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APPLICATION OF THE RANDOM DECREMENT TECHNIQUE IN THE DETERMINATION OF DAMPING OF SOILS

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SUMMARY

The purpose of this investigation is to examine the feasibility of using a new analysis technique called Random Decrement to accurately extract damping coefficients of soils from random input excitation. The damping coefficient of soil was determined in the Drnevich resonant column apparatus. In the testing, the frequency of the sinusoidal excitation was first varied to produce resonance and the damping was then determined from the frequency response curve and also from the logarithmic decrement of the free response curve. By disconnecting the sine-wave generator and connecting a white noise generator, damping values were then redetermined by the random decrement technique. From the limited data obtained to date, good correlation between the two cases has been indicated. However, an extensive experimental program that encompasses all variables that affect damping of soils is needed for verification of the applicability of the technique. Nevertheless, the initial data indicated that the possibility of in-situ determination of damping can be realized.

INTRODUCTION

As more and more sophisticated analytical techniques to predict site response 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 use in such analytical procedures (6,7,8,9).

The dynamic shear modulus needed to evaluate local soil effects during large earthquakes are presently determined using laboratory techniques and in-situ tests. An in-situ test to determine the shear modulus of a soil deposit at strain levels equivalent to those experienced during a strong earthquake has recently been developed (10,11), whereas 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.

The purpose of this investigation was to examine the feasibility of using a new analysis technique called Random Decrement Technique to accurately extract damping coefficients of different soil types from their

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response to random loading. The validity of the technique will allow us to be able to extract the damping coefficient of different soil types from in-situ records; hence, a field testing for determining damping will be a reality.

Random Decrement analysis is a method currently used in the aerospace industry to measure damping in aircraft in flight. It is a simple, direct and precise method for translating the response time history into a form meaningful to the observer. It has been developed over the past few years for measurements of damping in different types of structures subjected to random excitation when only response data is available. After analysis, a signal results that is the free vibration response of the structure. This signal is independent of the input to the structure and represents that particular structure tested for a linear system and an equivalent structure for non-linear systems.

The basic concept of the "Random Decrement signature" is based on the fact that the random response of a structure is composed of two parts: a) a deterministic part (impulse and/or step function), and b) a random part. By averaging enough samples of the same random response, the random part will average out, leaving the deterministic part. It can be shown that by proper digital processing, the deterministic part that remains is the free decay response from which the damping can be measured. Hence the Random Decrement Technique uses the free decay responses of a system under random loading to identify its vibration parameters, namely frequencies and damping.

In this study, damping characteristics were determined by the resonant column test first under sinusoidal excitation, and then by disconnecting the sine-wave generator and connecting a white noise generator damping of the soil was then redetermined. The validity of the method was then assessed based on the comparison of the two methods.

ANALYTICAL PROCEDURE

"Random Decrement" has been developed and explored initially by H. Cole (2) and continued by J.C.S. Yang (12,13,14,15,16), which advanced the state-of-the-art in the measurement of damping in structures subjected to random excitation when only response data is available. After analysis, a signal results that is the free vibration response of the structure. This signal is independent of the input of the structure and represents that particular structure tested. It was originally developed as a technique for determining damping characteristics of models being tested in wind tunnels (2,3). Subsequently, the method is being used to measure damping in buildings, machinery systems, etc. The method is currently used in the aerospace industry to measure damping in tunnel models and aircraft in flight (1). Also, the detection of small flaws (fatigue cracks, etc.) is possible by monitoring the high frequency characteristics of structures (3, 4, 5). This application is now under development for detection of cracks in highway bridges carrying traffic, and in offshore platforms (13, 15). In fact, the technique is a general method of analysis that is applicable to the wide class of problems in which a system is subjected to an unknown random input and the only measured quantity is the system response. The procedure itself is a linear, ensemble averaging technique that requires less computer time than the conventional spectral or correlation approaches.

The analysis of the system response yields a signature that is dependent on the system characteristics and is relatively independent of the excitation. This signature represents a free vibration response curve of the actual structure for a linear system and of an equivalent structure (i.e., averaged nonlinear properties which reflect actual energy dissipation, etc.) for nonlinear systems.

Fig. 1 shows the procedure for obtaining a signature. A time history (velocity, acceleration, strain or displacement, etc. versus time) is divided into an ensemble of segments of equal lengths, τ_{max}, each beginning at a selected amplitude y_s (or for example, $\ddot{y}_s$, if the time history is in terms of acceleration). Also, the segments are chosen such that half the segments have an initial positive slope and the other half have an initial negative slope. These segments are then ensemble averaged to give a signature of length τ_{max} whose initial amplitude is y_s. The initial slope is zero since an equal number of positive and negative slopes will, for most systems, average to zero.

For a linear single degree-of-freedom system, the signature becomes the damped cosine wave describing the motion when the system is subjected to the initial displacement y_s and then released. In practice, however, linear systems have many degrees of freedom and the signature is a combination of modes, although it still represents the free vibration response to an initial displacement. For multi-mode problems, the response records will be bandpass filtered to isolate different frequency bandwidths. Damping values will be calculated for each case to obtain the variation of damping with amplitude and frequency. For nonlinear systems, the signature represents the free vibration response of a system in which the nonlinear properties are averaged to a value dependent on the amplitude.

The starting value y_s can be chosen arbitrarily. The freedom to select the initial value (bias level) is one of the main advantages of the method. If the record is nonstationary and contains periods of low level vibration in which the signal-to-noise ratio is very low, the initial amplitude can be chosen above this level and the low amplitude portion of the record is disregarded.

The accuracy of the signature depends on the record length in terms of the number of cycles of data. The convergence is fast (5) which is important when analyzing records of marginal length.

The advantage of the Random Decrement Technique is that it is a simple, direct, and precise method for translating the response time history into a form meaningful to the observer. In comparison to the spectral power density method, where damping is measured by the half-power bandwidth method, it was found that the method showed a large measurement variance, especially when the bandwidth was small or the spectral peak was not well defined. In addition, when two modes are close, the classical method cannot be applied. In the Random Decrement Technique as part of the analysis, the records can be filtered to isolated modes if the modes are not too close together. When the modes are close together, a numerical curve fitting technique (14) can be applied to the Random Decrement signature to separate the modes and extract the damping ratios.

RESONANT COLUMN TEST DEVICE

The applicability of the random decrement technique on the determination of damping of undisturbed and remolded soils can be determined by a variety of laboratory testing methods. The most widely used methods are cyclic triaxial shear, cyclic simple shear, cyclic torsional shear, and resonant column.

The resonant column method is a relatively nondestructive test. The primary advantage of using this device as the main testing method in this work is that at very small shearing strains, less than 0.001 percent damping value can be obtained from a soil specimen by both the resonant frequency and the random decrement methods consequently at different intervals of time without introducing the effects of previous measurements at that pressure. An additional advantage of the resonant column test device is that damping can also be determined at higher shearing strain levels (0.01 to 1.0 percent) and, in such cases, a new sample can be prepared for either case.

The resonant column test method determines modulus and damping in soils by means of propagating waves in a cylindrical soil specimen. If a torque is applied to the specimen, shear waves are propagated and if a sinusoidal axial compression is applied, compressional waves are propagated. In the test, the frequency of the forced vibration is varied until a resonant condition is attained. The resonant frequency plus the magnitude of applied longitudinal impulses or torsion and the magnitude of the resulting motion are used to calculate the modulus, damping and strain amplitude. When torsion is applied, shear modulus and damping are obtained as a function of shear strain amplitudes. When axial impulses are applied, Young's modulus and damping are obtained as a function of axial strain amplitude. To date, several resonant column devices have been developed. The general theory for each of these devices is essentially the same. However, the physical details, such as end conditions, specimen geometry, and methods of excitation, vary.

The resonant column apparatus at the Civil Engineering Department of the University of Maryland is the "Drnevich" device. The device consists essentially of a coil-magnet drive system which is attached to a top cap seated on a membrane-encased cylindrical soil specimen, a transducer to monitor the motion of the drive system, a linear variable differential transformer (LVDT) to detect the vertical height change of the soil specimen, and a confining chamber.

TESTING PROCEDURE AND RESULTS

The soil specimen was made of sand, chosen basically as one which had been tested by other researchers, and whose characteristics have been determined and reported in the literature. This was done for verification of our data from the resonant column test.

In the resonant column, the samples were twisted at the top by sinusoidal forces through the magnetic coils under uniform confining pressure. The frequency of excitation was adjusted to produce resonance of the system. Damping was then determined using the steady-state method and also from the decay of free vibration.

In the next step, by disconnecting the sine-wave generator and connecting a white noise generator, random forces were then applied on the soil sample. The damping values were then redetermined by the random decrement technique.

The frequency spectrum of the system was found through computer analysis of the recorded signal for the sample undergoing random excitation. Fig. 2 shows a computer generated power spectral density curve of one of the tests. From the power spectral density curves appropriate narrow band filters were selected to isolate individual modes for random decrement analysis. A typical random decrement free vibration decay curve is shown in Fig. 3. Damping coefficients were then calculated from the logarithmic decrement of the random decrement free response curve.

Fig. 4 shows the damping values of soil by both the sinusoidal vibration computed from the resonant frequency of the soil sample and that from the random vibration by the random decrement method. As can be seen, good correlation exists between both methods. Though not all variables have been studied, the initial results lend credibility of the method and therefore, the ability to detect damping from random signals.

CONCLUDING REMARKS

Determination of the feasibility of the use of Random Decrement for the determination of the damping characteristics and natural frequency of soil samples in the laboratory will lead to a credible application of the Random Decrement technique for samples in the field. Thus, field testing for the determination of damping will be a possibility. The significance of field determination of damping is of importance since existing information on damping is based on laboratory test results which are complicated by specimen disturbance, the inability to reapply the natural in-situ stress conditions to the test specimen and the inability to account for the cementation that exists in natural soil, in the laboratory samples.

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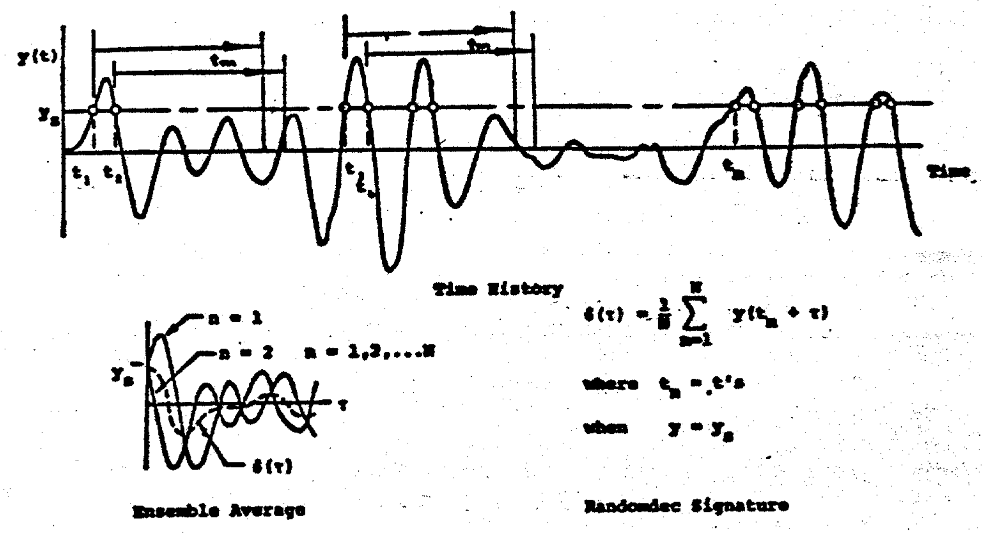

Figure 1 - Evolution of Randomdec Signature

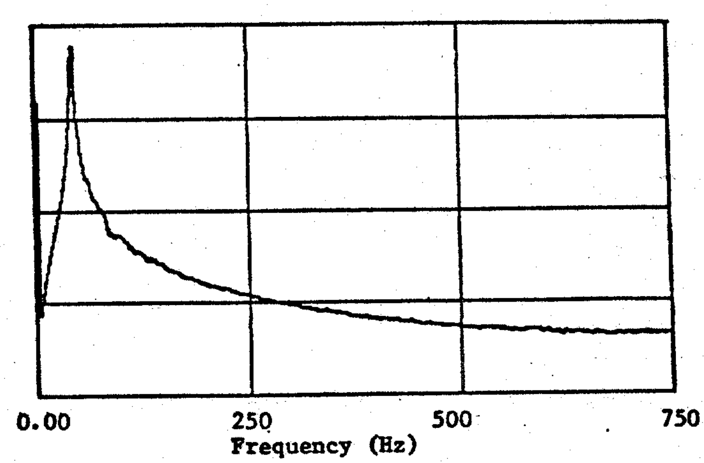

Figure 2 - Power Spectral Density Curve

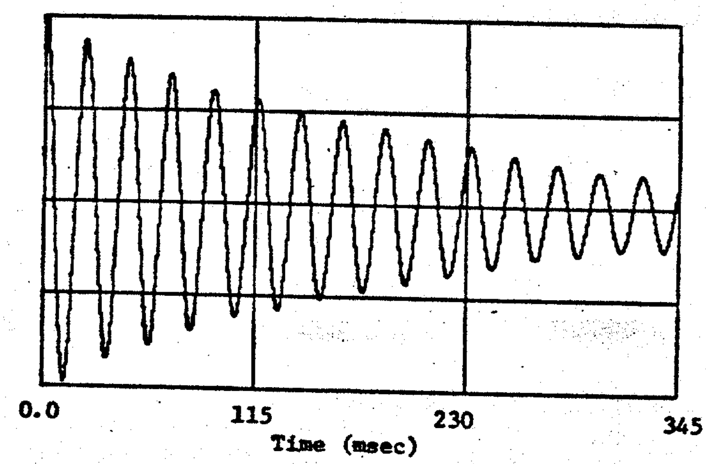

Figure 3 - Random Decrement Free Vibration Decay Curve

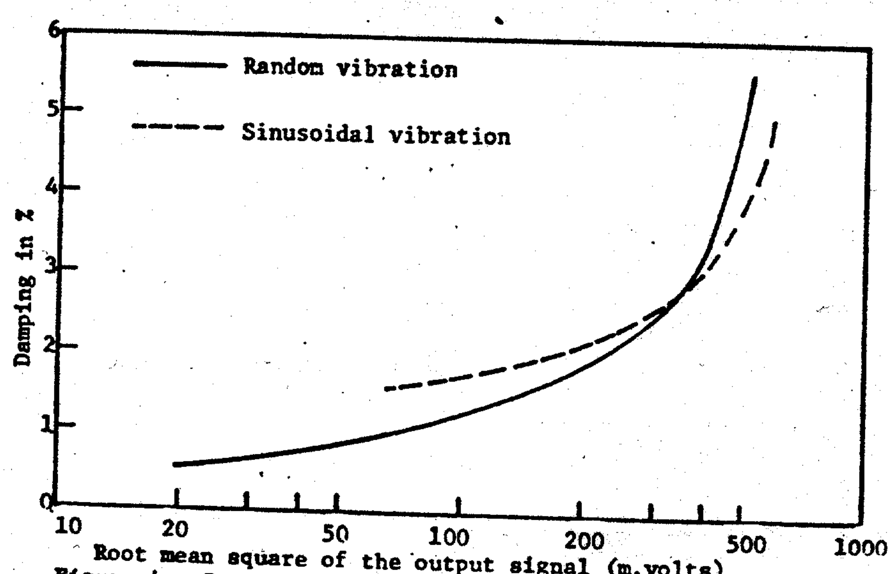

Figure 4 - Comparison of Damping Values Obtained from Random and Sinusoidal Vibrations at Different Levels of Strain