Regulations in Finland for seismic design of nuclear facilities

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Internal and external events in Acts and Regulations in Finland

Seismic design criteria for Hanhikivi 1

- Design Basis and DEC C Earthquake
- Vibration analyses and design criteria according to ASCE

Other sources of vibration for reference: airplane crash

Summary and conclusions

Internal and external events in Acts and Regulations

- Nuclear Energy Act 1987/990
  - External site-specific conditions mentioned generally (Art 19.) Construction license can be granted *if the location of the nuclear facility is appropriate with respect to the safety of the planned operations*

- STUK Regulation on the Safety of Nuclear Power Plants (Y/1/2018)
  - Replaced the previous Government Decree 717/2013 on 1.1.2016 and was updated in 2018
  - Section 14 Protection against external events affecting the safety
  - These are general requirements that external hazards shall be taken into consideration in design

YVL Guides referring to internal and external hazards

- YVL B.1 *Safety Design of an NPP*
  - *general design principles and defense in depth principles*
  - *separation principles*
- **YVL B.7** *Provisions for internal and external hazards at a nuclear facility*
- YVL B.8 *Fire protection at a nuclear facility*
- YVL A.7 *Probabilistic risk assessment and risk management of a nuclear power plant*
  - requires PRA for internal and external hazards
  - preliminary PRA in connection with construction license application
- YVL A.11 Security of a nuclear facility
  - airplane collision
  - explosion pressure waves etc.

Guides available at: https://www.stuk.fi/web/en/regulations/stuk-s-regulatory-guides/regulatory-guides-on-nuclear-safety-yvl-

Contents of YVL B.7

GUIDE YVL B.7

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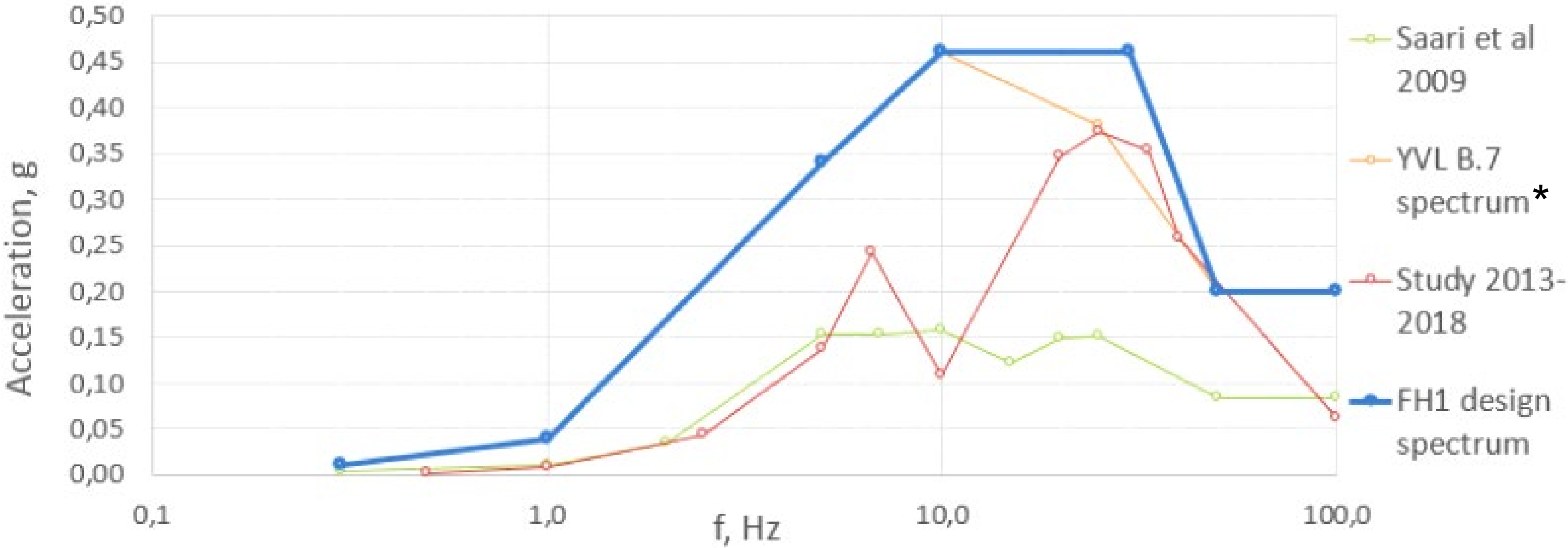
Design basis earthquake and DEC C

- Peak ground acceleration (PGA) and shape of ground response spectrum
- Frequency of exceedance at most $1 \cdot 10^{-5}$/year (Design basis earthquake)
- Site specific values proposed by the license applicant, reviewed by STUK and its consultants
- Design basis PGA shall be at least 0.1 g according to IAEA recommendation
  – at sites in Southern Finland the calculated design basis PGA is less than 0.1 g
- DEC C –analyses down to lower frequencies ($\sim 1 \cdot 10^{-7}$/year)
  – typically, 2 – 3 times design PGA
  – e.g., by seismic margin assessment
- Other sources of external vibrations
  – airplane crash, pressure waves
- The licensee submits to STUK for review and acceptance reports on seismic design basis and design principles

Seismic design criteria for Hanhikivi 1

- Approved in 2018 after lengthy studies
  - Design basis PGA = 0,2 g
  - DEC C PGA = 0,35 g



*An example of an approved site spectrum in the Explanatory memorandum of YVL B.7

ASCE/SEI 4/16, Seismic Analysis of Safety-Related Nuclear Structures

Chapter 2, Seismic input

- Design (or evaluation) Response Spectrum (DRS) at the free surface shall be computed as a mean 5 % damped
- Horizontal (H) and Vertical (V) DRS dependent on each other according to defined V/H ratio

Chapter 3, Modelling of structures, Response Levels:

- 1: Used nominal strength capacity of steel and concrete members < 50 %,
  no significant cracking in concrete
- 2: 50 % ≤ used capacity ≤ 100 %,
  significant cracking in concrete
- 3: limited permanent distortion < used capacity < large permanent distortion

Table 3-1. Viscous Damping Expressed as a Fraction of Critical Damping

Structure Type	Response Level 1	Response Level 2	Response Level 3
Welded aluminum structures	0.02	0.04	0.04
Welded and friction-bolted steel structures	0.02	0.04	0.07
Bearing-bolted steel structures	0.04	0.07	0.10
Prestressed concrete structures (without complete loss of prestress)	0.02	0.05	0.07
Reinforced concrete structures	0.04	0.07	0.10
Reinforced masonry shear walls	0.04	0.07	0.10

Design Basis Earthquake (Response Level 1)

DEC C Earthquake (Response Level 2)

ASCE/SEI 4/16, Seismic Analysis of Safety-Related Nuclear Structures

Chapter 6, Input for subsystem analysis

- Acknowledge that the degree of used capacity of structural framework can be different than vibration resistance design of subsystem
- Demand-to-capacity ratio D/C

Table 6-1. Estimating Subsystem Response Levels

Response Level	*D/C*
1	≤ 0.5
2	≈ 0.5 to 1.0
3	≥ 1.0

Commonly measured data show that criteria for cable trays are very conservative

Table 6-2. Damping Values for Subsystems

	Damping (% of critical)		
Type of Subsystem	Response Level 1	Response Level 2	Response Level 3
Piping	5	5	5
Distribution systems			
Cable trays 50% or more full and ZPA of support locations of 0.25*g* or greater	5	10	15
For other cable trays, those with rigid fireproofing and conduits	5	7	7
Massive, low-stressed mechanical components (pumps, compressors, fans, motors, etc.)	2	3	[a]
Light-welded instrument racks	2	3	[a]
Electrical cabinets and other equipment	3	4	5[b]
Liquid-containing metal tanks—impulsive mode	2	3	4
Liquid-containing reinforced concrete tanks—impulsive mode[c]	3	5	7
Sloshing mode (metal and concrete tanks)	0.5	0.5	0.5

[a] Should not be stressed to Response Level 3.
[b] 5% damping may be used for anchorage and structural failure modes that are accompanied by at least some inelastic response. Response Level 1 damping values shall be used for functional failure modes such as relay chatter or relative displacement issues that may occur at a low cabinet stress level.
[c] If an unlined tank is intended to function as a liquid retention barrier, then the tank should not be stressed beyond Response Level 1.

ASCE/SEI 43-05, Seismic Design Criteria for SSC in Nuclear Facilities

TABLE 1-4. Structural Deformation Limits for Limit State

Limit State	Structural Deformation Limit
A	Large permanent distortion, short of collapse *Significant damage*
B	Moderate permanent distortion *Generally repairable damage*
C	Limited permanent distortion *Minimal damage*
D	Essentially elastic behavior *No damage*

TABLE 3-4. Summary of Maximum Response Level for Damping

Elastic buckling conditions control design	Response Level 1
Generation of in-structure spectra	Response Level 1 (Response Level 2, if justified)
Limit State D	Response Level 2
Limit States A, B, or C:	
Elastic analysis	Response Level 3*
Inelastic time-history response analysis	Response Level 1 (Response Level 2, if justified)

Note:
* Only to be used with adequate ductile detailing. However, functionality of SSCs must be given due consideration. Response Level 3 corresponds to Limit State C; Response Level 3 may also be used for Limit States A and B.

YVL B.7, ref. 19. Recommendations for Revision of Seismic Damping Values in Regulatory Guide 1.61, NUREG/CR-6919, U.S. Nuclear Regulatory Commission, Washington, DC, 2006.

TABLE 3-2. Specified Damping Values for Dynamic Analysis

	Damping (% of Critical)		
Type of Component	Response Level 1	Response Level 2	Response Level 3
Welded and friction-bolted metal structures	2	4	7
Bearing-bolted metal structures	4	7	10
Prestressed concrete structures (without complete loss of prestress)	2	5	7
Reinforced concrete structures	4	7	10
Reinforced masonry shear walls	4	7	10
Piping	5	5	5
Distribution systems:			
• Cable trays 50% or more full and in-structure response spectrum Zero Period Acceleration of 0.25 g or greater	5	10	15
• For other cable trays, cable trays with rigid fireproofing and conduits	5	7	7
Massive, low-stressed mechanical components (pumps, compressors, fans, motors, etc.)	2	3	—*
Light welded instrument racks	2	3	—*
Electrical cabinets and other equipment	3	4	5**
Liquid containing metal tanks:			
• Impulsive mode	2	3	4
• Sloshing mode	0.5	0.5	0.5

Notes:
* Should not be stressed to Response Level 3. Use damping for Response Level 2.
** May be used for anchorage and structural failure modes that are accompanied by at least some inelastic response. Response Level 1 damping values shall be used for functional failure modes such as relay chatter or relative displacement issues that may occur at a low cabinet stress level.

Structural resistance and layout in the protection of a nuclear power plant and spent fuel storage against an airplane crash

- YVL A.11, Security of a nuclear facility. Appendices B and C
- IAEA Safety Report Series No. 87, Safety Aspects of Nuclear Power Plants in Human Induced External Events: Assessment of Structures. Vienna, 2018.

Events to be taken into account

Small APC

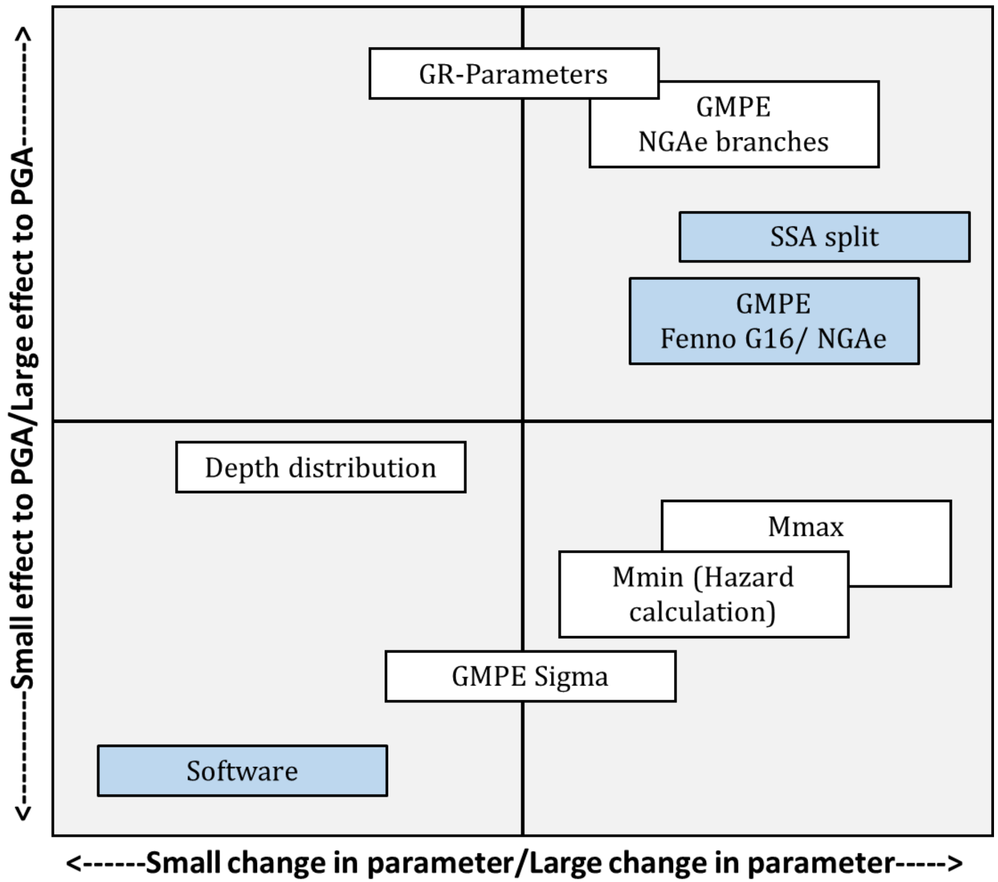
- Aviation accident
- Class 2 postulated accident
- Failure criteria for normal postulated accidents apply
- The equivalent highest allowable annual dose is 5 mSv

Large APC

- Intentional act
- Design Extension Condition
- No additional failures independent of the crash
- The highest equivalent allowable annual dose is 20 mSv

DBC 1, Normal operation
radiation dose limit 0,1 mSv / year for the entire site
DBC 2, Anticipated events
radiation dose limit 0,1 mSv
DBC 3, Class 1 postulated accidents
radiation dose limit 1 mSv
DBC 4, Class 2 postulated accidents **(DBE)**
radiation dose limit 5 mSv
DBC 5, Design extension conditions **(DEC)**
radiation dose limit 20 mSv
DBC 6, Severe accidents
release < 100 TBq Cs-137 equivalent
no acute health effects

Results from a recent Seismic sensitivity study



Parameters affecting seismic hazard:

- Gutenberg – Richter (GR) parameters
- Ground motion prediction equations (GMPE)
    - Differences between NGA-East branches
    - Between Fenno-G16 and NGA-East
    - Sigma*
- Seismic source area (SSA)
- Depth distribution of the hypocentre
- Maximum Mmax and Minimum Magnitudes Mmin
- Software OpenQuake/EZFrisk

Summary and Conclusions

- Legislation and regulations
- Site layout topics, internal and external hazards
- Seismic design criteria and practical design point of view of Hanhikivi 1
- Other vibration related external hazards
- Seismic hazard sensitivity study results

Thank you for your attention!