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VCI TECHNICAL GUIDELINE

THE SEISMIC LOAD CASE IN PLANT ENGINEERING

Design, dimensioning and construction
of structures and components in the chemical industry
based on DIN EN 1998-1

March 2022 – Rev. 03/23

This document is the English translation of the German document

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Overview of the major changes to the VCI-Guideline 2012

1) Incorporation of the innovations from the National Annex to Eurocode 8 Part 1 (DIN EN 1998-1/NA:2021) updated in 2021 with regard to the description of the seismic action; in particular:

Section 5.1:	Zone-free description of the seismic action; maximum value (plateau) of the response spectrum $S_{aP,R}$ as input value for the calculation of the response spectrum (previously: a_{gR})
Table 5.1:	Adaptation of the Hazard statement codes under consideration
Section 5.2:	Soil factor S dependent on the ground condition at the site and on the spectral acceleration in the plateau range $S_{aP,R}$
Clause 5.4(2):	Description of the vertical component of the seismic action

2)	Sections 1(4) & 5.1(2):	Note that even in areas of very low seismicity, proof of seismic safety may be required
3)	Section 3:	Extension of the definitions of terms by the term "components"
4)	Sections 4 and 7.2:	Notes on anchor design
5)	Section 4.c:	Extension of the notes on conceptual and structural design by further pictorial explanations
6)	Section 6.1.b:	Note on damping values and behaviour factors for silos and tank structures
7)	Section 6.2:	More detailed explanation on non-linear static calculation methods
8)	Section 6.4:	Explanatory additions to the parameter description for the simplified design equation for non-structural components
9)	Clause 7.2(1):	Verification of the functionality of safety-relevant elements at the ultimate limit state
10)	Clause 10(5):	Determination of seismic action for plants with low residual operating time
11)	Clause 10(6):	Note on possible non-linear static calculation methods for the assessment of existing facilities
12)	Entire document:	Editorial changes and additions

Changes within revision of March 2023:

1)	Sect. 5.2 of commentary:	Reference to amendment DIN EN 1998-1/NA/A1:2023
2)	Entire document	Editorial changes and additions

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Introduction

In 2009, the German Chemical Industry Association (VCI) in cooperation with the Chair of Structural Analysis and Dynamics of RWTH Aachen, published the first edition of the technical guideline "Der Lastfall Erdbeben im Anlagenbau” (*The Seismic Load Case in Plant Engineering*). Based on DIN 4149:2005, which was valid at the time, this guideline gave recommendations for handling the seismic load case in plant engineering in the chemical industry and related industries, from which additional hazards can emanate in the event of an earthquake.

In the course of the harmonisation of technical codes in Europe, DIN 4149:2005 was replaced by DIN EN 1998-1 and expanded through the inclusion of additional parts of DIN EN 1998 (Eurocode 8). With the National Annex DIN EN 1998-1/NA:2021, the seismic action for building sites in Germany is no longer defined in terms of zones, but site-specifically instead. In addition, national and international experiences and standard developments have necessitated further adaptations of the guideline.

This new edition of the VCI guideline will provide operators and planners with guidelines for structural design and construction of facilities for use in the chemical industry and related industries based on the state of the art in technology. The guideline is primarily intended for use when designing and executing new facilities. However, the guideline also provides useful recommendations with respect to safety and economic efficiency when dealing with existing facilities (“brown field facilities”). It should be noted, though, that immission control laws do not generally require existing facilities to be adapted to the current state of the art in technology. The commensurability of the retrofitting measures must be assessed on a case-by-case basis, which means individually for each facility and for every single requirement.

As before, this guideline is limited to important changes and supplements to DIN EN 1998-1 that are relevant to applications in chemical facilities. It is therefore necessary to apply the guideline in combination with the standard. For facilities whose seismic response differs from that of common buildings, the guideline provides references to the other parts of the DIN EN 1998 series of standards. Accordingly, users should have adequate experience in applying DIN EN 1998 and should have an adequate general understanding of the effects of earthquakes on industrial building structures. In order to ensure continuity and a good overview, the structure of the current guideline, like the structure of the previous editions, is based on the section numbering of DIN 4149:2005. This means that some sections may not be organized thematically just like DIN EN 1998-1, but references to the corresponding sections of the standard are provided.

More detailed remarks and explanations of the theoretical background are still compiled in the *commentary document to the guideline*.

1. Scope

(1) This guideline applies in combination with DIN EN 1998-1:2010 and DIN EN 1998-1/NA:2021 for the earthquake-resistant design, dimensioning and construction of facilities (new facilities) used in the chemical industry or related industries. For elements and structures whose seismic response differs from that of common buildings, the guideline refers to the relevant parts of the DIN EN 1998 series of standards.

(2) The guide also contains procedures for the assessment and suggestions for the improvement of the seismic resistance of existing industrial facilities.

(3) The guideline takes into account the load-bearing structures of facilities, free-standing vessels, silos, tanks, columns, as well as non-structural building components, (process) engineering components, parts and piping present in the facilities.

(4) The regulations of the guideline also apply in areas of very low seismicity according to DIN EN 1998-1 clause 3.2.1 (5).

2. Normative references

(1) In addition to the standard references in DIN EN 1998-1 sections 1.1.3 and 1.2 as well as the respective national annexes, the following documents are relevant for the application of this guideline (the latest edition of the referenced document including all amendments applies in each case):

- Administrative technical building regulations of the German federal states
- DIN EN 199x series of standards with their national annexes, if available
- The Act on Prevention of Harmful Effects on the Environment Caused by Air Pollution, Noise, Vibrations and Similar Processes (BImSchG)
- The 12th Ordinance for the Implementation of the Federal Immission Protection Act (Hazardous Incident Ordinance – 12. BImSchV)
- Regulation (EC) No 1272/2008 on classification, labelling and packaging of substances and mixtures (CLP Regulation)

3. Terms and definitions

(1) The definitions in section 1.5 of DIN EN 1998-1 apply. Furthermore, the following terms are defined:

Facilities in the sense of this guideline are buildings, sections of buildings, supporting structures with their process engineering components, installations and piping, as well as vessels, silos, tanks and columns.

Components in the sense of this guideline are non-structural parts of the building or of process engineering that are located within a building / part of a building / supporting structure.

4. Conceptual and structural design

4.a Supporting structures of facilities

(1) The rules of DIN EN 1998-1 section 2.2.4 (Special measures) must be considered.

(2) The rules of DIN EN 1998-1 sections 4.2.1 to 4.2.3 (Characteristics of earthquake resistant buildings) must be considered.

(3) Bracing systems should be arranged and connected by floor diaphragms in such a way that a direct load transfer of horizontal loads is ensured and torsional vibrations are avoided. Individual structural systems located next to each other must have their own bracing systems; adequate joint width between the individual structures must be provided.

(4) Different types of foundations and foundation depths within a structural system should be avoided. In addition, the recommendations of DIN EN 1998-1 section 2.2.4.2 (Specific measures for foundations) and DIN EN 1998-5 sections 5.1 (General requirements for foundations) and 5.2 (Rules for the conceptual design of foundations) are to be taken into account.

4.b Free-standing vessels, silos, tanks and columns

(1) Tanks as well as vessels or silos mounted directly on the ground or foundation should be anchored evenly along the entire circumference. Shell stability must be ensured at and near the highly stressed shell base by selecting adequate wall thicknesses.

(2) Elevated vessels, tanks and silos must be secured by suitable measures to prevent them from overturning and from sliding (e.g. bracing systems and anchors).

(3) As a general rule, anchors and fasteners should be designed as non-dissipative elements (see 7.2.b (4)).

(4) Pipe connections to vessels, silos, tanks and columns must provide adequate deformation capacity.

4.c Non-structural components and piping within the supporting structure

(1) The substructures of components (equipment, tanks, pipes, parts of the facade, and similar components) must be designed to withstand the design seismic action. The following effects are to be prevented through adequate earthquake-resistant design and detailing:

- Overturning (tipping)
- Falling down
- Shifting which results in damage
- Tearing off of pipelines and hoses
- Swinging of suspended components affecting adjacent components and structures

(2) As far as plant and process engineering allows, heavy components are to be mounted at low elevations and in the centre or symmetrically within the supporting structure in order to reduce the seismic effects on these components and to achieve a reasonable vibration behaviour of the supporting structure.

(3) The substructures of components should be designed so that resonance effects between components and the supporting structure are avoided. If a flexible substructure is required for the operation of the plant (e.g. for rotating machines, near expansion joints in the supporting structure, or similar situations), special care must be taken on the design of pipe connections and the location of nearby other components. If necessary, damping elements must be installed to restrict the movement of the component.

(4) Suspended components are to be designed with adequate bracing in the horizontal directions to prevent such components from swinging and swaying. Additionally, adequate distance to directly adjacent components must be provided.

(5) Pipe connections on vessels and other technical components must be designed with adequate deformation capacity.

(6) As a general rule, anchors and fasteners should be designed to be non-dissipative (see 7.2.c (2)).

(7) For the design of masonry infill walls, the rules of DIN EN 1998-1 section 4.3.6 must be considered.

5. Seismic action

5.1 Seismic action at the plant site (location)

(1) The key parameter for determining the seismic action at the plant site is the spectral response acceleration $S_{aP,R}$ in the plateau range of the response spectrum for the ground condition A-R (rock). The value $S_{aP,R}$ relevant at a plant site in Germany is to be taken from the normative digital annex of the standard. DIN EN 1998-1/NA:2021 Figure NA.1 shows schematically the distribution of the plateau value $S_{aP,R}$ zone-free for a return period of $T_{NCR} = 475a$ (reference return period).

(2) In accordance with clause 3.2.1 (5), DIN EN 1998-1 generally does not specify requirements for structures in areas of very low seismicity. However, for precautionary reasons, the application of at least section 4 of this guideline (Conceptual and structural design) is recommended for these types of structures. Beyond that, verification of structural stability in the event of an earthquake is required even in cases of very low seismicity for structural layouts with unfavourable mass distributions and for components within buildings (components that have not been designed for wind loads).

5.2 Ground conditions, geology and subsoil

(1) The rules of DIN EN 1998-1 section 3.1 (Ground conditions) and the related rules of DIN EN 1998-1/NA:2021 apply.

(2) In addition to the subsoil conditions, the local deep geology conditions are to be taken into account when determining the relevant seismic action following DIN EN 1998-1/NA. The definition of the three possible soil classes accounting for deep geology is given in DIN EN 1998-1/NA:2021 NDP re. 3.1.2(1). DIN EN 1998-1/NA:2021 Figure NA.G.1 provides an informative schematic presentation of the spatial distribution of the geological soil classes. If the geological soil class is not known, an enveloping response spectrum may be used in accordance with DIN EN 1998-1/NA:2021 NDP re. 3.2.2.1(4) and 3.2.2.2(2) P.

(3) The soil factor S is assigned in dependence of the ground condition and the value of spectral acceleration $S_{aP,R}$ (DIN EN 1998-1/NA:2021 Table NA.2).

5.3 Importance factors

(1) The risk of damage to the facility or the component is determined by the combination of its damage potential and the possible damage effects regarding health and safety, environmental protection and the operational reliability of lifeline systems. For all three categories, an importance factor is assigned to the facility/component in accordance with Tables 5.1 to 5.3. The highest of these three importance factors is decisive for the structural design. When designing a structure in which components or sub-systems with different risk potentials are present, the highest importance factor of all sub-systems is decisive for the structure.

(2) Assigning an importance factor less than 1.0 to facilities of the chemical industry or related industries is not permitted.

(3) Separate buildings and separate facilities that can deform independently of one another during an earthquake (adequate joint width required), can be verified separately from each other. In this instance, the buildings and facilities may be assigned different importance factors.

Table 5.1: Importance factors γ_I and γ_a regarding health and safety

		Effects				
		within facilities	immediate vicinity (block within the plant)	within the plant (fenced in)	outside the plant	large area outside the plant
Damage potential [1]	**Non-volatile toxic substances:** H-stmts.[2] 331, EUH029, 301[3], 311[3], 340[3], 350[3], 360[3], 370[3] with vapour pressure < 0.1 hPa **Flammable and oxidising substances:** H-stmts.[2] 221, 223, 226, 261, 271, 272	**1.0**	**1.0**	**1.0**	**1.0**	**1.1**
	Non-volatile very toxic substances: H-stmts.[2] 330, 300[3], 310[3] with vapour pressure < 0.1 hPa **Highly/extremely flammable substances:** H-stmts.[2] 220, 222, 224, 225, 242, 250, 260 **Oxidising gases:** H-statement[2] 270	**1.0**	**1.1**	**1.2**	**1.2**	**1.2**
	Volatile & highly vol. toxic substances: H-stmts.[2] 331, EUH029, 301[3], 311[3], 340[3], 350[3], 360[3], 370[3] with vapour pressure ≥ 0.1 hPa **Volatile very toxic substances:** H-stmts.[2] 330, 300[3], 310[3] with vapour pressure ≥ 0.1 and < 100hPa **Explosive substances:** H-stmts.[2] 200, 201, 202, 203, 205, 240, 241 **Extremely flammable liquefied gases:** H-stmt[2] 220 (liquefied)	**1.1**	**1.2**	**1.3**	**1.4**	**1.4**
	Highly volatile very toxic substances: H-stmts.[2] 330, 300[3], 310[3] with vapour pressure ≥ 100 hPa	**1.2**	**1.3**	**1.4**	**1.5**	**1.6**

[1] Only gases and liquids are taken into account for flammable, highly flammable, extremely flammable and oxidising substances. For toxic to very toxic substances, the vapour pressure at 20°C is used as the measure of the volatility.

[2] Hazard statement code according to CLP Regulation (EC) No. 1272/2008 adopted on Dec. 16, 2008, on classification, labelling and packaging of substances and mixtures

[3] Relevant only for the vicinity (within the plant)

Table 5.2: Importance factors γ_I and γ_a regarding environmental protection

	Effects		
	No consequences for the environment outside the plant	Minor consequences for the environment outside the plant	Large-scale consequences for the environment outside the plant
Impact on the environment (Endangerment of animals/plants by water or air pollution)	**1.0**	**1.2**	**1.4**

Table 5.3: Importance factors γ_I and γ_a regarding lifeline facilities

	Requirements		
	Normal require-ments on the availability	High requirements on the availability	Very high requirements on the availability
Retention systems, traffic routes, escape routes	**1.2**	**1.2**	**1.2**
Lifeline structures (Fire stations, extinguishing systems, rescue service stations, power supply, pipe bridges)	**1.3**	**1.4**	**1.4**
Emergency power supply*, safety systems*	**1.4**	**1.5**	**1.6**
*Systems that are necessary to transfer operational processes to the safe state.			

5.4 Basic representation of the seismic action

(1) The rules of DIN EN 1998-1 section 3.2.2.1 (General information on the basic representation of seismic action) apply.

(2) The shape and description of the elastic acceleration response spectrum for the horizontal and the vertical seismic action are to be taken from DIN EN 1998-1/NA:2021, Figure NA.2. The control periods depend, inter alia, on the given ground conditions. They are specified for the horizontal response spectrum in DIN EN 1998-1/NA 2021 Table NA.1 and for the vertical response spectrum in Table NA.3.

(3) The horizontal design spectrum for linear calculation is to be taken from DIN EN 1998-1, section 3.2.2.5.

(4) If it is necessary to take the vertical component of the seismic action into account (cf. clause 6.2 (4) of this guideline), the vertical design spectrum is derived from the equations for the horizontal design spectrum, but using the following reference parameters in accordance with DIN EN 1998-1/NA:2021 Table NA.3: $a_{vg} = 0.7 \cdot a_g$, soil factor $S = 1.0$, control periods $T_B = 0.05\ s, T_C = 0.2\ s, T_D = 1.2\ s.$

(5) In deviation from DIN EN 1998-1 section 3.2.3, it is not recommended to represent the seismic action in terms of acceleration time histories or related parameters over time.

5.5 Combination of the seismic action with other actions

(1) The combination factors $\psi_{2,i}$ used to combine variable actions in the seismic design situation according to DIN EN 1990 section 6.4.3.4 are specified in Table 5.4 of this guideline. The combination factors are derived from the values specified in Table NA.1.1 of DIN EN 1990/NA and consider the specific circumstances in plant engineering.

(2) In deviation from the rules of DIN EN 1998-1 (Table 4.2 and DIN EN 1998-1/NA:2021 Table NA.5, respectively), the factor used to determine the combination factors $\psi_{E,i}$ is always to be set to φ = 1.0.

(3) The design value of seismic action A_{Ed} must be determined for the decisive operating load configurations. These load configurations must be defined for each case with respect to the particular operating procedures.

(4) Constrained forces are to be considered as variable operating loads if they have an unfavourable effect in the seismic design situation.

Table 5.4: Combination factors $\psi_{2,i}$ derived from DIN EN 1990/NA, Table NA.1.1

Action	Combination factors ψ_2
Live loads	
Storage areas	0.8
Operational areas	0.15
Office space	0.3
Hauled loads	0.8
Variable machine loads, vehicle loads	0.5
Brake- and startup loads	0
Assembly loads, other short-term or rarely occurring loads	0
Operating loads	
Variable operating loads	0.6*
Operating pressures	1.0
Operating temperature	1.0
Wind loads	0
External temperature effects (temporary)	0
Snow loads	0.5
Probable settlement differences of the subsoil	1.0
* Operating loads that are hardly variable are to be considered as permanent load G_k. When an individual component is investigated (local consideration) its operating loads are to be fully considered ($\psi_2 = 1{,}0$). This also applies for the verification of the direct load-bearing elements of the primary structure on which the component is supported. Operating loads are those loads that occur at maximum value during the regular production process.	

6. Principles of calculation

(1) Essential changes to the load-bearing structure or to the distribution of masses during the lifetime of a structure require verification of the seismic safety of the structure. This also applies in cases when the bearing capacity is increased.

6.1 Modelling

6.1.a Load-bearing structures of facilities

(1) When modelling the load-bearing structures of facilities, it is recommended to take advantage of the simplifications permitted by DIN EN 1998-1 section 4.3.1 if possible. In case of planar models, the spatial effects resulting from torsion must be considered.

(2) The computational model of the load-bearing structure must represent the stiffness and mass distribution realistically. The horizontally and vertically active masses of the non-

structural components can generally be simplified as point masses in the analysis of the load-bearing structure (cf. section 6.1.c of this guideline). In this case, possible mass eccentricities must be taken into account.

(3) The reference value of structural damping can usually be assumed as 5 % viscous damping when using the elastic response spectrum.

(4) For facilities that are equipped with seismic protection systems to dissipate seismic energy as depicted in section 9 of this guideline, the resulting non-linearities must be considered in the computational model of the structure.

(5) The influence of the subsoil must be taken into account in the structural analysis if the resulting effects have a significant influence on the vibration characteristics of the facility. For this purpose and as simplification, single springs with dynamic spring characteristics can be employed.

(6) If a detailed numerical consideration of the soil-structure interaction is required, the damping characteristics of the soil are to be adapted to the actual ground and foundation conditions (see explanations and DIN EN 1998-5).

(7) If a soil survey suspects soil changes resulting from dynamic action (this includes permanent deformations due to compaction or other changes in the grain structure as well as the reduction in the shear stiffness of the soil, for example due to soil liquefaction), these effects must be considered in the computational analysis of the facility (DIN EN 1998-5; see also DIN EN 1998-5/NA:2021 normative annex NA.H). If necessary, soil improvement measures must be conducted.

6.1.b Free-standing vessels, silos, tanks and columns

(1) The computational model must represent realistically the stiffness and mass distribution as well as all other properties relevant for the dynamic response.

(2) The influence of the subsoil must be taken into account in the calculation if the resulting effects have a significant influence on the vibration characteristics of the facility. For this purpose and as simplification, single springs with dynamic spring characteristics can be employed.

(3) When analysing liquid-filled tanks, hydrodynamic effects are to be taken into account. This includes consideration of interaction effects between the tank shell and the stored liquid. A method for simplified consideration of these interaction effects is provided in the commentary document. Liquids can be assumed to be incompressible.

(4) When determining the stresses on the supporting structure of a silo or container for granular goods, the mass of the stored good can be, as a simplification, assumed as rigidly connected to the silo shell. If not estimated more precisely, the effective mass of the silo contents may be assumed to be 80 % of the total mass. For the dimensioning of the silo shell, the pressure approach according to DIN EN 1998-4 clause 3.3 (5) – (11) must be considered.

(5) The damping value for liquids may be assumed to be 0.5 % unless another value is specified. For granular material, the damping should not be assumed higher than 5 %.

(6) At the ultimate limit state, the behaviour factor q should not be chosen greater than 1.2 for steel tanks/silos and not greater than 1.5 for reinforced concrete tanks/silos. For possible substructures of tanks/silos, a larger behaviour factor may be applicable. In such cases, however, the ductility reserves of the substructure must be verified (see explanations on clause 5.4 (3)). additionally, the stress on the elevated tank/silo itself should first be determined on the assumption of an elastic substructure.

(7) When modelling very slender vertical parts of a facility like columns and chimneys, the rules of DIN EN 1998-6 section 4.2 apply.

6.1.c Non-structural components and piping

(1) Non-structural components may be modelled independently from the load bearing structure of the facility using suitable equivalent statical systems as long as they do not influence significantly the vibration characteristics of the load-bearing structure (cf. clause 6.1.a (2) of this guideline).

(2) When modelling above-ground pipes, the rules of DIN EN 1998-4 section 5.4.1 apply.

(3) For the analysis of buried pipes, the modelling of the seismic action is essential. Thereby, DIN EN 1998-4 section 6.3 must be considered.

6.2 Methods of analysis

(1) As in DIN EN 1998-1, the lateral force method of analysis and the modal response spectrum analysis may be used.

(2) According to DIN EN 1998-1 section 4.3.3.4.2, a facility may be designed based on non-linear static analyses. Design based on time history (dynamic) analyses is not recommended.

(3) The horizontal components of the seismic action must be assumed to occur simultaneously. The resulting stresses are to be combined according to DIN EN 1998-1 section 4.3.3.5.1.

(4) The vertical component of the seismic action can normally be neglected in the calculation of the load-bearing structure. Nonetheless, the vertical accelerations must be taken into account, regardless of the magnitude of the vertical acceleration, when designing such parts of the supporting structure that are listed in DIN EN 1998-1 clause 4.3.3.5.2 (1) as well as for the design of beams that support large masses. For these structural elements, the horizontal and the vertical components of the seismic action must be assumed as occurring simultaneously.

(5) For the calculation of foundations and retaining structures, the rules of DIN EN 1998-5 sections 5.3 (Design values of action effects) and 7.3 (Methods of analysis) as well as DIN EN 1998-1 section 4.4.2.6 must be considered.

(6) For the calculation of silos, the rules of DIN EN 1998-4 section 3.3 (Analysis of silos) must be considered.

(7) For the calculation of tank structures, the rules of DIN EN 1998-4 section 4.3 (Methods of analysis) must be considered.

(8) For the calculation of above-ground pipes, the rules of DIN EN 1998-4 section 5.4 (Methods of analysis) must be considered.

(9) For the calculation of buried pipes, the rules of DIN EN 1998-4 section 6.4 (Methods of analysis) must be considered.

6.3 Displacement analysis

(1) The rules of DIN EN 1998-1 section 4.3.4 apply.

6.4 Non-structural components and piping

(1) For the design of non-structural components and their anchoring and substructures, the maximum expected horizontal seismic load F_a may be determined according to the simplified equation (1); it is applied at the centre of mass of the component in the decisive horizontal direction.

$$F_a = 1.6 \cdot S_{e,max} \cdot \gamma_a \cdot m_a \ [kN] \quad (1)$$

where:

$S_{e,max}$	=	maximum value (plateau) of the elastic response spectrum [m/s²], determined with the importance factor of the building γ_I =1.0 and the damping correction factor η applicable to the building structure $S_{e,max} = 2.5 \cdot S \cdot \eta \cdot a_{gR} \cdot 1.0 = S \cdot \eta \cdot S_{aP,R}$
S	=	Soil factor
η	=	Damping correction factor to account for structural damping of the building/supporting structure; $\eta = \sqrt{10/(5+\xi)} \geq 0.55$; if $\xi = 5$ % then $\eta = 1.0$; if $\xi = 2$ % then $\eta = 1.2$
ξ	=	Value of the viscous damping of the building/supporting structure [%]; cf. clause 6.1.a (3) of this guideline
γ_a	=	Importance factor of the part / component according to section 5.3 of this guideline [-]
m_a	=	mass of the element / the component [t]

(2) Alternatively, the horizontal load F_a can be determined, considering the installation height of the component above ground as well as the dynamic behaviour of the load-bearing structure using equation (6.5) of the commentary document. If the floor response spectrum for the installation level of the component is known, equation (6.5) of the explanations can be used analogously.

(3) The horizontal load F_a must be applied in combination with the permanent loads and the unfavourable horizontal and vertical operating loads.

(4) If components of the facility span several levels of the supporting structure (e.g. columns), the design force F_a may be distributed among the individual horizontal bearing points according to the mass distribution of the component.

(5) For the design of the component itself, F_a is to be distributed on the equivalent static system of the component according to its mass- and stiffness distribution. Also in this case, F_a must be applied in combination with all permanent loads and the unfavourable operating loads.

(6) Hydrodynamic effects can be neglected in the design of liquid-filled vessels and their anchoring if the effect's influence on the stress of the vessel and its anchors is insignificant. Otherwise, the section 6.2(7) of this guideline is to be followed.

(7) For components with a total load of up to 10 kN, for single metal pipes with a nominal width of up to DN 100, as well as for lines whose support spans were selected according to Annex 2 of AD 2000 code of practice HP 100 R, a structural protection against dropping and tipping over is sufficient. Adequate elasticity of pipes as well as flexible connections to equipment and vessels must be ensured.

(8) If pipe static calculations are required, it is necessary to verify by calculation also the supports of the pipes concerned up to the point where the force is transferred into the load bearing structure.

(9) If relative displacements can result in potentially damaging stresses on components or installations (e.g. on pipes between two buildings), these relative displacements must be taken into account in the design of the components.

7. Safety verifications

7.1 General information

(1) The rules of DIN EN 1998-1 section 4.4.1 apply.

(2) In deviation from DIN EN 1998-1/NA:2021 (NDP re. 2.1(1)P), verification of damage limitation may be performed according to section 7.3 (cf. DIN EN 1998-1 section 2.1).

(3) The combination factors $\psi_{2,i}$ to be used for the variable actions in the seismic load case combination are to be taken from Table 5.4.

7.2 Ultimate limit state

(1) The ultimate limit state includes, in analogy to DIN EN 1998-4 section 2.1.2, the verification of the functional capability of safety-relevant elements of the facility or component.

(2) The reference probability of exceedance ($\gamma_I = 1.0$) for the ultimate limit state is 10 % in 50 years, which corresponds to a reference return period of 475 years.

7.2.a Supporting structures of facilities

(1) For the supporting structures of facilities, safety verifications at the ultimate limit state must be performed according to DIN EN 1998-1 section 4.4.2.

7.2.b Free-standing vessels, silos, tanks, and columns

(1) For silos, safety verifications at the ultimate limit state must be performed according to DIN EN 1998-4 section 3.5.2.

(2) For liquid-filled vessels and tanks, safety verifications at the ultimate limit state must be performed according to DIN EN 1998-4 section 4.5.2.

(3) For slender, free-standing constructions like columns and chimneys, safety verifications at the ultimate limit state must be performed according to DIN EN 1998-6 section 4.7.1.

(4) For safety verification of anchoring at the ultimate limit state, stresses should be determined using the behaviour factor $q = 1.0$ and, thus, the anchors should be designed linear-elastic. Under certain conditions, ductile behaviour may be assumed in the design of anchors (see DIN EN 1992-4 clause 9.2 (3) b) for anchors in concrete; see DIN EN 1998-1 clause 6.5.2 (5)P for anchors in steel elements).

7.2.c Non-structural components and piping

(1) Non-structural components as well as their anchoring and substructures must be verified for the design forces specified in section 6.4 of this guideline.

(2) When verifying non-structural components at the ultimate limit state, it should be ensured that fasteners and anchors behave linear-elastically. Under certain conditions, ductile behaviour may be assumed in the design of anchors (see DIN EN 1992-4 clause 9.2 (3) b) for anchors in concrete; see DIN EN 1998-1 clause 6.5.2 (3) for anchors in steel elements).

(3) For safety verifications of above-ground pipes at the ultimate limit state, the rules of DIN EN 1998-4 sections 5.2.2 and 5.6 apply.

(4) For safety verifications of buried pipes at the ultimate limit state, the rules of DIN EN 1998-4 section 6.5 apply.

7.3 Verification of damage limitation

(1) Damage limitation verifications may be performed, for example for the purpose of ensuring operational safety if this is desired by the operator of the facility.

(2) The seismic action taken as a basis for the verification of damage limitation depends on the desired damage limitation objective and must, therefore, be determined by the operator of the facility. It is recommended to perform the verification of damage limitation for 50 % of the seismic action for the ultimate limit state design.

(3) Damage limitation verifications are to be performed based on linear-elastic analysis. The elastic response spectrum must take into account the structural damping in an appropriate manner. The reduction factor n introduced in DIN EN 1998-1 clause 4.4.3.2 (2) is not to be applied in the scope of this guideline.

7.3.a Supporting structures of facilities

(1) For supporting structures of facilities, damage limitation verifications are to be performed according to DIN EN 1998-1 section 4.4.3.

7.3.b Free-standing vessels, silos, tanks, and columns

(1) For silos, damage limitation verifications are to be performed according to DIN EN 1998-4 section 3.5.1.

(2) For liquid-filled vessels and tanks, damage limitation verifications are to be performed according to DIN EN 1998-4 sections 4.1.2 and 4.5.1.

(3) For slender, free-standing constructions like columns and chimneys, damage limitation verifications are to be performed according to DIN EN 1998-6 section 4.9.

7.3.c Non-structural components and piping

(1) Non-structural components as well as their anchoring and substructures must be verified for the equivalent horizontal force F_a specified in section 6.4 of this guideline. If the equivalent horizontal force F_a is calculated using equation 6.5 of the commentary document, the behaviour factor of the component is to be set to $q_a = 1.0$ (cf. clause 7.3 (3)).

(2) For damage limitation verifications of above-ground pipes, the rules of DIN EN 1998-4 section 5.2.1 apply.

(3) For damage limitation verifications of buried pipes, the rules of DIN EN 1998-4 section 6.5 apply.

8. Specific rules

(1) For the design of reinforced concrete structures, the specific rules of DIN EN 1998-1 section 5 apply.

(2) For the design of steel structures, the specific rules of DIN EN 1998-1 section 6 apply.

(3) For the design of composite steel-concrete structures, the specific rules of DIN EN 1998-1 section 7 apply.

(4) For the design of timber structures, the specific rules of DIN EN 1998-1 section 8 apply.

(5) For the design of masonry structures, the specific rules of DIN EN 1998-1 section 9 apply.

(6) For the design of foundations and retaining structures, the specific rules of DIN EN 1998-5 apply.

9. Seismic protection systems

(1) The following subclauses primarily comprise basic principles and methodical information.

(2) The general approaches for seismic protection of structures can be distinguished into four categories: Protection can be achieved through adequate strength and stiffness, by providing sufficient ductility, by installing dampers or through base isolation. Each of these approaches is described in more detail in the commentary document to this guideline.

(3) The concept of adequate strength and stiffness as well as the dissipative design concept are covered by the rules of DIN EN 1998-1.

(4) The vibrational energy acting on the structure can be reduced by the use of passive or active spring/damper systems.

(5) For the design of base isolation and of base isolated structures, the rules of DIN EN 1998-1 section 10 apply.

10. Assessment of existing facilities

(1) The seismic safety of existing facilities depends not only on correct seismic design but also on flawless construction and the current condition of the facility.

(2) The rules of DIN EN 1998-3 (Assessment and retrofitting of buildings) apply. To adopt these rules to facilities of the chemical industry or related industries, the subsequent subclauses apply in addition.

(3) Whenever existing facilities that are establishments or part of an establishment (BImSchG § 3, 5a) of the upper tier-category are modified with respect to their load bearing structure or with respect to the usage and also as part of the regular review of the safety report according to the 12. BImSchV, even the effects of earthquakes have to be assessed.
If this assessment reveals deficits regarding seismic safety, the plant must be retrofitted in an appropriate manner (section 10.2).

(4) If the thresholds of substance holdup specified in Annex I column 5 of the 12. BImSchV (of the upper-tier category) are reached or exceeded in the establishment, the design, construction, operation and maintenance of safety-relevant facility components have to be documented.

(5) If the remaining operating time of the existing facility is less than 15 years, the level of the seismic action used for the verifications at the ultimate limit state may – in agreement with the responsible authorities – be reduced in a simplified manner by multiplying the importance factor of the facility by the factor 0.75.

(6) When assessing the load bearing capacities of existing facilities by numerical analyses, also non-linear static calculation methods can be useful (cf. section 6.2).

10.1 Assessment of the current condition

(1) The assessment of the current condition of a facility in terms of its seismic resistance is based on the following

- Building documents and initial static calculation document,
- Drawings and parts lists of the facility components,
- Relevant standards and directives, including those in effect at the time of design and construction,
- On-site inspections of the building and its facility components.

The reliability of the building condition assessment increases with the completeness of the information it is based upon.

(2) The assessment of the building condition must be based on the following information:

- Horizontal bracing system in terms of the earthquake-resistant design criteria,
- Type of foundation,
- Prevailing ground conditions,
- Dimensions of the building, section properties of load-bearing elements, as well as mechanical properties,
- Condition of the materials used (corrosion, material flaws),
- Quality of execution,
- Standards and directives which the original construction of the building was based upon,
- Present or planned use of the structure in terms of the importance category,
- Operating loads, filling levels, operating temperatures, etc.,
- Type and scale of previous and existing damage; if applicable, type and scope of previous retrofitting measures.

(3) The goal of the condition assessment and the subsequent evaluation is the localisation of highly vulnerable areas of the facility and the identification of the biggest risks. The evaluation form given in the commentary document to this guideline may be used for this purpose.

(4) If the results of the evaluation indicate significant or severe deficiencies, numerical analyses must be performed and the structure and/or component must be retrofitted, if necessary.

10.2 Retrofitting

(1) Any need for action to reduce the risk posed on humans and on the environment is to be determined taking into account the principle of commensurability.

(2) Retrofitting measures focus primarily on structural improvements / strengthening. The goal of these measures is to raise the structural stability of the facility to an appropriate level.

(3) For the retrofitted structure, the structural stability must be verified according to section 7.2 of this guideline. The damage limitation verifications according to section 7.3 of this guideline may be performed if desired by the facility operator.

(4) Within the verification calculations, uncertainties regarding the actual condition of the considered structure are to be taken into account, for example by reducing the properties on the resistance side by dividing them by a confidence factor according to DIN EN 1998-3 clause 3.3.1 (4) and clause 3.5 (1), respectively.

(5) The computational models may be calibrated regarding the facility's stiffness- and mass characteristics using the results of on-site measurements of the eigenfrequencies.

(6) In terms of an economical solution, the risk to humans and to the environment can also be reduced by operational measures so that the necessity and the extent of structural improvements changes accordingly.

11. Bibliographical references

The relevant literature is specified in the commentary document to this guideline.