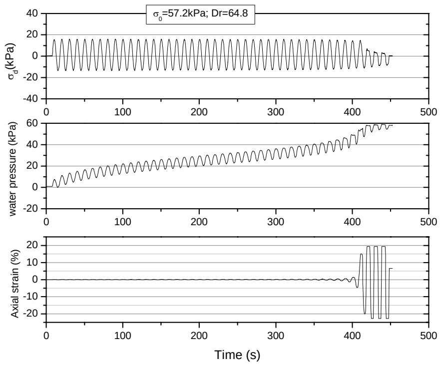

Fig. 1 Time history of saturated test

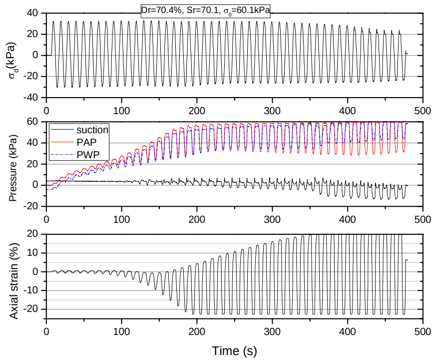

Fig. 2 Time history of unsaturated test

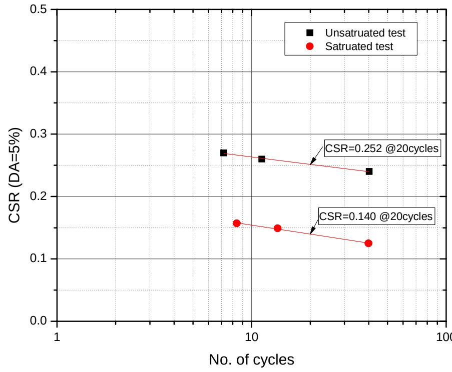

Fig. 3 No. of cycles versus CSR

Fig 3 depicts the relationship between number of cycles and CSR (Cyclic Stress Ratio, $\sigma_d/2\sigma'_0$) to cause double amplitude axial strain, DA, of 5%. If we choose the CSR to induce DA of 5% at 20th cycle as liquefaction resistance, the liquefaction resistance ratio (liquefaction resistance of unsaturated case/ liquefaction resistance of saturated case) was 1.8 for medium dense Inagi sand with Sr of about 70%.

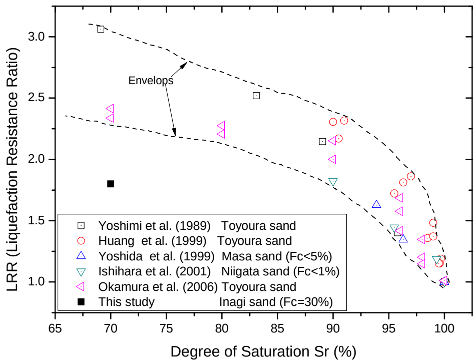

Fig.4 Relationship between Sr and LRR

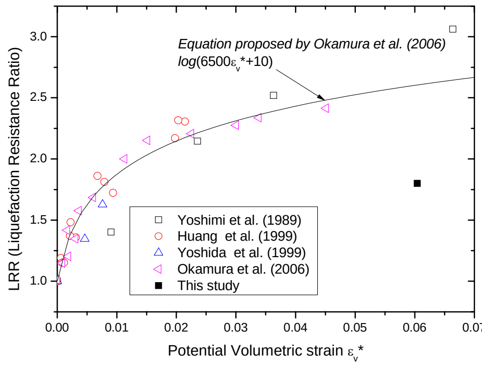

Fig.5 Potential volumetric strain versus LRR

The data of LRR (Liquefaction Resistance Ratio) under different degree of saturation obtained by previous researches and this study were summarized in Fig. 4. It shows that data of previous study scattered within two envelopes as shown by dash lines and the test result in this study is below the lower limit envelope. Fig. 4 implies that the degree of saturation may not be the only factor that affects liquefaction resistance of unsaturated material and fines content may be an important one among all factors. Okamura et al. (2006) proposed an empirical equation which related LRR to potential volumetric strain, a theoretical maximum volumetric strain of the material. Fig. 5 shows the equation and some test data, from which the equation shows a good agreement with test data except conditions at high potential volumetric strain (e.g. ε_v*>0.06). This result implies that liquefaction resistance of unsaturated material may not be controlled by the potential volumetric strain of the material only; fines content also needs to be considered.

4 CONCLUSIONS

Liquefaction resistance of medium dense Inagi sand with Sr of about 70% was studied. The study shows that liquefaction resistance of this unsaturated material increased 1.8 times with respect to that of fully saturated case. Combining with previous studies, liquefaction resistance of unsaturated material may not be explained by degree of saturation or the potential volumetric strain of the material only; fines content also needs to be considered.

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