LIQUEFACTION TEST UNDER A PARTIAL DRAINAGE CONDITION AND ITS APPLICATION

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SYNOPSIS

A liquefaction test method has been developed to evaluate liquefaction resistances under partially drained conditions. Effects of drainage conditions and frequencies on liquefaction are evaluated by conducting several series of liquefaction tests under different conditions of drainage including a perfectly undrained condition. It is found that the strength increase due to partial drainage can be well represented by a non-dimensional parameter consisting of frequency, permeability and length of drainage path.

INTRODUCTION

A conventional type of liquefaction test based on dynamic shear apparatuses is usually performed under a perfectly undrained condition(1). Foundation subsoils for harbor and ocean structures are completely submerged and usually located at a relatively shallow depth. In such cases, some degree of drainage effect on liquefaction resistances may be taken into account in evaluating liquefaction potentials. In the present paper, the test method and procedures to evaluate such effects are first described and test results are presented so as to estimate the liquefaction resistances in the field with different conditions of drainage.

THE METHOD TO CONTROL THE DRAINAGE CONDITION

The real drainage system during an earthquake may be governed by the length of drainage path, L and the permeability, k of the seismically endangered layer, and further influenced by the rate of the cyclic loading, f.

Consider a soil element in the ground shown in Fig.1. It is assumed that the dissipation of the excess pore water pressure induced by an earthquake will occur according to Darcy's law, namely

$$v = ki = k(H/L) = (k/L)H = \alpha H \tag{1}$$

$$\alpha = k/L \tag{2}$$

, where v: velocity, H: head due to the excess pore water pressure induced, L: length of drainage path, and i: hydraulic gradient. The relation between H and v is linear for a given value of k/L.

To simulate the actual drainage condition in the dynamic triaxial test an equivalent drainage system may be established as follows: The drainage control circuit consists of a drainage control valve with micro-meter and a burette with the area of A_b as shown in Fig.2. The calibration of the drainage control valve can be performed by measuring the quantity of water,

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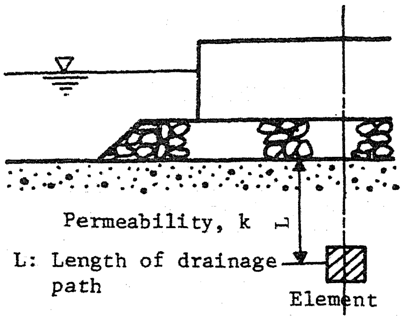


Fig.1 Drainage Condition in The Ground

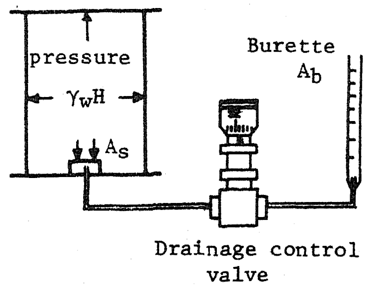


Fig.2 Schematic Drawing of The Partial Drainage System

$q = v_b x A_b$ flowing in the burette with the area of A_b under the applied water pressure, $\gamma_w H$ in the triaxial cell, determining the velocity, v_b for the pressure head, H, then fitting it with the v-H relations obtained in the constant head permeability test for various values of k/L. The value of α determined by using the velocity v_b is indicated by α_b and the α corrected by the area of the specimen to be used is indicated by α_s, which is equal to $A_b/A_s x \alpha_b$.

TEST PROCEDURES

Using the dynamic triaxial apparatus, which is described elsewhere(2), each series of repeated loading tests was conducted either under a perfectly undrained condition or under different conditions of drainage. Testing conditions used are following; for perfectly undrained conditions, a series of liquefaction tests were conducted under the constant confining pressure, σ_c=100kN/m^2 and the frequency of f=1Hz. On the other hand, for partially drained conditions, 6 series of liquefaction tests were conducted under σ_c=100kN/m^2 and different combinations of the f from 1 to 5 Hz and the α_b from 2.5x10^{-5} to 3.85x10^{-4} sec^{-1}.

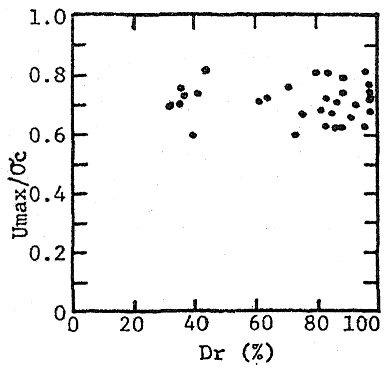


Fig.3 u_{max}/σ_c versus D_r in Perfectly Undrained Conditions

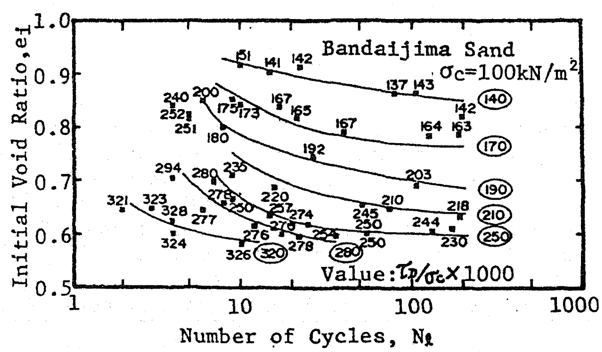


Fig.4 Relations between The Void Ratio, e_i and The Number of Cycles, N_l for The τ_d/σ_c in Undrained Conditions

The sample is Bandaijima sand taken from Niigata, where severe disasters were caused by liquefaction of saturated sands in Niigata Earthquake, 1964. The physical properties of Bandaijima sand is e_{max}=1.007, e_{min}=0.510, G_s=2.671, D_{10}=0.25mm, D_{60}=0.48mm and coefficient of uniformity, U_c=1.9.

TEST RESULTS AND DISCUSSION

e_i-N_1-τ_d/σ_c Relations for Perfectly Undrained Conditions

The liquefaction tests under a perfectly undrained condition were conducted on the basis of the conventional method, in which the number of repetition corresponding to a sudden increase of axial strain was adopted as the failure criterion. The pore water pressure ratio, u_{max}/σ_c corresponding to the initial liquefaction is shown in Fig.3.

Fig.4 shows the relations between the initial void ratio, e_i and the number of repetition, N_1 to cause liquefaction for the stress ratio, τ_d/σ_c indicated by multiplying 1000. It is noted that liquefaction resistances are neither influenced by the permeability of the sample nor by the frequency of the cyclic loading for perfectly undrained conditions.

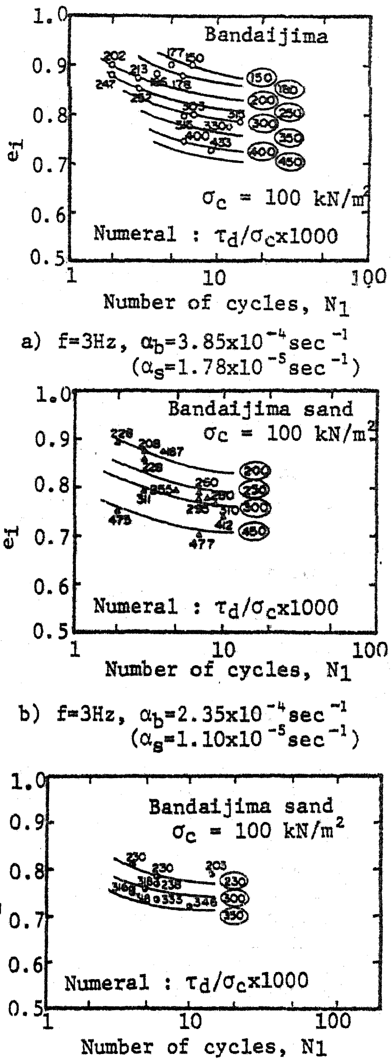
e_i-N_1-τ_d/σ_c Relations for Partially Drained Conditions

Since it is found difficult in some cases to use the same criterion as that for perfectly undrained conditions, the number of repetitions corresponding to u_{max}/σ_c=0.80 is adopted as the failure criterion for partially drained conditions. This means that the upper limit of of u_{max}/σ_c for perfectly undrained conditions as shown in Fig.3 has been adopted as the failure criterion. Fig.5 shows the relations between the void ratio and the number of repetitions to cause initial liquefaction for τ_d/σ_c indicated by multiplying 1000 for three different conditions.

Liquefaction Resistances for N_1=10

The stress ratio, τ_d/σ_c required to cause initial liquefaction at N_1=10 can be obtained for each condition of drainage from Fig.4 and Fig.5.

Fig.6 shows the relation between the stress ratio τ_d/σ_c to cause initial liquefaction at N_1=10 and the relative density for various conditions of drainage and frequency. It can be seen from Fig.6 that the τ_d/σ_c for N_1=10 increases as the α_b



a) f=3Hz, α_b=3.85x10^{-4}sec^{-1} (α_s=1.78x10^{-5}sec^{-1})

b) f=3Hz, α_b=2.35x10^{-4}sec^{-1} (α_s=1.10x10^{-5}sec^{-1})

c) f=5Hz, α_b=3.85x10^{-4}sec^{-1} (α_s=1.78x10^{-5}sec^{-1})

Fig.5 Relations between e_i and N_1 for Given Values of τ_d/σ_c in Partially Drained Conditions increases with the f unchanged and it decreases as the f increases with the α_b unchanged. In addition the effect of drainage and frequency is remarkable in a relatively denser state and not so significant in a looser state.

Comparisons between The Undrained and Partially Drained Liquefaction Resistances

In case of partially drained conditions, both the permeability and the frequency are important factors affecting liquefaction resistances. The strength increase due to partial drainage has been examined and expressed in terms of the non-dimensional parameter $\bar{\alpha} = \alpha_s/f = k/(fL)$ for different relative densities as shown in Fig.7, in which $(\tau_d/\sigma_c)_p$ indicates the stress ratio causing liquefaction in 10 cycles for partially drained conditions and $(\tau_d/\sigma_c)_u$ indicates that for undrained conditions.

Fig.7 may be used to evaluate the effects of drainage and frequency on the liquefaction resistances in the field. In this case, the undrained strength can be considered to express a kind of index property in evaluating liquefaction potentials.

CONCLUSIONS

The method to evaluate the effects of partially drained conditions on liquefaction resistances has been investigated. It is clarified that the liquefaction resistances in partially drained conditions depend largely on the permeability, k and length of drainage path, L and frequency, f of the repeated loading. The strength increase due to partial drainage can be evaluated in terms of the non-dimensional parameter, $\bar{\alpha}=k/fL$.

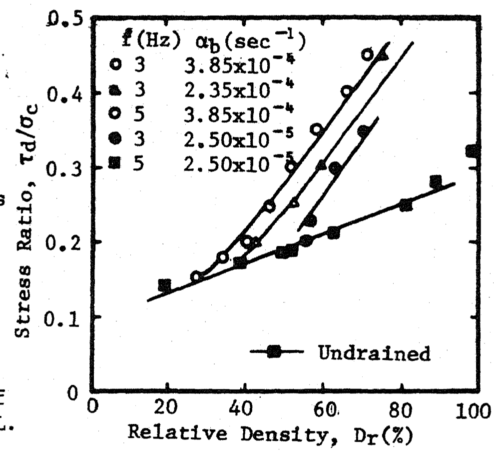


Fig.6 τ_d/σ_c Causing Liquefaction in 10 Cycles versus D_r for Various Conditions of f and α_b

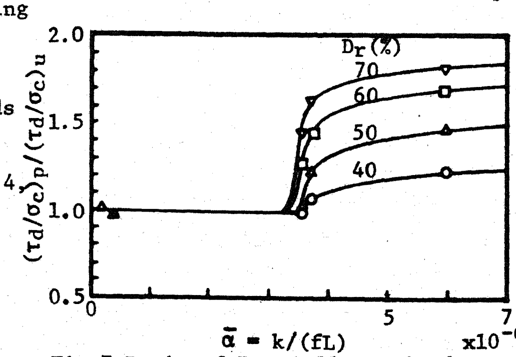


Fig.7 Ratio of Partially Drained Strength to Undrained Strength versus k/(fL)

REFERENCES

(1) H.B.Seed and K.L.Lee, "Liquefaction of Saturated Sands during Cyclic Loading", ASCE, Vol.92, No. SM6, November, 1966.

(2) Y.Umehara, K.Zen and K.Hamada, "Liquefaction of Saturated Sands in Dynamic Triaxial Tests", Report of the Port and Harbor Research Institute, Vol.15, No.4, December, 1976.