Use of Random Loading in Soil Testing

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Introduction

As more and more sophisticated analytical techniques to predict site respone to earthquake loading and soil-structure interaction are developed and refined, more accurate input parameters must likewise be obtained. One of the most important is the knowledge of the dynamic characteristics of the site material. Thus, considerable effort has been directed towards the development of, or improvement of, methods to determine the required dynamic soil properties for such analytical procedures (Richart et al. 1970, Yong et al. 1977).

The two primary dynamic soil properties are the shear modulus and the damping values, both of which depend on the magnitude of the strain and must be evaluated in terms of induced strain in a soil specimen or a soil deposit.

The dynamic shear modulus needed to evaluate local soil effects during large earthquakes are presently determined using laboratory techniques and in-situ tests. The soil damping properties for use in response calculations are presently determined using only laboratory techniques, as there is as yet no test for determining usable data in-situ.

One of the difficulties of field testing of damping is in the extracting of damping from the response signal of soil deposits subjected to random loading. The difficulty of analyzing random response is overcome by the use of a method called random decrement technique (Cole, 1971). It is a fast converging method for extracting meaningful information from random data. It is a process by which segments of the random vibration response of a transducer placed at a certain location in a soil deposit which is subjected to random excitation are ensemble averaged to form a signature which is representative of the free vibration decay curve at the location considered, from which damping and natural frequency could be identified. Thus, the two primary dynamic soil properties could be determined by the random decrement technique either in the laboratory or by field testing.

The objective of this work was twofold; first to determine the dynamic soil properties from both sinusoidal and random vibrations and to compare the results. This is important because almost all laboratory testing

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utilizes the same type of force excitation, namely sinusoidal loading, though loading such as earthquake loading is of a random nature. Thus, for the measured laboratory value of modulus and damping to be consistent with those occurring in the field during earthquakes, random loading should be used in laboratory testing. This objetive was accomplished by performing a comprehensive testing program covering a wide range of variables. The damping and modulus were calculated for both sinusoidal and random vibrations over a wide range of strains.

The second objective was to assure that extrapolation techniques of different field test data are correct, and to determine the relationship the laboratory determined properties bear to the field values the effect of the frequency content of the exciting random force on the dynamic soil properties was studied. The results of this study are presented in this paper.

In this study, the logarithmic decrement method was used in evaluating damping for sinusoidal loading because it utilizes the free vibration decay curve from which damping can be measured. The reason for using this method is that the random decrement method results in a signature that is the free decay curve from which damping and resonant frequency are also calculated using the logarithmic decrement method.

Experimental Program

The Drnevich resonant column apparatus was used in this study for evaluation of the dynamic properties.

For the sinusoidal loading test, the input signal was generated by a variable frequency sine wave oscillator. For the random vibration test, the excitation was provided by a random wave generator. The output of the random wave generator (white noise generator) was passed through a bandpass filter, then connected to the drive coils via a power amplifier. Response was recorded on a magnetic tape with an FM tape recorder. A schematic of the device used in this test program is shown in Fig. 1.

After construction of the sample and assembly of the apparatus, the random vibration was first applied by connecting the white noise generator to the driving coils. The amplitude of the response vibration was adjusted to a predetermined value of acceleration (root mean square, RMS) that was read on the multimeter. At each response level, the exciting force was also measured on the multimeter in terms of millivolts. The response signals at each level were recorded on the magnetic tapes. The recorded response signal was passed through a bandpass filter, then through a signal amplifier before it was fed into a micro-computer for discretization and digitization. The computer analysis was continued until 1000 segments or more had been ensemble averaged resulting in a random decrement signature.

By disconnecting the random wave generator and connecting the sine wave oscillator sinusoidal torques were appled to the soil sample. To accomplish comparison between the two vibration methods at the same strain value the response level was kept at the same RMS as that of the random excitation. The response signal at each strain level were then recorded on the magnetic tapes for later analysis in the computer.

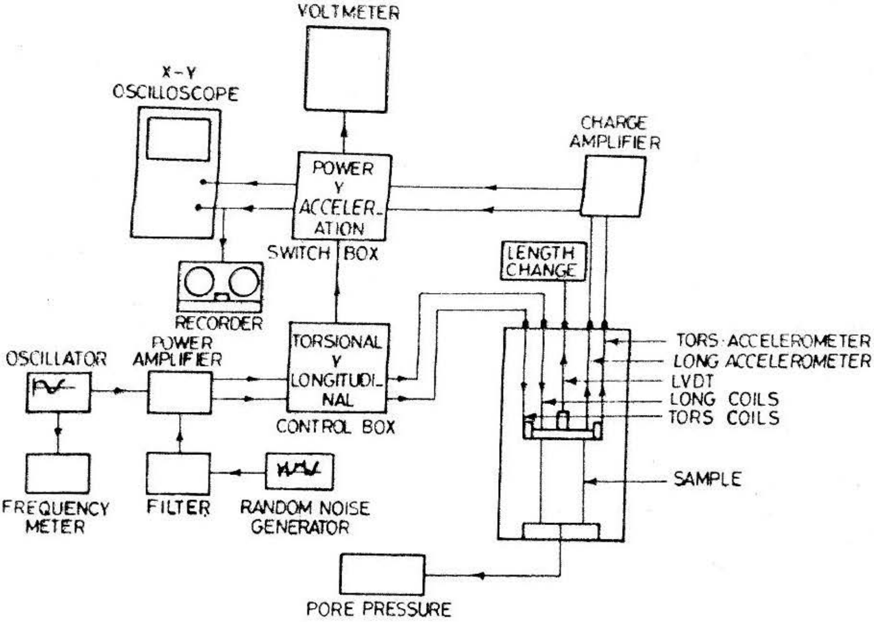

FIGURE 1 Schematic Diagram of the Resonant Column Electronics

The experimental program in this study was planned to explore the applicability of the random decrement method in measuring the dynamic properties of soil samples in the laboratory. To accomplish this task, it was necessary to perform tests that cover a wide range of varibales. The results of such tests will clarify the applicability and limitations of the random decrement technique and the conditions under which it is valid.

Three different sands were used in this investigation. The general description of these sands is discussed below.

Ottawa Sand—Ottawa sand passing the No. 16 sieve and retained on the No. 30 sieve was used. It has an effective grain size of 0.6 mm and a uniformity coefficient of 1.2. The minimum and maximum void ratios that were obtained in this study were 0.52 and 0.58 respectively.

Monterey #O Sand—The Montery #*O* sand was obtained from the National Bureau of Standards. In this research, the minimum void ratio obtained was 0.59 and the maximum void ratio was 0.69.

Georgia Sand—The Georgia sand was used to study the effect of the size of grain particles on the dynamic soil properties. This sand was categorized into three groups. Group one included particle sizes passing sieve No. 16 and retained on sieve No. 30, group two included particles passing sieve No. 30 and retained on sieve No. 50 and group three included particles passing sieve No. 50 and retained on sieve No. 100. All three groups had void ratios close to each other, the void ratios were 0.77, 0.76 and 0.78 respectively.

Five series of dynamic tests were performed in this study. A detailed description of these tests follows.

Series I—Tests in series I were performed to determine the variation of damping and shear modulus with confining pressure. The three levels of confining pressure were 15, 25, and 35 psi (103, 172 and 241 kN/m^2). All other tests were run under 15 psi confining pressure.

Series II—Tests in this series were designed to study the effect of the previous strain history. In some of the tests sinusoidal vibration were first applied followed by the random vibrations. In others random vibrations were first applied on the specimen and then sinusoidal vibrations were applied. To be consistent and to avoid the effect of number of cycles, the number of cycles was kept at about 1000.

Series III—Tests in this group were run to determine the effect of the frequency content of the exciting force on the dynamic characteristics of sand under random vibrations. The signal from the white noise generator was passed through a low pass filter before being connected to the drive system. The low pass frequencies, which will be called cut off frequency f_c, used in this series were 50, 200, 1000 and 2000 Hz, whereas the cut off frequency used in all other series was 1000 Hz. In all cases, the high pass frequency was zero.

Series IV—Sepecimens of dense and loose sands were tested in this series. All other tests were run on loose samples.

Series V— Group V tests were run to study the effect of grain size on the values of damping and shear modulus. Three different sizes of Georgia sand were tested. Included were sizes passing No. 16 and retained on No. 30, passing sieve No. 30 and retained on No. 50, and passing sieve No. 50 and retained on sieve No. 100.

In all of the above test series, the magnitude of shear strain was varied from approximately 1.5×10^{-3} percent to 4×10^{-2} percent to study the effect of shear strain amplitude on the dynamic properties of the soil.

Results and Discussion

The computer generated power spectral density curve of one of the tests is shown in Fig. 2. This frequency spectrum was found through the computer analysis of the recorded response of a sample undergoing random vibration. A typical random decrement free vibration decay curve is shown in Fig. 3. Decrement coefficient were then calculated from the logarithmic decrement of the random decrement free response curve.

Figure 4 shows the damping values of sands used by both the sinusoidal and random vibration. As can be seen, good correlation exists between both the methods. In all cases, damping values obtained from random loading were slightly higher than those obtained from sinusoidal loading. On the other hand the shear modulus values obtained from the two loading types agree strongly with each other (Fig. 5.)

The confining pressure effect on damping is shown in Fig. 6. It

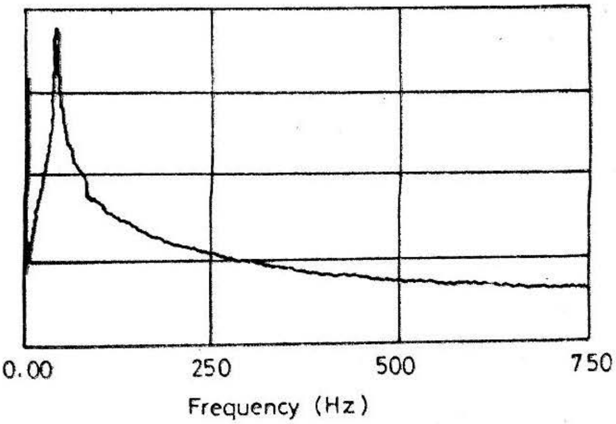

FIGURE 2 Power Spectral Density Curve

shows that damping decreased as the confining stress increased for both loading types. As for the effect of the confining pressure on shear modulus it can be seen from Fig. 7 that both loading types showed the same trend.

The results of the effect of strain history, density and grain size also showed good agreement between the two types of loading.

When the effect of different cut-off frequencies was investigated, the results (Fig. 8) showed that the higher the frequency content of the exciting load the closer was the agreement of the damping ratios from the sinusoidal and random loading. Thus, the exciting forces currently in use in field testing of soils will indicate higher damping values than if sinusoidal loading is used. That is, field testing should be corrected to obtain damping for white noise excitation unless the field loading used itself is a white noise. The cut-off frequencies meanwhile, showed a slight influence on the shear modulus (Fig. 9).

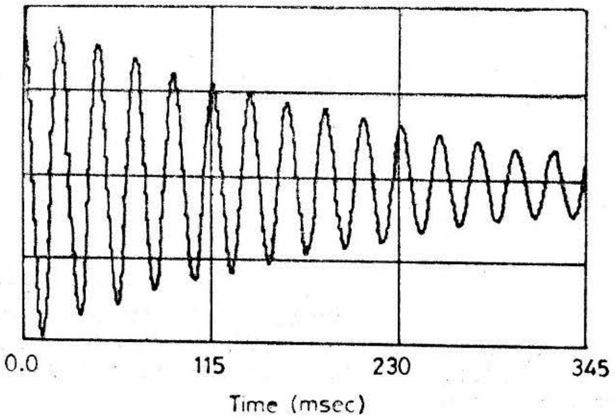

FIGURE 3 Random Decrement Free Vibration Decay Curve

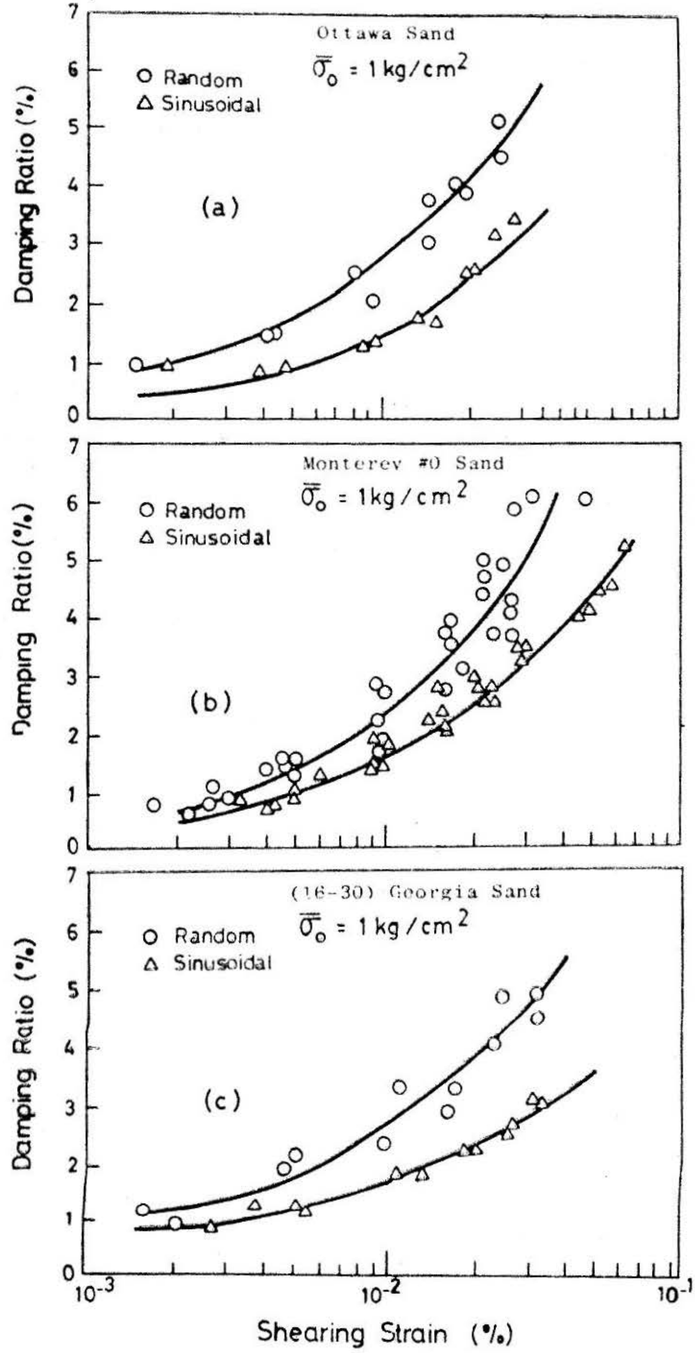

FIGURE 4 Effect of Shear Strain Amplitude on Damping Ratio

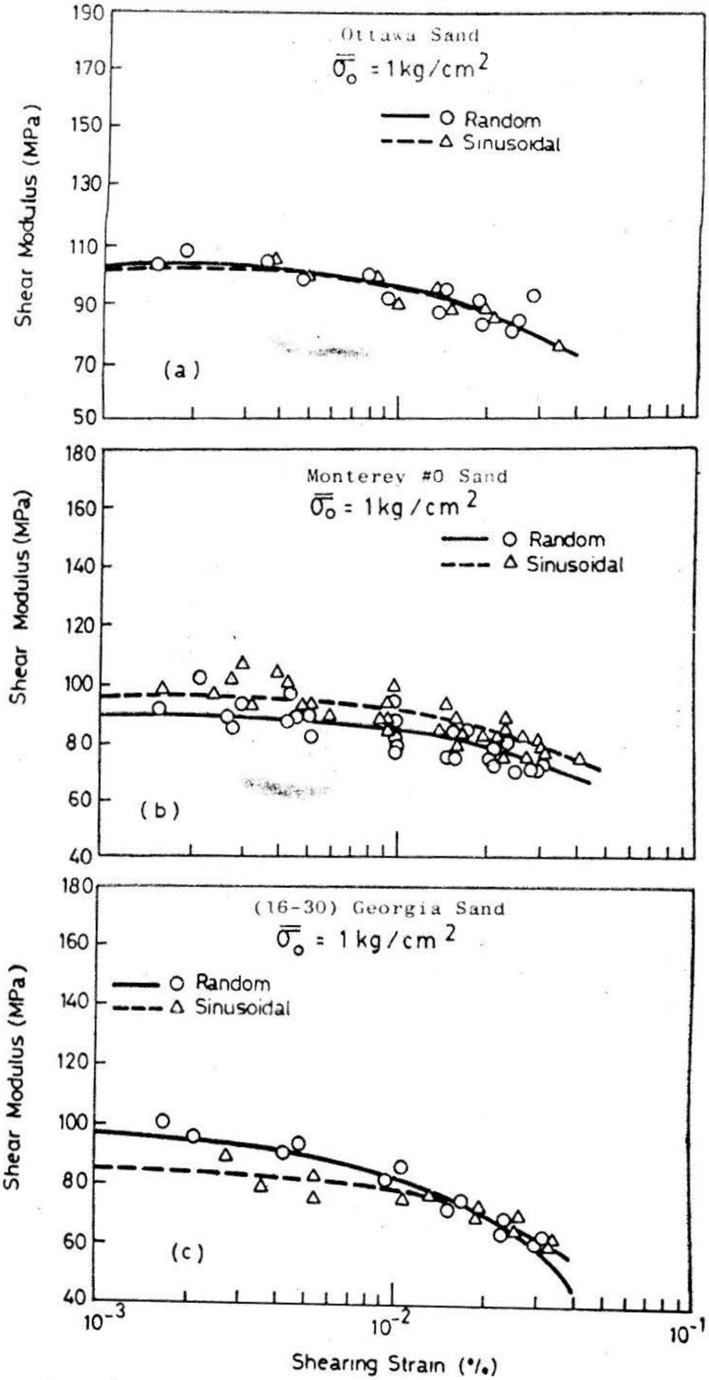

FIGURE 5 Effect of Strain Level on Shear Modulus

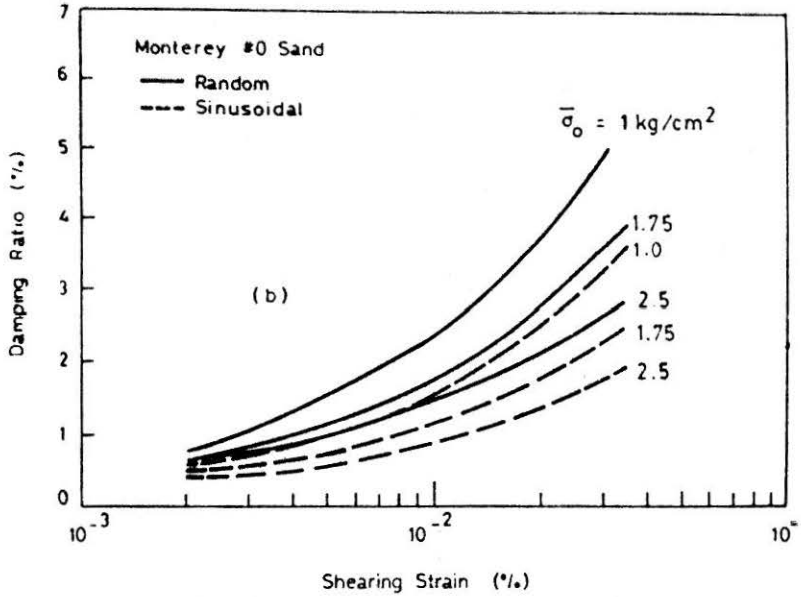

FIGURE 6 Effect of Effective Confining Stress on Damping Ratio of Monterey # 0 Sand

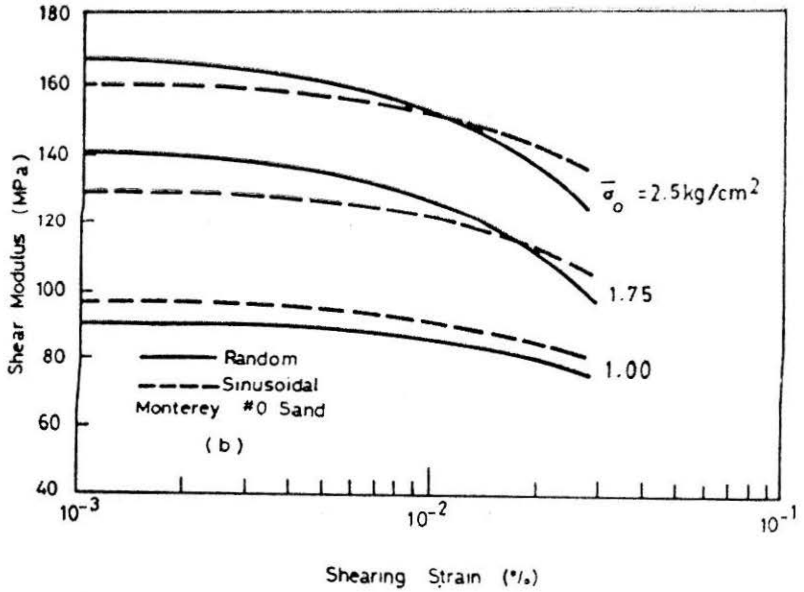

FIGURE 7 Effect of Effective Confining Stress on Shear Modulus Monterey # 0 Sand

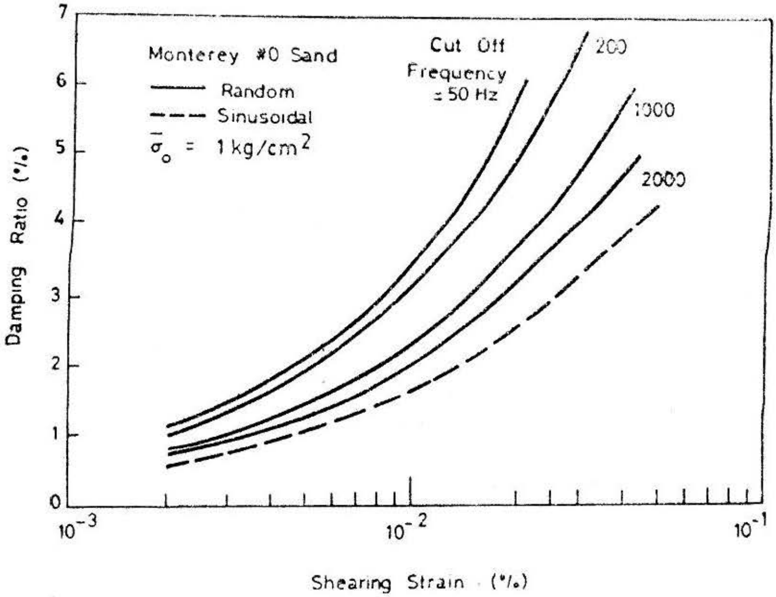

FIGURE 8 Effect of Cut-off Frequency on Damping Ratio

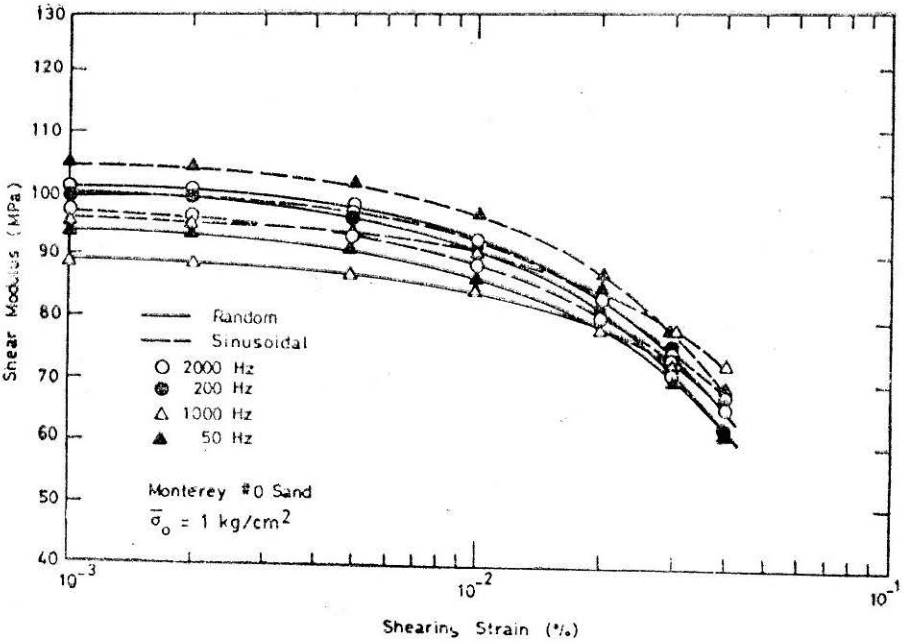

FIGURE 9 Effect of Cut-off Frequency on Shear Modulus

Conclusion

The data from the experimental program showed a good agreement between the modulus and damping obtained from the application of sinusoidal or random loading. That is, the dynamic properties of dry cohesionless soil were not influenced by the type of loading applid within the range of variables tested.

The effect of the variation of the frequency content of the random loading to simulate the impulsive type loading used in field testing of soil was considered by passing the random signal through a filter before connecting it to the drive system. By varying the cut-off frequency of the bandpass filter; it was found that the damping values obtained by the random decrement technique increased as the cut-off frequency decreased. However the shear modulus was not affected.

REFERENCES

COLE, H.A. (1971) : "Methods and Apparatus for Measuring the Damping Characteristics of a Structure," *United States Patent No. 3620069.*

RICHART, F.E., HALL, J.R. and WOODS, R.D. (1970) : "*Vibration of Soil and Foundations,*" Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

YONG, R.N., AKIYOSHI, T. and JAPP. R.D. (1977) : "Dynamic Shear Modulus of Soil Using a Random Vibration Method," *J. of Soil and Found.*, Japanes SSMFE, 17:1.