CODE SPECIFICATIONS AND REGULATORY REQUIREMENTS FOR SEISMIC DESIGN, ANALYSIS AND TESTING OF STRUCTURES, COMPONENTS & SYSTEMS

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SYNOPSIS

This paper provides a brief summary and current status of the U.S. National Codes, Standards and applicable government regulatory requirements being used in the design of safety-related structures, components and systems for nuclear power plants. It also describes the requirements established by other codes for seismic design of the building structures. Several working groups within the Code Committee consist of many experts, representing licensing and inspection authorities, manufacturers, consultants, constructors and utilities. Together they have developed several seismic codes, standards, report and draft standards for safety-related structures, component and system. The scope and progress of these codes and standards has been described in this paper.

RESUME

Cet article est un bref résumé des codes nationaux, des normes et des directives gouvernementales qui doivent être utilisés pour le calcul des divers systèmes et composantes des centrales nucléaires et des structures du dispositif de sécurité de ces centrales. On y décrit également les règlements d'autres codes sur le calcul sismique des bâtiments. Les groupes de travail à l'intérieur des comités chargés de la rédaction des normes comprennent plusieurs spécialistes, des consultants, des industriels et des entrepreneurs qui, ensemble, ont élaboré de nombreux codes et règlements concernant les centrales nucléaires. On décrit dans cet article la portée et l'évolution de ces codes.

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INTRODUCTION

The requirement for the seismic design, analysis and testing of the safety-related structures, components and systems important to public safety are provided in regulatory standards, regulatory guides, standard review plans, Federal regulations and standards developed by the NRC*. Several industry codes and standards are also either issued or being prepared by American National Standards Institute (ANSI) in light of the current state-of-the-art knowledge. ANSI Standards are developed in cooperation with American Society of Civil Engineers (ASCE), American Concrete Institute (ACI), American Institution of Steel Construction (AISC), American Nuclear Society (ANS), American Society of Mechanical Engineers (ASME), and Institute of Electrical and Electronic Engineers (IEEE). In addition to these standards, technical reports have been prepared by architect-engineering firms, reactor manufacturers, equipment manufacturers and consultants in order to achieve standardization of design.

Several codes and standards have also been either prepared or revised for seismic regulation applicable to buildings by the National Bureau of Standards, National Seismic Foundation, Structural Engineers Association of California, Uniform Building Code, and American Concrete Institute Code Committee for buildings.

Appendix A shows the list of codes of federal regulations, NRC Regulatory Guides and Industry Codes developed by industry and government agencies.

CODE OF FEDERAL REGULATION

10 CFR Part 50, Appendix A, General Design Criteria for Nuclear Power Plants

General Design Criteria 2 of 10 CFR Part 50 of Appendix A requires that structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes without loss of capability to perform their safety functions. The design bases for these structures, systems, and components should include, appropriate consideration of the most severe of the natural

*NRC refers to the U.S. Nuclear Regulatory Commission.

phenomena that have been historically reported for the site and surrounding area.

10 CFR Part 100, Reactor Site Criteria and Appendix A Seismic and Geologic Siting Criteria

Regulation 10 CFR 100 describes the basic criteria in evaluating license applications for either construction or operating permit for nuclear power plants required by 10 CFR 50. This regulation also describes the radiation dose limit to the population which must not be exceeded during a major hypothetical accident. The purpose of the Appendix A of 10 CFR 100 is to set forth the principal seismic and geological considerations which guide the Commission in its evaluation of the suitability of proposed sites for nuclear power plants and the suitability of the plant design bases established in consideration of the seismic and geological characteristics of the proposed sites in order to provide reasonable assurance that the nuclear power plant can be constructed and operated at a proposed site without undue risk to the health and safety of the public.

This appendix also defines the Safe Shutdown Earthquake(SSE) for which safety-related systems must be designed to remain functional. This appendix further defines an Operating Basis Earthquake (OBE) which can be specified by the applicant after considering the seismology and geology of the region surrounding the site. If OBE is exceeded, shutdown of the plant is required. Presently the maximum vibratory ground acceleration of the OBE is required to be at least one-half of the SSE. However, this requirement is being debated at length and has been relaxed in several applications that OBE can be less than one-half of the SSE.

USNRC REGULATORY GUIDES & STANDARD REVIEW PLANS

NRC Regulatory Guides are issued to describe and make available the public methods acceptable to the NRC staff of implementing specific parts of the Commission's regulation. Brief summaries of these guides are summarized below.

Regulatory Guide 1.60 provides the NRC requirements for the shape of the horizontal and vertical design response spectra. The horizontal-component ground-design response spectra of the SSE or the OBE on sites underlain by rock or soil, without soil-structure interaction effects, should be linearly scaled from Figure 1 of this guide, in proportion to the maximum horizontal ground acceleration specified for the earthquake.

Based on the study by Newmark and Blume, (1,2,&3), the NRC regulatory staff has determined the above-mentioned design response spectra. These design spectra are based on a statistical evaluation of the actual response spectra of sixteen strong-motion earthquakes recorded at sites underlain by various geologic materials.

Regulatory Guide 1.61 states the regulatory position for the damping values for seismic design of nuclear power plants. Acceptable material damping values, expressed as a percentage of critical damping

are shown in Table IV of this guide.

Regulatory Guide 1.12 specifies the regulatory position for the instrumentation required for earthquakes. It requires the installation of triaxial time-history accelerographs, triaxial peak accelerographs, and triaxial response-spectrum recorders at appropriate locations on the seismic Category I structures, systems, and components. The purpose for installing these instruments is to provide data on the input motion and the responses of the containment structures and other seismic Category I structures, systems, and components. This guide refers to ANSI N18.5 with certain exceptions.

Regulatory Guide 1.29 provides a method for use in identifying and classifying nuclear plant structures, systems and components to remain functional and withstand the effects of safe shutdown earthquake.

Regulatory Guide 1.48 provides the regulatory position for seismic Category I fluid system components to withstand loading combinations within the design limits specified in the appropriate ASME Code, depending on code classification for vessels, piping, pumps, acting valves, and nonacting valves.

Regulatory Guide 1.70 provides standard format and content requirements of safety analysis reports for nuclear power plants. Section 2.5 of this guide provides information regarding the seismic and geologic characteristics of the site and region surrounding the site. Section 3.2.1 of this guide provides criteria for the identification of the structures, systems, and components important to safety. These structures, systems and components are to be designed to withstand the effects of SSE and remain functional. Section 3.7 of this guide on seismic design provides information for seismic input, seismic system analysis, seismic sub-system analysis and seismic instrumentation. Section 3.10 of this guide provides criteria for seismic qualification of seismic Category I instrumentation and electrical equipment.

Regulatory Guide 1.92 describes methods acceptable to regulatory staff for combination of the response of individual modes in response spectrum modal dynamic analysis and in time-history dynamic analysis.

Regulatory Guide 1.100 describes NRC staff position with respect to verifying the adequacy of the seismic design of electric equipment for all types of nuclear power plants. This guide refers to IEEE 344 with certain exceptions.

Regulatory Guide 1.122 describes methods acceptable to the NRC staff for developing two horizontal and one vertical floor design response spectra at various floors or other equipment-support locations of interest from the time-history motions resulting from the dynamic analysis of the supporting structure.

Regulatory Guide 1.143 furnishes design guidance acceptable to the NRC staff relating to seismic design and quality group classification for radioactive waste management systems, structures, and components.

Regulatory Guides from other divisions provide guidance for seismic design of the fuels facilities and siting.

INDUSTRY STANDARDS

Several standards and codes for seismic design and analysis have been prepared by national code committees. Brief summaries of these standards and codes have been summarized below.

ANSI N18.4 (ANS-2.1), Guidelines for Determining the Vibratory Ground Motion for the Design Earthquake for Nuclear Facilities

This standard is intended to provide a basis for evaluating seismic hazard at nuclear facilities. Geological and seismological factors that should be taken into account in determining vibratory ground motion for the Design Earthquake are set forth in this standard. Factors affecting the dynamic behavior of the material underlying the site are stated to aid in evaluating soil response effects. Surface faulting, stability of the in-situ materials or structures, and earthquake-caused water waves, such as tsunami, are not within the scope of this standard.

ANS-2.14, Determination of the Shape of Response Spectra for Use in Nuclear Facilities Design (Under Preparation)

This standard is intended to be used in conjunction with Appendix A to 10 CFR 100 and the proposed standard under development by ANS-2.1, "Guidelines for Determining the Vibratory Ground Motion for the Design Earthquake," (N18.4). The shape and level of design response spectra are of primary use in facility seismic design. The response spectra in turn are predicated upon the frequency content, length, and amplitude of the site free field earthquake time-history, which in turn is dependent upon earthquake source mechanism and size, hypocentral distance and wave path materials. The standard will define the effect of these variables upon site free field response spectra.

ANSI N18.5 (ANS-2.2), Earthquake Instrumentation Criteria for Nuclear Power Plants

This standard defines the minimum requirements for an earthquake instrumentation system to be installed at nuclear power plants in order to provide information on the input vibratory ground motion and resultant vibratory response of representative Category I structures, equipment and piping should an earthquake occur. By comparing this information with the vibratory motions used in the seismic design of the facility, an evaluation can be made as to whether or not the design vibratory motions have been exceeded.

ANSI N643 (ANS-2.10), Guidelines for Retrieval, Review, Processing and Evaluation of Records Obtained from Seismic Instrumentation

This standard is intended for use at water-cooled nuclear power plants and may be used for guidance, where appropriate, at other types of nuclear power plants. The standard will cover general philosophy associated with the use of data obtained from seismic instrumentation

specified in ANS N18.5 - 1974, Revision 1, Earthquake Instrumentation Criteria for Nuclear Power Plants. Specifically, the standard presents an overall guideline for retrieval of recorded data, specifications for data reduction, specifications for analysis, and guidelines for the interpretation of results. The standard does not deal with operator procedures to accomplish plant shutdown due to seismic activity, restarting of plants after shutdown due to seismic activity, or any power operator functions.

ANSI N180 (ANS-2.7), Guidelines for Assessing Capability for Surface Faulting at Nuclear Power Reactor Sites (Under Preparation)

This document is intended to provide applicants and consultants with guidelines for investigations directed toward assessing the potential for surface faulting at nuclear power reactor sites.

ANSI N635 (ANS-2.12), Guidelines for Combining Severe Environmental Phenomena to Determine Design Basis

This standard will provide guidelines for selecting combinations of natural hazards, combinations of manmade hazards, and combinations of natural and manmade hazards to be used in the design of power reactor structures, systems, and components.

Probability level acceptance criteria will be provided for selecting combinations of hazardous events at a particular site. Methods for calculating probabilities of combinations will be presented.

ANSI N174 (ANS-2.11), Guidelines for Evaluating Site-Related Geotechnical Parameters for Nuclear Facilities

This standard presents guidelines for evaluating site-related geotechnical parameters for nuclear facilities. Aspects considered include geology, ground water, foundation engineering, and earthwork engineering. These guidelines identify the basic geotechnical parametersto be considered in site evaluation, and in the design, construction, and performance of foundations and earthwork for nuclear facilities. Also included are tabulations of typical field and laboratory investigative methods useful in identifying geotechnical parameters. Those areas where interrelationships with other standards may exist are indicated.

ANSI XXX (ASCE), Seismic Analysis of Safety Class Structures

Under the sponsorship of the American Society of Civil Engineers, this standard will include acceptable design procedures and methods of analysis and reference acceptable design limits and criteria used in the seismic design of all Safety Class structures included in a nuclear facility. Modal analysis-response spectra, modal analysis-time-history, foundation-structure interaction procedures, combined directions of load for the seismic design of buildings, construction of floor response spectra, acceptable bases for simplified seismic analysis methods, and acceptable damping factors will also be included in this standard.

ANSI 41.7 (IEEE 344), Recommended Practices for Seismic Qualification of Class IE Equipment for Nuclear Power Generating Stations

These recommended practices provide direction for establishing procedures to verify that the Class IE equipment can meet its performance requirements during the following one SSE (Safe Shutdown Earthquake) preceded by a number of OBEs (Operating Basis Earthquakes).

This standard also provides guidance for the seismic qualifications of Category I electrical equipment which must demonstrate the ability to perform its required function during and after forces resulting from the SSE either by mathematical and/or testing of equipment under simulated seismic conditions.

ANSI NXXX (ASME), Section III Divisional, Appendix N, Dynamic Analysis (1978)

This appendix describes one or more acceptable steps for seismic dynamic analysis. Technical areas of dynamic analysis used in nuclear component design are described in this appendix. The design of nuclear components requires consideration of the seismic and other dynamic inputs which are defined in the Design Specifications for the component. In order to determine the specific seismic design for each component, a dynamic system analysis is required to show how seismic loading is transmitted from the defined ground motions to all parts of the buildings, structures, equipment, and components.

ACI-ASME 359, Code for Concrete Reactor Vessels and Containments (ASME Section III, Division 2 Code - 1977)

This code establishes load combinations and allowable stress criteria for loads generated by the safe shutdown earthquake and operating basis earthquake for concrete containments, tendons and concrete reactor vessels.

ACI 349-76, Code Requirements for Nuclear Safety-Related Concrete Structures

The ultimate acquired strength of the nuclear safety-related structures for the earthquake loads generated by the operating basis earthquake and loads generated by safe shutdown earthquake are established in this code. This code also requires the consideration of the dynamic response characteristics of the concrete structure and its foundation and surrounding soil for the determination of earthquake loads. Load factors for OBE and SSE are established in this code.

ANSI N690 (AISC), Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities

Under the sponsorship of American Institute of Steel Construction, this ANSI N690 standard "Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities" is under preparation. This standard will specify load combinations and allowable stress criteria for earthquake loads. This standard will

present the design and analysis requirements for steel safety class structures other than pressure retaining components and their supports. This standard also will include requirements on materials, fabrication, erection, inspection and quality assurance procedures consistent with the use of structural steel in safety class nuclear structures.

ATC 3-06, NSF 78-8, NBX SP 510, Tentative Provision for the Development of Seismic Regulations for Buildings

This document (4) contains tentative seismic design provisions for use in the development of seismic code regulations for design and construction of buildings. The provisions represent the result of a concentrated effort by a multidisciplinary team of nationally recognized experts in earthquake engineering. Design professionals, researchers, Federal agency representatives, staffs from the model code organizations and representatives from state and local governments from throughout the United States were involved. The provisions are comprehensive in nature and deal with earthquake resistant design of the structural system, architectural and non-structural elements and mechanical-electrical systems in buildings. Both new and existing buildings are included. They embody several new concepts which are significant departures from existing seismic design provisions. An extensive commentary documenting the basis for the provisions is also included in this standard.

ACI 318-77, Appendix A - Special Provisions for Seismic Design

This appendix provides provisions for types of members and systems covered when a ductile moment-resisting space frame or equivalent must be provided by design for structures located in an area where an earthquake of such magnitude as to cause major damage to construction has a high probability of occurrence during the lifetime of that structure.

This appendix is applicable to monolithic or composite special ductile frames with cast-in-place beam-column connections and to special shearwalls used with special ductile frames. Requirements for seismic load resisting members under Appendix A are based on the strength method of design.

ACI 318-77, Commentary

This commentary provides basis for the Appendix A ACI 318-77. The philosophy behind the special provisions is to minimize seismic forces by producing a ductile energy-absorbing structural system containing elements the strength of which tends to develop through the formation of plastic hinges rather than through less ductile flexural, shear, or compression failures.

The provisions of Appendix A are based to some extent on the information and recommendations contained in: "Design of Multistory Reinforced Concrete Buildings for Earthquake Motions" (5) and "Seismic Resistance of Reinforced Concrete Beam-Column Joints". (6) Modifications and extensions were made based for the most part on engineering practice as represented in the seismic recommendations (7 and 8) of

the Structural Engineers Association of California, unpublished research data from additional beam-column tests at the Portland Cement Association laboratories, and analysis of studies of damage to buildings resulting from catastrophic earthquakes, namely: Skopje (1963) (9), Anchorage (1964)(10,11) and Caracas (1967) (12,13).

The provisions of Appendix A are intended to apply to reinforced concrete structures located in a seismic zone where major damage to construction has a high probability of occurrence, and designed with a substantial reduction in total lateral seismic forces due to the use of lateral load-resisting systems consisting of ductile moment resisting space frames, with or without special shearwalls. Seismic zoning maps are under the jurisdiction of a general building code rather than of ACI 318-77. They do not apply to reinforced concrete frames alone. The maps are used to determine the seismic design loads and special structural requirements for regions of different seismicity. The zones are usually designated as areas of equal probability of risk of damage, such as Zone 0-no damage, Zone 1-minor damage, Zone 2-moderate damage, and Zone 3-major damage.

CONCLUSIONS

Codes and Standards, developed by the industry and the U.S. regulatory agency, have been presented. Effort to standardize seismic design and analysis has been extensive, considering the amount of time and research data necessary to develop each document. These standards provide common bases for generating input motions, methods of analysis, testing techniques, and acquisition of seismic data for design of structures and components in the U.S.A. Coordination of the current state-of-the-art in the field of earthquake engineering for International Codes and Standards is desirable to resolve seismic design concerns.

REFERENCES

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7. Seismology Committee, "Recommended Lateral Force Requirements and Commentary, Structural Engineers Association of California, 1967, pp. 1-90.

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12. "Caracas Earthquake Damage Reported by the Portland Cement Association Team", ACI JOURNAL, Proceedings V.65, No. 4, April 1968, pp. 292-294.

13. Sozen, M. A., "The Caracas Earthquake of July 29, 1967", ACI JOURNAL, Proceedings V. 65, No. 5, May 1968, pp. 394-401.

APPENDIX A

Code of Federal Regulations

10 CFR Part 50 Appendix, General Design Criteria for Nuclear Power Plants

10 CFR Part 100, Reactor Site Criteria and Appendix A, Seismic and Geologic Siting Criteria

NRC Regulatory Guides

Division 1 (Power Reactors)

1.12 Instrumentation for Earthquakes (April 1974)
1.29 Seismic Design Classification (September 1978)
1.48 Design Limits and Loading Combination for Seismic Category I Fluid System Components (May 1973)
1.60 Design Response Spectra for Seismic Design of Nuclear Power Plants (December 1973)
1.61 Damping Values for Seismic Design of Nuclear Power Plants (October 1973)
1.70 Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants (November 1978)
1.92 Combining Model Responses and Spatial Components in Seismic Resonse Analysis (February 1976)
1.100 Seismic Qualification of Electric Equipment for Nuclear Power Plants (August 1977)
1.122 Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components (February 1978)
1.XXX Linear and Non-Linear Time-History Methods of Dynamic Analysis (Under Preparation)
1.XXX Earthquake Instrumentation Data Handling for Nuclear Power Plants (Under Preparation)
1.143 Design Guidance for Radioactive Waste Management Systems, Structures and Components Installed in Light Water Cooled Nuclear Power Plants (July 1978)

Division 3 (Fuels and Materials Facilities)

3.14 Seismic Design Classification for Plutonium and Fuel Fabrication Plants
3.17 Earthquake Instrumentation for Earthquakes
3.24 Guidance on the License Application, Siting, Design, and Plant Protection for an Independent Spent Fuel Storage Installation

Division 4 (Environmental and Siting)

4.7 General Sites Suitability Criteria for Nuclear Power Stations

NUMBER	TITLE
ANSI N18.4 (ANS-2.1)	Guidelines for Determining the Vibratory Ground Motion for the Design Earthquake for Nuclear Facilities
ANSI N643 (ANS-2.2)	Earthquake Instrumentation Criteria for Nuclear Power Plants
ANSI N180 (ANS-2.7)	Guidelines for Assessing Capability for Surface Faulting at Nuclear Power Reactor Sites
ANSI N643 (ANS-2.10)	Guidelines for Retrieval, Review, Processing and Evaluation of Records Obtained from Seismic Instrumentation
ANSI N174 (ANS-2.11)	Guidelines for Evaluating Site-Related Geotechnical Parameters for Nuclear Facilities
ANSI N635 (ANS-2.12)	Guidelines for Combining Natural and External Man-Made Hazards at Power Reactor Sites
ANS-2.14	Determination of the Shape of the Response Spectra for Use in Nuclear Facilities Design (Under Preparation)
ANSI N41.7 (IEEE Std. 344-1975)	IEEE Recommended Practices for Seismic Qualification of Class IE Electric Equipment for Nuclear Power Generating Stations
ANSI N690 (AISC)	Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities (Under Preparation)
ANSI NXXX (ASCE)	Seismic Analysis of Safety Class Structures (Under Preparation)
ACI 349-76 including commentary	Code Requirements for Nuclear Safety-Related Concrete Structures
ACI 318-77 including commentary	Building Code Requirements for Reinforced Concrete Appendix A - Special Provisions for Seismic Design
NBS Special Pub. 510 ATC 3-06 NSF 78-8	Tentative Provisions for the Development of Seismic Regulations for Building, prepared by Applied Technology Council associated with Structural Engineers Associates of California (June 1975)
ASME Boiler Pressure at Vessel Code, Section III, Division 1, Appendix N	Dynamic Analysis Methods