Assessment of the Undrained Response of Sands under Limited and Complete Liquefaction

Mohamed Ashour, M.ASCE[1]; Gary Norris, M.ASCE[2]; and Tung Nguyen[3]

Abstract: The technique presented deals with the assessment, based on drained test behavior and formulation, of the undrained postcyclic stress-strain behavior of sands under limited or complete (full) liquefaction and its associated strength. At present, there is no particular procedure that allows assessment of such undrained postcyclic behavior that could develop full (pore-water pressure ratio, $r_u=1$) or limited ($r_u<1$) liquefaction. The prediction of the undrained postliquefaction (full or limited liquefaction) response presented here is based on basic properties of sand such as its relative density (Dr_c) [or $(N_1)_{60}$ blowcount], the effective angle of internal friction (φ), the roundness of the sand grains (ρ), and the drained axial strain at 50% stress level (ε_{50}). The technique presented accounts for the excess pore-water pressure induced by cyclic loading (Δu_c) and the postcyclic excess pore-water pressure generated under undrained monotonic loading (Δu_d).

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Postliquefaction Phenomenon in Saturated Sands

The postliquefaction stress-strain behavior and strength of a completely liquefied soil (pore-water pressure ratio, $r_u=1$), or a soil under limited liquefaction ($r_u<1$), are still subjects of considerable research interest. Seed (1979) addressed this issue experimentally showing the strain generated resistance of saturated sand under undrained monotonic loading after first being completely liquefied by cyclic loading and losing all of its static strength (Fig. 1). Upon undrained compressive monotonic loading following complete or limited liquefaction with its associated drop in effective confining pressure ($\bar{\sigma}_3$), sand eventually responds in a (suppressed) dilative fashion (Fig. 2). However, sand under limited liquefaction with a drop in confining pressure short of complete liquefaction ($\bar{\sigma}_3>0$) may experience initial (restrained) contractive behavior that is then followed by dilative behavior (Fig. 2). The undrained postliquefaction response of sand after complete liquefaction reflects a concave upward undrained deviatoric stress stiffening versus undrained axial strain response regardless of its initial conditions (density or confining pressure) before cyclic loading/liquefaction. The same is true for sand with limited liquefaction after initial restrained contractive behavior whereby its effective stress path reaches the failure line and thereafter marches up the failure line due to restrained dilative behavior. The difference is that it does not start from $\bar{\sigma}_3=0$, as does the completely liquefied soil. It should be noted that the characteristics of the postliquefaction response of sand do not rely on the method of liquefying the sand, i.e., whether it is from static or cyclic loading (Vaid and Thomas 1995). It depends on the sand's relative density and effective stress. The technique presented allows assessment of the postliquefaction liquefaction stress-strain behavior of sand with limited or complete liquefaction based on drained test behavior. Such assessment requires only basic properties of the sand such as its relative density [or $(N_1)_{60}$], the effective angle of internal friction (φ), the roundness of the sand grains (ρ), the drained axial strain at 50% stress level (ε_{50}), and the residual confining pressure ($\bar{\sigma}_3$) if greater than zero.

[1]Associate Professor, Dept. of Civil and Environmental Engineering, Univ. of Alabama, Huntsville, AL 35806 (corresponding author). E-mail ashour@eng.uah.edu.

[2]Professor, Dept. of Civil Engineering, Univ. of Nevada, Reno, NV 89557.

[3]Project Engineer, California Dept. of Transportation (CALTRANS).

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Method of Analysis

Norris et al. (1997) developed a technique that was formulated later by Ashour and Norris (1999) to assess the undrained behavior of sand under compressive monotonic loading from its drained behavior. That technique employs a series of drained tests, with volume change measurements, on samples isotropically consolidated to the same confining pressure, $\bar{\sigma}_{3c}$, and void ratio, e_c, to which the undrained test is to be subjected. However, the drained tests are rebounded to different lower values of effective confining pressure, $\bar{\sigma}_3$, before being sheared. Such a technique allows the assessment of undrained behavior of sand isotropically consolidated to $\bar{\sigma}_{3c}$ that is subjected to compressive monotonic loading (no cyclic loading). During an isotopically consolidated undrained (ICU) test, the application of a deviatoric stress, σ_d, in compressive monotonic loading causes an additional pore-water pressure, Δu_d, that results in a lower effective confining pressure, $\bar{\sigma}_3$, i.e.

$$\bar{\sigma}_3=\bar{\sigma}_{3c}-\Delta u_d \quad \text{(No cyclic loading)} \tag{1}$$

and an associated isotropic expansive volumetric strain, $\varepsilon_{v,\mathrm{iso}}$, the same as recorded in an isotropically rebounded drained triaxial test (prior to shear loading). However, in the undrained test, the volumetric change or volumetric strain must be zero. Therefore,