Kraftindustrins betongdag 15.3.2023
Nyligen genomförda seismiska analyser i Loviisa NPP Finland

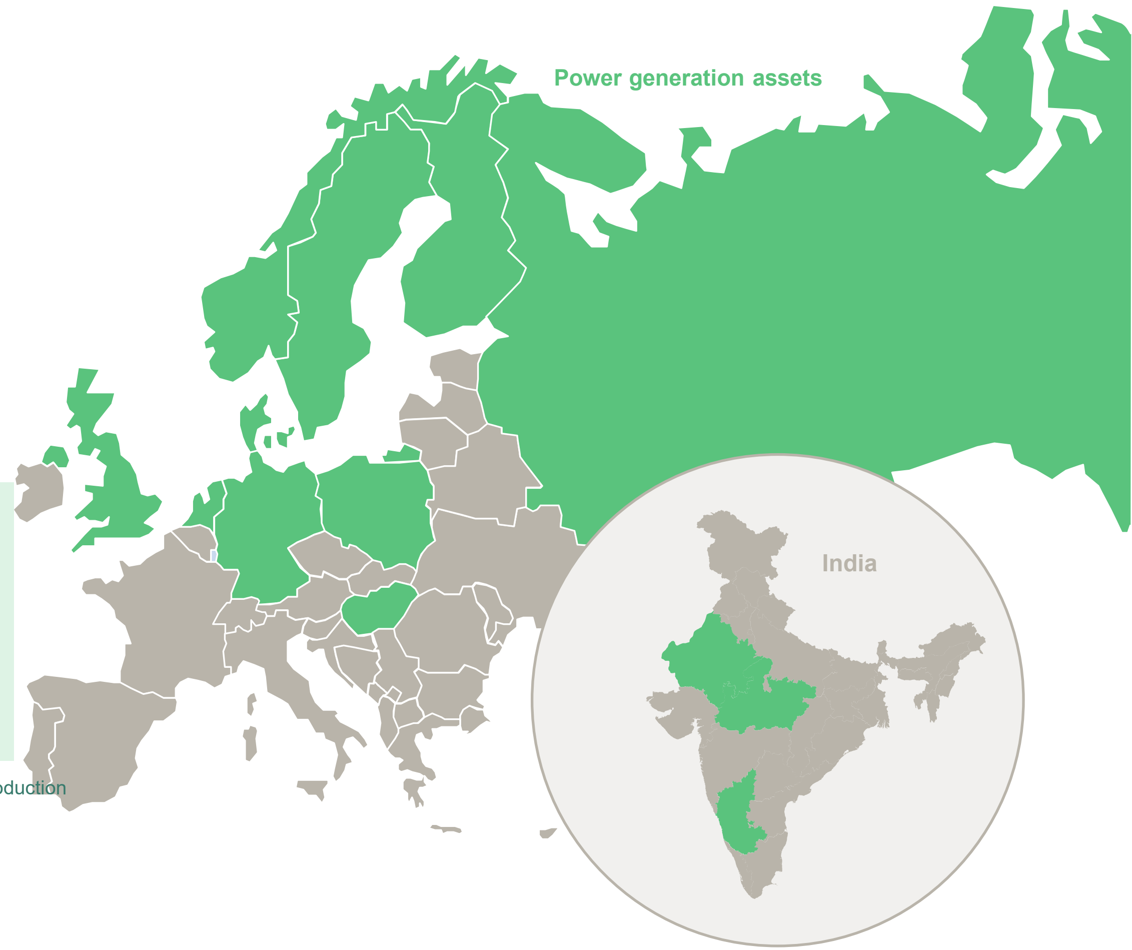
Timo Leppänen / Fortum Finland

Fortum in brief

Key figures 2021		
Sales	EUR	~112 bn
Comparable EBITDA	EUR	3.8 bn
Total assets	EUR	~150 bn
Personnel		19,140

Main businesses	Sales (€)	Volume[1]	Capacity
Power	34.3 bn	188 TWh	47.1 GW
Gas	60.0 bn	370 TWh	7.4 bcm
Heat	1.2 bn	33 TWh	16.9 GW

1) For Power - Power generation, for Gas - Long-term gas supply contracts and for Heat – Heat production



The figures will change after divestment of Uniper.

Fortum’s nuclear fleet




	LOVIISA	OLKILUOTO	OSKARSHAMN	FORSMARK
Commercial operation started	Unit 1: 1977 Unit 2: 1981	Unit 1: 1978 Unit 2: 1980 Unit 3: (Under construction)	Unit 1: 1972* Unit 2: 1974* Unit 3: 1985	Unit 1: 1980 Unit 2: 1981 Unit 3: 1985
Generation Capacity	Unit 1: 507 MW Unit 2: 507 MW **Total: 1,014 MW**	Unit 1: 890 MW Unit 2: 890 MW (Unit 3: 1,600 MW) **Total: 1,780 MW (3,380 MW)**	Unit 1: 473 MW* Unit 2: 638 MW* Unit 3: 1,400 MW **Total: 1,400 MW**	Unit 1: 984 MW Unit 2: 1,116 MW Unit 3: 1,159 MW **Total: 3,259 MW**
Fortum’s share	100% 1,014 MW	27% 473 MW	43% 602 MW	22% 724 MW
Yearly production Fortum’s share of production	8 TWh 8 TWh	14 TWh 4 TWh	11 TWh 5 TWh	25 TWh 6 TWh
Share of Fortum’s Nordic production	19%	9%	11%	13%
Majority owner Fortum’s share	Fortum	Pohjolan Voima 26.6%	Uniper 43.4%	Vattenfall 22.2%
Operated by	Fortum	Teollisuuden Voima (TVO)	OKG Aktiebolag	Forsmarks Kraftgrupp

*Out of operation; on decommissioning phase

RESPONSIBILITIES

Loviisa: Fortum is the owner, licensee and operator with all the responsibilities specified in the Nuclear Energy Act, Nuclear Liability Act, and other relevant nuclear legislation

Other units: Fortum is solely an owner with none of the responsibilities assigned to the licensee in the nuclear legislation. Other responsibilities are specified in the Companies Act and the Articles of Association and are mostly financial.

49

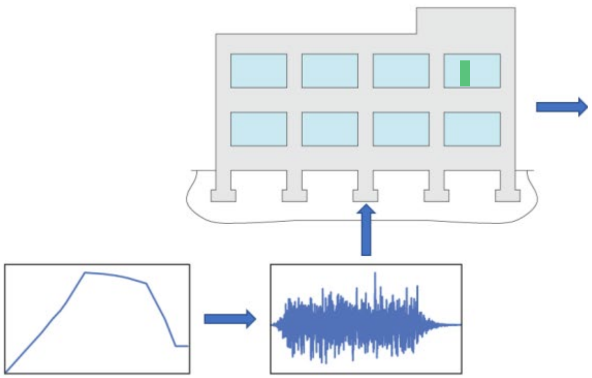
Loviisa Nuclear Power Plant

- 2 × VVER-440 pressurized water reactors of Russian origin. Electricity output 507 MW / Unit.
- Loviisa 1 commercial use started 1977 (License till 2027). Loviisa 2 1980 (License till 2030). 16.2.2023 Fortum was granted a new operation license until 2050 for both units.
- No seismic design for buildings/equipment during original design at 1970s. Seismic study has been of interest in new license application.
- Seismic project started 2015 and is still ongoing: 1) Seismic hazard evaluation, 2) Floor response spectra calculation, 3) Building strength analyses 4) Seismic walkdown and equipment qualification, [5) Seismic PRA]

fortum

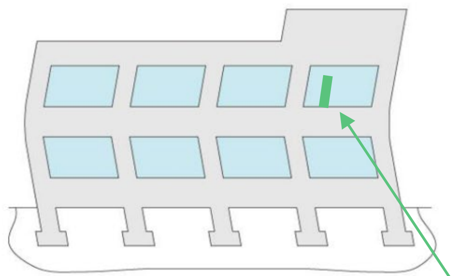
Seismic Analysis of NPP equipment, Floor response spectrum

In Loviisa there are appr. 2000 equipment per unit that need to remain functional during design basis earthquake: Primary loop, tanks, pumps, motors, electricity cabinets, valves, pipes etc.



Ground Response spectra = Design Basis Earthquake

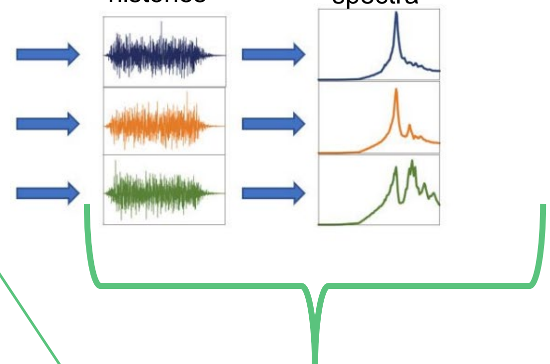
Artificial time history corresponding to response spectra exerted to building.



Dynamic analysis of building: Natural frequencies and response e.g. using modal superposition method

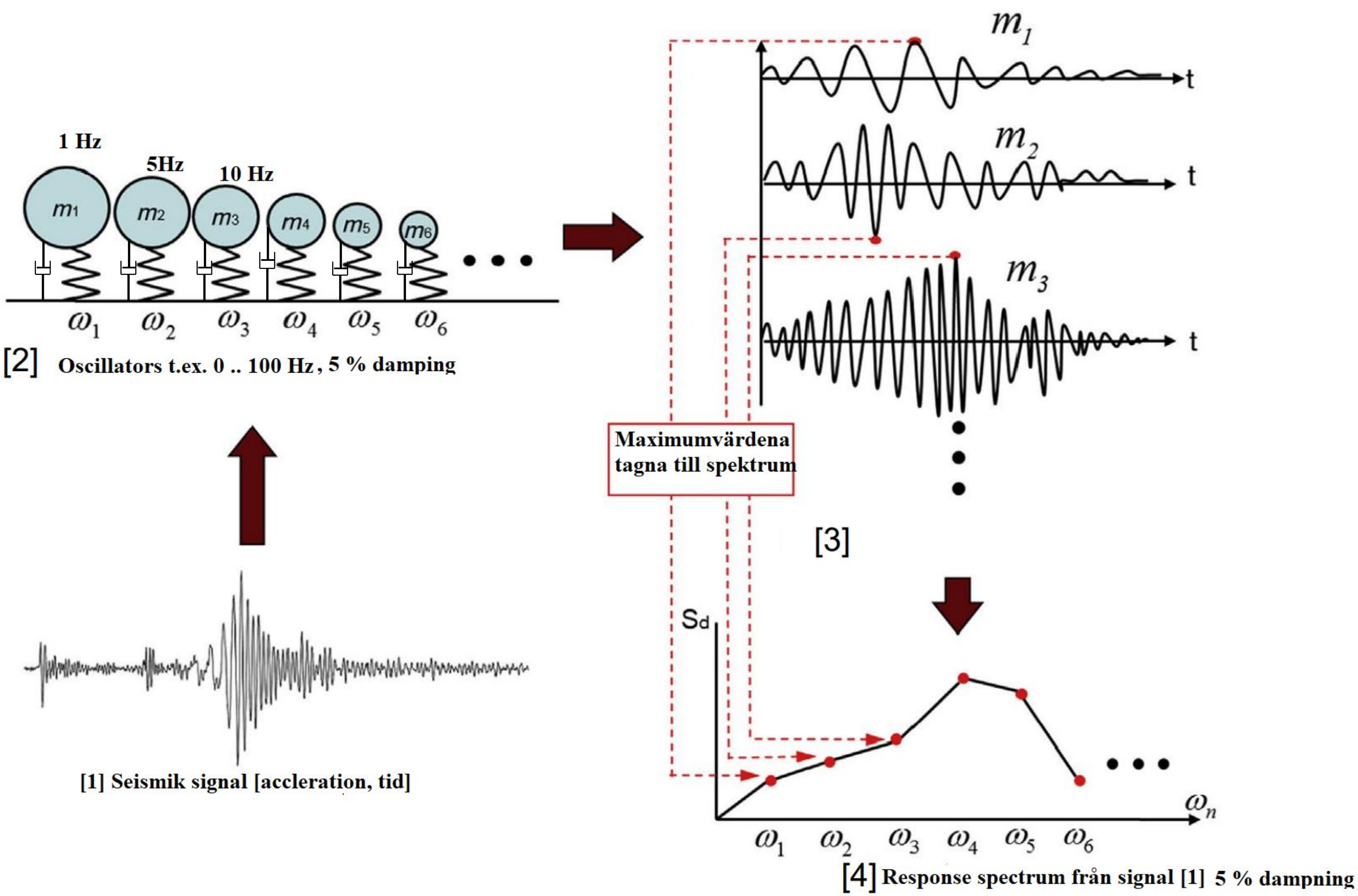
Floor time histories

Floor Response spectra



Floor response spectrum is load for:
- Design of equipment anchorage
- Dynamic analysis of equipment
- Shake table tests

Response spectrum



Ground Motion Design Response Spectrum

EN 1998

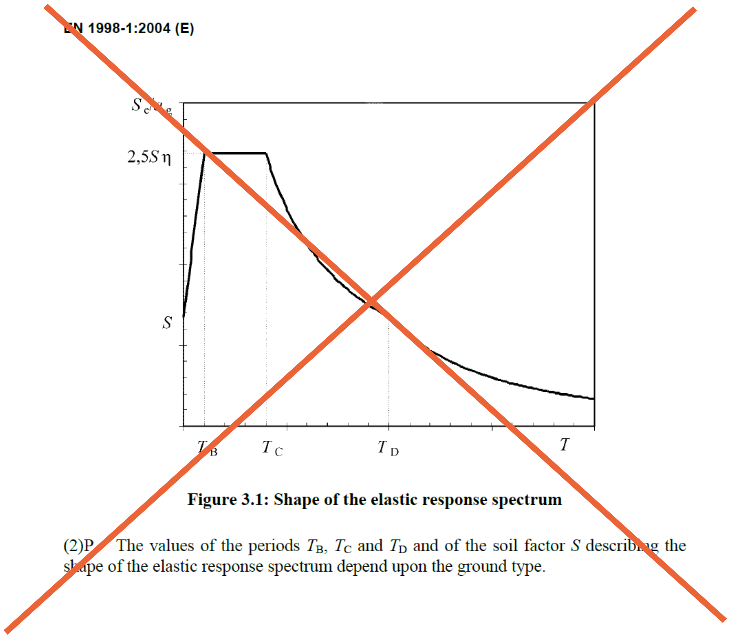

EN 1998-1:2004 (E)

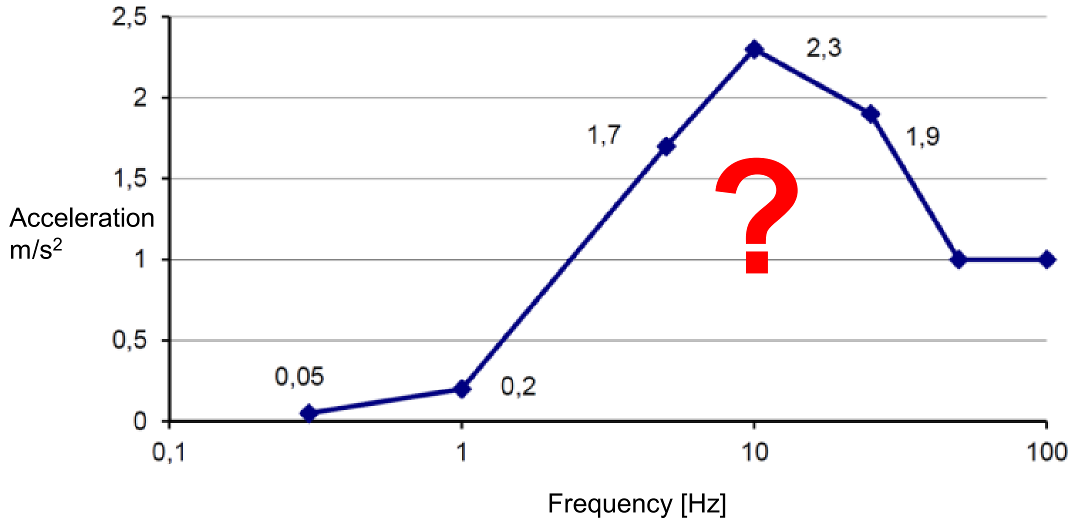
Figure 3.1: Shape of the elastic response spectrum

(2)P The values of the periods T_B, T_C and T_D and of the soil factor S describing the shape of the elastic response spectrum depend upon the ground type.

Return period T = 1/475 years

Not applicable for NPP

Finnish nuclear regulations (YVL 2.6)
Horizontal ground motion design response spectra for NPP design



Return period T = 1/100 000 years

Peak ground acceleration 0.1g (IAEA minimum)

50 % confidence level

5 % damping

fortum

1) PSHA (=Probabilistic Seismic Hazard Analysis)

Probabilistic Seismic Hazard Analysis (PSHA)

1. Seismic Source Area (SSA) definition.
2. Maximum magnitude distribution.
3. Seismic catalogue and definition of earthquake recurrence parameters for each SSAs.
4. Select ground motion prediction equations.
5. Seismic Source Characterization (SSC) logic tree.
6. Hazard calculation and presentation of different hazard products.
7. Software e.g. HAZ45 or OpenQuake.

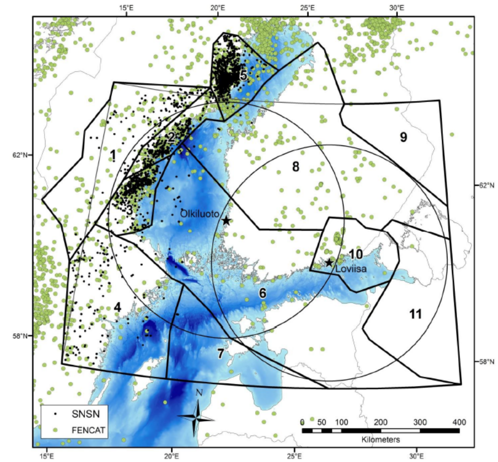
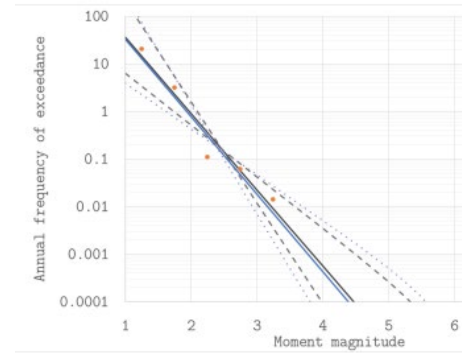
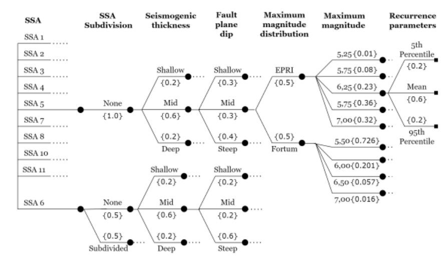
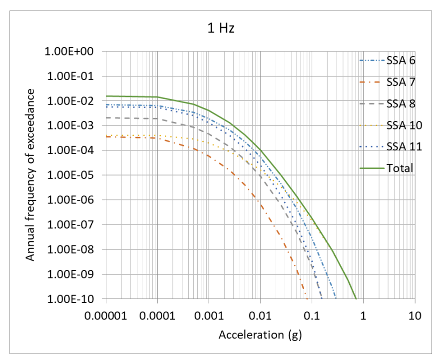
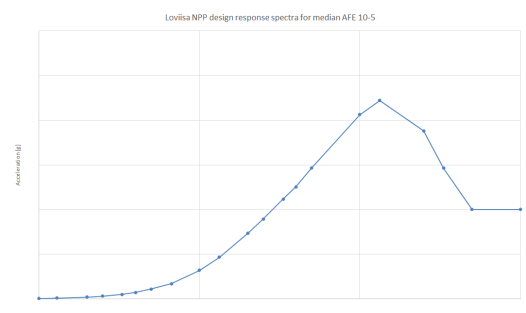


Figure 6.2.1 *Earthquake epicenters (based on Figs. 2.6.2.1–2.6.2.3) and the seismic source area model (SSA). Each SSA model polygon is labeled with a number. The study area is shown with an arcuate area and submodels around Loviisa and Olkiluoto power plant sites are marked with black star and a 300 km radius circle.*









2) Floor response spectra calculation

fortum

Building modelling, CAD

Loviisa buildings modelled by Microstation CAD as solid structures. Models include reinforced concrete and steel structures in all details.

- LO1 Reactor Building
- LO1&LO2 Turbine and control building
- LO1&LO2 Automation buildings
- LO1 Roofed tank area
- LO1 Emergency feedwater pumping station
- LO1 Auxiliary building
- LO1 Laboratory building
- LO2 Seawater pumping station
- LO2 Spent nuclear fuel storage building
- LO1&LO2 Emergency diesel generator building

The most time-consuming part of the LO seismic analysis

- Drawing retrieval from archive
- Modeling from drawings
- Laser scanning

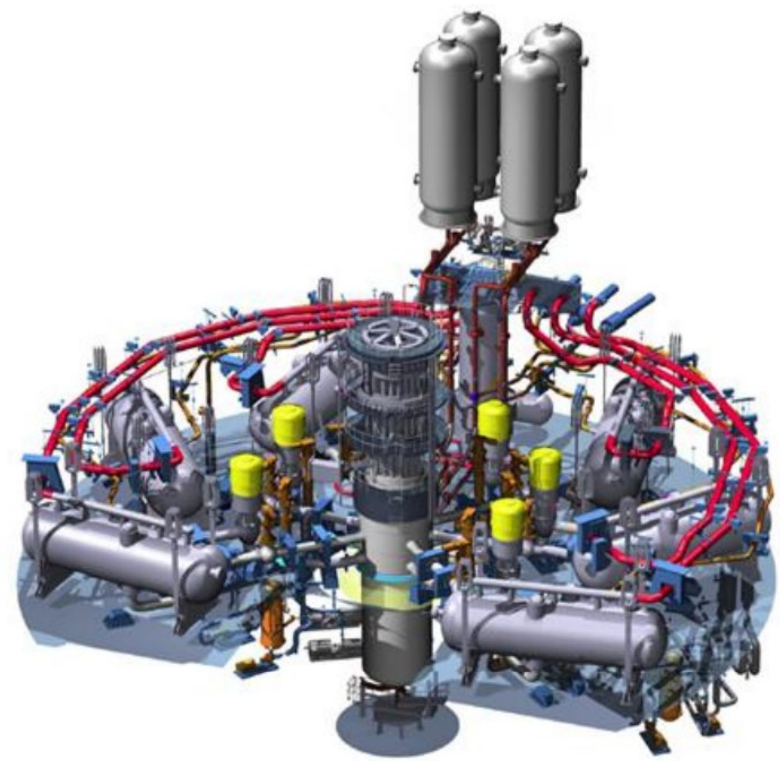
Equipment location and weight

In dynamic analysis significant equipment mass needs to be realistically described in calculation model.

The location and mass of the equipment in analyzed buildings assessed:

- Visual assessment, measurements at site. All buildings and rooms checked.
- 360° videos of buildings and their rooms.
- Archive, equipment drawings.

Loading plans of the buildings generated. Not done before.

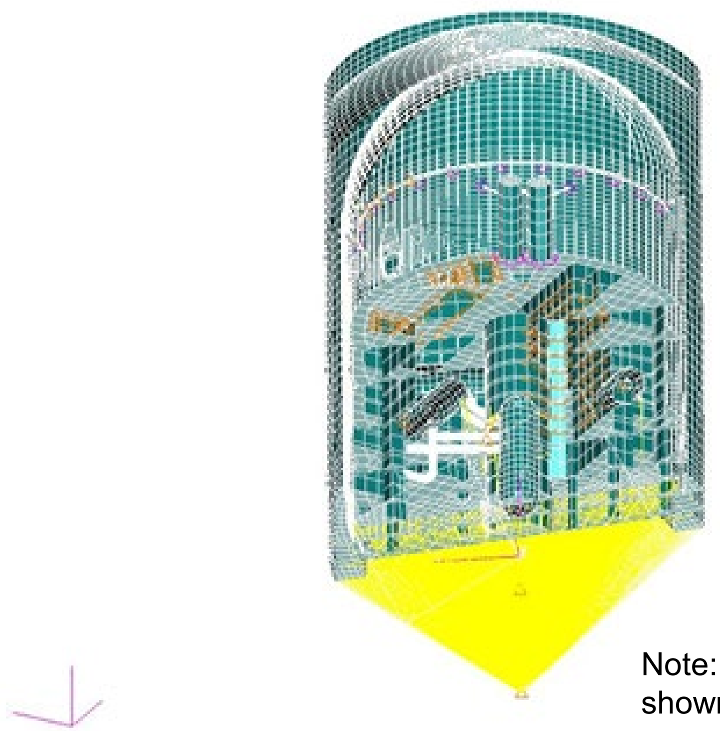


Loviisa primary loop

fortum

Floor response spectra FEM analysis, Abaqus

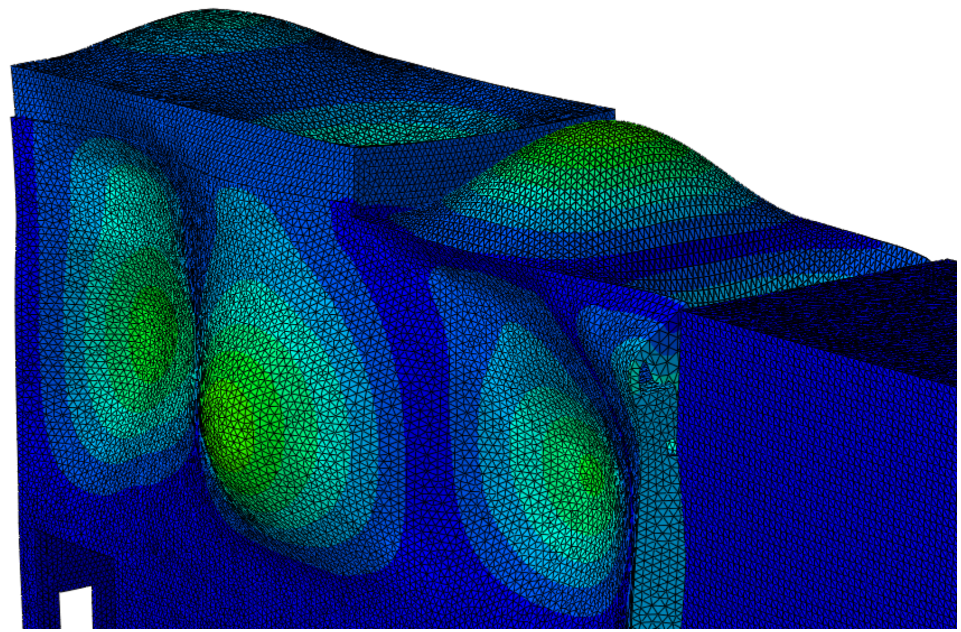
- Microsoft CAD *.sat file of the building imported to Abaqus
- Detailed CAD model cleaned for FEM analysis. Some details and e.g. openings smaller that 1 m x 1 m removed.
- Model meshing by 10-node quadratic tetrahedral elements
- Primary loop and some large tanks modelled by shell elements in reactor building
- Most equipment modelled as mass points & surface mass
- Second stage concrete mass considered
- Snow and live load mass portions as per recommendations in ASCE 4-16 (ASCE = American Society of Civil Engineers)



Note: VVER 1000 analysis model shown here as an example

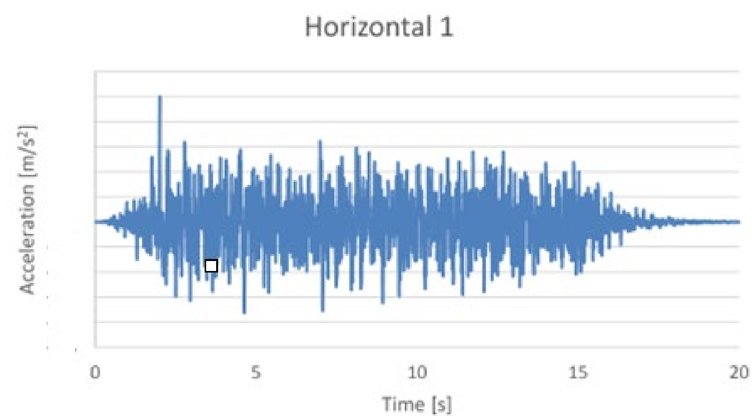
Floor response spectra FEM analysis, Abaqus

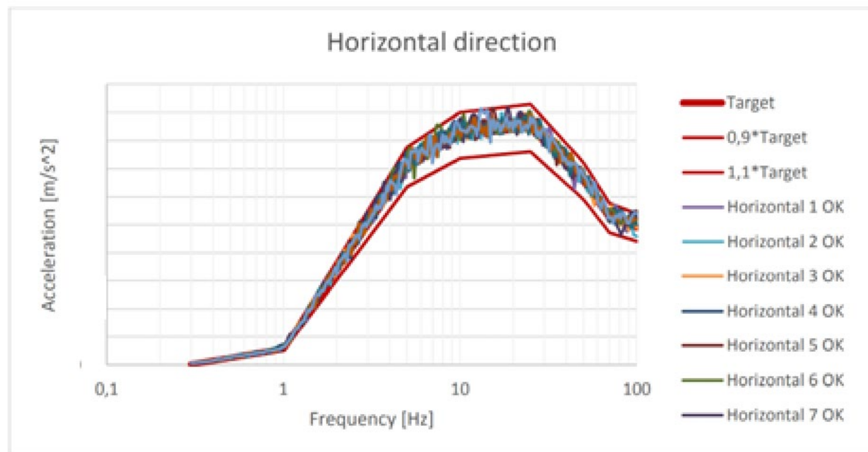
- Natural frequencies within range 0 Hz – 100 Hz solved
- Appr. 90 % of system effective mass hoped to be included in these natural modes.



Seismic excitations corresponding to Loviisa DBE

- 15 artificial time histories generated from DBE ground response spectrum. (Several softwares, SIMQKE)
- 5 x-direction, 5 y-direction ja 5 z-direction
- Time history duration 20 s
- 15 excitations to be statistically independent and to match the target spectrum by +-10 %
- Guides ASCE 4-16, KTA, NUREG

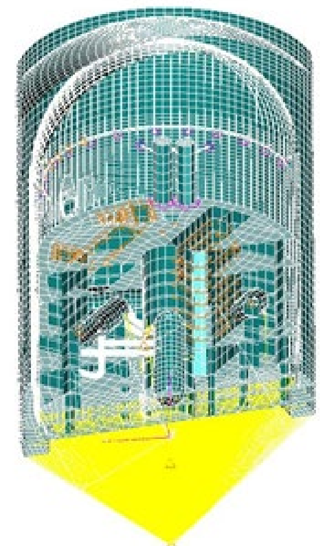


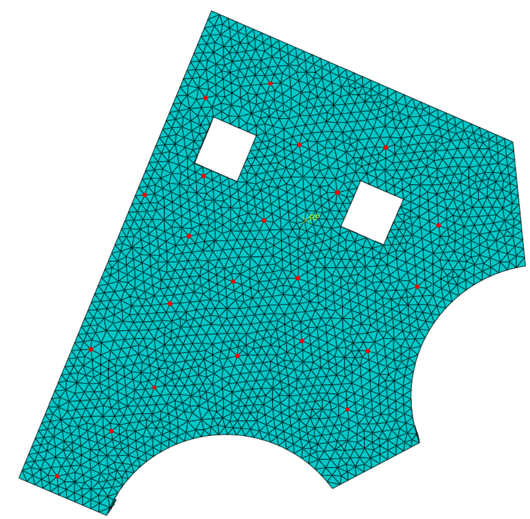


fortum

Floor response spectra FEM analysis

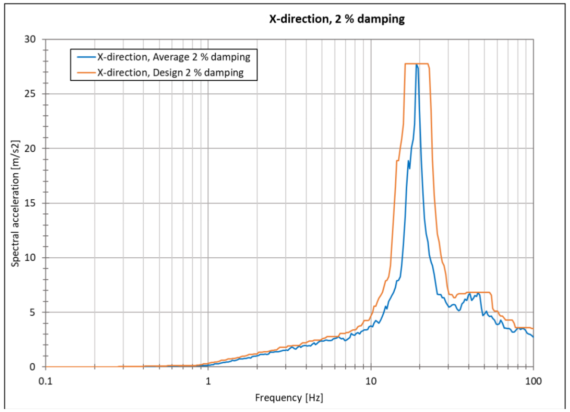
- Soil described by springs. See ASCE 4-16.
- Fixed base analysis allowed for hard rock sites. Loviisa rock shear wave velocity appr. 3000 m/s
- Earthquake excitation in time domain exerted in X,Y,Z directions in ”Bigmass” i.e. point mass locating at the end of springs.
- ”Bigmass” appr 10^6 times building mass. Translational degrees of freedom released but rotations fixed in Bigmass point.
- Building response to seismic excitation in time-domain solved by mode superposition method.
- 15 excitations given in time domain, timestep 2 ms.
- Damping 4 % for concrete structures
- Response output points for building slabs, walls or sometimes for a single S1 equipment

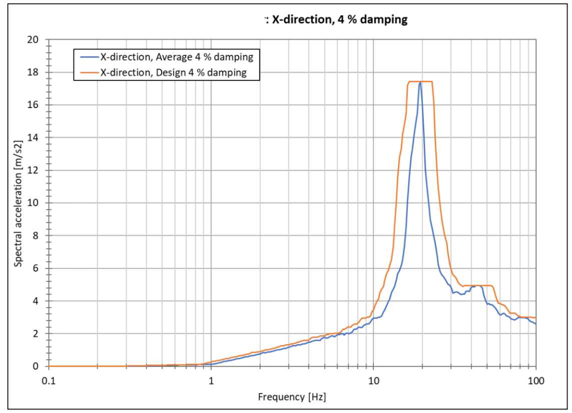


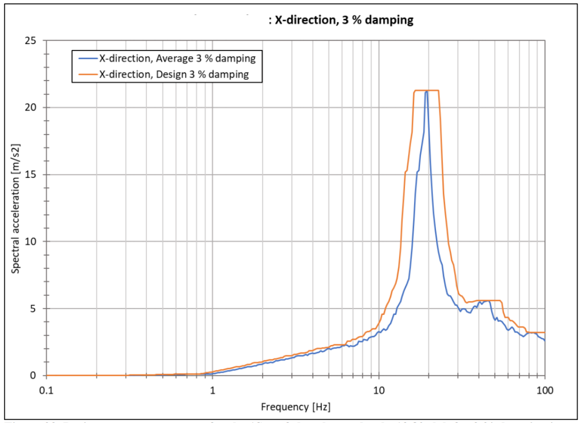


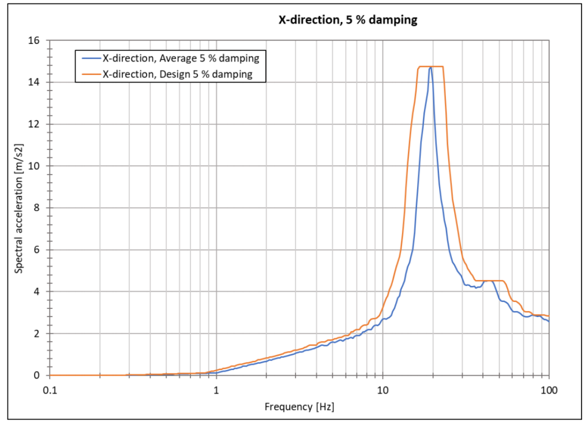
Floor response spectrum

- Floor response means here envelope response of all output points included in the slab / wall.
- Average of 5 time history excitations per direction taken
- Peak broadening 15 % as per ASCE 4-16
- No 15 % peak reduction adopted as suggested by ASCE 4-16
- Spectra for 2 %, 3 %, 4 %, 5 % and 7 % damping. (Optionally for 10 % and 15 %)









fortum

Floor response spectra, Observations

Notes

- E-modulus taken acc. EN1992 based just on concrete strength class. Peak broadening to consider variation.
- Cross-sections cracking. Sometimes envelopes from two analysis of 1) uncracked and 2) cracked (50 % stiffness reduction) seen in industry practice.
- Incoherence of seismic waves. See ASCE 4-98 or ASCE 41-77 for coefficients to reduce ground response spectrum. Reduces high frequency response of floor response spectrum.

ASCE 4-98

3.3.1.10 Wave Incoherence
The assumption of vertically propagating plane shear and compressional waves when performing SSI analysis is usually conservative in terms of predicting in-structure responses. In the absence of analyses to

TABLE 3.3-2. Reductions to Ground Response Spectra

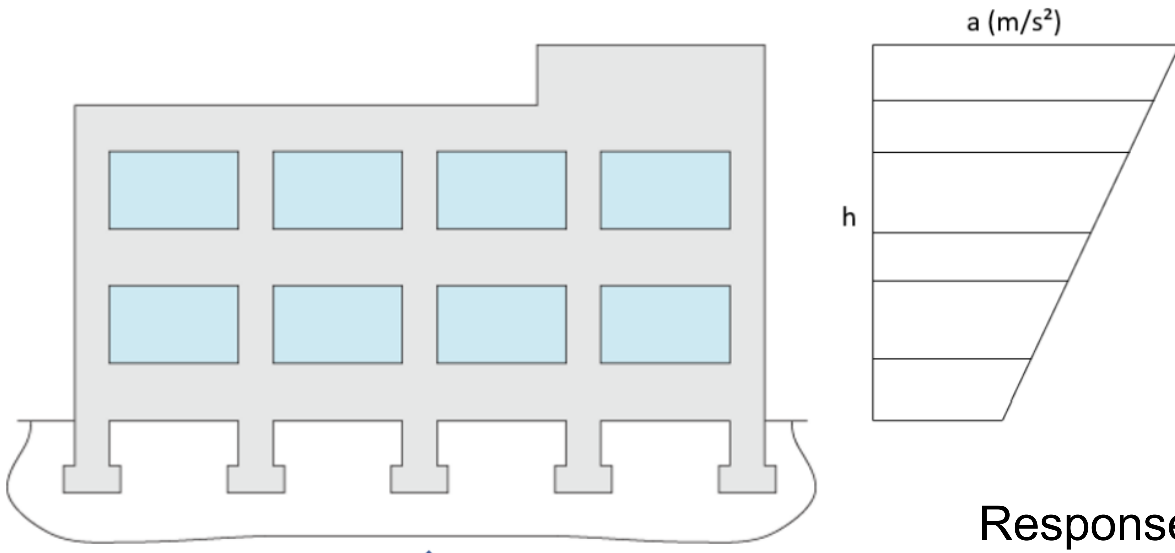
Frequency (Hz)	Reduction Factor for Plan Dimension of 150 ft	300 ft
5	1.0	1.0
10	0.9	0.8
≥25	0.8	0.6

ASCE 41-77

8.5.1.1 Base Slab Averaging. The RRS factor for base slab averaging, RRS_{bsa}, shall be determined using Eq. (8-15) for each period of interest. RRS_{bsa} shall not be taken as less than the value computed when $T = 0.2$ s. Where base slab averaging is used with the LSP or LDP, in addition to a model with a flexible base condition, the effective period used to compute RRS_{bsa} shall be assumed to be 1.5 times that obtained from the flexible base model.

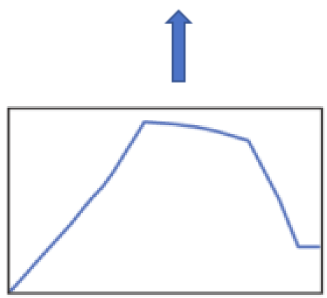
3) Building strength analysis

Seismic Analysis of NPP buildings



Acceleration profile in all spatial direction. (x,y,x)

F = m*a



Design Ground Response spectrum

- Inelastic effects of the structure considered by the behavioral factor, q =1.5. See EN 1998-1, Chapter 3.2.2.5
- Reinforcement A500HW

Response spectrum analysis

- Number of natural modes: Participating mass ≈ 90 % of system (building, equipment, water) mass in all directions
- Mode combination acc. CQC method

Building strength analysis

- Buildings analyzed acc. EN1990, EN1991, EN1992 and EN1998. Note 100-30-30 rule.
- Member cracking considered by modifying the elastic modulus of reinforced concrete as follows:
- Coefficients taken from ASCE 4-16:

$$E_{cr} = \gamma_E \, E_{cm}$$

$$G_{cr} = \gamma_G \, G_{cm}$$

Table 3-1 Factors for cracked modulus

Type of Member	γ_E	γ_G
Perimeter Walls, Partition Walls	0,7	1,0
Columns	0,7	1,0
Slabs and Beams	0,5	1,0
Pool Walls	1,0	1,0

1 $1.0G + 0.3Q_{LO} + 0.2Q_{SN} + A_{Ed,x} + 0.3A_{Edy} + 0.3A_{Ed,z}$

2 $1.0G + 0.3Q_{LO} + 0.2Q_{SN} + A_{Ed,x} - 0.3A_{Edy} - 0.3A_{Ed,z}$

3 $1.0G + 0.3Q_{LO} + 0.2Q_{SN} + A_{Ed,x} - 0.3A_{Edy} + 0.3A_{Ed,z}$

4 $1.0G + 0.3Q_{LO} + 0.2Q_{SN} + A_{Ed,x} + 0.3A_{Edy} - 0.3A_{Ed,z}$

5 $1.0G + 0.3Q_{LO} + 0.2Q_{SN} - A_{Ed,x} + 0.3A_{Edy} + 0.3A_{Ed,z}$

6 $1.0G + 0.3Q_{LO} + 0.2Q_{SN} - A_{Ed,x} - 0.3A_{Edy} - 0.3A_{Ed,z}$

7 $1.0G + 0.3Q_{LO} + 0.2Q_{SN} - A_{Ed,x} - 0.3A_{Edy} + 0.3A_{Ed,z}$

8 $1.0G + 0.3Q_{LO} + 0.2Q_{SN} - A_{Ed,x} + 0.3A_{Edy} - 0.3A_{Ed,z}$

9 $1.0G + 0.3Q_{LO} + 0.2Q_{SN} + 0.3A_{Ed,x} + A_{Edy} + 0.3A_{Ed,z}$

10 $1.0G + 0.3Q_{LO} + 0.2Q_{SN} + 0.3A_{Ed,x} - A_{Edy} - 0.3A_{Ed,z}$

11 $1.0G + 0.3Q_{LO} + 0.2Q_{SN} + 0.3A_{Ed,x} - A_{Edy} + 0.3A_{Ed,z}$

12 $1.0G + 0.3Q_{LO} + 0.2Q_{SN} + 0.3A_{Ed,x} + A_{Edy} - 0.3A_{Ed,z}$

.
.
.
.
.

fortum

Building strength analysis

In-situ casted reinforced concrete NPP buildings capable to carry (M5.0) earthquake acc. EPRI

Buildings made of prefabricated reinforced concrete elements (?)

fortum


Thank you
Follow us:
www.fortum.com
Twitter.com/fortum
Linkedin.com/company/fortum
Join the change
fortum