Lessons Learned from NRC Systematic Evaluation Program Seismic Review

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In October 1977, the Nuclear Regulatory Commission approved initiation of Phase II of the Systematic Evaluation Program (SEP) which consists of a plant-specific reassessment of the safety of 11 older operating nuclear reactors. Many safety criteria have rapidly evolved since the time of initial licensing of these plants. The purpose of the SEP is to develop a current documented basis for the safety of these older facilities by comparing them to current criteria. Phase I of the SEP developed a comprehensive list of 137 topics of safety significance which collectively affect the plant's capability to respond to various Design Basis Events (DBEs). Seismic Design Consideration is one of the 137 safety topics.

The nuclear power plant facilities under review in the SEP received construction permits between 1956 and 1967. The Standard Review Plan (SRP) first issued in 1975, along with the Regulations 10 CFR Part 50, Appendix A and 10 CFR Part 100, Appendix A constitute current licensing criteria for seismic design reviews. As a result, the original seismic design of the SEP facilities vary in degree from the Uniform Building Code up through and approaching current standards. Recognizing this evolution, the staff found that it is necessary to make a reassessment of the seismic safety of these plants.

The SEP seismic review of these eleven plants addresses only the Safe Shutdown Earthquake (SSE), since it represents the most severe event that must be considered in the plant design. The scope of review includes three major areas: the integrity of the reactor coolant pressure boundary; the integrity of fluid and electrical distribution systems related to safe shutdown and engineered safety features; and the integrity and operability of mechanical and electrical equipment and engineered safety features systems (including containment). Since the SEP plants were not designed to current codes, standards, and NRC requirements, it is necessary to perform "more realistic" or "best estimate" assessments of the seismic capacity of the plant facilities and to consider the conservatisms associated with original analysis methods and design criteria. Therefore, the SEP review starts with development of a set of review criteria, an intensive evaluation of the seismic hazard at each site and ends with an assessment of the seismic capacity of the plants.

In this paper, the review methodology, acceptance criteria and findings from the review of five plants are presented. The general conclusions are:

Structures - Most of the safety-related structures possess adequate seismic design margins when evaluated against the SEP acceptance criteria.

Piping Systems - In certain cases, modifications were required for support systems (anchorages, support frames, etc.).

Mechanical Equipment - Some modifications were needed for supports and/or equipment itself.

Electrical Equipment - The anchorage and support systems for most of the electrical equipment required upgrading.

1. Introduction

In October 1977, the Nuclear Regulatory Commission approved initiation of Phase II of the Systematic Evaluation Program (SEP) which consists of a plant-specific reassessment of the safety of 11 older operating nuclear reactors. Many safety criteria have rapidly evolved since the time of initial licensing of these plants. The purpose of the SEP is to develop a current documented basis for the safety of these older facilities by comparing them to current criteria. Phase I of the SEP developed a comprehensive list of 137 topics of safety significance which collectively affect the plant's capability to respond to various Design Basis Events (DBEs). Seismic Design Consideration is one of the 137 safety topics.

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The SEP seismic review of these eleven (11) plants address only the Safe Shutdown Earthquake (SSE), since it represents the most severe event that must be considered in the plant design. The review starts with a detailed review of the respective plant docket files, the development of a set of review criteria, an intensive evaluation of the seismic hazard at each site, and ends with an assessment of the seismic capacity of the plants. Since these plants were originally not designed for same requirements, they are categorized into two groups for review based on the original seismic design and the availability of seismic design documentation. Different approaches are used to review the plant facilities in each group. The approaches are:

Group I: Detailed NRC review of existing seismic design documents with limited reevaluation of the existing facility to confirm judgements on the adequacy of the original design with respect to current requirements.

Group II: Licensees were required to reanalyze their facilities and upgrade, if necessary, the seismic capability of their facility. The staff will review the licensee's reanalysis methods, scope and results. A limited independent NRC analysis will be performed to confirm the adequacy of the licensee's method and results.

In this paper, only the results (methodolgoy, acceptance criteria, and findings) from the review of five (5) Group I plants are presented.

2. General Philosophy and Approach

The primary objective of SEP seismic review is to make an overall safety assessment of the seismic capability of the existing plant and, if necessary, to modify the design to assure the ability to safely shutdown in the event of an earthquake. Current review criteria, as defined in the Standard Review Plan (SRP) and the criteria and guidelines developed for seismic review of older plants were used to assess safety margins. Conformance with the SRP would imply acceptability; however, significant differences in analysis methods and criteria were expected since these plants were originally designed to the criteria developed 10-15 years ago. As a result the staff developed a more reasonable and realistic approach for reanalyses including the use of ductility reduction methods, non-linear analysis methods, higher damping and other factors identified in Reference 3. The reanalyses performed as described would ensure an adequate seismic design.

As discussed above, the SEP seismic review addresses the Safe Shutdown Earthquake (SSE) only, since it represents the most severe event that must be considered in the plant design. The scope of the review includes three major areas: the integrity of the reactor coolant pressure boundary; the integrity of fluid and electrical distribution systems related to safe shutdown and engineering safety features; and the integrity and operability of mechanical and electrical equipment and engineering safety feature systems (including containment). A detailed review of the facilities was not performed; rather the review relied upon sampling representative structures, systems and components. Confirmatory analyses using a conservative seismic input were performed for the sampled structures, systems and components. The site specific spectra and more sophisticated analysis techniques were used, if the conservative sample result indicated overstresses. The results of these analyses served as the principal basis for a conclusion on the overall facilites.

3. Review Methods

The review started with a detailed review of the plant seismic documentation, which was followed by a site-visit. The purpose of this site-visit was: (1) to observe the as-built plant specific features relative to seismic design of the facilities, (2) to obtain seismic design information which was not available in the docket, (3) to discuss the docket review findings with the utility company staffs, and (4) to identify sample structures, systems and components for which the confirmatory analyses (or audit analyses) would be performed.

When a structure was evaluated, it was judged adequately designed if the results from the structural analysis met one of the following three criteria:

A. The loads generated from confirmatory analysis were less than original loads;

B. The seismic stresses from confirmatory analysis were low compared to the yield stress of steel or the compressive strength of concrete; or

C. The seismic stresses from confirmatory analysis exceed the steel yield stress or the concrete compressive strength, but estimated reserved capacity (or ductility) of the structure is such that inelastic deformation without failure would be expected.

If one of the above criteria were not satisfied, a more comprehensive reanalysis was required to demonstrate its design adequacy.

For piping reevaluation, the results from the audit analysis of each of the sampled piping systems was compared with ASME Code requirements for Class 2 piping systems at appropriate service conditions. This comparison provided the basis for reevaluating the structural adequacy of piping systems.

Because limited documentation exists regarding the original specifications applicable to procurement of equipment, as well as for the qualification of the equipment, the seismic review of equipment was based on expert experience and judgement. Two levels of qualification were performed, structural integrity and operability. The results of this reevaluation of equipment serve as the basis for modifications or reanalysis.

4. Review Criteria

Since the SEP plants were not designed to current codes, standards, and NRC requirements, it is necessary to perform "more realistic" or "best estimate" assessments of the seismic capacity of the facility and to consider the conservatisms associated with original analysis methods and design criteria. A set of review criteria and guidelines are described in the following documents:

A. NUREG/CR-0098, "Development of Criteria for Seismic Review of Selected Nuclear Power Plants," by N. M. Newmark and W. J. Hall, May 1978.

B. "SEP Guidelines for Soil-Structure Interaction Review," by SEP Senior Seismic Review Team, December 8, 1980.

These documents provide guidance for:

1) selection of the earthquake hazard;
2) design seismic loadings;
3) soil-structure interaction;
4) damping and energy absorption;
5) methods of dynamic analysis;
6) review analysis and design procedures; and
7) special topics such as under ground piping, tanks and vaults, equipment qualification, etc.

These criteria are considered to more accurately represent the actual stress level in structures, systems and components during a postulated earthquake event and consider, to certain extent, nonlinear behavior of the systems. For the cases that are covered by these criteria, the SRP and Regulatory Guides are to be used for the review.

5. Conclusion

As a result of the review of these five SEP plants (the review of the original design analyses, the results of confirmatory analyses, and the feedback from the plant owners), the following general conclusions can be drawn:

Structures - Most of the safety-related structures were found to possess adequate seismic capacity to resist the postulated seismic loads when evaluated against the SEP acceptance criteria. A few structural elements (bracings, columns, beam connections, etc.) were identified which required modifications.

Field Erected Tanks - Most of the field erected tanks required modifications. Four potential failure modes were identified: (1) anchor bolts overstress due to tension caused by tank overturning, (2) weld failure at tank wall and anchor bolt chair, (3) buckling of side wall, and (4) failure of reinforced concrete foundations. These tanks were designed assuming the tank wall is rigid. Reanalysis considering flexibility of the tank walls resulted in the identification of these potential failure modes.

Piping Systems - All piping systems which have been upgraded as a result of NRC IE Bulletin 79-14, "Seismic Analyses and As-Built Drawings" were found capable of resisting the postulated seismic loads. However, the placement of pipe supports for piping which was designed using the "Lateral-Deflection and Forced-Evaluation Curves" method and was not reanalyzed as part of NRC IE Bulletin 79-14 effort, was found deficient in that some piping was found to be in resonance with the supporting structure. Modifications to stiffen these systems (raise their frequency) was required.

Mechanical Equipment - Most mechanical equipments were found capable of withstanding the postulated seismic loads except for two items:

1) Long-shaft vertical pumps with cast iron casings were not adequately supported. Modifications were necessary to reduce casing stresses by installing lateral braces to the vertical intake suction pipe. In general due to poor toughness, cast iron pump casing and support systems should not be used due to its low allowable stress.

2) Motor operated valves had identifiable overstresses at juction between valves and small pipe lines (4"ø and under) due to valve eccentricity.

Electrical Equipment -

1) The anchorage and support systems for most of the electrical equipment require modifications to assure structural integrity. (Note: the function capability is being resolved generically as part of USI A-46, Seismic Qualification and was not reviewed in SEP).

2) A set of guidelines and criteria for the structure evaluation of cable trays is being developed by utility companies through a generic testing program. These guidelines and criteria will be applied on a plant specific basis to evaluate the adequacy of existing cable tray support systems. This generic approach was followed because of the significant differences between "current licensing criteria" for seismic cable trays and existing designs in older operating plants.

6. References

[1] Code of Federal Regulations, U. S. General Service Administration, January 1980.

[2] Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, NUREG-0800 (formerly published as NUREG-75/087), July 1981.

[3] NEWMARK, N.M. and HALL, W.J., "Development of Criteria for Seismic Review of Selected Nuclear Power Plants," NUREG/CR-0098, May 1978.

[4] SEP Senior Seismic Review Team (SSRT), "Guidelines for SEP Soil-Structure Interaction Review," December 8, 1980.

[5] U. S. Atomic Energy Commission Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," December 1973.

[6] BERNREUTER, D.L., "Seismic Hazard Analysis," NUREG-1582 Report, Vols. 2-5, October 1981.

[7] U. S. Atomic Energy Commission TID-2074 Report, "Nuclear Reactors and Earthquakes," August 1963.