Recommended Revisions to Nuclear Regulatory Commission Seismic Design Criteria

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Summary

Task Action Plan (TAP) A-40 was developed by consolidating specific technical assistance studies initiated by the Nuclear Regulatory Commission (NRC) Division of Operating Reactors to identify and quantify the conservatism inherent in the seismic design sequence of current NRC criteria. Task 10 of TAP A-40 provided a technical review of the results of the other nine engineering and seismological tasks in TAP A-40 and recommended changes to the existing NRC criteria based on this review.

We used the team approach to accomplish the objectives of Task 10 in an efficient manner and to provide the best technical product possible within the limited time available. The team consisted of a core group of Lawrence Livermore National Laboratory personnel and selected consultants.

The recommendations summarized in this paper were not based solely on the results of the tasks in TAP A-40 but went far beyond that data base to encompass all available and appropriate literature. Some recommendations are based on the expertise of core members and consultants that stem from unpublished data, research, and experience.

Copies of the pertinent sections of the Standard Review Plan (SRP) and Regulatory Guides as well as the reports developed under TAP A-40 were provided to the participants. These reports, other available engineering literature, and the experience of the consultants and core group provided technical basis for the recommendations.

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1. Introduction

The Nuclear Regulatory Commission (NRC) initiated the Task Action Plan A-40 (TAP A-40) to identify and quantify the conservatism inherent in the seismic design criteria for nuclear power plant structures. The TAP A-40 program consisted of ten tasks. Each task investigated and analyzed a particular area of the NRC seismic design criteria chain. The tasks comprising this program were:

- Task 1. Quantification of Seismic Conservatisms
- Task 2. Elastic-Plastic Seismic Analysis
- Task 3. Site-Specific Response Spectra
- Task 4. Seismic Aftershocks (cancelled)
- Task 5. Nonlinear Structural Dynamic Analysis Procedures for Category I Structures
- Task 6. Soil-Structure Interaction
- Task 7. Earthquake Source Modeling
- Task 8. Analysis of Strong-Motion, Near-Field Data
- Task 9. Development of Seismic Energy Attenuation Functions
- Task 10. Review and Implementation

Investigations of the conservatisms inherent in the following were included in these tasks:

- Regulatory Guide 1.60 spectra
- Regulatory Guide 1.60 time histories
- Damping
- Soil-structure interaction
- Broadening of spectral peaks
- Nonlinear structural response
- Subsystem response
- Site-specific response spectra.

Task 10 of the TAP A-40 program provided a technical review of the results of the other tasks and recommended changes to the existing NRC seismic design criteria.

This paper summarizes the Phase I efforts of Task 10 of the TAP A-40 program.

TAP A-40 was developed by consolidating specific technical assistance studies initiated by the Division of Operating Reactors and Systems Safety to identify and quantify the conservatism inherent in current seismic design criteria. The Division of Project Management managed TAP A-40 until it was transferred to the Division of Reactor Safety Research in August, 1978. Most TAP A-40 studies into the engineering response characterization of structures and components have been completed and are included in Phase I of the TAP A-40 review and implementation. Phase II comprises studies of seismological characterization of ground motion.

The Phase I effort was intended to review relevant TAP A-40 studies, incorporate the state-of-the-art procedures (especially the experience of nationally recognized experts), and provide short-term improvements in the current seismic design criteria until results are obtained from the Seismic Safety Margins Research Program (SSMRP) [1].

Task 10 is intended to bring the SRP and Regulatory Guides up to the current state of the art in seismic design. The results of the TAP A-40 program and the recommendations of Task 10 will also help the NRC staff to review existing plants under the Systematic Evaluation Program (SEP). A team approach was used to accomplish the objectives of Task 10. This approach enabled us to obtain the best technical product possible within the limited time available. The team consisted of a core group of Lawrence Livermore National Laboratory (LLNL) personnel and selected consultants.

The recommendations summarized in this paper were not based solely on the results of the tasks in TAP A-40 but went far beyond that data base to encompass all available and appropriate literature. Some recommendations are based on the expertise of core members and consultants that stem from unpublished data, research, and experience.

The consultants participating in this effort were:

R. L. Cloud, R. Cloud Consultants;
W. J. Hall, University of Illinois;
R. P. Kennedy, Structural Mechanics Associates;
N. M. Newmark, University of Illinois;
J. Roesset, University of Texas; and
J. C. Stepp, FUGRO.

A final report (NUREG/CR-1161) [2] has been published as a NUREG document and includes observations and recommendations in the areas of:

- Ground motion;
- Soil-structure interaction;
- Structures;
- Equipment and components; and
- Testing.

Specific recommendations include:

- Changes in the specification and application of ground motion for the design of structures and equipment.
- Significant changes to the philosophy and specifications for soil-structure interaction analysis.
- More specific guidelines for the seismic design and analysis of special structures such as buried pipes, conduits, and aboveground vertical tanks.
- Specific criteria for the combination of high-frequency modal response.
- The allowance of limited amounts of inelastic energy absorption in the design response of Category I structures.
- Revision of damping values for design, based on the type and condition of the structure and the stress levels of interest.
- Direct generation of in-structure response spectra for equipment design.
- Accounting for uncertainties in the generation of in-structure response spectra through multiple analyses with variation of parameters and through the use of probabilistic in-structure response spectra generated on the basis of nonexceedance criteria. The requirement to broaden spectra is thereby eliminated.
- The option to use randomly selected multiple time histories (real or synthetic) for time-history analysis.
- Reduction in the number of operating basis earthquake (OBE) cycles required for design.

- In-situ testing of selected aspects of nuclear power plants to ensure greater confidence in design methods.

A brief discussion of the major areas included in the report as well as the general philosophy adopted in making our recommendations follows.

2. General Philosophy

It was decided that it would be beneficial if a general philosophy and objective for the SRP could be established to allow the SRP to be more flexible and provide a degree of uniformity and consistency with respect to the recommendations made in the final report. The following philosophy and objectives were generally agreed upon by LLNL core members and consultants:

- SRP recommendations should be made with the purpose of indicating the nature of the performance that is required to ensure that adequate margins of safety exist, but at the same time are not so restrictive as to preclude the use of new and more rational approaches when these can be documented and checked readily against other approaches.
- LLNL core members and consultants adopted the following performance specification as the basis for the recommendations made:

  > Based on the occurrence of a safe shutdown earthquake (SSE), the analysis procedures and parameter values selected should be such that if an earthquake with a peak acceleration equal to the SSE occurred, the probability of exceeding the response levels used for design (i.e., forces, stresses, displacements) would be about 10^{-1}.

3. Ground Motion

A review of the data base currently available in the area of ground motion for the design of nuclear power plants has been made as part of TAP A-40. Although the tasks related to source modeling and near field ground motion input studies are incomplete at this writing, it is clear that a case can be made for the use of site specific spectra in lieu of the current R.G. 1.60 spectra. Preliminary results from Task 3 provide additional confirmation for the use of site specific spectra determined by such techniques as those proposed by Newmark and Hall in NUREG/CR-0098 [3] in which peak ground accelerations, velocities, and displacements are required to construct the response spectrum, not just peak ground accelerations. Thus, it is our best judgment now to recommend replacement of the existing R.G. 1.60 response spectra with the more site specific response spectra recommended by Newmark and Hall. Other recommendations in this area include:

- Revisions and clarifications to Standard Review Plan Section 2.5.2.
- Multiple time histories (real and synthetic) for analysis and design.

4. Soil-Structure Interaction

Considerable advances in computational techniques for soil-structure interaction (SSI) have been made over the last few years. Unfortunately, only a small amount of field data is available, and experimental verification of analytical techniques has not been accomplished. It is important that methods be devised to validate any analytical method for soil-structure interaction in order to reduce the controversy in this area.

This validation probably includes large-scale testing. The recommendations herein are, therefore, based on TAP A-40 reports in references [4 - 7] and the expertise and engineering judgment of the consultants and core members. Several general recommendations and observations follow:

1. References in the SRP to "finite element" and "lumped parameter" techniques of soil-structure interaction analysis should be removed. Two categories of analytical techniques called the "direct solution" (analysis performed in one step) and "substructure" (analysis performed in three steps) approaches should be identified instead. This terminology is more descriptive of the two broad categories of analytical methods.
2. Either the direct solution or substructure approach may be used for soil-structure interaction analysis as long as it is properly applied and within the limitations discussed below. Performing independent analyses with each technique and enveloping the results should not be required.
3. All soil-structure interaction analyses must recognize the uncertainties prevalent throughout the phenomenon, including:
   a. Transmission of the input motion at the site.
   b. The random nature of the soil configuration and material characteristics.
   c. Uncertainty in soil constitutive modeling.
   d. Nonlinear soil behavior.
   e. Coupling between the structures and soil.
   f. Lack of symmetry in soil and structures, which are usually assumed to be symmetrical.
   g. The degree of moisture in soils and rocks, which varies with time and may not be represented adequately.
   h. Effects of separation or loss of contact between the foundation and the soil.
4. Relatively simple methodologies need to be established by which soil-structure interaction analysis results may be checked for feasibility.
5. In view of the large uncertainties, it is not clear that complex, expensive calculations are justified or necessary to develop a soundly engineered design.

5. Structures

There are many areas of conservatism in the current NRC criteria for the seismic design of nuclear power plant structures. This section of the report attempts to identify some of these areas and make recommendations to reduce these often excessive levels of conservatism. A variety of topics are covered, including:

- Special structures (buried pipes, conduits, etc. and aboveground vertical tanks).
- Modal response combinations.
- Inelastic seismic design and analysis of structures.
- Damping values for seismic design of nuclear power plants.

Additionally, because of the redundancy in Standard Review Plan (SRP) sections 3.7.2 and 3.7.3, a recommendation was made that SRP sections 3.7.2 and 3.7.3 should be combined and rewritten into one section and that a new SRP section should be written devoted to special structures.

6. Equipment and Components

This section of the final report presents recommendations for upgrading the seismic design criteria for subsystems, equipment, and components by eliminating unnecessary conservatism in the Standard Review Plan and Regulatory Guides and upgrading them to the state of the art. Some recommendations are aimed at clarification of the SRP and Regulatory Guides, while others are specifically intended to reduce excessive conservatism.

The performance of actual power plants during earthquakes tends to verify the assertion that excessive conservatism is introduced during the seismic design methodology chain for structures, subsystems, equipment, and components.

Areas covered in that section of the report [2] include:

- Direct generation of in-structure spectra.
- Effects of uncertainties on in-structure spectra.
- Generation of in-structure spectra for structures that have limited inelastic response.
- Eccentricity considerations for in-structure design response spectra.
- Number of earthquake cycles during plant life.

7. Unique Aspects of Design of Nuclear Power Plants

We have little experience in the way nuclear power plants actually perform when subjected to the extreme loads postulated in design. Therefore, we lack a completely adequate basis to justify the design criteria we use. To gain confidence in our criteria and the performance of systems and components, and to understand them better, a more vigorous use of testing is required. Therefore, the following has been recommended:

- The SRP should require more testing for seismic design. To increase confidence in analytical methods, in-situ testing of structures, systems, and components that are qualified by analysis should be emphasized. Additionally, emphasis should be placed on obtaining margins on critical items of equipment, particularly those for which redundant items are typically installed.

8. Conclusions

Much more research is needed to quantify the conservatism in the seismic design sequence. The recommendations in this report reflect recent increased understanding of the art of seismic design and the relative degree of uncertainty in the elements of the seismic design sequence. To ensure that adequate margins of safety exist, NRC criteria for the seismic design of nuclear power plants should indicate clearly the nature of the required performance but should not be so restrictive that improved approaches are precluded. Thus, specific recommendations in this report are made for the purpose of clarity; other methods that provide a similar degree of conservatism are equally acceptable.

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