and Altschaeffl (1971), who first suggested that collapse settlement would be a function of principal stress ratio.

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UNDRAINED SHEAR STRENGTH OF LIQUEFIED SANDS FOR STABILITY ANALYSIS[a]

Discussion by Fumio Tatsuoka[3]

Eq. (7) is proposed to predict from SPT N values the undrained critical strength s_u (critical) that controls postliquefaction flow failure of a soil mass. Eq. (7) is based on many field data supplemented by cyclic undrained triaxial test data, assuming that s_u(critical) be equal to the yield strength s_u(yield, $N_c \geqq 100$), which is the cyclic shear stress amplitude s_u(yield) that triggers liquefaction after 100 or more cycles N_c in uniform cyclic undrained tests. I think that (7) grossly underestimates the s_u(critical) value of dense sands as shown next.

Fig. 14 shows s_u(yield)/σ'_c ($= \sigma_d/2\sigma'_c$) defined for a double amplitude axial strain of 10% from typical tests. It is seen that s_u(yield, $N_c \geqq 100$) increases only slightly with the relative density D_r, while at smaller N_c, s_u(yield) increases at a much larger rate with D_r. A similar trend can be seen for curve 1 in Fig. 15, which represents s_u(yield)/σ'_c defined for a double-amplitude shear strain of 15% at different N_c values from uniform cyclic undrained torsional shear tests (Tatsuoka et al. 1982) (note that all the results shown in Fig. 15 are for isotropically consolidated hollow cylindrical specimens, and they should be corrected when applied to K_0 conditions). Fig. 15 also shows other strengths (divided by σ'_c): for curve 2, the *maximum* single-amplitude shear stress of two sets of irregular cyclic stresses that induced a maximum double-amplitude shear strain γ $(DA)_{max}$ of 15% (Tatsuoka et al. 1986) (the irregular cyclic stresses were from two acceleration time histories recorded on the ground during a major earthquake); for curve 3, the peak strength from monotonic drained tests (Fig. 16); and for curve 4, the maximum shear stress until an arbitrarily selected shear strain γ of

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[a] November, 1992, Vol. 118, No. 11, by Timothy D. Stark and Gholamreza Mesri (Paper 2613).

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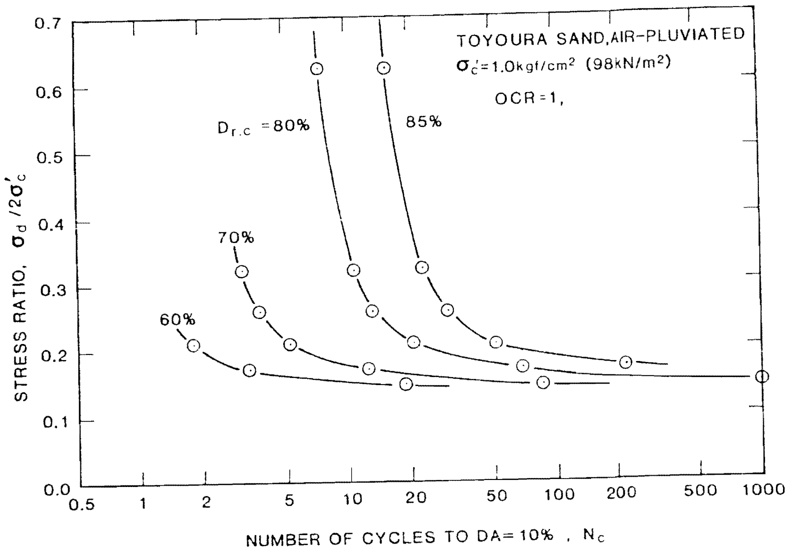

FIG. 14. Cyclic Undrained Triaxial Test Results (Tatsuoka et al. 1988)

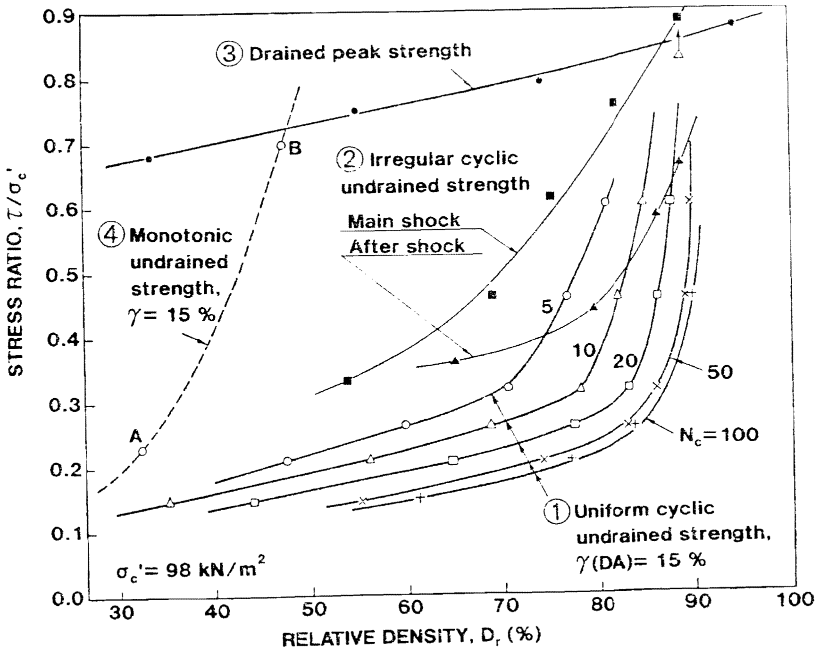

FIG. 15. Results of Different Types of Torsional Shear Tests on Isotropically Consolidated Air-Pluviated Toyoura Sand

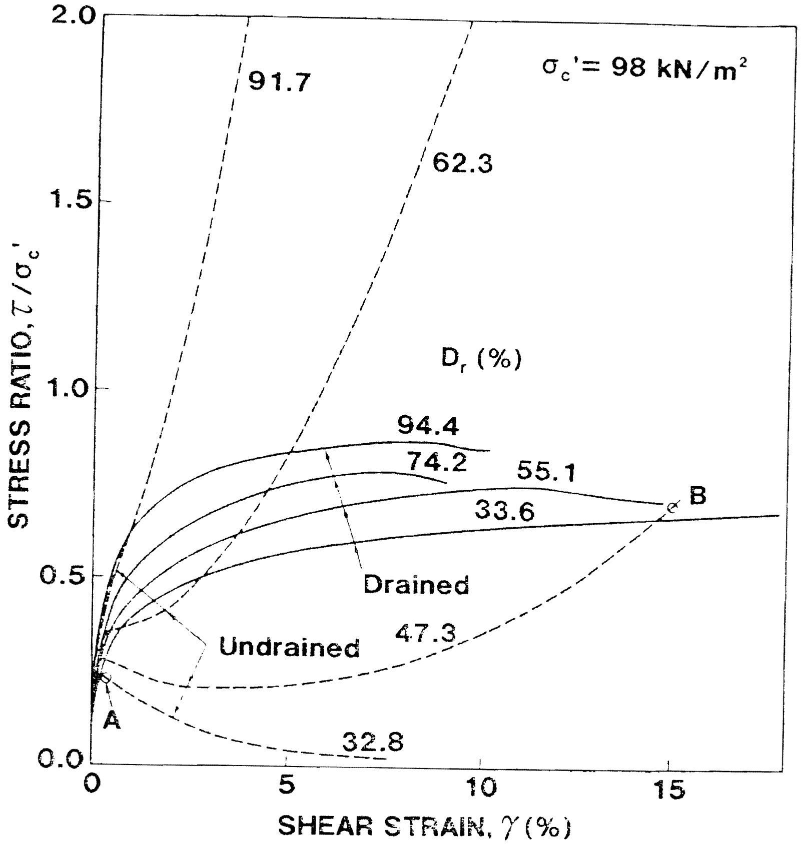

FIG. 16. Shear Stress Ratio-Shear Strain Relations from Monotonic Drained and Undrained Torsional Shear Tests (Fukushima 1982)

15% was induced in two monotonic undrained test (Fig. 16). The points A and B correspond to those in Fig. 16. These results suggest that in this case, for D_r larger than about 40%, s_u(yield, $N_c \geqq 100$) is smaller than s_u(critical).

Eq. (4) is proposed to predict the yield strength s_u(yield, mob), which controls the triggering of liquefaction for $M = 7.5$. For $(N_1)_{60-cs}$ less than about 24, s_u(critical) [(7)] = 0.5 · s_u(yield, mob) [(4)]. By correcting for the difference between uniform and random loading, 0.65 times "s_u(yield) for the relation of curve 2 in Fig. 15" corresponds to s_u(yield, mob) [(4)]. As assumed in the paper, 0.65 · "s_u(yield) for the relation of curve 2" is similar to "s_u(yield, $N_c = 15$) for the relations of curve 1." Then, for D_r larger than about 40%, "s_u(critical) as estimated from the relation of curve 4" is substantially larger than these s_u(yield) values as opposite to that suggested by (4) and (7).

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Closure by Timothy D. Stark[4] and Gholamreza Mesri[5]

The writers wish to thank Tatsuoka for his interest in the paper, and for his test results pertaining to the undrained critical strength of dense sands. Eq. (7) relates undrained critical strength ratio to SPT N-values and was developed for loose or liquefiable sands. This corresponds to soils with a $(N_1)_{60-cs}$ less than or equal to 20 as was stated for (4). A value of $(N_1)_{60-cs}$ equal to 20 corresponds to a relative density (D_r) of approximately 65%.

It is encouraging to note that the yield strength ratio at $D_r = 60\%$ extrapolated to $N_c = 100$ in Fig. 14 and yield strength ratios for $N_c = 100$ and relative densities of 65, 50, 40, and 30% in Fig. 15 provide estimates of $s_u(\text{critical})/\sigma'_{vo}$ close to those estimated by (7) as shown in Fig. 17. It should be noted that the curve for $N_c = 100$ in Fig. 15 was extrapolated to $D_r = 30\%$. A more detailed response to Tatsuoka's remarks concerning "relations 2 and 4 in Fig. 15" is not possible because neither the meaning nor the discusser's interpretation of "relations 2 and 4" is clear to the writers.

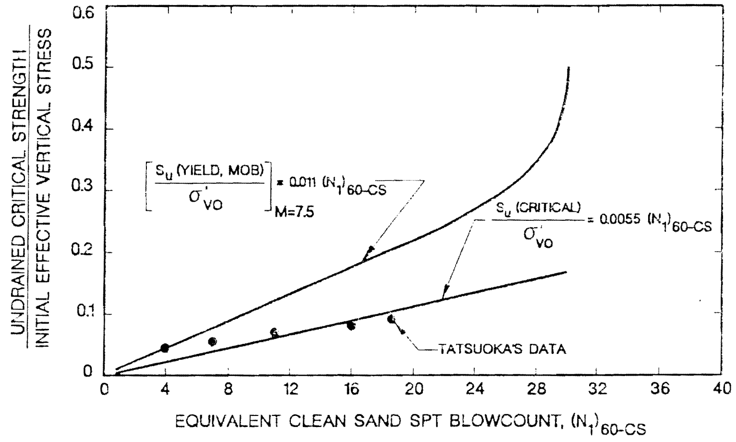

FIG. 17. Relationship between Undrained Critical Strength Ratio and Equivalent Clean Sand Blow Count

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