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Impact of Insufficient Energy Content in the Design Time History on the Structure Response*

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INTRODUCTION

In the design of nuclear power plants, it is often desirable to use the time history method in the soil-structure interaction analyses to determine the plant floor response to seismic loads. Because many design criteria are specified in terms of design response spectra, the artificial time history needs to be generated under the requirement that the response spectra of the artificial history should envelop the given design response spectra. However, recent studies indicate that the artificial time history used in the plant design may have insufficient energy in the frequency range of interest, even though the response spectra of the design time history closely envelop the design response spectra. Therefore, the proposed changes in the NRC Standard Review Plan requires that when a single time history is used in the seismic design, it must satisfy requirements for both response spectra enveloping and matching a power spectra density (PSD) function in the frequency range of interest. The use of multiple artificial time histories (at least five time histories) in the plant design is also suggested in the new Standard Review Plan.

This paper presents an investigation of the effects of the insufficient energy content in the design time history on the response of the soil-structure system. Numerical studies were carried out. Both the real earthquake records and the artificial time histories were used as the input motions in a simple lumped-mass soil-structure interaction model. The results obtained from this study provide a better understanding of the effects of the insufficient energy content in the design time history on the structural response.

ARTIFICIAL TIME HISTORY

The development of the design time history to be used at the base of the soil-structure interaction system requires that the response spectra of the generated artificial time history should envelop the design response spectra for all damping values used in the analyses [Standard Review Plan, 1975]. The peaks in the calculated floor response spectra need to be broadened by ± 10% of the frequencies corresponding to the peaks to account for the uncertainties in the analyses. There are a number of methods in the generation of the artificial earthquake time history whose spectra envelop the given design response spectra. The artificial time history can be generated from the modification of the Fourier components of the existing earthquake accelerogram (Tsai, 1972, Rizzo et al., 1973). The Fourier components are intensified or damped repeatedly until

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the response spectrum of the modified time history closely match the desired response spectrum. The artificial time history can also be generated from the superposition of the sinusoidal functions (Levy and Wilkinson, 1976) and from the theory of random vibration (SIMQKE, 1976).

Numerical Study

In order to study the effects of the insufficient energy content in the design time history on the response of the soil-structure systems, frequency calculations on a simple lumped-mass soil-structure interaction model (see Fig. 1) were carried out. Both the earthquake time histories and the artificial time histories were used as the design time histories at the base of the soil-structure system which has a fundamental frequency of 7.3 Hz. The four earthquake time histories used in the study were:

1. Taft, 1952 Kern County earthquake;
2. Imperial Valley, 1934 El Centro earthquake;
3. Washington Highway Laboratory, 1949 Olympia earthquake; and
4. Hollywood Storage Basement, 1971 San Fernando earthquake.

The acceleration time history and the corresponding Fourier spectrum of these four earthquakes are shown in Figs. 2 to 5, respectively. Linear time history analyses were carried out. The calculated frequencies of the soil-structure system under these four histories are shown in Table 1. They are 7.55 Hz, 7.35 Hz, and 7.1 Hz for the 1952 Kern County, the 1934 El Centro, and the 1949 Olympia histories, respectively. The calculated dominant frequencies are close to the actual frequency of the system, except in case 4 (Hollywood storage basement, 1971 San Fernando earthquake) which produces a calculated dominant frequency of 6.1 Hz (17% difference compared with the actual frequency). Examination of the Fourier spectrum of the 1971 San Fernando earthquake record (see Fig. 5) reveals that the Fourier components do not have sufficient energy content in the frequency range of 6.5 Hz to 7.5 Hz. Thus, the response of the system is driven by the strong Fourier component at frequency of 6.1 Hz which can be clearly identified from the Fourier spectra shown in Fig. 5. This example indicates that insufficient energy content in the design time history may shift the dominant frequency of the soil-structure system which, in turn, shifts the peak frequency of the calculated floor response spectra. Since the floor response spectra are usually narrow-bounded, the shifting of the dominant frequency of the soil-structure system will have significant influence on the subsequent design and analyses of the plant equipment and systems.

Figure 6 shows an artificial acceleration history and the corresponding Fourier spectrum and the response spectrum. As can be seen from Figure 6, the response spectrum of the artificial time history closely match the given design response spectrum. However, the Fourier spectrum of the history shows that the design time history does not have sufficient energy in the frequency range of 6 - 8 Hz. As a result, the calculated frequency of the soil-structure system from this history is about 6.2 Hz. Figure 7 shows the calculated floor response spectrum which has a peak frequency of 6.2 Hz. This example demonstrates that the design time history may have insufficient energy content in the frequency range of interest, even the spectra of the design history closely match the design response spectra. As a result, the calculated frequency of the soil-structure system is shifted. The degree of frequency shifting is closely related to the Fourier components of the design history.

Figures 8, 9 and 10 show another three artificial time histories and the corresponding Fourier spectra. These three design histories closely match the Regulatory Guide 1.60 design response spectrum. The calculated dominant frequency of the soil-structure system from these three histories are 7.5 Hz, 7.37 Hz and 7.0 Hz. The Fourier spectra indicates that these three histories contain sufficient energy in the frequency range of interest (i.e. 7 - 8 Hz). Note that the synthetic history, which produces a calculated frequency of 7.5 Hz, contains a strong Fourier component at frequency of 7.5 Hz, whereas the other two histories contain a strong Fourier component at frequency of 7.37 Hz and 7.30 Hz, respectively. Therefore, the calculated frequencies agree well with the actual frequency of the soil-structure system.

CONCLUSIONS

A study was carried out to investigate the effects of insufficient energy content in the design time history on the structure response. The major conclusions drawn from this study are:

1. This study confirms recent studies that the artificial time history used in the plant design may have insufficient energy in the frequency content of interest, even though the response spectra of the design time history closely matches the design spectra. The most significant effect of insufficient energy in the design history is the shifting of the calculated frequency of the soil-structure system which, in turn, shifts the peak frequency of the calculated floor response spectra. The degree of frequency shifting is closely related to the Fourier components of the design time history. Since the floor spectra are usually narrow-bounded, the shifting of peak frequency has significant impact on the subsequency design and analyses of the plant equipment and systems. Therefore, it is very important that the design time history contain sufficient energy in the frequency range of interest.

2. Prior to the execution of the complicated soil-structure interaction analyses, the energy content of the design time history should be examined. Even the response spectra of the design time history closely matches the design response spectra. The Fourier spectrum is a useful tool for examination of the energy content of the design time history. Furthermore, the design time history should be used in the frequency predictions of a simple model with the known system frequency. Since the peak frequency in the calculated floor response spectra is generally broadened by ± 10%, the calculated system frequency should not differ by more than 10% of the actual frequency of the system. A wide range of frequency predictions should be carried out to assure that the design time history has sufficient energy in all frequency content. Frequency predictions by multiple time histories (real earthquake records or artificial time histories) is an alternate way to assure that the design time history has sufficient energy content.

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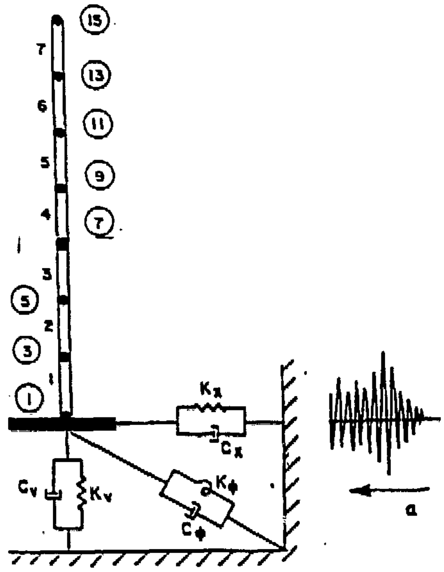
Table 1. Computed Frequencies

Ground Motion	Calculated Dominant Frequency (Hz)
(1) 1952 Taft, Kern County	7.55
(2) 1934 El Centro, Imperial Valley	7.35
(3) 1949 Olympia, Washington Highway Test Lab.	7.10
(4) 1971 San Fernando, Hollywood Storage Basement	6.10

Fig. 1. Lumped-Mass Model



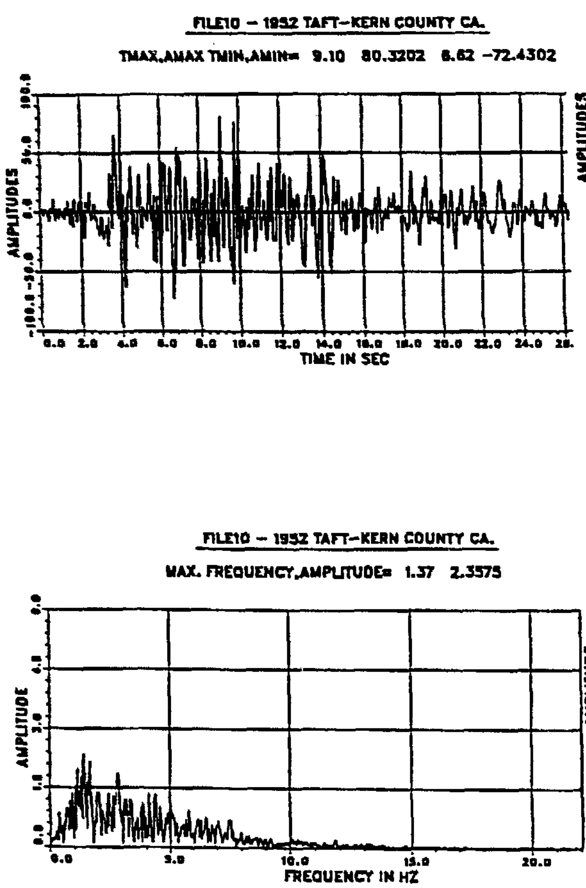


Fig. 2. 1952 Taft Record

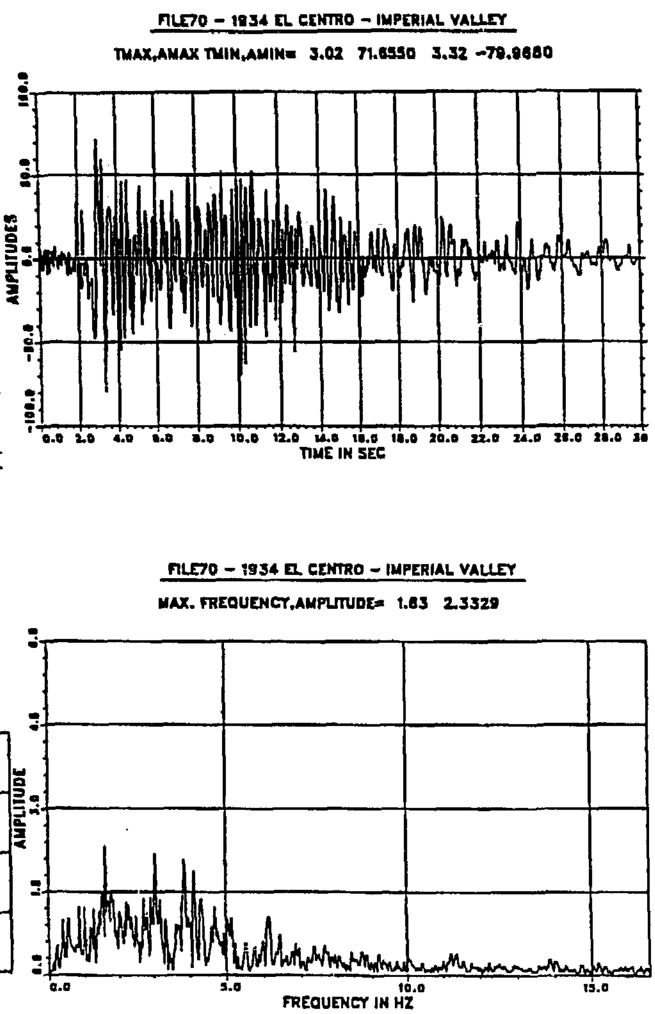


Fig. 3. 1934 El Centro Record

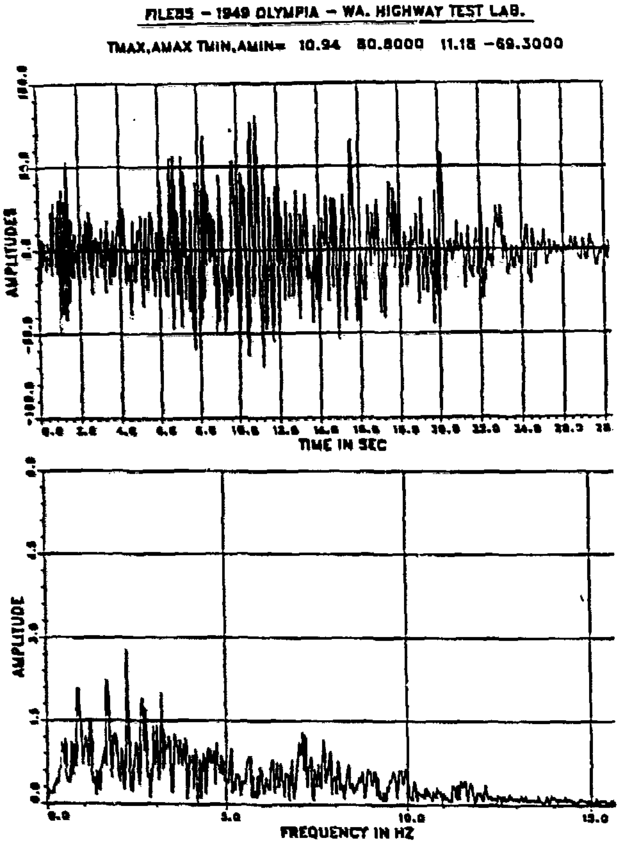


Fig. 4. 1949 Olympia Record

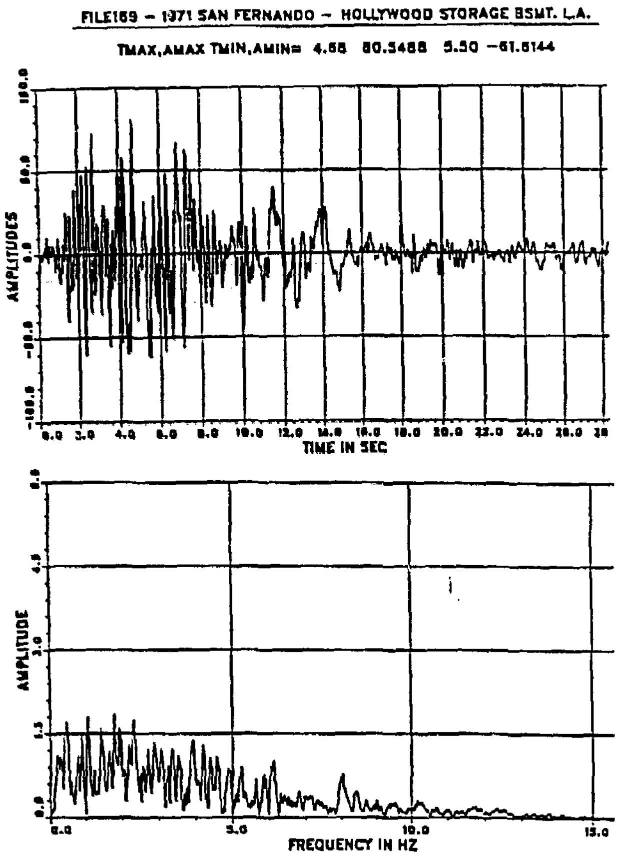
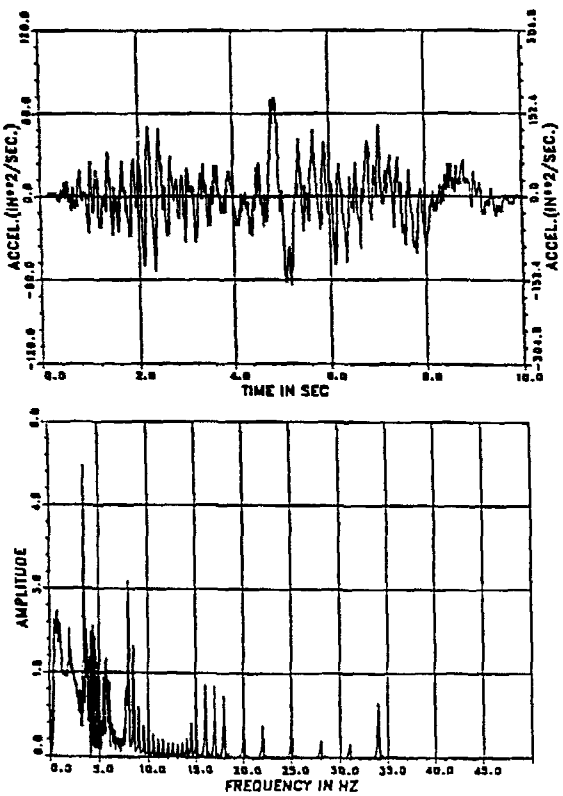


Fig. 5. 1971 San Fernando Record



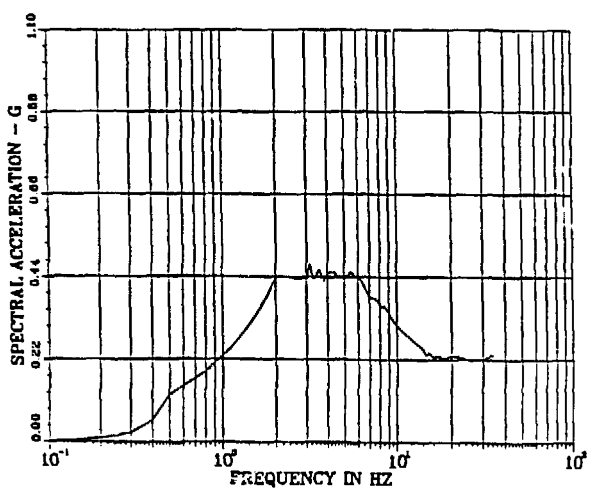


Fig. 6. Synthetic History

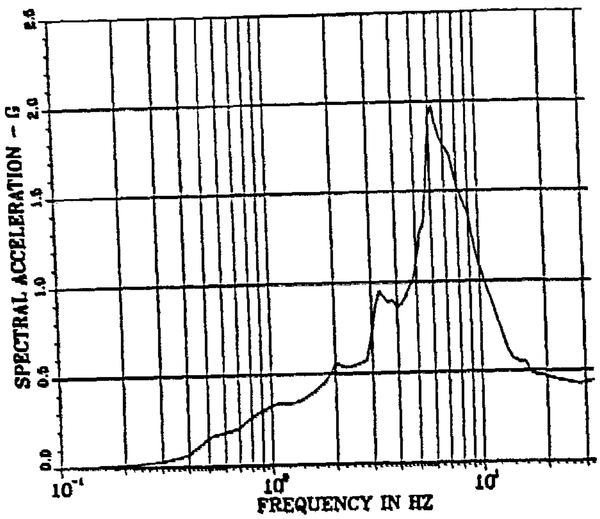


Fig. 7. Calculated Floor Spectrum

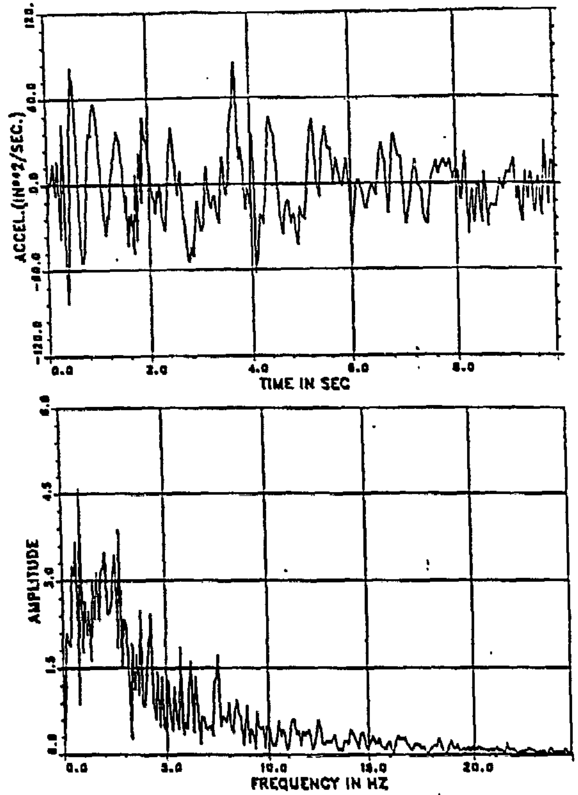


Fig. 8. Synthetic History #1

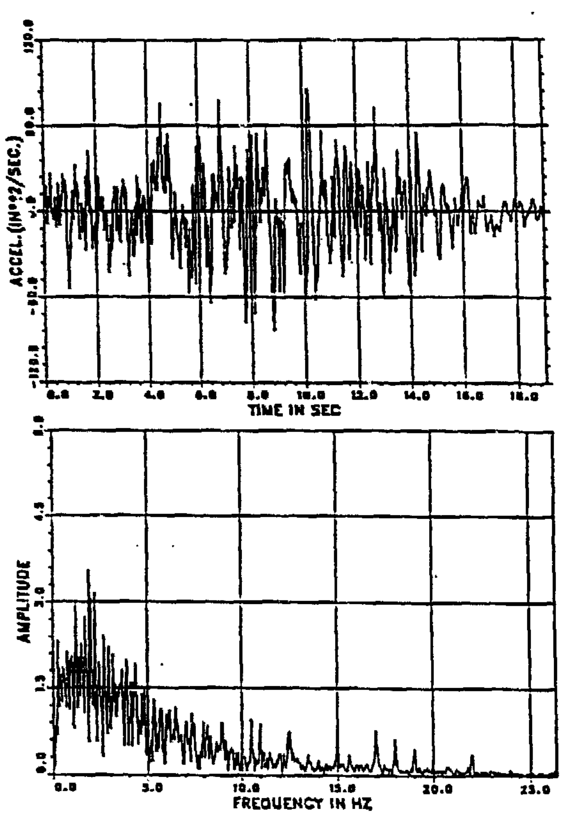


Fig. 9. Synthetic History #2

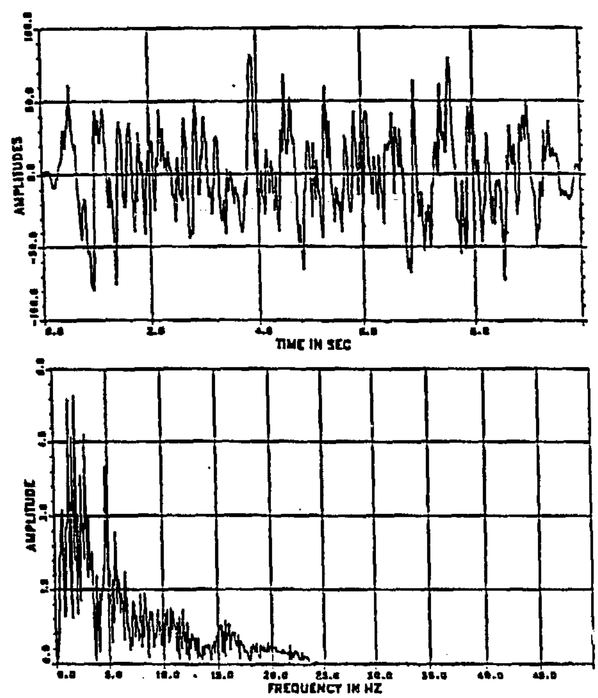


Fig. 10. Synthetic History #3