A STATISTICAL STUDY ON ARTIFICIALLY GENERATED EARTHQUAKE RECORDS

by

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ABSTRACT: A statistical study has been done to investigate (i) the variation of spectral responses of structures due to artificially generated earthquake records with identical statistical properties, (ii) the effect of duration of strong shaking phase of artificial earthquakes on the response of structures, and (iii) the number of earthquake records needed for time-history response analysis of a structure in a seismic region. The results indicate that the flexible structures are more sensitive to the inherent statistical variations among statistically identical earthquake records. Consequently several records must be used for time-history response analysis. A sample of eight or more records appear to provide a good estimate of mean maximum response. The duration of strong shaking can significantly affect the maximum response. Based on the results, it is suggested that for the purpose of estimating peak response, the strong shaking duration of the input earthquake motion should be at least three times the natural period of the structure. As the maximum responses due to statistically identical ground motion records are observed to be approximately normally distributed, it is rationally possible to choose a design value based on the mean, standard deviation of the spectral response values and tolerable probability of exceedance.

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INTRODUCTION

One of the important problems in aseismic design is the choice of a loading condition which must account for the effect of earthquakes the structure is likely to encounter during its serviceable life. At present three alternatives are available to the designer. Arranged in the order of increasing complexity, these alternatives are: the quasi-static equivalent load approach as given in National Building Code of Canada (5) and other building codes, a dynamic approach employing the response spectrum technique (2), and finally a complete dynamic analysis to determine the time-history response of the structure.

In many situations a complete dynamic analysis for determining the time-history response is the only approach suitable in estimating the seismic loading. For example, in the study of multi-degree of freedom system allowing for yielding of components in the system, the validity of response spectrum technique becomes unclear. Another example can be found in the design of mechanical and electrical equipments to be used in nuclear powerplants. These equipments are generally complicated structures and have to satisfy certain stringent requirements during an earthquake . Mathematical modelling of such structures are in general complex. The difficulty is further compounded by the uncertainty in the estimation of the amount of damping present in the equipment. These two difficulties make the use of the response spectrum technique unsuitable. One viable way to ensure satisfactory performance is proof testing of such equipment under simulated seismic conditions.

Whether a time-history dynamic analysis is carried out by computation or by experimentation, it is necessary to use a ground motion record input to excite the system under study. The reliability of the analysis then depends on the proper choice of the input earthquake record. Due to the limited number of actual earthquake records available, earthquake ground motion records have been generated by computer simulation (1, 7). These simulation techniques assume that the ground motion at a given site is a random process with specific statistics. The statistics commonly used are the peak acceleration, and the predominant period. More recently, other statistics such as the duration of strong shaking, the manner in which the ground motions build-up and decay are used (4, 8).

The present paper is a statistical study on artificially generated earthquake records. The purpose of the study is to provide answers to the following questions:

(i) Within a sample of artificially generated records with the same statistics, what sort of variations among records can be expected?

(ii) What is the effect of duration of strong shaking on the response of structures?

(iii) How many earthquake records are needed for time-history analysis in order to obtain a reliable estimate of seismic loads?

COMPUTER SIMULATED EARTHQUAKE RECORDS

The procedure used to generate earthquake records is similar to that suggested by Ruiz and Penzien (8). The acceleration at bedrock is simulated by a Gaussian shot noise obtained as the product of a stationary white noise of given intensity and a deterministic function of time. This deterministic function of time essentially controls the duration of strong shaking, and also the manner in which the motions build-up and decay. The filtering effect of a soil layer is simulated by a damped linear single degree of freedom system. The natural frequency and damping of this filter are chosen to approximate the predominant effect of the fundamental modes in the behaviour of the soil layers. The bedrock motions generated are fed at the base of this single degree of freedom system and the response of this system is taken as the earthquake motions at the ground surface. Therefore, in the generation of artificial earthquake records, it is necessary to supply the following pieces of information:

(i) the maximum acceleration,

(ii) the characteristics of the filter, i.e. natural frequency and damping value of the single degree of freedom system,

(iii) the duration of strong shaking, and

(iv) the manner in which the motions build up to and decay from the phase of strong shaking.

In Canada, guidance of the anticipated maximum ground acceleration at a given site can be obtained from the EMR Earthquake Probability Analysis (9). Depending on the local geology and soil conditions at the site one can estimate the appropriate frequency and damping value to be used in the second order filter (3). However, there is less guidance on the choice of duration of strong shaking and the proper envelope function to describe the build-up and decay of ground motion. From the standpoint of structural response it is felt that the duration of strong shaking has a more predominant role than the manner in which the motions build-up and decay. Therefore, it is assumed in this paper that the maximum acceleration value, the ground filter frequency, and damping are predetermined. The key parameter of study is the effect of duration of strong shaking on structural responses. In all the samples of simulated earthquake records used in this study, negligible build-up and decay time of 0.01 second is used and all records are scaled to a peak acceleration of 10%g. A value of 0.6 as the fraction of critical damping and a period of 0.4 second are used as the filter characteristics. The pseudo velocity spectrum hereafter referred as velocity spectrum, is used as a measure of structural response. The velocity spectrum responses are computed for 2% critical damping.

RESULTS AND DISCUSSION

The velocity spectra of eight statistically identical simulated earthquake records are shown in Fig. 1. These ground motion records have a strong shaking duration of six seconds. Considerable scatter exists between the individual curves and the average curve. This is particularly true at longer periods of $T > 0.4$ sec. In other words, flexible structures are more sensitive to the inherent statistical variations among statistically identical records than stiff structures. In the design context, therefore, one should be more careful in interpreting results based on a single record analysis, if the structure is flexible. As seen from Fig. 1, a difference of plus or minus 100 per cent from the mean is not uncommon. In this case, a designer can either design prudently, or obtain more results based on other similar records to obtain a statistical average.

Figure 2 shows the statistical variation of mean spectral velocity responses of seven ensembles of eight records each. Each of these ensembles was obtained with a different seed and thus represent random samples of the population of artificial earthquakes under study. It may be noted that though there is a large variation in spectral values for different records within an ensemble (Fig. 1), the variation in means of different ensembles is relatively small (Fig. 2). The narrow band of scatter also suggests that an ensemble of eight records could be considered as a reliable sample from the population of artificial earthquakes of identical statistical properties.

The effect of duration of earthquake motion on the velocity spectrum is shown in Figure 3. Each of the curves shown represent average spectral values from eight statistically identical samples of ground motion excitation of a specified strong shaking duration. The following observations are made about the effect of strong shaking duration.

(1) In general, an increase in the duration of strong shaking causes an increase in the spectral value. This is particularly true for structures with periods greater than 0.4 sec.

(2) The velocity response of a structure depends on the duration of strong shaking in the following manner. If the duration of strong shaking is short compared with the natural period, say up to 2 to 3 times the natural period, the response is generally small. This is due to the fact that a large response usually needs a few cycles of motion before it can be built up. One may therefore conclude that for a reasonable estimation of the peak response of a structure, the strong shaking duration of the input earthquake motion should be at least three times the period of the structure.

Assuming appropriate values are used for the maximum acceleration, and the filter characteristics i.e. damping and frequency, the job of interpreting the results obtained by using artifically generated earthquake records still remains. This is because as shown earlier, variation in maximum responses computed from statistically identical records exists. Proper interpretation of results can be obtained only if the frequency distribution of the velocity spectral values are known. Based on computer simulation, the frequency distribution histograms of spectral velocity values for structures with periods of a half, one, and two seconds are shown in Fig. 4. The sample size in each case is 64. All records have a strong shaking duration of 6 seconds. Normal curves with appropriate mean and standard deviation are superimposed onto the histograms. A comparison between the fitted normal curve and the histogram suggests that the distribution of spectral values, and hence the maximum response of the structure, is approximately normally distributed. If this postulate is accepted, then, one can rationally interpret the results of the analysis based on artificially generated earthquake records. For example, if a structure is subject to n different, but statistically identical artificially generated ground motion records, one obtains n different values of response, each being the maximum response due to one ground motion record. The mean $\overline{x}$ and standard deviation s of these maxima can then be calculated. Probability statements can then be made on the chosen design value. For example there is a 50% probability that the response of the structure will exceed the design value if the design value chosen is $\overline{x}$, while the probability of exceeding the design value is reduced to 16% if the design value is taken to be $\overline{x} + s$.

It is of interest to note that similar observation on the distribution of spectral values has been made by Newmark, Blume and Kapur (6) on analyzing response spectra from real earthquake records.

CONCLUSION

A statistical study is made on the maximum responses of single degree of freedom systems under excitation from artificially generated earthquake records. The findings are:

(i) Flexible structures are more sensitive to the inherent statistical variations among statistically identical records. As a result, for the purpose of estimateing earthquake loading, they should be analyzed more carefully by subjecting them to excitations from several ground motion records.

(ii) A sample size of eight records or more appears to provide a good estimate of mean maximum response.

(iii) The duration of strong shaking can significantly affect the maximum response. To obtain a reasonable estimate of the peak response, the strong shaking duration of the input earthquake motion should be at least three times the natural period of the structure.

(iv) The maximum responses due to statistically identical ground motion records are approximately normally distributed. Therefore, it is rationally possible to choose a design value based on the mean, standard deviation of the maximum response values and the tolerable probability of exceedance.

Since earthquake ground motions are very complex and the present state-of-art does not allow an accurate determination of such motion, it is believed a nondeterministic approach to study the structural sensitivity to ground disturbance is a promising way to obtain design load value for accounting the effects of earthquakes.

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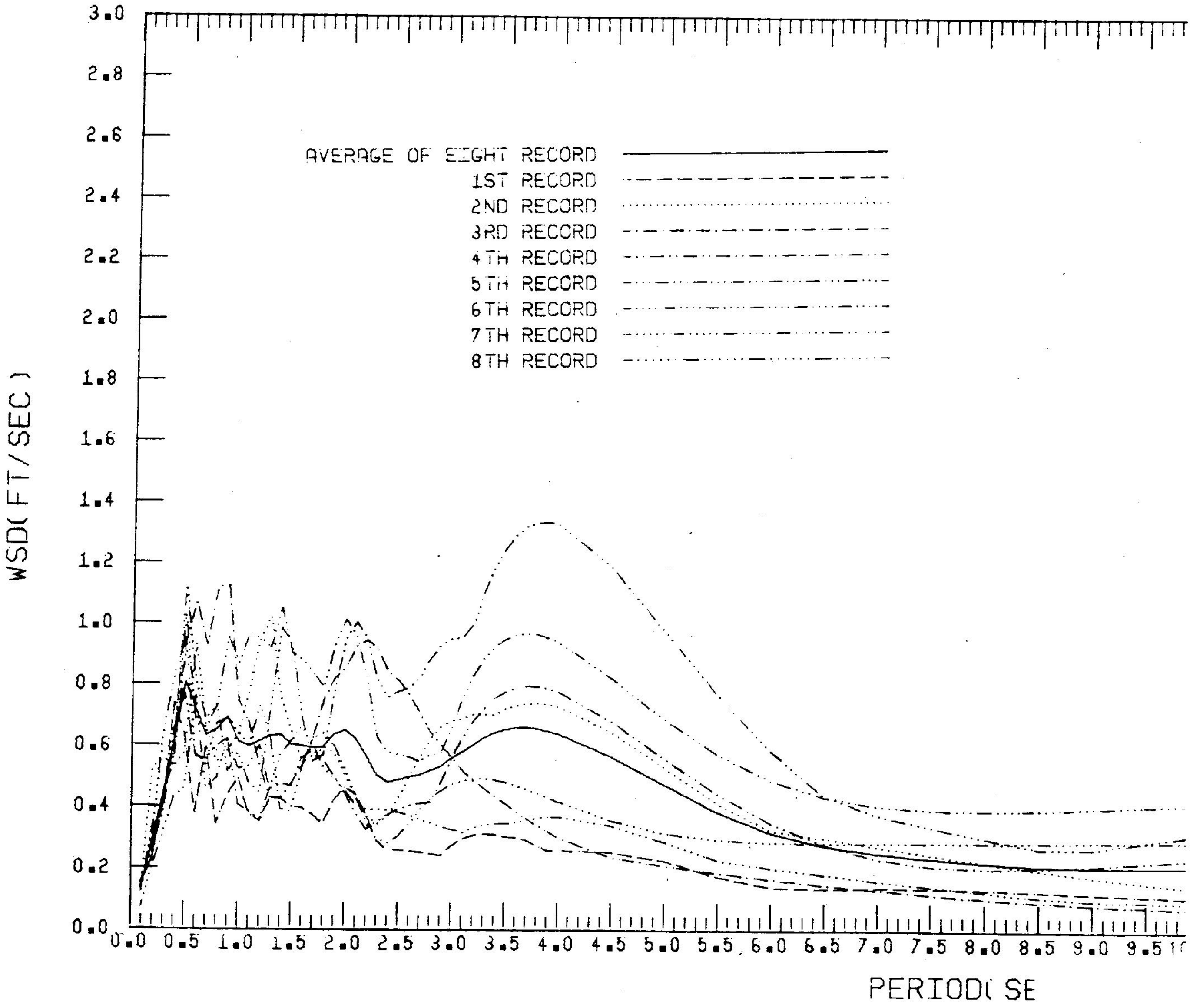

FIG. 1 VARIATION IN SPECTRAL VELOCITY RESPONSES OF STATISTICALLY IDENTICAL EARTHQUAKE RECORDS

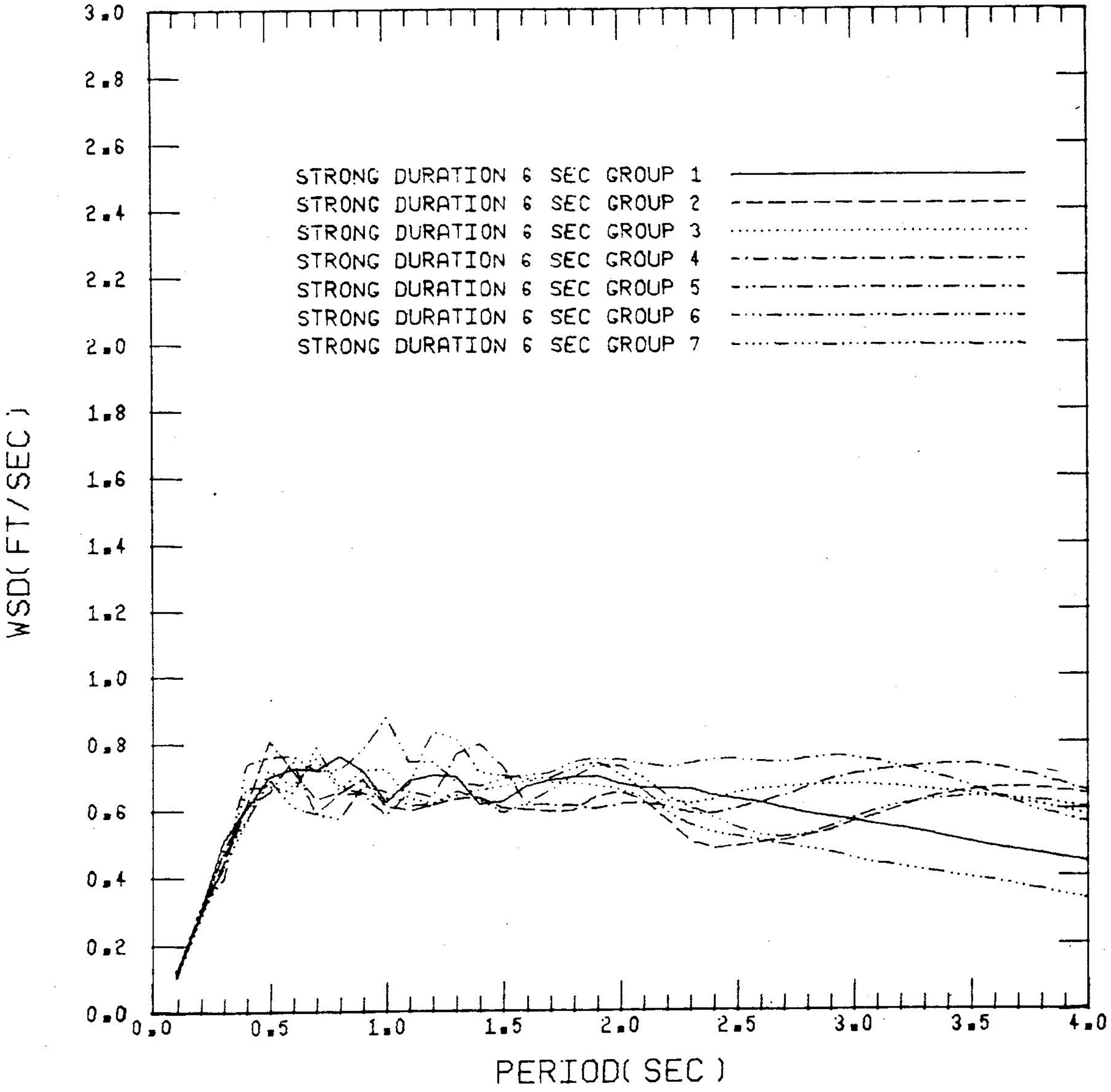

FIG. 2 VARIATION OF MEAN SPECTRAL VELOCITY RESPONSES OF STATISTICALLY SIMILAR ENSEMBLES OF EARTHQUAKE RECORDS

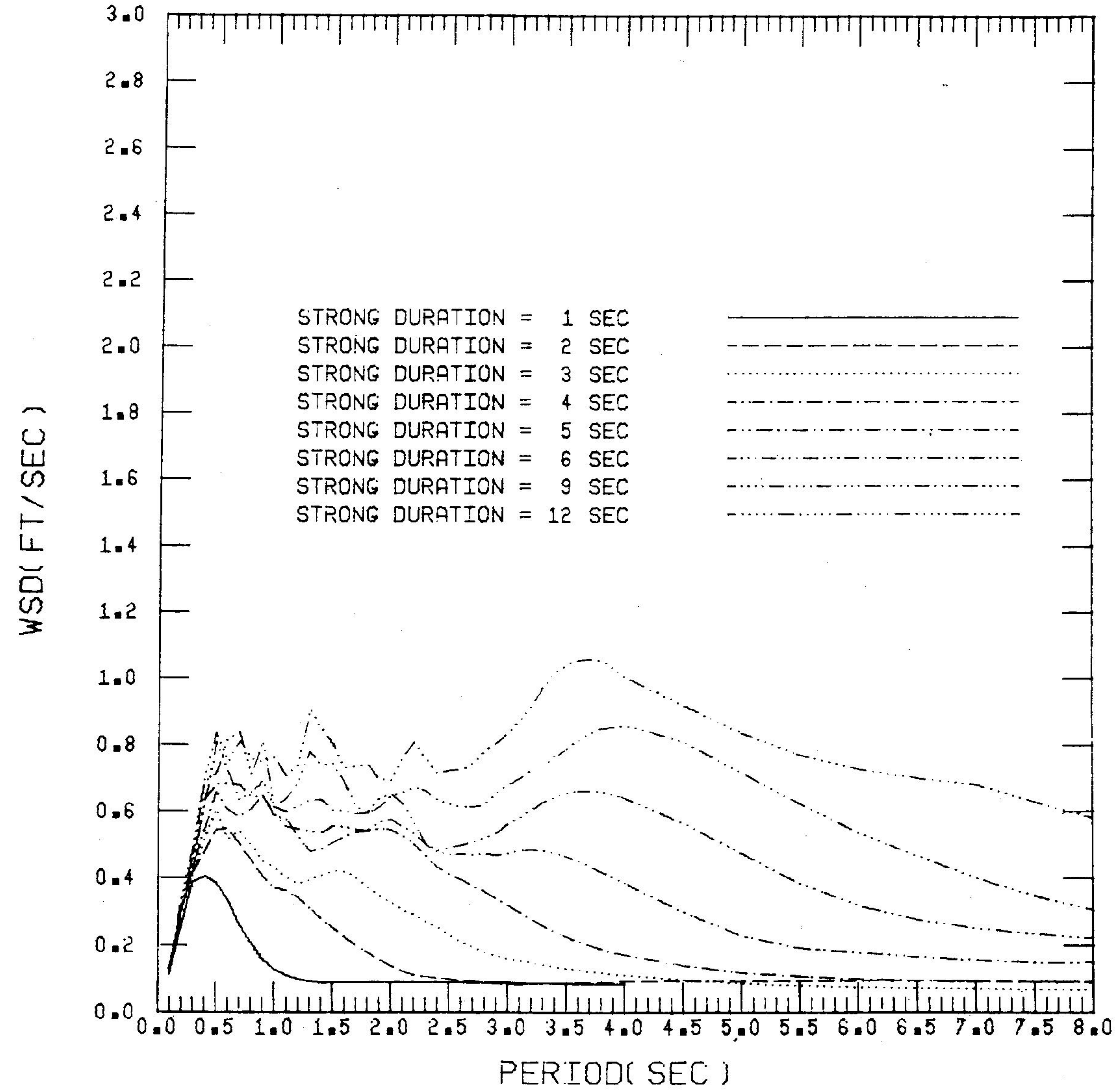

FIG. 3 THE EFFECT OF DURATION OF STRONG SHAKING

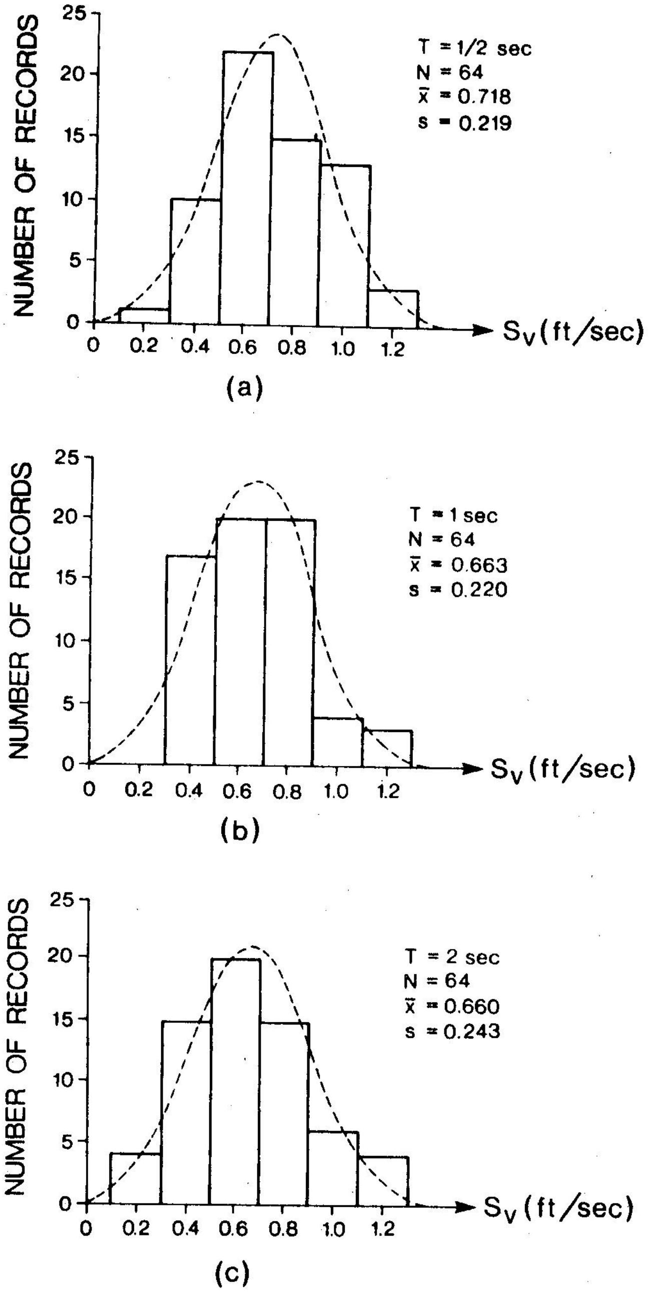

FIG. 4 FREQUENCY DISTRIBUTION HISTOGRAMS OF SPECTRAL VELOCITY