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CYCLIC UNDRAINED TESTS ON GRAVEL-LIKE MATERIAL USING CUBIC TRIAXIAL APPARATUS

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SUMMARY

Cubic undrained shear tests were performed by using a cubic triaxial apparatus in static manners on crushed sandstone. Attempts were made to reduce the membrane penetration errors in experimental data by gluing thin brass plates on the surface of rubber membranes. Test results show that the samples compacted by tamping are of anisotropic nature in pore pressure development as well as shear distortion, and that the cyclic resistance of samples depends on the particle size of the material. Finally, the shape of the failure surface is examined in the octahedral stress plane.

INTRODUCTION

This text concerns with the cyclic undrained behavior of a coarse-grained material. The good performances of coarse materials against seismic liquefaction are attributed to the immediate dissipation of possible excess pore water pressure in consequence of their high permeability. However, the quick dissipation cannot be expected when the drainage path is either very long or impeded by a layer of less pervious soil.

So far, most laboratory shear testings conducted in cyclic undrained manners on gravely materials have been triaxial tests (Refs.1,2,3). Some of the difficulties encountered in testings are due to the large size of grains. Firstly, a specimen has to be sufficiently greater than the grain diameter in order to keep the specimen being a uniform continuum. Secondly, the membrane penetration error is said to underestimate the excess pore water pressure during undrained loadings; more significantly when grain is coarser. It is frequently practiced, consequently, to reduce the particle size by crushing or sieving the original material. Hence, more study is needed of the effects of reduced grain size on cyclic test results. Furthermore, the triaxial device cannot generate a stress state other than an axisymmetric one. Since the axisymmetric situation is rarely the case in reality, some examination is needed on this point.

TESTING APPARATUS

The same apparatus as was described in Ref.4 was employed in the present study. A cubic soil sample, measuring 10 cm * 10 cm * 10 cm in size, has rubber membranes of 0.8 mm thickness on its six faces. Three principal stresses are applied independent of one another through the membranes on a sample. An attempt was made to eliminate the membrane penetration by placing between soil and each membrane two sheets of filter papers between which nine thin square plates of brass were inserted. Being 0.3 mm thick, the rigidity of plates were expected to prevent the membrane penetration (Ref.5). A small spacing was left among those plates in order to avoid their possible interaction. The filter papers were used to keep the plates in position.

SAMPLE PREPARATION AND TESTING PROCEDURE

The tested material is a subangular to angular crushed greywacke sandstone with Gs = 2.70 which was obtained in the Surathani Province of South Thailand. A sieving attained a uniform gradation of either 9 or 1.8 mm. This size of particles is less than 1/11 of the size of the specimen, and seems to be sufficiently small (Ref.6).

A cubic sample was made by tamping its surface by five layers. Dry unit weight of 1.6 g/cm^3 was attained. Since the tamping was conducted inside the apparatus, a heavy tamping was possible to cause grains to damage rubber membranes, although they were protected by filter papers and brass plates. Hence, a dry density of more than 1.6 g/cm^3 was not possible. A water saturation was achieved by applying a back pressure and Skempton's B parameter greater than 0.98 was observed. Following the isotropic consolidation under σ_c' = 98 kN/m^2, undrained cyclic shear was started, while the mean total pressure $(\sigma_1+\sigma_2+\sigma_3)/3$ maintained constant.

The vertical and horizontal axes of reference are denoted by Z, X, and Y, respectively (Fig.1). With three principal stresses, σ_z, σ_x, and σ_y, thus defined, Fig.1 illustrates several radial loading paths in the octahedral stress plane (same idea as in Ref.4). All the tests were static and stress-controlled. The alternate loading in ZC and ZE directions is the conventional cyclic triaxial test whose axial direction is vertical.

UNDRAINED TEST RESULTS

Elimination of Membrane Penetration Errors The effects of brass plates are demonstrated by the stress paths of monotonic undrained triaxial compression tests (ZC). Fig.2 shows that the sample with brass plates generated higher pore water pressure than that with regular membranes. Although the membrane penetration error was not necessarily 100% eliminated by the brass plates, the observed pore pressure is substantially free of the penetration error.

Typical Cyclic Results Figs.3 and 4 show the undrained cyclic behaviour of a sample of 9 mm particles. The amplitude of the octahedral shear stress, τ_{oct}, is 55 kN/m^2. Fig.3 indicates that the pore pressure development is much greater in the first cycle than in the following cycles. In particular, the excess pore water pressure or the effective stress at the end of the second cycle is already close to that after the tenth cycle, suggesting that the 100% liquefaction is unlikely to occur within an additional few cycles. Moreover, the effective stress state in, for example, the tenth cycle moves up along the failure locus. The cyclic natures of the gravely material as described above are similar to those of dense sands.

The stress-strain curve of the same test is presented in Fig.4. The strain amplitude increased with number of cycles only gradually, which is also the same behavior as dense sands. Note the small difference in strain amplitudes between the fourth and tenth cycles. The tangential slope of the curve, except in the first cycle, increased with shear loading, because the effective stress increased simultaneously as well (see Fig.3).

Effects of Anisotropy Results of three types of undrained test are compared in Figs.5 and 6, where the amplitude of τoct is 42 kN/m^2. As was already observed in Fig.3, 100 % liquefaction is not likely to occur. The ZC-ZE test developed a greater amount of pore pressure than the XC-XE test. Since these two tests are identical triaxial tests except the orientation of axis of loading, it seems that the anisotropic characteristic of the material (inherent anisotropy) results in different extent of pore pressure generation. The development of shear distortion (the maximum γoct in respective cycle) with number of cycles shows a similar trend in Fig.6.

RS 90-270 tests were carried out to investigate the reasonable way of cyclic tests on gravely materials. This type of test has an identical stress state in positive and negative directions of loading, and is similar to the cyclic simple shear in a level ground during earthquakes. Furthermore, the orientation of τoct stress is always horizontal in the octahedral stress plane, and hence free of effects of inherent anisotropy. Therefore, in order to model the behavior of level ground during horizontal shaking, the RS 90-270 test is the most appropriate type of loading that the present device can accomplish. As seen in Figs.5 and 6, the RS 90-270 and ZC-ZE tests reveal more or less similar rates of developments of pore pressure and distortion. Hence, the ZC-ZE test which is the commonly-practiced cyclic triaxial test seems reasonable for the study of cyclic behavior of anisotropic gravely materials.

The use of ZC-ZE test in practice is supported by Fig.7 in which two types of test give similar relationships between stress ratio and number of cycles to γoct = 2.5%. It should be borne in mind, however, that the limitation of the above conclusion is found in the rather large amplitude of shear stress as well as the lack of consideration on the insitu Ko consolidation.

Effects of Particles Size It is often practiced in laboratory testings on gravely materials that the grain size of a material is reduced by sieving because of a limited size of specimens. Hence, it is important to examine the possible effects of particle size on cyclic behavior of a gravely material.

Fig.8 demonstrates the development of pore pressure with number of cycles during an undrained RS 90-270 test of τoct = 42 kN/m^2. A sample of 9 mm particles had slightly greater pore pressure than a sample of 1.8 mm grains. This suggests that the underestimation of pore pressure for coarser grains due to membrane penetration is already eliminated by the use of brass plates. The difference between samples of two particle sizes is even larger when the development of shear distortion is examined in Fig.9. The larger particle size resulted in the greater shear distortion. Fig.10 compares the relationships between the stress ratio and the number of cycles required for γoct = 2.0%. It is evident that samples of 9 mm particles give lower cyclic resistance. In other words, cyclic testings on samples of reduced particle sizes possibly overestimate the cyclic strength of gravely materials.

FAILURE CRITERION OF GRAVELY MATERIAL

Fig.3 revealed that the significant deformation of the gravely material is induced not by the substantial pore pressure but by the shear stress level close to the failure locus. In this regard, the shape of the failure envelope was studied in the octahedral stress plane by running monotonic drained tests towards the radial directions in the octahedral plane (Fig.1). All the tests were performed without brass plates. The penetration error in measured strains was corrected later by the amount which was determined by isotropic compressions with and without brass plates on membranes in one of X, Y, and Z directions.

Due to the limited extent of sample deformation in the present device, failure stress could not be directly measured. Hence, an approximate measure was taken in which contour lines of octahedral shear strain, γoct, were drawn in the octahedral stress plane (Fig.11). It was expected that the contours would converge to the ultimate failure loci with increasing γoct. The values of γoct employed range from 0.07% to 2.0%. The irregularity of contours at minor γoct vanished with the increase of γoct, and eventually a smooth contour with γoct = 2.0% was obtained. This contour gives a reasonable idea of the shape of the failure locus, although it is not necessarily identical by 100% with the locus.

A comparison was made in Fig.11 between the experimental shape of the failure locus thus derived and the Mohr-Coulomb locus which have the equal strength in ZC direction. Findings in the figure are:

- experimental strength in XC or YC direction is less than that given by the Mohr-Coulomb criterion. This is probably because the inherent anisotropy of the material.
- around triaxial extensional directions (XE and ZE), experimental strength is slightly greater than the Mohr-Coulomb strength. Reasons for lack of anisotropy between XE and ZE are unknown.

CONCLUSIONS

Cubic triaxial testings were carried out in undrained manners on compacted samples of a gravely material. Membrane penetration error was eliminated by placing pieces of thin brass plates on the membranes. Consequently, the following conclusions were drawn:

1) The brass plates functioned satisfactorily.
2) Cyclic behavior of the compacted gravely material is similar to that of dense sands,
3) Cyclic triaxial testing in the vertical direction of axis (XC-ZE) is a reasonable measure to obtain the cyclic strength of the anisotropic material,
4) Testing on samples of reduced particle size possibly overestimates the cyclic strength,
5) Shape of the failure surface in the octahedral plane is different from that of Mohr-Coulomb criterion.

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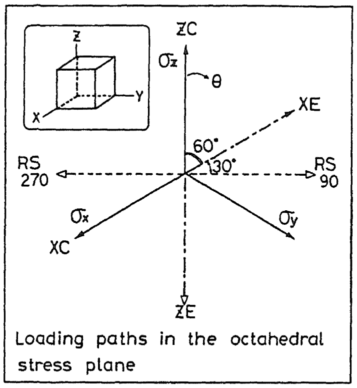

Fig.1 Loading paths in the octahedral stress plane.

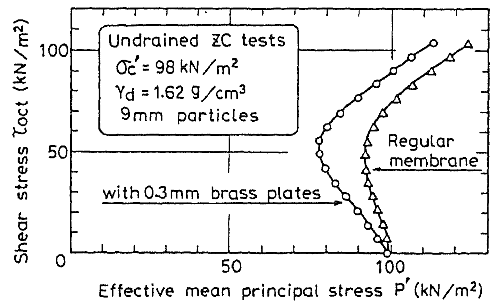

Fig.2 Reduction of penetration errors by thin brass plates attached on membranes.

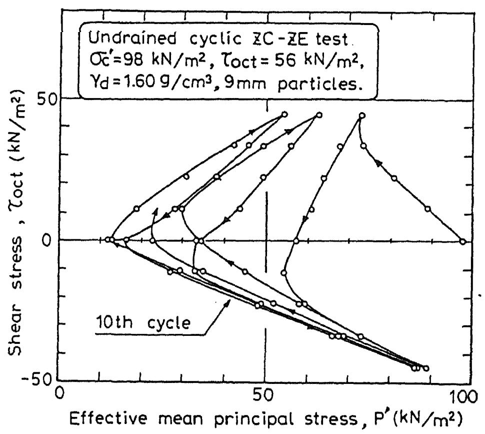

Fig.3 Stress path diagram of undrained ZC-ZE test on sample of 9 mm particles.

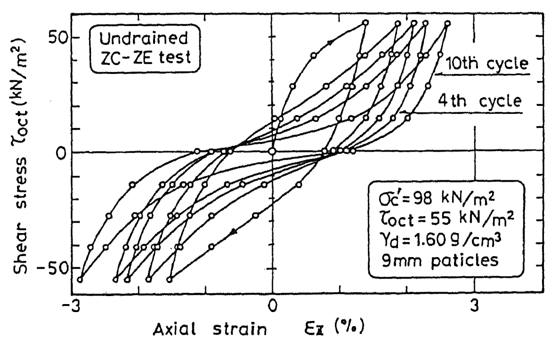

Fig.4 Stress-strain behavior in undrained ZC-ZE test on sample of 9 mm particles.

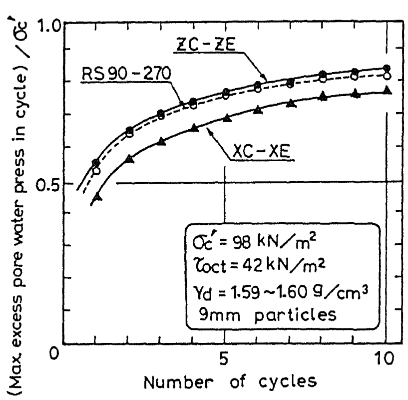

Fig.5 Development of excess pore water pressure with number of loading cycles in different directions.

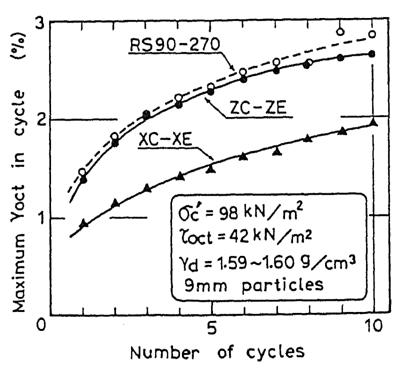

Fig.6 Shear distortion increasing with number of cycles when loaded in three directions.

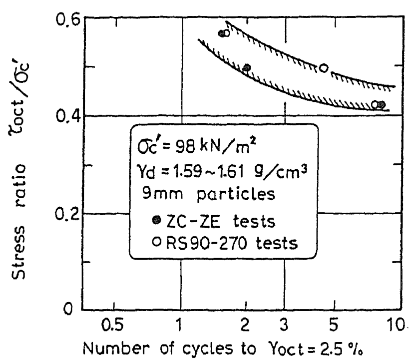

Fig.7 Relationship between stress ratio and number of cycles to γoct = 2.5% in ZC-ZE and RS 90-270 test.

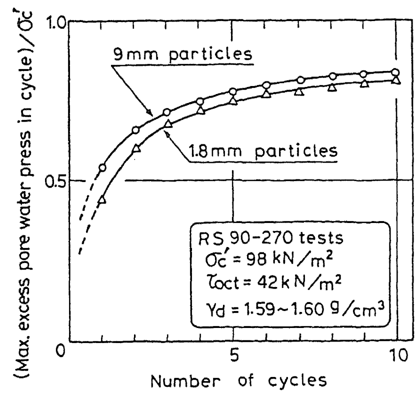

Fig.8 Effects of particle size on development of excess pore water pressure with number of cycles.

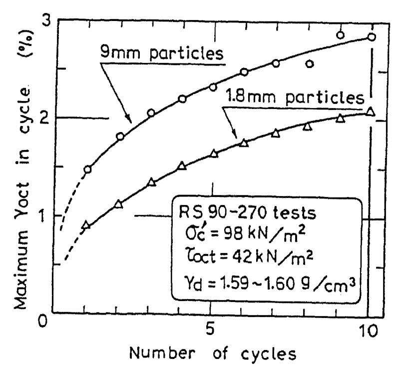

Fig.9 Effects of particle size on development of shear distortion with number of cycles.

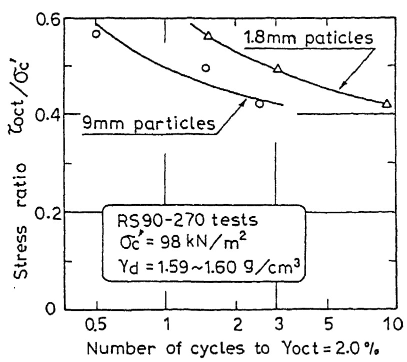

Fig.10 Effects of particle size on relationship between stress ratio and number of cycles to γoct = 2.0%.

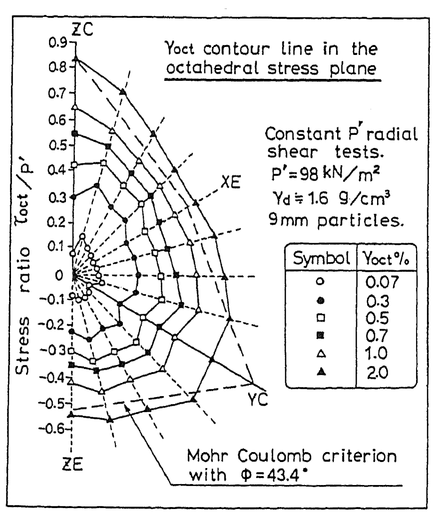

Fig.11 γoct contour lines in the octahedral stress plane obtained by drained monotonic tests.