EQUIPMENT RESPONSE BY SECONDARY RESPONSE SPECTRUM TECHNIQUE

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INTRODUCTION

Response spectrum method is widely used to calculate the maximum structural responses given the response spectra of the ground design motion. The displacements velocities or accelerations, thus computed are sufficient for the design of the structure. For the qualification or design of the subsystems, however, one uses the instructure response spectra. Instructure spectra are obtained by a time-history analysis.

Recently, it was shown that the response spectrum method may also be used to obtain instructure response spectra (1). Here the input is described by the secondary ground design spectra, defined as the spectra of the responses of series of damped simple oscillators each subjected to the prescribed ground design motion. This concept was also used to estimate the upperbound instructure response spectra of structures (2).

In the nuclear power plant industry the artificial time-histories used for instructure spectra development are standardized. Thus, once the secondary ground spectra at selected frequencies and damping values are obtained the use of the time-histories may be eliminated. This leads to more economical analysis and thus the engineer has more flexibility in design. Herein, such a synthetic accelerogram is used to develop a set of secondary ground spectra. Instructure response spectra obtained by time-history analysis and secondary response spectrum technique are compared.

THEORETICAL BACKGROUND

For convenience, the formulation below will be limited to accelerations, however, extension to velocities or displacements is direct.

Consider a structure subjected to a given earthquake ground acceleration time-history $\ddot{u}(t)$. The contribution of the n th mode of vibration, $\underline{\ddot{x}}_n(t)$, to the structure acceleration response may be calculated by means of the well known Duhamel integral equation

$$\underline{\ddot{x}}_n(t)=\lambda_n \underline{Q}_n \int_0^t \ddot{h}_n(t_1)\,\ddot{u}(t-t_1)\,dt_1 \qquad (1)$$

where $\underline{Q}_n$ is the n th mode shape vector normalized with respect to the mass matrix $\underline{M}$; $\lambda_n=\underline{Q}^T\underline{M}\underline{1}$ is the n th mode participation factor; $h_n(t)$ is the impulse response function of the n th mode.

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Next consider the contribution of the n th modal response to the k th instructure spectral acceleration vector. This involves filtering of the modal response through a spectral simple oscillator with frequency ω_k and damping β_k

$$\underline{\ddot{z}}_n(t)=\int_0^t \ddot{h}_k(t_1)\,\underline{\ddot{x}}_n(t-t_1)\,dt_1 \qquad (2)$$

where $h_k(t)$ is the impulse response function of the spectral simple oscillator. Substituting for $\underline{\ddot{x}}_n(t)$ from Eq.(1) and changing the order of integration, Eq.(2) may be put into the form

$$\underline{\ddot{z}}_n(t)=\lambda_n\underline{Q}_n\int_0^t \ddot{h}_n(t_2)\int_0^{t-t_2} \ddot{h}_k(t_1)\,\ddot{u}(t-t_2-t_1)\,dt_1\,dt_2 \qquad (3)$$

The expression given in Eq.(3) is exact and forms the basis of the secondary response spectrum technique. Now let the k th secondary ground acceleration time-history to be

$$\ddot{u}_k(t)=\int_0^t \ddot{h}_k(t_1)\,\ddot{u}(t-t_1)\,dt_1 \qquad (4)$$

Note that this accelerogram depends only on the spectral frequency and damping under consideration and the ground design motion. Then, defining the k th secondary ground design spectra as

$$S_a^k(\omega_n,\beta_n)=\max\left[\int_0^t \ddot{h}_n(t_1)\,\ddot{u}_k(t-t_1)\,dt_1\right] \qquad (5)$$

the maximum value of the spectral acceleration vector due to the n th mode of vibration may be written as

$$\left\{\underline{\ddot{z}}_n(t)\right\}_{\max}=\lambda_n\underline{Q}_n S_a^k(\omega_n,\beta_n) \qquad (6)$$

The modal maxima may now be combined by the SRSS procedure to obtain the instructure spectral accelerations corresponding to the k th spectral frequency and damping; this is the only source of approximation involved in the secondary spectrum technique.

SECONDARY GROUND SPECTRA

Typical secondary spectra for 2 percent spectral damping and 2, 10 and 34 cps spectral frequencies are shown in Fig. 1. The secondary spectra corresponding to the spectral frequency of 34 cps match the ground design spectra as expected. For lower spectral frequencies the secondary spectra exhibit a pronounced spike at the frequency under consideration.

The nature of the peak amplifications of the secondary spectra were also investigated. It was found out that the amplifications, which are a measure of the resulting instructure spectra, follow very closely the peaks and valleys of the corresponding ground spectra.

APPLICATION

A coupled, three dimensional (108 DOF) "stick" model of a containment external shell, internal structure and steam line support structure was analized for comparison purposes. Time-history analysis was performed under the action of one horizontal component of earthquake. The synthetic accelerogram used to generate the secondary ground spectra was designated as the ground design motion. The maximum ground acceleration was 0.1 g's.

Figures 2 through 4 depict the comparisons of instructure spectra at different structural locations for various spectral damping values. As may be seen the behavior of the secondary spectrum method is quite satisfactory. The deviations from the time-history analysis results at the structural frequencies are below 10%. For the case studied the saving in the computer cost, with respect to the time-history analysis, was about ten fold.

The influence of the method of modal maxima combination was also investigated. Instructure spectra were computed both by SRSS and by "ten percent" (TPER) methods. For structural locations where the dominant response is due to closely spaced modes, the SRSS method underestimated the response at spectral frequencies near closely spaced mode clusters, while the TPER method overestimated the response away from them. The comparison shown in Fig. 4 is typical. This may be overcome by using a hybrid technique: the modal maxima corresponding to a spectral frequency are combined by TPER or SRSS procedures depending on whether the spectral frequency is within 10% of closely spaced mode clusters or not. Then, the under/over-estimation appears to be minimized.

REFERENCES

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2. Atalik, T. S., "On Upperbound Instructure Spectra," 5th SMIRT Conf., Paper No. K9/7, Berlin West Germany, Aug. 1979.

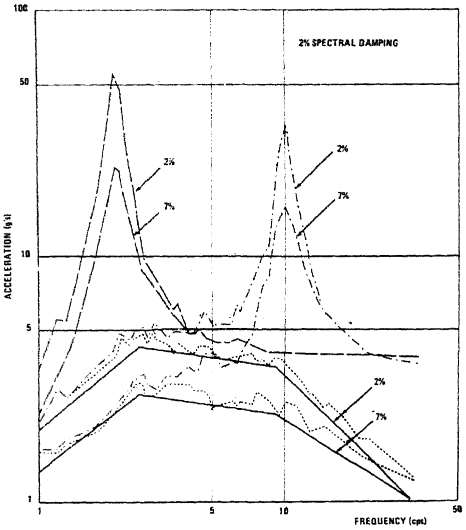

FIGURE 1. TYPICAL SECONDARY SPECTRA

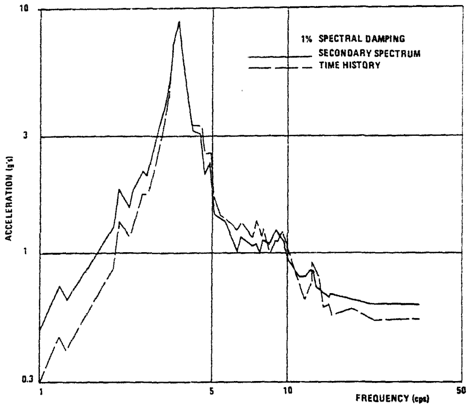

FIGURE 2. CONTAINMENT SHELL TOP INSTRUCTURE SPECTRA

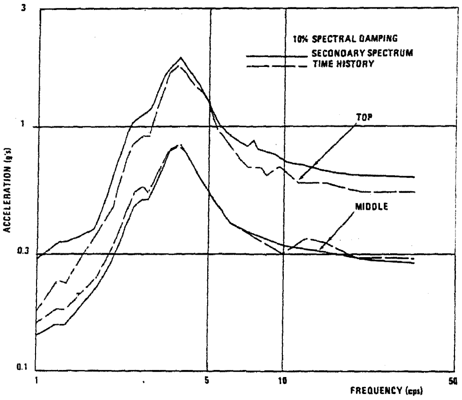

FIGURE 3. CONTAINMENT SHELL TOP AND MIDDLE INSTRUCTURE SPECTRA

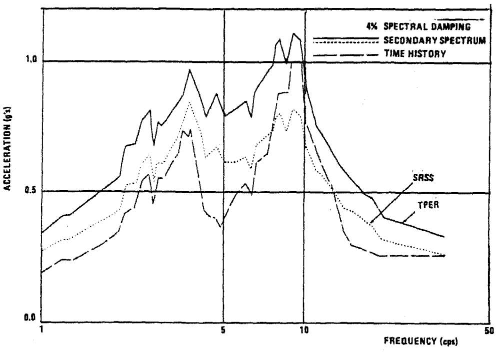

FIGURE 4. CONTAINMENT INTERNALS TOP INSTRUCTURE SPECTRA