SURVEY OF ASEISMIC DESIGN DATA FOR NUCLEAR POWER PLANTS

by

D. S. Mehta[I], P. T. Kuo[II] and A. A. Vizzi[III]

SYNOPSIS

A survey of the basic design criteria for nuclear plants all over the world was conducted, and the results are presented in tabulated forms. Information concerning design maximum ground acceleration amplitudes, ground response spectra, and location of various plant sites are included. Historical development of the design criteria and present practice within the United States of America are discussed.

INTRODUCTION

Safety requirements for nuclear power plants dictate the importance of design considerations that are necessary to withstand earthquake forces. The integrity of the structure, equipment, nuclear steam supply system, and components of nuclear power plants must be ensured for public safety. The history of seismic activities all over the world has demonstrated that there are few areas, if any, where the earthquake problem can be completely neglected. Because of the high degree of safety required for a nuclear power plant, the dynamic analysis of each important structure is more critical and necessary than conformance of a static analysis of the conventional building code. Design and analysis of the structure becomes a challenge due to the state-of-the-art development in earthquake engineering and inherent uncertainty with regard to the magnitude of the ground acceleration and its associated ground design spectra. The purpose of this paper is to present the basic design considerations for earthquakes used in the past and current nuclear power plants throughout the world.

HISTORICAL DEVELOPMENT IN THE UNITED STATES

In view of the severe consequences due to the potential failure under an earthquake event, dynamic analyses are required for structures, systems and components that are essential to power generation and public safety. The basic criteria defining the characteristics of a potential earthquake hazard for which the structure is designed have been changed significantly throughout the past decade. The USAEC publication of TID 7024 (1) first established the general requirements on seismic criteria for the design of a nuclear power plant. Basically, it called for the proper determination of a maximum ground

---

I Engineering Specialist, Bechtel Power Corporation, Gaithersburg, Maryland

II Engineering Specialist, Bechtel Power Corporation, Gaithersburg, Maryland

III Project Engineer, Bechtel Power Corporation, Gaithersburg, Maryland

acceleration associated with an existing earthquake record and a ground response spectrum. A variety of available acceleration records and response spectra were adopted at the early stage of the development. Among the most frequently used earthquake records were El Centro 1940, N-S component; Taft 1952; and Helena 1935 EW normalized to design ground accelerations of the site.

The average strong-motion spectrum obtained from four large-magnitude earthquake records (El Centro 1940, El Centro 1934, Olympia 1949, and Taft 1952) was published in Housner's paper (2) and USAEC report TID 7024 (1). It has a characteristic amplification factor of 2.3 at a period of 0.25 second for 2 percent of the critical damping and converges to 1 at the period of 0.04 seconds. This standardized spectrum, along with adequately selected actual earthquake records, has been used as a basic design criterion for some years and on various projects.

A smoothed-response spectrum with an amplification factor of 4.3 for 2 percent of the critical damping from a period of 0.15 second to 0.50 second was published by Newmark and Hall (3). For many current nuclear power plants (4), a modified version of the Newmark smoothed-response spectrum with the characteristic amplification factor of 3.5 for 2 percent of the critical damping from a period of 0.15 second to 0.50 second has been widely adopted (Figure 1). The modified Newmark spectrum converges to the ground acceleration at 0.03 second. It is apparent that a higher degree of conservatism has been added in the current criteria than previously established criteria. Furthermore, in order to have a time history record compatible with the specified smoothed spectrum, the use of the computer-simulated accelerogram which results in a response spectrum enveloping the smoothed design spectrum has also been introduced into nuclear industry. This added sophistication leads to even greater conservatism in the establishment of the basic design criteria.

Paper by Newmark, et al. (13) presents the comparison for current recommendations with previous design spectra for Nuclear Power Plant in U.S.A.

Damping values and the stress levels of the materials were also of major concern. Along with the proposed spectra, Newmark suggested various damping values (3) for different materials and associated stress levels.

SURVEY OF DATA

Table 1 gives ground design horizontal and vertical ground acceleration data for the design of nuclear power plants in the United States. Detailed descriptions and evaluations of regional geology, site geology, earthquake history, and evaluation of the geologic and seismic characteristics of the site are included in Preliminary and/or Final Safety Analysis Reports filed with the United States Atomic Energy Commission. It also shows the Uniform Building Code (5) zone classification. Figure 2 shows the seismic risk map of the United States and maximum zonal acceleration for various zones in the United States.

Table 2 gives the seismic design coefficients for static and dynamic analyses of nuclear power plants in Japan. Locations of these plants are shown in Figure 3. Static seismic coefficients are based on the Japanese Building Code.

Table 3 gives ground design accelerations for some nuclear power plants in Spain (6), Switzerland, Taiwan, India, and Korea. Tarapur Nuclear Station, Units 1 and 2, in India has been designed by equivalent static analysis with 0.10 horizontal and 0.067 vertical ground acceleration. The Soviets build their reactors at selected sites free from earthquakes (7). Under the Yugoslav regulations, power plants must be aseismically designed to meet the requirement for intensity VII on the Mercalli-Cancani-Sieberg scale even if they are located in areas of comparatively low seismic activity (8). For areas of high seismic activity, much more stringent rules are applicable in Yugoslavia. In France (9), for the two seismic sites at Marcoule Phenix near Avignon and at Fessenheim Unit 1 in Alsace, the design basis earthquakes with an intensity of Mercalli VII and the maximum credible earthquake with an intensity of Mercalli VIII are considered.

SUMMARY

The basic seismic criteria used in the design of nuclear power plants all over the world are presented, but emphasis is primarily given to the practice in the United States. In the light of rapid development in the computer technology and further understanding of earthquake engineering, it is inevitable that the requirements for the seismic design for a nuclear power plant will also change with time. It is difficult to foresee any future development at present. However, in the authors' opinion, there are few areas which deserve more attention and more research effort.

The most needed effort should be directed to the prediction of earthquake characteristics for a given site. It is generally recognized that a low-intensity earthquake might have a higher amplification factor than a high-intensity earthquake, depending on the local geological condition, etc. The use of a standardized spectrum ignores this fact which could considerably either overestimate or underestimate the response for certain sites.

In addition to amplitude of maximum vertical ground acceleration, proper shape and characteristics of a vertical ground response spectrum should be established.

In order to improve and learn more about earthquake engineering and verifications of the procedures of the dynamic mathematical model and analyses, a proper seismic instrumentation program is highly recommended. Currently, for various nuclear power plants in the United States and Japan, and for many tall structures in California, an extensive seismic instrumentation program is implemented.

ACKNOWLEDGMENT

Thanks are extended to Mr. A. J. Bingaman, Chief Civil-Structural Engineer of Bechtel Power Corporation; Dr. Kiyoshi Muto, President of Muto Institute of Structural Mechanics; Mr. David S. L. Chu, Vice-President of Taiwan Power Company; Dr. John D. Stevenson, of Westinghouse Electric Corporation; Mr. J. R. Buchanan, Assistant Director of Nuclear Safety Information Center, Oak Ridge National Laboratory; and Mr. D. K. Croneberger of Gilbert Associates, Incorporated, for their kind assistance in furnishing seismic data of nuclear power plants.

REFERENCES

(1) Nuclear Reactors and Earthquake. Division of Technical Information, United States Atomic Energy Commission, TID 7024, August 1963.

(2) Housner, G. W. Behavior of Structure During Earthquakes. Journal of Engineering Mechanics, ASCE 85 (EM4), October 1959.

(3) Newmark, N. M., and Hall, W. J. Seismic Design Criteria for Nuclear Reactor Facilities. Fourth World Conference on Earthquake Engineering, 1969, B-4, pp. 37-50.

(4) Tsai, N. C., et al. Seismic Analyses of Structures and Equipment for Nuclear Power Plants. Bechtel Corporation, Topical Report, BC-TOP-4, Revision 1, September 1972.

(5) Uniform Building Code (USA), 1970 Edition.

(6) Gluckmann, A. L. Reactor Containment Structures Abroad. Specialty Conference, Power Division, August 1965.

(7) Soviet Power Reactors - 1970 Report of the United States of America Nuclear Power Reactor Delegation Visit to the Union of Soviet Socialist Republics, 1970; Division of Reactor Development and Technology, USAEC.

(8) Carbom, L., Obradovic, J., and Mojovic, L. Analysis of Criteria and their Application in Site Selection of Nuclear Power Plants in Yugoslavia. Containment Siting of Nuclear Power Plants, IAEA, April 1967.

(9) Plichon, E. E. Dynamic Analysis of Nuclear Power Plant Behavior to Seismic Excitation. Nuclear Engineering and Design 12 (1970), North-Holland Publishing Company, Amsterdam.

(10) Design Data and Safety Features of Commercial Nuclear Power Plants, Volume II. Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL-NSIC-55, January 1972.

(11) Wiegel, R. L. Earthquake Engineering, Prentice-Hall, Englewood Cliffs (Design Spectrum by G. W. Housner).

(12) Muto, Kiyoshi. Muto Institute of Structural Mechanics (Private Correspondence). November, 1972.

(13) Newmark, N. M., Blume, J. A., and Kapur K. K. Design Response Spectra for Nuclear Power Plants, American Society of Civil Engineers National Structural Engineering meeting, April 9-13, 1973, San Francisco, California.

TABLE 1*

ASEISMIC DESIGN DATA (USA)

Name of Plant	Location	Seismic Data			
		A	B	C	D
Aguirre Nuclear Station	Puerto Rico	0.20	0.10	67	-
Arkansas Nuclear One Units 1 and 2	Arkansas	0.20	0.10	67	1
Duane Arnold Energy Center	Iowa	0.12	0.06	80	1
Bailly Generating Station, Nuclear 1	Indiana	0.15	0.08	67	1
Beaver Valley Power Station	Pennsylvania	0.125	0.06	67	1
Brown Ferry Nuclear Unit 3	Alabama	0.20	0.10	-	1
Brunswick Steam Electric Plant Units 1 and 2	North Carolina	0.16	0.08	67	1
Calvert Cliffs Nuclear Power Plant Units 1 and 2	Maryland	0.15	0.08	67	1
Donald C. Cook Plant Units 1 and 2	Michigan	0.20	0.10	67	1
Cooper Nuclear Station	Nebraska	0.20	0.10	50	2
Crystal River Plant Unit 3	Florida	0.10	0.05	67	0
Davis-Besse Nuclear Power Station	Ohio	0.15	0.08	67	1
Diablo Canyon Nuclear Power Plant Units 2 and 3	California	0.20	0.15	67	3
Enrico Fermi Atomic Power Plant	Michigan	0.10	0.05	75	1
J.M. Farley Nuclear Plant Units 1 and 2	Alabama	0.10	0.05	67	1
James A. Fitzpatrick Nuclear Power Plant	New York	0.15	0.08	67	2
Forked River Nuclear Generating Station	New Jersey	0.22	0.11	67	1
Edwin I. Hatch Nuclear Power Plant Units 1 and 2	Georgia	0.15	0.08	67	0
Hutchinson Island Plant Units 1 and 2	Florida	0.10	0.05	67	0
Indian Point Nuclear Units 4 and 5	New York	0.15	0.10	70	1
Kewaunee Nuclear Power Plant	Michigan	0.12	0.06	67	1

TABLE 1*(Continued)

Name of Plant	Location	Seismic Data			
		A	B	C	D
La Salle County Station Units 1 and 2	Illinois	0.15	0.08	67	1
Limerick Generating Station Units 1 and 2	Pennsylvania	0.12	0.06	67	1
Palisades Plant, Unit 1	Michigan	0.20	0.10	67	1
Peach Bottom Units 2 and 3	Pennsylvania	0.12	0.05	67	1
Pilgrim Station, Unit 1	Massachusetts	0.15	0.08	67	2
Pilgrim Station, Unit 2	Massachusetts	0.15	0.08	67	2
Grand Gulf Nuclear Station	Mississippi	0.15	0.075	67	0
Greenwood Energy Center Units 2 and 3	Michigan	0.12	0.06	67	1
Turkey Point 3 and 4	Florida	0.15	0.05	67	0
Oconee Nuclear Station Units 1, 2 and 3	South Carolina	0.10	0.05	67	1
Alvin W. Vogtle Units 1, 2, 3, and 4	Georgia	0.20	0.12	67	2
Fast Flux Testing Facility	Washington State	0.25	0.125	67	2
Oyster Creek No. 1	New Jersey	0.22	0.11	-	1
Nine Mile Point No. 1	New York	0.11	-	-	1
Nine Mile Point No. 2	New York	0.10	0.05	67	1
R. E. Ginna Unit 1	New York	0.20	0.08	100	3
Quad Cities No. 1 and 2	Illinois	0.24	0.12		1
H. B. Robinson No. 2	South Carolina	0.20	0.10	67	2
Monticello	Minnesota	0.12	0.06	67	0
Ft. St. Vrain	Colorado	0.10	0.05	67	0
Surry No. 1	Virginia	0.15	0.07	-	1
Ft. Calhoun	Nebraska	0.17	0.08	-	1
Maine Yankee Atomic Power Plant	Maine	0.10	0.05	67	2
McGuire Nuclear Station Units 1 and 2	North Carolina	0.12	0.06	67	1
Midland Nuclear Power Plant Units 1 and 2	Michigan	0.10	0.05	67	1
Millstone Nuclear Power Station Unit 1	Connecticut	0.17	0.07	67	2
Millstone Nuclear Power Station Unit 2	Connecticut	0.17	0.09	67	2
Newbold Island Nuclear Generating Station Units 1 and 2	New Jersey	0.15	0.08	-	1

TABLE 1*(Continued)

Name of Plant	Location	Seismic Data			
		A	B	C	D
North Anna Power Station Unit 1 and 2	Virginia (overburden)	0.18	0.09	67	2
	(rock)	0.12	0.06	67	2
Point Beach Nuclear Plant Units 1 and 2	Michigan	0.12	0.06	67	0
Prairie Island Nuclear	Minnesota	0.12	0.06	67	1
Rancho Seco No. 1	California	0.25	0.13	67	2
Salem Nuclear Units 1 and 2	New Jersey	0.15	0.08	67	1
San Onofre Nuclear Unit 1	California	0.50	0.25	67	3
San Onofre Nuclear Units 2 and 3	California	0.67	0.33	67	3
Seabrook Nuclear Station	New Hampshire	0.17	0.08	67	2
Sequoyah Nuclear Units 1 and 2	Tennessee	0.14	0.07	71	2
Shoreham Nuclear Power Station	New York	0.15	0.07	71	1
Susquehanna Steam Electric Station Units 1 and 2	Pennsylvania	0.10	0.05	67	1
Three Mile Island Units 1 and 2	Pennsylvania	0.12	0.06	67	1
Trojan Nuclear Plant	Oregon	0.25	0.15	67	2
Virgil C. Summer Station	South Carolina	0.15	0.10	67	2
Waterford Steam Electric Station	Louisiana	0.10	0.05	67	0
Watts Bar Nuclear Units 1 and 2	Tennessee	0.18	0.09	67	2
Zimmer Nuclear Power Station Units 1 and 2	Ohio	0.10	0.05	70 to 80	1
Zion Station Units 1 and 2	Illinois	0.17	0.08	62.5	1

Information for this table from USAEC open files, USAEC facilities license application records, nuclear power plant Preliminary and/or Final Safety Analysis Reports. Design accelerations are either approved or yet to be approved by USAEC (Ref. 10).

TABLE 2. ASEISMIC DESIGN DATA (JAPAN) (12)				
Name of Plant	Location	Seismic Data		
		E	F	G
Onagawa	Miyagi (1)	0.48	0.24	250
Fukishima (No. 1, 2, 3)	Fukishima (2)	0.48	0.24	180
Hamaoka	Shizuoka (3)	0.48	0.24	300
Mihama	Fukai (4)	0.48	0.24	300
Takahama	Fukai (5)	0.48	0.24	270
Shimane	Shimane (6)	0.48	0.24	200
Tokai	Ibaragi (7)	0.48	0.24	-
Tsurugga	Fukai (8)	0.48	0.24	250
Genkai	Saga (9)	0.48	0.24	150
Fugen Atr	Fuki (10)	0.48	0.24	250

TABLE 3. ASEISMIC DESIGN DATA (OTHERS)				
Name of Plant	Location	Seismic Data		
		A	B	C
UEM, José Cabrera	Spain	0.15	0.15	50
Nuclear De Central Lemoniz 1	Spain	0.10	0.05	67
Central Nuclear De Asco	Spain	0.20	0.10	50
Zorita	Spain	0.15	-	67
NOK, Breznau No. 1	Switzerland	0.12	0.12	67
NBK, Breznau No. 2	Switzerland	0.12	0.12	67
Chin Shan	Taiwan	0.3	0.15	67
Koushent	Taiwan	0.4	-	50
Tarapur Units 1 and 2	India	0.10	-	67
Ko-Ri Unit 1	Korea	0.20	0.10	67

NOTATIONS (TABLES 1, 2, 3)

A Horizontal ground acceleration in g (gravity), for design basis earthquake (DBE); or maximum hypothetical earthquake (MHE); or safe shutdown earthquake (SSE). (DBE, SSE or MHE - The strongest vibratory ground motion that could occur at the site.)

B Operating basis earthquake (OBE) horizontal ground acceleration in g. (OBE - The maximum intensity earthquake for which a plant can be permitted to continue to generate power without a thorough check of all safety-related items.)

C Vertical earthquake ground acceleration in percent of horizontal values.

D Uniform Building Code (USA) zone classification.

E Design seismic coefficient static horizontal, g ($C_o \times 3 \times 0.8$).

F Design seismic coefficient static vertical, g ($C_o \times 1.5 \times 0.8$).

G Design seismic coefficient dynamic horizontal, gal.

C_o Seismic coefficient; for most of the cases $C_o = 0.20$.

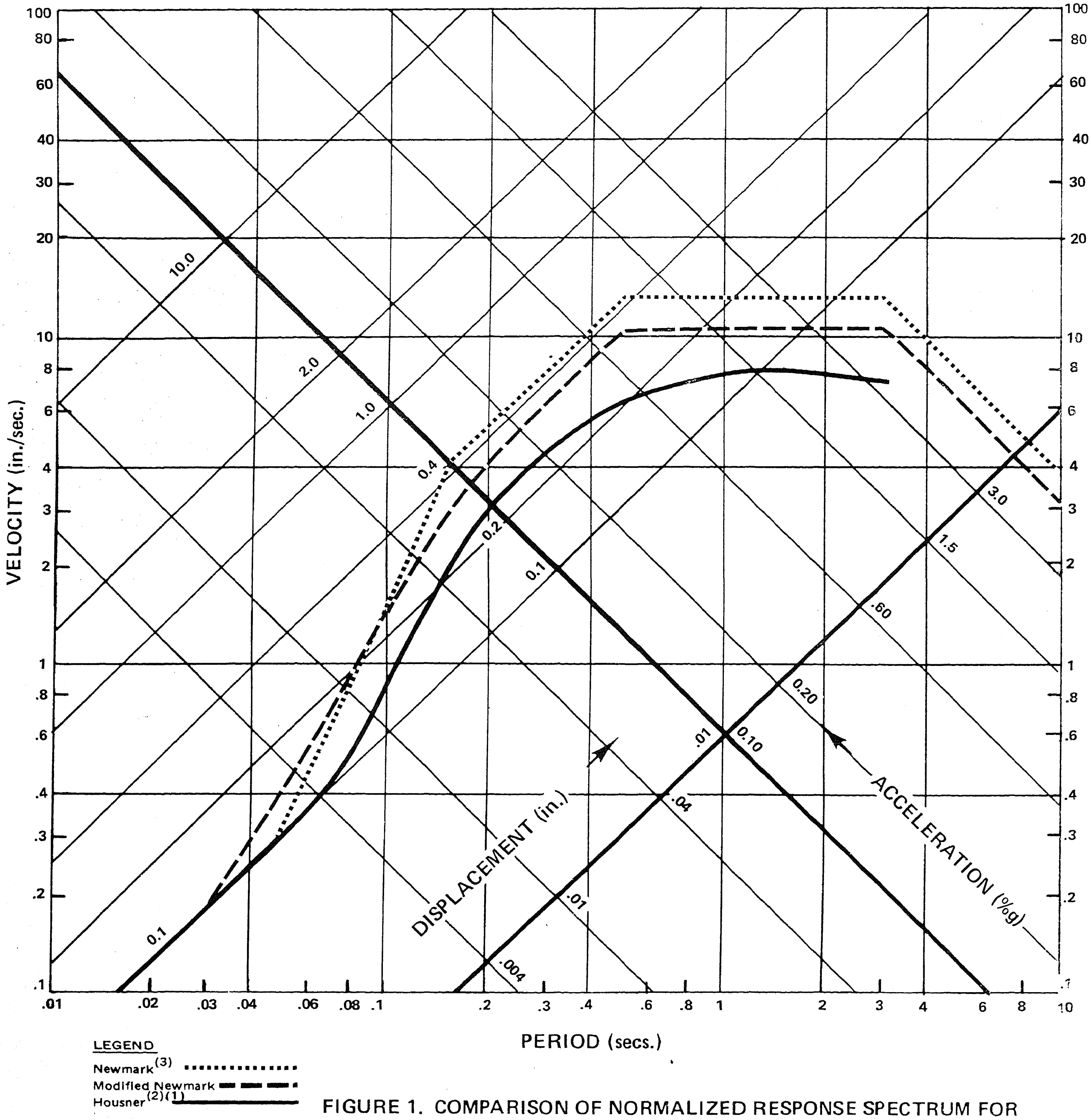
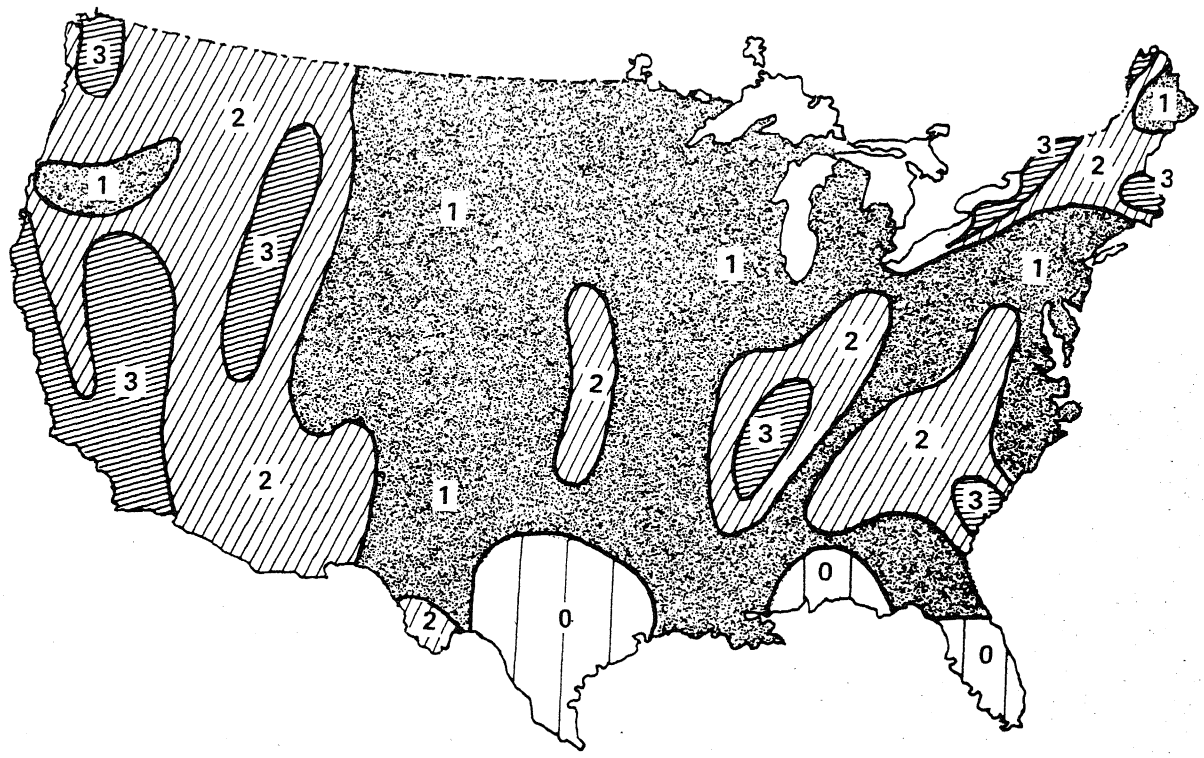


FIGURE 1. COMPARISON OF NORMALIZED RESPONSE SPECTRUM FOR EARTHQUAKE GROUND MOTION OF THE INTENSITY 0.10 g. (CRITICAL DAMPING OF TWO PERCENT)[



MAXIMUM ZONAL ACCELERATION (II)

ZONE	GENERAL DEFINITION	ASSOCIATED ACCELERATION, % g
0	No damage	4
1	Minor damage	8
2	Moderate damage	16
3	Major damage (not near a fault)	33
3	*Major damage (near a* great fault)	50

FIGURE 2. SEISMIC RISK MAP OF THE UNITED STATES (Ref. 5).

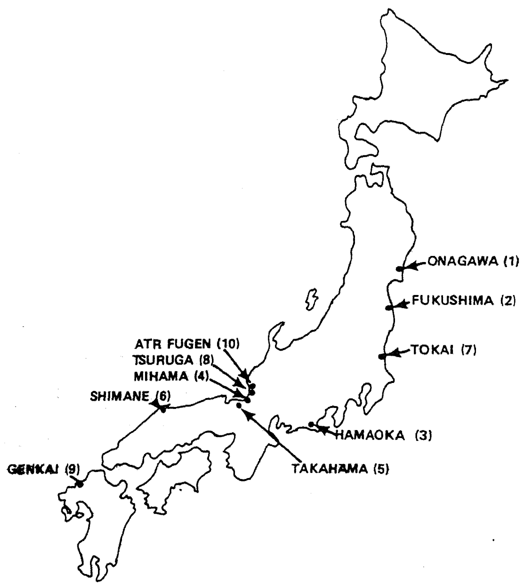


FIGURE 3. LOCATION OF NUCLEAR POWER STATIONS - JAPAN (Ref. 12).