Development of Probabilistic Floor Spectra for Loviisa Nuclear Power Plant

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ABSTRACT

The procedure used in this study for generating probabilistic floor response spectra follows the methodology developed under seismic safety margins research program (SSMRP) conducted in the beginning of eighties in the U.S. This approach will provide a complete description of seismic environment for equipment and piping and can be used directly in seismic PSA studies. The end result of the study will be mean and mean-plus-one-standard-deviation amplified response spectra in selected nodal points in the structure. In seismic PSAs, the uncertainty in structural response is required and this is given by mean and mean-plus-one-standard-deviation response spectra. In the procedure for probabilistic floor spectra generation there are five main tasks, namely, the development of control motion; the development of soil and structural models; the latin hypercube sampling for setting up the input values for each earhquake simulation and the last step is the actual response analysis.

1 INTRODUCTION

This study is a part of seismic probabilistic safety assessment (PSA) for Loviisa Nuclear Power Plant. The purpose of the current task is to determine the floor response spectra which can be used in estimating seismic fragilities of the plant equipment. The first task in spectra generation is the determination of the control motion. In order to do this, the target ground spectral shape, the peak ground acceleration (PGA) and the duration and envelope curve for the acceleration time-history have to be fixed. In addition to the control motion, the structural model has to be set up and the uncertainty in control motion as well as in the properties of the structural model is taken care of by making the response calculations repeatedly with different values for the control motion and for the properties of the structural model. For selecting the input values for response simulations the latin hypercube sampling method is used. This method is one variation of the Monte Carlo method but the advantage of latin hypercube sampling is that the amount of simulation runs can be kept small and at the same time, however, the total range of variation of the input parameters is covered. Throughout the structural analysis the linear theory was adopted and the dynamic response calculations were made with the aid of the mode superposition method. The properties of the structural

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models which were assumed to be random were the modal frequencies and the modal damping ratios. Floor spectra were calculated for the reactor building and for the turbine/control building. The spectra were evaluated for three damping ratios, namely, 2 %, 5 % and 10 %. The distribution of the resulting spectra were given by calculating for each spectral frequency the mean value over all simulations as well as the standard deviation over all simulations.

2 DEVELOPMENT OF THE CONTROL MOTION

In Loviisa plant site the bedrock is at the ground level so that the free-field control motion is at the same time the motion at the surface of the bedrock. In these conditions the soilstructure-interaction (SSI) effects are neglicible and the control motion can be applied directly to the structural model. The shape of the target ground response spectrum with which the individual acceleration time histories were matched was taken from ref./1/. This spectrum was developed for Swedish conditions and its mean feature is that the maximum spectral velocity is located in relatively high frequency band around 10 Hz. This spectrum was generated for low seismicity areas, where the near-field earthquakes are the main contributors to the seismic hazard. Finland is, like Sweden, a low seismicity area and the spectral shape from /1/ was adopted for this study. The damping ratio for the target spectrum was taken to be 5 %. The peak ground acceleration in horizontal direction was taken to be 10 % of g and according to /1/ the corresponding value in vertical direction was taken to be 8.4 % of g.

The target spectra were assumed to be design spectra so that the exceedande probability for them is 16 % and the distribution of spectral accelerations was assumed to be lognormal. A coefficient of variation of 0.2 has been related to the spectral accelerations of the target spectra /2/ and this value has been interpreted as an average value calculated over all frequencies. Thirty simulated acceleration time-history sets were constructed and each set consists of three orthogonal components from which one is vertical and two are horizontal. The duration of each time history was 7 seconds and the trapezoidal envelope curve was used. The criteria for matching the spectra of generated time histories with the target spectra were as follows: The mean calculated from each group of thirty spectra should deviate less than 1 % from the target, and correspondingly the coefficient of variation of each spectra group should lie between the values of 0.19 and 0.21. As a result of this control motion development 30 earthquake acceleration time-history sets were generated. Each set has the same propability, namely 1/30. The time-histories in each set were defined by 701 points and the constant time-step of 0.01 seconds was used.

3 DEVELOPMENT OF STRUCTURAL PROPERTIES

The uncertainty of structural properties were taken into account by assuming that the frequency and the damping ratio of each mode are random variables. The dispersion of both modal frequencies and the damping ratio was assumed to obey the lognormal distribution. The damping ratio was assumed to be the same for all modes and the median value was assumed to be 5 % and the coefficient of variation was 0.35. The same constant modal damping ratio was used for both concrete and steel framed structures. The median value for the modal frequency of each mode was the value obtained from mode extraction run of the finite element model when best estimate values for structural properties were used and the value of 0.25 was used for the coefficient of variation. These selections for structural properties and their dispersion are typical and applied in the PSA studies of the past /3/.

4 LATIN HYPERCUBE SAMPLING /4/

In this study the latin hypercube sampling (LHS) technique is used to establish samples for the simulation runs of the model. The random variables to be sampled are the control motion, the modal dampings and the modal frequencies. LHS is a special type of Monte Carlo simulation which provides reasonably accurate results based on a reduced number of calculations. In LHS each random variable is divided into n different non-overlapping intervals (in this case n=30) on the basis of equal probability. For each random variable one value is selected per interval by random sampling within each interval. The n latin hypercube samples are then obtained by pairing of the values of the k random variables. A 30 x k matrix is thus formed where each row contains specific values of each of the k input variables to be used in each of the simulation runs and each column contains the 30 samples of each random variable. This sampling scheme ensures that each of the input variables has all portions of its distribution presented by the input values. The expected value and variance of the output of the simulation runs are estimated by simple statistics.

5 CALCULATED FLOOR SPECTRA AT SELECTED POINTS

The floor spectra were calculated for the reactor building and for the turbine building. The reactor building is a concrete structure whereas the turbine/control building is a steel framed structure. For both buildings a three dimensional structural model was set up. For reactor building the spectra were determined for five different levels. As an example of the reactor building spectra the response spectrum for the main operation floor and in horizontal direction is depicted in Figure 1. The damping ratio for which the spectrum is generated is 2 %. For turbine/control building the spectra were computed for five different floor levels. As an example, the floor spectrum for the main operation level and in transversal, horizontal direction is depicted in Figure 2. Also in this case, the damping ratio of the spectrum is 2 %.

6 CONCLUSION

A typical feature of the generated spectra is that they contain two or more spectral peaks. This reflects the properties of the three dimensional element models which contain eigenfrequencies in a very broad range. In this analysis all the eigenfrequencies up to 50 Hz were accounted for in the mode superposition. Also this feature is partially due to the properties of ground response spectra which had the range of acceleration amplification up to 50 Hz.

The results of the above described study will be used in sismic fragility analysis of equipment in the plant and they form one part of the seismic PSA study which is currently carried out for the Loviisa Plant.

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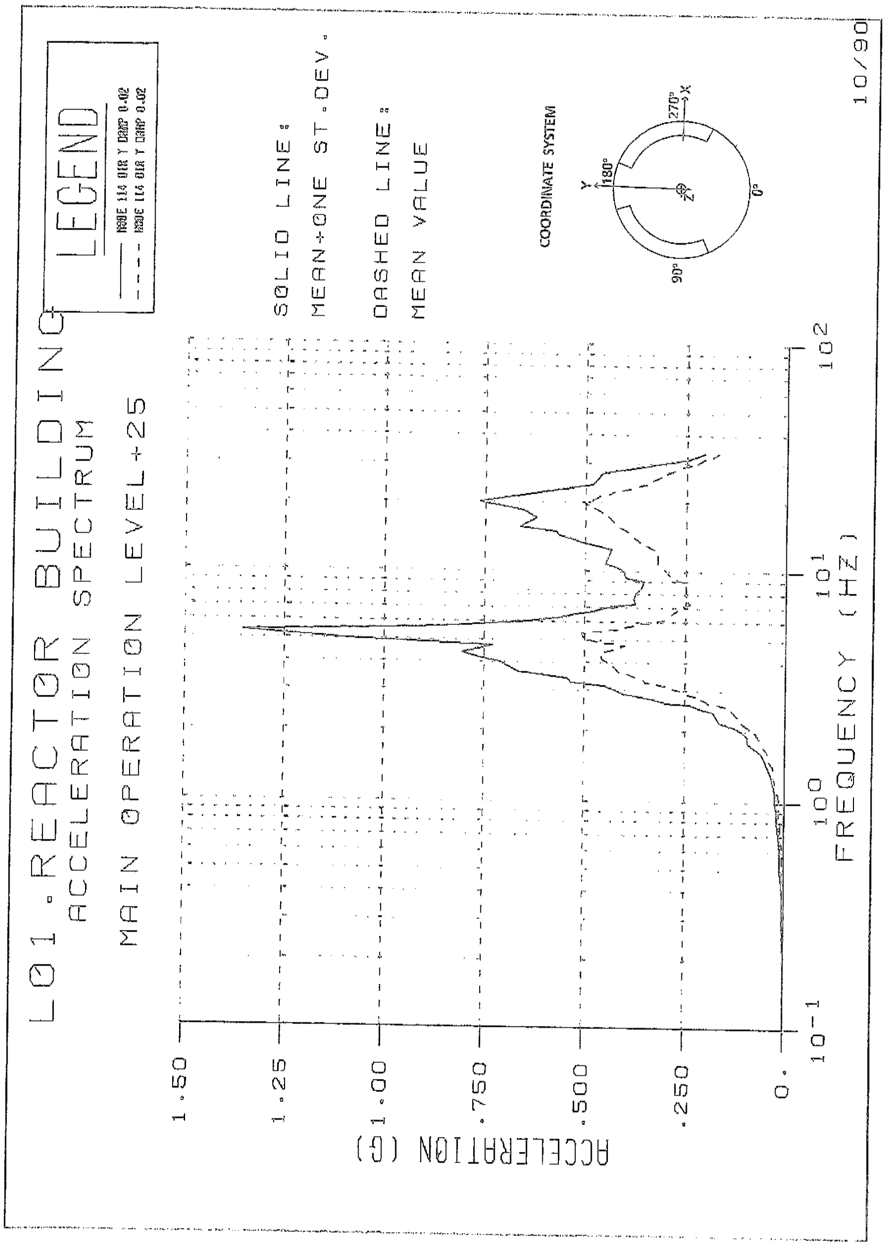

Figure 1. Reactor building, the horizontal response spectrum of the acceleration on the floor level of 25 m at 2 % damping in the y-direction.

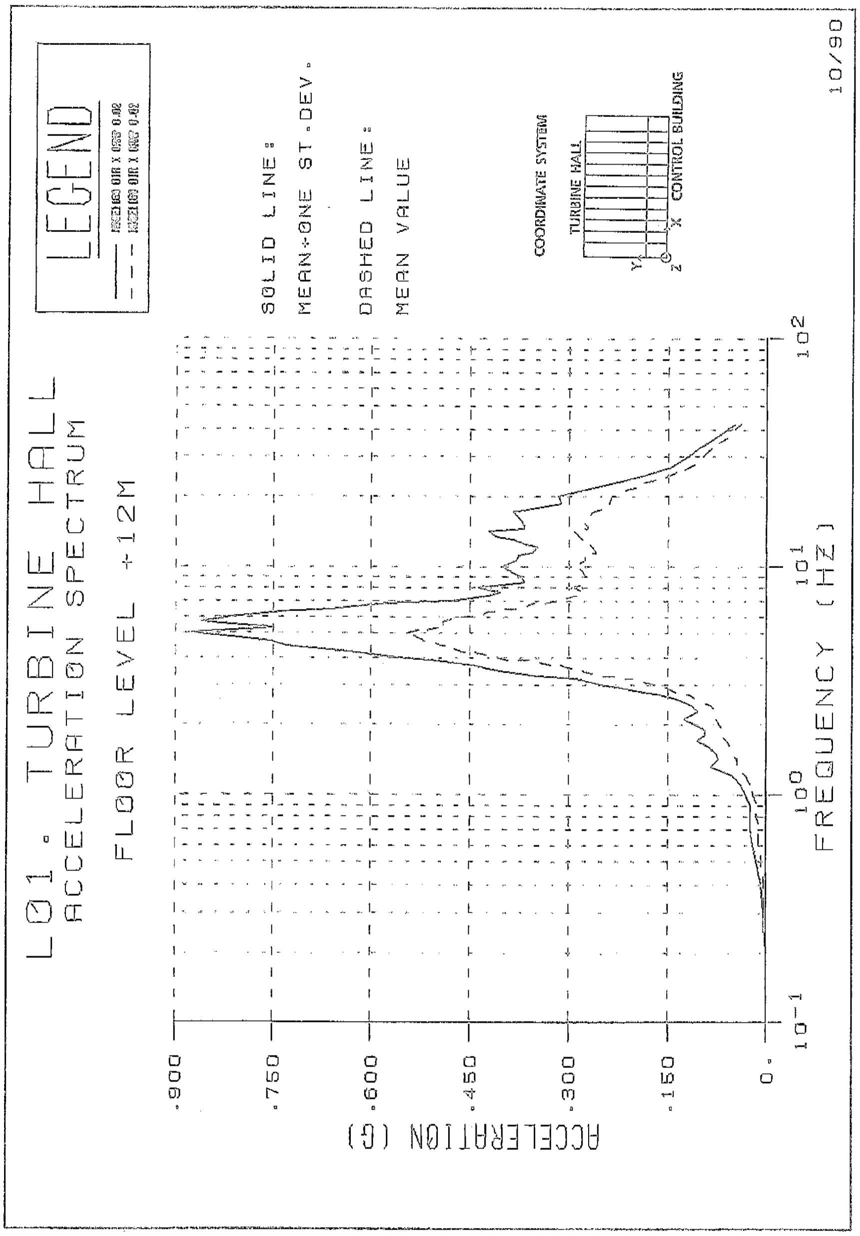

Figure 2. Turbine Hall, the horizontal response spectrum of the acceleration on the floor level of 12 m at 2 % damping in the x-direction.