A FRAMEWORK OF RISK-INFORMED SEISMIC SAFETY EVALUATION OF NUCLEAR POWER PLANTS IN JAPAN

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Abstract

A framework of risk-informed seismic design and safety evaluation of nuclear power plant is under consideration in Japan so as to utilize the progress in the seismic probabilistic safety assessment methodology. Issues resolved to introduce this framework are discussed after the concept, evaluation process and characteristics of the framework are described.

1. INTRODUCTION

Probabilistic safety assessment (PSA) has been applied to improvements in nuclear power plant (NPP) design and maintenance in Japan. Examples are revision of plant maintenance rules, rationalization of in-service testing and inspection (IST and ISI) of systems and components and evaluation of management measures and procedures against severe accident. Currently it is considered to incorporate risk insight obtained through PSA into safety evaluation of NPPs for external events.

The present paper describes a framework of plant safety evaluation for earthquake based on seismic PSA under consideration. It includes determination of design basis earthquake, acceptable response of structures, systems and components (SSCs) to the design basis earthquake at basic design review stage, and evaluation of seismic risk of detailed design at detail design review stage. After that several technical problems to be solved for applying the framework are summarized.

2. BASIC CONCEPT OF CURRENT SEISMIC DESIGN METHOD

Currently seismic design and safety evaluation of NPP in Japan is performed by the deterministic method. In seismic design SSCs of NPP are categorized into class A and others based on their seismic importance: SSCs which are highly important to safety are categorized into class A and most important facilities of class A such as reactor pressure vessel are categorized as class As. And it is demonstrated that the response of SSCs in class A is within an elastic range against design basis ground motions due to postulated earthquakes around the site. It is also demonstrated that SSCs in class As will not lose their safety function against an extreme ground motion caused by the limiting earthquake. Postulated earthquake is determined based on evidences of past damaging earthquakes and information about active faults which have evidence of dislocation up to recent eras. The limiting earthquake beyond design basis earthquake is determined by taking into account the existence of active faults with lower activity, seismo-tectonic structure and the near field earthquake due to unidentified active faults in the vicinity of the site.

3. NECESSITY OF INTRODUCTION OF PROBABILISTIC METHOD INTO SEISMIC SAFETY EVALUATION

In this procedure there is a possibility that an unreasonably large earthquake of a quite low expected frequency controls the design basis ground motion. It is known that there is a large variability in the design basis ground motion. Experts have relied on their judgment as to the majority opinion in the
academic society to prepare so-called conservative set of ground motions and design parameters for both safety design and licensing application and safety evaluation in the licensing review process till now. In this case there is a question how conservative is conservative enough and who should right expert to do such judgment. It is difficult to find appropriate and rational answers to these questions in the current framework.

4. PROPOSED FRAMEWORK OF SEISMIC DESIGN AND SAFETY EVALUATION

In order to overcome or circumvent these difficulties, we are deliberating a new framework for seismic design and safety evaluation of NPP. A schematic diagram of the proposed framework of seismic design and safety evaluation is shown in Figure 1. In the current framework it is confirmed that important SSCs do not lose their safety function. The proposed framework has two review stages: basic design review stage - evaluation of design basis ground motion and basic design concept of a plant — and detailed design review stage — evaluation of detailed seismic design and seismic risk of a designed plant.

In this framework a plant will be designed such that the plant has seismic safety level enough and rational to meet the safety criteria (safety goal). A concept of ‘risk’ or ‘safety level’ is explicitly introduced in each review stage: evaluation of design basis ground motion, basic design and detailed design of a plant.

New key items included in the framework are explained along the figure.

5. SEISMIC SAFETY EVALUATION AT BASIC DESIGN REVIEW STAGE

It is required to demonstrate at basic design review stage that design of SSC of a plant withstand maximum-scale earthquakes predicted for the site in such a way that no failure and no loss of functions of safety related systems occurs. Particularly it is important to evaluate and review on the level of design basis ground motion and the level of a margin for seismic response (stress or strain, etc.) to its permissible limit.

The design basis ground motion is evaluated by taking account of seismic hazard evaluation results. That is, the level of the design basis ground motion is determined with the relation to a necessary safety level (permissible expected risk level), in which succeeding seismic design will be expected to meet a safety goal. Rational design basis ground motion can be established by this procedure. For example, when target CDF is assumed to be $10^{-5}/y$, design basis ground motion is determined at an exceedance probability of around $10^{-4}/y$ in the seismic hazard curve, since the ratio of CDF vs. frequency of design basis ground motion is evaluated around $10^{-1}$ to $10^{-2}$.

At basic design of a plant, necessary safety margin for seismic response of important SSCs can be determined rationally by referring past experiences and insights obtained from seismic risk (safety) evaluation of existing NPPs.

6. SEISMIC SAFETY EVALUATION AT DETAILED DESIGN REVIEW STAGE

At detailed design review stage, it is necessary to evaluate and review from the following two aspects: confirmation of actual seismic margins of SSCs and risk (safety) evaluation of a designed plant. Concerning the first item, it is necessary to evaluate and review on actual (realized) margins for seismic responses (stress or strain, etc.) of designed important SSCs to their permissible limits according to their seismic importance.

Second, seismic safety evaluation for the designed whole plant is performed by the seismic PSA, which should cover by nature the earthquakes beyond the design basis earthquake, in order to demonstrate that the plant is designed safe sufficient to meet a safety goal. Appropriateness of the
seismic design is confirmed with the result of the seismic safety evaluation that core damage frequency, for example, meets the safety criteria.

If a safety goal should not be met, modifications in plant design will be required. In an actual case the PSA result is utilized to pick up seismically induced dominant accident sequences and dominantly contributing factors against seismic events. The result is feed back to detailed seismic design of important SSCs to improve plant safety rationally. The PSA result will be used to pick up important human actions at earthquakes also.

7. SEISMIC SAFETY EVALUATION METHODOLOGY

There have been proposed several kind methodologies for seismic safety evaluation methodology. First recommendation and typical one of methodologies is seismic PSA, which includes seismic hazard evaluation, fragility evaluation for SSCs and system analysis for a plant. Another typical one is seismic margin analysis, which gives a seismic margin of a plant against the design ground motion. The latter method can not give a safety degree directly in comparison with a safety goal, and therefore it does not show quantitatively how enough safe a plant is.

There are some other simplified seismic safety evaluation method, for example, a method in which minimal safety systems necessary for safe shut-down survive at a ground motion larger enough than the design level.

8. TECHNICAL PROBLEMS TO BE SOLVED

This framework will be effectively applied to actual plant seismic design and review with the existing methodologies and database. Methodologies necessary to seismic safety evaluation have been developed and trial evaluations for actual plants have been performed. For example, seismic hazard curves were evaluated with experts’ opinion and judgment, and core damage frequency for a standard type BWR was evaluated with components’ fragility data of our plants. The result showed that the plant has a large seismic margin.

However, it is desired to continue to develop and improve methodologies and database for more effective application, in order to introduce recent and state-of-the-art progress in science and technology of seismology and relating academic field. Examples of technical problems to be improved are shown below.

Evaluation methods for design ground motion — faulting models, evaluation of ground motion from unidentified seismic sources, elicitation of expert opinion and judgment, etc.

Seismic design and fragility evaluation — design criteria, new categorization of SSCs, components’ fragility database, etc.

System analysis method — multiple failure problem, effectiveness of redundancy of safety systems and components against earthquakes, etc.

9. CONCLUSIONS

A framework of risk-informed seismic design and safety evaluation of nuclear plant was proposed, and the concept, procedure and characteristics of the framework were described. This framework can realize rational utilization of resources necessary to secure enough safety. This framework can also give much information on residual risk beyond seismic design base, predicted seismically induced accident scenario and relative plant vulnerabilities, important human actions at earthquakes, etc. Cost-effective countermeasures against earthquakes, if required, can be discussed based on this evaluation method rationally.
Along this framework practical procedures will be studied in more detail and methodologies and database necessary to the evaluation will be developed for more practical use in our country.

**FIG. 1. Schematic diagram of a proposed framework of seismic design and safety evaluation.**