PORE PRESSURE BUILDUP IN INITIALLY SHEARED SAND SUBJECTED TO IRREGULAR EXCITATION

by

K. Ishihara[I] and H. Takatsu[II]

SYNOPSIS

Dynamic triaxial torsion shear tests were performed on saturated sand samples subjected initially to horizontal shear stress. Torsional loads with irregular time histories were applied to the samples either under conditions of lateral confinement or under constant lateral pressures. Also, irregular loads were applied either with their maximum peaks oriented towards or opposite to the direction of initial horizontal shear. The effects of these loading conditions on the pore pressure buildup characteristics of sand are discussed.

INTRODUCTION

A soil element beneath a slope is subjected to a horizontal shear stress as well as a deviator stress in geostatic conditions as shown in Fig.1. When dynamic shear stresses due to an earthquake are superimposed on the horizontal plane of the soil element below the water table, pore pressure may build up and liquefaction may occur. Therefore, stability analysis of slopes during earthquakes requires some knowledge of pore pressure buildup and liquefaction potential of initially sheared soils which are subjected to irregualr dynamic shear stresses. When the dynamic stress is cyclic with constant amplitudes, the resistance to liquefaction may be evaluated on the basis of triaxial or torsion shear test results (Lee and Seed, 1967; Yoshimi-Ohoka, 1975), irrespective of the orientation of initial shear. However, if the shear stress changes are erratic, the resistance to pore pressure buildup may be different depending upon whether the maximum spike in irregular loading is oriented towards the direction of initial shear or away from it. It was the objective of this investigation to study the effect of the orientations of these two shear stresses on the pore pressure buildup characteristics of sand.

TEST PERFORMANCE

The test equipment used in this study was the same as that used in a previous investigation (Ishihara and Yasuda, 1975). Hollow cylindrical specimens 7cm high, 10cm and 6cm in outer and inner diameters, respectively, were enclosed in a triaxial chamber and consolidated under a vertical stress ($\sigma_v' = 1\ \mathrm{kg/cm^2}$) and a horizontal stress ($\sigma_h' = 0.5\ \mathrm{kg/cm^2}$) producing an anisotropic state of consolidation with $K_0 = 0.5$. An initial torsional shear stress, τ_0, was also applied under drained conditions. Then, irregular time histories of torsional shear stress having the same wave form as the acceleration records taken at the time of the Niigata (1964) and Tokachioki (1968) earthquakes but with varying amplitudes were applied to the samples under undrained conditions. The time histories used resemble what was referred to as shock type loading (Ishihara-Yasuda, 1975). During dynamic loading, two kinds of control over the static stress system were employed as follows (Ishihara-Li, 1972).

[I] Associate Professor of Civil Engineering, University of Tokyo, Bunkyo-ku, Tokyo, Japan.

[II] Graduate Student of Civil Engineering, University of Tokyo, Bunkyo-ku, Tokyo, Japan.

(a) ACOT-tests ---- The entry of water into the cell is inhibited and the change in cell pressure is monitored. Since the vertical loading piston is designed so that its cross sectional area is exactly the same as that of the specimen, the sample can be twisted without producing lateral displacement. This type of stress control may simulate the behavior of a soil element lacated far away from a sloping surface (B. in Fig.1).

(b) ACT-tests ---- The cell pressure is kept unchanged and the sample is free to deform in the lateral direction, accompanied by vertical displacement. This state of stress is considered to simulate the behavior of a soil element located near the sloping surface (A. in Fig.1).

All tests were performed using a fine sand secured from the Fuji river bed near Tokyo in Japan. The mean diameter and uniformity coefficient were 0.40mm and 3.2, respectively. The maximum and minimum void ratios were 1.03 and 0.48, respectively.

TEST RESULTS AND DISCUSSIONS

Fig.2 shows typical records of shear stresses, shear strains, and pore pressures that were obtained in ACOT-tests in which the maximum stress ratio, τ_{max} / σ_v', was 0.35 and the initial stress ratio, τ_0 / σ_v' was 0.20, where τ_{max} denotes the maximum stress through a given time history of torsional shear stress. Fig.2(a) refers to the test record where the initial stress is oriented in the direction in which the maximum stress occurs, whereas the result of tests where the initial and maximum stresses are oppositely directed are shown in Fig.2(b). It is seen that the behavior of the samples is different between these two cases even though all other test conditions were the same except for the directions of the two shear stresses. After the passage of the maximum shear stress, the developed pore pressures remained almost the same and these values, termed the residual pore pressure, u_r, were read off and plotted in Fig.4(a) versus the maximum stress ratio, τ_{max}/σ_v', together with all the other data from tests with the same time history (NS-component, Niigata earthquake). Similar plots are also shown in Fig.4(b),(c), for other time histories used in this investigation. The figures generally show that, in the range of smaller maximum shear stress ratios, residual pore pressures are larger for cases where the direction of maximum shear stress coincides with that of initial shear stress than for the case when the maximum shear stress is oriented away. However, this tendency is reversed as the maximum shear stress ratio increases. It is also shown that, for a specified condition of stress application, there is an upper bound for the residual pore pressure beyond which it never exceeds for any further increase in the maximum shear stress ratio. These limiting pore pressures, denoted by u_{rl}, are plotted collectively in Fig.6.

Typical results of ACT-tests are presented in Fig.3 in which two sets of records were compared to each other: one with the initial and maximum shear stresses oriented in the same direction and the other with stresses oriented oppositely. In the same way as with ACOT-test results, the residual pore pressures at the end of dynamic tests were read off and plotted in Fig.5 against the maximum stress ratios. It is shown from Fig.5 that, in ACT-tests, the limiting residual pore pressures are generally much smaller than those in ACOT-tests shown in Fig.4. However, the reversal of the direction of the maximum shear stress with respect to that of the initial shear stress still affects the pore pressure buildup, although to a lesser degree, with the result that samples with the two shear stresses oriented in the same direction develop larger residual pore pressures than do samples with the two shear stresses oriented in opposite directions in the small range of τ_{max} / σ_v'. Test results also showed that the samples deformed vertically as well as horizontally while sheared in the torsional mode.

The limiting residual pore pressures as read off from Fig.5 are further plotted in Fig.6 versus the initial shear stress ratio. In Fig.6, results of additional torsion tests employing the initial shear stress ratios $\tau_0/\sigma_v' = 0.1$ and 0.25 are also presented. Fig.6 indicates that the limiting residual pore pressures are always greater for ACOT-tests than for ACT-tests, and decrease as the initial shear stress is increased. It is also seen that the application of the dynamic shear in a direction so that its maximum is oriented towards the direction of the initial shear yields smaller limiting residual pore pressures than does the application of the dynamic shear oriented in the opposite direction. In this study, three kinds of shock-type stress time histories were used. The limiting observed residual pore pressures did not change significantly even when the stress time history used for the tests was changed from one pattern to another as long as the wave form could be classified as being of the shock-type according to the rule proposed previously (Ishihara-Yasuda, 1975).

CONCLUSIONS

Several series of torsional shear tests on saturated sand subjected to initial shear disclosed that when an irregular torsion shear stress is applied with its maximum peak oriented to the same direction as the initial shear, the samples exhibited more resistance to pore pressure buildup than when the irregular load was applied in the opposite direction. It was also shown that an increase in initial shear stress tends to make sand samples more resistant to pore pressure buildup. Moreover, failure accompanying large shear strains generally occurs in initially sheared samples before pore pressures develop fully to become equal to the initial confining pressure (liquefaction). It was further discovered that lateral confinement of samples during torsional loading causes much more pore pressure development than for samples without lateral confinement.

REFERENCES

Ishihara, K. and Li, Sang-Il (1972) : "Liquefaction of Saturated Sand in Triaxial Torsion Shear Test", Soils and Foundations, Vol.12, No.3, pp.19-39

Ishihara, K. and Yasuda, S. (1975) : "Sand Liquefaction in Hollow Cylinder Torsion under Irregular Excitation", Soils and Foundations, Vol.15, No.1, pp.45-59

Lee, K.L. and Seed H.B. (1967) : "Dynamic Strength of Anisotropically Consolidated Sand", Proc. ASCE, SM5, pp.169-190

Yoshimi, Y. and Oh-oka, H. (1975) : "Influence of Degree of Shear Stress Reversal on the Liquefaction Potential of Saturated Sand", Soils and Foundations, Vol.15, No.3, pp.27-40

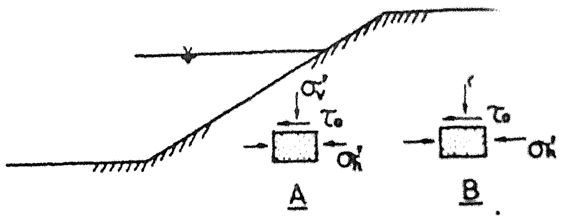


Fig.1 Initially Sheared soil element beneath a slope

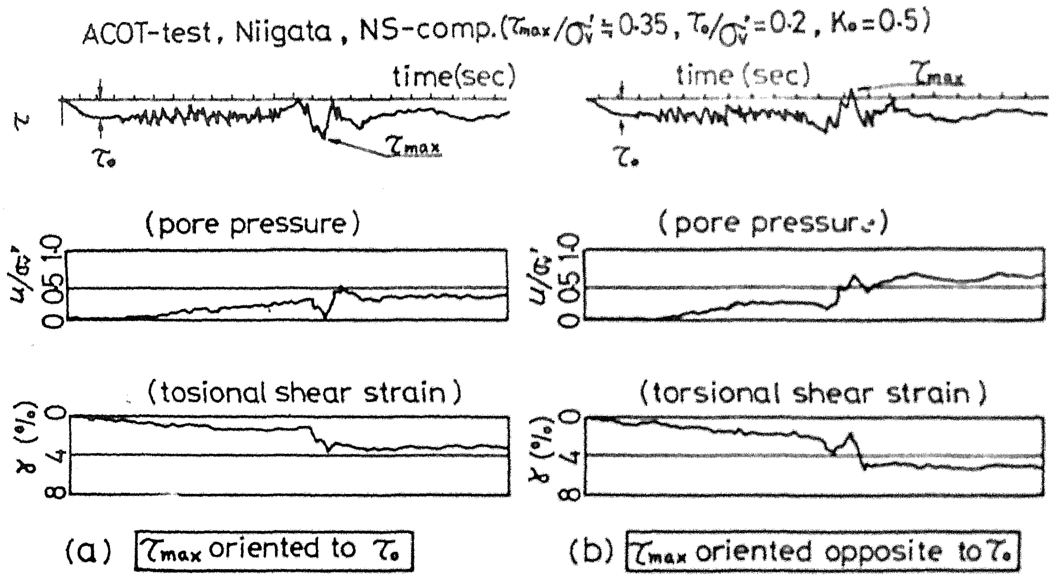


Fig.2 Comparison of torsion test results when mutual orientations of the maximum and initial shear stresses are changed

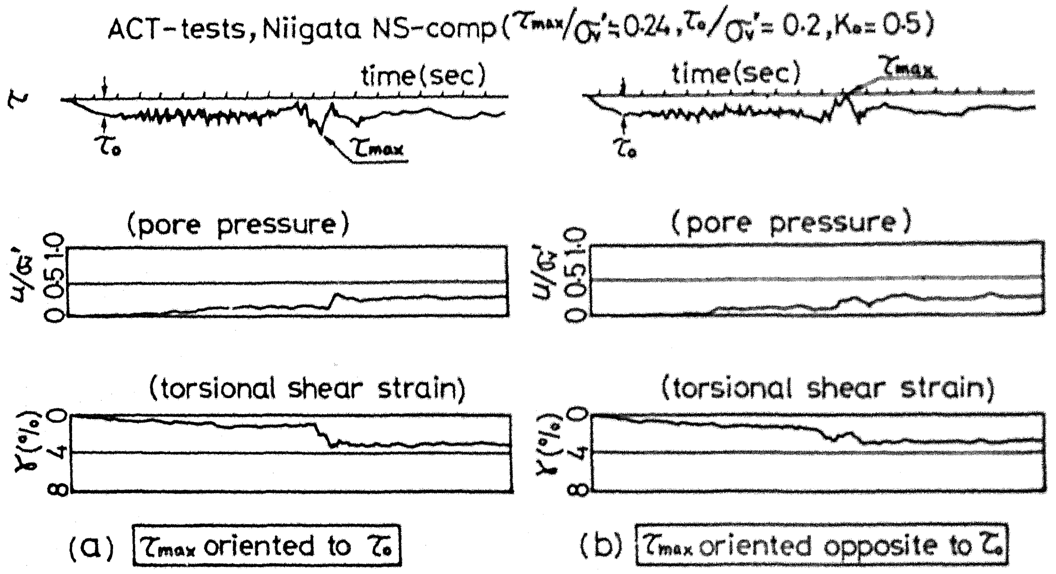
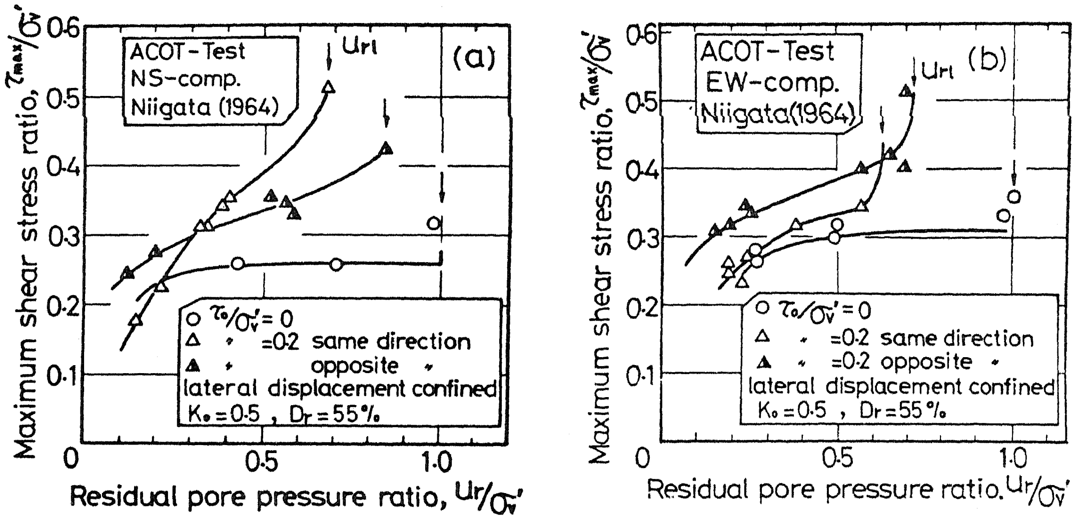


Fig.3 Comparison of torsion test results when mutual orientations of the maximum and initial shear stresses are changed



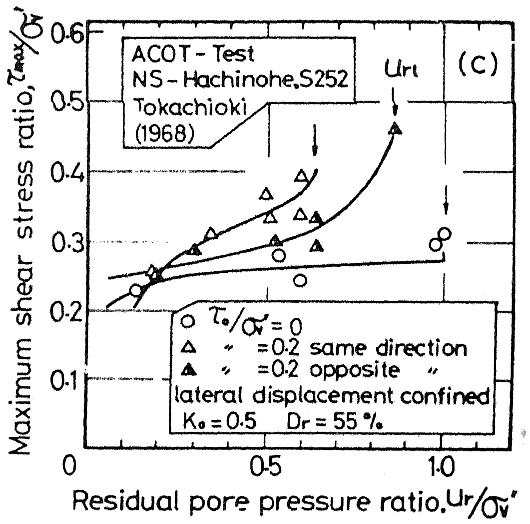


Fig.4 Relationship between the stress ratio and the residual pore pressure ratio (ACOT-tests)

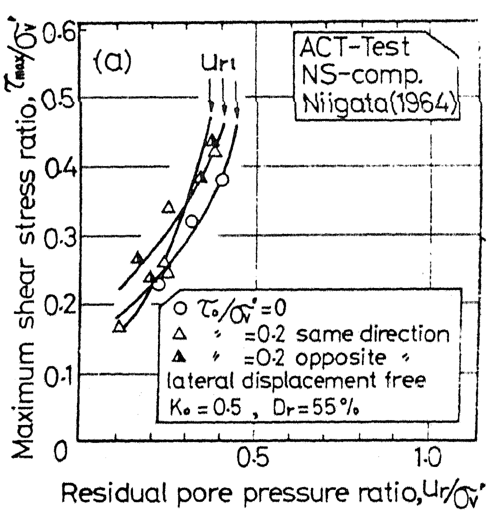


Fig.5 Relationship between the stress ratio and the residual pore pressure ratio (ACT-tests)

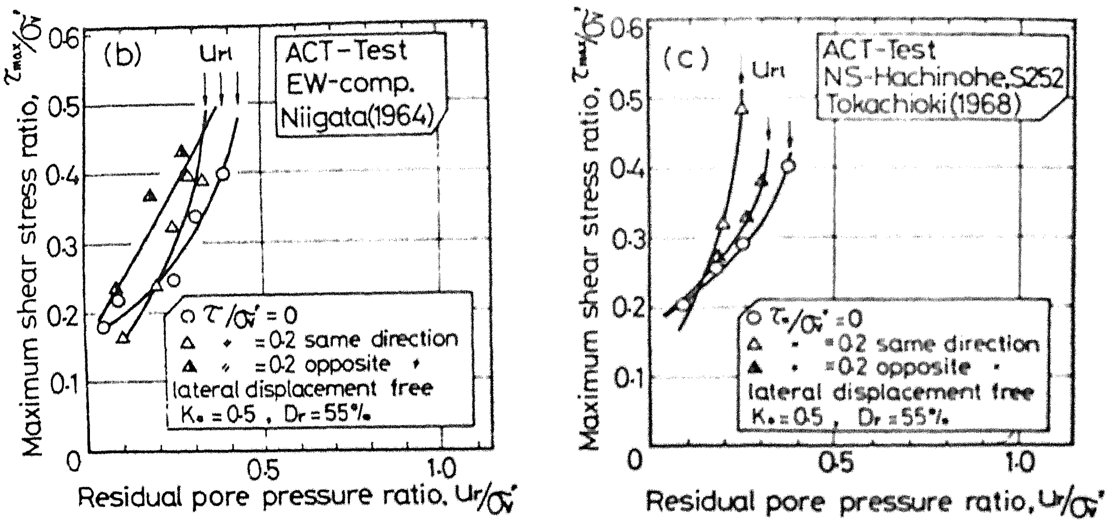


Fig.5 Relationship between the stress ratio and the residual pore pressure ratio (ACT-tests)

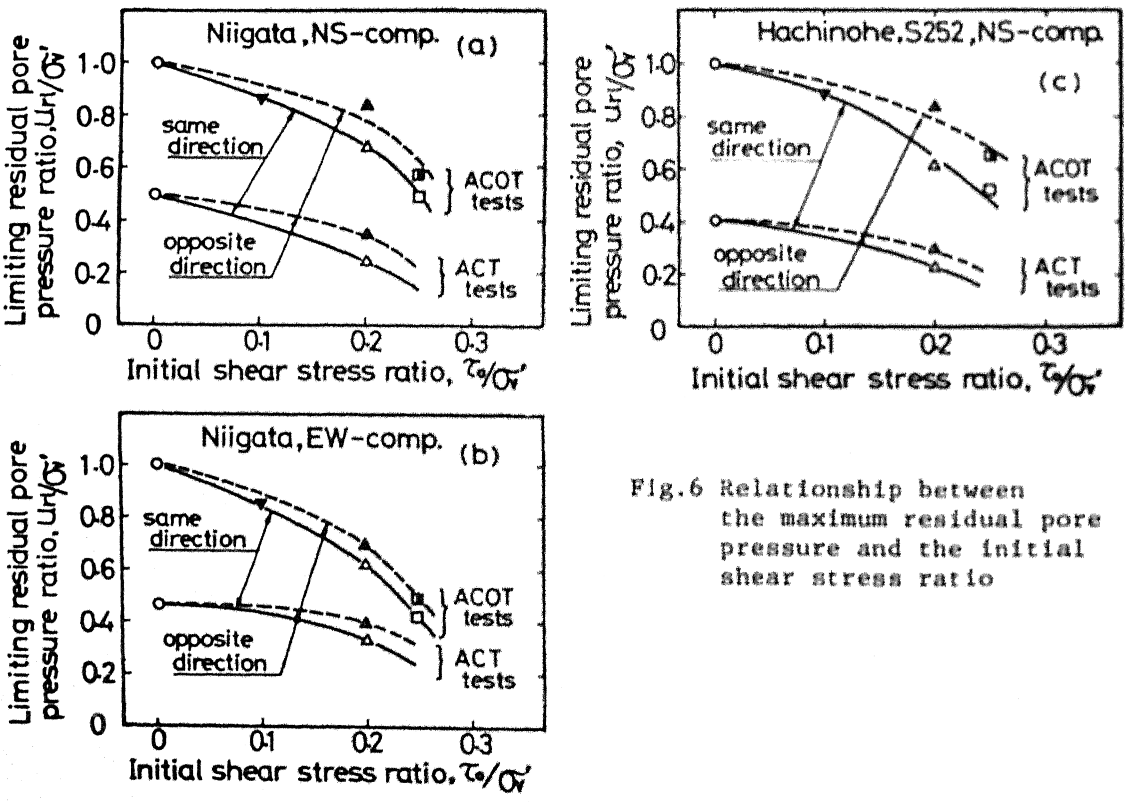


Fig.6 Relationship between the maximum residual pore pressure and the initial shear stress ratio