A UNIFIED APPROACH TO THE SEISMIC ANALYSIS OF BUILDINGS AND EQUIPMENT

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ABSTRACT

A unified approach which utilizes recent developments in probabilistic structural dynamics and random processes has been studied to determine seismic design forces for buildings and equipment. The method considers earthquakes as random processes and uses the extreme value statistics to develop relations between earthquake design response and power spectra. The design power spectra are then used as input to the building to determine building response power spectra using random vibration theory. The building response which include response accelerations and floor response spectra are obtained from building response power spectra using relations between power and response spectra. This unified approach does not use the time-history method for generating floor response spectra for equipment design. The calculations of building response and floor response spectra are performed in single step by the method of complex response.

INTRODUCTION

The seismic analyses of buildings and equipment have customarily been performed using the response spectrum method. In this method, the site design spectra are used for the seismic analysis of buildings while the floor design response spectra at equipment locations are used for the seismic analysis of equipment. The floor design response spectra generally are obtained by the time-history method which involves three steps: (1) development of spectra-compatible time-history from given site design spectra; (2) dynamic analysis of buildings using spectrum-compatible time-history developed in step (1) as input for determining structural response time-histories at locations of equipment; and (3) computation of floor design response spectra using structural response time-histories obtained in step (2). Although this method for obtaining floor design response spectra is straightforward, the difficulty lies in selecting the most appropriate spectrum-compatible time-history to be used in step (1) among available infinite number of spectrum-compatible time-histories. Studies have shown that the difference in resulting peak values of floor design response spectra can easily be more than 30% [1] if different spectrum-compatible time-histories are used in the building response analysis. This leads to the problem of uncertainty in equipment design when using floor design response spectra generated by spectrum-compatible time-histories.

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The need for alleviating this uncertainty has led to the development of methodologies which compute floor design response spectra directly from site design response spectra without using the time-history method. An approach which utilizes recent developments in probabilistic structural dynamics and random processes was studied for directly generating floor design response spectra [1,2]. In this approach, the building response accelerations for building seismic design are also obtained at the same time the floor design response spectra are generated. This unified approach for determining seismic design forces for buildings and for equipment eliminates the usual two-step method for obtaining above seismic design information. It also provides more reliable floor response spectra for the seismic design of equipment.

METHOD OF ANALYSES

The method taken in the unified approach for determining building seismic response accelerations and for generating floor response spectra is shown in Figure 1. The method has the following features:

- Earthquakes are considered as random processes.
- The extreme value theorem of stochastic processes is used to develop the relations between site response and power spectra.
- Power spectra of the response of a linear system to stochastic processes are determined by random vibration theory.
- Floor response spectra and building response accelerations are obtained using the response power spectra through relations between response and power spectra.

All the computations of this method are performed in the frequency domain using the method of complex response. Detailed descriptions of the method are given in References 1 and 2.

NUMERICAL RESULTS

The mathematical model shown in Figure 2 was used to demonstrate the unified approach for generating floor response spectra and for determining building response accelerations. The same model was used for generating floor response spectra and building response accelerations using the time-history approach. The U.S. NRC horizontal site design spectra with a maximum acceleration of 0.25 g were used in both the unified and time-history approaches for computing the floor response spectra and building response accelerations. In the unified approach, the U.S. NRC design spectra were considered as the average response spectra of a random process. In the time-history approach, six distinct spectrum-compatible synthetic earthquakes from the same site design spectrum were used.

The floor acceleration response spectra at node 9 obtained by both the unified and time-history methods are compared in Figure 3. A comparison of these response spectra illustrates that the unified approach accurately predicts the frequency values at which peak and lowest responses occur. The magnitude of the spectra predicted by both approaches are also in good agreement. The building response accelerations along the height of the mathematical model as obtained by both methods are compared in Table 1. The differences in building response accelerations are insignificant for engineering purposes.

CONCLUSIONS

The accuracy of the unified approach establishes its capability of directly computing the floor response spectra and building response accelerations. The unified approach eliminates the need for generating spectrum-compatible synthetic earthquakes and for performing time-history analyses. Because it implicitly considers all possible earthquake motions whose response spectra are compatible with the site seismic design spectra, the unified approach provides more reliable building and equipment seismic design forces.

REFERENCES

1. Chen, P. and Chen, J., "Generation of Floor Response Spectra Directly from Free-Field Design Spectra," Proceedings of Second International Conference on Microzonation, San Francisco, CA, November 26 to December 1, 1978.

2. Chen, P. and Chen, J., "The Use of Extreme Value Theorem in Generating Floor Response Spectra", Proceedings of Second ASCE Specialty Conference on Probabilistic Mechancis and Structural Reliability, Tucson, Arizona, January 10 to 11, 1979.

TABLE 1. COMPARISONS OF BUILDING RESPONSE ACCELERATIONS

Node	Unified Approach (g)	Mean of Six Synthetic Time-Histories (g)
9	1.27	1.21
7	0.62	0.63
4	0.44	0.45

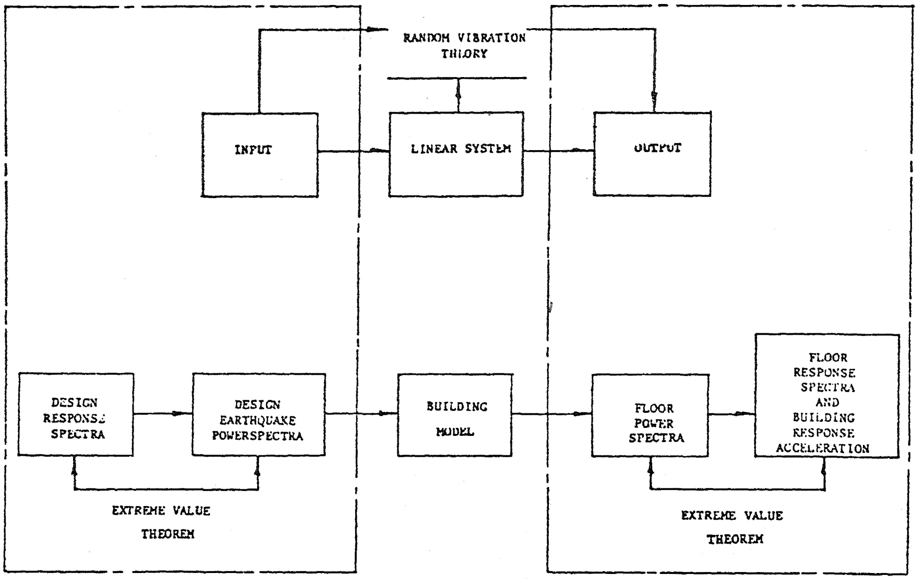
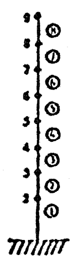


FIGURE 1. SCHEMATIC REPRESENTATION OF UNIFIED APPROACH FOR DETERMINING RESPONSE ACCELERATION AND FLOOR RESPONSE SPECTRA



Elev.	WEIGHT (kips)	AREA (ft^2)	SHEAR AREA (ft^2)	I (ft^4)
195'-0"	31,700			
		3,180	1,100	13,140,530
153'-0"	23,740			
		3,180	1,100	13,140,530
110'-0"	35,500			
		3,700	1,475	13,488,265
80'-0"	56,730			
		14,300	7,033	62,907,890
60'-0"	108,300			
		18,926	10,055	63,058,140
36'-0"	94,120			
		16,900	9,520	72,437,030
18'-0"	81,710			
		15,950	10,200	73,262,500
0'-0"	104,839			
		19,790	12,718	91,202,000
-26'-0"				

FIGURE 2 MATHEMATICAL MODEL STUDIED

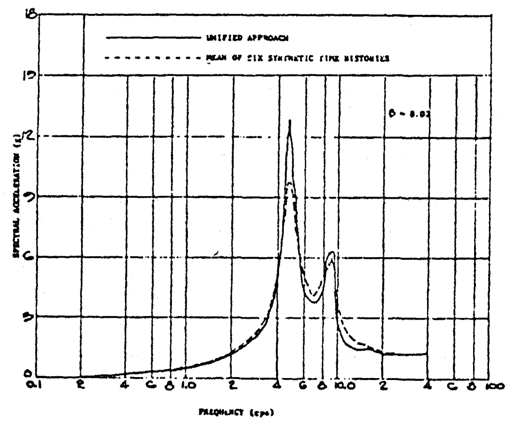


FIGURE 3. FLOOR ACCELERATION RESPONSE SPECTRA AT NODE NO. 9