Discussion and Response

PEAK VERSUS RESIDUAL SHEAR STRENGTH IN GEOSYNTHETIC-REINFORCED SOIL DESIGN

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Zornberg, J.G., 2002, "Response to 'Peak Versus Residual Shear Strength in Geosynthetic-Reinforced Soil Design' ", *Geosynthetics International*, Vol. 9, No. 4, pp. 387-390.

Discussion by J.P. Giroud

Thank you for the detailed response to my discussion. I am glad Dr. Zornberg pursued the theoretical approach I proposed, and I am glad it confirms the role of the peak strength. However, I am puzzled by the friction angles used. In my discussion, I used 35° and 37.5°, values I took from the paper. Dr. Zornberg uses 39.5° and 42.5° in the response to my discussion. I cannot find these two values in your paper. Could you please comment on this apparent discrepancy between friction angles?

Response by J.G. Zornberg

Many thanks again to J.P. for his input. The reason for the higher friction angles is that plane strain conditions were taken into account in the analyses. Below is some additional information on Monterey 30 sand (earlier commercialized as Monterey 0 sand, which was widely used in liquefaction-related studies at UC Berkeley).

MONTEREY NO. 30 SAND

Monterey No. 30 sand is a clean, uniformly graded sand classified as SP in the Unified Soil Classification System. The particles are rounded to subrounded, consisting predominantly of quartz with a smaller amount of feldspars and other minerals. The average particle size for the material is 0.4 mm, the coefficient of uniformity is 1.3, and the coefficient of curvature is about 1.1. The maximum and minimum void ratios of the sand are 0.83 and 0.53, respectively. To obtain the target dry densities in the model slopes, the sand was pluviated through air at controlled combinations of sand discharge rate and discharge height. The unit weights for the Monterey No. 30 sand at the target relative densities of 55% and 75% are 15.64 kN/m^3 and 16.21 kN/m^3, respectively.

Two series of triaxial tests were performed to evaluate the friction angle for the Monterey No. 30 sand as a function of relative density and of confining pressure. The tests were performed using a modified form of the automated triaxial testing system developed by Li et al. (1988). The specimens had nominal dimensions of 70 mm in diameter and 150 mm in height and were prepared by dry tamping. Figure 3 in the paper shows the increase in peak friction angle with increasing relative density at a confining pressure of 100 kPa. Of particular interest are the friction angles obtained at relative densities of 55% and 75%, which correspond to the relative density of the backfill material in the models. The estimated triaxial compression friction angles (ϕ_{tc}) at these relative densities are 35° and 37.5°, respectively. Although the tests did not achieve strain values large enough to guarantee a critical state condition, the friction angles at large strains appear to converge to a residual value, ϕ_r, of approximately 32.5°. This value agrees with the critical state friction angle for Monterey No. 0 sand obtained by Riemer (1992). As the residual friction angle is mainly a function of mineralogy (Bolton 1986), Monterey No. 0 and Monterey No. 30 sands should show similar ϕ_{cs} values.

Of particular interest is the effect of the intermediate effective principal stress under plane strain conditions, which has been found to increase the peak friction angle of sand relative to that measured in conventional triaxial compression tests (Ladd et al. 1977). Plane strain is the prevailing condition in reinforced soil structures (e.g., Jewell 1990), and friction angles for this condition had been considered in previous centrifuge studies that evaluated the performance of reinforced soil walls (Jaber 1989). Considering the experimental difficulties involved in accurately evaluating plane strain friction angles, ϕ_{ps}, these values were inferred based on correlations with the friction angles obtained under triaxial compression conditions, ϕ_{tc}. Specific correlations for the sand used in this study were obtained from results of plane strain tests performed using Monterey sands. Lade and Duncan (1973) reported plane strain friction angles for Monterey No. 0 sand, obtained from true triaxial tests on cubical specimens. Additionally, Marachi et al. (1981) reported the results of a series of tests on Monterey No. 20 sand obtained using triaxial and plane strain devices. The friction angle ratios ϕ_{ps}/ϕ_{tc} for Monterey No. 0 and Monterey No. 20 sands are indicated in Figure 12. The friction angle ratios for the two Monterey sands increase with increasing relative density of the sand. Based on this correlation, the ratios ϕ_{ps}/ϕ_{tc} used in this study for Monterey No. 30 sand at 55% and 75% relative densities are 1.13 and 1.14, which yields plane strain

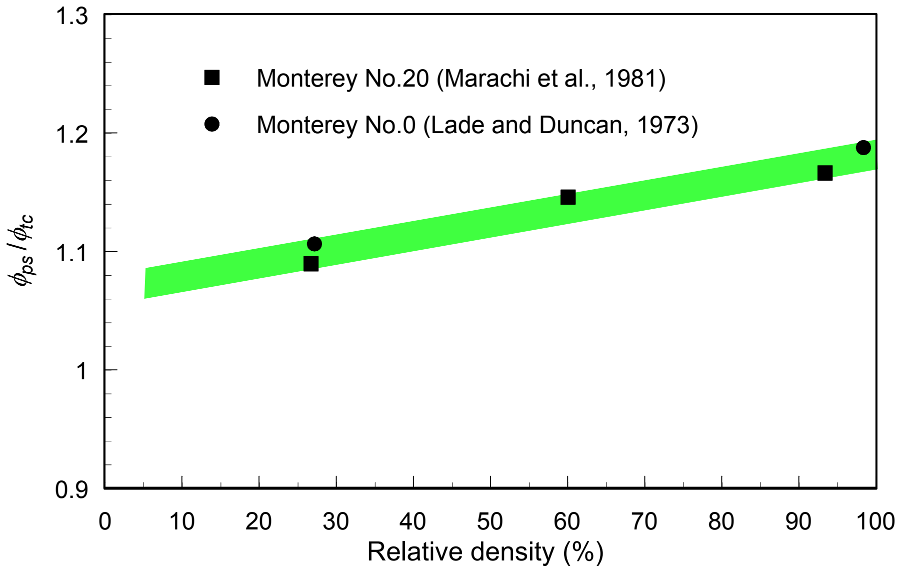

Figure 12. Ratio of friction angles under plane strain and triaxial compression conditions for Monterey sand.

friction angles of 39.5° and 42.5º, respectively.

The average strength increase ratio recommended by Kulhawy and Mayne (1990) is:

$$\phi_{ps} = 1.12\ \phi_{tc} \qquad (2)$$

which is in good agreement with the correlation obtained specifically for Monterey sands and provides additional confidence in the plane strain values selected in the current study.

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