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Random Displacement Modulus and Damping Determination

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SYNOPSIS: Modulus and damping values were determined for both undisturbed and remolded silty sand specimens by cyclic triaxial methods utilizing both sinusoidal and random displacement stroke control. Remolded specimens were prepared at 3 different dry unit weights using a preparation technique that gave the same formation factor as the undisturbed specimen. Results indicated that the random displacement method tends to produce results which are similar to those obtained by the sinusoidal procedure at shearing strain levels less than 10^{-1} %. At shearing strain levels greater than 10^{-1} % the random displacement method gives lower modulus and higher damping ratio values when compared to the sinusoidal procedure. In addition, stress history effects as demonstrated by the location of the cycle in the record being analyzed were observed not to be important over the sample unit weights investigated.

INTRODUCTION

During the course of a seismic event soil material undergoes a displacement which is a function of time. The displacement of the soil mass as a function of time results in changing shear modulus and material damping characteristics of the soil. Cyclic triaxial modulus tests using random displacement-time histories were conducted to evaluate this effect on silty sand material remolded to three different densities.

The conversion of a irregular series of earthquake cycles into an equivalent uniform cyclic stress history is an integral part of current seismic response analyses of soil structures . The Miner cumulative damage method (Miner 1945) and equivalent uniform cycle method (Seed and Idriss 1971, Seed et al. 1975, Lee and Chan 1972) are two methods currently in use for this conversion. The cumulative damage theory was developed for metal fatigue. According to this theory, when metals are subjected to cyclic loading, they undergo progressive weakening until they eventually fail. The primary assumptions governing this are: (1) the loading pattern is sinusoidal, and (2) no work hardening takes place in the specimen. Because the loading is assumed to be sinusoidal, each load cycle has the same incremental damaging effect as every other load cycle. While each cycle causes the same amount of incremental damage regardless of where in the pattern it occurs, the cumulative damage will, of course, increase with each . To determine the cumulative damage, a relationship between stress level and number of cycles to failure must be established for the material in question. In contrast, the equilibrium cycle procedure involves representing the destructive energy of irregular earthquake cycles with an equivalent series of uniform cycles. To do this, an arbitrary average stress level is chosen to which all other irregular stress levels of the earthquake are converted. This average stress level is some fraction of the maximum stress level recorded during the earthquake. All other irregular stress cycles can then be converted to an equivalent number of cycles at the average stress level . A relationship between stress level and the number of cycles to failure for the material being studied is required. Adding these equivalent cycles from each stress level gives the total number of equivalent cycles for the entire earthquake. The number of equivalent cycles at the average stress level will have the same damaging effect on the soil as the earthquake. The equivalent uniform series thus developed is much easier to work with, both experimentally and analytically, than the actual irregular stress-time history.

The purpose of the following study was the following: (1) to verify that shear modulus and material damping results using the equivalent cycle approach (sinusoidal loading history) gave similar results as when determined using an irregular loading history, and (2) investigate the effect of stress history.

SAMPLE PREPARATION

Undisturbed and remolded silty sand samples were employed in this study. A grain size distribution of the material is presented in Fig. 1. A non-dimensional parameter called the formation factor (F) based on the conductivity of the pore fluid system has been developed to describe the packing characteristics of soil (Archie 1942). The formation factor (F) is defined as the ratio of the conductivity of the electrolyte (water + salt) occupying the pore space of a saturated soil sample to the conductivity of the soil-electrolyte mixture. The formation factor has been used to quantify and predict the porosity, shape, anisotropy and cementation of soil both in the field and in the laboratory (Archie 1952, Arulanandan and Dafalias 1979, Delft Soil Mechanics 1975). Mulilis (1975) showed that for a sand material the relationship between the formation factor and the density is linear for four different methods of compaction for relative densities between 30% and 90%.

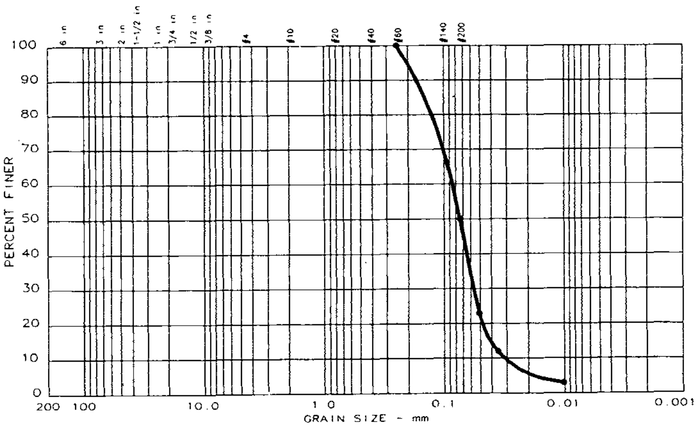


Fig. 1. Grain Size Distribution of Material Tested

The formation factor was shown to increase with the method of remolding in the following order:

1. pluviation through air (lowest F)
2. horizontal high frequency vibrations (dry)
3. moist tamping
4. horizontal high frequency vibrations (moist)(highest F)

In addition Mulilis (1975) also showed that cyclic stress ratio to cause initial liquefaction increases with increasing formation factor.

Remolded specimens were prepared at 3 different dry unit weights using a kneading/vibration preparation technique that gave the same formation factor as the undisturbed specimen. The sample dry unit weights employed in this study were the following 16.8 kN/m^3, 16.6 kN/m^3, and 15.7 kN/m^3. Formation factors were determined for both undisturbed and remolded saturated specimens using a General Radio Company, type 1605A, impedence comparator in combination with a conductivity cell for remolded samples, Photo 1. The conductivity of the saturated undisturbed specimen was determined between end platens in a triaxial cell under an effective stress similiar to the test program. Measurements were made at a frequency of 1000Hz.

TEST PROCEDURE

Cyclic triaxial modulus tests using random displacement-time histories were conducted to evaluate the effect of stress history on silty sand material. The random displacement-time history utilized in the study is presented in Fig. 2 . The displacement time history employed was a portion of the 1940 El Centro S90W earthquake record. Shear modulus and material damping were evaluated for three different hysteresis loops at each displacement level. The three hysteresis loops chosen to be evaluated were located on the displacement time history: (1) before peak, (2) peak, and (3) after peak as shown in Fig. 2. The purpose in selecting the three hysteresis loops was to evaluate the effect on the cyclic soil properties of the order in which the sample was subjected to displacements of varying magnitudes. Results were analyzed after 5 consecutive cycles of the displacement-time history. The maximum displacement level for the random time history was increased in steps until the x-y plot of load versus deformation would no longer form closed loops. After each sequence of loading pore water pressures were allowed to dissipate.

Photo 1. Conductivity Apparatus

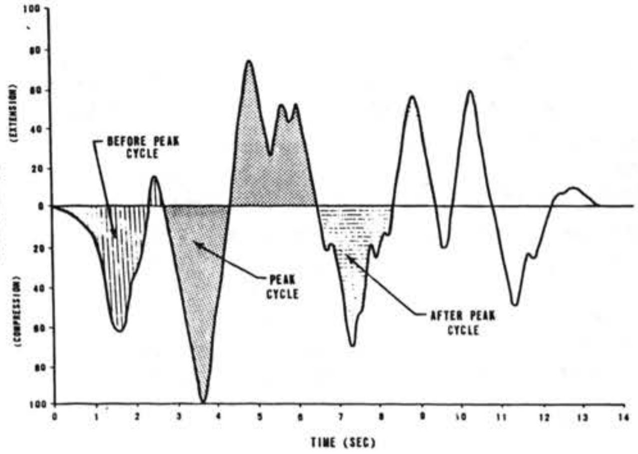


Fig. 2. Displacement Time History

The sinusoidal and random displacements were placed on the specimen using a electro-hydraulic MTS system in conjunction with MTS Model 411 Arbitrary Function Generator.

TEST RESULTS

The results of the individual cyclic triaxial random displacement tests are presented in Figs. 3 thru 5. The test results are presented to define the shear modulus (G), and material damping ratio (D) versus shearing strain amplitude (1) curve for each sample. Properties of each soil specimen and applicable test conditions are summarized in Table 1. At lower shearing strain levels ($<10^{-1}\%$) shear modulus and material damping computed for the three different cycle conditions produce similar results for all unit weights, while at higher strains ($>10^{-1}\%$) for the densest material (16.8 kN/m^3) there is a tendency for the "before peak" cycle to produce higher shear modulus and lower damping.

Cyclic triaxial modulus and material damping test results obtained utilizing sinusoidal and random displacement-time histories on both undisturbed and remolded silty sand material are compared in Fig. 6. The random displacement modulus and material damping curves presented in Fig. 6 are the average curves drawn through data points representing the three hysteresis loops: (1) before peak, (2) peak, and (3) after peak. The sinusoidal displacement-time cyclic triaxial test was conducted on a natural intact sample. In contrast, the random displacement-time cyclic triaxial test utilized a remolded soil sample (Fig. 4).

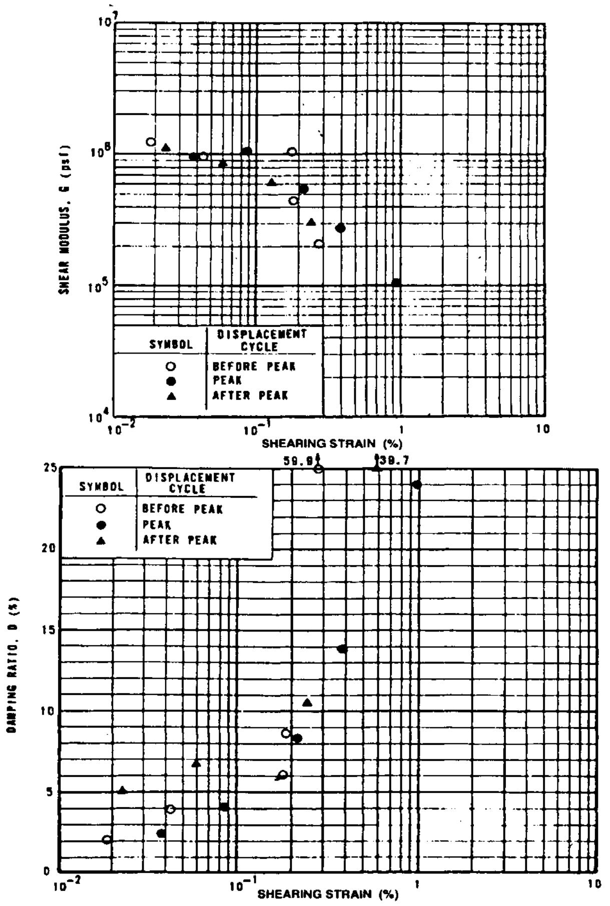
At lower shearing strain levels ($<10^{-1}\%$) the shear modulus determined by either sinusoidal or random displacement time histories for this specimen produced similar results, while at higher strains ($>10^{-1}\%$) the shear modulus determined by the random procedure was lower. In contrast, the sinusoidal and random displacement -time histories produced similar material damping results at low shearing strain levels ($<10^{-1}\%$) but at higher strain ($>10^{-1}\%$) material damping determined by the random procedure was higher.

SUMMARY AND CONCLUSIONS

Silty sand material was remolded using a technique which gave a formation factor similar to a natural undisturbed specimen. Remolded specimens produced in this manner were tested using a cyclic triaxial apparatus to evaluate modulus and damping results under a random displacement time history. An undisturbed specimen was also tested using a sinusoidal displacement time history. Based on the above study the following conclusions can be reached.

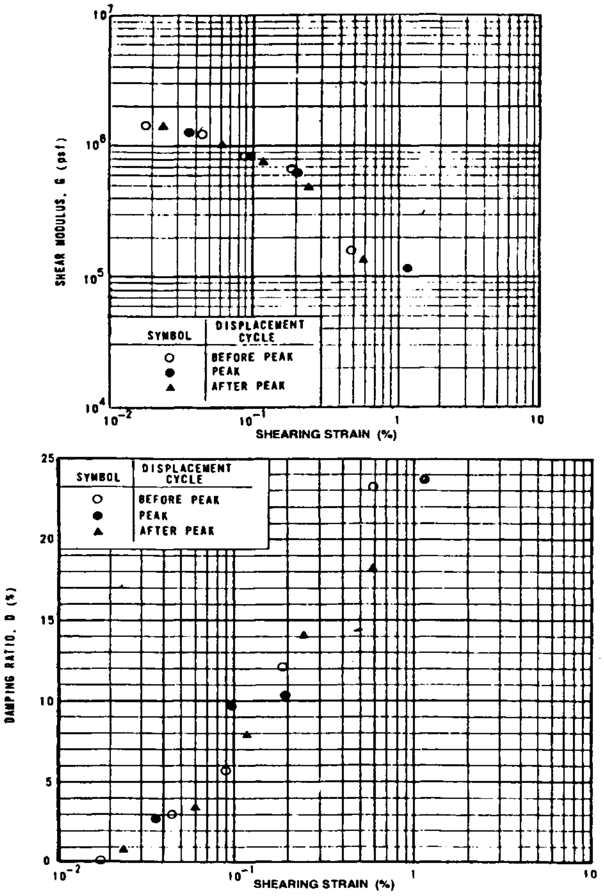
1. Remolded samples tested using a random displacement technique produce similar shear modulus and material damping results as an undisturbed sample tested using sinusoidal displacement for shearing strains less than 10^{-1} %. At higher strains ($>10^{-1}$%) the shear modulus was lower and material damping was higher when using the random procedure.

2. For remolded samples at lower shearing strain levels ($<10^{-1}$%) the shear modulus and material damping computed for hysteresis loops before peak, peak and after peak produce similar results for unit weights ranging from 15.7 kn/m^3 to 16.8 kN/m^3. For higher strains ($>10^{-1}$%) there is a tendency for the densest material studied (16.8 kN/m^3) to produce a higher shear modulus and lower material damping for the before peak cycle.



Note: 1 psf = 994 kPa

Fig. 3. Random Displacement Cyclic Properties Test, ML, Dry Unit Weight = 15.7 kN/m^3 w=17.3% , Effective Stress = 145 kPa



Note: 1 psf = 994 kPa

Fig. 4. Random Displacement Cyclic Properties Test, ML, Dry Unit Weight = 16.6 kN/m^3 w= 21.1% , Effective Stress = 145 kPa

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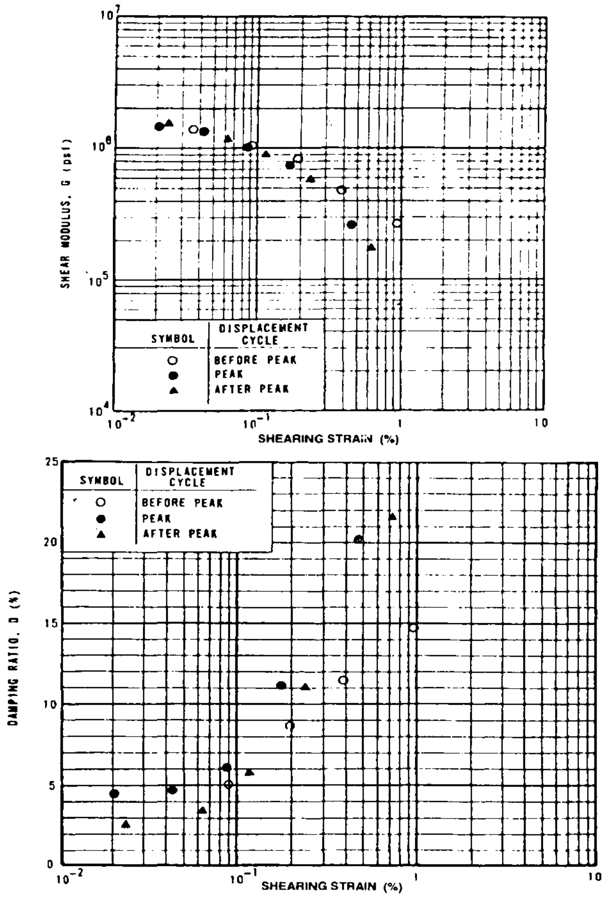
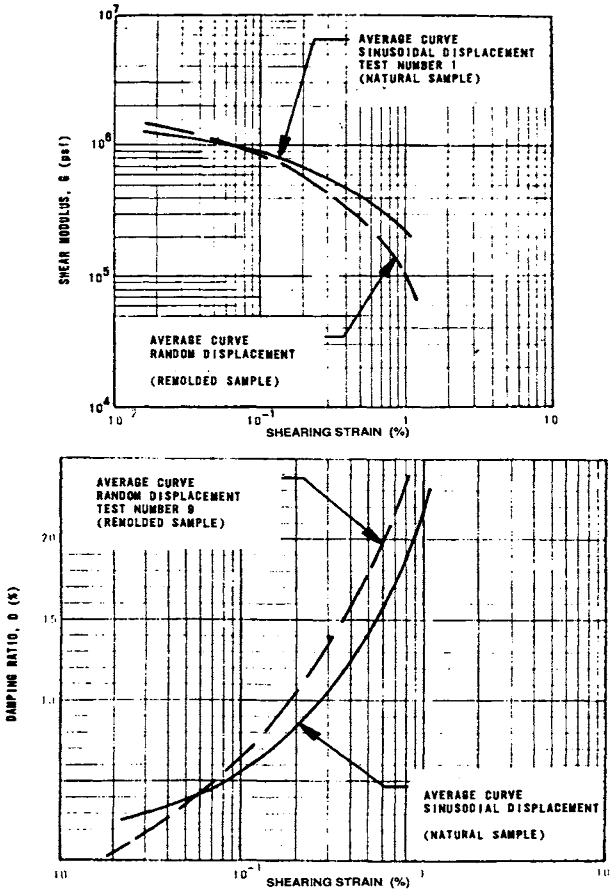


Note: 1 psf = 994 kPa

Fig. 5. Random Displacement Cyclic Properties Test, ML, Dry Unit Weight = 16.8 kN/m^3, w = 15.5 %, Effective Stress = 145 kPa

TABLE I. Summary of Test Samples

Test Sample/ Loading	Dry Unit Weight (kN/m^3)	Compaction Water Content	Void Ratio (e)	Effective Stress (kPa)	Type of Sample
1/Random	16.8	15.5	0.55	145.0	Remold
2/Random	16.6	21.1	0.58	145.0	Remold
3/Random	15.7	17.3	0.66	145.0	Remold
4/Cyclic	16.5	17.3	0.58	145.0	Undist.



Note: 1 psf = 994 kPa

Fig. 6. Comparison of Random and Sinusoidal Displacement Modulus and Damping Curves, ML, Dry Unit Weight ~16.5 kN/m^3, w = 17.3 %, Effective Stress = 145 kPa