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Design of nuclear power plants against seismic events —

Part 3:
Civil structures

Conception parasismique des installations nucléaires —

Partie 3: Ouvrages de génie civil

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Foreword

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This document was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 6, *Reactor technology*.

A list of all parts in the ISO 4917 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

In accordance with IAEA Safety Standards Series No. SSR-2/1 protective measures against seismic events are required, provided earthquakes must be taken into consideration.

Earthquakes belong to the group of design basis events that requires taking preventive plant engineering measures against damage and which are relevant with respect to radiological effects on the environment.

Design of nuclear power plants against seismic events —

Part 3:
Civil structures

1 Scope

This document applies to civil structures of nuclear power plants with water cooled reactors in order to achieve the safety objectives given in ISO 4917-1. For other nuclear facilities the applicability of the document needs to be checked in advance, before it might be applied correspondingly.

This document specifies the requirements for civil structures that must be met for the verification of their load-bearing capacity in case of a seismic event. Additionally, requirements are specified pertaining to the verification of the serviceability of civil structures as far as necessary for maintaining their safety-related function in case of a seismic event (e.g. deformation and crack-width limitations).

This document will be applied under the presumption that the geology and tectonics of the plant site have been investigated with special emphasis on the existence of active geological faults and lasting geological ground displacements, and that the site has been deemed suitable for a nuclear installation.

To achieve these goals, this document deals with the requirements specific to the seismic design of civil structures above and beyond their conventional design. The basic requirements of these precautionary measures are dealt with in ISO 4917-1.

This document does not apply to cranes, to detachment devices for lifting equipment nor to the supporting and mounting constructions of components.

This document is independent of national standards. Recommendations, given in Annex A, are mainly based on the KTA Design-Philosophy and European standards. Alternatively other equivalent standards or regulations can be used in case the general requirements given in this document can be met.

NOTE The term civil structures as used in this document comprise buildings and structural members made of reinforced concrete, pre-stressed concrete, steel, as well as steel composite structures and masonry. Among others, these include the containment, crane runways, platforms, fastening constructions and canals.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4917-1:—, *Design of nuclear power plants against seismic events— Part 1: Principles*

ISO 4917-4:—, *Design of nuclear power plants against seismic events — Part 4: Components*

IAEA Safety Standards Series No, SSG-67, *Seismic Design for Nuclear Installations*, INTERNATIONAL ATOMIC ENERGY AGENCY VIENNA (2021)

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
structural member damping
damping of a structural members (e.g. plate, beam) including bordering influences and effects from secondary elements (screeds, floor coverings, etc.)

Note 1 to entry: For equal load levels, structural element damping is larger than material damping.

3.2
geometric non-linearity
non-linear relationship between force and path values caused by equilibrium and kinematic considerations for the deformed system

3.3
homogenous soil
rock
soil or rock with a near constant shear-wave velocity throughout its stratum thickness and a ratio of a stratum thickness-to-foundation-radius larger than 4

Note 1 to entry: In case of squared foundations, the radius of an area equivalent circle applies.

3.4
soil-structure interaction
interaction relationship between local soil or rock conditions and the vibration behaviour of the building via its foundation

Note 1 to entry: This interaction comprises the kinematic interaction and the interaction due to the inertial forces of the structure.

3.5
impedance functions
complex frequency dependent foundation stiffness values in the subsoil; their real and imaginary parts characterize stiffness and damping

3.6
interaction
<kinematic> interaction of the foundation with the subsoil, whereby the foundation is assumed as being massless and rigid

3.7
material damping
damping caused by internal micro-plastic deformations

Note 1 to entry: The material damping is measured in the laboratory excluding bordering influences and the like; it is dependent on the load level.

3.8
material non-linearity
non-linear relationship between stresses and strains caused by a non-linear material behaviour

3.9
radiation damping
damping due to energy being radiated into an adjacent medium, e.g. from one structural member to a bordering member or from foundation to the subsoil

3.10
Rayleigh damping
damping defined by a matrix, $\boldsymbol{C}$, that is a linear combination of the mass matrix, $\boldsymbol{M}$, and the stiffness matrix, $\boldsymbol{K}$

3.11
overall building damping
damping of the total building or partial building structures made of many structural and nonstructural members, including the influence from, e.g. non-load-bearing components, interaction with equipment, friction in connections and effects from energy dissipation

Note 1 to entry: For equal load levels, overall damping is significantly higher than structural member damping.

3.12
upper limit frequency
frequency above which no significant seismic response in structures and sub-systems would occur

3.13
load bearing capacity
resistance of a structure or a structural component for forces that produce stresses or deformations.

3.14
building response spectrum
<in-structure response spectrum> response spectrum at a specific point or level of the building structure (it corresponds to floor response spectrum)

4 Seismic event

The seismic event to be assumed for the design basis earthquake shall comprise

a) ground response spectra both in horizontal and vertical direction together with the rigid-body accelerations and the strong motion duration specified in ISO 4917-1:—, 5.5, or

b) artificial acceleration time histories compatible with the ground response spectra specified in ISO 4917-1:—, 5.3.3, or

c) recorded acceleration time histories as specified in ISO 4917-1:—,5.5.

The excitation to be applied and superposed shall be as specified in ISO 4917-1:—, 6.3.1.

5 Structure analysis

5.1 Basic requirements

The analyses shall be performed and documented in a transparent fashion. The load-bearing behaviour of the structure shall be described in the documentation.

The range of variation of the analysis assumptions, in particular with regard to stiffness values, load support conditions, mass distributions and the vibration model, shall be documented and, if so required, estimated on the basis of limit value considerations.

5.2 Modeling

5.2.1 General

The basic requirements regarding modeling are specified in ISO 4917-1:—, 6.3.2. Regarding modeling of civil structures, the requirements under this section shall additionally be complied with.

Provided all decisive influences from torsion and eccentricities between the centers of gravity and the centers of stiffness are taken into account as given in ISO 4917-1:—, 6.3.2, any accidential torsions coming from unplanned scattering of masses and their distribution on a floor may be neglected.

NOTE In the case of decisive torsional effects coming from the excitation due to non-vertical propagating waves, incoherent waves or phase-lag between waves an approximation with an accidental torsion approach is possible (additional eccentricity between center of mass and stiffness).

Any modeling by equivalent beams subjected to axial and torsional loads shall take into account the influence from torsion and eccentricities between the centers of gravity and the centers of stiffness. Furthermore, existing deformabilities of individual structural members not accounted for in the beam model that would, however, have a relevant influence on their structural behaviour or that of connected components shall be taken into account in verifying the earthquake safety of structural members and components.

5.2.2 Geotechnical parameters, dynamic subsoil properties

In the dynamic analysis of a building the influence of the subsoil and foundation on the vibration behaviour shall be considered. The mechanical properties of the subsoil under dynamic loading shall be taken into account.

NOTE The mechanical properties of the subsoil under dynamic loading are significantly different from those under static loading. The main influencing factors are the shear strain amplitude and the number of loading cycles, the omnidirectional mean static pressure under the foundation as well as the void ratio and degree of saturation of the soil.

The design of nuclear power plants against seismic events shall be based on geotechnical assessments and investigations. The procedures chosen to be applied for determining the dynamic subsoil properties shall be in accordance with the specific subsoil conditions. In-situ procedures and laboratory tests should be applied. The whole process of assessment and determination of subsoil properties is not covered by this code. More detailed requirements may be found e.g. in IAEA NS-G 3.6.C, KTA 2201.2.

Possible changes of the subsoil that might occur as a result of earthquakes should be adressed. These are mainly the permanent vertical deformations resulting from soil compaction and reduction of the shear strength due to changes in the soil grain structure.

The following data on dynamic subsoil properties for the individual soil layers should be defined as the basis of a dynamic analysis:

— dynamic shear modulus, G_0, supplemented by appropriate upper and lower limit values;

— Poisson ratio, ν;

— material damping in terms of the damping ratio, D;

— mass density, ρ;

— shear wave velocity, v_s, and compression wave velocity, v_p, for small shear strains (if Poisson's ratio is given, v_p is not needed);

— relationships for the dynamic shear modulus reduction and the material damping to shear strains.

5.2.3 Material characteristics (parameters)

Regarding concrete, reinforcing steel, pre-stressing steel, structural steel and masonry, the material characteristics (parameters) to be used in the analysis model for static loads may be as specified in the relevant national documents.

NOTE If no national standard is available for a sufficient definition of material parameters information can be found in the European standards EN 1992-1-1, EN 1993-1-1, EN 1994-1-1 and EN 1996-1-1.

5.2.4 Effective stiffness

The stiffness values of structural members may basically be determined under the assumption of a linear-elastic behaviour of the structural material without any stiffness reduction.

A possible stiffness reduction due to cracking shall be taken into account for reinforced or pre-stressed concrete structural members, if this may have a significantly adversely effect on the vibration behaviour of the respective building structures and resulting loads of the structural members. The stiffening effect of not-load-bearing structural members, e.g. the infilling of masonry, shall be considered in the building models, provided, this has a significantly adversely effect on the vibration behaviour.

NOTE 1 In particular the torsional stiffness of reinforced concrete structural members can be reduced due to cracking and can strongly influence the design results.

NOTE 2 The contribution of non-load bearing elements can lead to an additional eccentricity between the centre of mass and stiffness. If their contribution does not vanish due to e.g. cracking it can decisively impair the overall dynamic behaviour of the building.

Stiffness values and eccentricities of connections in steel structures and their supports shall be taken into account, if they may have a significantly adversely effect on the vibration behaviour of the respective building structures and on the resulting loading of structural members. The stiffness values may be varied to account for the flexibility of, for example., framework corners or bolt connections.

5.2.5 Contributing masses

The building structure analysis shall account for the seismic masses derived from the permanent masses (building structure and components), the masses of quasi-permanent live loads and the ratio of variable live loads existing during operation. Recommended ratios of variable live loads that should be considered are given in Table A.2.

The building analysis may be simplified by considering the components as being decoupled from the building, provided, the masses of the components are included in the mass of the building and the uncoupling criteria according to ISO 4917-1:—, A.5 are satisfied.

In stick models the rotary inertias shall explicitly be considered.

NOTE In 3D models the rotary inertia is generally implicitly considered.

5.2.6 Damping

Damping may be assumed to be a viscous (velocity dependent) effect. It should be distinguished between the dynamic analyses of buildings (associated with "overall building damping") and of individual structural members (associated with “structural member damping”).

NOTE 1 The overall building damping includes besides the material damping and the damping of structural members in particular the damping due to interactions with non-load-bearing components and equipment, too.

In the dynamic analysis, the different damping of the building structure and of the subsoil shall be considered.

The damping behaviour of buildings and partial building structures is in general largely determined by the overall building damping. Therefore, the analyses for verifying the ultimate limit state (ULS) and the serviceability limit state (SLS) and for determining building response spectra may be based on high damping ratios. Recommended values are given in column A of Table A.1.

For-buildings whose damping behaviour is exclusively determined by material damping and structural member damping, the verification of the serviceability limit state (SLS) and the determination of the building response spectra shall be based on reduced damping ratios without the effect of overall building-damping. Recommended values are given in column B of Table A.1.