STUK

GUIDE **YVL 2.6** / 19 DECEMBER 2001

SEISMIC EVENTS AND NUCLEAR POWER PLANTS

This Guide remains in force as of 1 June 2002 until further notice. It replaces Guide YVL 2.6, issued on 19 December 1988.

Third, revised edition
Helsinki 2002
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ISBN 951-712-618-2 (print)
ISBN 951-712-619-0 (pdf)
ISBN 951-712-620-4 (html)
ISSN 0783-2346

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Authorisation

By virtue of the below acts and regulations, the Radiation and Nuclear Safety Authority (STUK) issues detailed regulations that apply to the safe use of nuclear energy and to physical protection, emergency preparedness and safeguards:

- Section 55, paragraph 2, point 3 of the Nuclear Energy Act (990/1987)
- Section 29 of the Council of State Resolution (395/1991) on the Safety of Nuclear Power Plants
- Section 13 of the Council of State Resolution (396/1991) on the Physical Protection of Nuclear Power Plants
- Section 11 of the Council of State Resolution (397/1991) on the Emergency Preparedness of Nuclear Power Plants
- Section 8 of the Council of State Resolution (398/1991) on the Safety of a Disposal Facility for Reactor Waste
- Section 30 of the Council of State Resolution (478/1999) on the Safety of Disposal of Spent Nuclear Fuel.

Rules for application

The publication of a YVL guide does not, as such, alter any previous decisions made by STUK. After having heard those concerned, STUK makes a separate decision on how a new or revised YVL guide applies to operating nuclear power plants, or to those under construction, and to licensees' operational activities. The guides apply as such to new nuclear facilities.

When considering how new safety requirements presented in YVL guides apply to operating nuclear power plants, or to those under construction, STUK takes into account section 27 of the Council of State Resolution (395/1991), which prescribes that *for further safety enhancement, measures shall be taken which can be regarded as justified considering operating experience and the results of safety research as well as the advancement of science and technology.*

If deviations are made from the requirements of a YVL guide, STUK shall be presented with some other acceptable procedure or solution by which the safety level set forth in the guide is achieved.

Translation. Original text in Finnish.

1 General

The safety of the use of nuclear energy in Finland is regulated by the Finnish Radiation and Nuclear Safety Authority (STUK). The general procedures for STUK's regulatory control of nuclear power plants are set forth in Guide YVL 1.1.

In the design of nuclear power plants not only internal events are considered but also threats arising from external events and natural phenomena. External events include, i.a., severe weather conditions, floods and seismic events. This guide addresses seismic events threatening the integrity, tightness and operability of structures and components in the first place. All structures, components and systems important to safety must be designed to withstand seismic loads in order to assure the safety of the nuclear power plant.

The Government Resolution (395/1991), section 20, paragraph 1, prescribes that *the most important nuclear power plant safety functions shall remain operable in spite of any natural phenomena estimated possible on site or other events external to the plant. In addition, the combined effects of accident conditions induced by internal causes and simultaneous natural phenomena shall be taken into account to the extent estimated possible.*

The Guide YVL 1.0 further specifies this general rule by stating that these *natural phenomena include at least freezing that hinders the operation of the final heat sink or blockage due to some other reason, thunderstorm, earthquake, storm wind, flooding, exceptionally hard rain or drought and exceptionally low sea level. Other events external to the plant are at least electromagnetic disturbances, oil leaks, crashing aeroplanes, explosions, releases of poisonous gases and unauthorised plant site entry.*

Violent seismic activity very seldom occurs in Finland but worst-case consequences at the nuclear power plants could be so significant that it is necessary to take precautions against them. This guide gives general requirements for the design and demonstration of seismic resistance at nuclear power plants as well as for the monitoring of earthquakes and their effects during the operation of the nuclear power plants. These requirements aim to assure that seismic threats to safety remain extremely small.

This guide does not apply to underground repositories for nuclear waste.

2 Design basis earthquake

When applying for a construction licence for the nuclear power plant, a description of the design basis earthquake used in seismic design shall be given. A design basis earthquake means the probabilistic estimate of a site-specific earthquake with the severest impact. It shall be so defined that, in the current geological circumstances, stronger earthquakes are anticipated not more often than once in a hundred thousand years (1×10^{-5}/y) on median level. The definition of design basis earthquake shall be presented and justified, and, in addition to the area's seismic history, also regional and local geology as well as tectonics shall be considered.

The external impact of the design basis earthquake on the nuclear power plant shall be presented in the form of a seismic ground response spectrum. The ground response spectrum represents the maximum vibrations of a family of idealised single-degree-of-freedom damped oscillators with a given damping ratio anchored in site bedrock as a function of the natural frequencies of the oscillators.

The design basis earthquake's seismic ground response spectrum shall be based on information and measurement results describing the plant site as well as possible. The spectrum shall be scaled to correspond to vertical and horizontal peak ground acceleration (PGA) values and, if necessary, a separate spectrum for both directions of vibration shall be given. Attached to this guide is an example of an acceptable spectrum.

The vertical and horizontal PGA values used shall be justified. The minimum value of the horizontal component shall be 0.1g [7]. The vertical component's value shall then be at least two thirds of the horizontal component's value.

For calculations made for structures and components, the impact of the design basis earthquake can also be presented with an acceleration-time diagram constructed using the ground response spectrum. The acceleration values used and the method of their derivation shall be presented and justified.

In case the loading caused by the design basis earthquake is to be modelled by other methods, a separate approval for the method in question shall be obtained from STUK.

3 Seismic classification

3.1 General

The nuclear power plant's design shall be such that a design basis earthquake will not compromise reactor shutdown, decay heat removal and the containment function, or the confinement of radioactive materials. To assure the aforementioned, the structures and components of nuclear power plants are to be classified into the seismic categories **S1** and **S2** according to their required resistance to earthquakes. Seismic classification shall be presented in connection with the Guide YVL 2.1 -compliant safety classification attached to a licence application.

Seismic classification follows the general principles below. In addition, it can be justified by probabilistic methods.

3.2 Seismic category S1

Seismic category S1 comprises
- structures and components whose failure could cause an accident situation directly or indirectly leading to a reactor core melt
- structures and components restricting the release of radioactive substances in nuclear fuel from the nuclear power plant into the environment
- the structures and components of a system important to nuclear safety, including at least two redundant subsystems
- systems and structures assuring the subcriticality of stored nuclear material
- radioactive waste tanks containing such amounts of radioactive material in an easily released form that the failure of the tanks in consequence of an earthquake would cause a dose exceeding the threshold limit of 5 mSv for the critical group given in subsection 2.1.1 of Guide YVL 7.1.

These structures shall maintain their integrity, leaktightness, operability and proper position in a loading situation caused by a design basis earthquake. If justifiable, some components may be assigned only a certain feature, e.g. leaktightness, which must be maintained in a loading situation induced by a design basis earthquake.

3.3 Seismic category S2

Seismic categroy S2 comprises all other structures and components. No earthquake resistance requirements relating to their own operation and integrity are set but their failure must not compromise structures and components in seismic category S1.

4 Seismic design of structures and components

4.1 General

The general principles below shall be considered when earthquake resistant nuclear power plant structures and components are designed:
- Structures shall be designed and components located such that the loads exerted by them on buildings occur as close to ground level as possible.
- The shape of load-bearing structures shall be as regular and simple as possible.
- A building's various parts shall be as centrally located as possible with regard to bracing structures.

Detailed design aspects are presented in the guide IAEA 50-SG-D15 [7].

4.2 Loads

The seismic design of structures and components assigned to seismic category S1 shall consider loads generated by a design basis earthquake. To determine the loads, dynamic analyses shall derive the floor response spectra or acceleration-time diagrams corresponding to the ground response spectrum of those building levels housing the structures and components under examination. In the case of low buildings, static methods may also be used for the analysis of levels whose maximum elevation from the foundations is 10 metres. Median acceleration determined for the bedrock, multiplied by the factor 1.5, will then be chosen as the dimensioning acceleration.

In the dynamic analysis of buildings, mass and stiffness characteristics essentially affecting vibration behaviour shall be modelled. The chosen values of the damping ratio shall be justified. No analysis of the dynamic interaction between buildings and the bedrock is required but uncertainty factors relating to source information and spectral peaks at natural frequencies shall be considered. Applicable instructions are given in Guide YVL 3.5 and in [7].

The highest horizontal and vertical acceleration values arising at the component locations shall be used in the dimensioning of individual structures and components. Relative vibration displacements between buildings or building sections shall be considered in case they generate significant loads. The horizontal acceleration component of each object is chosen according to its structurally weakest direction, whenever this can be established. In other cases components will be chosen for two vertical horizontal directions (the object main directions). These components can be combined in accordance with standard ASCE 4-98 [11], for example.

Other simultaneous loads shall be added to loads generated by the design basis earthquake. They include loads from normal operation and loads simultaneously generated by possible operational transients caused by an earthquake. The design basis earthquake need not be considered simultaneously with the loading generated by a postulated accident situation.

Loads shall be incorporated in dimensioning and strength calculations in accordance with an approved standard. In the combining of structural loads, the formula

$$q_d = g + q_A + \sum 0.5 q_{ki}$$

shall be applied, which is based on [4]–[6], and in which

q_d = dimensioning load
g = constant load
q_A = dynamic load generated by a design basis earthquake
q_{ki} = all changing loads with a long-term percentage of ≥ 50%.

As the partial safety coeffient of the loads, the value 1.0 may be used. As the material design strength, characteristic strengths will be used [4]. A dynamic load comprises inertial forces generated within a structure and within the components supported by it.

4.3 Dimensioning principles

In documents to be submitted in connection with an application for a construction licence for a nuclear power plant, the dimensioning principles for the earthquake resistance of various types of sructures and components shall be given, including their methods of support, anchoring and protection. In addition, a plan shall be presented for the demonstration of compliance with the requirements as regards the operation of various types of structures and components in earthquake situations.

Structure and component specific seismic plans as well as dimensioning calculations needed in calculations to consider earthquake loads in accordance with subsection 4.2 shall be given in documents pertaining to structural and component design.

Building structures in seismic catgory S1 shall be dimensioned to withstand loads generated by a design basis earthquake. Sufficient earthquake resistance shall be assured in category S2 as well, based on the dynamic analysis of buildings, for example.

Dimensioning calculations for seismic category S1 pressure equipment, other mechanical structures and components, and their supports and anchorages in particular, shall consider loads generated by a design basis earthquake, unless the loads can be justifiably considered minor compared with other design loads. Guide YVL 3.3 sets forth requirements concerning piping supports and anchorages.

5 Demonstration of earthquake resistance

5.1 General

The licencee shall demonstrate that seismic category S1 structures and components meet the requirements for earthquake resistance established in subsection 3.2. Demonstration may be in the form of analyses, tests or empirical assessments. Such clarifications or their result documentation are to be presented in connection with STUK's pre-commissioning inspections required for the types of structure or component in question.

The results of a design-phase PSA shall also demonstrate that the implementation of seismic design is acceptable from the viewpoint of the nuclear power plant's overall safety.

5.2 Analyses

The earthquake resistance of pressure equipment and the steel containment structure is to be demonstrated by a stress analysis conducted in accordance with Guide YVL 3.5 for design basis earthquake induced loads.

5.3 Tests

The earthquake resistance of active components and their parts, such as piping actuators, shall be experimentally demonstrated. Experimental methods include, among others

- shake table (one, two or three dimensional)
- hydraulic, electric and mechanical exiter
- impact hammer
- pressure wave.

Experimental methods are discussed in more detail in the guide IAEA Safety Series No. 50-SG-D15 [7].

5.4 Experimental assessment

The earthquake resistance of a component or structure can be assessed based on an earlier report prepared for a corresponding item in conformity with subsection 5.2 or 5.3. Commensurate experiences of occurred earthquakes may be utilised as well.

5.5 Electrical and I & C components

The type tests of electrical and I & C components shall include sufficient requirements for the duration of mechanical stress against the design basis earthquake. The durability of intercomponent cabling and connections shall be demonstrated by analyses and/or tests.

5.6 Design phase PSA

The most important initiating events, due to earthquake-induced failures and malfunctions, shall be incorporated in the design phase PSA. When choosing the initiating events, the following factors shall be considered: S2 category structures and components plus their supports as well as experiences of the susceptibility to failure of different types of structures and components in actual earthquakes of varying magnitudes. The possibility of failure chains attributable to the simultaneous dynamic loading of large component entities and of common cause failures shall be analysed.

Other requirements for design phase PSA and PSA-based safety objectives are set forth in Guide YVL 2.8.

6 Control during construction and operation

6.1 Design

The design basis earthquake of the nuclear power plant and the general principles followed in the facility's earthquake design shall be presented in the Preliminary and Final Safety Analysis Reports or associated topical reports.

Earthquake induced loads shall be considered in the structural plans of S1 category structures and components. Earthquake related requirements are given in chapters 4 and 5.

6.2 Plant walkdowns

The scope and implementation of the seismic design of structures and components shall be visually inspected by plant walkdowns prior to the nuclear power plant's commissioning. The inspections shall be carried out by competent technical experts and under STUK's supervision. The appropriateness of seismic support and anchorage solutions as well as potential seismic risk factors requiring further measures shall be noted in the inspections. Any deviations affecting safety shall be reported to STUK.

6.3 Seismic sensors

Seismic sensors shall be located in the site bedrock to verify vibration data and assumptions used in the definition of a design basis earthquake. In addition, the reactor building shall have at least two sensors: one attached to the base plate and the other above the level housing safety-important structures and components.

The sensors shall be suitable for design basis acceleration and frequency values. The sensors shall be capable of recording, reliably and at sufficiently short intervals, the accelerations of occurring earthquakes in vertical directions and in two mutually perpendicular horizontal directions.

Sensor results shall be available after a significant earthquake when the necessary scope of inspections of safety-important structures and components as well as the prerequisites for continued plant operation are assessed.

It will not be necessary to install sensors in a nuclear power plant unit or other nuclear facilities located in the immediate vicinity of a nuclear power plant unit equipped with sensors.

6.4 Periodic inspections

Records yielded by seismic sensors and the availability of components shall be regularly checked during plant operation. Observations exceeding set threshold values shall be recorded as spectra. Procedures shall be specified in instructions and included in periodic inspection programmes.

7 Definitions

For the purposes of this guide

Peak ground acceleration (PGA)
means the maximum acceleration of seismic ground motion at a given site.

Ground response spectrum
means the presentation of seismic ground motion as a plot of the maximum acceleration of a family of idealised single-degree-of freedom oscillators which are anchored in the site bedrock and have a given damping ratio as a function of the natural frequencies of the oscillators.

Damping ratio
means the damping coefficient (the ratio of the viscous damping force to velocity) for a single-degree-of freedom oscillator expressed as a percentage of the critical damping coefficient (i.e. of the maximum value of the damping coefficient at which periodically attenuating oscillation is possible).

Design basis earthquake
means a loading condition due to ground motion used for the seismic design of a nuclear facility. The design basis earthquake shall be chosen so that the occurrence of stronger ground motion at the site is extremely improbable.

Design response spectrum (or ground response spectrum of the design basis earthquake) means the ground response spectrum caused by the design basis earthquake.

Floor response spectrum
means the acceleration due to seismic ground motion as a function of the oscillation frequency at the floor levels where the structure or piece of equipment under consideration is supported.

An anticipated operational transient
means such a deviation from normal operational conditions as is milder than an accident and which may be expected to occur once or several times over a period of a hundred operating years.

An accident
means such a deviation from normal operational conditions as is not an anticipated operational transient. There are two classes of accident: postulated accidents and severe accidents [Guide YVL 2.2].

8 References

1 The Nuclear Energy Act 990/1987.

2 The Nuclear Energy Decree 161/1988.

3 Government Resolution No. 395/1991 on the general regulations for the safety of nuclear power plants.

4 The National Building Code of Finland (RakMK).

5 RIL 144-1997, Guidelines on loading of structures. [1]

6 RIL 131-1991, Concrete standards and dimensioning tables. [1]

7 IAEA Safety Series No 50-SG-D15, Seismic Design and Qualification for Nuclear Power Plants.

8 IAEA Safety Series No 50-SG-S1, Earthquakes and Associated Topics in Relation to Nuclear Power Plant Siting.

9 IAEA Safety Series No 50-SG-S2, Seismic Analysis and Testing of Nuclear Power Plants.

10 IAEA Safety Series No 50-SG-S8, Safety Aspects of Foundations of Nuclear Power Plants.

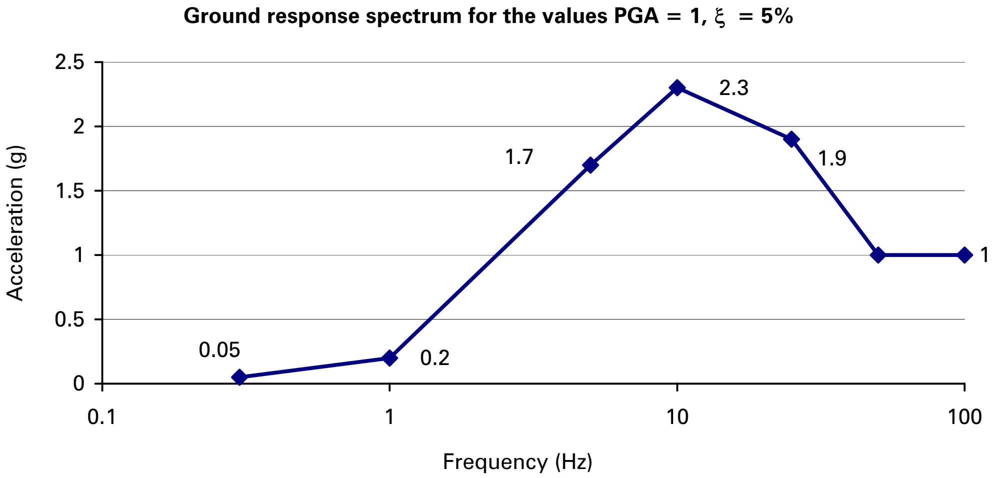
11 ASCE 4-98, "Seismic Analysis of Safety-Related Nuclear Structures".

[1] RIL, The Association of Finnish Civil Engineers

APPENDIX

An example of an acceptable ground response spectrum corresponding to peak ground acceleration PGA = 1 g and the damping ratio ξ = 5%

Ground response spectrum acceleration values are directly proportional to peak ground acceleration (PGA), which corresponds to the spectrum value at frequencies exceeding 50 Hz. At frequencies below 50 Hz, accelerations decrease with increasing values of the damping ratio ξ of an idealised single–degree–of–freedom oscillator anchored in the bedrock. The spectrum applicable to the bedrock of Finland's land area south of the 63rd latitude north, corresponding to the values PGA = 1 and ξ = 5%, can be presented as follows:



The acceleration values corresponding to the below frequencies are:

Frequency (Hz)	0.3	1	5	10	25	50	100
Acceleration (g)	0.05	0.2	1.7	2.3	1.9	1	1

The spectrum shape applies to both vertical and horizontal accelerations. The spectrum shape is to be scaled using an actual PGA value, which is vertically 2/3rds of the horizontal PGA value. The spectrum shape for other ξ values is to be defined separately.

An excerpt from STUK's decision No. C30/78 of 6 Nov 2001.