COMPARISON OF BUILDING RESPONSE AND FREE FIELD MOTION IN EARTHQUAKES

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SYNOPSIS

Observations of earthquake damage suggest that structures on large foundations respond with less intensity than do smaller structures. Studies of records suggest that the accelerations imparted to large structures approach an average of the free field excitation over some "transit time" related to the size of the building. A numerical technique for averaging the acceleration is presented herein (Eq. 1). The resulting response of the structure may be reduced by a factor of 2 or 3 from the free field spectral response in the high frequency region, with a significant effect in design. An approach to torsional motion also is presented.

INTRODUCTION

The first paper that attempted to provide a rational explanation for observed reduction in response behavior apparently was that by Yamahara in 1970 (Ref. 1). The same general procedure is given by Scanlan (Ref. 2). Both references provide a general relationship between the average acceleration over the width of the foundation as a function of the wave length of the acceleration pulse and the width of the foundation. A better measure of the effect of an earthquake on a large building is given by the use of a time-average acceleration over a transit time. This approach does not require an assessment of the frequencies included in the earthquake motion, but is based on a time averaging of the acceleration record. The resulting effects can be demonstrated best through calculation of the response spectrum from the averaged acceleration record.

The Hollywood Storage Building and the adjacent P.E. Lot constitute one of the few sites where motions have been measured in the basement of a building and nearby in the free field. The building (Ref. 3) is 51 feet in the N-S direction, 217.5 feet in the E-W direction, 150 feet high and supported on piles. The basement accelerograph is located in the S-W corner of the building. The free field instrument is located 112 feet due West of the S-W corner of the building. In Ref. 3 the shear wave velocity in the upper strata under the building is shown as being approximately 1500 to 2000 fps and can be considered as possibly the wave propagation velocity in the near surface zone.

Response spectra have been reported for this building in both the 1971 San Fernando earthquake and the 1952 Kern county earthquake. Typical of the results are those shown in Figs. 1 and 2, which give the response spectrum for the Hollywood Storage Building basement and for the P.E. Lot in the South Direction for a damping value of 5 percent of critical. In Fig. 1 it will be seen that for periods less than about 0.4 seconds there is a decrease by a factor of 2 to 2.5 in the response spectrum for the building basement compared with that for the P. E. Lot whereas for longer periods the response spectra are practically identical. For the same site in the Kern County earthquake, (Fig. 2) considerably further away, only slight attenuation was observed.

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The natural periods of the Hollywood Storage Building were given in Ref. 3 as 0.5 seconds in the E-W direction and as 1.2 seconds in the N-S direction. It will be observed in Figs. 1 and 2 that these periods are in the range where practically no change in the response spectrum is observed. As such it appears that there is practically no soil-structure interaction under this building, but that the major effect is one of smoothing out, or averaging, the acceleration input from the earthquake motions.

NUMERICAL AVERAGING TECHNIQUE

The averaging technique that was employed in the calculations reported herein was made with the California Institute of Technology (Ref. 4) earthquake acceleration time histories. The procedure was essentially one of selecting a value of transit time, τ, chosen for convenience as values of 0, 0.02, 0.04, 0.08, 0.12, and 0.16 seconds. In effect the transit interval was moved along the acceleration time history in the time domain. For a given positioning of the τ interval the velocity was calculated at the beginning and the end of the interval and the corresponding average acceleration assigned to the mid-point of the interval. In this way an average acceleration time history was computed by use of Eq. (1), given later herein, and the modified response spectrum was calculated.

Calculations were made for the Hollywood Storage P.E. Lot records for both the San Fernando and Kern County earthquakes (Figs. 3 and 4) for various transit times for both horizontal components of motion using the averaging technique described. The spectrum for a transit time of 0 seconds is the unmodified response spectrum for the P.E. Lot. The response spectrum for the building is shown by the dashed line in each figure. It is nearly identical with the computed value for the P.E. Lot for a transit time of about 0.08 seconds in both figures. Nearly the same results were obtained for the East direction. It appears from these studies that either the longest dimension of the building, or the mean or geometric mean of the dimension, controls the effective transit time. For a mean geometric dimension of the building of 105 feet and a seismic velocity of 1500 fps one finds τ = 0.07 which is in the range of the value observed as giving the best agreement in both directions.

In the case of the Kern County earthquake (Fig. 4) there is little attenuation as compared to Fig. 3, suggesting that for a large distance to the source (approximately 74 miles) the major motions are associated with surface waves having a much longer wave length than those of the closer San Fernando earthquake (approximately 22 miles).

In the same manner calculations were made for two close-in earthquakes, namely the Pacoima Dam record for the San Fernando earthquake (Fig. 5) and one of the Ancona earthquakes (Fig. 6). Both show a substantial reduction as the transit time increases, consistent with the low level of observed damage of buildings designed to resist only moderate earthquakes in the Ancona region.

TORSIONAL MOTION

Torsional components of ground motion can be as important as the translational components in determining the base input to be used for design. Using the principle of least square fitting of an acceleration record over a time interval τ, between two points a and b, where $b = a + \tau$, it can be shown that the angle ($\ddot{\alpha}$) between the fitted straight line and the line representing the mean value of acceleration in this interval ($\ddot{\phi}$) is as given by the expressions below.

$$\ddot{\phi} = \frac{1}{\tau}\{\dot{\rho}(b) - \dot{\rho}(a)\} \qquad (1)$$

$$\ddot{\alpha} = \frac{6}{\tau^2}\{\dot{\rho}(b) + \dot{\rho}(a)\} - \frac{12}{\tau^3}\{\rho(b) - \rho(a)\} \qquad (2)$$

In these expressions $\ddot{\rho}$ is the acceleration time history, and $\dot{\rho}$ and ρ are computed velocities and displacements respectively. This procedure involves computations requiring a highly accurate time history. The problem of torsional base input to a structure is currently under investigation and results are not yet avaiable.

CONCLUDING REMARKS

The numerical averaging procedure described is an effective and rapid method for obtaining the effect of a building's size on its response. The method predicts reduced response in the high frequency domain, of particular design importance for close-in earthquakes. It is hoped that in the future instruments will be located in such a way in structures and in the free field to provide further information relating to the phenomena described.

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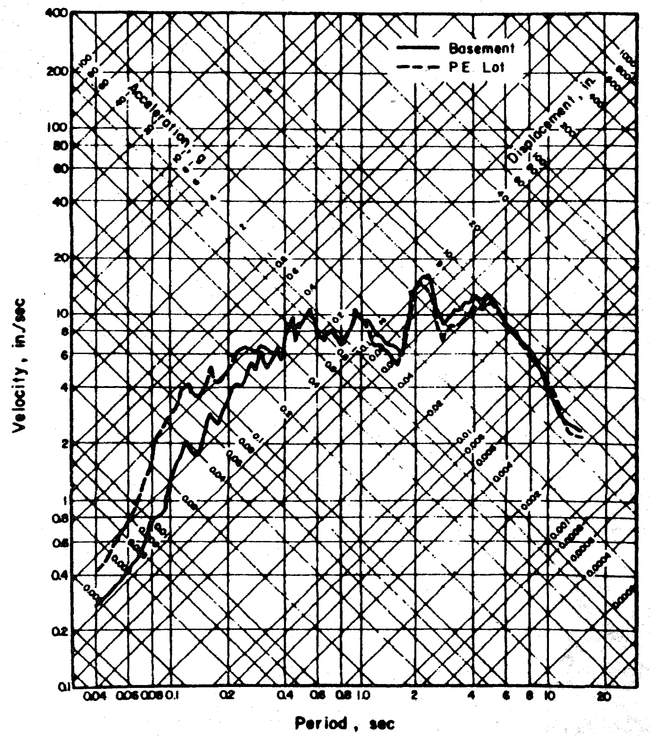

FIG. 1 HOLLYWOOD STORAGE BUILDING BASEMENT AND P.E. LOT, SAN FERNANDO EARTHQUAKE, 9 FEB, 1971 - 0600 PST, COMPONENT SOUTH, DAMPING 5 % OF CRITICAL

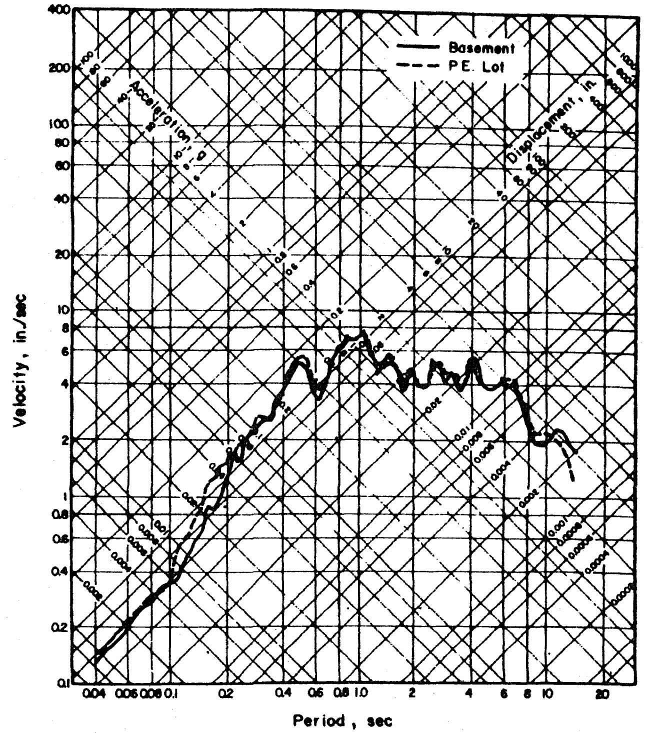

FIG. 2 HOLLYWOOD STORAGE BUILDING BASEMENT AND P.E. LOT, KERN COUNTY EARTHQUAKE, 21 JULY, 1952 - 0453 PDT, COMPONENT SOUTH, DAMPING 5 % OF CRITICAL

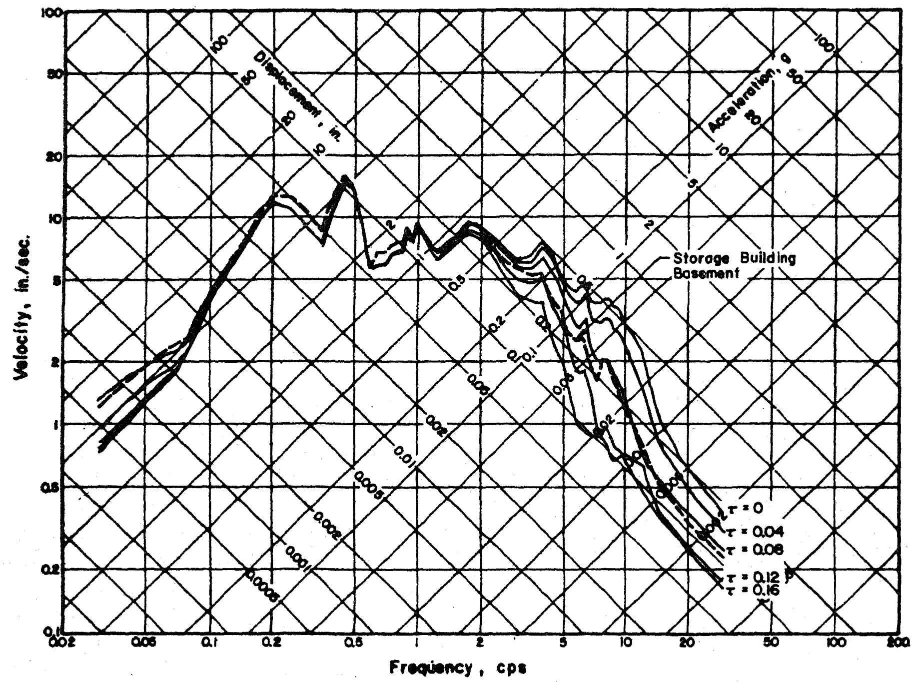

FIG.3 HOLLYWOOD STORAGE P.E. LOT, SAN FERNANDO EARTHQUAKE, 9 FEB, 1971, COMPONENT SOUTH, DAMPING 5 % OF CRITICAL, τ = 0, 0.04, 0.08, 0.12, AND 0.16 SEC.

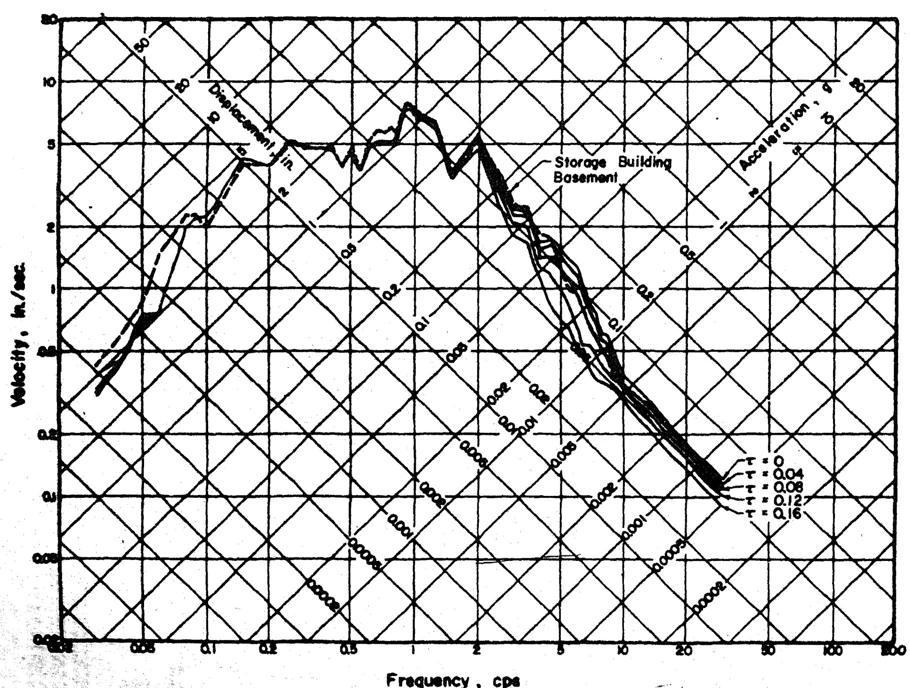

FIG.4 HOLLYWOOD STORAGE P.E. LOT, KERN COUNTY EARTHQUAKE, 21 JULY, 1952, COMPONENT SOUTH, DAMPING 5 % OF CRITICAL, τ = 0, 0.04, 0.08, 0.12, AND 0.16 SEC.

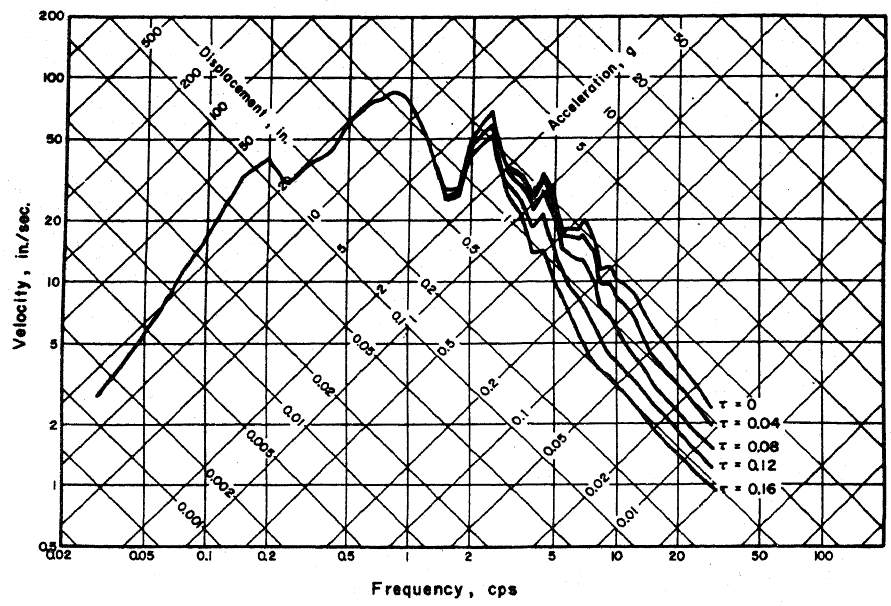

FIG. 5 PACOIMA DAM RESPONSE SPECTRUM 9 FEB 1971, S16E, DAMPING 5% OF CRITICAL, τ = 0, 0.04, 0.08, 0.12, 0.16 SEC.

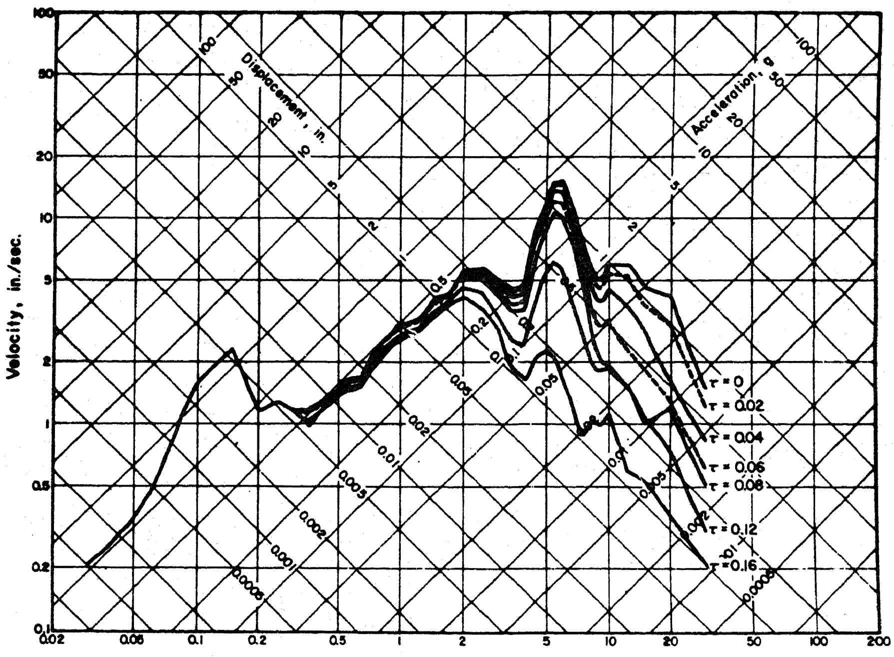

FIG. 6 ANCONA, ROCCA, 14 JUNE, 1972, COMPONENT NORTH, DAMPING 5% OF CRITICAL, τ = 0, 0.02, 0.04, 0.06, 0.08, 0.12, AND 0.16 SEC.

DISCUSSION

N.C. Donovan (U.S.A.)

This paper assumes that nearby free field sites have the same motion with a time lag equal to a transit time. Field displacement measurements made during a Nuclear Blast (Donovan and Degenkolb, 1975) showed that motions on closely adjacent systems are similar but vary continuously over very short distances even on uniform soil conditions. What would be the additional attenuation effect of this variation, especially with respect to the critical estimates of torsional motion ?

Author's Closure

Not received.