THE DEVELOPING OF GROUND RESPONSE SPECTRA FOR EXTREME SEISMIC EVENTS IN SOUTHERN FINLAND

Pentti E J VARPASUO[1], Jouni SAARI[2] And Yrjo NIKKARI[3]

SUMMARY

The purpose of the current paper is to present the task, the methods and the results for the ground response spectra for nuclear construction sites in southern Finland. The results of this study will form a key design in formation for the design of the plant structures, piping and equipment.The first task of the study was the development of attenuation relationships for southern Finland. For this task the approach of tektonically and geologically similar regions was adopted. For these regions the Saguenay region and the southwestern Australia were chosen. The second task in the study was the division of the southern Finland to six source areas and the determination of magnitude recurrence relationships for these source areas. The identified sources for the study were: 1) swedish coast, 2) Aland archipelago-Estonian coast strip, 3) Bothnian gulf-lake Ladoga strip, 4) the bottom of Bothnian gulf- White sea strip, 5) Riga bay - Latvia area, 6) background seismicity. The third task of the study was the seismic hazard determination of the investigated area it was done for the different frequencies. The frequency band investigated covered frequencies from 0.5 Hz up to 50 Hz and the number frequency points were about 10. The conclusion of the study is that ground response in southern Finlands low seismicity precambrian rocks is from 0.1- 0.15g for zero period acceleration and that the spectral shapes of the obtained spectra are quite flat, amplification factors being less than three and the spectral peaks are located at frequencies higher than 10 Hz.

INTRODUCTION

The purpose of the present work is the estimation of seismic hazard in territory of Finland in areas of possible locations of atomic power stations in Olkiluoto and on the island of Hästholmen, in Loviisa. In the given report the results of works obtained in 1998 for the Loviisa area given. Because there are no registered strong motion acceleration recordings of earthquakes in Finland, the earthquake recordings from Saguenay and Newcastle regions from Canada and Australia were taken as sources of initial data because of their geological and tectonical similarity to Finland. Theoretical bases of determination of seismic hazard, questions of seismicity of a southern part of Finland, initial data on earthquakes and techniques of their processing, are considered below

REGIONAL SEISMICITY IN FENNOSCANDIA

Finland is situated on the Baltic shield, which is the one of the seismically quietest areas in the world. According to the fault plane solutions of earthquakes the push from the North Atlantic Ridge in the NW-SE direction seemsto be the major stress related to the seismicity of Finland. Other factors of the stress field, such as glacial rebound and local seismotectonics, are more local. Earthquake recurrence rates in Fennoscandia are very low if compared with plate boundary regions worldwide. In fact, stable continental regions like Fennoscandia account for less than one per cent of global moment release rate. Nonetheless, Fennoscandia is an active seismic region, albeit at low earthquake recurrence rates and with low historical maximum magnitudes. Although instrumental earthquake observations started in Finland in the 1920's, local short period recordings started in 1956 [Ahjos and Saari, 1984]. The events in Finland and in Fennoscandia have been predominantly instrumentally located since

[1] *Fortum Engineering Ltd, Rajatorpantie 8, Vantaa 01019 IVO, FINLAND. FAX. +358 10 856 2223*
[2] *Fortum Engineering Ltd, Rajatorpantie 8, Vantaa 01019 IVO, FINLAND. FAX. +358 10 856 2223*
[3] *Fortum Engineering Ltd, Rajatorpantie 8, Vantaa 01019 IVO, FINLAND. FAX. +358 10 856 2223*

the mid 1960's. Intraplate earthquakes tend to occur on old zones of crustal weakness reactivated by present stress field. Given the low earthquake recurrence rates and small magnitudes of the Fennoscandian shield region, the earthquake data is not likely to be complete and completeness varies geographically. Local high gain seismic recording stations would be needed to record the small events that characterize most of the regional seismicity. During the historical era, the interpretation is more accurate on land than in the water areas, when relatively small earthquakes are concerned. However, there is a relatively long history of dense population in southern Finland, Estonia and central Sweden, especially in the coastal areas. It has been shown that the radius of perceptivity of 100 km of a Finnish earthquake is related to magnitude of the order of M=3.8-4.0. Therefore it can be concluded, that it is very unlikely, that continental or submarine events larger than M=4.0 have remained undetected for the last two or three centuries. Based on the above judgement, the earthquake catalog is considered quite representative for magnitudes M> 4.0, since 1750. The seismic characteristics of Finland suggest that areas within a distance of 500 km from the nuclear power plant sites are considered large enough to include all significant seismic events. The FENCAT earthquake catalog was used in this study [Ahjos and Uski]. This catalog encompasses the whole of Fennoscandia and adjacent areas inside a window of about 55-80 °N and 10 °W-45 °E. The catalog includes all documented historical events in the region since 1375. The instrumental magnitudes are based on the Richter's classical local magnitude scale, ML, modified for the Fennoscandian region. The uncertainty of macroseismic magnitudes is assumed to be 10% at best. Within 500 kilometers of the sites, most of the earthquakes in the catalog are small (M<5.0) and well below the threshold of engineering concern. Only one event, which occurred in 1894 (M=5.1) in central Sweden can be classified as a moderate (M≥5.0) earthquake. Only a few historical events were significantly felt. Since 1880, the highest intensity at the Loviisa site is only MSK-64 IV based on the isoseismal maps for earthquakes between 1880 and 1980 according to reference. MSK-64 intensity IV is partially described as: felt indoors by many people, outdoors by few, some awakened, vibration is like that due to the passing of a heavily loaded truck, windows, doors and dishes rattle, Noticeable in standing motor cars. In the Loviisa site the maximum observed intensity is higher: VI. According to the FENCAT earthquake catalog, the Olkiluoto data set includes 936 earthquakes (M=1.5-5.1) and 36% of these (339 events) were located by seismic instruments. The data set for the Loviisa site includes only 299 events (M=1.5-4.9) and 25% of these (75 events) were located by seismic instruments. Within a distance of 500 km from Olkiluoto, a clear majority (72%) of the seismic events have occurred in Sweden. The areas in southern Sweden (Telemark-Vänern region) and the eastern coast of Sweden are well known belts of higher seismicity. These belts are outside the Loviisa data set, but both of the data sets include a small part of the northern Bothnian Bay-Kuusamo seismic belt in the north. The most prominent seismotectonic zone of the Loviisa area shows considerable (300-400 m) vertical displacements along the eastern coast of Sweden. This zone, over 200 km west of Loviisa, separates the inland Precambrian bedrock from the offshore Phanerozoic sedimentary rocks. Southern Finland, Estonia, Latvia and western Russia are characterized generally by a lower seismic activity. However, two NW-SE oriented belts of relatively high seismic activity run through Finland. The northern zone of higher activity runs from the southern Bothnian Bay towards Ladoga. The other active belt runs from the Åland archipelago to southeastern Estonia. The zones are distinguished from their surroundings particularly by the occurrence of relatively large earthquakes. The epicenters of the largest historical and isnrumentally observed earthquakes in Fennoscandian area are depicted in Figure 1. Historical events (-1964) with magnitude M ≥3.5 and instrumentally located (1965-) events with magnitude M ≥ 3.0 are shown by light and dark blue filled circles, respectively. Years of occurrence for the closest events are given. The number of overlapping epicenters is denoted in parenthesis. The period of pronounced seismic activity from 1920 to 1941 brings out the same seismic belts as Figure 1. The outlines of the seismic belts of southern Finland are based primarily on the data of presented in FENCAT. Both of these seismically active belts are characterized by long NW-SE oriented fracture zones

The data of seismicity of territory around Loviisa with radius 500km are investigated. This source area is divided into six source zones including, in addition to Finnish territory, also territories of Sweden, Latvia, Estonia and Russia. For each source zone there are three classes of magnitudes, namely 2-3, 3-4 and 4-5, the total numbers of events for classes 2-3 and 3-4 are given for time period between 1880-1995 and for class 4-5 for time period between 1750-1995. The annual event rates are used directly for seismic hazard analysis, as well the greatest magnitudes registered in the used catalog for each source zone. Each zone was divided into sub-zones, each of which in its turn represents the quadrilateral area. The vertices of these quadrilateral areas are given with global longitudinal and latitudinal coordinates. These coordinates formed the geometrical initial data for the analysis. Let us consider in more detail seismicity of the researched territory. The zone that has greatest seismicity is the zone 3. The zone extends from Swedish coast of the Bothnian gulf to Ladoga lake and its length in north-southeast direction is five hundred kilometers. The total number of events greater than two in magnitude for this zone is 87. The zone that has the smallest seismicity is the zone 1 that has only one event. The zone six is named Latvian zone and its occupies the eastern Baltic see and part of Estonia and Latvia. Zone six is not the smallest by surface area and its surface area is about one fourth of the surface area of zone one. Smallest source area by surface area is the zone four. The zone four is named the northern end the Bothnian gulf-Kuusamo area and its surface area is only 15% from zone one, but its seismicity is quite elevated and the zone contains 14 events of interest. The software used in the hazard analysis task uses three parameters characterizing the seismicity of individual source zones. These parameters are: 1) the total, annual number of earthquakes greater than the lower bound selected for the analysis; 2) the Richter b-coefficient of the source zone; 3) the maximum possible event for each source area.

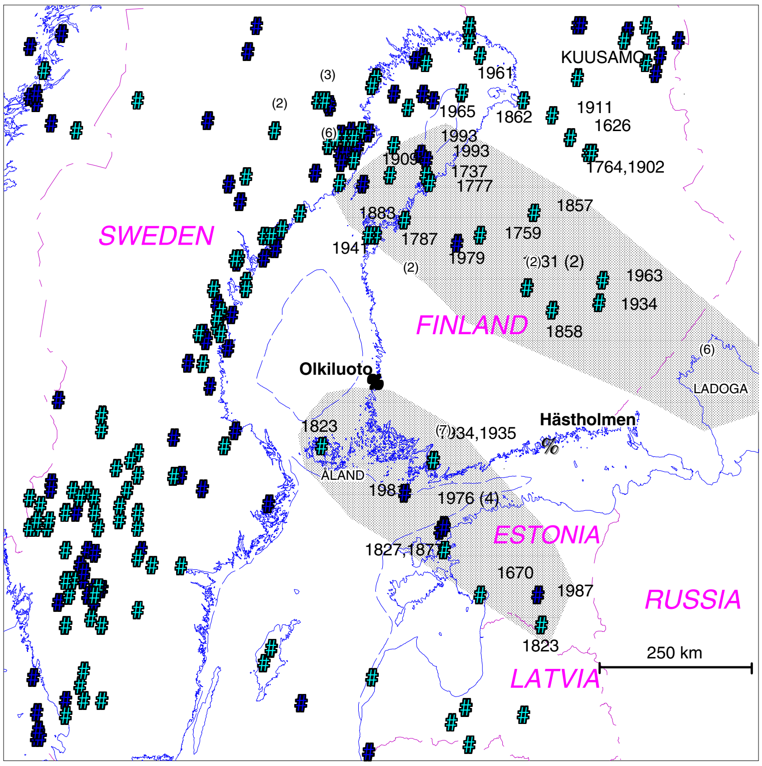

Figure 1 Largest earthquakes in the areas of Olkiluoto and Hästholmen.

DIVISION OF THE SOURCE AREA TO SPECIFIC SOURCE ZONES

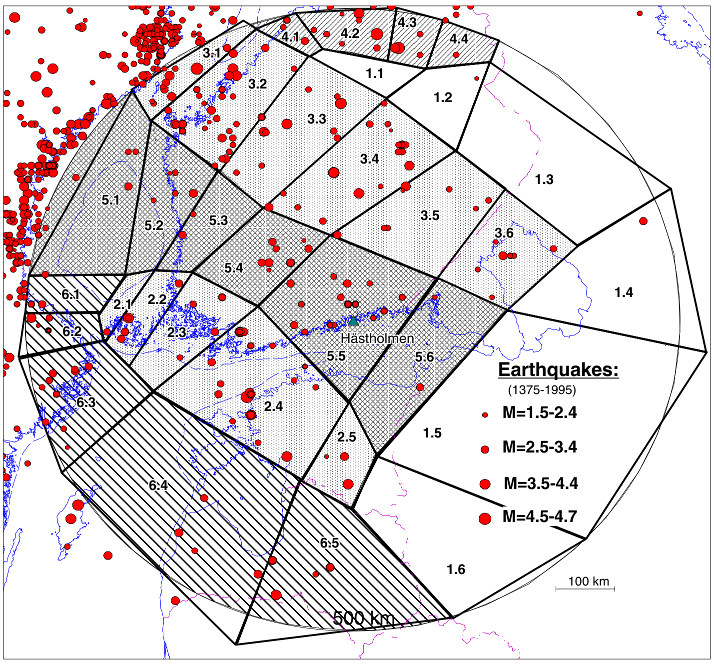

Figure 2. Source area delineation for Loviisa site seismic hazard assessment

ATTENUATION OF GROUND ACCELERATION

Ground motions were estimated from an attenuation relationships of two different types. The first attenuation equation used is of the form

$$\ln(y) = C1 + C2 * M + C3 * \ln(R + h), \quad (1)$$

where y is the strong motion parameter of interest; M is earthquake magnitude, R is the distance from the earthquake epicenter to the site; h is the depth of earthquake focus; and C1, C2 and C3 are regionally dependent coefficients. In this study, the ground acceleration registrations were selected from those geological and tectonical regions that were judged to be similar to the investigated area. The second principle for choosing these areas was the availability of registrations. By use of this procedure the Saguenay region from Eastern Canada and the Newcastle region from Australia were chosen. These are both moderate seismicity, intraplate regions and the registrations were observed on the bedrock. In case of Saguenay, the bedrock was of Precambrian formations, similar to Fennoscandia, but in case of Newcastle the rock formations were sedimentary rocks. This difference in rock formation was the weakness of Newcastle data in respect of its similarity to Fennoscandia, but in other respects also this area was similar to Fennoscandia. The reason for selecting these similar areas as the source of basic data for attenuation is that there are no strong motion acceleration recordings available from Fennoscandia. In Fennoscandia, the earthquakes occur mainly at depths from 5 km to 20 km. The (80%) majority of the hypocenters are in the depth range of 10 -20 km. In spite of the small amount of shallow earthquakes they are important when seismic risk is concerned. Therefore the Newcastle events (depths <5 km) complete essentially the data of Eastern Canada with depths from 10 km to 30 km. All magnitude scales are designed to be as compatible as possible with the original local magnitude (ML). Unfortunately, this is rarely the case. In addition, different regions have their own modified ML-scale. In Fennoscandia, for example, the ML estimations vary 0.1 - 0.5 unit between different regional formulae applied, on the average. In addition, in most of the local magnitude scales, the standard deviation of individual station magnitudes is about 0.2 units. The uncertainties related to magnitude estimates are taken into account by adding 0.25 units to the values of maximum magnitude observed historically. For the determination of coefficients, which are included in equation (1), the method of non-linear optimization is used. The method consists in the nonlinear curve-fitting problem that is solved with the aid of the least-squares method. The initial data for Saguenay events consist of digitized, three component acceleration registrations for eleven Saguenay events, four Miramichi events and some additional registrations for Nahanni1 and Nahanni2 events. The digital SMA recordings for Newcastle events consist of four three component recordings. These events were converted to g units from SMA recordings by appropriate conversion coefficient. Synthesized recording for Kelunji earthquake complemented the instrumentally recorded Newcastle events. The Kelunji synthesized recording was amplified to magnitude level of 5.6 from the instrumentally recorded event the magnitude 2.3. The acceleration histories were plotted on the basis of the digital recordings. From acceleration plots the response spectra for 5% damping were computed

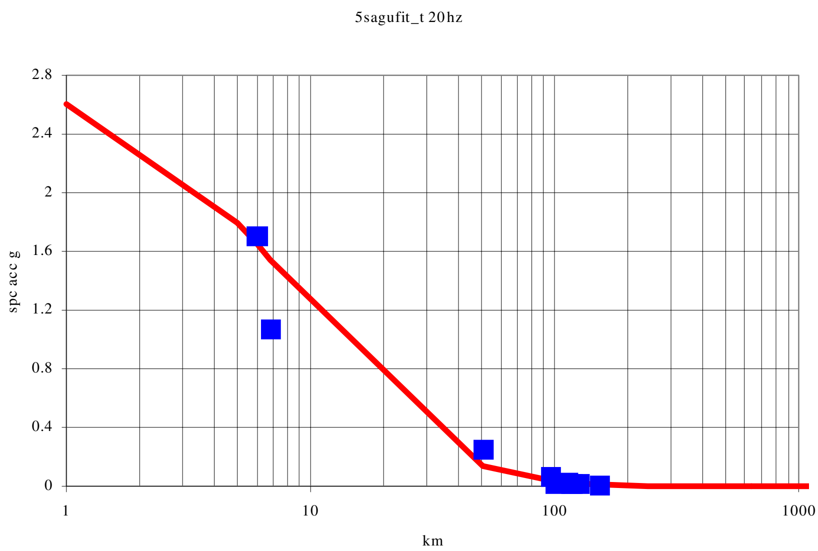

Figure 3. Attenuation fit to equation (1) for spectral accelerations at 20 Hz for Saguenay transversal component

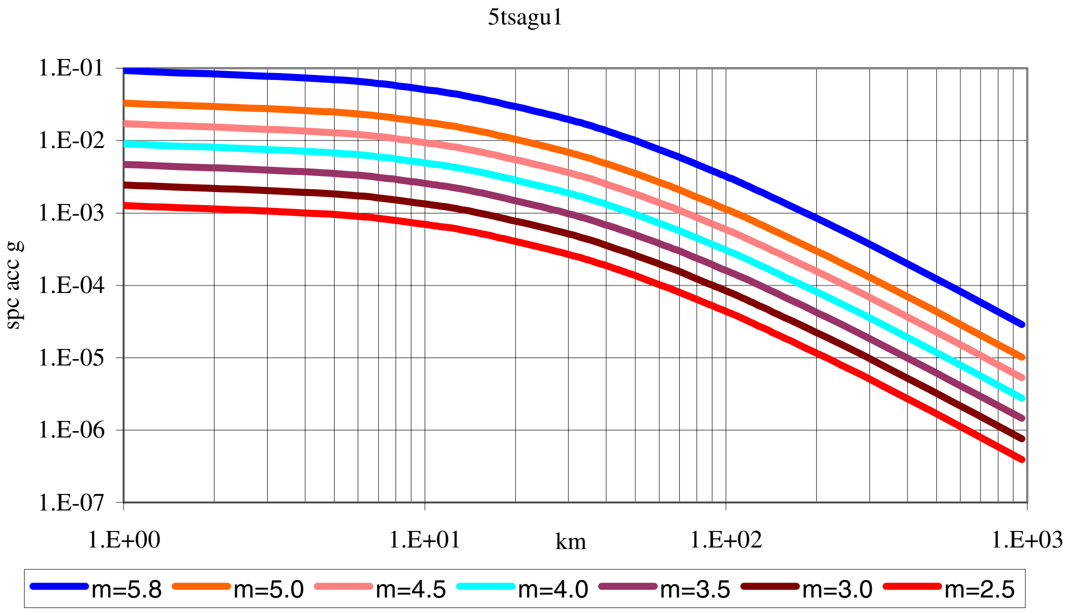

Figure 4. Attenuation fit to Dahle attenuation equation for Saguenay transversal records for spectral accelerations at 1Hz.

The other attenuation equation type used in the study is reported by [Dahle and Bungum, 1990]. The Saguenay and Newcastle recordings were also fitted to Dahle equation. The typical plot of the fit is presented in Figure 4

In Figure 4 the hypocentral distance is the argument axis and the magnitude value is the parameter. The Dahle attenuation is used as input for SEISRISK III [Bender and Perkins, 1987] in table form. The parameter in the attenuation tables is the earthquake magnitude and the argument is the hypocentral distance R. All attenuation relationships are developed for solid bedrock and all site effects are excluded from this investigation because the feasible target sites are solid rock sites. The total amount of acceleration records used in the study was 36. This number is considered quite adequate for the purposes of the study. The aim in choosing the available intraplate recordings was not obtain largest possible number but the best possible relevance to the target regions geological

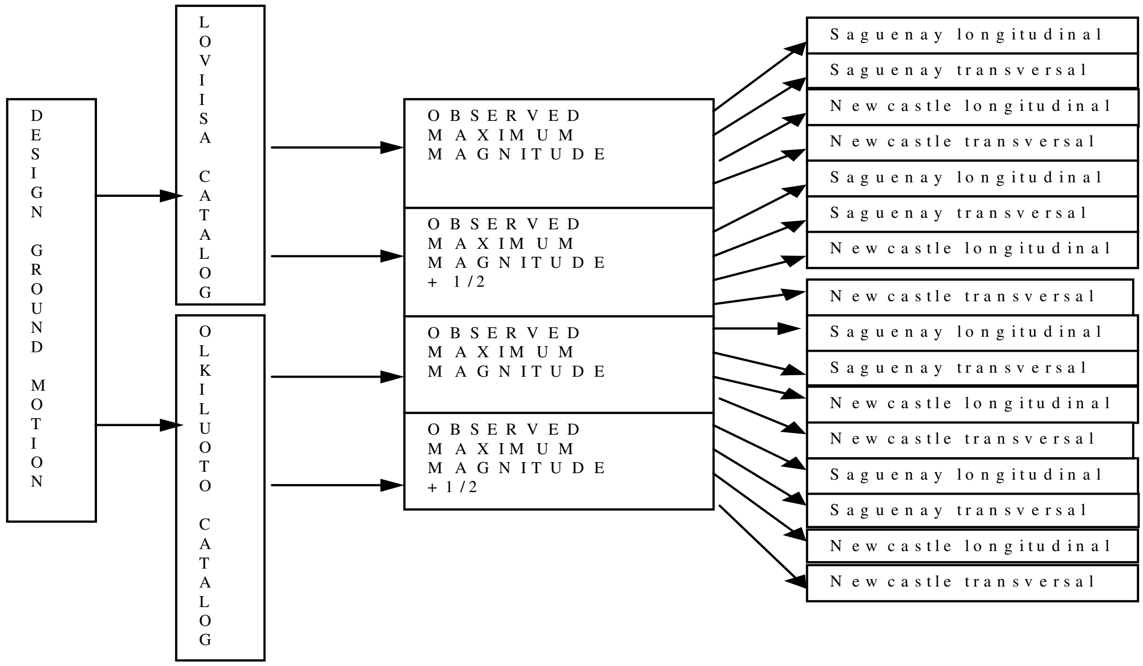

Figure 5. Logic three structure for treating uncertainties in probabilistic seismic hazard analysis

and seismological conditions: precambrian solid rock, moderate seismicity about the same level to be expected in Fennoscandia, intraplate conditions.

DECISION TREE FOR THE TREATMENT OF UNCERTAINTIES

The code basis for the ground motion estimation in probabilistic seismic hazard studies stipulates the median spectra for mean return period of 100 000 years [Reg. Guide DG-1015, 1992]. The decision three used in the treatment of uncertainties in this study is presented in Figure 5:

Each branch end node in logic-tree of characterize the credible alternative inputs to probabilistic seismic hazard analysis and their likelihoods. The end node likelihood can be calculated by multiplying the branch likelihoods leading to end node. The sum of end node likelihoods as well as branch likelihoods at each level must be one.

RESULTS

By preparing the initial data according to the previous sections, the further analysis was carried out on Fortran Computer Program for Seismic Risk Analysis described in [Bender and Perkins, 1987]. The resulting unsmoothed spectra for Loviisa and Olkiluoto sites are given in Figure 6 and 7:

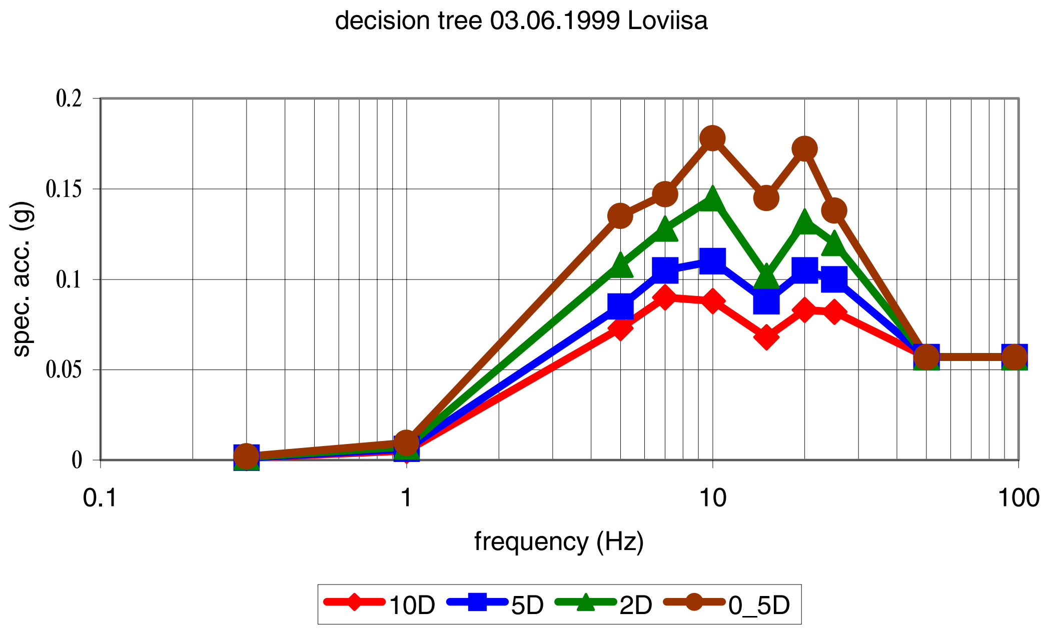

Figure 6. The resulting median ground response spectra for 100 000 years return period for Loviisa site

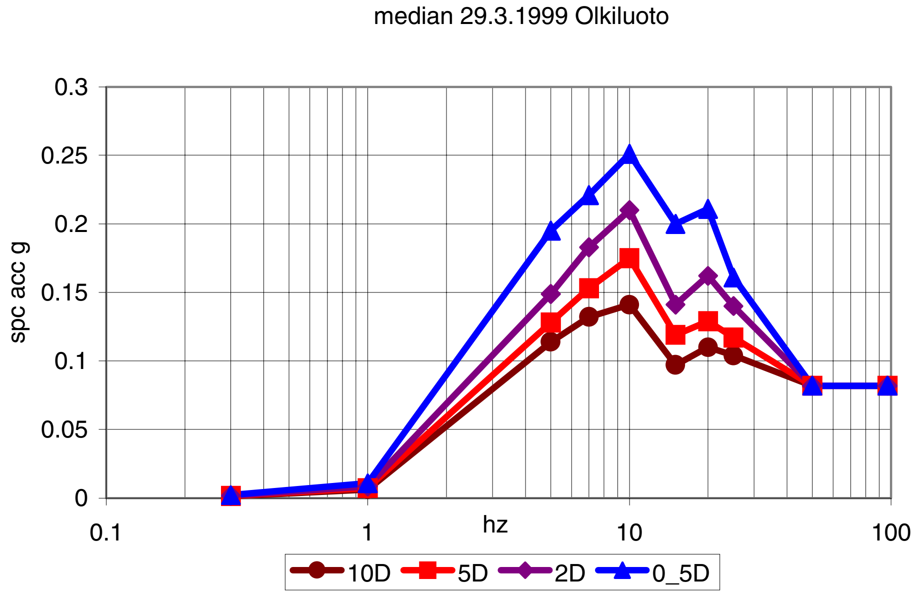

Figure 7. The resulting median ground response spectra for 100 000 years return period for Olkiluoto site

CONTOUR CURVES FOR SPECTRAL ACCELERATIONS IN SOUTHERN FINLAND

In addition to site spectra for Loviisa and Olkiluoto the contour maps for spectral accelerations with 5% damping in window 21-31 °E, 60-63 °N were generated. Five frequency values were used in map generation, namely, 1,5,10,20 and 97 Hz. The resulting map for median spectral acceleration contours for 100 000 return period at 1 Hz is given in Figure 8. The decision tree structure in contour generation was Olkiluoto catalog, observed maximum magnitude +0.5 units and Saguenay and Newcastle transversal and longitudinal attenuations for western half of the target window and Loviisa catalog, observed maximum magnitude +0.5 units and Saguenay and Newcastle transversal and longitudinal attenuations for eastern half of the window.

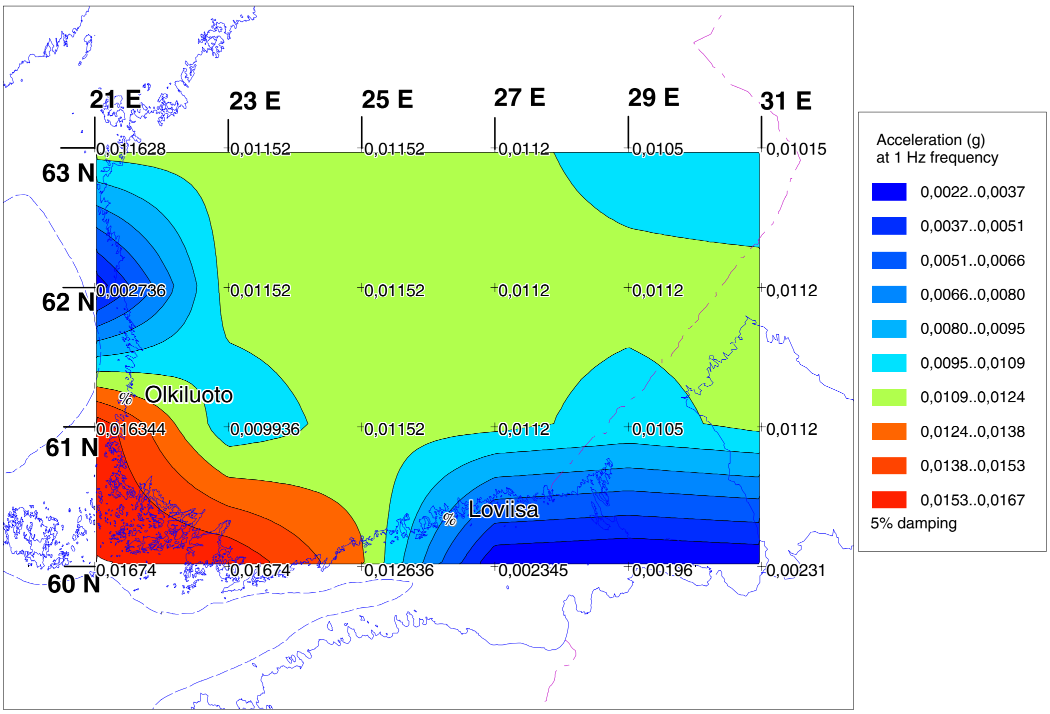

Figure 8. Spectral acceleration contours for 1Hz frequency.

REFERENCES

Ahjos, T., Saari, J., Penttilä, E. and Korhonen, H. 1984. Earthquakes and seismic hazard in Finland. Engineering Geology, 20:1-12.

Ahjos, T. And Uski, M. 1992. Earthquakes in northern Europe in 1375-1989. Tectonophysics, 207: 1-23.

Bender B. , Perkins David M. SEISRISK III: A Computer Program for Seismic Hazard Estimation, U. S. Geological Survey Bulletin 1772, United States Governement Printing Office; Washington: 1987.

Dahle A., Bungum H., Kvamme L. B., Attenuation Models inferred from Intraplate Earthquake Recordings, Earthquake Engineering and Structural Dynamics, vol 19, 1125-1141(1990).

Draft Regulatory Guide DG-1015, Identification and Characterization of Seismic sources, Deterministic Source Earthquakes, and Ground Motion, U.S. Nuclear Regulatory Commission Office of NuclearRegulatory Research, November 1992.