OFFICIAL DOCUMENTS

Federal nuclear and radiation safety supervision authority of Russia
(Gosatomnadzor of Russia)

FEDERAL CODES AND RULES
IN ATOMIC ENERGY UTILIZATION

RULES FOR DESIGN OF SEISMIC RESISTANT NUCLEAR POWER PLANT **NP-031-01**

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These federal codes and rules establish the requirements to providing safety of land-based nuclear power plants with all types of reactors under seismic impacts, categorizing seismic resistance of nuclear power plant elements, establishing seismic impact parameters, providing seismic resistance of civil engineering structures and bases of nuclear power plant facilities, process, electrical components, automatics and communication facilities.

These rules supersede federal codes and rules in the field of atomic energy utilization “Codes for seismic nuclear power plant design” PN AE G- 5-006-87.

The revised rules take into account the provisions of the federal laws “On atomic energy utilization” “On radiation safety of the population”, the requirements of federal codes and rules in atomic energy utilization as well as a set of maps “General seismic zoning of the territory of the Russian Federation” (OSR-97) and the recommendations of the IAEA Guidelines (No. 50-SG-D15, Vienna, 1992 and No. 50-SG-S1 (rev. 1), Vienna, 1994).

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The present rules supersede Codes for seismic nuclear power plant design. PN AE G-5-006-87.

List of abbreviations

NPP – nuclear power plant
PFPE – possible focal point of earthquake
MCE – maximum credible earthquake
MSK-64 – Medvedev-Shponkhoyer-Karnik seismic intensity scale
NOF – failure in normal operation
NO – normal operation
GSZ – general seismic zoning
OSR-97 – set of maps “General seismic zoning of the territory of the Russian Federation” approved by the Russian Academy of Sciences
DBA – design basis accident
DBE – design basis earthquake
SMZ – seismic microzoning
FS – feasibility study
GSZR – general seismic zoning refinement

Legend

$\boldsymbol{A}$	- transversal section area of a structure element
$\boldsymbol{E}$	- module of material elasticity
$\boldsymbol{I}$	- inertia moment of a structure’s element cross-section
$\boldsymbol{J}$	- seismic intensity
$\boldsymbol{N_i}$	- element stress from seismic impact along the coordinate *i*
$\boldsymbol{R}$	- design resistance
$\boldsymbol{T_i}$	- *i*- form period of self-excited vibrations of a facility

a_i - seismic acceleration along the coordinate *i*
g - acceleration of gravity
p - .probability of a random value
δ - logarithmic vibration decrement
σ - .design stresses
(σs)1 - group of reduced total membrane stresses with account taken of seismic impacts
(σs)2 - group of reduced membrane and total bending stresses with account taken of seismic impacts
(σs)3w - group of reduced bolt and stud tensile stresses with account taken of seismic impacts
(σ)4w - group of reduced bolt or stud stresses with account taken of seismic impacts
(σs)s - bearing stresses with account taken of seismic impacts
(ts)s - shear stresses with account taken to seismic impacts

MAIN TERMS AND DEFINITIONS

Accelerogram – vibration acceleration time dependence.

Analogue (fitted) accelerogram – accelerogram recorded under a real earthquake and taken for seismic resistance calculations taking into account its conformity to seismotectonic and ground conditions of a nuclear power plant site.

Earthquake accelerogram – accelerogram on free ground surface during an earthquake.

Response accelerogram – accelerogram of a structure resulting from calculations of forced vibrations under seismic impact.

Floor accelerogram – response accelerogram for individual elevations of a facility where components are installed.

Synthesized accelerogram – accelerogram obtained by analytical way, based on statistical processing and analysis of a number of accelerograms and (or) spectra of real earthquakes with account taken of local seismic conditions.

Vibration strength of an element – ability of a nuclear power plant element to preserve its strength during and after vibration action.

Vibration resistance of an element – ability of a nuclear power plant element to perform its functions and to maintain its parameters within the values specified by the standards and technical specifications for the products, under vibration action in specified modes.

Geodynamic zone – joint area of two tectonic Earth crust blocks within which relative displacements at neo-tectonic and quaternary development stages are established.

Geodynamic conditions – NPP position relatively to geodynamic zones.

Dynamic method of analysis – impact calculation method in the form of ground vibration accelerograms at a facility base by means of numerical integration of motion equations.

Linear-spectral method of analysis – method for seismic resistance calculation in which seismic load values are determined by response spectra, depending on frequency and forms of self-excited vibrations of a structure.

Maximum credible earthquake – maximum intensity earthquake on a nuclear power plant site with the return period of once per 10 000 years.

Failure in normal plant operation – failure in NPP operation at which a deviation from the established operational limits and conditions occurred.

Normal pant operation – operation of a nuclear power plant within operational limits and conditions established by the design.

Linear oscillator – linear oscillating system with a single degree of freedom, characterized by a specific period of self-excited vibrations and attenuation.

Plant site – territory within the guarded perimeter on which main and auxiliary buildings and facilities of a nuclear power plant are located.

Design accident – accident for which initiating events and final states are defined in the design as well as safety systems are foreseen, providing for mitigation of its consequences within the limits established for such accidents, with account taken of a safety system single failure criterion or of one human (personnel) error, independent on the initiating event.

Design earthquake – maximum intensity earthquake on a nuclear power plant site with the return period of once per 1000 years.

Plant location area – territory comprising the nuclear power plant site on which seismic events capable of affecting the plant safety are possible to occur.

Plant site seismicity – intensity of likely DE and MCE seismic impacts on the plant site, measured in points on the MSK-64 scale.

Seismological study for a nuclear power plant – set of activities for GSZR of the area and SMZ of competitive sites in order to refine seismicity of the area established according to GSZ maps and to determine DE and MCE parameters.

Seismic microzoning – a set of special activities for predicting the influence of rock specific near-surface composition, properties and state, nature of their watering and relief on the site ground vibration parameters.

N o t e. A near-surface section part is understood as upper strata having a substantial influence on the earthquake intensity increment.

Seismic resistance of a nuclear power plant elements – property of a nuclear power plant elements to preserve their ability, in case of an earthquake, to perform the assigned functions in compliance with the design.

Spectrum of dynamic factors – dimensionless spectrum obtained by dividing response spectrum values by maximum ground acceleration.

Response (reaction) spectrum – totality of absolute values of the linear oscillator's maximum response accelerations under the impact set by the accelerogram, taking into account the oscillator proper frequency and damping parameter.

Floor response spectrum – totality of absolute values of the linear oscillator's maximum response accelerations under the impact set by the floor accelerogram.

Generalized response (reaction) spectrum – spectrum obtained from processing response spectra for a set of real (analogue) accelerograms, corresponding to a given probability of being exceeded.

GSZ refinement – set of geologic-geophysical, geodynamic and seismological activities in order to identify geodynamic areas, active fractures, PFPE zones and to determine their parameters; to justify the plant siting within the limits of the Earth crust block not disturbed by active fractures, to refine the area seismicity and to define the on-site DE and MCE parameters for medium grounds.

1. PURPOSE AND FIELD OF APPLICATION

1.1. This document was developed with account taken of the Federal law "On atomic energy utilization", General nuclear power plant safety provisions", other federal codes and rules in the field of atomic energy utilization.

1.2. This document is intended for nuclear power plants the designs whereof have not been approved at the time of its putting into effect. The deadline and the scope of activities for bringing the nuclear power plants under construction and in operation in compliance with this document are determined on a case-by-case basis, according to the procedure established by the national safety regulating authorities.

1.3. This document establishes the requirements to providing safety of land-based nuclear power plants with all types of reactors under seismic impacts.

2. FUNDAMENTALS

2.1. The plant design should include:

plant site seismicity data for design bases;

seismic resistance calculations for the plant civil engineering structures and the foundations of its buildings and facilities, floor accelerograms and response spectra at the elevations supporting process components of the Ist and IInd seismic resistance categories;

seismic resistance calculations and (or) experimental justification for process and electrical components, automatics and communication facilities with account taken of floor accelerograms and response spectra;

development and justification of antiseismic precautionary and protective actions.

2.2. The site seismicity corresponding to DE and MCE, in relation to which the seismic resistance requirements for plant systems and components are to be met, is established for a nuclear power plant.

2.3. The MCE and DE should be characterized by a mean value and seismic impact standard intensity deviation and parameters: maximum accelerations, period and duration of violent vibrations as well as by a set of analogue or synthesized accelerograms and response spectra, modelling characteristic types of on-site seismic impacts.

2.4. In compliance with the requirements of the General nuclear power plant safety provisions, a seismic-resistant plant should ensure safety under seismic impacts up to the MCE as well as electric and thermal power production (output) up to the DE level.

N o t e. The requirement to the plant seismicity in terms of power and heat output may be refined by the plant customer.

2.5. The plant site seismicity and seismic impact parameters should be based on the seismological studies taking into account specific geodynamic, seismic, seismotectonic, seismological, ground and hydrogeological conditions in compliance with Appendices 1 and 2.

2.5.1. In the phase of investment justification and development of standard nuclear power unit designs, it is allowed to use standard seismic impact values in compliance with Appendix 3.

2.5.2. In the phase of FS (of the design), the calculations of the nuclear power plant seismic resistance should be performed with account taken of the DE and MCE parameters established for specific geodynamic, seismotectonic, seismological, ground and hydrogeological conditions of the plant location.

2.5.3. During renovation (or lifetime extension) of a nuclear power plant, the checking seismic resistance calculations should be performed taking into account possible changes in natural and ground conditions during the NPP construction and operation.

2.6. The buildings, facilities, civil engineering structures and foundations, process and electrical components, pipelines, instruments, other plant systems and elements, depending on the degree of their responsibility for providing safety under seismic impacts and operability after an earthquake should be ranked into three seismic resistance categories, taking into account their safety class according to the requirements of the General nuclear power plant safety provisions:

2.6.1. The Ist seismic category includes:

1st and 2nd safety class nuclear power plant elements according to the General nuclear power plant safety provisions;

safety systems;

normal operation systems and their elements whose failure, under seismic impacts up to the MCE, can lead to radioactive product release in the plant process rooms and the environment in the amount exceeding the values established for a design basis accident by the acting Radiation Safety Codes;

buildings, facilities and their foundations, components and their elements the mechanical damage whereof under seismic impacts up to the MCE due to power or temperature impact on the above mentioned components and systems can result in their failure in operation;

other systems and components whose ranking in the Ist seismic resistance category is justified by the design and approved according to the established procedure.

2.6.2. The IInd seismic resistance category should be assigned to plant systems and their elements (not ranked to the Ist category) the failure in operation whereof, separately or together with other systems and elements, can lead to interruption in electric power and heat generation as well as to safety class 3 systems and elements which are not ranked in the Ist seismic resistance category.

2.6.3. The III^{d} seismic resistance category should be attributed to all remaining buildings, facilities and their bases, structures, components and elements, not ranked in the Ist and IInd seismic resistance categories.

2.7. The elements of the same system can be ranked in different seismic resistance categories with taking special actions for their separation (isolation, control valves and so on). The elements and assemblies used for separation are assigned a higher seismic resistance category.

2.8. The nuclear power plant elements should be designed so that the failure of elements of a lower seismic category would not lead to failure in operation or to degradation of elements belonging to a higher seismic category.

2.9. The Ist seismic category elements of a nuclear power plant should:

preserve their ability to perform functions related to providing nuclear power plant safety during and after an earthquake of intensity up to the MCE inclusively;

maintain their operability under an earthquake of intensity up to the DE inclusively and after its passage.

2.10. The IInd seismic resistance category NPP elements should preserve their operability after the passage of an earthquake with intensity up to the DE inclusively.

2.11. The NPP design should provide for testing the operability of Ist and IInd seismic category plant elements and contain technical measures to restore their seismic resistance after an earthquake of the DE intensity.

2.12. The designing of III^{d} seismic resistance category elements of a nuclear power plant should be performed in compliance with the current regulatory documents the requirements whereof cover civil and industrial facilities.

2.13. The calculations of Ist seismic resistance category plant components for seismic impacts should be performed with simultaneous account taken of seismic loads by three space components. For IInd seismic resistance category buildings and structures it is allowed to take seismic impact into account separately by components.

2.14. The calculations of the plant systems and components which are assigned the Ist and IInd seismic resistance categories for seismic impacts should be performed in compliance with this document as well as with other regulatory documents establishing the requirements to seismic resistance calculation and covering the plant systems and components.

2.15. When calculating the plant systems and components of Ist and IInd seismic resistance category for seismic impacts, the vibration attenuation parameters (logarithmic vibration decrements) should be based on special justifications. In case there are no data, the logarithmic vibration decrement values are allowed to be taken according to Table 2.1.

Table 2.1

Logarithmic vibration decrements of civil engineering structures and pipelines

Type of structure	Logarithmic vibration decrement δ at calculated stress values σ depending on structure's design material resistance *R*	
	$\sigma = 0{,}67R$	$\sigma \geq 0{,}9R$
Conventional reinforced concrete structures	0,25 (4)	0,44 (7)
Pre-stressed reinforced concrete structures	0,12 (2)	0,31 (5)
Welded steel structures	0,12 (2)	0,25 (4)
Bolted steel structures	0,25 (4)	0,44 (7)
Large diameter (> 300 mm) components and piping systems	0,12 (2)	0,19 (3)
Small diameter (≤ 300 mm) components and piping system	0,06 (1)	0,12 (2)

Note.

1. The recommended vibration attenuation values in percentage from the critical value are bracketed.

2. In the interval of calculated stress values σ from 0,67R to 0,9R, the values of logarithmic vibration decrement are allowed to be taken by interpolation.

2.16. When designing nuclear power plant systems and components, the NO and NOF loads are allowed not to be taken into account in combination with the MCE seismic loads if their probability of occurrence does not exceed 10^{-3}.

2.17. For newly designed nuclear power plants, regardless of the site seismicity, the seismic accelerations corresponding to the MCE, should be not less than 0,1g. Seismic accelerations corresponding to the DE are to be taken as not less than 0,05g.

3. SEISMICITY DETERMINATION FOR NUCLEAR POWER PLANT LOCATION AREA AND SITE

3.1. In the first phase of development of the feasibility study (investment justification), the seismicity of the NPP location area is allowed to be established according to OSR-97 for II[nd] category grounds by their seismic properties (medium grounds). The site seismicity should be determined by the seismicity of the area, with account taken of specific site grounds using Appendix 1.

N o t e. The area seismicity for medium grounds is allowed to be taken on the basis of a set of maps OSR-97 approved by the Russian Academy of Sciences:

for DE: according to the OSR-97-B map;

for MCE: according to the OSR-97-D map.

3.2. In the phase of development of the feasibility study (the design), the plant site seismicity and the DE and MCE parameters should be defined on the basis of plant seismological studies in compliance with the requirement of items 3.3 -3.7 of this document and the recommendations of Appendices 1 and 2 .

3.3. The GSZR of the NPP location area with account taken of specific geodynamic, seismotectonic and seismological conditions:

3.3.1. should be performed with account taken of the recommendations provided in Appendix 2 for nuclear power plants located within the limits of earthquake intensity zones of more than 6 according to the OSR-97-B map.

3.3.2. is allowed to be based on the analysis of archival seismological, geological-geophysical and geodynamic materials using field studies in the reduced volume for nuclear power plants located within the limits of earthquake intensity zones of 6 and less, according to the OSR-97-B map.

N o t e. In case the MCE intensity established by the analysis of archival materials exceeds 7 for medium grounds, the GSZR of the area should be performed on the basis of NPP seismological studies with account taken of the recommendations contained in Appendix 2.

3.4. The site seismicity for individual plant buildings and facilities should be determined using SMZ data with account taken of the GSZR of the plant location area.

N o t e. Depending on engineering-geological and hydrogeological conditions, the site seismicity for different buildings and facilities of the same seismic resistance category can be different.

3.5. For areas with earthquake intensity of 6 and less according to the OSR-97-B map it is allowed to exclude instrumental recording of ground vibration under earthquakes from the SMZ-related set of activities.

3.6. The plant site seismicity and the DE and MCE parameters should be determined taking into account joint analysis of the GSZR results for the plant location area and the plant site SMZ with account taken of initial on-site seismic impact data.

3.7. To develop the feasibility study (of the design) the GSZR results for the plant location area and the plant site SMZ should include:

maps-diagrams of geodynamic zones and active faults in the plant location area and on the plant site;

maps-diagrams of PFPE zones in the plant location area;

maps-diagrams of the plant site SMZ for natural and man-induced changed conditions;

explanatory notes for maps-diagrams of geodynamic zones and active faults, PFPE zones and SMZ;

DE and MCE parameters including intensity, maximum acceleration (velocity, displacement), period and duration of seismic vibrations, reaction (response) spectra and earthquake accelerograms for characteristic types of seismic impacts for natural ground conditions and taking their possible man-induced changes into account.

3.8. The seismic, geotechnical and geodynamic monitoring of the natural environment stability should be carried out over the plant construction and operation periods, based on monitoring (regime) observations in the plant location area and on the plant site.

4. CIVIL ENGINEERING STRUCTURES AND BASES

4.1. The plant civil engineering structures, buildings, facilities and their foundations of seismic resistance categories I and II should comply with the provisions of this document, the requirements of building codes and rules and other regulatory documents regulating the designing of NPP buildings and facilities.

4.2. The NPP design should include layout and structural solutions providing seismic resistance of safety-significant plant civil engineering structures, buildings and facilities including the following:

buildings and facilities should have a simple symmetric shape in plan with locating the building (facility) stiffness centre near its centre of mass;

lengthy civil engineering structures, buildings and facilities as well as parts of buildings with height differential of more than 5 m should be normally separated by antiseismic seams;

main bearing structures of the buildings and facilities should generally be continuous by height and in plan, within the limits of a section between antiseismic seams.

4.3. When calculating plant civil engineering structures, buildings and facilities for seismic impacts, it is necessary to perform:

definition of vibration and stressedly-deformed state parameters of buildings, facilities, their internal structures and foundations taking into account damping and foundation interaction;

calculations of floor accelerograms and floor response spectra with account taken of buildings- and facilities-foundation interaction;

definition of the strength of structure elements, support assemblies and embedded items with account taken of strength characteristics of structural materials under dynamic loads.

4.4. When designing plant civil engineering structures, buildings and facilities, seismic loads should be taken into account in load combinations regulated by building codes and rules.

The process loads should be taken into account in combination with seismic loads in compliance with Table 4.1.

Table 4.1

Load combinations for civil engineering structure calculation for seismic impacts

Category of seismic resistance	Number of load combination	Loads and impacts				
		Corresponding process ones			Seismic ones	
		NO	NOF	DBA	DE	MCE
I	1	+	-	+	-	+
I	2	-	+	-	-	+
I	3	+	-	+	+	-
II	4	+	-	+	+	-
II	5	+	-	-	+	-
II	6	-	+	-	+	-

N o t e s.

1. The load combination No. 1 is applied for structures which, in compliance with the Rules for design and operation of nuclear power plant confining safety systems form part of the sealed enclosure.

2. The sign “+” means that it is necessary to include these loads in the corresponding combination.

The sign “-“ means that these loads are not included in the corresponding combination.

4.5. The design diagram (model) of buildings and facilities should reflect specific features of their geometry as well as mass and stiffness distribution, significant for seismic resistance assessment.

4.5.1. When determining the structures’ vibrations and stressedly-deformed state parameters, the design diagram is allowed to be taken in the form of a system with lumped masses. The lumped masses should be located at floor levels, in major components support points and in other characteristic points.

4.5.2. To calculate floor accelerograms and response spectra of buildings and facilities it is allowed to use simplified dynamically similar bar models. To provide dynamic similarity the stiffness values of the simplified model bars should be assumed as equivalent to those of vertical civil engineering structures (columns and walls) between mass concentration elevations. The equivalence condition is the equality of single displacements of mass concentration nodes in the simplified model and in the detailed space model of the facility.

The walls and columns of multi-storey buildings are allowed to be modelled using shearing bars, in case the storey height does not exceed its dimensions in plan.

4.5.3. The design models of buildings and facilities should reflect the nature of their interaction with the foundation soil. When modelling ground base, foundation and facility interaction, consideration should be given to their specific connections and boundary conditions.

4.5.4. The models of buildings and facilities foundations should be developed with account taken of specific features of the ground massif (its bedding, layers thickness and length, physical, elastoplastic, viscous and inertia properties of each layer grounds).

4.6. When assessing seismic resistance of civil engineering structure elements, the orientation of the seismic impact horizontal component should be taken by the most adverse direction for this element.

4.7. The vertical component of the seismic impact should be taken into account for:

buildings (facilities) of seismic resistance category I as acting simultaneously with the horizontal components;

large-span structures of seismic resistance category II (bridges, trestles, covering trusses, containment intermediate floor disks as acting separately from the horizontal components.

4.8. The bearing capacity of building and facility bases should be calculated taking into account three space components for the most adverse orientation of the seismic impact vector.

4.9. The stressedly-deformed state of civil engineering structures is allowed to be defined using a linear-spectral method, taking into account the recommendations contained in Appendices 4, 5 and 6. For Ist seismic resistance category buildings and facilities it is recommended to perform calculations using a dynamic method with setting an impact in the form of accelerograms.

4.9.1. In the phase of investment justification and development of standard NPP designs, standard seismic impacts determined in accordance with Appendix 3 are recommended to be used for preliminary calculations that demonstrate seismic resistance.

4.9.2. To adapt a standard design to the specific plant site it is necessary to perform the seismic resistance checking calculations taking into account initial ground seismic vibrations on this site.

4.10. It is necessary to perform calculations of floor accelerograms and response spectra for support elevations of Ist and IInd seismic resistance category process components.

4.11. When defining the building and facility vibration parameters, energy losses in civil engineering structures and bases should be taken into account.

The parameters of civil engineering structure vibration attenuation (logarithmic vibration decrements and others) should be taken on the basis of special (field, model, experimental and computed) justifications. In case there are no data, the values of civil engineering structure logarithmic vibration decrements are allowed to be assumed according to Table 2.1.

The energy losses in the base should be determined with account taken of the facility-base interaction.

4.12. The seismic resistance of the building and facility foundations should be performed taking into account the dependence of physical-mechanical properties of the ground on its stressed state.

4.12.1. For assessing seismic resistance of the building and facility bases, the base ground stability should be checked at peak values of the overturning moment as well as the dynamic stability of the base ground. The dynamic stability of the cohesionless water-saturated grounds should be assessed on the basis of experimental studies.

4.12.2. For the NPP reactor department building foundation, the calculation results should demonstrate that the criteria for tilts and settlements under seismic impacts established by design rules for the nuclear power plant reactor department foundation are not exceeded.

4.13. As to nuclear power plants located in seismicity zones with the MCE intensity of more than 7, the justification of the building and facility seismic resistance should be demonstrated by the previous operating experience or by tests, field investigations or model-based studies.

5. PROCESS COMPONENTS AND PIPELINES

5.1. The seismic resistance should be justified for components, pipelines and their support structures belonging to seismic resistance categories I and II.

5.2. The seismic resistance of components and pipelines under seismic impacts specified by the floor accelerograms and (or) floor response spectra should be justified using computational and (or) experimental methods.

5.3. The seismic resistance of components and pipelines should be justified in compliance with the current regulatory documents and the provisions of this document.

N o t e. In case there are differences in seismic resistance categories for components and pipelines, established according to the Codes for components and pipelines strength calculations at nuclear power facilities, it is necessary to take the highest category.

5.4. The combination of loads for justifying seismic resistance of components, pipelines, their support structures, bolts and studs of seismic resistance categories I and II should be taken in accordance with Tables 5.1 - 5.4.

Table 5.1

Load combinations and permissible stresses for components and pipelines

Seismic resistance category	Combination of loads	Calculated group of stress categories	Permissible stress
I	NO+MCE	$(\sigma_s)_1$ $(\sigma_s)_2$	1,4 [σ] 1,8 [σ]
	NOF+MCE	$(\sigma_s)_1$ $(\sigma_s)_2$	1,4 [σ] 1,8 [σ]

	NO+DBA+DE (MCE)*	$(\sigma_s)_1$ $(\sigma_s)_2$	1,4 [σ] 1,8 [σ]
	NO+DE	$(\sigma_s)_1$ $(\sigma_s)_2$	1,2 [σ] 1,6 [σ]
	NOF+DE	$(\sigma_s)_1$ $(\sigma_s)_2$	1,2 [σ] 1,6 [σ]
II	NO+DE	$(\sigma_s)_1$ $(\sigma_s)_2$	1,5 [σ] 1,9 [σ]
	NOF+DE	$(\sigma_s)_1$ $(\sigma_s)_2$	1,5 [σ] 1,9 [σ]

* For pipelines and components providing the hermetic enclosure functioning.

Table 5.2

Load combination and permissible stresses for bolts and studs

Seismic resistance category	Combination of stresses	Calculated group of stress categories	Permissible stress
I	NO+MCE	$(\sigma_s)_{3w}$ $(\sigma_s)_{4w}$	1,4 $[\sigma]_w$ 2,2 $[\sigma]_w$
	NOF+MCE	$(\sigma_s)_{3w}$ $(\sigma_s)_{4w}$	1,4 $[\sigma]_w$ 2,2 $[\sigma]_w$
	NO+DBA+DE (MCE)*	$(\sigma_s)_{3w}$ $(\sigma_s)_{4w}$	1,4 $[\sigma]_w$ 2,2 $[\sigma]_w$
	NO+DE	$(\sigma_s)_{3w}$ $(\sigma_s)_{4w}$	1,2 $[\sigma]_w$ 2,0 $[\sigma]_w$
	NOF+DE	$(\sigma_s)_{3w}$ $(\sigma_s)_{4w}$	1,2 $[\sigma]_w$ 2,0 $[\sigma]_w$
II	NO+DE	$(\sigma_s)_{3w}$ $(\sigma_s)_{4w}$	1,5 $[\sigma]_w$ 2,3 $[\sigma]_w$
	NOF+DE	$(\sigma_s)_{3w}$ $(\sigma_s)_{4w}$	1,5 $[\sigma]_w$ 2,3 $[\sigma]_w$

* For bolts and studs providing the functioning of the hermetic enclosure.

Table 5.3

Load combinations and permissible bearing stresses

Seismic resistance category	Combination of loads	Stress category	Allowed stress
I	NO+MCE	$(\sigma_s)_s$	2,7 [σ]
	NOF+MCE	$(\sigma_s)_s$	2,7 [σ]
	NO+DBA+DE (MCE)*	$(\sigma_s)_s$	2,7 [σ]
	NO+DE	$(\sigma_s)_s$	2,5 [σ]
	NOF+DE	$(\sigma_s)_s$	2,5 [σ]
II	NO+DE	$(\sigma_s)_s$	3,0 [σ]
	NOF+DE	$(\sigma_s)_s$	3,0 [σ]

* For components, systems and elements providing the functioning of the hermetic enclosure.

Table 5.4

Load combinations and permissible profile shearing stresses

Seismic resistance category	Combination of loads	Stress category	Allowed stress	
			bolts and studs	for structure's elements except for studs and bolts
I	NO+MCE	$(\tau_s)_s$	0,7 $[\sigma]_w$	0,7 $[\sigma]$
	NOF+MCE	$(\tau_s)_s$	0,7 $[\sigma]_w$	0,7 $[\sigma]$
	NO+DBA+DE (MCE)*	$(\tau_s)_s$	0,7 $[\sigma]_w$	0,7 $[\sigma]$
	NO+DE	$(\tau_s)_s$	0,6 $[\sigma]_w$	0,6 $[\sigma]$
	NOF+DE	$(\tau_s)_s$	0,6 $[\sigma]_w$	0,6 $[\sigma]$
II	NO+DE	$(\tau_s)_s$	0,8 $[\sigma]_w$	0,8 $[\sigma]$
	NOF+DE	$(\tau_s)_s$	0,8 $[\sigma]_w$	0,8 $[\sigma]$

* See footnote for Table 5.3.

5.5. The permissible displacements (deflection, shear, displacement, etc.) should be determined depending on operating conditions for components and pipelines (choice of clearances, admissible distortions, etc.). The allowed displacements for components and pipelines should be determined depending on operating conditions (inadmissible collisions, inadmissible distortions, joint seal failure and so on).

5.6. The seismic loads for components and pipelines should be set taking into account a simultaneous seismic impact by three space components in the form of response spectra and (or) accelerograms for different coordinate axes.

Two types of seismic loads should be taken into consideration to justify components and pipelines seismic stability:

inertia loads resulting from the system dynamic vibrations at a given seismic impact;

loads arising from relative displacement of component and pipeline supports under a seismic impact.

5.7. When designing components and pipelines, the logarithmic vibration decrement values are to be taken in compliance with Table 2.1 when there are no additional data.

5.8. The seismic resistance of components and pipelines should be provided in accordance with the methods of the acting codes and rules in the field of atomic energy utilization. In case there are no methods for particular elements of components and pipelines, the designing should be supported by justification of applied methods and seismic resistance (strength) criteria, taking into account seismic impacts.

5.9. The software products having a qualification certificate issued by the state safety regulating authorities in atomic energy utilization should be used to justify seismic resistance of components and pipelines.

5.10. When justifying seismic resistance of large-size components, the influence of components vibration on their support elements should be taken into account.

5.11. The aseismic design of legthy elements of components and pipelines should be performed taking into account different seismic loading conditions for support structures using floor accelerograms and response spectra characteristic for component support element resting points.

5.12. In justifying seismic resistance of component and pipeline valves, the requirements of the regulatory document "Nuclear power plant component and pipeline valves. General technical requirements" should be taken into account.

5.13. The seismic resistance of components assigned to seismic resistance categories I and II and partially liquid-filled should be demonstarted taking into account hydrodynamic impacts under seismic vibrations of the liquid.

6. ELECTRICAL AND I&C EQUIPMENT, AUTOMATICS AND COMMUNICATION FACILITIES

6.1. The seismic resistance should be justified for electrical and I&C components, automatics and communication facilities, cable routes including their support and structural elements (hereinafter referred to as products) of seismic resistance categories I and II.

6.2. The seismic resistance (vibration stability and vibration strength) justification should be performed using experimental and (or) calculation methods.

6.3. The products should be tested for vibration stability and vibration resistance in order to demonstrate their seismic resistance by experimental method. The Ist seismic resistance category products are tested under the impact of real or harmonic loads equivalent to the MCE seismic impact while the IInd seismic resistance category products are tested under the impact of real or harmonic loads equivalent to the DE-related seismic impact.

6.4. The products should be tested in assembled, secured, adjusted and operable state under the mode simulating the operational state.

6.5. If the mass and overall dimensions of the products do not allow testing them in full set at test facilities, the tests are allowed to be conducted by groups of products or electrical panels.

6.6. The parameters of load conditions are monitored during tests in the fastening base of the products. The method for securing the product at the test bench plate should be similar to its fastening in operation.

6.7. The seismic resistance of the products should be provided under load combinations given in Table 6.1.

Table 6.1

Load combinations for electrical and I&C components, automatics and communication facilities

Seismic resistance category	Combinations of loads
I	NO+MCE, NOF+MCE, NO+DBA+DE(MCE)*
II	NO+DE, NOF+DE

* For electrical and I&C components, automatics and communication facilities providing the functioning of the sealed enclosure.

6.8. The floor accelerograms and floor reaction spectra for the locations where the products are installed at the nuclear power plant serve as initial data for designing and testing the products for seismic resistance.

6.9. The seismic resistance justification of the products for which there are no codes and rules in the field of atomic energy utilization should contain a detailed description of the used methods and criteria according to which the seismic resistance was demonstarted.

7. ANTISEISMIC PRECAUTIONARY AND PROTECTIVE ACTIONS

7.1. To ensure the automatic reactor scram in case of earthquakes of a given intensity, a seismometric monitoring and alarm system, connected to the reactor emergency protection system, should be provided for.

7.2. The seismometric monitoring and alarm system should provide generation of the command for automatic emergency reactor scram under seismic ground impact corresponding to the DE as well as automatic recording of the sensors vibrations at the level of the reactor plant building footing.

7.3. The NPP design should include technical measures and organizational actions for protection of the plant personnel, communication and personnel warning facilities and physical protection systems in case of seismic impacts.

Appendix 1
(recommended)

TAKING INTO ACCOUNT GROUND CONDITIONS FOR DEFINING THE PLANT SITE SEISMICITY

Ground category by seismic properties	Ground	NPP site seismicity J_{site} under area seismicity $J_{ar.}$, intensity point
I	Rocky grounds of all types (including permafrost and permafrost thawed soils) unweathered and weekly weathered, large fragmental, compact, low-moisture laden grounds consisting of magmatic rocks, containing up to 30 % of argillo-arenaceous filler; weathered and heavily weathered rocky and earth hard-frozen (permafrost) grounds at temperature of -2°C and lower during construction and operation according to the principle I (preservation of the foundation soils in frozen state)	$J_{site} = J_{ar} - 1$
II	Weathered and heavily weathered rocky grounds including permafrost grounds, with the exception of those ranked in category I; large fragmental grounds except for those ranked in category I, gravel sands, coarse and medium-coarse, compact and medium-compact, low-humid and humid; fine and pulverescent sands, compact and medium-compact, low-humid; clayey grounds with consistency index of $jL \leq$ 0,5 at porosity factor of e < 0,9 – for clays and loams and e < 0,7 – for clay sand; permafrost earth, ductile-frozen or loose-frozen as well as hard-frozen at temperature higher than -2°C during construction and operation according to principle I	$J_{site} = J_{ar.}$

III	Loose sands, independently on humidity and coarseness, gravel sands, coarse and medium-coarse, compact and medium-compact, humid and water-saturated, clayey grounds with consistency index of jL > 0,5, clayey grounds with consistency index of $jL \leq 0,5$ at porosity factor $e \geq 0,9$ – for clays and loams and $e \geq 0,7$ – for clay sand, permafrost earth during construction and operation according to principle II (the base ground thawing is allowed)	$J_{site} = J_{ar.} + 1$

N o t e s.

1. This Table should be used for preliminary refinement of the plant location area seismicity, taking into account the site ground conditions and their possible changes in the process of NPP construction and operation. The NPP site seismicity should be definitely determined on the basis of the SMZ results.

2. Ranking the site grounds in the I[st] category by their seismic properties is allowed if their thickness in the plant building (facility) base exceeds 30 m.

3. If the adverse grounds have total thickness of more than 5 m within the limits of 10-m thick non-homogeneous layer of the ground (counting from the planning elevation), then the grounds are assigned a more unfavourable category by their seismic properties.

4. For underground water level rise and ground (including subsided ground) watering, anticipated in the process of the plant building (facility) operation, the ground category by seismic properties should be determined depending on its properties (humidity, consistency) in wetted state.

5. The grounds of the plant building (facility) base should be considered as non-permafrost (judging by their post-thawing state), on the permafrost earth grounds if the thawing area extends to sub-base non-frozen ground.

6. Clayey and sandy grounds are ranked among category III grounds by seismic properties, if the level of underground water is at a depth of less than 5 m from the plan surface and if there are no data on their consistency or humidity.

7. When siting a nuclear power plant within the PFPE areas on the I[st] category grounds by their seismic properties, the reduction in the site seismicity by 1 point relative to the plant location area seismicity when defining the site seismicity in MCE terms is not allowed.

Appendix 2
(recommended)

GENERIC PROGRAMME OF ACTIONS FOR REFINING NUCLEAR POWER PLANT SITE GEODYNAMIC AND SEISMIC CONDITIONS

I. The goal of activities is to determine the site seismicity and the DE and MCE parameters.

II. Main objectives

1. Identification of geodynamic zones and active faults and determination of their parameters.
2. Refinement of PFPE zone location and parameters and assessment of seismic mode parameters.
3. Justification of the NPP site location within the limits of a homogeneous Earth crust block not damaged by active faults.
4. Identification of places for possible initiation of primary Earth surface deformations under earthquakes up to the MCE inclusively and evaluation of their parameters. Primary ground deformations: ground disturbances related to the earthquake source going out on the free surface.
5. Definition of dynamic properties of base rocks (grounds) down to a depth of 100 m.
6. Assessment of impacts from the site engineering-geological and hydro-geological conditions on the intensity and spectral distribution of vibrations in case of earthquakes.
7. Account taken of the impact caused by the site engineering-geological and hydro-geological conditions on the intensity and spectral vibration distribution in case of earthquakes.
8. Determination of the DE and MCE parameters of a given probability of not being exceeded for natural and man-induced changes in the plant site conditions.

III. Investigation content

1. Assessment of the impact due to distant earthquake sources at the GSZ level of the Russian Federation territory on a scale of 1: 2 500 000 and smaller.

1.1. Obtaining initial data on remote earthquake sources in order to make a decision on whether a nuclear power plant may be located in the considered region.

1.2. Determination of mean values and DE and MCE standard deviations for medium grounds from distant (transit) earthquake sources.

2. The GSZR of the plant location area is recommended to be performed on a scale of 1: 500 000 and smaller at the radius from 150 to 320 km from the nuclear power plant.

2.1. Justification of NPP alternative sites within the limits of the solid Earth crust blocks not disturbed by regional, active fults as lengthy as 30 km and more.

2.2. Identification of PFPE zones, definition of their parameters and seismic mode parameters.

2.3. Refinement of the area seismicity and determination of the DE and MCE parameters for alternative nuclear power plant sites for medium grounds.

3. Refinement of geodynamic and seismotectonic conditions of the NPP site on a scale of 1:50 000 and smaller at the radius of 25 km and more from the nuclear power plant.

3.1. Study of geodynamic tectonic conditions in order to mark out geodynamic zones and active faults, determination of their parameters (structure sequence, length, width, amplitude, period of relative motion of the Earth crust adjacent blocks, degree of dynamic activity (long-term speed of the Earth crust deformation) and drawing-up maps-diagrams of geodynamic zones and active faults.

3.2. Determination of locations and parameters of the nearest PFPE zones and their minimum remoteness from the plant site.

3.3. Justification of the NPP site (alternative sites) location within the limits of a solid Earth crust block not disturbed by geodynamic zones and active faults as lengthy as 3 km and longer.

Notes.

1. Seismically active fault: discontinuous disturbance the Earth crust to which the past or recent seismic occurrences are timed (earthquake sources, paleoseismic dislocation, seismic dislocation).

2. Tectonically active fault: tectonic fault within the area whereof the displacement of adjoining blocks by 0,5 m and more took place over the last 1 ml. years (quaternary period).

3.4. Determination of the plant site DE and MCE parameters from local PFPE zones for medium grounds.

4. Definition of ground (rock) properties for alternative NPP sites and refinement of the area seismicity on a scale of 1: 5 000 and smaller for the territory at the radius of 5 km and farther from the nuclear power plant, taking into account specific ground conditions.

4.1. Description of the NPP site grounds (rocks) to a depth of down to 100 m (layer-by-layer): thickness, density, velocity of propagation of longitudinal and transverse seismic waves; shear modulus (transversal elasticity modulus), longitudinal strain modulus, Poisson's ratio.

4.2. Assessment of the impact of relief features, geological-geophysical environment structure, ground properties and underground water level on the site seismicity.

4.3. Refinement of the area seismicity taking into account specific ground conditions.

4.4. Drawing-up maps-diagrams of the plant site SMZ.

5. Prediction of the NPP site grounds (rocks) characteristics and seismicity, taking into account design developments in terms of changes in natural conditions over the plant construction and operation period.

5.1. Prediction of grounds (rocks) properties in the building and facility bases under man-induced changed conditions to a depth of down to 100 m (layer-by-layer): thickness, density, velocity of propagation of longitudinal and transverse seismic waves (transversal elasticity modulus), longitudinal strain modulus, damping (hysteresis) coefficient, Poisson's ratio.

5.2. Prediction of DE and MCE parameters taking into account changes in ground properties and environment parameters during NPP construction and operation.

5.3. Preparation of recommendations for seismic, geotechnical and geodynamic monitoring of the natural environment in the process of NPP construction, operation and decommissioning.

6. Monitoring of stable geological environment state and properties over the period of NPP construction, operation and decommissioning.

6.1. Monitoring of seismic regime in the plant location area.

6.2. Monitoring of ground physical properties and hydro-geological conditions in plant building foundations.

6.3. Monitoring of the plant site geodynamic conditions.

6.4. Production of recommendations for taking into account changes in the geological environment state and properties.

IV. Composition of investigations

1. GSZ

1.1. Preliminary determination of the area seismicity for the MCE level according to the OSR-97-D map and of the area seismicity for the DE level according to the OSR-97-B map.

Note. The calculation of the seismic hazard on the Russian Federation territory was performed using a grid with a pitch of 25×25 km^2, the accuracy of isolines is commensurate with this value. Therefore, the seismic hazard assessment of all population sites located at a distance of up to 30 km from the boundaries of intensity zones should be refined by one or another method (GSZR, SMZ and so on) or they should be assigned to a more seismic hazardous area.

1.2. Generalization and analysis of justifying materials for general seismic zoning (GSZ-97): a set of maps and associated explanatory note and their use for determination of DE and MCE parameters from distant earthquake sources.

2. GSZR of the area

2.1. Analysis of archival materials on geological structure, recent tectonics, geophysical fields, seismicity, location area relief (maps on a scale of 1:1 000 000, 1:500 000, 1:200 000).

2.2. Drawing up structural-tectonic maps reflecting the discrete-hierarchical block model of the Earth crust in the region and the plant location area.

2.3. Field reconnaissance for the purpose of adapting geology, geomorphology, seismology data and grounds-related information to specific conditions.

2.4. Additional deciphering of aerial and space photographs, field geological-geomorphologic activities and morphometric analysis of the territory in order to refine materials and structural-tectonic maps, first of all, for newest, quarternary and recent tectonics, seismic dislocations and fast geological aseismatic processes.

2.5. Drawing up a map of geological-tectonic seismicity criteria.

2.6. Seismological studies:

refinement of a consolidated catalogue of historical and instrumentally recorded earthquakes;

building up a map of earthquake epicentres;

drawing up diagrams and section views of the observed large earthquake sources;

refining regional and local laws of intensity falling transversely and along seismogenic structures as well as by the area, drawing up a map of regions with different intensity decay;

drawing up a map of PFPE zones for the plant location area and determination of their mean parameters and standard deviations;

definition of DE and MCE initial parameters for different types of earthquake sources for medium grounds.

3. Refinement of the plant site geodynamic and seismotectonic conditions.

3.1. Analysis of available data:

topographic plans, geophysical, geodynamic, hydro-geological and engineering-geological maps on a scale of 1:50 000 - 1:10 000 and smaller;

consolidated geological-lithologic section views;

data on physical-mechanical properties of rocks and grounds.

3.2. Working out non-uniformly scaled discrete-hierarchical block models of the Earth crust.

3.3. Conduct of additional geological-geophysical investigations in order to refine parameters of heterogeneities and discontinuous disturbances and to delineate solid Earth crust blocks, not disturbed by active faults.

3.4. Refining distribution of seismic wave propagation velocity on the plant site territory to a depth of 100 m as well as position of the crystalline bed and bed disturbances in the plant location area.

3.5. Seismological studies including:

delineation of the area of medium ground occurrence;

instrumental recording of microearthquakes;

study of spectral vibration distribution under earthquakes, determination of the spectral ground characteristic;

refinement of parameters and position of local focal zones, initial DE and MCE parameters for medium grounds;

definition of generalized ground reaction spectra with a given probability of not being exceeded and initial set of DE and MCE analogue and (or) synthesized accelerograms for reference and (or) medium grounds. When selecting analogue accelerograms, it should be necessary to take into account that the earthquake accelerogram should be obtained at the day surface aside buildings and facilities as well as in a pit as deep as down to 1 m or at the foundation of a not high building (up to four storeys) without a basement.

4. SMZ.

4.1. SMZ of the plant alternative sites using the method of engineering-geological analogies.

4.2. Instrumental SMZ of the first-priority plant site using the methods of:

seismic stiffness;

recording of vibrations under microseismic waves and of vibrations excited by earthquakes, explosions and no explosive sources.

4.3. Building up seismic microzoning maps and drawing up associated explanatory notes.

4.4. Updating a set of calculated accelerograms, taking the SMZ into account.

V. Reporting document composition

1. Requirements to engineering survey and investigation materials.

1.1. Description of:

region’s and area’s newest tectonics, seismic tectonics and seismicity;

relief, geomorphology, tectonic structure, hydrogeology and seismicity of the plant site;

composition, state and properties of grounds and rock massifs in the building and facility bases;

hazardous geological processes and phenomena.

1.2. Representation on:

maps of the region and area newest tectonics, seismotectonic and seismicity;

maps of engineering-geological zoning and seismic microzoning of the plant site;

maps of hydro-geological conditions;

engineering-geological sections to a depth of about 100 m.

1.3. At engineering-geological and geoseismic section views it should be necessary to:

delineate and describe in the explanatory note all the layers (engineering-geological elements) which can affect the bearing capacity of the building and facility bases;

give normative characteristics and physical-mechanical properties of the grounds in natural and water-saturated states, for permafrost grounds: in natural and thawed states;

make a special emphasis on soft and dynamically unstable ground pockets and interlayers present in sections.

1.4. On the maps of the plant site engineering-geological zoning: emphasize and describe areas of possible surface settlement, soil liquefaction and reduction in bearing capacity of the bases under the impact of adverse factors (grounds' underflooding, drying, humidity change, freezing and thaw) as well as their combinations with the earthquake impacts and the seismicity of explosions, static and dynamic loads.

1.5. On the hydro-geological maps for two-three water-bearing horizons from the ground surface: show the depth of the underground (ground) water level and seasonal level variations, flow directions and velocity, filtration coefficients in different layers and other engineering-geological elements.

1.6. When locating a building or a facility on the bedrock foundation, show on the maps and section views weakened zones (zones of increased fracturing and tectonic disturbances) in the massif and give data on the rocks state and properties in these zones and non-disturbed blocks of the massif.

1.7. Give, in a tabular form, grounds characteristics to calculate bearing capacity and deformations of the bases, seismic impact parameters and to assess possible negative effects of hazardous geological processes (karst, suffusion, landslides and others) with account taken of possible geotechnogenious changes in ground properties (for instance, frozen ground thaw).

1.8. Assess likely tilts and displacements (settlement, rise, horizontal motion) over the whole period of NPP operation.

2. The report on the NPP site seismicity assessment should contain:

consolidated catalogue of regional earthquakes;

map-diagram of the area PFPE zones on a scale of 1:500 000;

diagram of geodynamic and seismotectonic conditions for site location on a scale of 1:50 000;

SMZ map to scale of 1:5000 indicating areas where it is not allowed to construct plant safety-significant buildings and facilities;

characteristic of medium and (or) reference grounds and DE and MCE parameters for the reference ground and specific site conditions;

peak acceleration values of the free ground surface with 50% probability of not being exceeded;

generalized reaction spectra of 84% probability of not being exceeded and their corresponding set of calculated accelerograms for specific ground conditions for the DE and MCE level.

3. Seismic, geodynamic and geotechnical monitoring of the stable state and properties of the geological environment in the course of time.

3.1. Generalization and analysis of geodynamic, seismological, hydro-geological and geotechnical survey and investigations in the period of survey for the feasibility study and the design in order to determine:

background parameters of the natural environment (environmental parameters established at the time of the facility start of operation);

needed and adequate density of a network of seismic and geophysical stations;

location of seismic and geophysical stations, parametric pits and benchmarks, optimal by the background interference level;

instrumentation scanning frequency (frequency of environmental parameters measurement).

3.2. Development of a programme for monitoring (regime) observations of the stability of geological environment state and properties.

3.3. Organization and conduct of observations in compliance with the programme for seismic, geodynamic and geotechnical monitoring of the stable state and properties of the geological environment over the period of NPP construction and operation.

3.4. Obtaining a series of values of the monitored natural environment parameters and monitoring their stability in time.

3.5. Accumulation of parameter change time series under continuous monitoring of the natural environment stability in the plant location area and on the plant site during its construction, operation and decommissioning.

4. Drawing up a consolidated report comprising:

the area seismicity according to the GSZ maps, characteristic of distant seismotectonic provinces and PFPE zones, associated explanatory note, including the site DE and MCE seismicity from distant PFPE zones;

GSZR map-diagram of the plant location area including PFPE zones and their parameters – zones of likely initiation of primary and secondary residual ground deformations and an associated explanatory note containing the characteristic of the intensity decay when moving away from focal zones as well as DE and MCE parameters for medium grounds;

maps-diagrams of geodynamic areas, active faults and an associated explanatory note containing the results of DE and MCE parameters determination taking into account local PFPE zones;

SMZ maps-diagrams of the plant site for natural and man-induced changed conditions and an associated explanatory note including zones of intensity increment, DE and MCE parameters, resonance periods of the site ground vibrations, velocity profiles, calculation results of spectral vibration characteristics of the site multilayered medium, description of areas where secondary residual ground deformations can possibly occur;

DE and MCE parameters: maximum acceleration values of the free ground surface with 50% probability of not being exceeded and ground response spectra of 84% probability of not being exceeded for different logarithmic vibration decrements 1,26 (20%), 0,63 (10%), 0,44 (7%), 0,31 (5%), 0,25 (4%), 0,12 (2%), 0,03 (0,5%) and their corresponding synthesized accelerograms in numerical and graphical form and an associated explanatory note;

assessment of the site ground dynamic stability under earthquakes up to MCE inclusively.

5. Review of the area GSZR and the site SMZ results according to the established procedure.

Appendix 3
(recommended)

STANDARD SEISMIC IMPACTS

1. Standard seismic impacts are recommended to be used for preliminary calculations of the plant seismic resistance in the phase of investment justification if geological-geophysical, geodynamic and seismological information is not complete.

2. Standard seismic impacts include:

site seismicity (in intensity points);

maximum ground accelerations;

spectrum of dynamic factors under different logarithmic vibration decrements δ;

set of synthesized ground accelerograms.

3. The plant location area seismicity J_{ar} (in intensity points) is defined for medium grounds using the maps OSR-97-B (DE) and OSR-97-D (MCE).

4. The site seismicity $J_{site} = J_{ar} \pm \Delta J$ (intensity point) is defined with account taken of the area seismicity J_{ar} and the seismicity increment ΔJ, specified depending on ground categories by seismic properties according to Appendix 1.

5. The acceleration corresponding to probability of not being exceeded and equal to 50% is taken as maximum ground acceleration for a given seismicity of the site. The maximum ground acceleration values, depending on the plant site seismicity, are given in Table P.3.1.

Table P.3.1

Maximum ground acceleration depending on NPP site seismicity

NPP site seismicity, J_{site} , magnitude	7	8	9
Maximum ground acceleration, a_0 , m/s^2	1,0	2,0	4,0

N o t e. Maximum ground accelerations in both horizontal directions should be taken as the same: $a_X = a_Y = a_0$. The maximum ground acceleration in vertical direction is: $a_z = 2/3a_0$.

6. The dynamic factor spectrum β for a given value of the logarithmic vibration decrement δ is determined as: $\beta(T, \delta) = a_{84\%}(T, \delta) / a_0$, where $a_{84\%}(T,\delta)$ – standard ground response spectrum corresponding to 84% probability of not being exceeded. The dynamic factor spectra β for DE and MCE are shown in Figure P.3.1 and given in Table P.3.2.

7. The set of synthesized accelerograms is built with account taken of the maximum ground acceleration a_0 and dynamic factor spectra β in compliance with the special methods approved according to the established procedure.

N o t e. The ordinates of the synthesized accelerogram reaction spectrum should not deviate from the standard spectrum ordinates by more than 10%.

Figure P.3.1. Spectra of dynamic factors for different logarithmic vibration decrement δ

Table P.3.2

Ordinates of dynamic factor spectra β of the standard response spectrum (accelerations) at 84 % probability of not being exceeded for different logarithmic vibration decrements δ

Vibration period, s	Dynamic factor β						
	For logarithmic vibration decrements δ						
	1,26	0,63	0,44	0,31	0,25	0,12	0,03
0,03	1	1	1	1	1	1	1
0,100	1,75	2,35	2,82	3,20	3,52	4,48	5,86
0,600	1,75	2,35	2,82	3,20	3,52	4,48	5,86
4,000	0,43	0,58	0,68	0,79	0,87	1,1	1,45

N o t e. The ordinates of dynamic factor spectra at vibration periods correspond to spectral curve breaking points.

Appendix 4
(recommended)

DETERMINATION OF FORCES IN CIVIL ENGINEERING STRUCTURE ELEMENTS FOR CALCULATIONS USING A LINEAR-SPECTRAL METHOD

1. The forces induced by design loads in civil engineering structure elements should be determined depending on forces corresponding to different seismic impact directions, according to the formulas given in Table P.4.1.

Table P.4.1

Design forces in civil engineering structure elements

It. No.	Type of civil engineering structure	Rated force value
1	Structures of I[st] seismic resistance category buildings (facilities)	The largest of values determined by the formulas: $N = \pm(N_X \pm 0.4N_Y \pm 0.4N_Z)$ $N = \pm(\pm 0.4N_X + N_Y \pm 0.4N_Z)$ $N = \pm(\pm 0.4N_X \pm 0.4N_Y + N_Z)$ $N = \pm\sqrt{N_X^2 + N_Y^2 + N_Z^2}$
2	Large-span II[nd] seismic resistance category structures (of bridges, trestles, roofing trusses, intermediate floor discs and others)	The largest of values determined by the formulas: $N = \pm N_X$ $N = \pm N_Y$ $N = \pm N_Z$
3	Structures of other II[nd] seismic resistance category buildings (facilities)	$N = \pm N_X$ $N = \pm N_Y$
4	Structures of III[d] seismic resistance category buildings (facilities)	According to building codes and rules

N o t e s.

...in an element from seismic impact in *X*-axis (horizontal) direction;
..in an element from seismic impact in *Y*-axis (horizontal) direction;
..in an element from seismic impact in *Z*-axis (vertical) direction.

2. When performing calculations using a linear-spectral method, the design force in an element resulting from seismic impact in *j* direction should be determined by root-mean-square summation by waveforms as:

$$N_j = \sqrt{\sum_{i=1}^{n_j} N_{ji}^2} \qquad (4.1)$$

where N_{ji}, N_{jjl} , N_{jm} – force in a given element corresponding to *i*-type (*l-type, m-type*) form of the building (facility) vibration due to seismic impact in *j* direction;

n_j – number of accounted vibration forms during calculations for seismic impact in *j* direction.

If the periods of some accounted natural vibration forms differ by not more than 10%, it should be necessary to take into account possible coincidence of peaks of the corresponding forces in time.

The forces N_{ji} should be determined from seismic loads S_{jik} applied to mass concentration nodes of the model in *j*-direction. The load values S_{jik} should be determined in compliance with the recommendations of it.3.

3. The design seismic load value in mass concentration node *k* under vibrations in *i* form should be determined according to the formula:

$$S_{jik} = K_e \eta_{ik} m_k \beta_i a_j , \qquad (4.2)$$

where K_e – coefficient taking into account special plant operating conditions (is assumed as per it. 4);

η_{ik} – form factor to be determined according to building codes and rules;

m_k – lumped mass in *k* node of the model;

βi – dynamic factor corresponding to *i* form of natural vibrations to be determined in compliance with it. 5;

a_j – maximum ground acceleration in *j* direction (in one of horizontal directions either *x* or *y,* or in vertical direction *z)*, to be determined in accordance with it. 6.

4. The coefficient K_e for structures where the development of inelastic deformations is not allowed by the plant safety conditions should be taken as equal to 1. The coefficient K_e for other structures is allowed to be taken as less than 1 but not less than the values given in Table P.4.2. The admissible level of inelastic deformations for I[st] and II[nd] seismic resistance category structures should be justified by the design.

Table P.4.2

Permissible minimum values of K_e factor

Type of structure	Rated force value
Structures of I[st] seismic resistance category buildings (facilities)	0,625
Structures of II[nd] seismic resistance category buildings (facilities)	0,5
Structures of III[d] seismic resistance category facilities	K_1 according to building codes and rules

N o t e. For structures of II[nd] seismic resistance category, not intended to store radioactive products and fluids, K_e is allowed to be taken as equal to 0,3.

5. The value β_i should be determined by the dynamic factor spectrum β_i (T_i, δ) corresponding to the accepted value of the logarithmic vibration decrement δ at $T = T_i$. The dynamic factor spectra should be based on the results of investigations, taking into account specific seismotectonic conditions of the plant site. In the phase of investment justification, it is allowed to use dynamic factor spectra β_i of the standard response (acceleration) spectrum according to Appendix 3.

6. The value a_j should be based on the results of survey, taking into account specific seismotectonic conditions of the plant site. It is allowed to use the recommendations of Appendix 3 in the phase of investment justification.

7. For I[st] seismic resistance category buildings and facilities it is recommended to take into account structures'space nature of operation when defining η_{ik} and T_i.

8. When calculating structures' elements for strength and stiffness, in addition to operating conditions coefficients, taken pursuant to building codes and rules, the coefficient of operating conditions m_{oc} is additionally introduced which takes into account short-term seismic impact and is determined according to building codes and rules, with no account taken of coefficients depending on earthquake recurrence.

Appendix 5
(recommended)

BASIC PROVISIONS FOR SEISMIC RESISTANCE CALCULATION OF LIQUID-CONTAINING RESERVOIRS

1. The calculation of the seismic resistance of completely water-filled reservoirs should be performed taking into account the mass of the liquid they contain.

2. The calculation of the seismic resistance of partially water-filled reservoirs should be performed taking into account the reservoir-contained liquid vibration under seismic impact.

3. The liquid contained in a reservoir with a relative depth of $\xi \le 0,75$ is allowed to be represented as a system consisting of two masses: kinematic mass m_1 and inertia mass m_2, mechanically related to the reservoir's design (Figure P.5.1).

The relative depth of the reservoir should be determined as:

$$\xi = h / B \,, \tag{5.1}$$

where *B* – width for reservoirs rectangular in plan and diameter for cylindrical reservoirs.

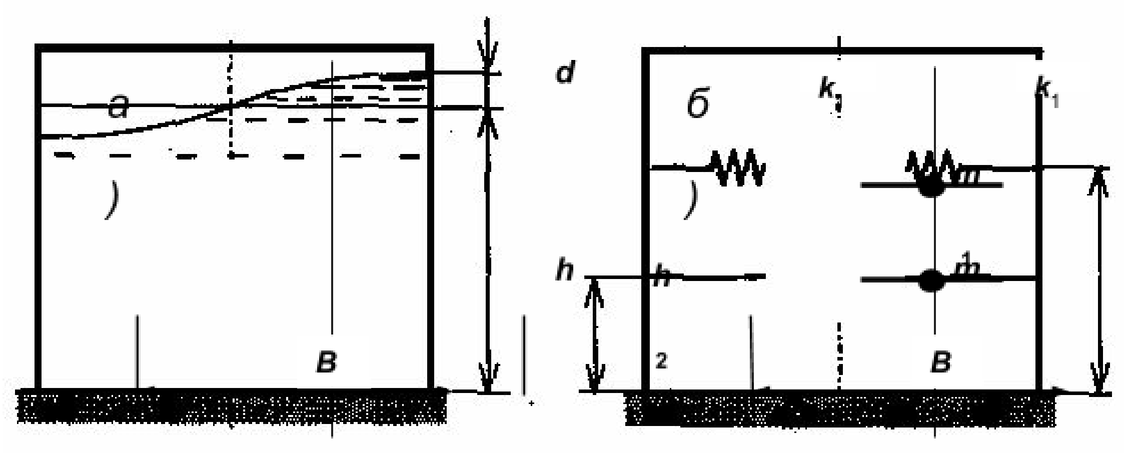

Figure P.5.1. Modeling of a liquid-containing reservoir:
a – reservoir liquid vibrations; *б* – liquid-containing reservoir design diagram
h – reservoir liquid level; *d* – wave height;
m_1 – kinematic mass; m_2 – inertia mass;
h_1, h_2 – connection of kinematic and inertia masses

In this case, the design parameters are allowed to be taken according to Table P.5.1.
The total stiffness of spring linkages k_1 should be taken according to the formula:

$$\sum k_1 = \omega^2 m_1 , \qquad (5.2)$$

where ω - circular frequency of the liquid surface vibrations.

Table P.5.1

Parameters for seismic resistance calculation of the reservoir with a relative depth of $\xi \le 0,75$

Rated parameter	Rectangular reservoir	Cylindrical reservoir
m_1	$m\dfrac{0,27\text{th}(3,16\xi)}{\xi}$	$m\dfrac{0,23\text{th}(3,68\xi)}{\xi}$
m_2	$m\dfrac{2\xi}{\sqrt{3}}\text{th}\dfrac{\sqrt{3}}{2\xi}$	$m\dfrac{2\xi}{\sqrt{3}}\text{th}\dfrac{\sqrt{3}}{2\xi}$
h_1	$h\left[1-\dfrac{\text{ch}(3,16\,\xi)-\beta}{3,16\,\xi\text{sh}(3,16\,\xi)}\right]$	$h\left[1-\dfrac{\text{ch}(3,68\,\xi)-\beta}{3,68\,\xi\cdot\text{sh}(3,68\,\xi)}\right]$
h_2	$0,38h\left[1+\alpha\left(\dfrac{m}{m_2}-1\right)\right]$	$0,38h\left[1+\alpha\left(\dfrac{m}{m_2}-1\right)\right]$
ω^2	$\dfrac{3,16g}{B}\text{th}(3,16\xi)$	$\omega^2 = \dfrac{3,68g}{B}\text{th}(3,68\xi)$

N o t e s.
1. The α, β coefficients should be taken as follows:
for calculation of the reservoir walls: α = 0, β = 1,0;
for calculation of base loads: α = 1,33, β = 2,0.
2. The *m* value in Table P.5.1 designates the total liquid mass in the reservoir.

4. The calculation of steel reservoirs for seismic impacts should be performed taking into account elastic deformations of the reservoir body.

5. The seismic resistance of the reservoirs' ground foundations should be provided by calculating their resistance to a special combination of loads with a view of non-admission of ground uplift from under the most stressed reservoir rim at maximum values of the overturning moment.

Appendix 6
(recommended)

BASIC PROVISIONS FOR CALCULATING LINEAR-LENGTHY STRUCTURES

1. To justify seismic resistance of linear-lengthy structures (pipelines, cable channels, trestles and so on) it is necessary to take into account forces which can arise due to structure's different sections covering by different phases of the seismic wave (Figure P.6.1).

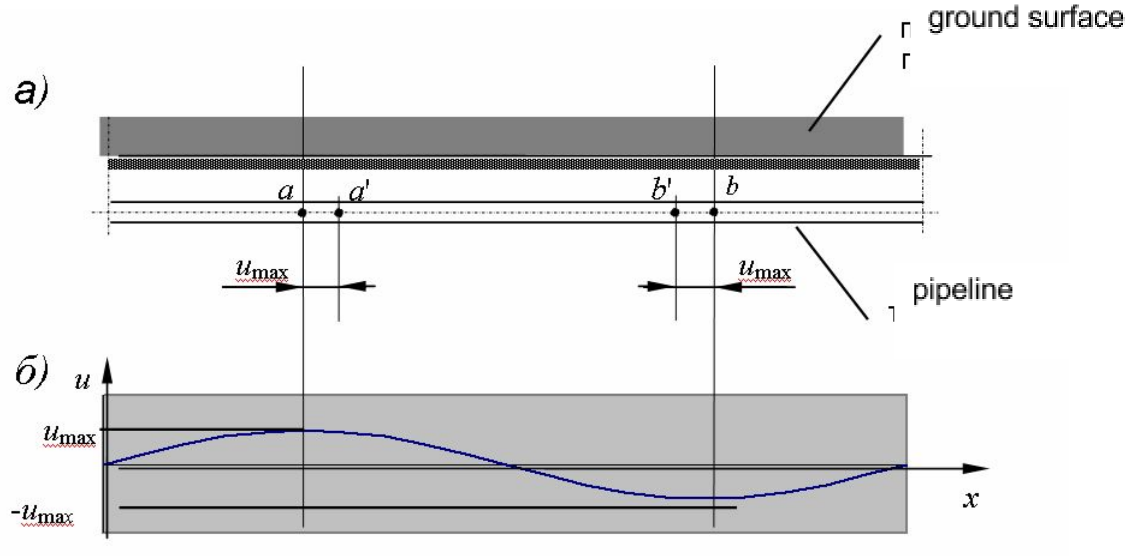

Figure P.6.1. Deformations of a linear-lengthy structure under passage of a longitudinal seismic wave:
a) – underground pipeline section;
б) – displacement under longitudinal wave passage;
a, *b* – position of pipeline assembly units prior to deformation;
a', *b*' – the same after deformation

2. The forces and displacements in linear-lengthy structures related to seismic wave passage should be determined depending on the wave type. The types of accounted seismic waves should be taken as per Table P.6.1.

Table P.6.1

Types of accounted seismic waves

Index of wave type	Wave type
1	Longitudinal
2	Transverse
3	Rayleigh wave

3. When justifying seismic resistance of linear-lengthy structures, it is necessary to take into account the forces resulting from mutual displacement of anchor supports due to their covering by different phases of seismic wave. Mutual displacements of anchor supports should be considered as antiphased.

4. For beam-typed linear-lengthy structures, located in the ground, the longitudinal force F_k and the bending moment M_k under passage of a *k*-type wave should be determined by the formulas (6.1) and (6.2):

$$F_k = EA \frac{v_{max}}{\alpha_k V_k} \leq F_t \; ; \qquad (6.1)$$

$$M_k = EI \frac{a}{(\beta_k V_k)^2} \; , \qquad (6.2)$$

где v_{max} Maximum velocity of ground particles motion under the earthquake;

a Maximum ground acceleration under the earthquake;

V_k Velocity of propagation of *k*-type wave;

α_k, β_k Coefficients to be determined according Table P.6.2;

F_t Stresses transferred to a structure due to ground friction;

A Area of a cross-section of a structure's element;

I Inertia moment of a structure's element cross-section.

Table P.6.2

Coefficients for calculation of ground-located beam-type structures

Coefficient	Wave type index *k*		
	1	2	3
α_k	1,0	2,0	1,0
β_k	1,6	1,0	1,0

5. The maximum speed of ground particles movement under an earthquake is allowed to be determined as:

$$v_{max} = v_0 \frac{a}{g} \; . \qquad (6.3)$$

The value v_0 should be taken depending on the ground category by seismic properties:

for I[st] category ground v_0 = 0,91m/s;

for 2[nd] category ground v_0 = 1,2 m/s.

The ground category by seismic properties should be taken in compliance with Appendix 1.

6. The F_t value should be defined as:

$$F_t = f_t \frac{\lambda_k}{4} \; , \qquad (6.4)$$

friction force between structure and ground per unit of length;

ıf *k*-type.

7. The a value should be taken on the basis of seismological conditions with account taken of specific seismotectonic and ground conditions of the plant site, in the phase of investment justification, in accordance with the recommendations of Appendix 3.

The V_k and λ_k values should be taken according to the results of determination of the plant site ground dynamic properties conducted in compliance with it.5 of Section II, Appendix 2.

It is allowed to take V_3 as equal to $0,9V_2$.

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