SHEAR BEHAVIOUR OF SAND UNDER STRESS REVERSAL

RESISTANCE DU SABLE AU CISAILLEMENT EN CAS DE RENVERSEMENT DES CONTRAINTES

СОПРОТИВЛЕНИЕ ПЕСКА СДВИГУ ПРИ ЗНАКОПЕРЕМЕННЫХ НАГРУЗКАХ

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SYNOPSIS. A series of drained and undrained triaxial (axi-symmetric) tests have been carried out on samples of a fine sand where they were subjected to stress reversal from triaxial compression to triaxial extension or vice versa,and the results obtained are compared with results of standard triaxial extension or compression tests.It is found that the anisotropy induced in the sand during triaxial compression changes the stress-strain behaviour of the material in triaxial extension when the stress system is reversed from triaxial compression to triaxial extension. Stress reversal does not affect the strength obtained from drained tests. During undrained tests, the stress paths of samples subjected to stress reversal lie on the yield surfaces and limiting state surface obtained from triaxial compression or triaxial extension tests except for small values of deviator stress. Stress reversal decreases the resistance of the sand to liquefaction.

INTRODUCTION

The standard triaxial (axi-symmetric) apparatus is widely used to study the strength-deformation characterstics of soils.Shear tests are carried out under two stress conditions: (i) triaxial compression tests where the intermediate principal stress is equal to the minor principal stress and the axial stress is the major principal stress, and (ii) triaxial extension tests where the intermediate principal stress is equal to the major principal stress and the radial stress and the radial stress is the major principal stress.

The deformation characteristics of a fine sand when subjected to reversal of stresses from triaxial compression conditions to triaxial extension conditions or vice versa have been investigated herein.The shear behaviour of this sand during triaxial compression and triaxial extension tests has been reported earlier (Thurairajah and LeLievre 1971; Thurairajah and Sithamparapillai 1972).

EXPERIMENTAL PROGRAM

Triaxial tests were carried out on saturated samples of sand,2 in.in diameter and 4 in.in height,with enlarged polished end platens 2.25 in. in diameter.The friction at the end platens was reduced by placing a 0.01 in. thick rubber disc on each platen with a thin film of silicone grease between the platen and the rubber disc (Bishop and Green 1965). Drainage from the sample was allowed at the bottom end only through a 0.5 in.diameter porous stone fixed to the centre of the end platen. The load applied to the sample by the triaxial cell piston was measured internally using an electrical resistance strain gauge type load cell attached to the bottom of the piston. The tests performed were strain-controlled tests carried out at an axial deformation rate of 0.003 in./min.

The material tested was the portion of fine Ottawa sand passing through No.60 sieve (0.25mm) and retained on No.200 sieve (0.074 mm).79% of this material was retained on No. 100 sieve (0.149 mm).The sand grains have a specific gravity of 2.65.

STRESS AND STRAIN PARAMETERS

The stress parameters used are the mean principal effective stress $p=(\sigma_a' + 2\sigma_r')/3$ and the deviator stress $q=(\sigma_a' - \sigma_r')$ where σ_a' and σ_r' are the axial and radial effective stresses respectively.The strain parameters used are the natural volumetric strain v and the natural shear strain ϵ given by $\delta\epsilon=(\delta\epsilon_a-\delta v/3)$ where $\delta\epsilon_a$ is the incremental natural axial strain. Compressive strains are considered to be positive.

DRAINED TRIAXIAL TESTS

The shear behaviour of the sand when subjected to triaxial compression or triaxial extension under drained conditions has been presented elsewhere (Thurairajah and Sithamparapillai 1972).Typical results of tests on samples which were consolidated under isotropic stresses and then subjected to reversal of stresses from triaxial compression to triaxial extension or vice versa are discus-

.sed in this section.

Drained Triaxial Compression-Extension Tests

The full line curves in Fig.1 show the variations of deviator stress q and volumetric strain υ with shear strain ϵ during a drained triaxial compression-extension test on a dense sample (void ratio e=0.522).The sample was initially consolidated under a cell pressure of 60 psi and then subjected to triaxial compression up to a conventional axial strain of 6.3%. The sample had reached the peak deviator stress value at this strain.At this stage the axial load on the sample was reduced and it was sheared under triaxial extension. The dotted line curves in Fig.1 give the results of a drained triaxial extension test on a dense sample (e=0.517) consolidated under a cell pressure of 60 psi.

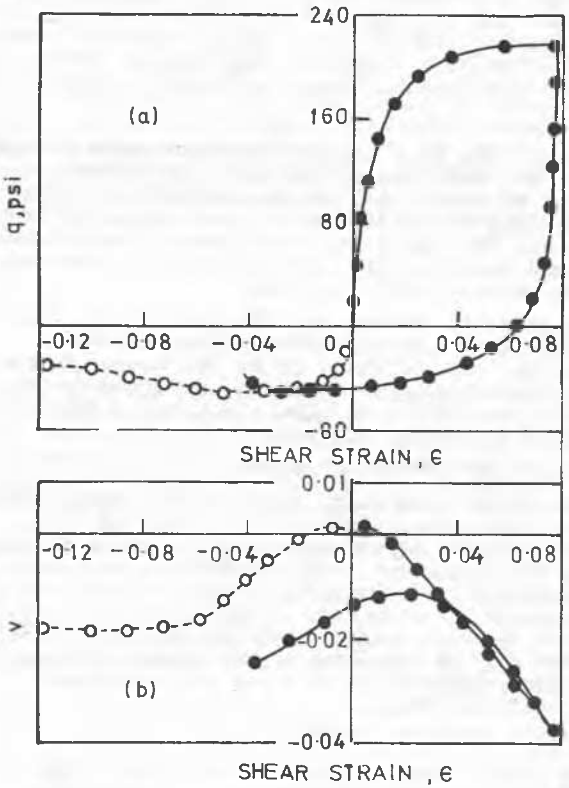

Fig.1.Drained Triaxial Compression-Extension Test on Dense Sand.

It is evident from Fig.1(a) that the reversal of stresses from triaxial compression condition to triaxial extension does not have any appreciable influence on the strength of the sample in triaxial extension.Similar behaviour has been observed with looser samples.Irrecoverable shear strain is seen to occur from the time the stress path moves from the triaxial compression zone to the triaxial extension zone.The anisotropy induced in the sand sample during the compression stage (Barden 1969) has altered the stress-strain behaviour of the material during the extension stage. This characteristic is similar to the Bauschinger effect in metals.

Fig.1(a) shows that the portion of the stress strain curve obtained for unloading from the compression side and reloading on the extension side is a smooth curve across the zero deviator stress line.This indicates that the deformation mechanism which produces the hysterisis loop during unload-reload cycle in the compression side or the extension side may be the same as that which produces the larger irrecoverable shear strains.Similar observations were made on clays by LeLievre and Wang (1971).

Drained Triaxial Extension-Compression Tests

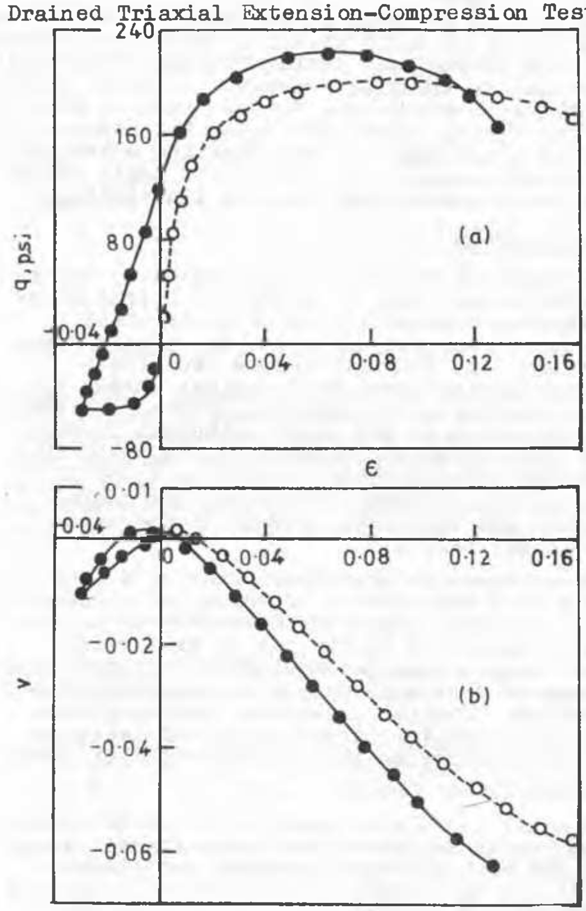

Fig.2.Drained Triaxial Extension-Compression Test on Dense Sand.

The variations of deviator stress q and volumetric strain υ with shear strain ϵ during a drained triaxial extension-compression test on a dense sample (e=0.509) are presented in Fig.2 by full line curves.The sample was initially consolidated under a cell pressure of 60 psi and then subjected to triaxial extension up to a conventional axial strain of -3.3% when the sample reached its peak value of q. At this stage, the axial load on the sample was increased and it was sheared under triaxial compression condition. For comparison purposes, the results of a drained triaxial compression test on a dense sample (e= 0.527) consolidated under a cell pressure of 60 psi are shown by dotted line curves in Fig.2.

Tests results show that the reversal of stresses from triaxial extension condition to triaxial compression does not have any appreciable influence on the strength of the sample in triaxial compression, for all states of packing of particles. Similar to triaxial compression-extension tests, the anisotropy induced during the extension stage has resulted in the alteration of the stress-strain characteristics during the compression stage.

UNDRAINED TRIAXIAL TESTS

In this section, results of typical undrained triaxial tests on isotropically consolidated samples of sand where the samples were subjected to stress reversal from triaxial compression to triaxial extension or vice versa are discussed. The undrained shear behaviour of the sand under triaxial compression and triaxial extension conditions has been presented elsewhere (Thurairajah and LeLievre 1971).

Undrained Triaxial Compression-Extension Tests

The results of an undrained triaxial compression-extension test on a dense sample (e= 0.517) consolidated under a cell pressure of 60 psi are shown by full line curves in Fig.3. The sample was first subjected to triaxial compression up to a conventional axial strain of 1.3%. At this stage the axial load on the sample was reduced and it was made to shear under triaxial extension condition. The dotted line curves in Fig.3 are the results of an undrained extension test on a dense sample (e=0.526) consolidated under a cell pressure of 60 psi. It is evident from this figure that stress reversal from triaxial compression condition to triaxial extension influences the stress path followed in triaxial extension at low q values. But, for large values of q the stress path lies very close to the yield surface (Thurairajah and LeLievre 1971) obtained from triaxial extension tests. The anisotropy induced during the compression stage is seen to have altered the stress-strain characteristics of the material during the extension stage.

The full line curves in Fig.4 are the results of an undrained triaxial compression-extension test on a loose sample (e=0.698) consolidated under a cell pressure of 60 psi. The sample was initially subjected to triaxial compression up to a conventional axial strain of 0.6% and then made to shear in triaxial extension. The dotted line curves in this figure are the results of an undrained extension test on a loose sample (e=0.688) consolidated under a cell pressure of 60 psi. The stress-strain characteristics are seen to be

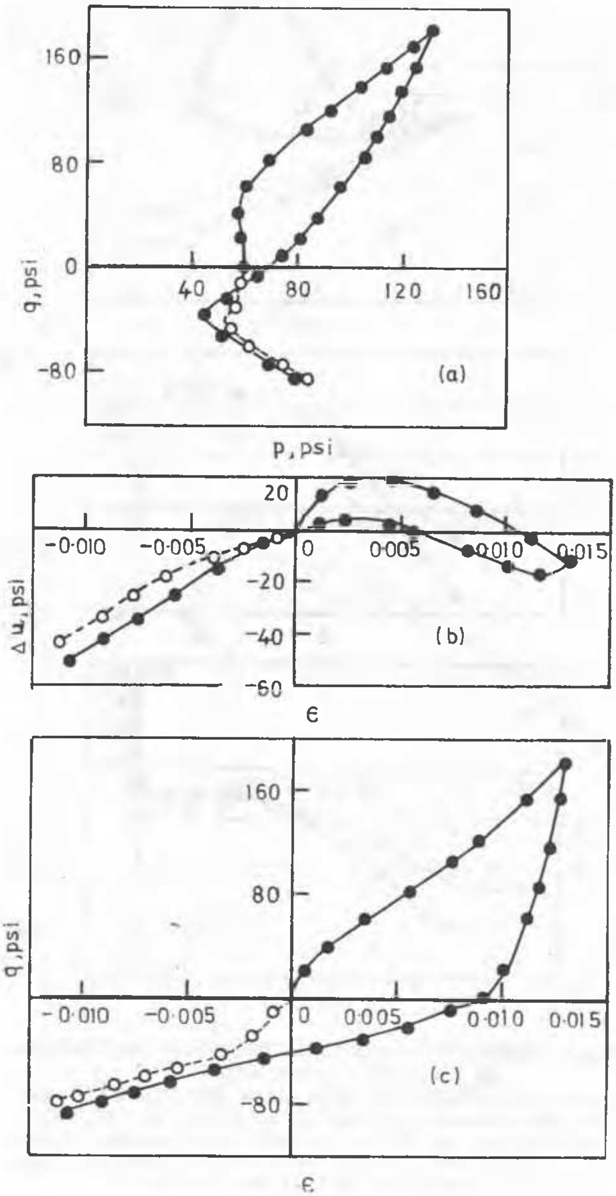

Fig.3 Undrained Triaxial Compression-Extension Test on Dense Sand.

affected by the stress reversal, similar to dense samples. It is also found that reversal of stresses from triaxial compression condition to triaxial extension has increased the positive pore water pressure developed during the triaxial extension stage showing that stress reversal decreases the resistance to liquefaction of sand (Finn, Bransby and Pickering 1970).

The results of an undrained triaxial compression-extension tests on a dense sample (e= 0.524) consolidated under a cell pressure of

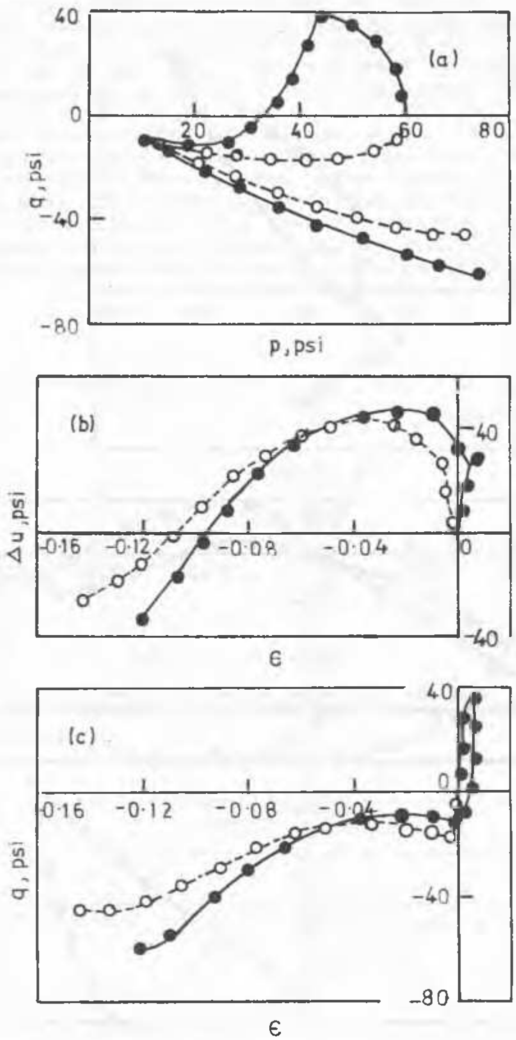

Fig.4 Undrained Triaxial Compression-Extension Test on Loose Sand

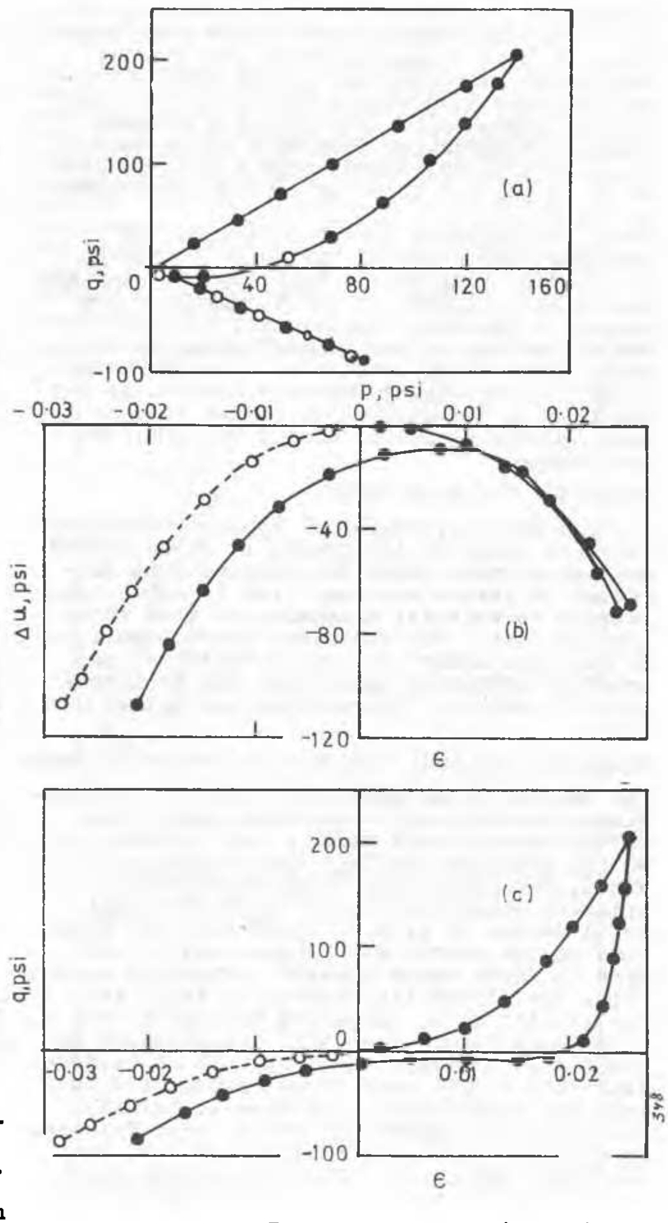

Fig.5.Undrained Triaxial Compression-Extension Test on Dense Sand

2 psi are shown by full line curves in Fig.5. The sample was initially sheared in triaxial compression up to a conventional axial strain of 2.5%.At this stage the axial load on the sample was reduced and it was made to shear in triaxial extension.The dotted line curves in Fig.5 are the results of an undrained extension test on a dense sample (e=0.516)also consolidated under a cell pressure of 2 psi Fig.5 (a) shows that the stress path followed by the sample subjected to a stress reversal from triaxial compression to triaxial extension lies on the limiting state surface (Thurairajah and LeLievre 1971) obtained from triaxial extension tests.

Undrained Triaxial Extension-Compression Tests

In Fig.6 the results of an undrained triaxial extension-compression test on a dense sample (e=0.520) consolidated under a cell pressure of 60 psi are shown by full line curves.The sample was initially sheared in triaxial extension up to a conventional axial strain of -0.3% and then in triaxial compression.The dotted line curves in Fig.6 and the results of an undrained triaxial compression test on a dense sample (e=0.526)also consolidated under a cell pressure of 60 psi.

The results of an undrained triaxial extension-compression test on a loose sample (e=0.664) consolidated under a cell pressure of 60 psi are shown by full line curves in Fig.7

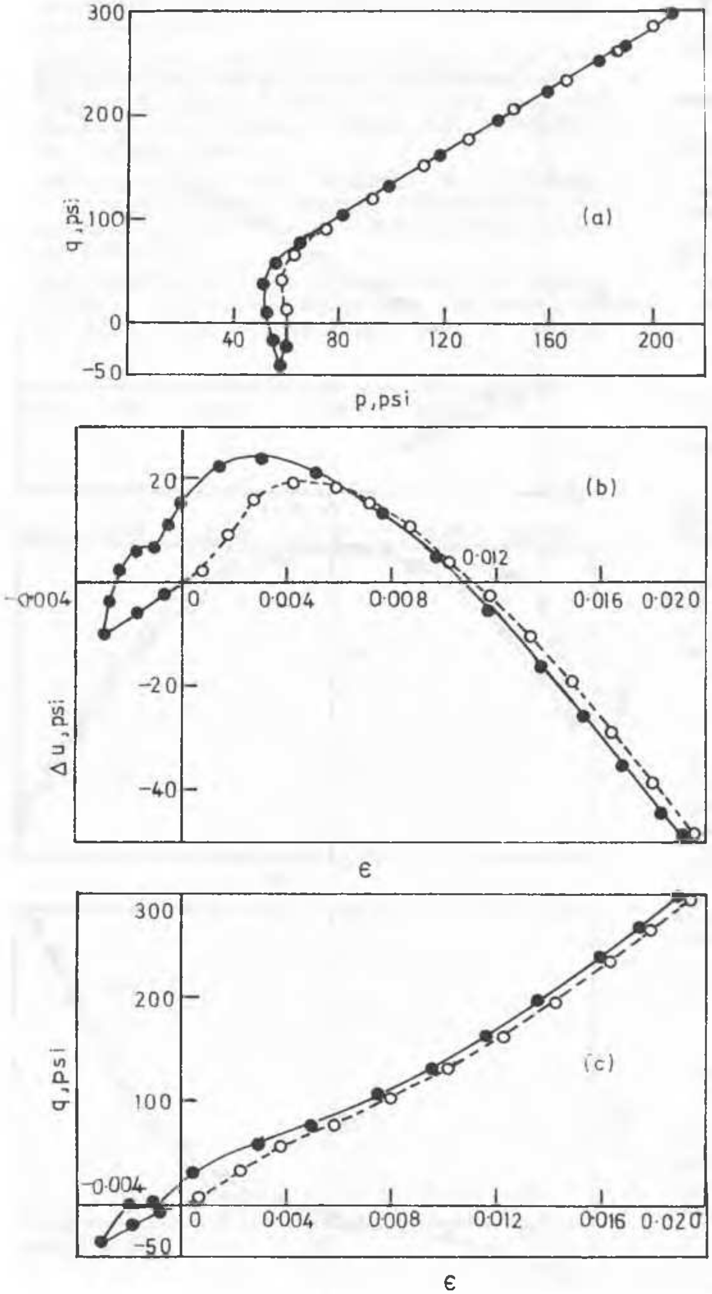

Fig.6 Undrained Triaxial Extension-Compression Test on Dense Sand

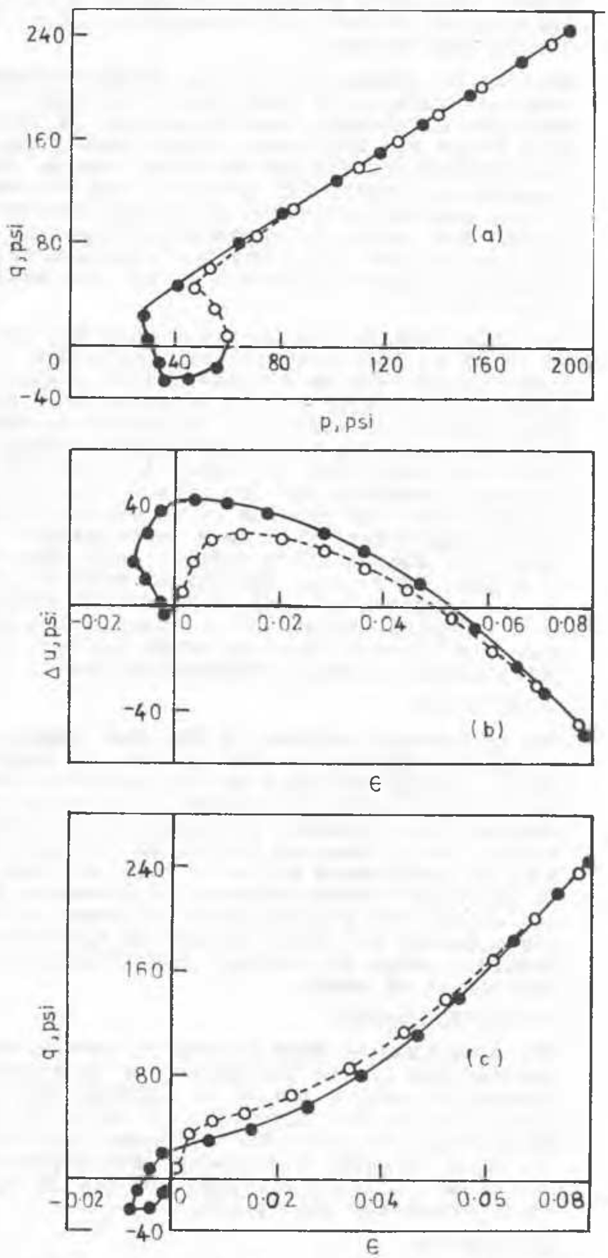

Fig.7 Undrained Triaxial Extension Compression Test on Loose Sand.

Here again the sample was first sheared in triaxial extension up to a conventional axial strain of -0.8% and then in triaxial compression. For comparison purposes, the results of an undrained compression test on a loose sample (e=0.669) consolidated under a cell pressure of 60 psi are presented in Fig.7 by dotted line curves.

Similar to undrained triaxial compression-extension tests, it is seen from Fig.6 and 7 that the anisotropy induced during the extension stage has influenced the stress-strain characteristics for the material during the compression stage. The stress paths followed by the samples, subjected to stress reversal, during the triaxial compression stage lie very close to the yield surface obtained from triaxial compression tests except for small values of q.

The full line curves in Fig.8 show the results of an undrained triaxial extension-compression test on a dense sample (e=0.524) consolidated under a cell pressure of 2 psi. This sample was initially subjected to triaxial extension up to a conventional axial strain of -2.3% and then made to shear in triaxial compression. The dotted line curves in Fig.8 are the results of an undrained triaxial compression test on a dense sample (e=0.525) consolidated under a cell pressure of 2 psi. Here again the stress path followed by the sample subjected to a stress reversal from triaxial extension to triaxial compression lies on the limiting state surface obtained from triaxial compression tests.

CONCLUSIONS

The anisotropy induced in the sand during a triaxial compression test alters the stress-strain characteristics of the material when the stress system is changed to triaxial extension from triaxial compression, or vice versa. During drained tests, the strength of sand is unaffected by the stress reversal. In undrained tests, reversal of stresses does not affect the stress paths followed by the tests, except for small values of q. Stress reversal seems to decrease the liquefaction resistance of sand.

ACKNOWLEDGEMENTS

The experimental work described herein was carried out in the University of Waterloo, Canada. The author wishes to express his gratitude to the University of Waterloo for sponsoring his visit, to Professor B.LeLievre for many valuable discussions and support, and to Mr.V.Shanmuganayagam for his assistance in preparing this paper.

REFERENCES

BARDEN,L.(1969), "A Quantitative Treatment of the Deformation Behaviour of Granular Material in Terms of Basic Particulate Mechanics,".Proc.Civil Engineering Materials Conf. Southampton, pp.599-612.

BISHOP,A.W., and GREEN,G.E.(1965), "The Influence of End Restraint on the Compression Strength of a Cohesionless Soil", Geotechnique vol.15, pp.243-266.

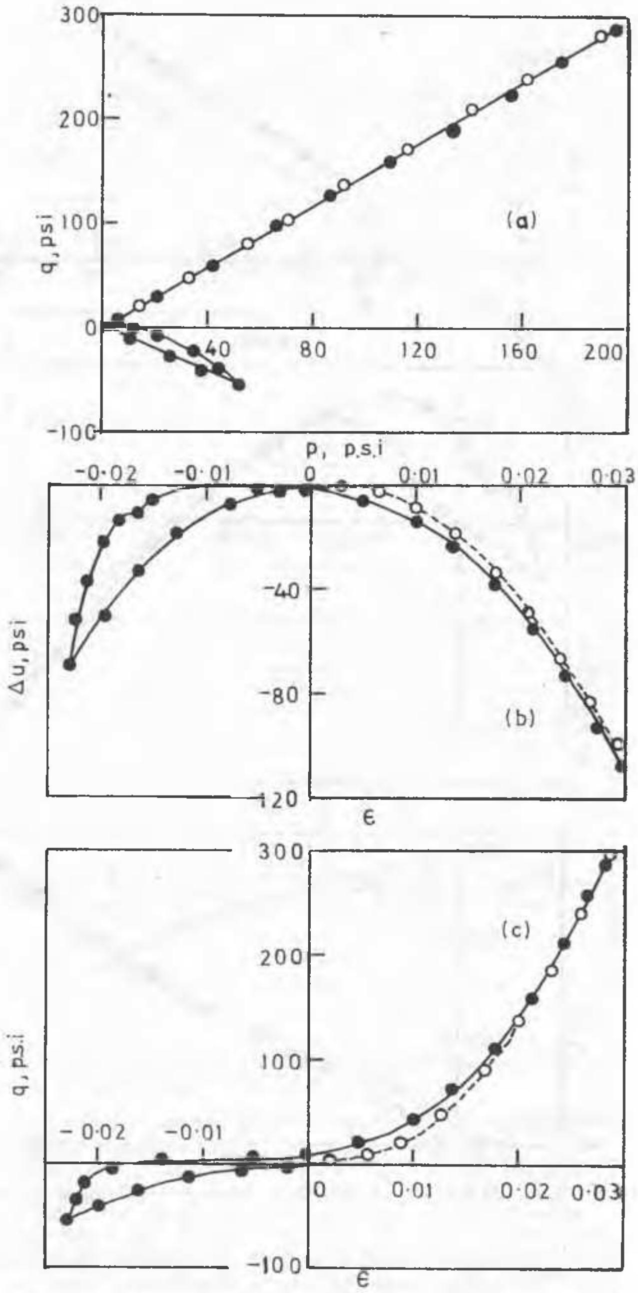

Fig.8. Undrained Triaxial Extension-Compression Test on Dense Sand.

FINN, W.D.L., BRANSBY, P.L., and PICKERING, D.J. (1970), "Effect of Strain History on Liquefaction of Sand," Journal of the Soil Mechanics and Foundation Division, ASCE, vol.96, pp.1917-1934.

LELIEVRE, B., and WANG, B. (1971), "Drained Shear Behaviour of a Clay Subjected to Stress Reversal", Proc. 4th Asian Regional Conf. on Soil Mech. & Found. Eng., Bangkok, vol.1, pp.37-42.

THURAIRAJAH, A., and LELIEVRE, B. (1971), "Undrained Shear Strength Characteristics of Sand", Geotechnical Engineering, vol.2, pp.101-117.

THURAIRAJAH, A., and SITHAMPARAPILLAI, V. (1972), "Drained Deformation Characteristics of Sand", Geotechnical Engineering, vol.3.