PEAK GROUND ACCELERATIONS AND THEIR EFFECT ON THE VELOCITY RESPONSE ENVELOPE SPECTRUM AS A FUNCTION OF TIME, SAN FERNANDO EARTHQUAKE, FEBRUARY 9, 1971

by

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SYNOPSIS

Because of the special interest to engineering seismology, six of the important accelerograms from the February 9, 1971, San Fernando Earthquake were chosen for detailed spectral analysis. The spectrum of the velocity response envelope as a function of time for 5 percent critical damping has been calculated for the horizontal components of these six records. The stations from which these accelerograms were obtained range from 6.9 to 42 kilometers in distance from the epicenter of the earthquake.

INTRODUCTION

The six records chosen for analysis are those for Pacoima Dam, Castaic (Old Ridge Route), 8244 Orion Avenue, 250 E. First Street, 445 Figueroa Street, and 646 S. Olive Street. The high accelerations of 1.25g experienced at Pacoima Dam stressed the importance of studying the effect of peak accelerations on the velocity response and its time duration.

Response spectrum analysis of strong-motion records has been very important for structural engineering. This analysis is based on the response of the single-degree-of-freedom viscously-damped linear oscillator[1]. The equation of motion of the linear oscillator is applicable in obtaining the response of small buildings and special structures such as elevated water tanks. When higher modes of response exist and cannot be ignored, the response of each mode of the multi-degree-of-freedom systems such as tall buildings, chimneys or towers can be calculated using this same equation of motion. Each modal response can then be superposed to obtain the total response of the system[3].

The response spectrum can be expressed in terms of displacement, velocity or acceleration and could involve the use of either the absolute or relative motions. Of these three forms of response, the relative velocity response is given preference in engineering seismology . With ω_0 the natural frequency of the oscillator, the relative displacement response and the absolute acceleration response can be approximated by respectively dividing and multiplying the relative velocity response by ω_0. Thus, the velocity response can be used to approximate the other two responses and since it gives very close to a horizontal plot for earthquake records, it has the advantage of keeping detailed information throughout the entire structurally important period range. Velocity response has a valuable relationship to the strain energy per unit mass. It can be shown that the relative velocity squared is proportional to the energy per unit mass in

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the system[1]. Since energy inputs and energy dissipations in a structure are important factors in structural engineering, the significance of obtaining directly the velocity response is apparent.

VELOCITY RESPONSE ENVELOPE SPECTRUM AS A FUNCTION OF TIME (VRES)

The velocity response spectrum has been calculated previously for five of the sites being presented in this paper by Hudson[2] and by Trifunac and Hudson[7]. It has been pointed out by Trifunac[6] and Perez[4,5], much more detailed information can be obtained by studying the response spectrum as a function of time.

The type of motion of the simple harmonic oscillator and how soon after a peak acceleration does it react has been studied by others. In essence the oscillator acts as a narrow band filter which amplifies the input frequencies centered around the natural period of the oscillator with $\pi/2$ delay of the response[6]. Consequently, any given response can be related to the specific ground acceleration that induced the motion.

A curve which lends itself to analysis can be generated by calculating the envelope of the relative velocity response as a function of time. The envelope of the response includes all the information required to calculate the maximum relative velocity as it is normally defined and in addition contains the history of the peaks of the response that vary in time with a period approximately equal to the period of the oscillator. For brevity, the relative velocity response envelope spectrum will be referred to as VRES.

In most engineering structures, the equivalent viscous damping is found to be in the range of 1 to 5 percent of critical damping. For this study, a 5 percent critical damping factor is chosen in calculating the velocity response spectrum.

The following is an explanation of the method by which the VRES as a function of time was produced. First, the oscillator response was calculated for 42 different undamped periods. The periods selected were: from 0.2 to 1.5 sec at intervals of 0.05 sec; from 1.5 to 2.0 sec at every 0.1 sec; and from 2.0 to 4.0 sec at every 0.2 sec. This scheme was chosen so as to obtain a good distribution density of the higher frequencies which are of a more oscillatory nature. For each period the envelope of the response was approximated by connecting the absolute values of all the peaks of the response curve. The envelope curve was then interpolated at equal time intervals of 0.1 sec for records of 16 sec or less in length and equal intervals of 0.2 sec for records greater than 16 sec.

These 42 periods, with their respective VRES's calculated at equal time intervals, generate a rectangular grid of spectral values. For visual ease, contours of equal amplitude can be produced by plotting interpolated values from the grid, giving a topographical map of the VRES amplitude values as a function of time and period. In the examples that follow (figures 1-3), contour maps are shown with each amplitude range identified by different shading. To the right of each topographical map the maximum relative velocity response spectrum is plotted in the usual manner, drawn to the same scale as the map. The topographical map shows the peaks and valleys of the VRES as a function of time and period, while the maximum velocity response spectrum shows the silhouette of the peaks.

COMMENTS OF THE VRES, SAN FERNANDO EARTHQUAKE

An examination of figures 1 thru 3 of the VRES indicates that maximum velocity response is not necessarily induced by peak accelerations. Of the 12 components analyzed, nine can be considered independent of maximum acceleration. The other three components lag within a cycle of the time of maximum acceleration. For example, the largest ground acceleration peak of the frequencies that induced maximum VRES levels in the Pacoima S 16° E direction had a value of 0.75 g. This peak occurred 3.1 seconds before maximum acceleration, and was only 60 percent of that maximum value. For the 8244 Orion Avenue site, west direction, the peak amplitude preceding maximum VRES values was 53 percent of maximum ground acceleration. In this case, the maximum VRES peak occurred more than 13 seconds after maximum ground acceleration.

High accelerations such as those experienced at Pacoima Dam do not appear to have as great an effect on the response as would be expected simply because the time duration is short or relatively nonsinusoidal[5]. When the ground acceleration approaches sinusoidal motion and is of a longer duration the effect on the response is easily observed. This response behavior is seen on Figures 1(c), 2(a), 3(a) and to a certain extent on Figure 3(d). In all four of these cases, the amplitude of the near sinusoidal ground motion was less than the maximum value, yet it induced maximum response.

The time duration spectra for the same levels that were used in calculating the VRES are shown in Figures 4, 5, and 6. The time duration spectrum represents the cumulative total time duration that the VRES equaled or exceeded a given level for the whole length of the acceleration record. A concept that is useful to structural engineering is to consider the total time duration of the different amplitude levels of VRES in terms of number of cycles that occurred for a particular level. Since the period of the velocity response of a given oscillator is approximately equal to the natural period of the oscillator due to its filtering properties, a family of straight lines indicating the number of cycles for a given velocity response level can be generated. These families of straight lines are also shown in Figures 4, 5, and 6.

Time duration of high values of VRES does not appear to be proportional to the time duration of the high acceleration portion of the accelerogram. For both components of the Pacoima Dam accelerogram, the high acceleration portion lasted about 7 sec; for the high response level of 160-200 cm/sec, the time duration is less than two sec for most periods. Perhaps more revealing from a structural point of view is that for all 12 components analyzed in this paper, the time duration of the highest levels of response for most periods was less than two cycles.

Lower levels of response do last for a larger number of cycles and could become just as critical as higher levels in inducing damage to manmade structures. Results in finding a correlation between damage and time duration of different levels must await future investigation.

CONCLUSIONS

The analysis of the records from six sites in the San Fernando Earthquake indicate that the maximum relative velocity response spectrum for 5 percent critical damping is not necessarily caused by the maximum ground acceleration, and maximum velocity response is not necessarily proportional to maximum acceleration.

The time duration of high velocity response envelope spectra levels are much less than the time duration of the high acceleration portion of the record. In terms of cycles of high velocity response envelope spectra levels there were less than two oscillations of response for all six sites. Perhaps this may shed some light on the small damage experienced on the Pacoima Dam.

Time duration spectrum as presented in this paper can become a useful tool in structural engineering in assesing damage to structures. But general statements about response spectrum as a function of time or the time duration spectrum must await further investigations.

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BIBLIOGRAPHY

1. Hudson, D.E., "Response Spectrum Techniques In Engineering Seismology." Proc., World Conf. Earthquake Engineering. Univ. of Cal.,Berkeley,1956.

2. Hudson, D.E., "Strong-Motion Accelerogram Processing." Strong-Motion Instrumental Data On The San Fernando Earthquake of Feb. 9, 1971. E.E.R.L. C.I.T. and the SFS, U. S. Dept. of Commerce, 1971.

3. Merchant, H.E. and D.E. Hudson, "Mode Superposition In Multi-Degree Of Freedom Systems Using Earthquake Response Spectra Data." BSSA 52,1962.

4. Perez, V., "Velocity Response Envelope Spectrum As A Function Of Time." To be published in the NOAA-EERI San Fernando Earthquake Report, 1973.

5. Perez, V., "Velocity Response Envelope Spectrum As A Function Of Time, Pacoima Dam, San Fernando Earthquake, Feb. 9, 1971." BSSA. To be published February, 1973.

6. Trifunac, M.D., "Response Envelope Spectrum And Interpretation Of Strong Earthquake Ground Motion." BSSA 61, 1971.

7. Trifunac, M.D., and D.E. Hudson, "Analysis For The Pacoima Dam Accelerogram, San Fernando, California Earthquake of 1971." BSSA 61,1971.

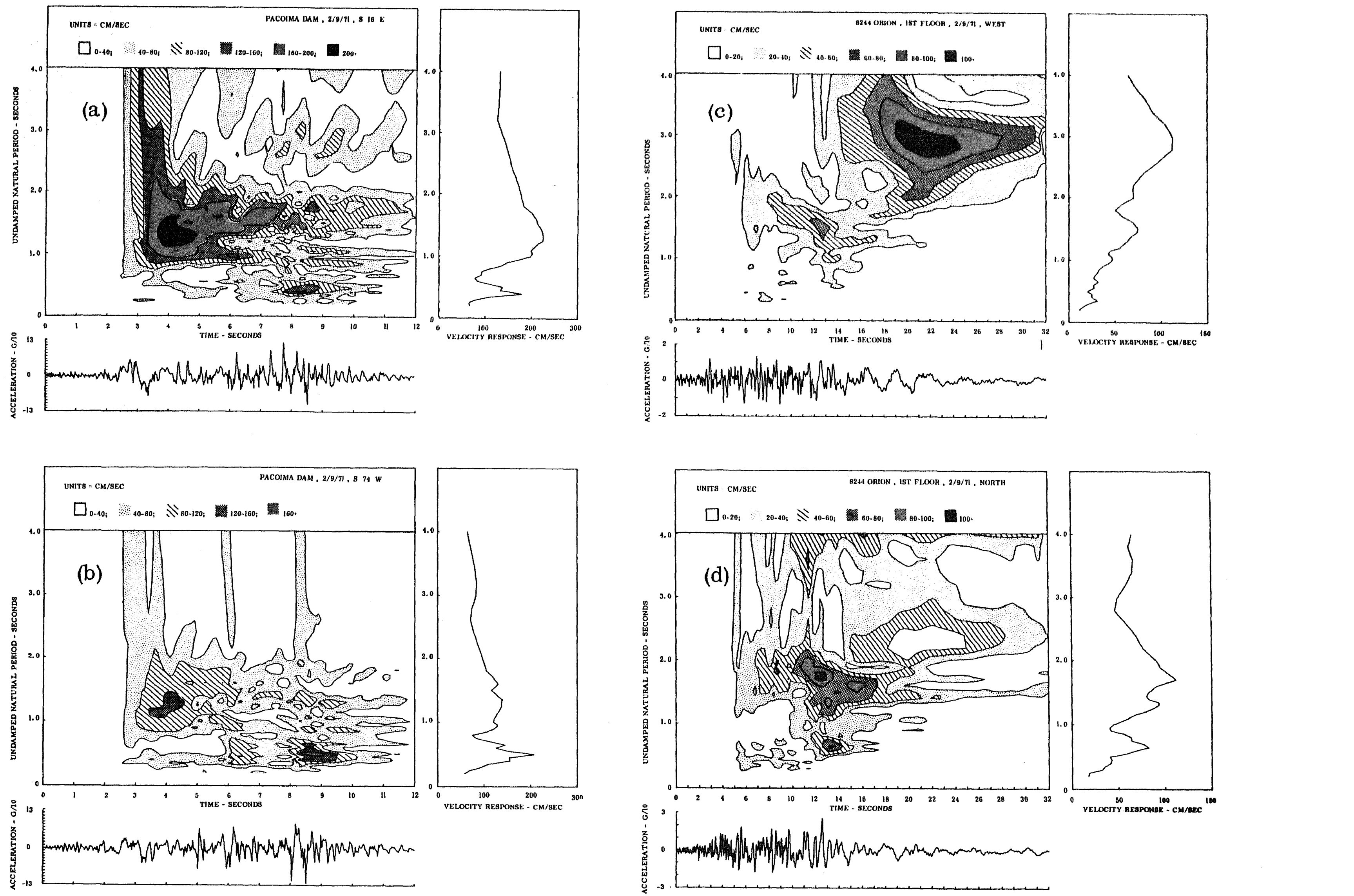

Figure 1. - Velocity response envelope spectra, 5 percent critical damping, San Fernando Earthquake, 2/9/71.

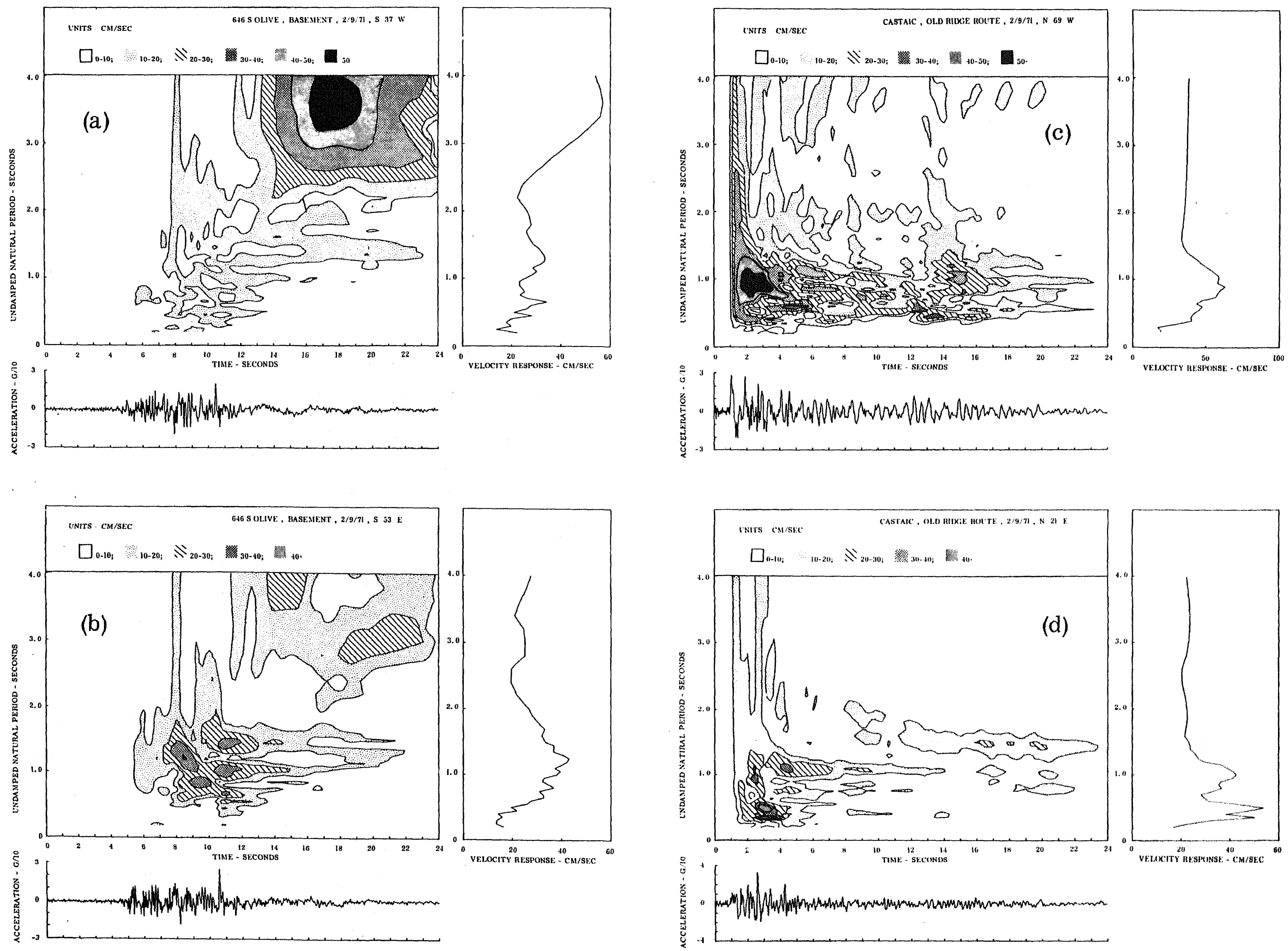

Figure 2. - Velocity response envelope spectra, 5 percent critical damping, San Fernando Earthquake, 2/9/71.

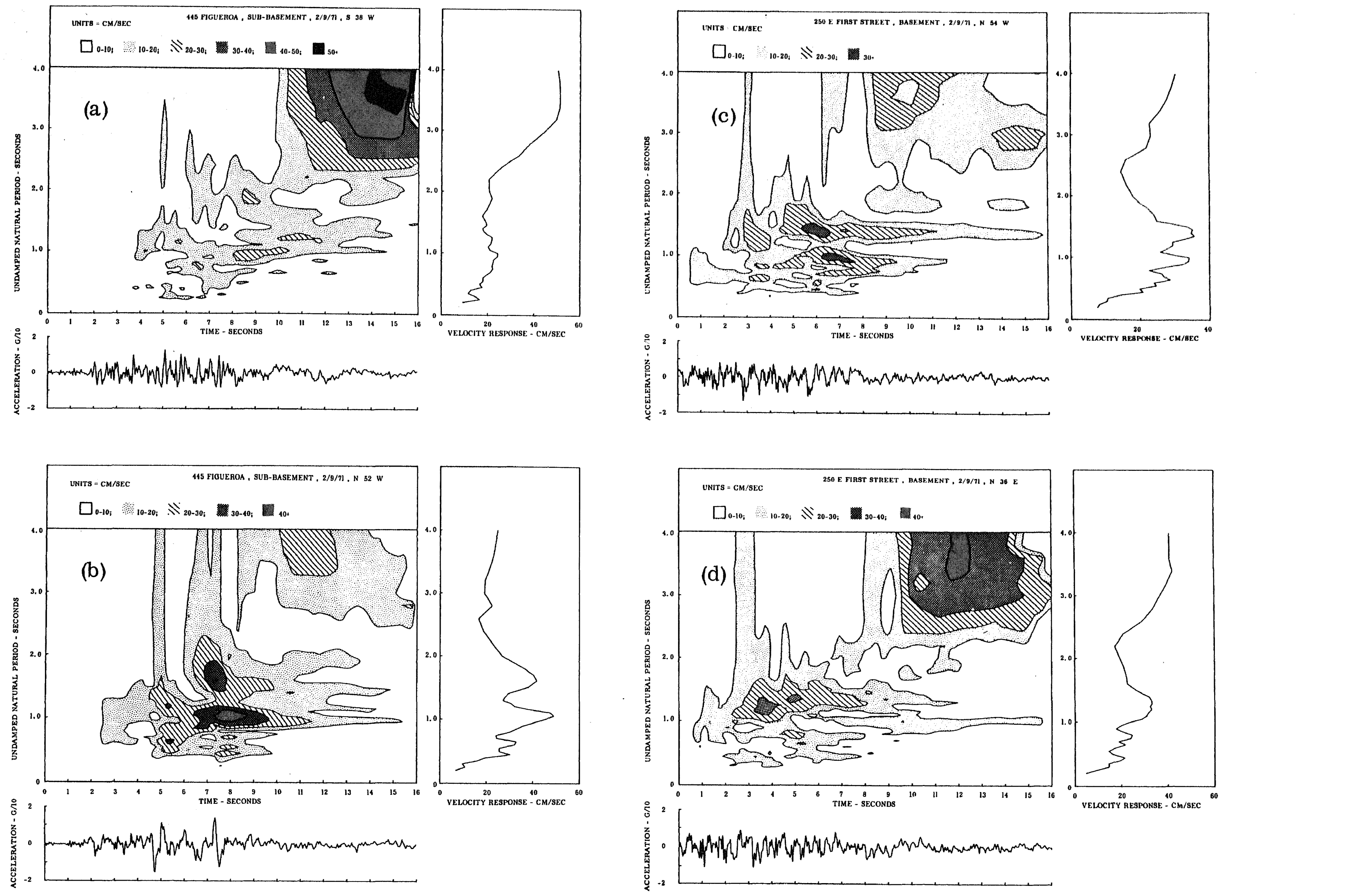

Figure 3. - Velocity response envelope spectra, 5 percent critical damping, San Fernando Earthquake, 2/9/71.

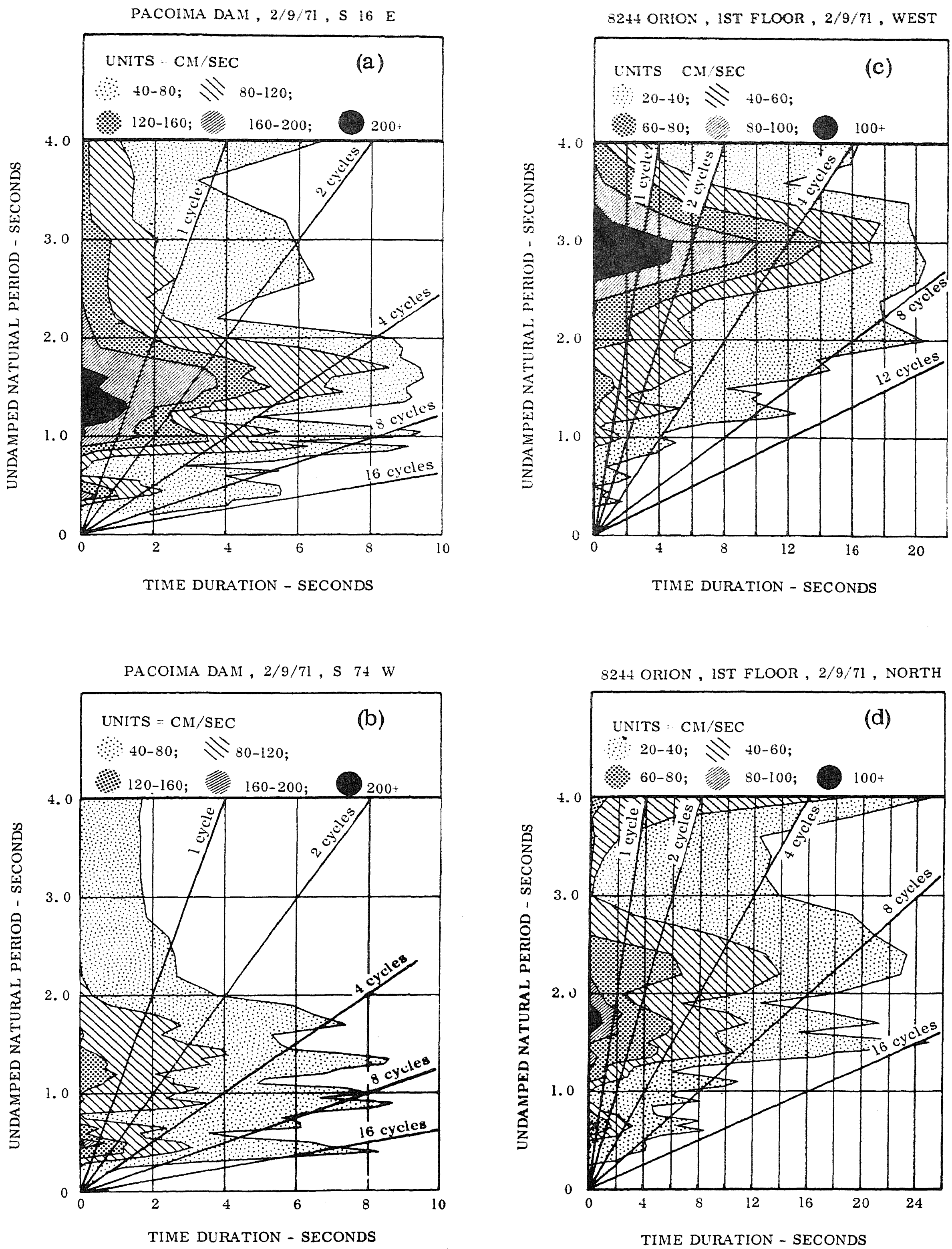

Figure 4. - Time duration of the velocity response envelope spectra, 5 percent critical damping, San Fernando Earthquake, February 9, 1971.

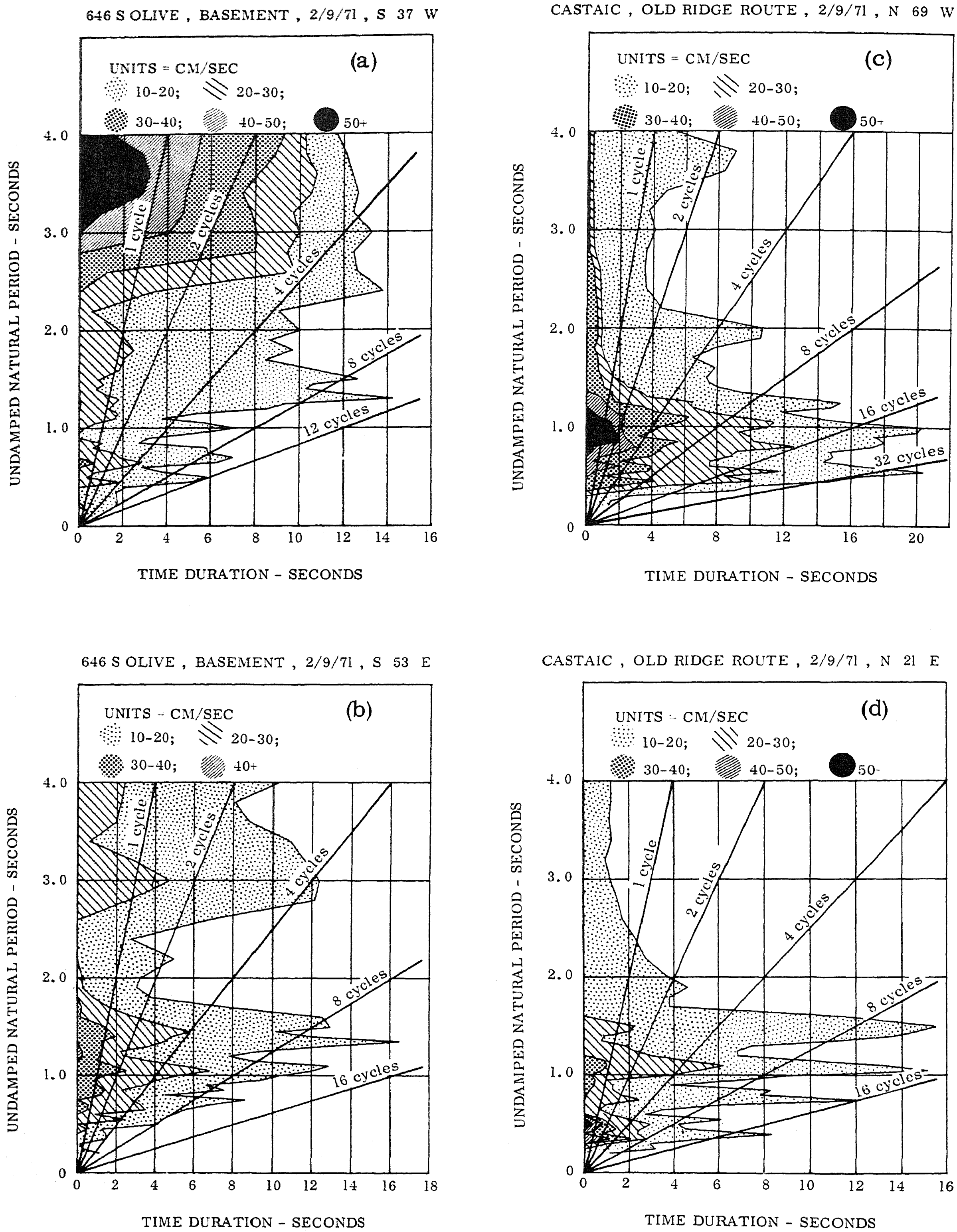

Figure 5. - Time duration of the velocity response envelope spectra, 5 percent critical damping, San Fernando Earthquake, February 9, 1971.

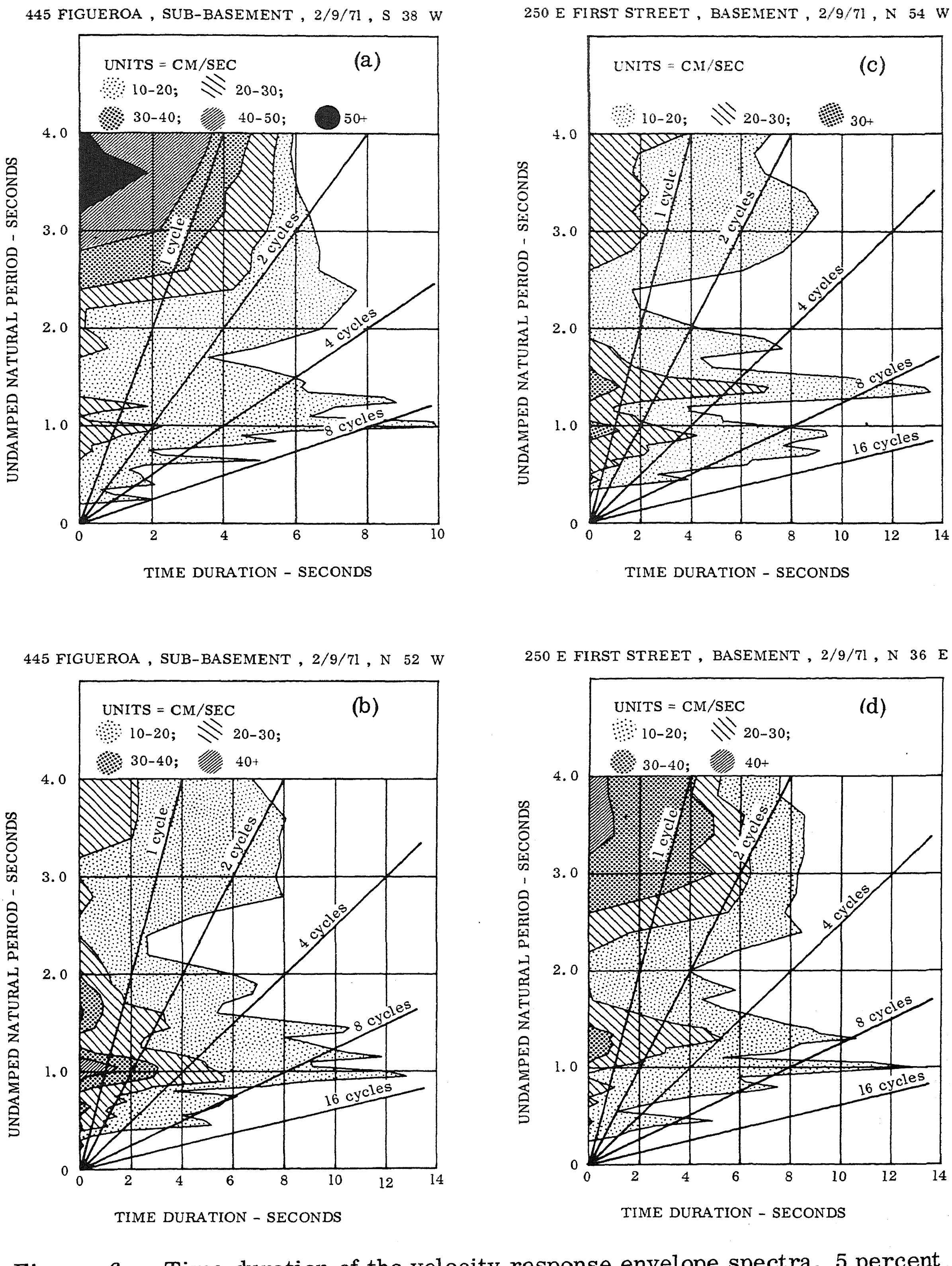

Figure 6. - Time duration of the velocity response envelope spectra, 5 percent critical damping, San Fernando Earthquake, February 9, 1971.