TECHNICAL NOTE

LIQUEFACTION RESISTANCE OF VOLCANIC SOIL FROM MOUNT PINATUBO IN THE PHILLIPPINES

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ABSTRACT

A laboratory investigation into liquefaction resistance of volcanic soil from erupted materials of Mount Pinatubo in the Philippines has been carried out for the purpose of using this local sand to construct 'super-dike' in highly seismic area. This paper presents results of undrained cyclic triaxial tests performed on the reconstituted volcanic soil. Samples were prepared by two different methods of dry deposition and wet tamping to have relative density ranging between 26% and 80%. Liquefaction resistance, or cyclic strength, was defined as the cyclic stress ratio at 5% double amplitude of cyclic axial strain in 20 cycles of sinusoidal load application. The results show that samples prepared by wet tamping method exhibited higher cyclic strength than samples prepared by dry deposition. A tendency was seen for the cyclic strength to decrease when the initial effective confining pressure increased. The first approximation of the relationship between cyclic strength and relative density of the soil was obtained for use in seismic design of the super-dike.

INTRODUCTION

Lahar sand, volcanic soil found abundantly in certain rivers of the Philippines and Indonesia, is a silty sand. It originates from pyroclastic materials deposition erupted from an active volcano and flowed down the river during heavy rainfall. In the Philippines, construction of a super-dike using this local sand is now under consideration in order to prevent catastrophic disasters caused by massive flow of Lahar sand which often takes place during the rainy season. For this kind of as-placed soil structures, an assessment of the liquefaction resistance of the fill material is a major concern to local engineers in this highly seismic area. It is well known that initial liquefaction, or simply liquefaction, at an instant when pore water pressure build-up during cyclic loading eventually becomes equal to the initial effective confining pressure, is usually accompanied by 5% double amplitude (DA) cyclic axial strain. Liquefaction resistance or cyclic strength can then be defined as cyclic stress ratio to cause 5% DA cyclic axial strain under any number of uniform loading cycles, such as 20 cycles, with appropriate correction factor to accommodate the irregularity and multi-directionality of actual seismic loading. Cyclic triaxial test could be performed in different laboratories with relatively good conformity. Even though the cyclic triaxial test is not the best representation of the actual conditions of field response during seismic loading, it is still preferred due to its convenience, versatility and repeatability.

MATERIAL AND TEST PERFORMED

Lahar sand used in this study was sampled from Pasig-Petreto river in Pampanga, Philippines (Mir, 1996). The grain size distribution curve is shown in Fig. 1. The sand had the mean grain size, D_{50}, of 0.27 mm, finer fraction ($\leq$0.075 mm) of 12%, and uniformity coefficient, U_c, of 7. The void ratio ranges from e_{min} = 0.649 to e_{max} = 1.161 with the density, ρ_s = 2.624. It should be pointed out that the grain size distribution of Lahar sand falls within the range associated with most liquefiable soils. According to Mir (1996), Lahar sand sampled at different locations exhibited different chemical properties: silicon dioxide content ranging from 51% to 66 %, aluminum oxide content 16% to 46% and calcium oxide from 0% to 14%. The angle of internal friction of a sample having the relative density of D_r = 62% was 42° as observed in undrained monotonic triaxial test.

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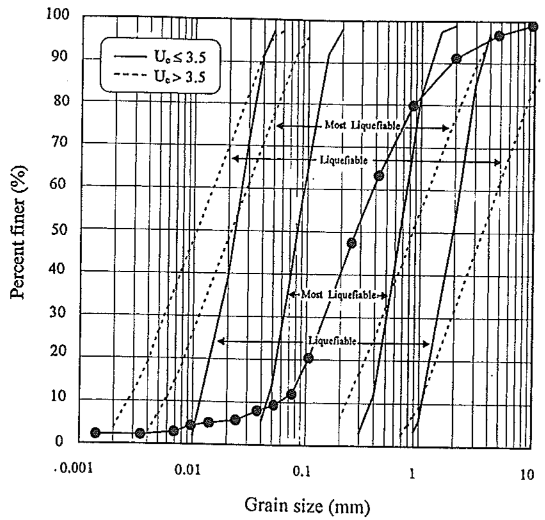

Fig. 1 Grain Size Distribution Curve of Lahar Sand Plotted into Grain Size Distribution of Liquefiable Soil Proposed by Japan Port and Harbor Association (1989)

Two methods of sample preparation were employed, i.e., dry-deposition and wet-tamping. The former was performed by pluviating oven-dry sand into mold using a cone-shaped funnel. In the latter method, the sand mixed with de-aired water having a water content of about 5% was strewn by hand into the mold in five lifts. At each stage of the lifts, the poured sand was gently compacted by using a metal rod. The soil density was controlled at prescribed different values by tapping and tamping the soil specimen for air-pluviated and wet-tamped specimens, respectively.

Conventional undrained cyclic triaxial tests were performed comparatively in Geotechnical Engineering laboratories at the Asian Institute of Technology (AIT) and at Kitami Institute of Technology (KIT). The testing procedures employed were identical for these two institutions. The cylindrical specimens having the dimension of 50 mm in diameter and 100 mm in height at AIT, and of 70 mm and 170 mm at KIT, respectively were isotropically consolidated to three different levels of the effective confining pressures, σ'_c, of 49 kPa, 98 kPa and 196 kPa. The pore pressure parameter B as measured at the end of consolidation was in excess of 0.96. Cyclic loading was applied by using a sinusoidal wave with a frequency of 0.1 Hz. The test was terminated as the double amplitude of cyclic axial strain reached to 15%.

It should be pointed out that the results from AIT and KIT were very similar to each other as examined in preliminary pilot tests for samples prepared by dry deposition, the results of which are shown in Fig. 2. In this comparative series of tests using the D_r values of 55% and 80% to 82%, the relationship between cyclic stress ratio and number of cycles, N_c, was similar. Accordingly, no distinction was made in this paper for the test results obtained at these two institutions. In this figure, the results of Toyoura sand specimens prepared by air-pluviation (Toki, et al., 1986) are also shown for comparison. Note that the curves of Lahar sand and Toyoura sand were similar to each other as examined at a medium density of D_r = 50%. However, Lahar sand was more resistant against the undrained cyclic loading at D_r = 80%.

RESULTS AND DISCUSSIONS

Effect of Sample Preparation

Figure 3 shows the relationship between cyclic stress ratio and N_c for two kinds of samples prepared by wet tamping and dry deposition. The samples prepared by wet tamping exhibited a higher cyclic strength than those prepared by dry deposition for the density in common. It should be mentioned that this tendency has been observed in

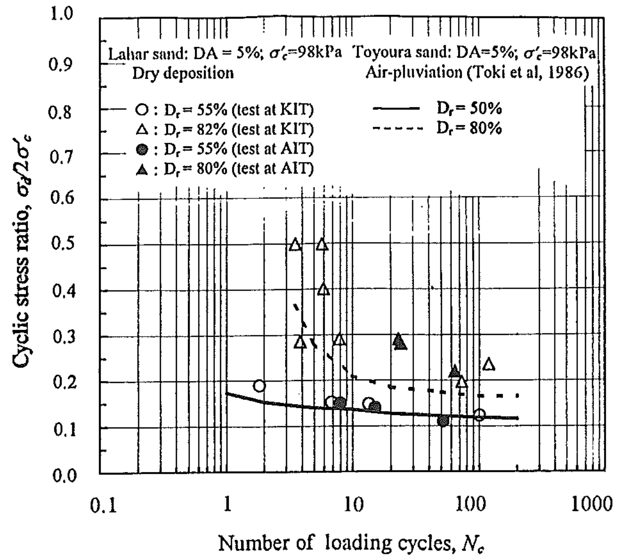

Fig. 2 Results of Comparative Tests Performed at AIT and KIT

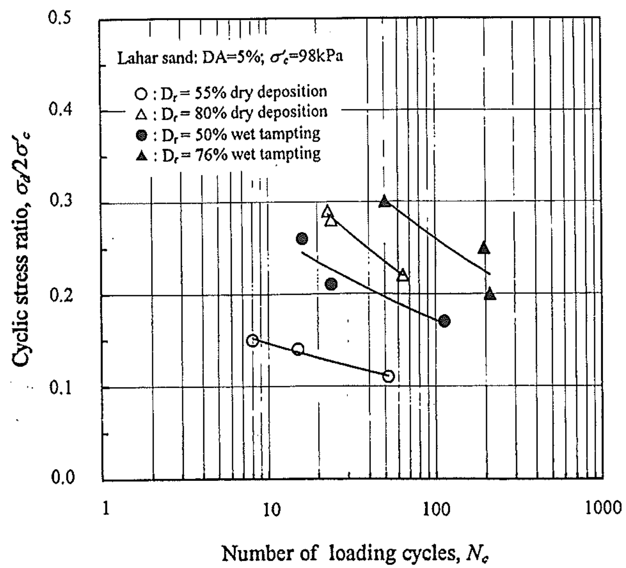

Fig. 3 Effects of Sample Preparation on Cyclic Strength of Lahar Sand

tests on similar sands and on clean sands worldwide. The difference of the cyclic resistance may be attributed to the difference in soil fabric created by different methods of sample preparation (Ladd, 1974; Mulilis, et al., 1977; Tatsuoka, et al., 1986a; and Ishihara, 1993).

Effect of Confining Pressure

Effect of confining pressure is evaluated by examining a correction factor K_σ given in Eq. (1), where CSR is defined as the cyclic stress ratio causing 5% DA axial strain in 20 cycles:

$$K_\sigma = \frac{CSR_{\sigma_c'}}{CSR_{\sigma_c' = 98\,kPa}} \quad (1)$$

Despite large scatter seen in Fig. 4, the correction factor K_σ for a confining pressure of 49 kPa (0.5 kgf/cm²) was approximately equal to 1.16 while for confining pressure of 196 kPa (2.0 kgf/cm²), K_σ was about 0.94. Note also that the stress-level dependency of the CRS was similar in a quantitative sense for both samples prepared by dry deposition and wet tamping. These trends are in accordance with experimental data presented by Vaid and Thomas (1994) using reconstituted samples of a variety of sand.

Effect of Soil Density

Effect of relative density as examined at DA = 5% can be seen in Fig. 5. For any DA axial strain value, the cyclic stress ratio at a given N_c increased as the density increased. As discussed previously, for the same relative density, the sample prepared by wet tamping showed a higher cyclic strength than the sample prepared by dry deposition. As shown in Fig. 6, the first approximation of the test data yielded the following relationship:

For 55% $\le D_r \le$ 82% of dry-deposition sample:

$$(\sigma_d / 2\sigma_c')_{DA=5\%, Nc=20} = -0.283 + 0.783\,(D_r / 100) \quad (2)$$

For 26% $\le D_r \le$ 76% of wet-tamped sample:

$$(\sigma_d / 2\sigma_c')_{DA=5\%, Nc=20} = 0.015 + 0.459\,(D_r / 100) \quad (3)$$

These equations for the relationship between relative density and the cyclic strength are expected to be used for evaluating the factor of safety against liquefaction of the sandfill constructed with a specified relative density under a certain seismic loading, (Tatsuoka, et al., 1986b; Ishihara, 1997 and 1993).

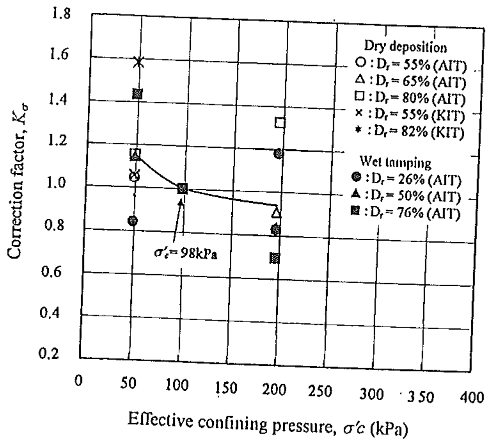

Fig. 4 Effect of Confining Pressure on the Cyclic Strength

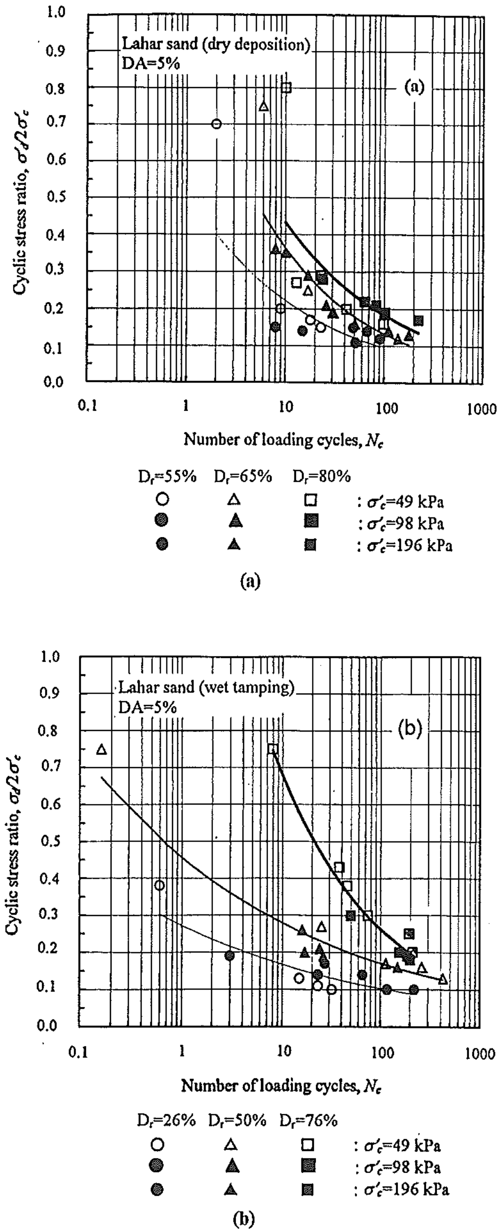

Fig. 5 Cyclic Stress Ratio Versus Number of Cycles to Cause DA = 5%: (a) Dry-Deposited Samples, (b) Wet-Tamped Samples

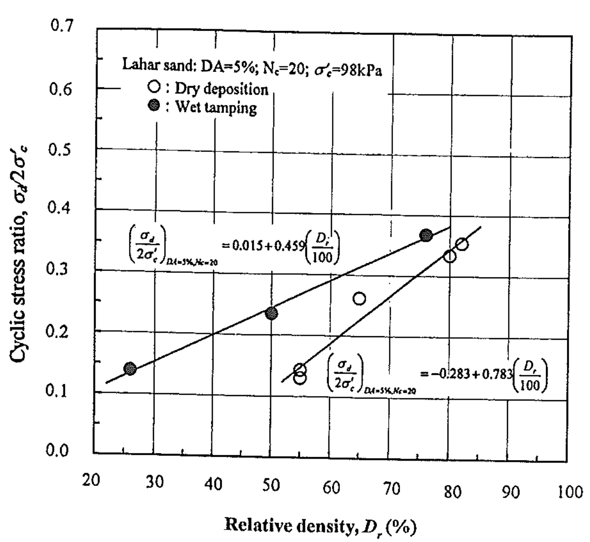

Fig. 6 Cyclic Strength Versus Relative Density

CONCLUSIONS

Undrained cyclic triaxial tests have been performed on Lahar sand, volcanic sand of mount Pinatubo in the Philippines. The following conclusions can be drawn from the tests:

1. Cyclic strength of reconstituted sample is highly influenced by its reconstitution method. This is mainly due to the nature of fabric structure (even not known exactly) created by different methods of reconstitution. Cyclic strength of samples prepared by wet tamping method is higher than samples prepared by dry deposition method. Thus the cyclic strength of reconstituted sample must specify the method of sample preparation.

2. Effective initial confining pressure influences the cyclic strength of sand. The tendency is to decrease the cyclic strength with increase in confining pressure. It is customary to use 1 kgf/cm² (98 kPa) confining pressure as a reference for the cyclic strength. A correction factor K_σ was observed as 1.16 at σ_c' = 49 kPa and 0.94 at σ_c' = 196 kPa. These values are not very much different from those of clean quartz-rich sand.

3. The liquefaction resistance of the sand depended strongly on the density as expected. The relationship between the cyclic strength and the relative density is obtained, which can be used in the seismic design of the fill using this volcanic sand.

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