The Seismic Hazard Study for Southern Finland

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Abstract

The aim of this study is to form the basis of the seismic design of nuclear power plants in Southern Finland. A catalogue of historical earthquakes in Fennoscandian area containing 1839 events and covering the period of 1467-1983 was compiled. The catalogue was divided into four statistically equivalent parts according to the registration accuracy of the tremors. Using the four aforementioned catalogues the seismic risk was evaluated for different return periods as a function of the intensity. Various extreme distributions were fitted in these results. On the basis of the distributions the best estimate of the seismic risk was combined. Related to the return period of 10000 years, its value varies between 5.5 and 6.0 on the MSK scale. In the second part of the work, design spectra using the same earthquake catalogue and Canadian attenuation functions of the acceleration and velocity were constructed. Finally, the time histories of the acceleration were calculated from the design spectra.

Introduction

Fennoscandia and especially the Baltic shield belong to the most quiet seismic areas in the world. The greatest earthquakes have been about 5 on the Richter's open scale. So traditionally the seismic design has been excluded from Finnish design codes. However, the strict safety regulations related to nuclear power plants imply that the seismic load also has to be included in the low seismicity areas.

There are two known possibilities for estimating the seismic risk, that is the probabilistic and the deterministic method. In Finland there are no seismically active faults in the sense that this term is understood in other parts of the world, and there are no registered acceleration histories. Therefore, the probabilistic method is practically the only alternative for obtaining quantitative information about the seismic risk. The basis of this study is the probabilistic method of C.A. Cornell /1/ and its computer application, the program EQRISK by McGuire /2/. Since the method is well-known it is not described here.

The risk calculations have been made for the area 59°-62°N x 19°-31°E. The combiled earthquake catalogue covers the area between latitudes 54° and 64°N, and longitudes 9° and 41°E. The larger region was chosen on the principle that the distance from the investigated area was at least 500 km to the boundary of the total region. Fig 1 shows the areas. The sites of the present Finnish nuclear power plants Hästholmen and Olkiluoto are also depicted in Fig 1.

Earthquake catalogue

The catalogue was compiled by the Institute of Seismology of the University of Helsinki. The catalogue is as complete as possible. It contains all the information which is available in the Norwegian, Swedish, Finnish, and Russian national catalogues. Some international sources were also used, and in addition Imatran Voima Oy organized a symposium with the Academy of Sciences of the USSR on the subject of the seismicity in Fennoscandia and Northwestern part of the Russian plain areas.

The list of earthquakes obtained contains 1839 events about which all the epicentral data are known. In Finland the instrumentally registered period began 1956. During this period there were 546 shocks. The first observed earthquake occurred in 1467. In the different historical eras the accuracy of registration has varied significantly. A general conclusion is that only the earthquakes with magnitude over 5 have always been observed. The list contains 8 such events. The magnitude of the greatest events is about 4 in Finland.

For the derivation of the attenuation equation a list was compiled including all the events the attenuation properties of which were known in the area concerned. Seventy-seven such cases were found. The attenuation function was calculated in the sense of a least square approximation. The obtained function is

$$I(m,r) = 4.611 + 1.426\,m - 1.548\,\ln(r+10), \qquad (1)$$

where I is the intensity, m the magnitude, and r the epicentral distance in km. The standard deviation of I is 0.557 in Eg. (1).

From the catalogue also the relationship between the epicentral intensity and the magnitude was calculated

$$I_0 = 0.963\,m + 1.449 \qquad (2)$$

In the analyses, Eg. (2) was used to restrict the intensity from Eg. (1) in the vicinity of the epicentre.

The basic parameters of risk analyses

The earthquake catalogue was divided into four different source materials as a function of magnitude and time span. The first material contained 316 shocks with m - 3.0 and the time period 1884 - 1983. The corresponding parameters for the other cases were: the second material 65, m - 4.0, 1600 - 1983, the third material 8, m - 5, 1467- 1983, the fourth material 543, m - 1.5, 1956 - 1983. The aim of this grouping was to form statistically homogenious source materials.

One important parameter of the EQRISK program is the Richter's b-value /3/ which relates the magnitude to the number of earthquakes. This constant can be defined in various ways. After thorough investigation only one b-value was calculated, and it was used in every analysis for all the source areas. The value was calculated from the first material, and was obtained as a medium value of the results related to a maximum likelihood method and a least square fit. Its value was 0.9.

The other significant parameter is the maximum possible magnitude. There are many possibilities for extrapolating its value, but these methods only give a rough and uncertain estimate /4/. However, in this study one of these methods has been used: the maximum magnitude observed has been increased by a given increment. In the 1st, 2nd, and 4th analysis its value was zero, and in the 3rd analysis 0.5.

In the risk calculations it was assumed that earthquakes act in accordance with a Poisson process, and in the materials two and three differences relate only to very short or medium time intervals, respectively. Therefore, the conclusion is that the Poisson process describes the registered occurrence of earthquakes in Fennoscandia satisfactorily.

The risk analyses

The risk calculations were made for every mesh point and plant site presented in Fig (1). The results were presented as contour maps of the intensity. From the source material 1 the intensity values were defined for the return periods of 100, 200 and 500 years. For the other source materials the return periods analysed were: 500, 1000, and 5000; 1000, 5000, 10000; 100 and 200 years. Thus, for every point 11 intensity values related to different return periods were obtained. The values of the investigated plant sites have been shown in Fig. 2.

Different extreme distributions can be fitted to the 11 points. In this study, the fitted equations have been the complements of two asymtotic distributions, that is the Gumbel III and the distribution presented by Kanda /5/. These equations are

$$F(I) = 1 - \exp(-((w-I)/(w-U))^k); \text{ Gumbel III} \qquad (3)$$

$$F(I) = 1-\exp(-((w-I)/(UI))^k); \quad \text{Kanda,} \qquad (4)$$

where the parameters u and k were solved by a least square method. The parameter w was also solved by the same method, but its lower bound was restricted in advance. The lower bound was estimated from the greatest historical tremors in the considered area. Two cases were analysed; firstly, according to the Osmussaari earthquake, w was 6.17 and secondly w was 7.32 based on the Oslo fjord earthquake. The obtained fits are represented in Fig (3).

The best estimate and confidence limits were estimated by weighting the calculated four fit functions. To determine the weights, the sum of the inverse values of the norm was formed. The curves were fitted in the sense of the norm. Thus, the weight of each curve was the ratio of the inverse value of the norm of the curve to the aforementioned sum. These weights can be interpreted as the values of a discrete density function, and using this information the best estimate and confidence limits were determined. Fig (4) shows the results for the Hästholmen plant site

From the risk analyses it can be concluded that the seismic risk is low in Southern Finland, and differences are small inside the area. However, the activity seems to be greatest in the Northwestern part of the observed area, and the Southeastern part is the most quiescent, but the difference is only about 0.5 on the MSK scale.

Construction of the design spectrum

In this part of the study design spectra related to the return period of 10 000 years were generated. Three acceleration histories were further derived from the spectra, two for horizontal and one for vertical direction. First the maximum values of the acceleration, the velocity, and the displacement were defined on the surface of the bedrock. No strong motion registrations have been made in Finland. Thus, the attenuation equations derived for Eastern Canada have been utilized. Two such equations were found for the peak acceleration and the velocity /6/, /7/. The similar statistical analyses as for the intensity were made for these parameters. The peak value of the displacement was obtained as a function of acceleration and velocity from the equation presented in the reference /8/.

The statistical differences were so minor that it was sufficient to define only one peak value of each parameter for Southern Finland. For the acceleration, velocity and displacement these values were 0.5 m/s, 0.02 m/s, 0.005 m, respectively. The design reponse spectra were constructed by applying the method described in the Canadian code /8/. The obtained spectrum of the horizontal movement is represented in Fig 5. The spectrum of the vertical movement was formed by multiplying the presented peak values by the coefficient of 2/3.

Acceleration histories were simulated by the program SIMQKE /9/. The duration of the histories was 12 sec, which has been used in Central Europe /10/. The damping coefficient of the spectra was 2 %. One of the calculated horizontal acceleraton histories is represented in Fig 6. The dominating frequencies of the simulated movements are between 3-6 Hz, and the peak of the power spectral density function always lies at 4 Hz.

Conclusion

In this study, the general outlines of the seismic risk analysis for Southern Finland have been presented. The result is that an earthquake with the intensity of 6 can occur by the annual probability of 10^{-4} within the considered area. The design response spectra have also been formed for the movement on the bedrock, and some of the related accelaration histories have also been calculated.

References:

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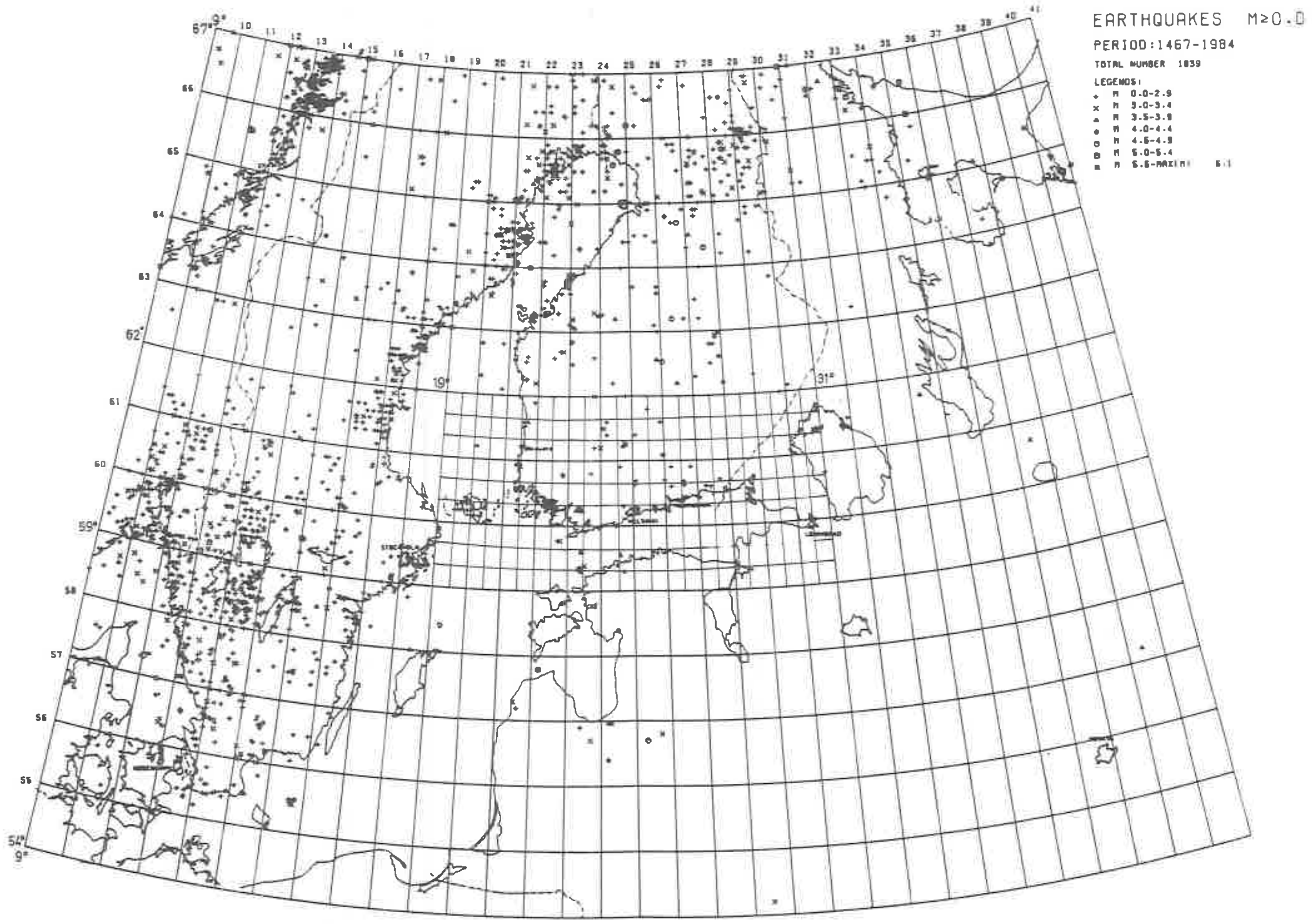

Fig 1 The investigated area

MEAN RETURN PERIOD	ANALYSIS 1		ANALYSIS 2		ANALYSIS 3		ANALYSIS 4	
	I	II	I	II	I	II	I	II
100	3.28	3.95					2.69	3.24
200							3.13	3.67
500	4.24	4.98	3.59	3.80				
1000	4.63	5.36	3.96	4.13	4.32	4.32		
5000			4.74	4.79	5.51	5.51		
10 000					5.99	5.99		

I :(HÄSTHOLMEN) LOVIISA PLANT
II : OLKILUOTO PLANT

Fig 2 The values in which the extreme distributions are fitted

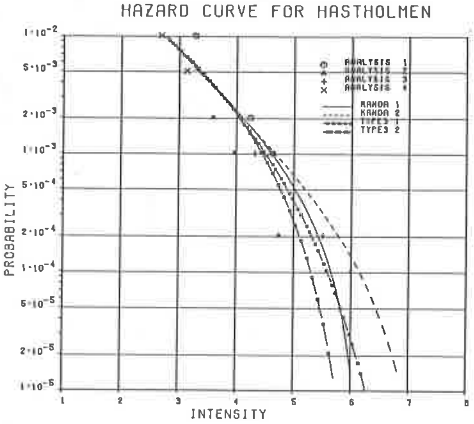

Fig 3 The obtained extreme fits for Hästholmen plant site

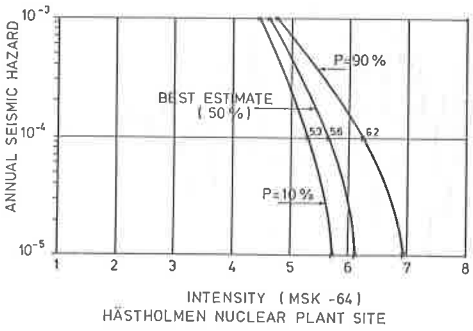

Fig 4 The best estimate curve for Hästholmen plant site

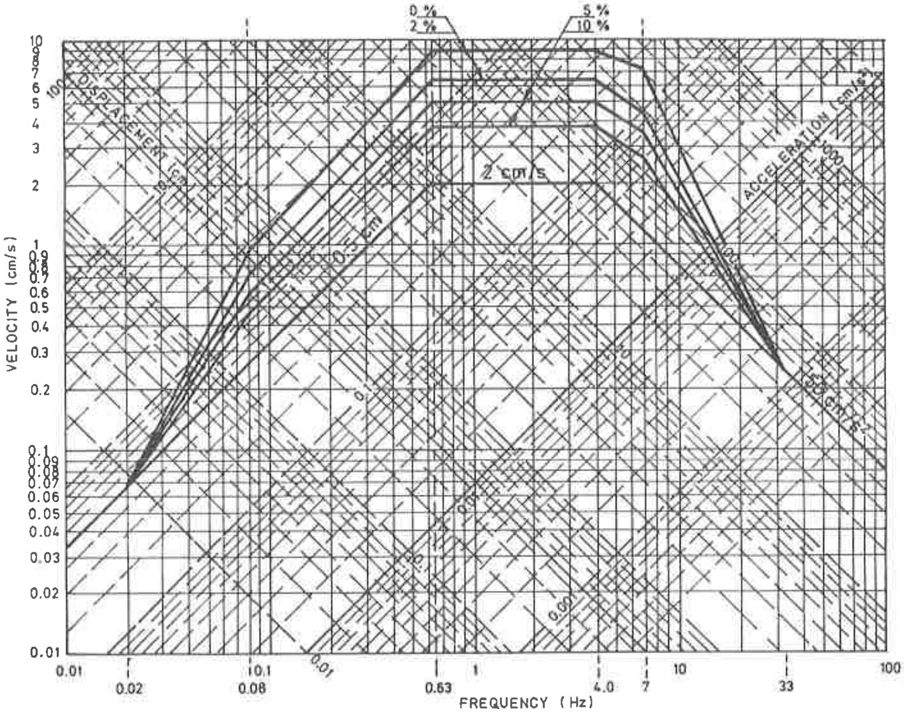

Fig 5 The spectrum of the horizontal movement

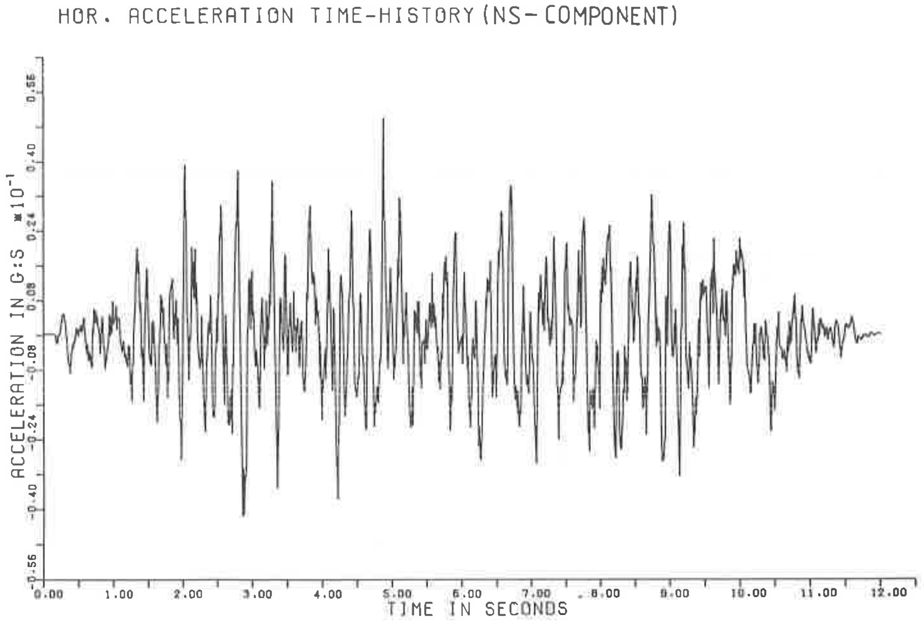

Fig 6 The calculated horizontal acceleration history