UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

SEP 1 3 1980

MEMORANDUM FOR: Harold R. Denton, Director
Office of Nuclear Reactor Regulation

FROM: Thomas E. Murley, Acting Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER NO. 103 "BEST ESTIMATE-EVALUATION METHOD (BE-EM) APPLIED CALCULATION OF THREE-DIMENSIONAL SEISMIC RESPONSE"

This Research Information Letter (RIL) describes how two techniques, Best Estimate and Evaluation Method, can be applied to the traditional seismic analysis and design of a nuclear power plant. The seismic analysis and design methodology chain is comprised of seismic input, soil-structure interaction, structural response and subsystem response. The objective of this study is to characterize the compounding effect of conservative assumptions made at various links of the seismic design chain. Future work should provide further insight on the overall conservatism in seismic analysis and design methodology as well as on relative conservatisms by selectively combining desired design links. An illustrative example is used in this study that links three-directional seismic excitation and structural response to compare the results of both techniques in terms of factors of comparison and probabilities of exceedance.

INTRODUCTION

NRC has established regulations, guides, and licensing review procedures that define seismic safety criteria for nuclear power plant design. These criteria collectively constitute a seismic methodology chain (SMC). The seismic safety criteria for nuclear power plant design were developed to ensure structural integrity and functional safety of buildings, equipment and components. They depart from the conventional earthquake engineering practice in detail and complexity. The overall SMC is considered sufficiently conservative to ensure safety, however, it is necessary to characterize the overall seismic safety and to improve it by establishing new criteria as may be required. Since this RIL summarizes results obtained from the Seismic Safety Margins Research Program (SSMRP), background information on the SSMRP is included.

SEISMIC SAFETY MARGINS RESEARCH PROGRAM (SSMRP)

The SSMRP will provide the methodology to determine safety margins in a nuclear power plant subjected to a large earthquake. The objectives of the SSMRP are to estimate the conservatisms (or lack of conservatisms) in the Standard Review Plan (SRP) seismic safety requirements and to develop improved requirements.

There is a need to reexamine the traditional process of seismic analysis and design of nuclear power plants in an overall system context. This need comes principally from the widely held belief that a compounding of conservatisms occurs in the current process. That is, at each stage of the current process, conservatisms are introduced to account for uncertainties, and these conservatisms compound from one stage to the next. However, in each stage only minimal compensations are made for the compounding of conservatisms because they are not quantified. For example, the earthquake used in the seismic design represents the maximum earthquake potential ("safe shutdown earthquake" (SSE)) considering the geology and seismology, and specific characteristics of the subsurface material. The earthquake motion is coupled to the bedrock and building foundation through the use of conservative soil properties to produce the highest responses (forces and stresses). Such responses are compared to conservative estimates of the strength or capacity of each structure or component.

The SSMRP will develop an improved deterministic seismic safety design methodology and a methodology to perform earthquake risk assessments of nuclear facilities. Risk will be measured by various failure probabilities and by the probable release of radioactive materials. The approach used integrates the elements of the seismic chain, including:

- Earthquake characterization
- Soil-structure coupling
- Structural building response
- Subsystem structural response
- Local failure or loss-of-function
- Systematics of how local failures could combine and lead to a release.

These elements will be characterized realistically and probabilistically, rather than conservatively and deterministically.

DESCRIPTIVE SUMMARY

In this concept, the systematic evaluation of the seismic analysis and design chain of a nuclear power plant can be simplified to encompass seismic input, soil-structure interaction, major structural response and subsystem response.

The objectives of the present study are:

(1) to introduce the concept of BE-EM with respect to the seismic analysis and design of nuclear facilities,

(2) to demonstrate BE-EM through an illustrative example showing the coupling effects between seismic input and structural response, and

(3) to show the sensitivity of response to three components of seismic motion.

Details of the study can be found in reference 1.

OVERVIEW OF ANALYSIS

The present investigation is an extension and coupling of two previous studies. The first addressed the topic of synthetic time-histories and their combination versus recorded ground motions. The second addressed the practice of enveloping and broadening of in-structure response spectra to account for uncertainties.

The key elements of the Best Estimate (BE) Method are:

(1) the base excitations were the three components of recorded ground motion applied simultaneously and with their recorded phasing;

(2) the variability in stiffness and structural damping was incorporated in the analysis by randomly sampling on the assumed distributions, and,

(3) the mean and mean-plus-one-standard-deviation (MSD) in structure response spectra, were generated.

The corresponding elements of the Evaluation Method (EM) are:

(1) The base excitations were synthetic time-histories applied in each of the horizontal and vertical directions independently. The resulting in-structure response spectra being combined by the square-root-of-the-sum-of-the-squares rule (SRSS); i.e., the spectral ordinate (S) at a point in direction 1 is computed by:

$$S_1 = (S_{11}^2 + S_{12}^2 + S_{13}^2)$$

where:

S_1 = response spectrum ordinate in direction 1 due to three components of motion (1, 2, 3) and

S_{1j} = response spectrum ordinate in direction 1 due to an excitation in direction j (j = 1, 2, 3).

(2) The variability in stiffness and damping was incorporated by smoothing and peak broadening of in-structure response spectra.

(3) The mean and MSD response spectra were generated.

Two quantities were used in the comparison of BE and EM response. Factors of Comparison (FOC) were computed as the quotient of the mean EM response spectra and the mean (or MSD) BE response spectra.

In addition, Probabilities of Exceedance (POE) were computed which estimated the probability of a BE response exceeding in corresponding EM response. Both FOC and POE vary over the frequency range of interest. The results demonstrated the conservatism of the design criteria defined by the EM procedure (subject to assumptions of the study).

CONCLUSIONS AND RECOMMENDATIONS

This study represents the first attempts to systematically compare two seismic methods. Future studies should include as many links of the SMC as appropriate to realistically analyze the phenomenon of interest. There are two key points to be emphasized in the BE-EM concept. For example, in the BE-EM concept, it could be misleading to compare a soil-structure interaction result such as base-mat response instead of a design parameter, including structural and subsystem response. Second, the basis of comparison will, in most cases, be statistical; that is, mean vs mean, mean vs MSD, mean vs point estimate, etc. When calculating a BE response, this will always be the case since BE by definition includes a measure of uncertainty. The EM may or may not be statistical.

The lack of recorded data makes it impossible to calibrate the BE of seismic response against true behavior. Therefore, each link in the SMC will require the formulation of alternative models. Comparisons will be made between these models and the design methodology.

Conservatism

The results from this study showed that the mean FOC, calculated from the floor response spectra (called in-structure response spectra in reference 1), varied between 1.5 and 8. The reason for the variation is that overestimation of response occurs at frequencies coincident with the natural frequencies of the structure. The FOC is indicating that the seismic design loads for piping, for example, are 1.5 to 8 times the value that would be calculated using real earthquakes.

The POE is a probabilistic method to determine the conservatisms in the structure. The POE varied between 10^{-1} to 10^{-5} for the study. Stated another way, if a number of earthquakes occurs, each with a peak acceleration equal to the SSE, the probability of exceeding the design seismic loads for piping would be 10^{-1} to 10^{-5}. The probability of earthquake occurrence was not considered in this study.

Floor Response Spectra

This study showed that the conservatism in floor response spectra at any single point in the structure varied with frequency. By making the floor response spectrum smoother, a more uniform conservatism can be

obtained. This means that typical floor response spectra should have sharp peaks broadened and lowered, and the valleys raised.

The study also pointed out that the conservatisms in the floor response spectra varied from point to point within the structure. This means there is no assurance that conservatism is applied where it is required or where it would do the most good. The variations in conservatism can be removed or placed in a specific manner to satisfy safety objectives by specifying target values of conservatism. These values would be specified in a seismic design performance specification. Results from the SSMRP, individual's judgement and other risk studies could be used to develop the target values.

Three Dimensional Response

The conservatisms described in the report resulted primarily from the methods used to account for the three components of motion. Present review criteria focus primarily on defining the peak horizontal ground-acceleration for the SSE. Little requirement is placed on the relation between the amplitude and phasing of peak acceleration for the three components, or the relationship between the three time-histories. This study showed that changes in relationship between the three components of motion time-histories significantly varied the seismic response. Therefore, it may be as important to review various aspects of the three components of motion as it is to review the SSE peak acceleration.

This study is the first attempt to systematically compare two seismic methods. Further research on the concept is intended in the near future, however, we suggest that the results of this preliminary study be reviewed and considered for future use in the regulatory review process.

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cc: F. Schroeder, DST, NRR
G. Knighton, RCSB, NRR

REFERENCE

S. E. Bumpus, J. J. Johnson and P. D. Smith, Lawrence Livermore National Laboratory, Livermore California, Best Estimate Method Versus Evaluation Method: A Comparison of Two Techniques in Evaluating Seismic Analysis and Design, NUREG/CR-1489, UCRL-52746, July 1980.

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<u>RECORD NOTE:</u>

A meeting has been held with the User Office and it was agreed that the research results on the BE-EM Project are at a point which merit preparation of this RIL. User Request Number NRR-76-8.

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