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ORIGINAL EARTHQUAKE DESIGN BASIS IN LIGHT OF RECENT SEISMIC HAZARD STUDIES

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ABSTRACT

For the purpose of conceiving the framework within which efforts have been made in the eastern countries to construct earthquake resistant nuclear power plants, a review of the development and application of the seismic zoning map of USSR is given. The normative values of seismic intensity and acceleration are discussed from the aspect of recent probabilistic seismic hazard studies. To that effect, presented briefly in this paper is the methodology of probabilistic seismic hazard analysis.

1. INTRODUCTION

The general phylosophy of design and construction of seismically resistant structures in the eastern countries during the past period can the conceived from the development of the codes and regulations for construction in seismically active areas in the former USSR. These codes have an essential influence on the level of protection of the nuclear power plants in all countries where WWER-type NPP's exist. It is within the framework of these codes that individual efforts have been put into developing seismic structures from both qualitative and quantitative aspects. Therefore, in order to conceive the basic principles for the foundation of the methodology for determination of an earthquake design basis for WWER-type nuclear power plants, a review of the development and application of the seismic zoning map of USSR is made.

Presented briefly is also the methodology of probabilistic seismic hazard analysis which is a powerful and rational tool for decision making in earthquake engineering. During the last decade, there has been an increased interest in the application of the seismic hazard analysis in the world. Extensive efforts have been made for improving the definition of seismic sources, the development of appropriate ground motion models and comprehensive treatment of uncertainties. Proper treatment of inherent and modelling uncertainties is very important for the seismic hazard assessment. The application of the results from the seismic hazard analysis is greatly important due to the current problems related to seismic safety of existing nuclear power plants. The reevaluation and possible necessary upgrading of the existing nuclear power plants is a complex and expensive task the realization of which requires proper decisions made on realistic bases and aimed at precizely defined targets. The seismic hazard analysis represents a rational basis for treatment of cases when new knowledge and data modify the basis on which the design parameters of already constructed nuclear power plants are defined or cases of occurrence of new earthquakes.

The results from the seismic hazard analysis enable quantification of a planned seismic design. To that effects, discussed is also the original earthquake design basis for WWER-type nuclear power plants.

2. SEISMIC ZONING MAP SZ-78 AND EARTHQUAKE DESIGN BASIS

The first seismic zoning map (SZ) has been elaborated by the Seismological Institute at the USSR Academy of Sciences in 1937. This map represents a constituent part of the "Regulations of Aseismic Construction" published by the People's Commissariat of the Communal Sector of RSFSR. It was followed by two modified versions and amendments to the seismic zoning map (PSP-101-51, SN-8-57). A variant of these modified versions is published in the book "Seismic Zoning of USSR" (Ref. 1). This map (SZ-69) is a constituent part of the "Construction Norms and Regulations", i.e., Chapter 12 "Construction in Seismic Regions, under index SNIP II-A 12-69 · (Ref. 2). In this period, the main characteristic of seismic zoning maps is that they define seismic intensity with no information on the average return period. However it is considered that in a non explicit way and as a mean value, the maps display earthquakes that occur once in 1000 to 2000 years.

In the seventies, a necessity arose in the USSR to include in the seismic zoning maps an information on return period of earthquakes, the zones of seismic sources and their activities. This was caused by the usage of new methods of computation of structures based on knowledge on the characteristics of ground motion as are the acceleration and velocity. To define these characteristics, the document "A Technical Task to Compose a New Normative Seismic Zoning Map of the Territory of USSR" was issued. The activities related to the map were coordinated by the Governmental Committee for Science and Technology in the period 1971-1977. As a result of these activities, regional seismic zoning maps were published as a constituent part of the construction standards SNIP II-7-81 (Ref. 3). Later in 1984, the seismic zoning map (SZ-78) of the whole territory of USSR was published in scale of 1:5 000 000 (Ref. 4). The characteristic of these maps is that the seismic intensity of 7, 8 and 9 degrees is given with an average return period of 100, 1000 and 10000 years.

The maps that are a constituent part of the standards show the seismic zones in which earthquakes of $M \geq 7.1$ are most likely to occur. These zones are not presented in the area of the Pacific ocean, Kamchatka and the Kurile Islands. The SZ-78 map displays the zones where earthquakes of the following M_{max} and focal depth are most likely to occur:

$6.1 \leq M \leq 7.0$, $h = 10 \div 20$ km
$7.1 \leq M \leq 8.0$, $h = 15 \div 30$ km
$M \geq 8.1$, $h = 20 \div 40$ km

Presented are also seismic zones of occurrence of earthquakes originating from deep foci:

$M \geq 7.1$, $h = 100 \div 150$ km in Vranchea, Romania;
$M \geq 7.1$, $h = 150 \div 300$ km in Hindu Kush, Afghanistan

Presented in the regions of the Pacific Ocean coaastal area are zones of lower or higher probability of occurrence of earthquakes with $M \geq 8.1$ for the next 70 years.

The assessment of the average return perods of a given intensity has been made on the basis of all the available seismological and geological data, definition of most probable seismic zones, definition of the seismicity of these zones, definition of the maximum possible magnitudes and definition of attenuation of intensity depending on distance and magnitude.

From the view point of practical application of the SZ-78 map, it represents a compulsory normative document for planning and realization of measures for seismic design and construction in USSR. The seismically active zones are divided into zones of 6, 7, 8 and 9 degrees according to the MSK-64 scale under consideration of II-nd category soil conditions, i.e., average soil conditions. For I-st category soil conditions, the intensity is decreased for a unit value, whereas for soil conditions of III-rd category, it is increased for a unit value. Depending on the method of computation of the structures for the corresponding seismic intensity, defined are the coefficients for determination of the equivalent seismic load and the amplitudes of maximum ground acceleration. For seismic intensities of 7, 8 and 9 MSK-64 scale, corresponding accelerations of 100, 200 and 400 cm/c^2 are defined. However, given in the manual for the usage of the map are also the probability distribution curves related to maximum acceleration and velocity for earthquakes of different intensities. To that effect, apart from the information on the average return period, the probability of exceedance of a certain acceleration level can be computed for any time period. From the curves and the examples presented in the manual it is, clear that the standard deviation of distribution is of the order of 0.3 logarithmic units.

The differentiation of the most probable seismic zones in respect to maximum magnitude M_{max} presented in the SZ-78 map allows the usage of these data for rough estimation of ground motion parameters as are the following:

- Maximum acceleration;
- Maximum velocity;
- Impulse width, i.e., time duration of ground motion with an amplitude exceeding 50% of the maximum level;
- Vibration period of soil corresponding to the maximum amplitude;
- Response spectra for damping of 0.05 of the critical, i.e., the maximum value of the spectrum and the corresponding resonance period.

Given in the manual for usage of the map SZ-78 are the empirical relationships and curves that determine the characteristics of ground motion depending on magnitude M of the earthquake and distance R to the corresponding location. These parameters are determined with an evaluated mean square error of 0.2 - 0.5 logarithmic units.

When designing nuclear power plants, two levels of seismicity are considered: the design earthquake (DE) and the maximum calculated earthquake (MCE) (Ref. 5, 6, 7). These are defined in terms of intensity level, the basic parameters of seismic motion - maximum acceleration, predominant period of vibration and duration of the intensive part of the ground motion, and a set of accelerograms (real, analogue and artificial). The average return period for DE is 100 years and for MCE it is 10 000 years to which correspond the subscripts 1 and 3 on the SZ-78 zoning map of USSR.

In case of non-existence of detailed seismic zoning maps approved by the corresponding state committees for preliminary studies, the DE value is taken to be the level of intensity appearing on the seismic zoning map (SZ-78) without the return period and the MCE value is assumed to be the DE intensity level increased by 1.

Detailed seismic zoning (DSZ) is a set of geological and geophysical operations carried out for the purpose of detecting zones of potential earthquake foci, determining the seismic characteristics of these zones and evaluating the seismic impact on average ground in the site vicinity and region. The DSZ site region results are used for zones with seismic intensity greater than 6 (SZ-78). The analysis of the available seismological and geophysical data on the site region and the onsite investigation are conducted for zones with a seismic intensity of 6 or less (SZ-78). If the analysis of the available data indicates an MCE intensity of more than 7, the seismic conditions at the site should then be specified on the basis of DSZ and SMZ studies. Seismic microzoning (SMZ) is carried out to predict the impact of the local geological conditions on the seismic ground motion parameters. The construction of NPP-s is not permitted on sites with an MCE intensity level of IX or above or in the immediate vicinity of tectonically active faults.

3. PROBABILISTIC SEISMIC HAZARD METHODOLOGY (PSHA)

During the last decade, the interest in application of the probability method in earthquake engineering and engineering seismology has significantly been increased. This, first of all, refers to the probabilistic seismic hazard analysis, which is a powerful and rational tool for decision making in earthquake engineering (Ref. 8, 10, 11, 12, 13, 14). Probabilistic seismic hazard analyses have advanced lately so that now there are no limits in specifying almost all possible types of earthquake sources, different models of seismic activity as well as any strong ground motion models. Almost all known methodologies for PSHA represent in fact advanced or modified versions of the main idea, i.e., the approach given by Cornell (Ref. 10). According to this approach, the seismic hazard at a given location is determined on the basis of spatially defined seismic sources, the activity of the seismic sources and a given ground motion model. The activity of each seismic source is expressed as recurrence relationship defined by an activity rate A and slope B. Activity rate A is the number of earthquakes above the lower bound magnitude, expected to occur within a specified time. Slope B defines the relative frequency of occurrence for different size earthquakes. In practice, the ground motion model is defined by an empirical relationship between the selected ground motion parameter on one hand and the earthquake size and distance on the other.

From these input data, the distribution functions of earthquakes to-site distance as well as the distribution functions of magnitudes and those of the ground motion parameters depending on magnitude and distance are easily defined. These distribution functions represent the randomness of the earthquake location, earthquake size and ground motion. The PSHA methodology involves integration over these distributions for the purpose of calculating the annual frequencies of occurrence of various levels of ground motion. The results from the seismic hazard analyses can be expressed as a frequency of exceedance curve that defines the probability of exceeding the given levels of ground motion at a given site during a specified time period. In the process of advancing the PSHA methodology, much efforts have been put in inproving the definition of the seismic sources and their activity as well as achieving a better accuracy of empirical models of strong ground motions. However, despite the evident results, there are still uncertainties because of which seismic hazard curves have to be computed. There are two types of uncertainties. The first are random or inherent uncertainties and are considered to be inherent in the physical processes from the viewpoint of present knowledge. Such an uncertainty is associated with the empirical model of ground motion due to strong earthquakes, i.e., scattering of data about the mean value. Such uncertainties cannot be reduced by the present knowledge and understanding of physical processes. The second type of uncertainties involves modelling uncertainties which result from a lack of knolwedge on the correct model or parameter value to be used in modelling of the physical processes. Such uncertainties are, for instance, related to the configuration of seismic sources and their activity as well as selection of the ground motion model. In solving these problems, the experts are offerring a wide range of solutions and models. These uncertainties could be reduced by acquisition of more data and performing more detailed investigations.

Proper treatment of uncertainties is a very important subject in PSHA. The random uncertainties are considered during integration over different distributions into a simple point estimate of the hazard. The modelling uncertainties are treated by using multiple inputs and are displayed as a range of uncertainty associated with that point estimate. When defining the seismic sources, several models, distributions or parameters are considered. Several models of magnitude distribution and ground motion distribution for given magnitude and distance are also considered. For the purpose of an easier organization and documentation, the uncertainties are treated through a "logic tree". Each node of the logic tree represents a certain PSHA input which, due to the uncertainties, is defined by several alternatives. The alternatives correspond to the exiting branches from that node. Each alternative, i.e., branch has a probability assigned according to its relative likelihood. Each end branch represents a possible combination of inputs to the PSHA. A seismic hazard analysis is performed for each end branch with a probability that is equal to the product of the probabilities of all the branches that are considered in that input combination. As a result, obtained is a family of hazard curves defining the uncertainties in the seismic hazard arising from the uncertainties in the PSHA inputs.

4. RECENT SEISMIC HAZARD STUDIES

In the United States, during a long period, efforts have been made for seismic evaluation of nuclear power plants, because of a perceived change in the seismic hazard in the Eastern United States and/or due to changes in seismic design requirements and practices by industry and the United States Nuclear Regulatory Commission (USNRC) (Ref, 15, 16, 17, 18, 19). The objective of these efforts is to evaluate the seismic safety of nuclear power plants for seismic effects greater than the plants design SSE. Several approaches were applied in making seismic safety decisions, based on seismic hazard analyses results, when the following indicators have been used as measures for seismic safety of nuclear power plants: seismic hazard at SSE, seismic plant margin, seismic core damage frequency and seismic offsite risk. The evaluation of these indicators of the seismic safety, depends, basically, on the results from the probabilistic seismic hazard analysis. For improvement and maturing of the probabilistic seismic hazard analysis methodology the following projects have contributed the most: The Seismic Hazard

Characterization Project, initiated by Lawrence Livermore National Laboratory (LLNL) at the request of USNRC, and Seismic Hazard Methodology for Nuclear Power Plants in the Eastern United States, performed by Electric Power Research Institute (EPRI), funded by industry formed Seismicity Owners Group (SOG). The first project, on the basis of previous efforts to define seismic reanalysis criteria for a selected number of older operating plants, relied upon assembling expert judgment and opinions from scientists knowledgeable about seismic hazard in the Eastern United States. The second project, was suggested by USNRC as a parallel project the results of which could be compared to those of LLNL. The results from these seismic hazard calculations can be used in a variety of ways as, quantification of a plant's seismic design basis, probabilistic seismic risk assessments, evaluation of the stability of licensing basis for existing plants, licensing of future plants, etc. The simplest characterization of a plant's seismic robustness is the SSE acceleration. Therefore, the hazard at the ground motion level, corresponding to a plant's SSE is a valuable indicator of the plant safety. The studies, related to the seismic hazard of existing power plant sites in the United States, indicate that the likelihood of exceeding the safe shutdown or design basis earthquake for nuclear power plants derived using deterministic techniques is of the order of 10^{-3} - 10^{-4} per year. Studies of similar contents and objectives have been carried out in West European countries and in Japan.

In the last few years, the interest for the application of the probabilistic seismic hazard analysis as a tool to asses adequacy of seismic design basis for existing nuclear power plants in Eastern Europe has increased. Seismic hazard studies for several existing power plant sites have been performed. Some of them have shown a need for the increase of design basis seismic ground motion parameter values for the purpose of upgrading.

5. CONCLUSIONS

During the past years, probabilistic hazard analysis has been used as a tool to assess the adequacy of seismic design basis and is an integral part of the various methodologies for evaluation of safety of nuclear power facilities. The recent seismic hazard studies shows that the results can be used in a variety of ways, including quantification of a plant's seismic design basis and probabilistic seismic risk assessments.

The seismic zoning maps of the territory of the USSR affected significantly the determination of the seismic design parameters of nuclear power plants constructed in the Eastern European countries. This results from the normative character of the maps, as well as the high authority of the institutions participating in their elaboration and issuing. Therefore, the seismic zoning maps, as the principal background of the original design basis, had the role of a very rigid frame in decision making, despite the adjustment of the seismic intensity prescribed by the regulations. More determined quantification of the outcome from the application of the seismic zoning maps can be carried out by analysis of the integral process of design and construction in the context of the final effect upon the seismic safety.

The performed seismic hazard analysis for some sites show the need for updating of the design basis seismic ground motion parameters. Therefore, it is necessary and rationally to carry out studies of the seismic hazard for a number of sites of nuclear power plants in Eastern Europe with the objective to identify and realize urgent short term seismic upgrades and provide the basis for creating conditions for planning and realization of long term upgrading.

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