ARTIFICIAL EARTHQUAKE GENERATION FOR NUCLEAR POWER PLANT DESIGN

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INTRODUCTION

The time history method has been one of the analytical tools applied in the seismic resistant design of nuclear power plants. The time histories used are required to be consistent with the specified design spectra.

Since the spectra of recorded strong motion earthquake or conventionally generated artificial time history have local peaks and valleys, iteration procedures must be applied to generate the artificial time history with desired spectra. References (1) to (4) described various methods of generating these kinds of artificial time history.

This paper describes a detail method for generating a time history which is consistent with a specified design spectra. There are several advantages of this method described herein. First of all, frequency content of the time history is well under control. Secondly, if one wishes to generate the three components of a earthquakes at one site, the inherent nature of this method will make the correlations among these three components to simulate closely the actual recorded time histories[5]. Thirdly, a single time history can be generated to match a spectra for different damping values.

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(1) Tsai, Nien-Chien, "Spectrum - Compatible Motion for Design Purpose," Proceedings of ASCE, Journal of Engineering Mechanis, April, 1972.

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A. Theoretical Procedures

The procedures[6] can be described briefly as follows:

1. Generate the initial power spectral density function at each predeterminated frequency ω from velocity response spectrum by using the recurrence equation[7]

$$S_o(\omega) = \frac{4\beta}{\omega}\left[\left(\frac{S_v'\omega}{R}\right)^2 \cdot \frac{1}{1 - e^{-2\beta\omega T}} - \sum_{n=1}^{N} S_o(\omega_n)\,d\omega\right]$$

and evaluates $S_o(\omega)\,d\omega$

where: S_v' = desired velocity response spectrum

T = equivalent duration = $s'\cdot CF$ (CF = scaling factor)

$R = \dfrac{\ell n\left(\frac{s'\omega}{2\pi A}\right)}{B}$ (A and B are constants)

s' = duration

β = damping

Note that $(1 - e^{-2\beta\omega T})$ is introduced here for transient behavior

2. Normalize the power spectral function, $S_o(\omega)$ to $S_n(\omega)$, such that the area under the curve $S_n(\omega)$ equal to 1

or $\int S_n(\omega)\,d\omega = 1$

3. Compute the amplitude of sinusoidal waves of each frequency ω_i by

$A_i^2 = 2S_n(\omega_i)\cdot\Delta\omega$

4. Simulate stationary process with unit variance by

$$Z_j(t) = \sum_{i=1}^{N} A_i \sin(\omega_i t + \phi i)$$

ϕi is the random phase angle distributed over the interval 0 to 2π. The number (N) of ϕi terms generated in the program can be manipulated from the input.

5. Simulate the non-stationary process $X_j(t)$ from the following equation:

$$X_j(t) = F_o(s', T_o) \cdot f_o(t) \cdot Z_j(t)$$

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(6) Hou, Shou-Nien, "Earthquake Simulation Models and Their Application," Department of Civil Engineering, MIT, Report Number R68-17, May 15, 1968.

(7) Cornell, C. A., private communication, March, 1973.

where:

$$F_o(S',T_o) = \left[2\ell n\left(\frac{2C_oS'}{T_o}\right)\right]^{-1/2} = \text{scaling factor of } X_j(t)$$

$$C_oS' = .25 + .75\frac{te}{s'}$$

$$T_o = \frac{2\pi}{\omega_o} = 2\pi\,\frac{\sigma_x}{\sigma_x{}'} = 2\pi\left[\frac{\int S_o(\omega)\,d\omega}{\int \omega^2 S_o(\omega)\,d\omega}\right]^{1/2} \quad (\omega_o = \text{mean frequency of } X_j(t))$$

$f_o(t)$ = deterministic shape function of excitation

6. Calculates the response spectrum from the following equation:

$$\ddot{y} + 2\beta\omega\dot{y} + \omega^2 y = X(t)$$

at the frequencies within the specified range.

7. Modify power spectral density functions by the ratio of

$$\left(\frac{\text{desired spectral values}}{\text{computed spectral values}}\right)^2 = \left(\frac{S_v{}'}{S_v{}''}\right)^2$$

8. Repeat steps 2 thru 7 for the specified number of cycles.

B. Iteration Technique

Because of the character of random process, generating a simulated time-history that will envelope a given spectrum often involves "trial and error." Mathematically, any time-history that satisfies the above condition is a valid one. Since the procedures employed by this program are stochastic in nature, the random number distribution often plays an important role in the resulting curve. Starting with different random numbers will result in distinct differences in the shape and values of the response curve.

Three procedures have been used within the program to improve a time history or to match spectra of different damping values by a single time history.

1. After prescribed number of iterations if the calculated response curve from the generated artificial time history generally does not match or envelope the design spectrum, change only the random seed number and start from the beginning.

2. If the calculated response curve generally matches or envelopes the design spectrum, but considerably large discrepancies occur at certain locations, keep the same random seed number and adjust the desired spectrum values locally within a range.

3. Increasing the number of terms of the generated random phase angles will result in a closer and faster convergence to the target response spectrum curve. Therefore, the number of iterations can be reduced.

Figure (1) shows a sample response spectrum curve. The design spectrum is indicated by the smooth line, and the calculated spectrum is indicated by the line with Δ symbols.

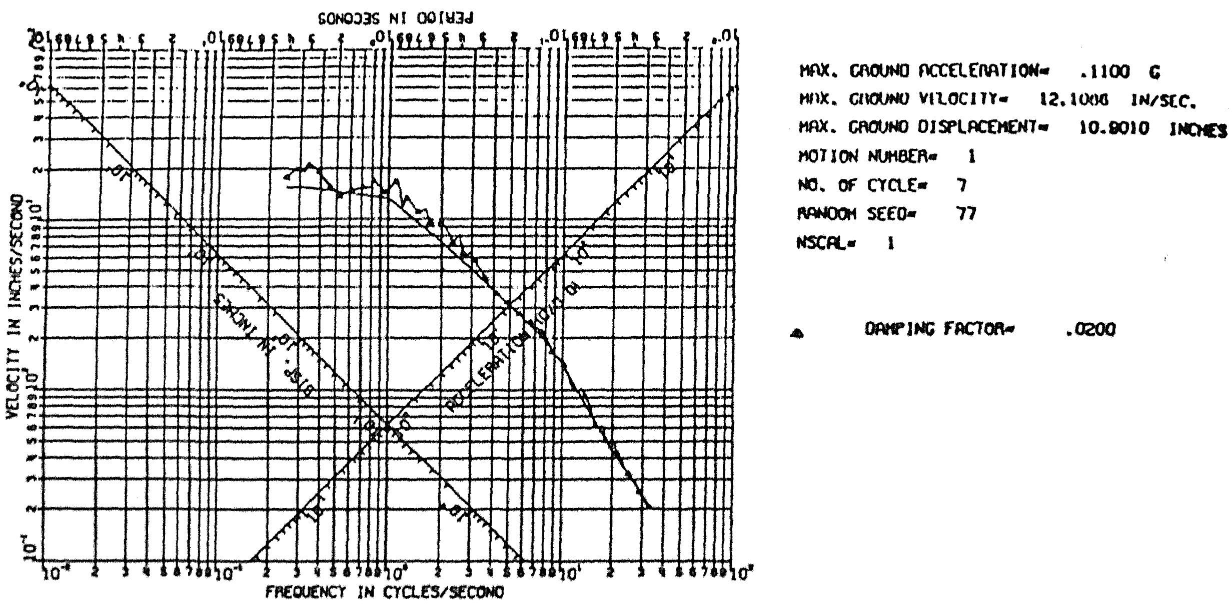
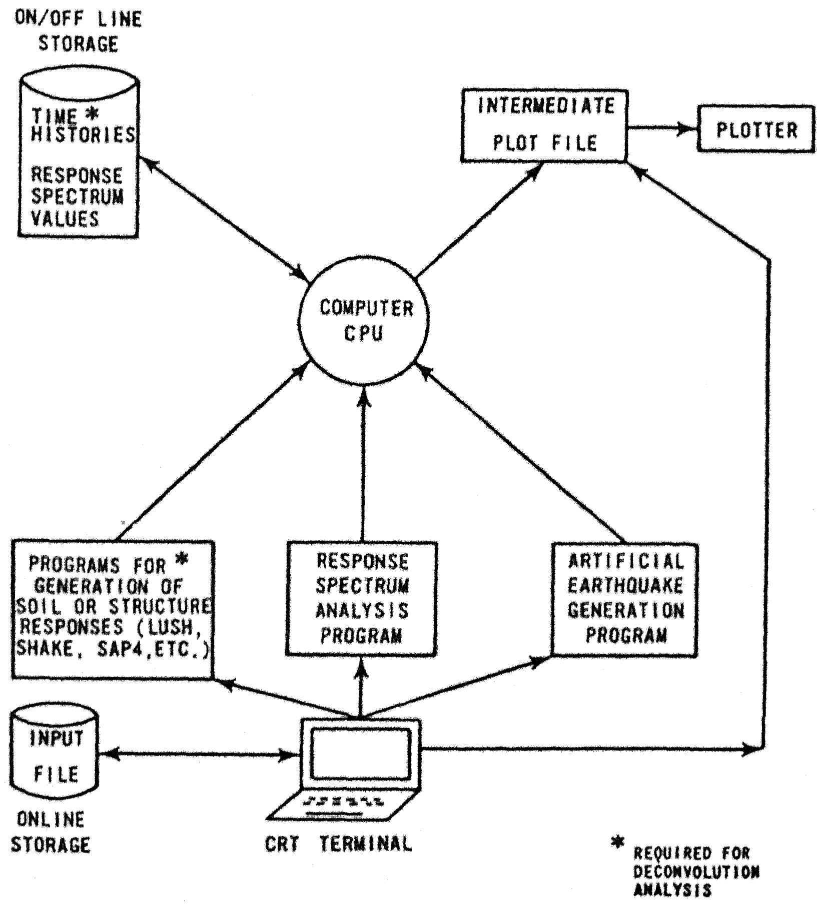


FIGURE (1)



INTERACTIVE GRAPHICS SYSTEM HARDWARE

FIGURE (2)

C. Interactive Graphics Systems

Follow the procedure previously described. Experience has indicated that several different artificial time-histories may be generated before a "good" one can be selected. Therefore, computer turn-around time and graphic output are important. With the implementation of an interactive graphics system, the required processing time can be cut drastically. By changing only this initial random number, different time histories can be generated. These types of changes can be performed easily on a time-sharing terminal. A CRT can then be used to view the graphic output of the computed and design spectrum values on the screen. Another advantage of using a CRT is the ability to detect large discrepancies between computed and design spectrum values. In that case, besides changing the random number or other input parameters, the program provides the capability of changing the desired spectrum values within the specified range. (Note that these desired spectrum values are used for the calculation of the initial power spectral density functions.)

The hardware and software configuration of this interactive graphics system is shown in Figure (2).

D. Conclusion

Due to the inherent iterative procedure, it is desirable to have an interactive graphics system incorporated into the program. Both the technique of generating artificial time history and the interactive graphics system are described here. Methods of achieving a better matching between the target spectrum and calculated spectrum are also described. It is also appropriate to point out that the articifical time history matches only the desired response spectrum of single degree of freedom oscillators. Care should be exercised in applying this kind of time history to other cases.

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