EFFECT OF ANISOTROPIC CONSOLIDATION ON LIQUEFACTION

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SYNOPSIS

It has become an established fact that the presence of initial shear stresses on soil elements and deposits have great influence on their static and dynamic behaviour, as well as the resistance to liquefaction and pore pressure generation in the case of saturated sands.

This investigation was carried out to determine the behaviour of saturated sand samples, consolidated anisotropically, under dynamic loads. A series of stress controlled cyclic triaxial tests, under undrained conditions, have been performed on sand samples consolidated under a range of different principal stress ratios. The anisotropic consolidation ratios were chosen as such to reflect and simulate the insitu stress conditions, and the generation of pore pressure with increasing numberoof cycles were determined under repeated loading. The concept of "liquefaction" was re-examined in light of the experimental results, and certain conclusions were reached regarding the pore pressure generation of saturated sands during earthquakes.

It is believed that scientific progress should be for the improvement of realistic assessments, taking into consideration every aspect of natural insitu conditions.

"Nature does not reveal all her secrets at once" Seneca

INTRODUCTION

Numerous research and investigation has been undertaken, in order to assess the dynamic behaviour and liquefaction characteristics of sands under initial stress conditions (Ref.1-11). But, even at present, certain contradictions in view-points still exist.

Regarding the controversies over the term of "liquefaction", even when applied to isotropically consolidated samples, whether a saturated sand sample with D_r = 70 % "liquefies with limited strain potential" (9) or whether "it is normally considered impossible for cyclic pore pressures to approach or equal the confining pressure" (1) is yet another concept to be clarified when applying the term of "initial liquefaction" to anisotropically consolidated samples (3,8).

Considering the statements made in the past five years, a wide spectrum of ideas may be observed:

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"In general, the presence of initial shear stresses tends to reduce the rate of pore pressure generation due to cyclic stress applications", as well as "direct experimental evidence shows the large effects of K_o on the stress ratios to cause initial liquefaction".(9) H.B.Seed (1976).

"The specimens having a K_o value less than unity exhibited a smaller resistance to liquefaction than specimens consolidated isotropically. Conversely, a greater resistance was mobilized in the specimens consolidated with a K_o value larger than unity". (5) K.Ishihara et.al. (1977).

"Smaller additional loads are required to cause liquefaction as K_c (σ_1/σ_3 ratio) increases, at constant void ratio and σ_3'c. When K_c is large a soil is more unstable and may, in the extreme be susceptible to " "spontaneous" liquefaction" (2).

Both Finn et.al. (4) and Prater (7,8), as well as Wenshao (11) through his entirely independent findings, have shown experimentally the effect of initial stress conditions, on samples under anisotropic consolidation conditions and a generalized conclusion of:

"for consolidation ratios

$$K_c = \frac{\sigma_{1c}}{\sigma_{3c}} > 1.0 ,$$

a greater resistance to liquefaction is developed", may be reached.

A.Casagrande (1976) had also stated that, "in general, the test specimens should be preconsolidated to a principal stress ratio of 2.0"(1).

ANISOTROPIC CONSOLIDATION

The most important factor is the assessment of a realistic and valid relationship between the stress conditions in the field and the conditions created in laboratory experimentation. In the light of the above-mentioned statements and previous experience, for the "realistic" determination of liquefaction behaviour and the in situ p.w.p. generation of normally consolidated deposits, it is assumed suitable to make dynamic triaxial testing on samples consolidated anisotropically, with principal stress ratios $K_c \geqslant 1.5$.

Evidently, the relationships become:

$\sigma_m' = \sigma_{1c} = \sigma_{3c}$ for isotropic consolidation

$\sigma_m' = (1+2K_o)/3(\sigma_{1c}) = (1+2K_c)/3.(\sigma_{3c})$ for anisotropic consolidation

and

$$\left(\frac{\tau}{\sigma_{1c}.(1+2K_o)/3}\right)_A = \left(\frac{\tau}{\sigma_{3c}(1+2K_c)/3}\right)_A = \left(\frac{\tau}{\sigma_1}\right)_I$$

It is also believed by the author that, for the realistic identification of the condition named "liquefaction", the generation of pore pressures (Δu) during cyclic loading should be related to the mean effective confining pressure (σ_m') since dynamic behaviour and in situ strength properties.

CYCLIC TRIAXIAL TESTS AND EXPERIMENTAL RESULTS

Stress controlled cyclic triaxial tests were carried out on saturated quartz sand (Podima) samples, 5.0 cm. in diameter and 10.0 cm. in height. Sand samples were placed by dry pouring, in five homogenous layers, in the loose state. Saturation was provided by slow water rise from bottom of specimen under incremental pressures. Drainage from top and bottom of specimen was used and after anisotropic consolidation was completed and full saturation ensured. (usually with back pressure $u_b = 3.0$ kg/c^2), undrained cyclic triaxial tests were carried out (at f = 1c/sec.) with pore water pressure measurements from bottom of the sample.

Results of cyclic triaxial tests and effect of anisotropic consolidation on liquefaction and/or cyclic strength deterioration (softening) is shown in Fig.1. Points along these strength curves show the dynamic stress ratios causing initial liquefaction ($\Delta u_{max} = \sigma_m'$ for isotropic consolidation) and a predatermined strain level (peakto peak ε_1= 10 %) and/or commencement of softening (N_m) for anisotropic consolidation to be reached after a corresponding number of cycles of stress repetitions.

In Figure 2, the "p-q" diagrams obtained from cyclic triaxial tests for saturated sand samples under initial isotropic and anisotropic consolidation condition are given. Test results have shown that, for loose isotropically consolidated samples the pore water pressure's rise up to the effective confining pressure causing initial liquefaction ($\Delta u_{maks}=\sigma_m'$), but for anisotropically consolidated samples under cyclic loading, the pore water pressure generation may be expressed (Fig.2) in the form,

$$\frac{\Delta u_{max}}{\sigma_m'} = 1 - \frac{3(K_c - 1)}{(1+2K_c)} \cdot \frac{1}{M} \qquad \text{Eq. (1)}$$

for $K_c > 1.5$; where $M = \dfrac{6 \sin \phi'}{3-\sin \phi'}$

A similar build-up, signifying failure of contractive sands, has also been suggested by Prater (8). The effect of K_c on maximum pore water pressure (Δu_{max}) generation is given in Figure 3, and a typical test result is shown Figure 4.

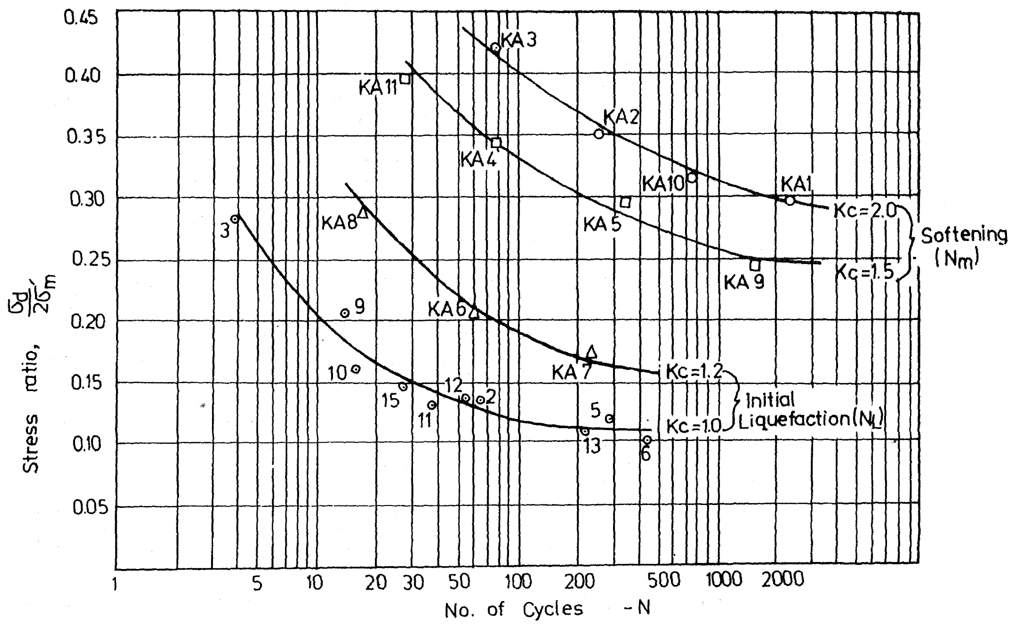

FIGURE. 1. EFFECT OF ANIZOTROPIC CONSOLIDATION ON LIQUEFACTION AND CYCLIC STRENGTH DETERIORATION (SOFTENING)-(3)

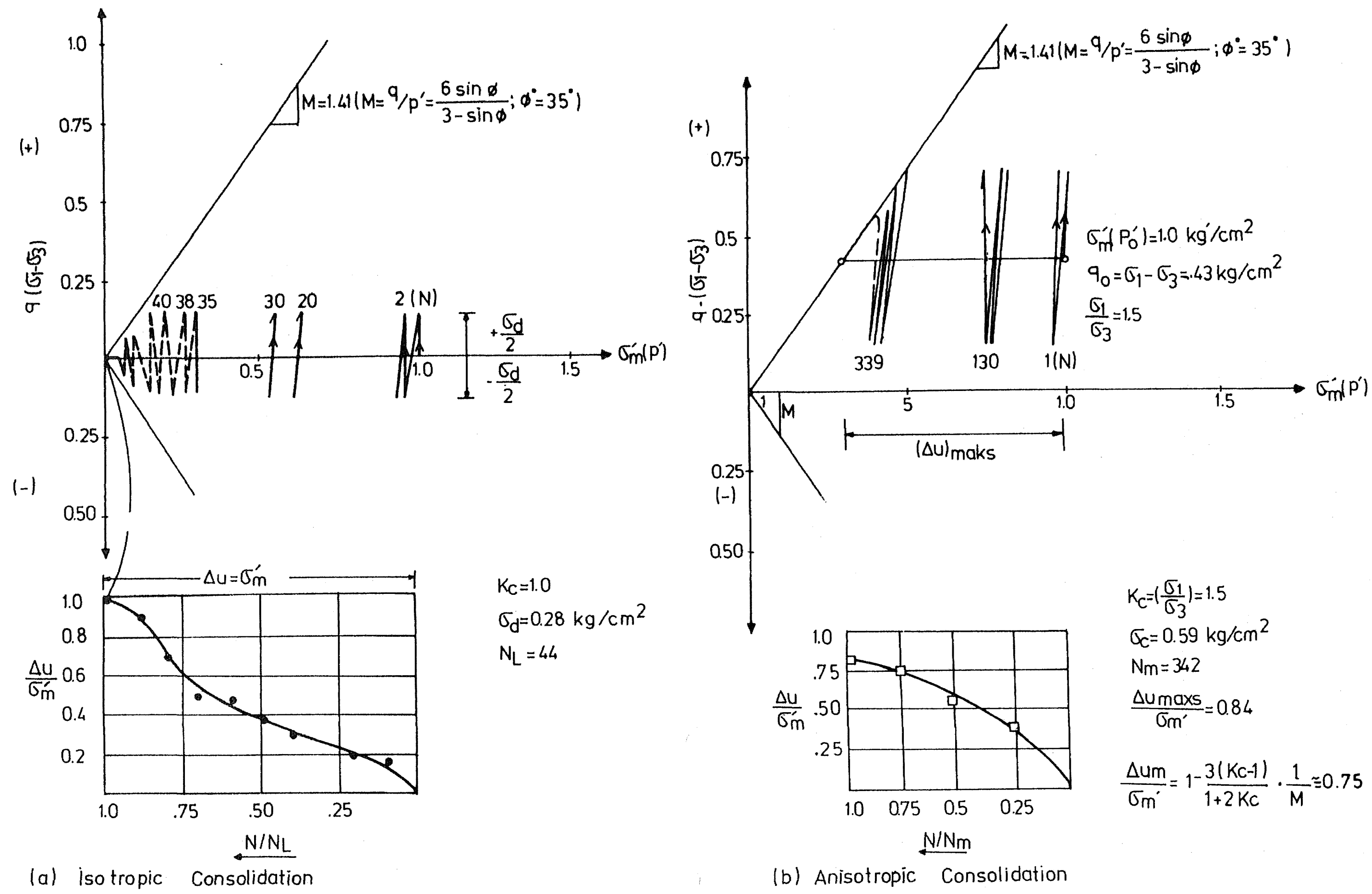

FIGURE. 2. THE 'P-q" DIAGRAMS AND P.W.P BUILDUP FOR ISOTROPIC AND ANISOTROPIC CONSOLIDATION (3)

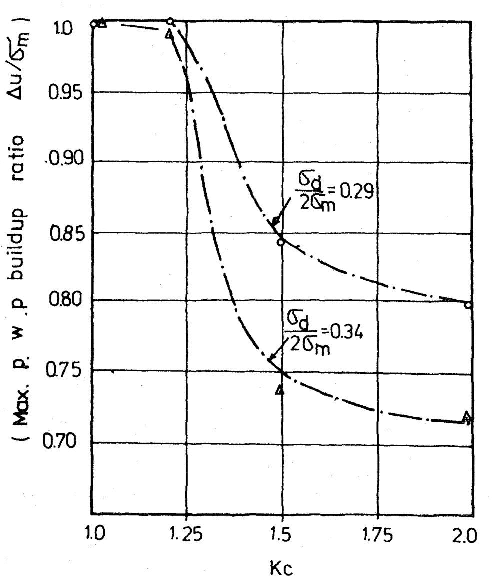

FIG. 3 . EFFECT OF Kc ON MAXIMUM P.W.P BUILDUP (3)

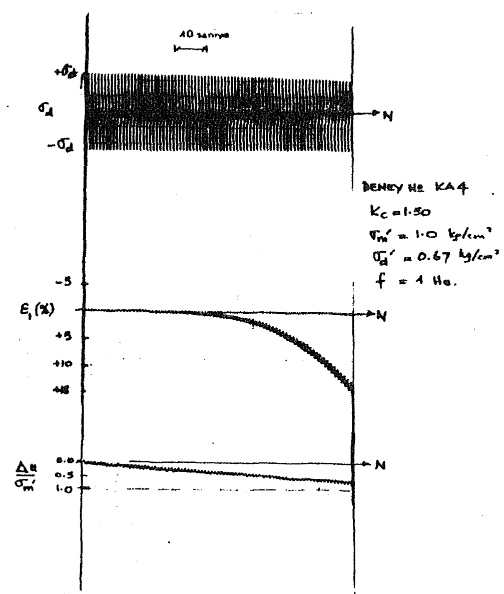

FIG. 4 . A TYPICAL DYNAMIC 3-AXI TEST RESULT, WITH Kc =1.5 .(3)

CONCLUSIONS

The generation of pore water pressures in sands under anisotropic consolidation or with in situ initial shear stresses, is a complex phenomenon and requires further theoretical and experimental research. This experimental research has indicated the necessity of a thorough investigation of the following factors:

(1) Anisotropical consolidation conditions, inducing certain type of structural anisotropy, produces a more stable soil structure (in comparison with isotropical consolidation under the same σ_m'), and anisotropically consolidated specimens are more liquefaction resistant.

(2) Initial liquéfaction ($\Delta u_{max} = \sigma_m'$) is not observed on anisotropically consolidated samples ($K_c \geqslant 1.5$) and maximum pore water pressure build up may be expressed in the generalized form,

$$\frac{\Delta u_{max}}{\sigma_m'} = 1 - c. \, f(K)$$

where c = strength parameter (c = 1/M in case of Eq.1)

K = A ratio of initial principal stresses.

(3) σ_m' should be preferred for the interpretation of pore water pressure generation.

(4) For anisotropically consolidated ($K_c \geqslant 1.5$) saturated sand samples (D_r =›50), initial liquefaction is highly improbable under cyclic loading. A "forced liquefaction" may be achieved in cyclic laboratory tests, but in nature it may be a "shock" which may cause a great strength loss in natural deposits under initial shear stresses.

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