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DYNAMIC PROPERTIES OF COHESIVE SOILS FROM IMPULSE TESTING

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SUMMARY

For the determination of the dynamic properties of soils almost all laboratory testing techniques use sinusoidal loading as the type of force excitation. In field testing seismic waves are generated by either an impact force or by detonation of small charges. Such generating systems transmit suitable impulse energies to the soil; however, the impact energy transmitted to the soil does not have the same frequency content in comparison to laboratory or earthquake loading. The objective of this study is to simulate the impulse type loading used in the field in laboratory testing, and to compare the results with those of conventional sinusoidal loading at different strain levels to ensure that the extrapolation of the different field data is correct.

INTRODUCTION

For the determination of the dynamic properties of soils, almost all laboratory testing techniques use sinusoidal loading as the type of excitation force. In field testing, waves are generated by either an impact force or detonation of small charges. Such generating systems transmit energies to the soil; however, the energy transmitted in the soil does not have the same frequency content as either laboratory or earthquake loadings. In order to determine the dynamic soil properties that can be used in ground motion evaluation and in soil structure interaction problems, nonperiodic loadings should be utilized in laboratory testing.

Under random loading several methods of data analysis could be used, including autocorrelation analysis, power spectral density analysis, the random decrement technique, and the maximum entropy method. Soil properties under random loading were determined in the laboratory by the autocorrelation function, the power spectral density function (Ref. 1), and the random decrement technique (Ref. 2,3,4). In general, the main problem with the techniques used in the analysis of random loading testing is that only the output (measured response) could be used. For an accurate determination of dynamic soil properties, an input-output relationship should be developed and utilized. Another problem encountered in random vibration tests is the ability to predict the displacement and strain under random loading tests. For the sinusoidal vibration test, the strain amplitude can be obtained using the deterministic approach; in random vibration tests, however, the uncertainty associated with the probabilistic nature of the random response signal should be considered.

The objective of this study is to compare the soil properties determined from conventional sinusoidal loading tests with those determined from impulse loading tests at different strain levels; these comparisons will provide an understanding of the relationship between conventional laboratory testing and the different types of field testing.

RANDOM VIBRATION ANALYSIS

Two sets of functions can be used to describe random processes: one based in the time domain (i.e., correlation function) and the other in the frequency domain (i.e., power spectral density function). The autocorrelation function is exactly proportional to the free vibration decay due to an initial displacement only for an ideal white noise input. The power spectral density function, as contrasted with the autocorrelation function, describes the general frequency composition of the data. The autocorrelation function and the power spectral density function are related through a Fourier transform. When the excitation is an ideal white noise, the damping ratio of a system can be obtained from the power spectral density of the response by the half-power bandwidth method.

A more reliable method of evaluating the damping and natural frequencies is based on the transfer function method, which uses both excitation and response. The transfer function of a system can be obtained from the relationship between the input spectral density and the output spectral density functions (Ref. 5). A distinct advantage of the transfer function method is that any type of excitation input can be used since the measurement being made is a response signal divided by the input causing it. Thus, by measuring and analyzing the excitation, the true response is obtained. In the transfer function method the damping and natural frequencies can be determined by a number of methods, including the magnitude of the transfer function (or peak-amplitude method), the real part of the transfer function, the imaginary part of the transfer function, and the Nyquist plot.

SOIL TESTED AND SAMPLE PREPARATION

The required specimens of cohesive soil for this study were prepared from kaolinite clay known as Edger Plastic Kaolin, EPK. This type of clay is a pure commercial kaolinite with a liquid limit of 52%, plastic limit of 31%, and specific gravity of 2.67. It was necessary to have available a large number of specimens for this study. The requirements were for specimens of clay with as high a degree of saturation as possible and with the clay structure duplicated as closely as possible, including the void ratio, degree of saturation, particle orientation or fabric, mineralogy, and composition of both the double layer and the pore water. Such duplication for large numbers of specimens could only be hoped for in remolded specimens extruded from compacted soil. To obtain compacted specimens with as high a degree of saturation as possible, the relationship between the moisture content and dry density for the EPK clay was first established using the modified compaction test. Then the optimum moisture content and curves of the degree of saturation were determined. Once the moisture-density-saturation relationship was established the required samples were then prepared at a specified moisture content and degree of saturation. The soil specimens for the dynamic properties measurements were then obtained from the compacted sample using a tube with an inner diameter of 3.81 cm and a height of 20.32 cm. The tube was first lubricated inside and outside to eliminate friction with the soil. The tube was pushed vertically into the compacted soil in the mold, so that all of the obtained specimens would have the same soil structure configuration with regard to the preferred particle orientation (Ref. 6). The properties of the remolded specimens have a void ratio of 1.3 and water content of 50% at the beginning of the testing program.

TEST EQUIPMENT AND EXPERIMENTAL PROCEDURE

For the purpose of this investigation the main testing equipment was the Drnevich-type resonant column apparatus. Methods, procedures, and apparatus descriptions of resonant column testing are presented in (Ref. 7). However, some modifications were introduced in the method of testing and analysis to accommodate random vibration testing. Provisions were also made for the purpose of testing cohesive soil specimens.

In the conventional sinusoidal torsional loading test, the excitation signals were generated by a variable frequency sine-wave generator. The shear moduli were calculated from the resonant frequencies, and the damping ratios were determined using the magnification factor method, which ultilizes the input current and output acceleration.

For the impulse loading test the excitation was generated by a built-in signal source in an FFT analyzer. The purpose of the FFT analyzer in random testing was to transfer the time history records of vibration signals from the time domain (magnitude vs. time) to the frequency domain (magnitude vs. frequency). This transformation of the random signals facilitated the extraction of the following vibration parameters that were needed to determine the dynamic soil properties: the signal intensity (amplitude), the system resonance, and the decay rate.

Two series of tests were performed to determine the dynamic properties of the soil specimens. The first series of tests was performed on the soil specimens using sinusoidal excitations, while the second series used impulse loading. Three confining pressures were used in the testing program, 34.45, 68.9, and 206.7 kPa.

In the sinusoidal testing the input, output, and resonant frequency of the system were recorded for different excitation levels. In the impulse testing, the excitations were applied to the soil specimens and the intensity of the signals were varied from low to high. The input and output were then analyzed by the FFT analyzer. For each test at a different strain level, the FFT analyzer provided the excitation and response time histories, excitation and response power spectral density function, and the transfer function.

To compare shear moduli and damping values from impulse loading tests with those obtained from sinusoidal vibration tests, both tests have to be at the same strain level. For the sinusoidal vibration test, the strain amplitude was obtained using a deterministic approach. In the impulse test, the root mean square (rms) strain was utilized. In this approach, the displacement power spectrum was constructed from the acceleration power spectrum of the response. The area under the displacement power spectrum is the mean square of the response. The displacement rms response was used in combination with the geometry of the specimen and equipment calibration factors to determine the rms strain.

RESULTS

Two different types of excitations were used in this study: sinusoidal, and impulse. Fig. 1 shows the input time domain functions of an impulse generated by the built-in signal sources in the FFT analyzer. The pulse is a sine wave burst at a frequency equal to the center of the span. Fig. 2 shows the input and response of the generated impulse in the frequency domain. As shown in Fig. 2, the frequency spectrum of the impulse signal is nearly flat over a wide frequency range, which is similar to that of a random excitation.

To compare the dynamic properties of the soils under impulse loading with those properties obtained from conventional sinusoidal tests, Fig. 3 is provided as an example of the data obtained. The damping values from impulse loading compared with those values obtained by conventional sinusoidal tests. From this figure it is concluded that the damping values from impulse loading were higher than the ones obtained by the sinusoidal vibration at the same rms strain. As the rms strain decreased, the differences in the damping values decreased.

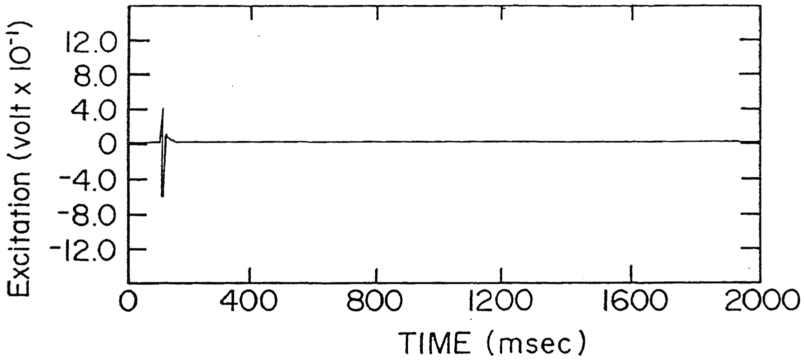

Fig. 1. Typical Excitation of an impulse in the time domain

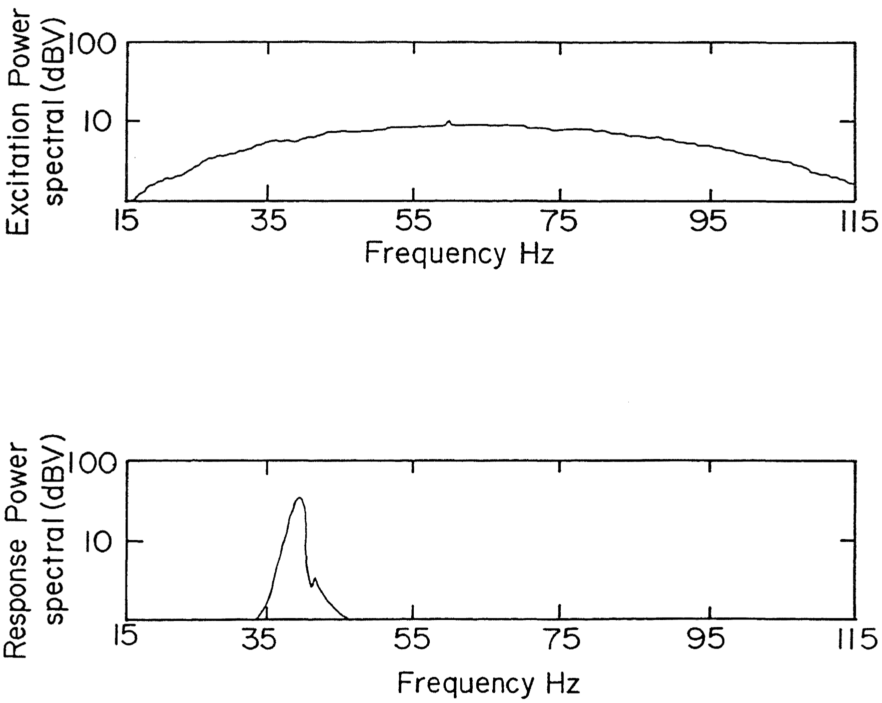

Fig. 2. Excitation and response of an impulse loading in the frequency domain

Similarly, the shear moduli from impulse, and sinusoidal vibrations were compared as shown in Fig. 4. The shear moduli of impulse and random loadings were lower than the shear moduli of sinusoidal loading at the same rms strain. At a low rms strain, the differences between both types of testing were small, and for higher rms strains the differences were larger.

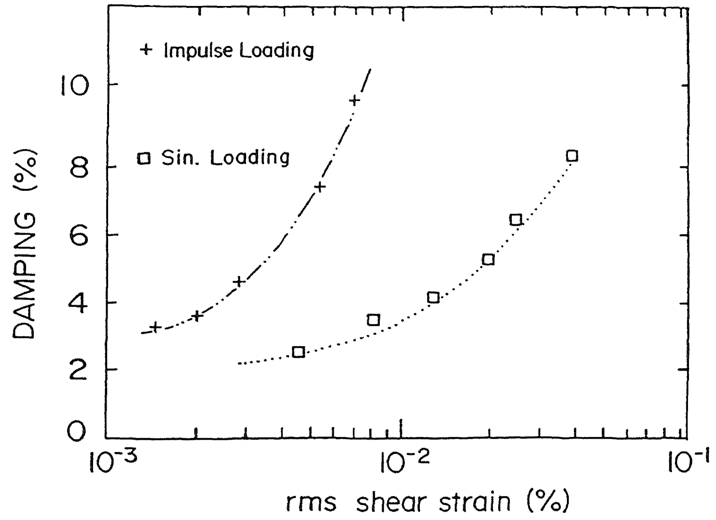

Fig. 3. Effect of type of loading on damping values as a function of rms strain (Confining pressure = 34.45 kPa)

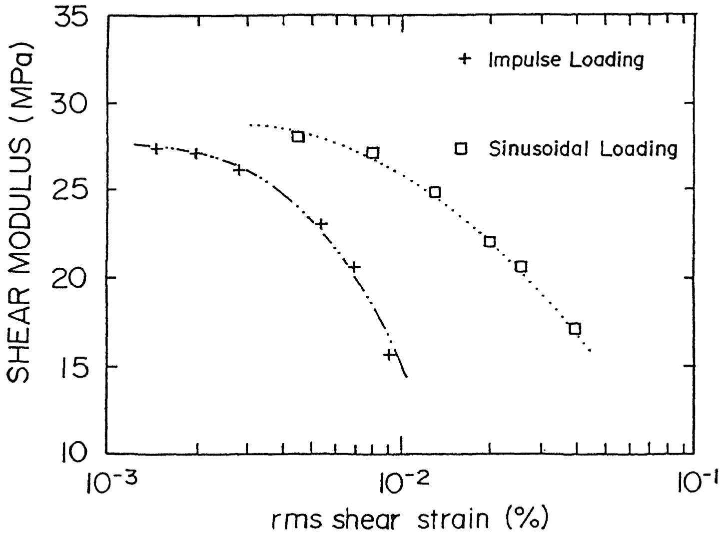

Fig. 4. Effect of type of loading on shear modulus as a function of rms strain (Confining pressure = 34.45 kPa)

CONCLUSION

It was found that impulse loading at different strain levels affects both the dynamic shear modulus and damping characteristics of cohesive soils. Shear moduli obtained from sinusoidal loading were higher than that obtained from impulse loading, while damping values were lower when determined from impulse loading than from sinusoidal loading. The differences increased as the strain amplitude increased. Thus corrections must be made when comparing data obtained from impulse field testing with that obtained from sinusoidal laboratory testing.

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