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ABSTRACT

It is known that reduction and degradation of soil strength and stiffness during cyclic loading typically result in damage to structural foundations and earth structures due to excessive settlement and tilting and may cause slope instability and embankment failure. Case histories, representing damages during earthquakes, due to this phenomenon are numerous. It is the guiding principle of this paper to present an overview of degradation characteristics of combined clay-shale samples under cyclic loading and describe how this phenomenon can be utilized in evaluating the seismic stability of slopes involving colluvium.

INTRODUCTION

It is known that the clays and silts exhibit non-linear and hysteresis behavior during cyclic loading (Chaney et al. 1991). A typical hysteresis loop during one cycle of loading consists of three stages of initial loading, unloading, and reloading as shown in Figure 1. The initial loading segment constitutes the backbone curve, which characterizes the non-linear stress-strain behavior of clays. The initial tangent to this backbone curve is designated the maximum shear modulus, G_{max}. The ratio of the maximum shear stress, τ_{max} and maximum shear strain, λ_{max} is defined as the secant modulus, G_s. The ratio of the energy dissipated to the maximum strain energy is defined as the damping ratio. Damping ratio is determined based on the area of hysteresis loop and the equivalent secant modulus.

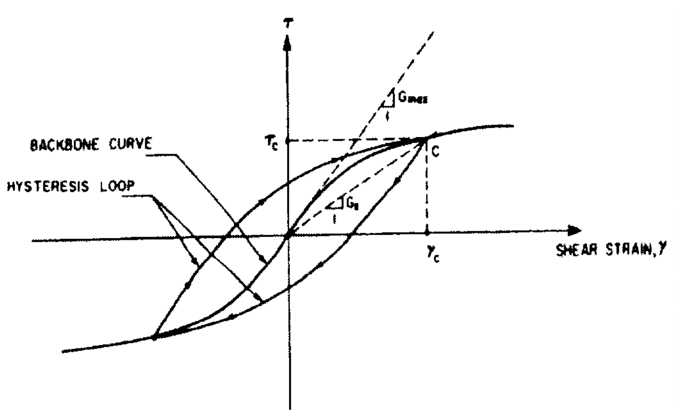

Fig.1 Typical Stress-Strain Hysteresis Loop (From Idriss et al. 1978).

The hysteresis loops are generated based on the most widely accepted Masing criterion (Masing 1926). Furthermore, the backbone curve is expressed in accordance with several different mathematical models including bilinear (Thiers and Seed 1969), multilinear, hyperbolic (Harding and Drnevich 1972), and Ramberg and Osgood (1943).

The clay soils display reduction in moduli, accompanied by degradation of the backbone curve, with increasing strain amplitude (Lin and Chen 1991). The degradation is primarily a function of number of cycles of loading (Chaney et al. 1991). Increasing number of cycles of loading, yield progressive degradation of soil stiffness (Matsui et al. 1991). This phenomenon is characterized as progressive softening of soil.

Degradation effects are expressed in terms of degradation index δ, which is the ratio of the N^{th} cycle secant shear modulus, G_N, and the first cycle secant shear modulus, G_1 (Idriss et al. 1978).

Vucetic and Dobry (1988) observed that with cyclic straining, the effect of degradation in the clay accumulates and the degradation index decreases monotonically with N. Furthermore, they found that the degradation index versus N plots as a straight line in a log-log scale for normally consolidated clay as well as overconsolidated clay with overconsolidation ratio (OCR) of 2. The slope of this line, known as the degradation parameter t, where $t = -(\log\delta/\log N)$, has been found to increase with increasing cyclic strain but decrease with increasing OCR.

The Vucetic and Dobry's approach in studying the behavior of clay soils, as described above, was adopted in the present study to prepare plots of degradation index with number of cycles for the combined clay-shale samples. A brief overview of compilation of experimental data will be presented herein along with analysis of test results.

RELATIONSHIP BETWEEN DEGRADATION INDEX AND NUMBER OF CYCLES

The preceding approach was employed to plot the degradation index versus the number of cycles. Accordingly, the degradation index was calculated for a given test by dividing the equivalent dynamic shear modulus of cycles 1, 5, 10, 20, 30, 40, 50, 60, and 70 by the equivalent dynamic shear modulus of the first cycle, and then these values were plotted against the number of cycles. A typical graph, representing logδ vs. logN, is shown in Figure 2. Since the range of the cyclic shear strain amplitudes employed in this research project was limited, no attempt was made to demonstrate the relationship between the degradation parameter, t and the cyclic shear strain, graphically.

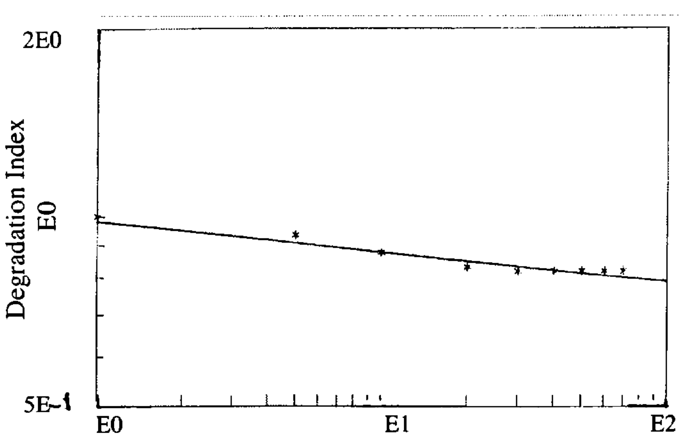

Fig. 2. Variation of Degradation Index with No. of Cycles

A straight line was fitted reasonably well to the data points for the majority of the tests when log-log scale was used. A direct comparison of various test results was made possible since the same scale was adopted in plotting all the graphs. Incidentally, the graphs were drawn separately in order to avoid confusion and provide flexibility for comparing any two sets of test data.

The gradient of the lines representing level ground varied from t = 11.17% to 15.87%. The variation in the degradation parameter, t for these tests follows the same trend as the tests conducted by Vucetic and Dobry. In other words, the degradation parameter, t increases with increasing cyclic shear strain.

As part of the present research study, some of the clay-shale samples were first displaced in both directions several times in order to reach the state of residual strength prior to superposition of cyclic loading application. The results obtained from these experiments exhibited very low values of degradation parameter. The degradation parameters varied from 0.0362 to 0.055. These significantly low values may be attributed to the deterioration effect of the formerly applied back-and-forth slow displacement for bringing the composite clay-shale samples to the state of residual strength.

CONCLUSIONS

It is evident that the degradation index is a function of number of cycles of loading application. It appears that the effect of degradation diminishes as the number of cycles increase. This stage is considered to herald the steady-state condition, without significant degradation of soil stiffness.

Furthermore, the test results of composite clay-shale samples representing the state of residual shear strength exhibit significantly lower values of degradation parameter, t when compared with those of level ground. This is partly due to the weakening of bonding at the interface of clay and shale samples representing the residual shear strength. The effect of excess pore water pressure is also paramount and will be investigated in the future.

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