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Definition of Statistically Independent Time Histories

By Chang Chen[1]

Introduction

The time history method has been one of the analytical tools applied in the seismic resistant design of nuclear power plant facilities. However, due to the erratic nature of ground motions, it is currently not possible to predict the time histories of future earthquakes. Furthermore, as a conservative approach, the basic input criterion in the nuclear industry is the smoothed design response spectra that represent the mean value plus one standard deviation of the calculated spectra of some selected strong motion accelerograms (4). Thus, when the time-history method is used, the input time history is required to have response spectra consistent with the design response spectra. One way of achieving this is to use a strong motion accelerogram and to normalize it such that the valleys of the zigzag response are consistent with the design response spectra. This is too conservative for the frequency regions where peaks of the zigzag response spectra occur.

Another method is to use all the strong motion accelerograms, selected in Ref. 4, as input one after the other and to take the mean value plus one standard deviation of the responses for design. This method is good for research but not practical for daily design work because of its high cost and time-consuming nature. The third technique is to use an ensemble of artifical time histories that possess an average ensemble response spectra consistent with the design response spectra. Ref. 5 gives a detailed survey and theory of generating these kind of artificial time histories. This method is sound in theory, but has the same drawback as the second method previously mentioned.

As necessity is the mother of invention, the nuclear power industry is now using an artifice of artificial time history with response spectra closely matching the design response spectra as input. This artifice can be generated either by suppressing or amplifying locally the spectra of a time history, or by an iteration method in generating the artificial time history (1).

Since three orthogonal components of earthquakes occur simultaneously, it is recommended that one either combines the responses from each of the three component inputs by the root-sum-square method or input the three independent components simultaneously (4). When considering simultaneous input of multiple components the term "statistically independent component time histories" has been used in the draft of the Seismic Task Group of ASCE Nuclear Structures

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and Material Committee, the draft of American Society of Mechanical Engineers (ASME) Task Group on Dynamic Analysis, and the draft of Institute of Electrical and Electronics Engineers (IEEE) Guide for Siesmic Qualification of Class IE Equipment for Nuclear Power Generating Stations. Until now, the criterion of statistical independence of time histories has not been clearly defined. Thus, it is the intention of this note to define the statistical independence of artificial time histories.

Method of Analysis

For the purpose of this analysis, the statistical independence of two variables, $x_1(t)$ and $x_2(t)$, is judged by the normalized covariance or correlation coefficient (2)

$$\rho_{12} = \frac{E[(x_1 - m_1)(x_2 - m_2)]}{\sigma_1 \sigma_2} \quad \ldots\ldots (1)$$

in which E = the mathematical expectation; and m_1, m_2, σ_1, and σ_2 = the mean values and standard deviations of x_1 and x_2, respectively. Strictly speaking, the statistical independence is satisfied only when the correlation coefficient, ρ_{12}, is zero. Since we know this is not a realistic criterion, the rational approach is to calculate the statistical properties of the correlation coefficients of the recorded strong motion accelerograms.

The input data used for this analysis are the 312 baseline corrected strong motion accelerograms written on a magnetic tape (3). Since each site has three components designated as H_1, H_2, and V, the 312 accelerograms represent records at 104 sites. The correlation coefficients for H_1 and H_2, H_1 and V, and H_2 and V are calculated for all 104 sites and their statistical properties are shown in Table 1.

TABLE 1.—Statistical Properties of Correlation Coefficients for Strong Motion Accelerograms Recorded at 104 Sites

Components (1)	True mean (2)	Standard deviation (3)	Absolute mean (4)	Absolute maximum (5)	Absolute minimum (6)
H_1, H_2	0.0029	0.2116	0.1632	0.6801	0.0014
H_1, V	0.0187	0.1774	0.1387	0.4957	0.0004
H_2, V	0.0055	0.1841	0.1321	0.7430	0.0005

TABLE 2.—Absolute Means of Correlation Coefficients of Strong Motion Accelerograms (4)

Components (1)	12 of 17 accelerograms selected by Blume, et al. (2)	13 of 14 accelerograms selected by Newmark, et al. (3)
H_1, H_2	0.1258	0.1481
H_1, V	0.1493	0.1241
H_2, V	0.1420	0.1368

Since the characteristics of strong motion accelerograms are affected in a complex manner by the source mechanism, travel path, and local geology (1), the method of selection of the strong motion accelerograms may influence the results. Thus, the absolute means of the correlation coefficients are also calculated for those strong motion accelerograms selected in Ref. 4. However, those strong motion accelerograms in Ref. 4 are not baseline corrected. Hopefully, this will not influence the results. Of the 17 records selected by Blume, et al., only 12 are available in Ref. 3 and 13 of the 14 records used by Newmark, et al. are available in Ref. 3. Thus the values in Table 2 are based on the data available in Ref. 3.

Conclusions

Even though the numbers of accelerograms selected in Tables 1 and 2 are quite different, the calculated absolute means of the correlation coefficients are not too much different. Based on this study, it is recommended that the statistically independent artificial time histories should be those with the absolute correlation coefficients less than or equal to 0.16. As a word of caution, because the artificial time history with response spectra closely matching the single degree-of-freedom design response spectra is nonunique, the application of this artifice to more complicated structures with several dominant modes should be exercised with care (1).

Appendix.—References

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