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Geoff Martin, USC: True nonlinear response analyses in the time domain- determination of nonlinear backbone curves.

Equivalent linear response analyses such as SHAKE, have reduced reliability in the case of softer soils, as ground shaking levels increase to values greater than about 0.4g, or where maximum shear strain amplitudes exceed 1 to 2 percent. For these cases, true nonlinear shear stress- shear strain models (including a failure criterion) can replicate the hysteretic soil response over the full time history of earthquake loading, and provide results reflecting transient or permanent ground deformations. However, for practical applications, one of the difficulties and a key issue for discussion is the determination of the so-called nonlinear backbone curve defining the shear stress – shear-strain behavior of soil strata at a given site. Such curves (combined with the Masing criteria for load-unload behavior) form the basis for input data needs of many nonlinear computer programs.

One approach is to use G/G_{max} versus shear strain amplitude curves commonly used for SHAKE analyses (such as those described by Vucetic and Dobry, 1991) to construct a backbone curve, using G values for a given strain amplitude as secant modulii for the backbone curve. However, such curves are generally not defined for shear strains greater than about 1-2% and an estimate of a strength asymptote and a failure strain is needed to extrapolate the remainder of the backbone curve. This requires a judgement call on the effect of the more rapid earthquake loading on static soil strengths, and site specific strength data is often not compatible with backbone curves constructed to say 2% strain based on generic G/G_{max} curves.

Useful shear modulus data to higher shear strain amplitudes up to 10% has been generated from the Rosrine Test program such as described by Hsu and Vucetic (1999). An example for a plastic silt (PI = 30.7%) is shown on the accompanying figure, where tests at higher strains were conducted using cyclic simple shear equipment at UCLA. Test results are compared with generic PI curves with reasonable agreement. Note that the nonlinear backbone curve constructed by the G/G_{max} curve agrees reasonably well with a rapid loading monotonic load test conducted following cyclic tests, as shown in the figure. Such tests on site specific samples could well form the basis for establishing more reliable backbone curves for nonlinear response analyses. Also note the plotted damping ratios determined from experimental hysteresis loops. Values are significantly higher than generic values when strains exceed 0.1%, and are similar to damping ratios computed from the backbone curve using nonlinear hysteresis loops generated assuming Masing criteria. However, it should be recognized that the generic G/G_{max} and damping ratio curves represent averages of test data and hence are not necessarily cross correlated. Hence it should not be expected that G/G_{max} and damping ratio curves can simultaneously be matched by nonlinear hysteretic models computed from a backbone curve. Note also that where hysteretic models are used in nonlinear response analyses, a nominal 2% viscous damping ratio would be included in analyses to account for low strain damping.

It would be valuable if the workshop could reach consensus on appropriate methods to establish nonlinear backbone curves for dynamic response analyses. The issues described above are further discussed by Qiu (1997) where the program DESRA was modified (DESRAMUSC) to incorporate a nonlinear backbone curve using the elasto-plastic Iwan model which has the versatility of using an array of elasto-plastic elements to match any given loading curve including a failure mode. The model automatically provides for hysteretic behavior during cyclic loading following the Masing rules.

References

Hsu, Chu-Chung and Vucetic, Maladen, (1999), "Results of Cyclic and Dynamic Simple Shear Tests on Soils from Tarzana and Rinadi Sites, Conducted for the Rosrine Project and other Research Purposes," UCLA Research Report No. ENG-99-205, June 1999.

Qiu, P., (1997), "Earthquake Induced Nonlinear Ground Deformation Analyses," Ph.D. Dissertation, Department of Civil Engineering, University of Southern California.

Vucetic, M. and Dobry, R., (1991), Effects of Soil Plasticity on Cyclic Response," Journal of Geotechnical Engineering, ASCE, 117(1), 89-107.

Tarzana P-1, PI=30.7