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The U.S. Nuclear Regulatory Commission Seismic Safety Research Program

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ABSTRACT

The seismic safety research program sponsored by the U.S. Nuclear Regulatory Commission is directed toward improving the evaluation of potential earthquake effects on nuclear power plant operations. The research has been divided into three major program areas: earth sciences, seismic design margins, and fragilities and response. A major thrust of this research is to assess plant behavior for seismic events more severe and less probable than those considered in design. However, there is also research aimed at improving the evaluation of earthquake input and plant response at plant design levels.

INTRODUCTION

Earthquakes are among the most severe of the natural hazards faced by nuclear power plants. Very large earthquakes simultaneously effect all safety systems and therefore, can jeopardize design concepts of redundancy and defense-in-depth through common mode and interdependent failure. The fundamental issues addressed by the NRC seismic research program are how to quantify and reduce the uncertainties in seismic hazard and response assessments and how to develop techniques to deal with these uncertainties in a regulatory environment. The seismic research results will (1) improve estimates of earthquake hazards by identifying potential earthquake sources and determining the propagation of seismic energy with distance, (2) assess earthquake effects on plants by determining soil response and the capability of structures, components and systems to withstand earthquakes larger than their design basis, and (3) validate or improve current seismic design criteria.

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NRC's seismic research has been divided into three major program areas: Earth Sciences, Seismic Design Margins, and Fragilities and Response.

This paper presents a summary of the major programs and projects described in the NRC seismic research program plan (U.S. NRC, 1987). The majority of the research in the Seismic Design Margins, and Fragilities and Response areas will be completed in 1990; research in the Earth Sciences area will continue at a reduced level-of-effort through the foreseeable future.

Earth Sciences

A major focus of the NRC research programs in geology, seismology, and geophysics continues to be identifying and defining potential earthquake sources or source zones in the Eastern and Central United States. Also included in this research is the use of that information in assessing seismic hazards with respect to nuclear power plants. Many unknowns exist regarding these issues, including a strong basis for seismic zonation, source mechanisms, characteristics of ground motion, and site-specific response. The NRC is addressing these uncertainties through research that encompasses sustained seismic monitoring, geologic and tectonic studies, neotectonic investigations, exploring the earth's crust at hypocentral depths, and conducting ground motion studies.

Two earthquakes, one historical and one recent have received considerable attention by the NRC staff. Many hypotheses have been proposed for the seismogenic mechanisms and potential location on the eastern seaboard of future earthquakes, the size of the 1886 Charleston earthquake. Some of these hypotheses would limit such an earthquake in both size and location while others would allow this earthquake to occur over very large areas of the Eastern United States and Canada. Presently none of these hypotheses is definitive, and all contain strong elements of speculation. Also, the January 9, 1982, New Brunswick, Canada, earthquake (M_b 5.7) may have regulatory implications. Although analyses of the ground motions and source characteristics of this event and its aftershocks have not been completed, it eventually may be concluded that a similar earthquake could occur anywhere within the New England Piedmont Tectonic Province. In accordance with Appendix A to 10 CFR Part 100 (Title 10, 1988), this would represent the largest historical earthquake in that province which includes most of New England and southern New York.

Interpretation of the Charleston and New Brunswick earthquake data could result in controlling earthquake ground motions being significantly greater than their original design values at some Eastern and Central U.S. nuclear power plants. The Commission could be faced with requiring significant reanalysis to verify existing margins and/or extensive structural and equipment modifications to meet the desired safety level.

Geological and geophysical investigations have been made along the Atlantic Coastal Plain to determine the extent of past Charleston-like earthquakes. One effort has been looking for evidence of seismically induced paleoliquefaction in northeastern North Carolina, central Virginia and southern New Jersey. Investigations in northeastern North Carolina are essentially completed and this research has determined that it is unlikely that moderate to large earthquakes have occurred in that area. These findings help support the conclusion that the causes of the 1886 Charleston earthquake are localized.

Another significant issue resulted from the discovery of substantial prehistoric, Holocene offset of the aseismic Meers Fault in southern Oklahoma. Research has shown that this is the only documented capable fault, as defined in Appendix A to 10 CFR Part 100 (Title 10, 1988), east of the Rocky Mountains and may have a significant impact on seismic hazard assessment in the eastern and central United States. Initial geologic evidence suggested that the neighboring Washita Valley Fault was also capable. However, detailed investigations at selected locations along the fault resulted in the conclusion that it is not.

The backbone of the NRC earth sciences program in the Eastern United States has been the seismographic networks deployed throughout the Eastern and Central United States. The NRC is currently funding seismographic networks in the following regions: Northeastern United States, Virginia, Charleston, S.C., the Southern Appalachian region, the New Madrid (Mo.) region, Ohio and Indiaua, eastern Kansas, and Oklahoma. An agreement was reached in 1986 between the U.S. Geological Survey (USGS) and the NRC to jointly support the establishment of the eastern portion of a national seismographic network. The national network is scheduled to be fully in place by fiscal year 1992. In the meantime, the currently NRC-funded networks in the Eastern and Central United States will be gradually phased out.

Seismic Design Margins

The initial objectives of seismic design margins related research have been successfully completed. A methodology has been developed (Budnitz et al., 1985) to assess the inherent capabilities of nuclear power plants to withstand earthquakes above the design level.

The Electric Power Research Institute (EPRI) has expanded upon this work (NTS Engineering, et al., 1988). Current research efforts involve an EPRI, Georgia Power and NRC cooperative seismic margins review of the Hatch Unit 1 plant. This effort will include an NRC sponsored fault tree analysis to complement the success path analysis (NTS Engineering, et al., 1988) sponsored by EPRI. Evaluations and documentation for the Hatch plant review should be finished in the spring of 1989 which will complete the original development goals for seismic margin reviews.

In a related area, the NRC staff is evaluating if the NRC seismic design margins methodology, with enhancements, can be used to address the Severe Accident Policy Statement (U.S. NRC, 1985a) for seismic initiators. These efforts are discussed in a paper by Kenneally et al., 1989.

Fragilities and Response

Research in this area is providing response and failure/capacity data on buildings, components and piping.

Buildings

This research will provide data on how earthquake motions are transmitted by the buildings to piping, mechanical and electrical equipment, and components. Monotonic and cyclic quasi-static tests have provided information on strength, stiffness, stiffness degradation, ductility and general load-deflection behavior up to specimen failure or facility capacity. The dynamic tests have provided information on the fundamental frequency of the building; acceleration and floor response spectra at various elevations in the building; and fundamental frequency, damping, and floor response spectra changes as a function of increased earthquake motion.

At issue is the magnitude of the differences between analyses and experiments on structural stiffness hence fundamental frequency. Dynamic test results on several configurations (1 to 4 inch wall thickness) indicate that analytical predictions of a buildings' fundamental frequency could be high by a factor of 2 (stiffness high by a factor of 4). Recent quasi-static test results on carefully constructed well instrumented models (4 to 6 inch wall thickness) provide excellent analytical-experimental comparisons.

Similar differences between analysis and experiments have been observed in other domestic and foreign data examined by the American Society of Civil Engineers (ASCE) Working Group on Stiffness of Reinforced Concrete Shear Wall Structures. Based on these differences, the working group is developing a position paper recommending new procedures for computing the stiffness of low aspect ratio shear walls typically found in nuclear power plant buildings.

A complementary NRC-sponsored program is assessing the significance of these analytical-experimental differences by comparing design and probabilistic risk assessment computations made with and without the reduced stiffness. These calculations will determine the effects of structural stiffness on plant risk and margin. A rock site BWR has been selected as the first of three plants to be evaluated. Results from this study will be completed in 1989. Two other evaluations, a rock site PWR and a soil site PWR, will be made in 1990 when all research in the building response area is due to be completed.

Components

This research will establish an experimental data base on seismic component fragility and will provide a basis for assessing the earthquake levels at which individual components and generic classes of components fail to perform their safety functions. Fragilities of switchgear panelboards, power supplies, and motor control centers have been evaluated and documented (Bandyopadhyay et al., 1987). Additionally, information on other electrical components such as circuit breakers, transformers, batteries, and relays have been collected. An international workshop was convened (U.S. NRC, 1985c).

To date, this effort has confirmed, through extensive evaluation of test data, the belief that the seismic resistance of safety-related electrical equipment is generally at or above previously used values. In addition, documentation for natural frequencies, amplification and damping of electrical cabinets as well as capacity levels for several equipment categories has been developed for use in the resolution of USI A-46, Seismic Qualification of Equipment in Operating Plants.

Currently, the testing of 15 electrical relay models involving 43 tests specimens will be completed in 1989. One objective of these tests is to validate the concept of qualification by similarity. That is, seismically qualifying one relay based on testing performed on another relay judged to be similar. A second objective is to determine how relay adjustments such as spring tension, end play and contact gap affect the resistance against seismically induced chatter/changes of state.

Piping

The plan for all piping research sponsored by the NRC is described in the Piping Research Program Plan (U.S. NRC, 1988), this paper is only addressing the seismic aspects of the NRC research program. The scope of the NRC-sponsored piping design research is directed primarily towards those research needs identified by the U.S. NRC Piping Review Committee in Volumes 2 and 4 of NUREG-1061 (U.S. NRC, 1984 and 1985b). These deal with design criteria for seismic and other dynamic loadings and include evaluations of new and current response prediction techniques, damping criteria, nozzle design, earthquake experience data, and high level dynamic testing of piping. The majority of these research projects have been completed, or will be completed in 1989.

In general, the research results have demonstrated very large margins-to-failure for piping subjected to dynamic inertia loads. New data from tests performed at high input levels and the review of earthquake experience data have done much in the last 4 years to improve our appreciation of the inherent robustness of welded steel piping. This knowledge has been factored into the development of new seismic evaluation procedures (e.g., seismic PRA's, seismic margin reviews, and USI A-46) in which new piping analyses are generally not thought to be necessary. Also, there have been slow, but positive steps, taken to revise piping design criteria based on the new research results.

COOPERATIVE EFFORTS

Whereas the issues presented in this paper reflect the NRC perspective, the NRC is not alone in sponsoring seismic research. Seismic safety research is being performed by other organizations within the United States. Most notably, the Electric Power Research Institute (EPRI) and the U.S. Geological Survey. Other countries, for example, Japan, France, and the Federal Republic of Germany are actively performing seismic research. There are several joint projects and significant interaction and cooperation in project planning.

CONCLUSION

The analytical and experimental research sponsored by the NRC quantifies and reduces uncertainties associated with current regulatory issues, and resolves concerns related to seismic design margins and the effects of degradation and aging not considered in seismic design, and seismic PRA or margins evaluations. This research improves current requirements by removing conservatisms where they are unnecessary and adding conservatisms where weaknesses in the regulations exist, thereby achieving a more balanced design. In addition, this research addresses more strategic questions invovling the overall view as to how important earthquakes are in the regulatory process.

The majority of the research in the areas of seismic design margins, and fragilities and response will be completed in 1990. Research in the area of earth sciences will continue, at a reduced level-of-effort, through the foreseeable future.

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