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U.S. ATOMIC ENERGY COMMISSION

REGULATORY GUIDE

DIRECTORATE OF REGULATORY STANDARDS

REGULATORY GUIDE 1.60

DESIGN RESPONSE SPECTRA FOR SEISMIC DESIGN OF NUCLEAR POWER PLANTS

A. INTRODUCTION

Criterion 2, "Design Bases for Protection Against Natural Phenomena," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Licensing of Production and Utilization Facilities," requires, in part, that nuclear power plant structures, systems, and components important to safety be designed to withstand the effects of earthquakes. Proposed Appendix A, "Seismic and Geologic Siting Criteria," to 10 CFR Part 100, "Reactor Site Criteria," would require, in part, that the Safe Shutdown Earthquake (SSE) be defined by response spectra corresponding to the expected maximum ground accelerations. This guide describes a procedure acceptable to the AEC Regulatory staff for defining response spectra for the seismic design of nuclear power plants. The Adviory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position.

B. DISCUSSION

In order to approximate the intensity and thereby estimate the maximum ground acceleration[1] of the expected strongest ground motion (SSE) for a given site, proposed Appendix A to 10 CFR Part 100 specifies a number of required investigations. It does not, however, give a method for defining the response spectra[1] corresponding to the expected maximum ground acceleration.

The recorded ground accelerations and response spectra of past earthquakes provide a basis for the rational design of structures to resist earthquakes. The Design Response Spectra,[1] specified for design purposes, can be developed statistically from response spectra of past strong-motion earthquakes (see reference 1). An extensive study has been described by Newmark and Blume in references 1, 2, and 3. After reviewing these referenced documents, the AEC Regulatory staff has determined as acceptable the following procedure for defining the Design Response Spectra representing the effects of the vibratory motion of the SSE, 1/2 the SSE, and the Operating Basis Earthquake (OBE) on sites underlain by either rock or soil deposits and covering all frequencies of interest. However, for unusually soft sites, modification to this procedure will be required.

In this procedure, the configurations of the horizontal component Design Response Spectra for each of the two mutually perpendicular horizontal axes are shown in Figure 1 of this guide. These shapes agree with those developed by Newmark, Blume, and Kapur in reference 1. In Figure 1 the base diagram consists of three parts: the bottom line on the left part represents the maximum ground displacement, the bottom line on the right part represents the maximum acceleration, and the middle part depends on the maximum velocity. The horizontal component Design Response Spectra in Figure 1 of this guide correspond to a maximum *horizontal ground acceleration* of 1.0 g. The maximum ground displacement is taken proportional to the maximum ground acceleration, and is set at 36 inches for a ground acceleration of 1.0 g. The numerical values of design displacements, velocities, and accelerations for the horizontal component Design Response Spectra are obtained by multiplying the corresponding values of the maximum ground displacement and acceleration by the factors given in Table I of this guide. The displacement region lines of the Design Response Spectra are parallel to the maximum ground displacement line and are shown on the left of Figure 1. The velocity region lines slope downward from a frequency of 0.25 cps (control point D) to a frequency of 2.5 cps (control point C) and are shown at the top. The remaining two sets of lines between the frequencies of 2.5 cps and 33 cps (control point A), with a break at a frequency of 9 cps (control

[1] See definitions at the end of the guide.

point B), constitute the acceleration region of the horizontal Design Response Spectra. For frequencies higher than 33 cps, the maximum ground acceleration line represents the Design Response Spectra.

The vertical component Design Response Spectra corresponding to the maximum *horizontal ground acceleration* of 1.0 g are shown in Figure 2 of this guide. The numerical values of design displacements, velocities, and accelerations in these spectra are obtained by multiplying the corresponding values of the maximum *horizontal ground motion* (acceleration = 1.0 g and displacement = 36 in.) by the factors given in Table II of this guide. The displacement region lines of the Design Response Spectra are parallel to the maximum ground displacement line and are shown on the left of Figure 2. The velocity region lines slope downward from a frequency of 0.25 cps (control point D) to a frequency of 3.5 cps (control point C) and are shown at the top. The remaining two sets of lines between the frequencies of 3.5 cps and 33 cps (control point A), with a break at the frequency of 9 cps (control point B), constitute the acceleration region of the vertical Design Response Spectra. It should be noted that the vertical Design Response Spectra values are 2/3 those of the horizontal Design Response Spectra for frequencies less than 0.25; for frequencies higher than 3.5, they are the same, while the ratio varies between 2/3 and 1 for frequencies between 0.25 and 3.5. For frequencies higher than 33 cps, the Design Response Spectra follow the maximum ground acceleration line.

The horizontal and vertical component Design Response Spectra in Figures 1 and 2, respectively, of this guide correspond to a maximum horizontal ground acceleration of 1.0 g. For sites with different acceleration values specified for the design earthquake, the Design Response Spectra should be linearly scaled from Figures 1 and 2 in proportion to the specified maximum horizontal ground acceleration. For sites that (1) are relatively close to the epicenter of an expected earthquake or (2) have physical characteristics that could significantly affect the spectral pattern of input motion, such as being underlain by poor soil deposits, the procedure described above will not apply. In these cases, the Design Response Spectra should be developed individually according to the site characteristics.

C. REGULATORY POSITION

1. The horizontal component ground Design Response Spectra, without soil-structure interaction effects, of the SSE, 1/2 the SSE, or the OBE on sites underlain by rock or by soil should be linearly scaled from Figure 1[2] in proportion to the maximum horizontal ground acceleration specified for the earthquake chosen. (Figure 1 corresponds to a maximum horizontal ground acceleration of 1.0 g and accompanying displacement of 36 in.) The applicable multiplication factors and control points are given in Table I. For damping ratios not included in Figure 1 or Table I, a linear interpolation should be used.

2. The vertical component ground Design Response Spectra, without soil-structure interaction effects, of the SSE, 1/2 the SSE, or the OBE on sites underlain by rock or by soil should be linearly scaled from Figure 2[2] in proportion to the maximum horizontal ground acceleration specified for the earthquake chosen. (Figure 2 is based on a maximum *horizontal ground acceleration* of 1.0 g and accompanying displacement of 36 in.) The applicable multiplication factors and control points are given in Table II. For damping ratios not included in Figure 2 or Table II, a linear interpolation should be used.

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[2]This does not apply to sites which (1) are relatively close to the epicenter of an expected earthquake or (2) which have physical characteristics that could significantly affect the spectral combination of input motion. The Design Response Spectra for such sites should be developed on a case-by-case basis.

DEFINITIONS

Response Spectrum means a plot of the maximum response (acceleration, velocity, or displacement) of a family of idealized single-degree-of-freedom damped oscillators as a function of natural frequencies (or periods) of the oscillators to a specified vibratory motion input at their supports. When obtained from a recorded earthquake record, the response spectrum tends to be irregular, with a number of peaks and valleys.

Design Response Spectrum is a relatively smooth relationship obtained by analyzing, evaluating, and statistically combining a number of individual response spectra derived from the records of significant past earthquakes.

Maximum (peak) Ground Acceleration specified for a given site means that value of the acceleration which corresponds to zero period in the design response spectra for that site. At zero period the design response spectra acceleration is identical for all damping values and is equal to the maximum (peak) ground acceleration specified for that site.

TABLE I

HORIZONTAL DESIGN RESPONSE SPECTRA RELATIVE VALUES OF SPECTRUM AMPLIFICATION FACTORS FOR CONTROL POINTS

Percent of Critical Damping	Amplification Factors for Control Points			
	Acceleration[1,2]			Displacement[1,2]
	A(33 cps)	B(9 cps)	C(2.5 cps)	D(0.25 cps)
0.5	1.0	4.96	5.95	3.20
2.0	1.0	3.54	4.25	2.50
5.0	1.0	2.61	3.13	2.05
7.0	1.0	2.27	2.72	1.88
10.0	1.0	1.90	2.28	1.70

[1] Maximum ground displacement is taken proportional to maximum ground acceleration, and is 36 in. for ground acceleration of 1.0 gravity.

[2] Acceleration and displacement amplification factors are taken from recommendations given in reference 1.

VERTICAL DESIGN RESPONSE SPECTRA RELATIVE VALUES OF SPECTRUM AMPLIFICATION FACTORS FOR CONTROL POINTS

Percent of Critical Damping	Amplification Factors for Control Points			
	Acceleration[1,2]			Displacement[1,2]
	A(33 cps)	B(9 cps)	C(3.5 cps)	D(0.25 cps)
0.5	1.0	4.96	5.67[3]	2.13
2.0	1.0	3.54	4.05	1.67
5.0	1.0	2.61	2.98	1.37
7.0	1.0	2.27	2.59	1.25
10.0	1.0	1.90	2.17	1.13

[1] Maximum ground displacement is taken proportional to maximum ground acceleration and is 36 in. for ground acceleration of 1.0 gravity.

[2] Acceleration amplification factors for the vertical design response spectra are equal to those for horizontal design response spectra at a given frequency, whereas displacement amplification factors are 2/3 those for horizontal design response spectra. These ratios between the amplification factors for the two design response spectra are in agreement with those recommended in reference 1.

[3] These values were changed to make this table consistent with the discussion of vertical components in Section B of this guide.

REFERENCES

1. Newmark, N. M., John A. Blume, and Kanwar K. Kapur, "Design Response Spectra for Nuclear Power Plants," ASCE Structural Engineering Meeting, San Francisco, April 1973.

2. N. M. Newmark Consulting Engineering Services, "A Study of Vertical and Horizontal Earthquake Spectra," Urbana, Illinois, USAEC Contract No. AT(49-5)-2667, WASH-1255, April 1973.

3. John A. Blume & Associates, "Recommendations for Shape of Earthquake Response Spectra," San Francisco, California, USAEC Contract No. AT(49-5)-3011, WASH-1254, February 1973.

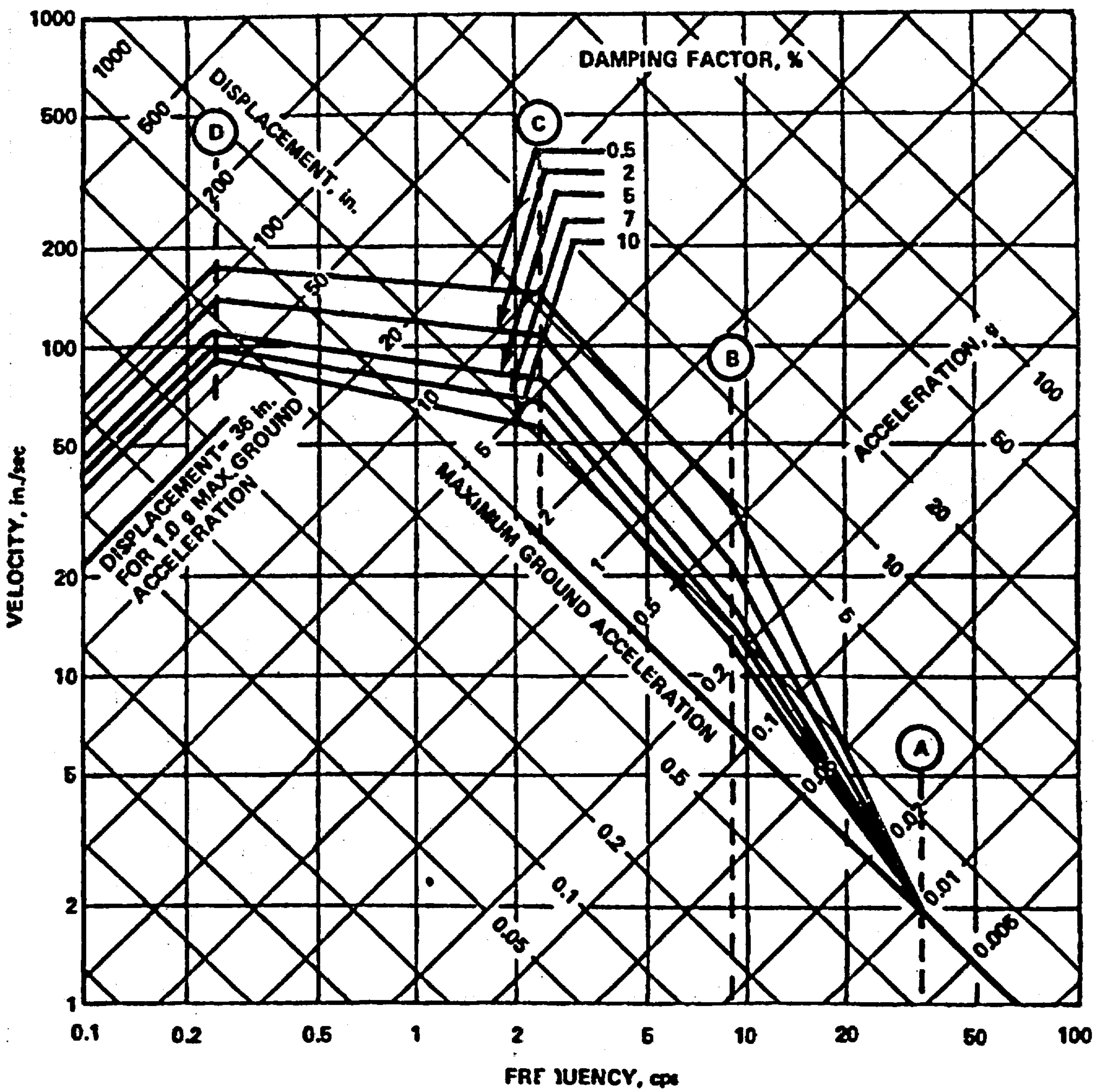

FIGURE 1. HORIZONTAL DESIGN RESPONSE SPECTRA – SCALED TO 1g HORIZONTAL GROUND ACCELERATION

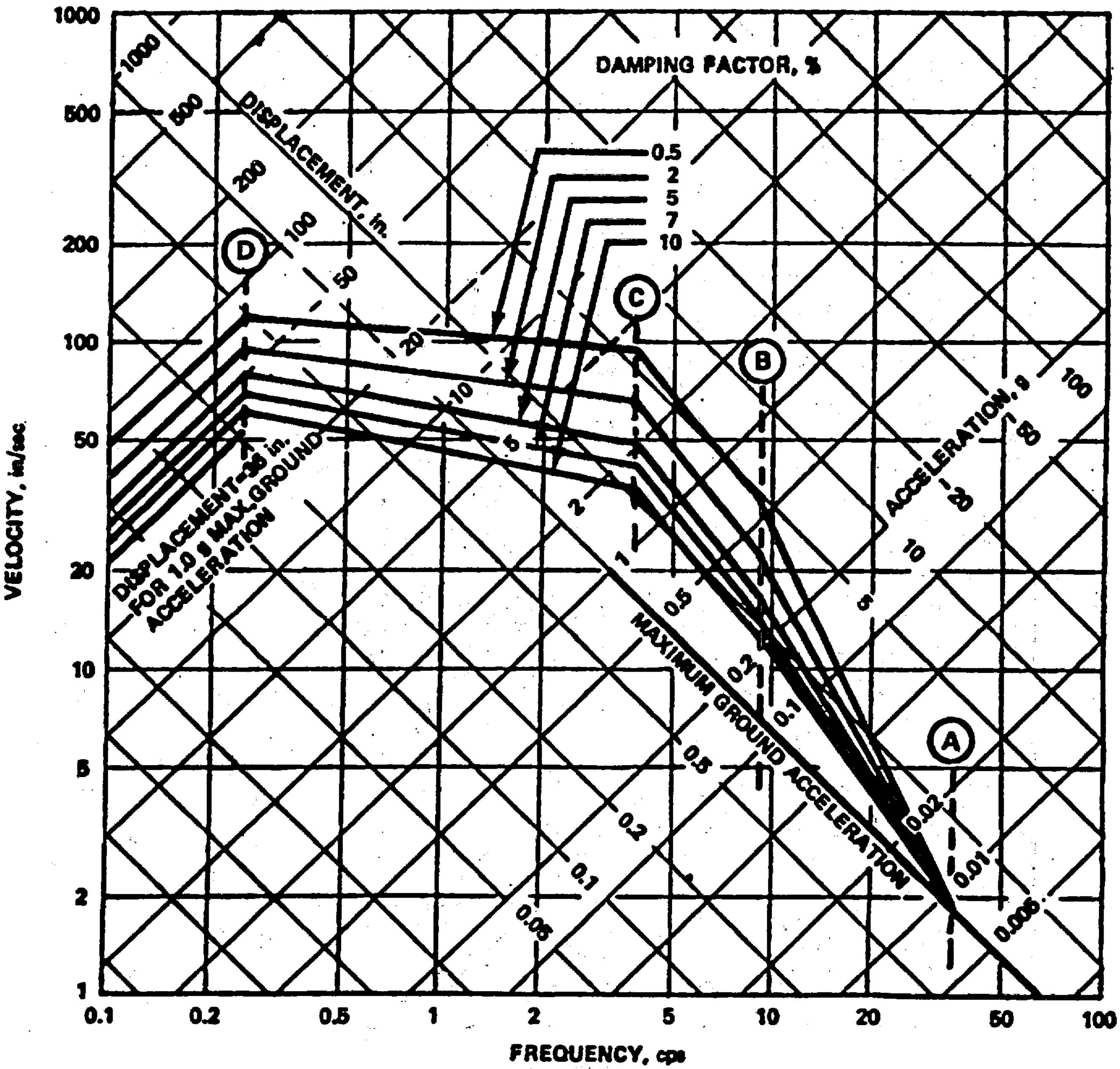

FIGURE 2. VERTICAL DESIGN RESPONSE SPECTRA – SCALED TO 1g HORIZONTAL GROUND ACCELERATION

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