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SEISMIC DESIGN CHARACTERISTICS OF THE NEW BUILDING FOR DIGITAL AUTOMATION EQUIPMENT FOR LOVIISA NUCLEAR POWER PLANT

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SUMMARY

The paper studies the design methods and specific characteristics structural solutions for the new building for digital automation equipment for Loviisa nuclear power plant. The excitation in the free field is defined by the acceleration response spectrum described in the YVL Guide 2.6. The spectral shape to be used to define this motion corresponds to a median (50 percentile) spectrum developed for hard rock sited. For the Loviisa plant upgrade buildings, the horizontal peak ground acceleration will be assumed equal to 0.1g. The vertical spectrum will be assumed equal to 2/3 of the horizontal spectrum. In order to form the analysis model used in the seismic response calculation of the new building for digital automation equipment the finite element model for turbine building and for the old electrical building has been merged to form the joint global model for all interconnected buildings. The floor response spectra for the floor elevations of the joint model are developed. The spatial location of the response spectra generation in the plane of the floors was the shear center of the respective floor slab. The spectra were generated in three directions for x-, y-, and z-directions and for the damping ratios of 0.5%, 2%, 5%, 7% and 15.The aim of this study is to show how seismic response analysis results were taken into account in selecting the most suitable structural solutions for the new building in very restrained location in order to keep the vibration response acceptable for electrical equipment and cabinets.

INTRODUCTION

This report describes the seismic structural analysis of for buildings in Loviisa NPP to be build in connection with the upgrading project of the plant automation. In this task the floor response spectra of the buildings are computed and the walls and columns of the first storey in one the buildings. The new buildings are located in the space between reactor and control building in the plant site. The input data for the analyses are the 3D – models for the buildings and the 3-component simulated ground motion corresponding to Finnish seismic YVL 2.6 – Guide "Seismic events at nuclear power plants" published by Finnish Centre for Radiation Protection (STUK) and valid since 19.12.2001. The constructions to be considered in this paper belong to the seismic safety class S1 according to reference [1]. The overall volumes of the four buildings to be analyzed are described iin Table 1:

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Building	Length, m	Width, m	Height, m	Height of pedestal structures, m
Lo 111	34,15	8,00	20,15	5,85
Lo 112	32,70	8,00	20,15	9,95
Lo211	31,15	8,00	20,15	9,95
Lo212	21,50	12,40	20,15	3,55

Table 1 Measures of the buildings to be analyzed

INPUT GROUND MOTION

Three independent acceleration time histories were developed to match the horizontal and vertical target response spectra. The characteristics of these time histories are as follows: Total duration = 15 seconds. Time step = 0.005 seconds. Figures 1 tand 2 show the traces of the x-component of three artificial time histories and the fit between the target spectrum according to YVL 2.6 –Guide and the spectrum of simulated motion [1]. The definition of the design specrum according to YVL 2.6 is given in Table 2:

Frequency, Hz	0,3	1,0	5,0	10,0	25,0	50,0	100,0
Acceleration, g	0,005	0,020	0,170	0,230	0,190	0,100	0,100

Table 2 Definition table of the design spectrum according to YVL 2.6

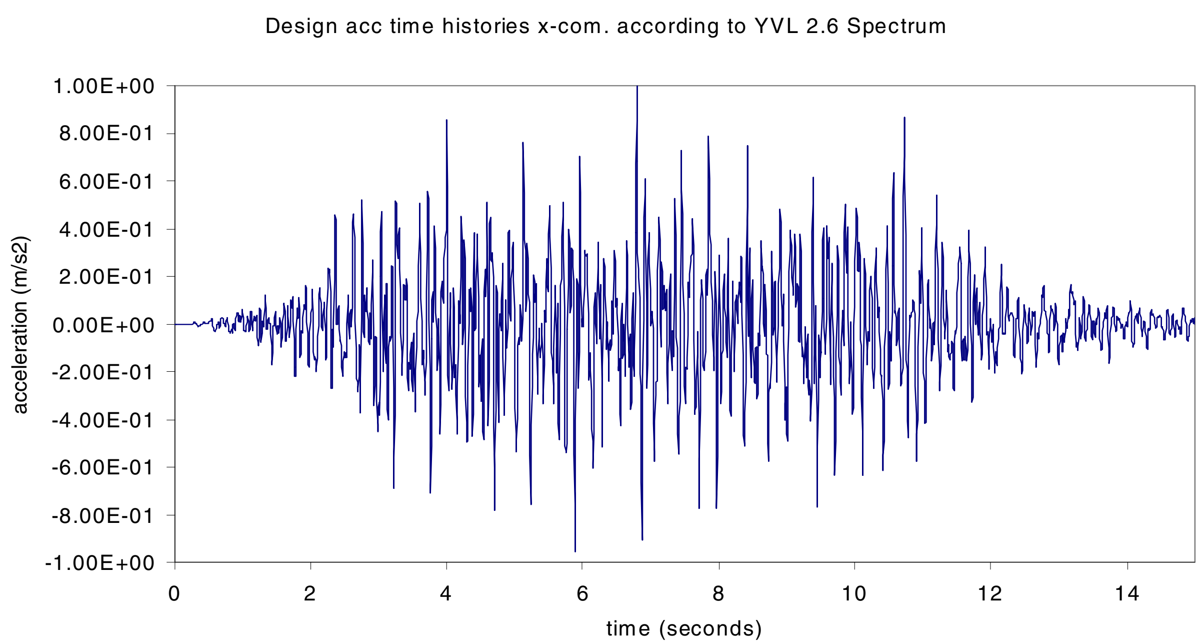

Figure 1 The x- component of simulated acceleration time history according to YVL 2.6.

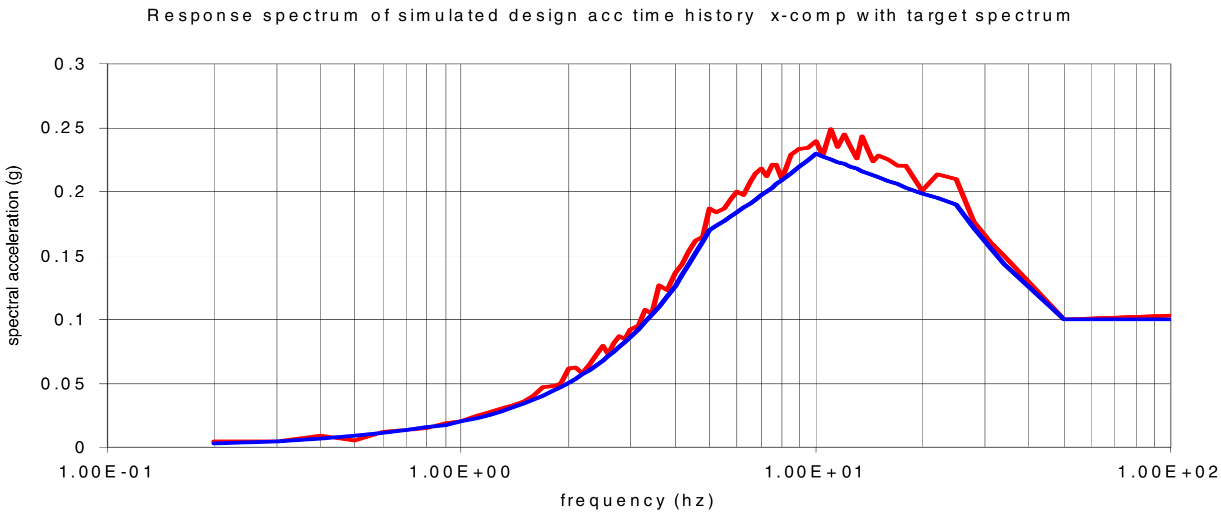

Figure 2 Response spectrum of simulated design acc time history x-comp with target spectrum

The simulation of the ground motion was carried out by response spectra fitting modifying the power spectral density function of the notion according to the fit results. The modulation function used in simulation was the function of time only so that resulting motion does not exhibit any evolutionary properties.

DESCRIPTION OF THE STRUCTURE

The buildings to be analyzed are denoted by the notations Lo1/1, Lo1/2, Lo2/1 and Lo2/2. The first number in notation meaning the unit of the plant and the second number the the number of the automation cabinet building per unit. The first three buildings all almost identical in overall dimensions but the fourth building is broader and shorter than the other buildings. In all buildings the floor area is approximately 250 sqaure meters. All buildings to be analyzed house electric and electronic cabinets and cable floor underneath the cabinet floors. The buildings contain also spaces for battery racks and ventilation equipment. All bearing structures are cast in-situ reinforced concrete structures.The structural concrete is of strength K30-2 and the reinforcing steel of the strength A500HW according to the Finnish concrete code [2]. All buildings are founded on solid rock foundation. The finite element model of the building Lo1/2 is depicted in Figure 3. The height locations of the elevations where the floor spectra are calculated as well as the thickness of the elevations and the general description of the purpose of the space located on this floor is described in Table 3:

Top of the elev., m	Thickness of plate, mm	The description of the purpose of space
+23.10	300	Roof elevation
+19.80	300	Cable space, roof
+16.80	300	Ventilation equipment, cables
+13.80	300	Floor of electronic cabinets
+11.70	300	Cable floor
+8.70	300	Elektroniikkakaappikerros
-46.60	300	Cable floor
+2.95	450 ,.. 850	Elevation of grade, bottom slab
-+0.15 ... -2.90	175 ... 200	Bottom slab of cable tunnels
-7.00	800	The bottom slab of cooling water tunnels

Table 3 The general description of the buildings and spaces

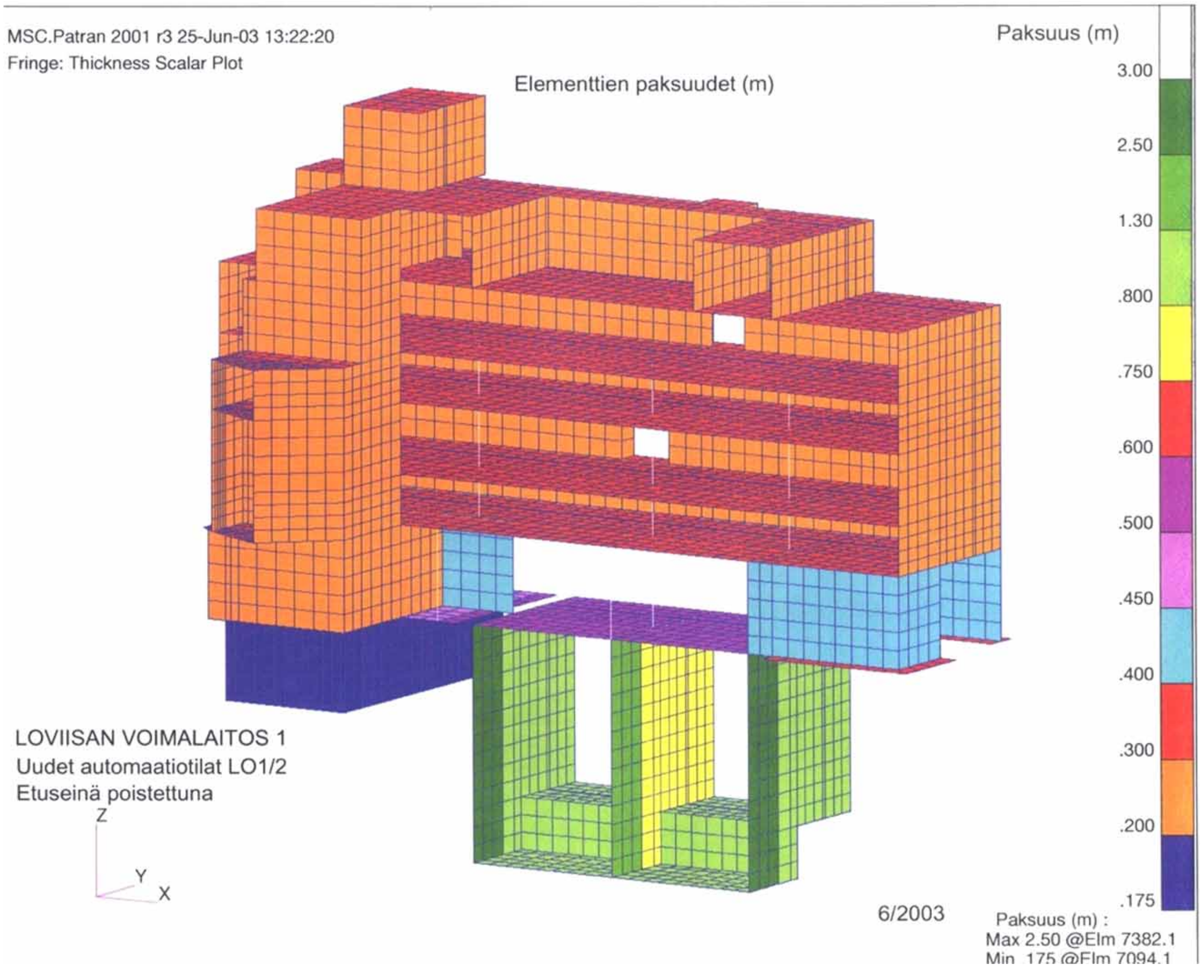

Figure 3 The 3D – structural model of building Lo1/2

MATERIAL PROPERTIES

The material properties of the construction materials used in analyses are collected in Table 1:

Name of the material	Density, kg/m^3	Young's modulus, MN/m^2	Poisson's ratio	Coeff. of thermal expansion, 1/ºK
Concrete K30	2400	27400	0,20	1,010"'
Reinforcing steel A500HW	7850	200000	0,30	1,0-l0'
Foundation rock, Pyterlite	2653	66200	0,21	-

Table 4 Material property parameters used in structural modeling

THE ANALYSING MODELS

The analyzing models of the automation buildings have been developed with the aid MSC.PATRAN 2001 (r3) modeling program [3]. The analyzing for the models was MSC.NASTRAN 2001 [4]. Each building was modeled for the analysis. The model comprises of all reinforced concrete structures. The walls and slabs has been modeled woth the aid of shell elements and the columns and stiffening beams with the aid of beam elements. The element models have been developed along the middle surfaces and center lines of the structures. The color code in the plots of the models depicts the thickness of slabs and walls.
The boundary conditions in the modles have been described with the aid of spring and damping elements depicting the properties of foundation soil. The parameters of springs and dampers have been computed using the building dimensions and soil properties utilizing the method described in reference [5]. The spring and damper parameters are described in Table 5:

Building	Lo 1/1	Lol /2	Lo 2/1	Lo 2/2
Spring constant X, kN/m	$1,11*10^9$	$9,73^*10^8$	$1,14*10^9$	$8,05^*10^8$
Spring constant Y, kN/m	$1,22^*10^9$	$1,11*10^9$	$1,30*10^9$	$1,01^*10^9$
Spring constant Z, kN/m	$1,4*10^9$	$1,22*10^9$	$1,40*10^9$	$1,13*10^9$
Spring constant XX, kNm/rad	$2,62*10^{10}$	$2,39^*10^{10}$	$2,96*10^{10}$	$3,24*10^{10}$
Spring constant YY, kNm/rad	$1,22*10^{11}$	$1,45*10^{11}$	$2,37*10^{11}$	$6,73*10^{10}$
Spring constant ZZ, kNm/rad	$1,10*10^{11}$	$1,35^*10^{11}$	$2,14^*10^{11}$	$7,34*10^{10}$
Damping constant X, kNs/m	$1,95^*10^6$	$1,44*10^6$	$1,88*10^6$	$1,33*10^6$
Damping constant Y, kNs/m	$2,14^*10^6$	$1,65*10^6$	$2,14^*10^6$	$1,66^*10^6$
Damping constant Z, kNs/m	$3,72*10^6$	$2,67*10^6$	$3,41^*10^6$	$2,76^*10^6$

Table 5 Spring and damping constants depicting the foundation soil

FLOOR RESPONSE SPECTRA

The input motion is applied to the element models of the buildings as enforced acceleration time history having three perpendicular components X, Y, Z. All analyses are linear.
The mode superposition method is used for calculating the structural responses. All modes, which have frequencies below 100 Hz are included in superposition. The damping ratio for reinforced concrete structures in taken to be 5% according to reference [5]. The same fraction from critical damping is applied to all modes. The duration of the computed response histories is 20 seconds. The time step in analyses is 0.0025 seconds. The duration of load acceleration time histories depictin the earthquake is 15 seconds.
The frequencies of the modes included in response analysis of building Lo 1/2 are depicted in Table 6. The locations of points where the structural response is computed for building Lo1/2 are given in Figure 4. An example of the floor response spectra plot has been given in Figure 5. The maximum spectral accelerations in response points for building Lo 1/2 are given in Table 7. The total number of nodes, whose frequency is below 100 Hz is 443 in the model of the building Lo 1/2.

No. of mode	Frequency, Hz	Descrition of mode
1, 2, 3	0,00	Rigid body motions in X-, Y- and Z-directions
4	4,73	Rocking mode of the building in YZ-plane
5	8,27	Rotation of the building around Z-axis
6	9,22	Rocking mode of the building in XZ-plane
7	12,93	Bending mode of the building in YZ-plane
8	14,02	Vertical mode of the building
9	15,49	Vertical mode of the building
10	16,58	The bending mode of the slab +16.80
11	17,09	The bending mode of the slabs_+6.60 and_ +16.80
12	17,53	The bending mode of the building in XY-plane
13	18,06	The bending of connection channel to reactor building
14	18,36	The bending mode of the slab +13.8
15	19,18	The bending mode of the slabs +8.70 and_+13.80
16	19,31	The bending mode of the slabs +8.70 and + 11.70
17	19,85	The bending mode of the slab +16.80
18	20,10	The bending mode of the slab+16.80
19 ... 443	20,58 ... 99,86	Higher modes

Table 6 Modes extracted from the model of building LO 1/2 for mode superposition analysis

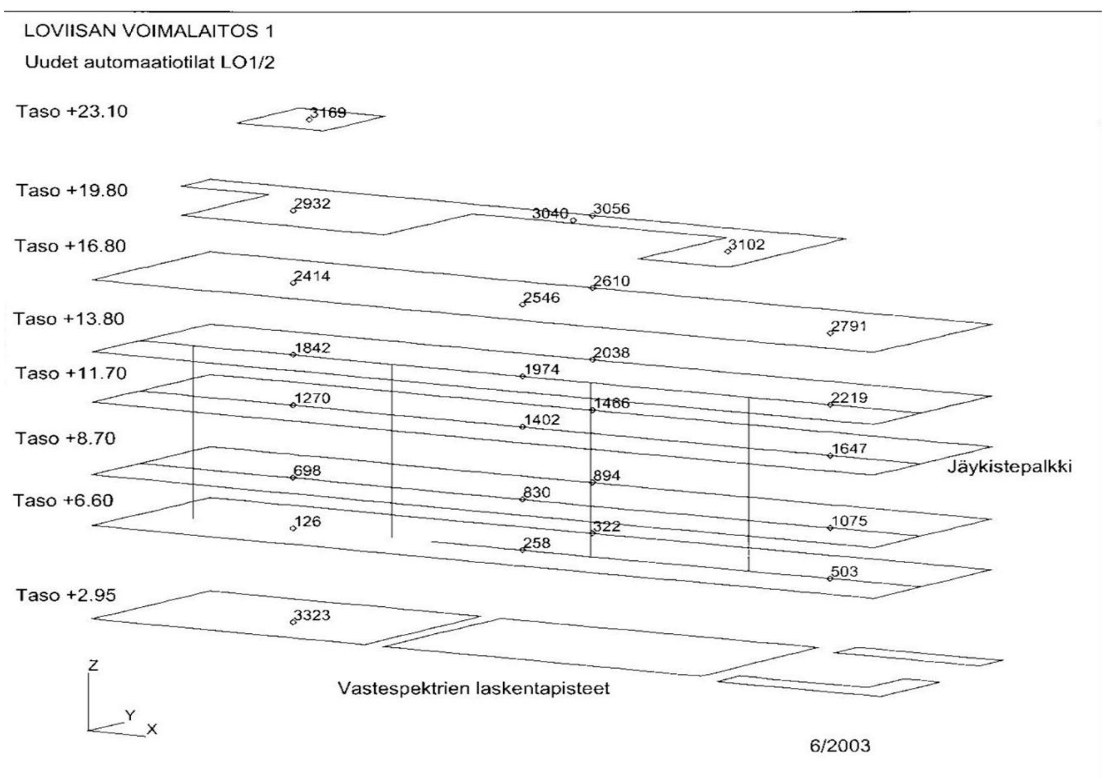

Figure 4 The location of response points for building Lo 1/2

Elev.	Point	X-direction		Y-direction		Z-direction	
		Kiihtyvyys, m/s^2	Taajuus, Hz	Kiihtyvyys, m/s^2	Taajuus, Hz	Kiihtyvyys, m/s^2	Taajuus,Hz
+2.95	3323	4,21	9,20	4,06	11,50	3,05	11,50
+6.60	258	16,24	9,20	10,95	13,00	14,82	23,00
	322	16,12	9,20	10,87	13,00	11,68	14,00
	126	13,63	9,20	7,69	13,00	3,34	9,60
	503	14,09	9,20	8,55	13,00	9,96	23,00
	830	19,07	9,20	14,73	13,00	13,48	16,50
+8.70	894	17,22	9,20	14,66	13,00	11,75	14,00
	698	19,21	9,20	11,13	13,00	12,14	20,25
	1075	18,02	9,20	10,88	13,00	13,77	17,25
	1402	23,03	9,20	15,67	4,80	16,26	16,50
+11.70	1466	22,03	9,20	15,63	4,80	12,70	14,00
	1270	23,36	9,20	14,17	4,80	16,63	20,25
	1647	22,60	9,20	13,99	4,80	16,01	17,25
	1974	25,31	9,20	19,78	4,80	23,15	16,50
+13.80	2038	23,42	9,20	19,74	4,80	12,73	14,00
	1842	25,91	9,20	17,90	4,80	21,39	18,75
	2219	25,11	9,20	17,11	4,80	18,72	17,25
	2546	28,25	9,20	26,37	4,80	43,27	14,00
+16.80	2610	26,36	9,20	26,31	4,80	13,05	14,00
	2414	29,30	9,20	23,49	4,80	11,79	14,00
	2791	27,95	9,20	21,90	4,80	28,37	21,00
	3040	29,01	9,20	28,54	4,80	22,11	14,00
+19.84	3056	28,11	9,20	28,51	4,80	13,27	14,00
	2932	32,92	9,20	25,55	4,80	12,59	14,00
	3102	30,09	9,20	25,45	4,80	13,96	25,00
+23.10	3169	48,26	1 9,20	26,32	4,80	13,42	14,00

Table 7 The peak spectral acceleration values for automation building Lo 1/2 for 2% damping ratio.

The selection of response points in spectra calculation for each elevation has been carried out according to following principles:

- The X- and Y- coordinate location of the center of gravity for whole building
- The X- coordinate location of center of gravity for whole building and at bottom of the slab and wall joint
- The Y- coordinate location of center of gravity for whole building and at the center of left end span of the slab
- The Y- coordinate location of center of gravity for whole building and at the center of right end span of the slab

The floor spectra in all plots have been calculate for damping ratios of 0.5%, 2%, 5%, 7% and 10%.

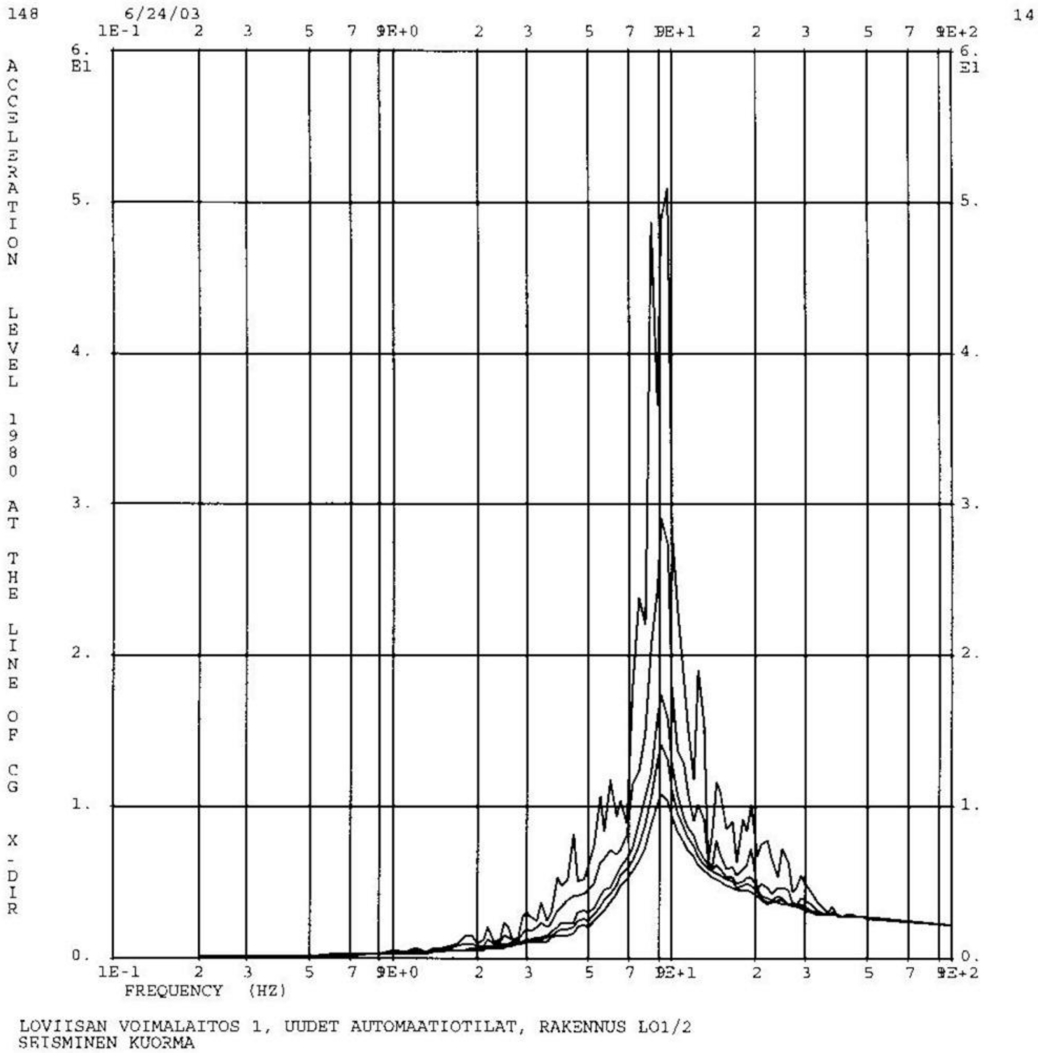

Figure 5   The floor response spectra at elevation +19.80 in X-direction for automation building Lo 1/2

THE PROPORTIONING OF THE FIRST STOREY VERTICAL STRUCTURS FOR THE BUILDING LO 1/1

The proportioning of lowest storey vertical structures for the anounts of reinforcing bars in walls and columns has been carried out for automation building Lo 1/1. The reason for the selection of building Lo 1/1 was that none of analyzed four buildings did not be deviate from other buildings.
The building Lo 1/1 has been proportioned for following loading combinations:
1. Dead load

2. Earthquake load
3. Live load
4. Snow load
5. Wind load

The combination of different loads with earthquake load has been done follows. First the seismic response of the building is calculated in three monitoring points that are at slab and wall joint in the location X - coordinate of center of gravity for whole building and at the elevations +6.60, +13.80 and +19.80. From the displacement time histories at these points 30 time points have been chosen, which give maximum values of displacements and storey drifts. After the selection on time points stress resultant analysis the dynamic analysis is repeated and all stress resultants for whole model are computed at selected time points. At the end the reinforcing bar amounts are calculated on the basis of static load cases and 30 seismic load cases. The following load combinations are proportioned in ultimate and serviceability limit state according to Finnish code for reinforced concrete, reference [2]. The used partial safety factors are given in Table 8. The obtained amounts for reinforcement are given in Figure 6.

1. 1.2 * KTl
2. 1.0*KT1+1.0*KT2
3. 1.2*KT1+1.6*KT3
4. 1.2 * KT I + 1.6 * KT3 + 1.6 * KT4
5. 0.9*KT1 + 1.6*KT5

Table 8 The partial safety factor used in the proportioning of structures

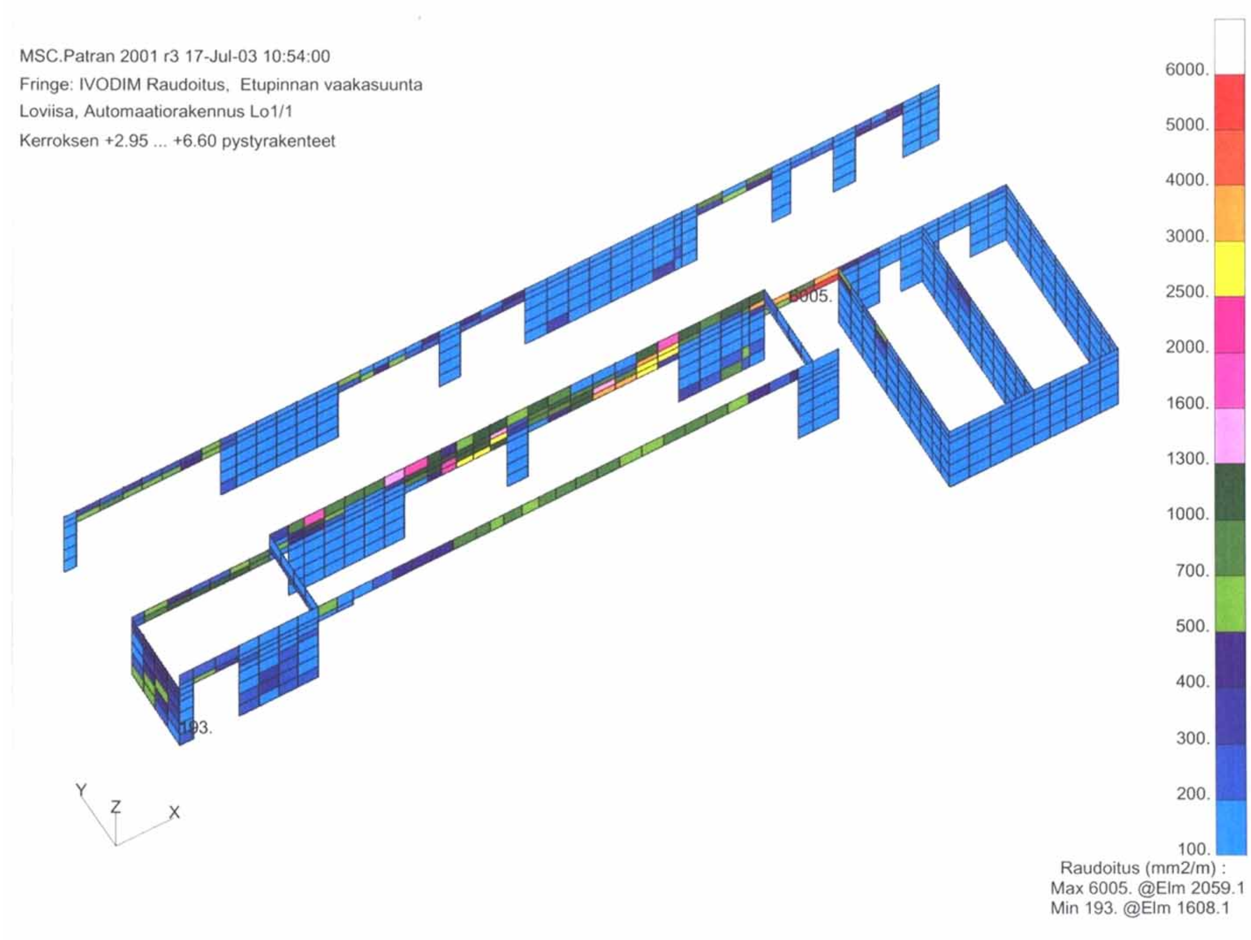

Figure 6 The horizontal reinforcement in front surfaces for storey +2.95 … +6.60 in (mm^2/m)

CONCLUSION

In this study the floor response spectra for 4 new buildings to be constructed in connection of automation upgrade of Loviisa plant units 1 and 2. The spectra has been calculated according to the Finnish seismic code for nuclear power plants YVL 2.6 valid since 19.12.2001. This code is new and these buildings are the first application of the code. A sample proportioning of the reinforcemet amounts for the vertical structures of the lowermost storey of building Lo 1/1 has also been carried out.

REFERENCES

1. Guide YVL 2.6, "Seismic events at nuclear power plants", Finnish Centre for Radiation Protection (STUK), Helsinki, December 2001.
2. "The code for concrete structures", B4, The Finnish Rules for Constructions, Ministry of Environment of Finland, 1998.
3. MSC.Patran, Version 2001. Release Guide, MSC.Software Corporation, Los Angeles, 2001.
4 . MSC.Nastran, Version 2001. Release Guide, MSC.Software Corporation, Los Angeles, 2001.
5 . ASCE STANDARD 4-86. Seismic Analysis of Safety-Related Nuclear Structures and Commentary on Standard for Seismic Analysis of Safety Related Nuclear Structures. American Society of Civil Engineers, New York, September 1986.