Safety Standards

of the
Nuclear Safety Standards Commission (KTA)

KTA 3401.2 (2016-11)

Steel Containment Vessels
Part 2: Design and Analysis

(Reaktorsicherheitsbehälter aus Stahl;
Teil 2: Auslegung, Konstruktion und Berechnung)

Previous versions of this Safety Standard
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Comments by the editor:

Taking into account the meaning and usage of auxiliary verbs in the German language, in this translation the following agreements are effective:

shall	indicates a mandatory requirement,
shall basically	is used in the case of mandatory requirements to which specific exceptions (and only those!) are permitted. It is a requirement of the KTA that these exceptions - other than those in the case of **shall normally** - are specified in the text of the safety standard,
shall normally	indicates a requirement to which exceptions are allowed. However, the exceptions used, shall be substantiated during the licensing procedure,
should	indicates a recommendation or an example of good practice,
may	indicates an acceptable or permissible method within the scope of this safety standard.

Fundamentals

(1) The safety standards of the Nuclear Safety Standards Commission (KTA) have the objective to specify safety-related requirements, compliance of which provides the necessary precautions in accordance with the state of the art in science and technology against damage arising from the construction and operation of the facility (Sec. 7 para. 2 subpara. 3 Atomic Energy Act - AtG) in order to achieve the fundamental safety functions specified in the Atomic Energy Act and the Radiological Protection Ordinance (StrlSchV) and further detailed in the Safety Requirements for Nuclear Power Plants as well as in the Interpretations on the Safety Requirements for Nuclear Power Plants.

(2) Basic requirements for the reactor containment are contained in the Safety Requirements for Nuclear Power Plants in Requirement No. 3.6, “Requirements for the containment system” as well as in Sec. 6 “Containment” of Interpretation I-2 “Requirements for the design of the reactor coolant pressure boundary, the external systems as well as the containment”.

Safety standard KTA 3201.4 “In-Service Inspections and Operational Monitoring” is intended to specify detailed measures which shall be taken to meet these requirements

The safety requirements cited above are transferred to specific requirements with respect to steel containment vessels by the following safety standards:

KTA 3401.1	Steel containment vessels; Part 1: Materials and product forms
KTA 3401.2	Steel containment vessels; Part 2: Design and analysis
KTA 3401.3	Steel containment vessels; Part 3: Manufacture
KTA 3401.4	Steel containment vessels; Part 4: In-service inspections
KTA 3405	Leakage test of the containment vessel
KTA 3413	Determination of Loads for the Design of a Full Pressure Containment Vessel against Plant-Internal Incidents

and, with respect to penetrations and airlocks, by the following safety standards:

KTA 3402	Airlocks on the Reactor Containment of Nuclear Power Plants - Personnel Airlocks
KTA 3403	Cable Penetrations through the Reactor Containment Vessel
KTA 3407	Pipe Penetrations through the Reactor Containment Vessel
KTA 3409	Airlocks on the Reactor Containment of Nuclear Power Plants - Equipment airlocks.

Furthermore, Safety Standard KTA 3404 applies to the isolation of operation-system related pipes penetrating the reactor containment vessel in the case of a release of radioactive materials into the reactor containment vessel.

(3) The task of the steel containment vessel is to resist the pressure and temperature loads which can occur during plant accidents connected with the release of radioactive materials inside the containment, in particular in conjunction with the leakage cross-sections of the primary coolant system to be assumed; thus, no unallowed release of radioactive materials to the environment becomes possible. For this reason, the containment and all penetrations and cooling systems, as far as their function is required for controlling the consequences of the accident, shall be designed such that, under consideration of the allowed leakage rate, they resist the dynamic, static and thermal loads occurring in conjunction with the above mentioned accidents and the consequential failures. During normal operation, the containment, furthermore, has the task of conducting the air flow.

(4) In the case of stationary light-water reactors, the containment is designed as a technically airtight steel sphere into which the pipe and cable penetrations as well as personnel and material locks are inserted. In order to comply with the above mentioned task, it is necessary to set up standards for technical and organizational measures, e.g.,

- choice and use of materials of high fracture toughness and good workability,
- design and construction in consideration of a well-suited stress flow,
- choice of fabrication and testing procedures and documentation of testing steps and results,
- unambiguous instructions regarding the activities during manufacture and processing of the materials.

(5) These measures are dealt with in the four Safety Standards KTA 3401.1, KTA 3401.2, KTA 3401.3 and KTA 3401.4. The compliance with the provisions laid down in the present Safety Standard regarding

a) load cases and loading levels,

b) design,

c) assessment of load-bearing capacity,

will ensure that the safety-related requirements for design, construction and analysis of the reactor containment vessel are satisfied.

1 Scope

This safety standard applies to the design and analysis of steel containments of stationary nuclear power plants with light-water reactors, including the nozzles integrally connected to the containment and the pressure retaining parts of the locks.

2 Definitions

(1) Design pressure (excess pressure) of the reactor containment

The design pressure of the reactor containment is the pressure determined in accordance with the requirements of KTA 3413, section 6.1.

(2) Design temperature of the reactor containment

The design temperature of the reactor containment is the maximum balanced temperature of the reactor containment atmosphere determined for accidents in accordance with KTA 3413, section 6.1.

(3) Design sub-atmospheric pressure

The design sub-atmospheric pressure is the maximum negative pressure determined in accordance with KTA 3413, subclause 6.1 (6).

(4) Nominal stress

Nominal stresses are stresses determined by calculation (e.g. analytical calculations) in which case notch effects from discontinuities due to component geometry are not taken into account.

(5) Test pressure (excess pressure) during first pressure testing

The test pressure (excess pressure) during first pressure testing is 1.1 times the design pressure multiplied with the ratio of yield strengths at test and design temperature, respectively.

(6) Test pressure (negative pressure) during first pressure testing

The test pressure (negative pressure) during first pressure testing is the test pressure determined in accordance with KTA 3401.3, section 10.7.

(7) Maximum pressure at accident

The maximum pressure at accident is the maximum pressure occurring in case of a loss-of-coolant accident (LOCA), which is to be determined in accordance with KTA 3413, section 6.

3 General principles

Unless otherwise stipulated below, the design and analysis of a containment shall be carried out in accordance with the principles of mechanical engineering and under consideration of the generally accepted standards of civil engineering.

4 Load cases and loading levels

4.1 General

(1) Load cases shall be classified in accordance with Section 4.2.

(2) Load cases relevant to the containment shall be correlated to loading levels in accordance with Section 4.4.

4.2 Load cases (Plant conditions)

4.2.1 General

(1) With respect to achieving the fundamental safety functions distinction shall be made between various plant conditions leading to the loadings shown in **Table 4-1**. The load cases result of a combination of loadings and shall be classified as follows:

a) design load cases (DF),

b) erection load cases (MF),

c) load cases from specified normal operation

ca) normal operation load cases (NB),

cb) anomalous operational load cases (AB),

cc) test load cases (PF),

d) accident load cases (ST),

e) redundancy-wide impact from an external event (EVA).

(2) From these load cases, those decisive for the containment vessel shall be correlated to the loading levels in accordance with Section 4.4.

4.2.2 Design load cases (DF)

(1) Design load cases are such on which the first dimensioning of wall thicknesses for components of the containment vessel is based. The calculation is based on the design pressure (excess pressure) and the design sub-atmospheric pressure.

Note:

As regards the final dimensioning of wall thicknesses, see subclause 5.1 (2).

(2) In the case of loads from internal pressure, the design temperature shall be considered to occur coincidentally with the design pressure.

4.2.3 Erection load cases (MF)

All loads resulting from the site, from construction and erection procedures shall be considered to be erection load cases of a specific condition of erection. Transportation and repair procedures shall, as necessary, be demonstrated as being allowable.

4.2.4 Load cases from specified normal operation

a) Normal operational load cases (NB)

Normal operational load cases are operating procedures for which the nuclear power plant is specified and which it is able to perform on the assumption of functional condition (undisturbed condition) of the plant components and systems. All related loads shall be considered.

b) Anomalous operational load cases (AB)

Anomalous operational load cases are operating procedures occurring upon malfunction of pant components and systems (undisturbed condition) unless continued operation is excluded on account of safety related reasons. All related loads shall be considered.

c) Test load cases (PF)

Test load cases are the pressure test, the leakage test and the in-service inspections.

Note:

The pressure level of the pressure test is specified in Sec. 10.2.2 and the test temperature in Sec. 10.2.3 of KTA 3401.3. The loadings shall be based on these specified values.

4.2.5 Accident load cases (ST)

Accidents are procedural events in the event of which the operation of the plant cannot be continued for safety reasons and for which the plant is designed. All loads related to accidents shall be considered.

4.2.6 Redundancy-wide impacts from an external event (EVA)

These external events are considered to be design-basis earthquake, aircraft crash and explosion pressure waves.

Note:

Due to the requirements for the plant as regards the protection against redundancy-wide internal impacts (plant-internal flooding, fire and explosions), which among others have been laid down in KTA safety standards 2101 - “Fire Protection in Nuclear Power Plants” and 2103 - “Explosion Protection in Nuclear Power Plants”, redundancy-wide internal events will not lead to loads on the reactor containment to be considered.

4.3 Loads

(1) All actions that cause loadings in the containment vessel shall be considered as loads. Here, distinction shall be made between the following loads:

a) permanent loads

the dead weight of the containment vessel, the dead weight of the components integrally connected with it, and other permanently acting loads.

b) pressure differences and temperature differences during

ba) normal operation

bb) anomalous operation

bc) test load cases (first pressure test, leakage test)

bd) accidents

be) redundancy-wide impact from an external event

In the case of pressure differences all pressures with their local and temporal distribution including locally acting pressures (e.g. jet forces due to pipe rupture close to the wall) shall be considered.

In the case of temperature differences the local and temporal distribution of temperatures including locally limited temperature fields (e.g., in the vicinity of pipe penetrations or due to pipe rupture close to the wall) as well as temperature gradients in the containment vessel cross-section under consideration of the influence of thermal insulation shall be taken into account.

c) static and dynamic loads resulting from attachments and internals as well as pipes and filling loads

Note:

The assignment of pipe loadings to the load cases shown in this safety standard is laid down in KTA 3407.

d) traffic loads

e) wind loads (assembly condition)

f) snow loads (assembly condition)

g) other dynamic loads (e.g., actions due to design-basis earthquake).

(2) Restraints of deformations (constraints due to, e.g., support structures, attachments and internals as well as pipe penetration assemblies) shall be considered.

(3) For those loadings to be included in the fatigue analysis of the reactor containment vessel, the number of stress cycles specified for the respective NPP shall be considered.

4.4 Loading levels

(1) The load cases shall be assigned to the loading levels 0, 1, 2 or 3 whose allowable stresses are specified in Section 6.

(2) The design load cases shall be assigned to loading level 0.

(3) Normal operational load cases, loss-of-coolant accidents and erection load cases without wind loadings shall be assigned to loading level 1.

(4) The following load cases shall be assigned to loading level 2:

a) erection load cases with wind loadings,

b) test loadings,

c) events leading to an increased negative pressure in the reactor containment, except for pipe ruptures outside the reactor containment.

Where a component, excepting its dead weight, is loaded by wind loads only, this load case shall be assigned to loading level 1.

(5) Pipe rupture inside and outside the reactor containment (except for loss-of-coolant-accidents) as well as the redundancy-wide external events as per clause 4.2.6 shall be assigned to loading level 3.

(6) In the case of the load cases “aircraft crash” and “explosion pressure wave”, the stress and stability analysis may be limited to undisturbed regions and to the support structure.

4.5 Correlation of load cases, loads and loading levels with the required stress and stability analyses

(1) All load cases and corresponding loads shall be listed in a specification which, in addition to grouping the load cases in accordance with loading levels, shall also specify which stress and stability analyses shall be carried out.

(2) **Table 4-1** shows this correlation in the case of a reactor containment vessel for a pressurized water reactor (PWR).

(3) For boiling water reactors (BWR) the correlation shall be determined in dependence of the plant-specific conditions in correspondence with **Table 4-1**.

5 Construction

5.1 General

(1) In the construction of the reactor containment vessel, including the support structures, cutouts, cutout reinforcements, locks, closures, equipment hatches and the attachments, the requirements of KTA 3401.1 “Materials” and KTA 3401.3 “Manufacturing” shall be considered in addition to the following requirements.

(2) The wall thickness and shape shall be chosen such that for all loading conditions the individual determining stress limits in accordance with Section 6 are adhered to.

5.2 Favourable design regarding stress

(1) Regions characterized by change of shape and by a changing point of load application shall be designed such that, under consideration of all loading conditions, the resulting local stress intensities are kept small.

(2) Cutouts and weld-attachments should have sufficient distance from the weld seams (longitudinal and circumferential seams) of the containment vessel shell.

5.3 Favourable design regarding materials, fabrication and testing

(1) The design and construction of the reactor containment shall be determined such (e.g. with regard to the location of weld seams and the spatial arrangement of the components of the reactor containment vessel), that testability is given for the primary and recurrent non-destructive testing in accordance with the requirements of KTA 3401.3 “Manufacture” and KTA 3401.4 “In-service Inspections”. Simplifications with regard to design meeting test and inspection requirements are allowed where the nominal operating stress in the region of the weld seam is less than or equal to 50 N/mm^2 and where this nominal operating stress is the essential part of the primary stress. The nominal operating stress is understood to be the primary membrane stress of the load cases assigned to loading level 1.

(2) If, due to the structural design of the nuclear power plant, the accessibility for the post-pressure-test examinations is restricted (e.g., in the vicinity of support structures, due to the liner or the concrete structures for debris protection), the permissibility of the restrictions shall be assessed as early as at the planning stage along with the authorized inspector under Sec. 20 of the Atomic Energy Act and the authorized expert under Civil Law.

(3) Cruciform weld seams shall be avoided. Load-carrying parts to be connected by welding shall be welded over the complete connecting cross-section. Fillet welds are (only) allowed on internally mounted cover plates for closing off nozzle pipes or on internally mounted leak-tight boxes because these weld seams primarily have a sealing function. Other fillet welds on pressure-retaining parts shall be avoided. Exceptions are permitted only by agreement with the authorized inspector under Sec. 20 of the Atomic Energy Act and the authorized expert under Civil Law.

5.4 Design amenable to maintenance

(1) Components of the reactor containment vessel shall be designed such that decontamination is possible.

(2) If components are required to be removed for maintenance or testing their disassembly should be possible with a least possible radiation exposure of the personnel.

5.5 Design details

5.5.1 Welded joints

The distance between welded joints should be larger than or equal to three times the wall thickness but shall not be smaller than 100 mm. In the case of T-joints, the smaller angle shall not be less than 30 degrees.

Loading levels	Load cases	a) Permanent loads	b) Overall internal pressure	b) Negative pressure or external overpressure	b) Local pressure increase	b) Temperature [1)]	c) External loading and loading moments	d) Traffic loads	e) Wind loads	f) Snow loads	g) Dynamic loads, excitation at foundation level	P_m	P_l or P_m+P_b or P_l+P_b	P_m+P_b+Q or P_l+P_b+Q	P_l+P_b+Q+F or P_m+P_b+Q+F	Stability analyses
		Loadings in accordance with Section 4.3										Stress analysis				
0	DF 1	X	X									X	X[2)]			
	DF 2	X		X								X	X[2)]			X
1	MF 1	X					X	X		X		X	X			X
	NB	X		X		X	X					X	X	X	X	X
	ST 1	X	X		X	X	X					X	X	X		
2	MF 2	X					X	X	X	X		X	X			X
	DP 1	X	X				X		X			X	X			
	DP 2	X		X			X		X			X	X			X
	ST 2	X		X		X	X					X	X	X[3)]		X
3	ST 4	X	X		X		X					X	X			
	ST 5	X		X	X		X					X	X			X
	EVA 1	X		X			X				X	X	X			X
	EVA 2	X		X			X				X	X	X			X

1) The pertinent temperature is generally the governing factor with regard to the allowable stresses. In case of the load cases checked off in this column, thermal stresses shall be considered additionally.

2) Instead of a primary stress analysis, simplified design standards are allowed (e.g., in the case of DF 1, design in accordance with AD 2000-Merkblätter B0 and B1).

3) In substantiated cases the secondary stress analysis and fatigue analysis need not be performed.

Explanations:

DF 1: Design load case with design basis overpressure

DF 2: Design load case with design basis underpressure

MF 1: Erection load case with continuous and intermittent loads

MF 2: Erection load case with continuous and intermittent loads plus wind loads

NB: Normal operation

DP 1: Pressure test with overpressure

DP 2: Pressure test with underpressure

ST 1: Loss-of-coolant accidents with pressure and temperature course including possible jet impingement and reaction forces

ST 2: Occurrences resulting in underpressure inside the reactor containment vessel: breakdown of ventilation system, occurrences near the end of loss of coolant accidents and small leaks

Note:
Load case ST 3 "Design-basis earthquake" has been omitted.

ST 4: Pipe rupture inside the reactor containment vessel, unless to be assigned to ST 1, including jet impingement and reaction forces, simultaneous with normal operation (NB) (without thermal stresses)

ST 5: Pipe rupture outside the reactor containment vessel including jet impingement and reaction forces, simultaneous with normal operation (NB) (without thermal stresses)

EVA 1: Design-basis earthquake, simultaneous with normal operation (NB) (without thermal stresses)

EVA 2: Aircraft crash and explosion pressure wave, simultaneous with normal operation (NB) (without thermal stresses)

Table 4-1: Correlation of load cases, loads and loading levels with the required stress and stability analyses for the reactor containment vessel of a pressurized water reactor (example)

5.5.2 Butt joints

(1) Butt joints shall normally be without offset of the median planes. If, however, an offset of median planes is specified, then the resulting stress elevations shall be demonstrated by computation.

(2) With regard to a non-specified offset of median planes, Sec. 5 of KTA 3401.3 applies.

(3) In case of butt joints of unequal wall thickness with a one-sided offset of edges and where s_1 is larger than $1.1 \cdot s_2$, or with a two-sided offset of edges and where s_1 is larger than $1.2 \cdot s_2$, the thicker plate shall be chamfered down in a ratio of 1:3 or smaller on one side or on both sides, respectively.

(4) In the corner region of adjoining plates with a one-sided offset of edges s_1 - s_2 larger than $0.1 \cdot s_2$, or a two-sided offset s_1 - s_2 larger than $0.2 \cdot s_2$, the chamfer shall be rounded off on one or on both sides in accordance with **Figure 5.5-1**.

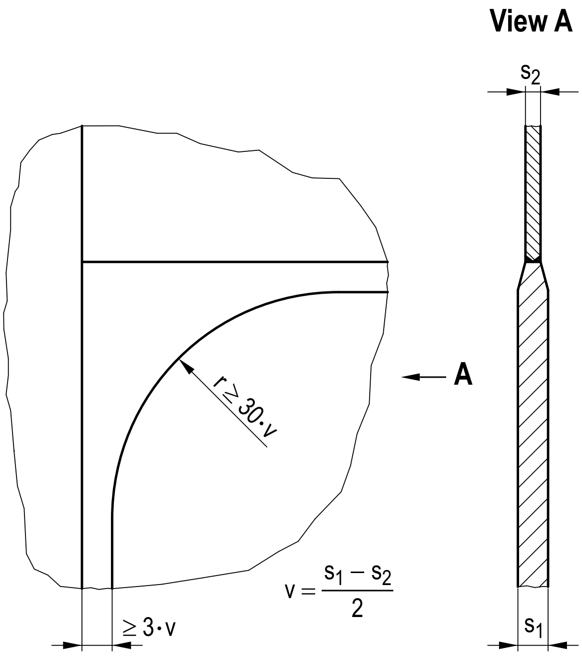

Figure 5.5-1: Wall thickness transition with rounded chamfer

5.5.3 Support structures

(1) Type and size of the support structures are dependent on the reactor type and on the structure of the reactor containment vessel including its attachments and internals. In addition to the clamping of the reactor containment vessel in the foundation, the support structure also may include separate supports for transferring loads from the attachments (e.g., condensation chamber, locks, pipes).

(2) In designing the transition zone of the clamping, i.e., where the reactor containment vessel wall emerges from the concrete structure, it shall be considered that additional stresses can be reduced by suitable design measures, e.g. the use of elastic foundation material. In this case, the ingress of moisture shall be prevented by means of seals.

5.5.4 Cutouts, cutout reinforcements and equipment hatches

(1) Weakening of the wall due to cutouts shall, depending on their type, arrangement and number, be compensated for by reinforcements. The reinforcements shall normally not be considerably thicker than required with regard to the allowable stresses. Cutouts shall normally be circular or elliptical.

(2) In case of angular cutouts, the corners shall normally be rounded off with the largest possible radius.

(3) Plates laid on and connected by welding to the containment vessel wall are not allowed.

(4) Cutouts in the basic body of the reactor containment vessel may be reinforced by designs favourable to stress given in a) through d) below; this is independent of the manufacturing procedure of the product form.

a) Cutout reinforcements where the weakening in the wall is accounted for by a sufficient increase of the wall thickness of the reactor containment vessel basic body. As far as possible, penetrations shall normally be grouped together in a reinforced circumferential zone or in single reinforced plates. The number of single plates shall be kept as low as possible by properly grouping the penetrations.

b) Cutout reinforcements by reinforcing pads of the reactor containment vessel basic body, where the reinforcing action is achieved only by the reinforcing pad.

c) Cutout reinforcements by a pipe-shape reinforcement of the reactor containment vessel basic body, where the reinforcing action is achieved only by a welded-in, preferably set-through, nozzle.

d) Cutout reinforcements using a combination of reinforcing the reactor containment vessel basic body by a ring-shaped thickening of the reactor containment vessel basic body and a welded-in, preferably set-through, nozzle.

(5) The design of cutouts shall comply with the requirements regarding the design of cable penetrations in accordance with KTA 3403 and the requirements regarding pipe penetrations in accordance with KTA 3407.

(6) Detachable connections in conjunction with cutouts are allowed if the requirements regarding leak-tightness are met.

(7) If erection openings for transferring large plant components are designed with detachable connections, the shell forces shall be transferred using deformation-resistant non-frictional connections, e.g., by means of a double-cover-plate-joint with high-strength bolts, or by means of interlocking hook-shaped flanges with wedge shaped or fitted pressure bars, or by means of fitted shear bolts.

(8) Nozzles shall be manufactured from forged and rolled bars, from forged seamless hollow bodies or from seamless pipes. Longitudinally welded nozzles may be employed if their nominal diameter is larger than or equal to 300 mm.

(9) Welded set-in nozzles shall basically be back-welded. Exceptions are permitted where for geometric reasons (e.g., small dimensions, fittings and valves) back-welding is impossible. In such cases, the root shall be machined. If a machining of the root is impossible, the testability of the weld seam shall be ensured by special measures.

6 Stress and stability analysis

6.1 General

(1) The internal forces and moments for the stress and stability analyses shall be performed on the basis of the theory of elasticity. The plastic behaviour of components of the support structure may be included in these analyses which, among others, also depends on the corresponding ratio of the maximum moment of plasticity to the maximum moment of elasticity.

(2) With the assumption of an ideally plastic material behaviour, this ratio equals 1.5 for pure bending in the case of isotropic plane load-bearing structures, whereas, in the case of anisotropic plane load-bearing structures and of profile bars different values may have to be assumed. These groups of structures are, therefore, dealt with in separate sections.

(3) The stress and stability analysis shall consider constraints; see sub-clause 4.3 (2). In addition, it shall be ensured that deformations of the reactor containment do not lead to an inadmissible contact with adjacent structures.

6.2 Isotropic plane load-bearing structures

6.2.1 General

The stress and stability analysis shall, in general, be performed by computation. If the computation is to be supplemented or replaced by experiments, the plant vendor, manufacturer and the authorized inspector under Sec. 20 of the Atomic Energy Act and the authorized expert under Civil Law shall in advance reach an agreement on the experimental program.

6.2.2 Determination of internal forces and moments

The internal forces and moments shall be determined in accordance with the theory of elasticity under consideration of all geometric discontinuities (e.g., change in shell shape, wall thickness transitions, penetrations) and of the restrictions of deformation in accordance with para. 4.3 (2) and shall be determined for the loading levels in accordance with Section 4.4.

6.2.3 Stress classification

6.2.3.1 General

(1) Depending on their causes and on their effects on the strength behaviour of the components, the stresses shall be classified into categories, that means into primary stresses, secondary stresses and peak stresses, and shall be limited in different ways with regard to their classification.

(2) Where in special cases the classification into the aforementioned stress categories is unclear the effect of plastic deformation on the mechanical behaviour shall be determining where an excess of the intended loading is assumed.

(3) Membrane stresses in the wall of the reactor containment vessel caused by forces and moments from pipes shall be classified into primary stresses.

Note:

The definitions and terms used hereinafter are taken from the theory of plane load-bearing structures (e.g., shells, plates, disks); they can, however, also be applied to other load-bearing structures and components (e.g., bars, beams).

6.2.3.2 Primary stresses

(1) Primary stresses (P) are stresses which satisfy the laws of equilibrium of external forces and moments (loads).

(2) Regarding the mechanical behaviour of a structure the basic characteristic of this stress is that in case of (an inadmissibly high) increment of external loads the distortions upon full plastification of the section considerably increase without being self-limiting.

(3) Regarding primary stresses distinction shall be made between membrane stresses (P_m, P_l) and bending stresses (P_b) with respect to their orientation normal to the wall of a component.

(4) In the case of plane load-bearing structures the membrane stresses are defined as the average value of the stresses distributed over the wall thickness. The bending stresses of plane load-bearing structures are defined as the linearly changing component of the stresses distributed over the wall thickness.

(5) Regarding the distribution of membrane stresses across the wall distinction is to be made between general primary membrane stresses (P_m) and local primary membrane stresses (P_l). While general primary membrane stresses are distributed such that no redistribution of stresses due to plastification occurs into adjacent regions, plastification in the case of local primary membrane stresses at discontinuities will lead to a redistribution of stresses. Conservatism requires that such a stress be classified as a local primary membrane stress even though it has some characteristics of a secondary membrane stress.

At stressed regions (discontinuities) a primary membrane stress may be considered a local primary membrane stress, if the distance over which the membrane stress intensity exceeds 1.1 times the allowable general membrane stress does not extend in the meridional direction more than $1 \cdot \sqrt{R \cdot s_c}$, where R is the minimum mid-surface radius of curvature and s_c is the minimum thickness in the region considered.

Two adjacent regions of local primary membrane stress intensity involving axisymmetric membrane stress redistributions that exceed 1.1 · S_m, shall not be closer in the meridional direction than $2.5 \cdot \sqrt{R \cdot s_c}$ where $R = (R_1 + R_2)/2$ and $s_c = (s_{c,1} + s_{c,2})/2$ where for the wall thicknesses $s_{c,i}$ of the two regions 1 and 2 considered the locally available values are to be used in accordance with the definition of local primary membrane stress.

Discrete regions of local primary membrane stress intensity resulting from concentrated loads (e.g. acting on penetrations) shall be spaced so that there is no overlapping of the areas in which the membrane stress intensity exceeds 1.1 of the allowable general membrane stress.

6.2.3.3 Secondary stresses

(1) Secondary stresses (Q) are stresses developed by constraints due to geometric discontinuities and by the use of materials of different elastic moduli under external loads, and by constraints due differential thermal expansions. Only stresses that are distributed linearly across the cross-section are considered to be secondary stresses.

(2) With respect to the mechanical behaviour of the structure the basic characteristics of secondary stresses are that they lead to plastic deformation when equalizing different local distortions in the case of excess of the yield strength. Secondary stresses are self-limiting.

6.2.3.4 Peak stress

(1) Peak stress (F) is that increment of stress which is additive to the respective primary and secondary stresses. Peak stresses do not cause any noticeable distortion and are only important to fatigue in conjunction with primary and secondary stresses.

(2) Peak stresses also comprise deviations from nominal stresses at hole edges not reinforced by tubes within tube hole fields due to pressure and temperature in which case the nominal stresses shall be derived from equilibrium of forces considerations.

6.2.4 Superposition and evaluation of stresses

6.2.4.1 General

(1) As shown hereinafter, for each load case the stresses acting simultaneously in the same direction shall be added separately or for different stress categories (e.g. primary and secondary stresses) be added jointly.

(2) From these summed-up stresses the stress intensity for the primary stresses and the equivalent stress range each for

the sum of primary and secondary stresses or the sum of primary stresses, secondary stresses and peak stresses shall be derived.

(3) The stress intensities and equivalent stress ranges shall be limited in accordance with Section 6.2.5.

6.2.4.2 Stress intensities

(1) The stress intensities, to be correlated to the different primary stresses shall be calculated in accordance with the maximum shear stress hypothesis or with the maximum distortion energy theory, and shall be compared to the pertinent allowable values.

(2) After first establishing a Cartesian coordinate system, the numerical sums of the coincidentally and directionally acting stresses shall be calculated individually for

a) the general primary membrane stresses,

b) the local primary membrane stresses,

c) the sum of the general primary membrane stresses or of the local primary membrane stresses and of the primary bending stresses.

For each of these three cases, the results shall be used to determine the stress intensities in accordance either with the maximum shear stress hypothesis or with the maximum distortion energy theory.

6.2.4.3 Equivalent stress ranges

(1) To avoid failure due to

a) progressive distortion (ratcheting)

b) fatigue

the stress ranges pertinent to the stress categories shall be determined.

(2) In case (1) a) the required stress tensors shall be formed taking the simultaneously acting stresses from primary and secondary stress categories, and in case (1) b) taking the simultaneously acting stresses from all stress categories.

(3) From the number of service loadings to be considered two service loadings shall be selected by using one fixed coordinate system so that the stress intensity derived from the difference of the pertinent stress tensors becomes a maximum. This maximum value is the equivalent stress range.

(4) Where, upon application of the maximum shear stress theory, the loading conditions to be considered show no change in the direction of principal stresses it will suffice to form the maximum value of the differences of any two principal stress differences of equal pairs of principal stress directions. This maximum value then is the equivalent stress range according to the maximum shear stress theory. A proof of allowability for the equivalent stress ranges determined for the sum of primary and secondary stresses is not required if the stress intensities do not exceed the 0.2% proof stress $R_{p0.2T}$ or the yield strength R_{eHT} in either of the loading levels 1 and 2.

6.2.5 Allowable stress values

(1) The allowable stress values shall be related to the 0.2% proof stress ($R_{p0.2T}$) or the yield strength (R_{eHT}) at the respectively relevant temperatures.

(2) The stresses allowed for the component also apply to the weld seams in conjunction with the manufacturing and quality assurance requirements in accordance with KTA 3401.3. If the equations of the AD 2000-Merkblätter are used in the design, then a weld seam factor of 1.0 may be applied.

(3) If, in the following, allowable stress values are specified as being larger than 1.0 $R_{p0.2T}$ or 1.0 R_{eHT}, they shall be considered fictitious stresses the adherence to which is meant to limit resulting deformations.

(4) For the stress intensities determined from the primary stresses in accordance with Section 6.2.4.2, and for the equivalent stress ranges as the sum of primary and secondary stresses in accordance with Section 6.2.4.3, the following limit values presented in terms of $R_{p0.2T}$ or R_{eHT} apply.

(5) In case of loading levels 0 and 1, the following limits apply:

a) $0.67 \cdot R_{p0.2T}$ for the stress intensity from general primary membrane stresses (P_m); however, the value of $R_{p0.2T}$ shall not exceed 370 N/mm^2 at room temperature and 320 N/mm^2 at 150 °C.

b) $0.75 \cdot R_{p0.2T}$ for the stress intensity from local primary membrane stresses (P_l) and from the sums of general primary membrane stresses and primary bending stresses ($P_m + P_b$), or from the sums of local primary membrane stresses and primary bending stresses ($P_l + P_b$).

(6) In the case of loading level 1, the following requirements apply in addition (5) a) and b):

a) $1.67 \cdot R_{p0.2T}$ for the equivalent stress range from the sums of general primary membrane stresses, primary bending stresses and secondary stresses ($P_m + P_b + Q$), or from the sums of local primary membrane stresses, primary bending stresses and secondary stresses ($P_l + P_b + Q$); however, the value of $R_{p0.2T}$ shall not exceed 370 N/mm^2 at room temperature and 320 N/mm^2 at 150 °C. The loss-of-coolant accident (ST 1) need not be considered in forming the equivalent stress ranges if in accordance with the specifications its assumed number of occurrences is smaller than 5. The sum of the primary and secondary stresses from ST 1 shall be limited to $1.67 \cdot R_{p0.2T}$. Here, temperature stresses in the reactor containment vessel wall which are in equilibrium with each other may be neglected. This also applies to temperature stresses in the nozzle regions of the reactor containment vessel zones embedded in concrete.

b) For the equivalent stress ranges determined in accordance with Section 6.2.4.3 from the sum of primary stresses, secondary; stresses and peak stresses, a fatigue analysis in accordance with Section 6.5 shall be performed.

c) In the case of loading level 2, the limit values according to (5) a) and b) and (6) a) may be increased by 10 %. In the case of test load cases and other substantiated loading conditions no secondary stress analysis and no fatigue analysis need to be performed.

d) In the case of loading level 3, only primary stresses need to be analyzed. Here, the limit values according to (5) a) and b) may be increased by 25 %.

(7) **Table 6.2-1** lists the limit values for the stresses and stress ranges for demonstrating the load-bearing capacity of the cross section.

6.2.6 Stability analysis

(1) The stability of pressure-retaining shells shall be analyzed assuming applicable geometries and loads in accordance with DIN EN 1993-1-6 and DIN EN 1993-1-6/NA, in which case the “linear elastic shell analysis (LA)” and the linear elastic bifurcation analysis (LBA)” shall normally be applied.

(2) Contrary to the demonstration of the load-bearing capacity of the cross section (adherence to the limit stress as per **Table 6.2-1**) listed under 1.00 times the (characteristic) loads, the stability shall be demonstrated with loads increased by partial safety factors (design loads).

(3) Action combinations with partial safety factors as per **Table 6.2-2** shall be used as loadings. Non-permanent loads shall not be considered if they have favourable effect.

Loading level	P_m [1]	$P_m + P_b$ or P_l or $P_l + P_b$	$P_m + P_b + Q$ [1] or $P_l + P_b + Q$	$P_m + P_b + Q + F$ or $P_l + P_b + Q + F$
0	$0.67 \cdot R_{p0.2T}$	$0.75 \cdot R_{p0.2T}$	—	—
1	$0.67 \cdot R_{p0.2T}$	$0.75 \cdot R_{p0.2T}$	$1.67 \cdot R_{p0.2T}$	fatigue analysis
2	$0.75 \cdot R_{p0.2T}$	$0.84 \cdot R_{p0.2T}$	$1.84 \cdot R_{p0.2T}$ [2]	fatigue analysis
3	$0.84 \cdot R_{p0.2T}$	$0.94 \cdot R_{p0.2T}$	—	—

1) In the demonstration $R_{p0.2T}$ shall be limited to the following values (see sub-clauses 6.2.5 (5) and (6)):
$R_{p0.2T} \leq$ 370 N/mm² at room temperature
$R_{p0.2T} \leq$ 320 N/mm² at T = 150 °C

2) For test load cases and other substantiated loading conditions no secondary stress analysis and fatigue analysis need be carried out.

Table 6.2-1: Limit values for the stresses and stress range and required analyses

Loading levels	Load cases	Loadings according to Section 4.3: a) Permanent loads	b) Overall internal pressure	b) Negative pressure or external overpressure	b) Local pressure increase	b) Temperature	c) External loading and loading moments	d) Traffic loads	e) Wind loads	f) Snow loads	g) Dynamic loads, excitation at foundation level	Combination coefficient for non-permanent loads
0	DF 2	1.35 [1]	—	1.50	—	—	—	—	—	—	—	1.00
1	MF 1	1.35 [1]	—	—	—	—	1.35	1.35	—	1.35	—	1.00
	NB	1.35 [1]	—	1.50	—	1.50	1.50	—	—	—	—	0.90 [2]
2	MF 2	1.35 [1]	—	—	—	—	1.35	1.35	1.35	1.35	—	1.00
	DP 2	1.35 [1]	—	1.35	—	—	1.35	—	1.35	—	—	1.00
	ST 2	1.35 [1]	—	1.35	—	1.35	1.35	—	—	—	—	1.00
3	ST 5	1.00	—	1.00	1.00	—	1.00	—	—	—	—	1.00
	EVA 1	1.00	—	1.00	—	—	1.00	—	—	—	1.00	1.00
	EVA 2	1.00	—	1.00	—	—	1.00	—	—	—	1.00	1.00

1) 1.00 in the case of favourable impact.
2) In the case of several simultaneously acting non-permanent loads (otherwise: 1.00)

Table 6.2-2: Partial safety factors for the action combinations to be demonstrated by the stability analysis to DIN EN 1993-1-6

6.3 Anisotropic plane load-bearing structures and frame structures

The stress and stability analyses shall be performed in accordance with the generally accepted standards for the design and construction of structural steelwork under consideration of the stress type and its assumed number of occurrence.

6.4 Bolted connections

6.4.1 General

(1) The forces to be transmitted shall be determined for all loading levels in accordance with Section 4.4. In the case of bolts subjected to tensile stress, their prestress shall be considered additionally if it was not already taken into account in the specification of allowable stresses.

(2) For the components to be joined, it shall be shown that the limit values for the stresses and stress range specified in Section 6.2.5 are not exceeded under consideration of the reduction of the cross-section due to the bolt holes.

(3) The minimum dimensions to be used for load-bearing bolts shall be those of M12 bolts. All bolted connections shall be secured. Securing is considered to be obtained by the specified bolt pre-loading.

(4) Such bolts shall be used only the strength of which corresponds at least to strength class 5.6 and the materials of which are permitted for use by KTA 3401.1.

(5) The allowable hole clearances for round holes and the limit values for oblong hole dimensions shall be taken from DIN EN 1092-2.

(6) Bolts shall be tightened

a) in the case of pre-loaded bolts as specified by the standard series DIN EN 14399 in accordance with DIN EN 1090-2,

b) in the case of other pre-loaded bolts to a suited technical rule, e.g. VDI 2230, Sheet 1.

The use of an initial tightening force with

$$F = 0.7 \cdot R_{p0.2RT} \cdot A_S$$

is also permitted in the case of pre-loaded connections. The initial tightening force used shall be used as basic value in the calculations.

The bolt pre-load shall be limited to 0.9 times the value of $R_{p0.2T}$, in which case $R_{p0.2T}$ is the 0.2% proof stress of the bolt material at the highest temperature to be expected. For tensile-loaded connections with sealing function as per clause 6.4.3.3, however, the requirements for pre-loading (initial tightening) apply as laid down in the respective design basis document.

(7) The data for tightening of pre-loaded bolts shall be entered on the design drawing.

(8) Where galvanized bolts are used, bolts, nuts and washers from the same manufacturer shall be used.

6.4.2 Transmission of shear forces

6.4.2.1 General

(1) Shear connections shall be designed to be symmetric to the plane in which the force acts. Therefore, in the case of butt-jointed plates, coverplates on both sides shall be used, without exception.

(2) The calculation of shear connections shall be carried out according to Sections 6.4.2.2 and 6.4.2.3.

(3) **Table 6.4-1** applies to the distances between edges and holes and the hole-to-hole distances.

(4) In connections with oblong holes the allowable bearing pressure at loading vertical to the longitudinal axis of the oblong holes shall be reduced to 60% of the allowable value for round holes.

(5) DIN EN 1090-2 shall govern the design of shear connections.

(6) Shear connections shall be designed such that all shear faces are located in the bolt shank area.

(7) The stresses for bolt connections shall be determined in accordance with clause 6.4.2.2.2. The following shall especially be considered:

a) for the shear loading analysis, the section in the shearing cross section (shank or core section) shall govern,

b) for the tensile loading analysis in case of bolts with metric ISO threads to DIN 13-1, the tensile-loaded section shall govern, otherwise the core section.

6.4.2.2 Combined shear/bearing pressure connections

6.4.2.2.1 Design

(1) For shear/hole bearing connections (SL/SPL) the following may be used:

a) body-fit bolts (e.g. to DIN 7968; for SLP),

b) high-strength body-fit bolts (e.g. to DIN EN 14399-8; for SLP) of strength class 10.9

c) high-strength bolts (e.g. to DIN EN 14399-4 or DIN EN 15048-1; for SL) of strength class 10.9 without body fit if the displacements to be expected in the connections are unobjectionable and loadings do not occur with changing directions.

(2) The bolt diameter and material thicknesses shall normally be correlated such that the following condition is satisfied:

$$\frac{\tau_{a\,vorh}}{\tau_{a\,zul}} \le 0.8 \cdot \frac{\sigma_{L\,vorh}}{\sigma_{L\,zul}} \qquad (6.4\text{-}1)$$

with:

$\sigma_{L,\,vorh}$: effective bearing pressure between bolt and hole wall of the component to be connected

$\tau_{a,\,vorh}$: effective bolt shear load

$\sigma_{L,\,zul}$: allowable bearing pressure as per **Table 6.4-2**

$\tau_{a,\,zul}$: allowable shear stress as per **Table 6.4-2**

Equation 6.4-1 shall only be satisfied if

$$\frac{\tau_{a\,vorh}}{\tau_{a\,zul}} > 0.5 \qquad (6.4\text{-}2)$$

(3) The allowable values of bearing pressure σ_L and shear stresses τ_a are shown in **Table 6.4-2**.

6.4.2.2.2 Verification

(1) In the following equations (6.4-3) to (6.4-5) the following is meant with

A_a : cross-section of bolt shank

F : section force (longitudinal force N, transverse force Q)

$Q_{SL\ zul}$: allowable transmittable force of a bolt per shear plane vertically to the bolt axis in a SL connection

$Q_{SLP\ zul}$: allowable transmittable force of a bolt per shear plane vertically to the bolt axis in a SLP connection

d : bolt shank diameter

n : number of bolts in the connection

m : number of shear bands

$\Sigma\, t_{min}$: smallest sum of plate thicknesses with bearing pressures acting in same direction

σ_L : bearing pressure between bolt and hole wall of the component to be connected

τ_a : bolt shear load

(2) The bearing pressure σ_L and the shear stress τ_a shall be calculated as follows irrespective of the effective stress ratios:

$$\sigma_L = \frac{F}{d \cdot n \cdot \Sigma\, t_{min}} \qquad (6.4\text{-}3)$$

The values $\sigma_{l,\ zul}$ for the part and the bolt are listed in **Table 6.4-2**. In the case of differing materials for the part and the fasteners, the design shall be based on the smaller value.

$$\tau_a = \frac{F}{n \cdot m \cdot A_a} \quad \text{with } A_a = \frac{\pi \cdot d^2}{4} \qquad (6.4\text{-}4)$$

$$\left.\begin{matrix} Q_{SL\ zul} \\ Q_{SLP\ zul} \end{matrix}\right\} = \tau_{a\ zul} \cdot \frac{\pi \cdot d^2}{4} \qquad (6.4\text{-}5)$$

The values for $\tau_{a\ zul}$ are shown in **Table 6.4-2**.

6.4.2.3 Friction-grip connections

(1) Friction-grip connections shall be fabricated with pre-loading as specified in accordance with sub-clause 6.4.1 (6).

(2) In case of differential thermal expansion between bolt shank and pre-loaded components, its influence on the initial

tightening force of bolts and thus on frictional resistance of the connection shall be taken into account.

(3) Bolts without body-fit (friction-grip connections) or body-fit bolts (friction-grip body-fit connections) may be used.

(4) The contact surfaces for friction-grip connections shall be prepared in accordance with DIN EN 1090-2, section 8.4. If a friction-resistant painting is used, its behaviour in case of heating shall always be determined by tests and be taken into account.

(5) In a friction-grip connection the allowable transmittable force Q_{GVzul} per high-strength bolt and contact surface shall be:

$$Q_{GVzul} = \frac{\mu}{\nu} \cdot F_V \qquad (6.4\text{-}6)$$

Where:

F_V : pre-stress force of the bolt

μ : static friction coefficient of the contact surfaces
The value given in chapter 8.4 of DIN EN 1090-2 depending on the preparation of contact surfaces shall apply unless the friction coefficient for the material of the component is experimentally determined by an acknowledged testing institute under consideration of the intended preparation of the contact surfaces and of the governing component temperature.
This value shall be reduced in correspondence to the ratio of $R_{p0.2T,B}$ to $R_{eH(S235)}$ if this ratio is less than 1.0 (see **Table 6.4-2** for the meaning of $R_{p0.2T,B}$).

ν : safety factor against gliding
loading level 1:
ν = 1.25 in the case of predominantly static loading, and
ν = 1.4 in the case of not predominantly static loading
loading level 2:
ν = 1.1
loading level 3:
ν = 1.0

The allowable bolt bearing pressure is:

loading level 1:
$2.0 \cdot R_{p0.2T,B}$
loading level 2:
$2.2 \cdot R_{p0.2T,B}$
loading level 3:
$2.5 \cdot R_{p0.2T,B}$

(6) In friction-grip body-fit connections the shear force Q_{GVPzul} per contact surface and shear plane is calculated as follows:

$$Q_{GVPzul} = 0.5 \cdot Q_{SLPzul} + Q_{GVzul} \qquad (6.4\text{-}7)$$

where Q_{SLPzul} is to be determined in accordance with equation 6.4-5 and Q_{GVzul} in accordance with equation 6.4-6.

(7) If GVP-joints are loaded with stress resultants of alternating signs, then the transfer of the force with the larger absolute value shall be demonstrated with Q_{GVPzul} and that with the smaller absolute value with Q_{GVzul}.

(8) For tensile-loaded components attached by friction-grip or friction-grip body-fit connections it may be assumed in the general stress analysis that 40% of the allowable transmittable force Q_{GVzul} to equation 6.4-6 of those high-strength bolts located in the considered section weakened by holes have been attached as friction-grip connection prior to weakening by hole (subtraction of force). In addition, the full section with total force applied shall be analysed.

(9) The bearing pressure σ_l in the components to be connected shall be demonstrated by calculation to equation 6.4-3 in which case the influence of frictional forces is not to be considered. An analysis of the shear stress τ_a is not required.

6.4.3 Tensile-loaded joints

6.4.3.1 General

(1) Tensile-loaded connections shall be designed such that usually occurring bending stresses in the bolts are avoided.

(2) Unavoidable bending stresses (e.g. due to component deformations or eccentric pressing) in bolts shall be accounted for in the analysis.

(3) Allowable deformations of the complete connecting structure shall be considered specifically.

(4) For tensile-loaded connections subject to additional transverse forces the requirements of clause 6.4.4 shall be met additionally.

6.4.3.2 Tensile-loaded connections without sealing function

(1) If the bolts of such connections without sealing function are not stressed by bending moments, they may be analysed by limiting the tensile stresses arising from external load in the stressed section of the bolts.

$$\sigma = \frac{F}{A_S} \le \sigma_{zul} \qquad (6.4\text{-}8)$$

with σ_{zul} as per **Table 6.4-3**.

(2) Bolts subject to unavoidable bending moments shall be analysed to satisfy VDI guideline 2230 or other suitable analysis procedures.

(3) High-strength bolts of strength classes 10.9 and 8.8 shall be pre-loaded as specified by sub-clause 6.4.1 (6).

(4) Other bolts shall be pre-loaded to meet the requirements of VDI guideline 2230.

(5) For bolted connections the failure of which does not impair the safety of the reactor containment, pre-loading may be waived.

6.4.3.3 Tensile-loaded connections with sealing function

(1) For tensile-loaded connections having sealing function, the load-bearing capacity shall be demonstrated to meet the requirements of KTA 3201.2, VDI guideline 2230 or other suitable procedures. The effectiveness of the sealing function shall be ensured by selecting an appropriated pre-load.

(2) In this case, the calculated tensile or bending tensile stress arising from internal pressure, required sealing force and external loads shall be limited to $0.67 \cdot R_{p0.2TS}$, in which case $R_{p0.2T,S}$ is the 0.2 % proof stress of the bolt material at the highest temperature to be expected.

6.4.4 Shear connections with external tensile loading

(1) Shear connections subject to external tensile loading shall be designed with pre-loading as specified by sub-clause 6.4.1 (6).

(2) In this case, the calculated tensile force of the bolt shall not exceed 60 % of the pre-stress force. If the maximum of this value is actually used in a friction-grip joint, then the allowable shear force per contact surface shall be reduced to 0.2 times the calculated value. In the case of friction-grip body-fit connections, this reduction applies only to the component term Q_{GVzul}. Intermediate values may be linearly interpolated.

(3) A fatigue analysis is not required for the tensile loading of bolts pre-stressed in accordance with para. 6.4.1 (6).

6.5 Fatigue analysis

6.5.1 General

A fatigue analysis shall be performed in order to avoid failure from fatigue due to repeated change in loading.

6.5.2 Load cases to be considered

(1) The demonstration of fatigue strength shall consider all load cases occurring during plant operation, under anomalous operating conditions and test conditions. Erection load cases and accidents shall not be considered.

(2) For reactor containment loadings arising from other systems, the load cycles to be considered shall be derived from the specifications of the pertinent systems or be covered by conservative assumptions which account for the total service lifetime of the plant.

6.5.3 Substantiation by way of calculation

(1) The stress ranges resulting from the load cases to be considered shall be determined at locations of possible fatigue cracking (e.g. at geometric discontinuities, in the area of welds, in the threaded portion of bolts). Fatigue cracking shall be excluded by complying with the allowable usage factor.

(2) The fatigue analysis shall be performed by an elastic analysis in accordance with clause 7.8.3 of KTA 3201.2. Fluid influences need not be considered here.

6.6 Shape deviations

(1) If the allowable shape deviations as per section 5 of KTA 3201.3 are adhered to, the reactor containment may be classified under manufacturing tolerance quality class B within the buckling limit state analysis to DIN EN 1993-1-6.

(2) Classification into manufacturing tolerance quality class A is permitted if it is proved that all imperfections classified in section 8.4 of DIN EN 1993-1-6 meet the requirements of manufacturing tolerance quality class A.

(3) Where manufacturing shape deviations exceed the limits fixed in section 5 of KTA 3401.3, they shall be considered within the buckling limit state analysis to DIN EN 1993-1-6 to be assumed higher-level imperfections within the substantiation by way of calculation. They shall only be left where they are if they do not impair the load-bearing capacity of the reactor containment.

Distances between edges and holes			Hole-to-hole distances		
Smallest distance	In direction of force application	$2 \cdot d_1$	Smallest distance	In direction of and perpendicular to direction of force application	$3 \cdot d_1$
	Perpendicular to direction of force application	$1{,}5 \cdot d_1$	Greatest distance	To ensure safety against local buckling	$6 \cdot d_1$ or $12 \cdot t$
Greatest distance	In direction of and perpendicular to direction of force application	$3 \cdot d_1$ or $6 \cdot t$		If no risk of local buckling exists	$10 \cdot d_1$ or $20 \cdot t$

d_1 : hole diameter

t : thickness of the thinnest part of the external components of the connection

Table 6.4-1: Distances between edges and holes distances of bolted connections

Type of stress	Type of connection					
	Body-fit bolts with hole clearance ≤ 0.3 mm (SLP)					Non-body fit bolts (SL) with hole clearance ≤ 1.0 mm
	Strength class 5.6	Strength class 8.8	Other bolts with 300 N/mm² ≤ $R_{p0.2T,S}$ ≤ 450 N/mm²	Other bolts with $R_{p0.2T,S}$ > 450 N/mm²	Strength class 10.9 with pre-loading ≥ 0.5 · F_V to DIN EN 1090-2 1)	
Bearing pressure σ_L	1.33 · $R_{p0.2T,B}$ ≤ α_S · 480 N/mm²				1.75 · $R_{p0.2T,B}$	1.50 · $R_{p0.2T,B}$
Shear stress τ_a	α_S · 160 N/mm² 2)	α_S · 196 N/mm²	0.53 · $R_{p0.2T,S}$	0.30 · $R_{p0.2T,S}$	α_S · 280 N/mm²	α_S · 240 N/mm²

For loading level 2 the allowable stresses may be increased by 10 % and for loading level 3 by 25 %.

1) By bolt pre-loading and the three-dimensional stress condition arising here from, the load bearing capacity of the connection can be improved with regard to failure of hole bearings. This may be accounted for by increasing the allowable bearing pressure.

2) Also see the explanations to section 6 in the documentation file (pp. D-10 to D-13).

Here, the following is meant::

$R_{p0.2T,B}$: 0.2% proof stress $R_{p0.2T}$ or yield strength R_{eHT} of the component material at the pertinent governing temperature

α_S = $R_{p0.2T,S}$ / $R_{p0.2RT,S}$

$R_{p0.2T,S}$: 0.2% proof stress $R_{p0.2T}$ or yield strength R_{eHT} of the bolt material at the pertinent governing temperature

$R_{p0.2RT,S}$: 0.2% proof stress $R_{p0.2T}$ or yield strength R_{eHT} of the bolt material at room temperature

Table 6.4-2: Allowable stresses for shear/bearing stress connections

Allowable tensile stress σ_{zul}	Strength class 5.6	Strength class 8.8	Other bolts with 300 N/mm² ≤ $R_{p0.2T,S}$ ≤ 450 N/mm²	Other bolts with $R_{p0.2T,S}$ > 450 N/mm²	Strength class 10.9
Pre-loaded connection	—	0.7 · F_V/A_S	—	—	0.7 · F_V/A_S
Non-pre-loaded connection	α_S · 150 N/mm²	α_S · 252 N/mm²	0.47 · $R_{p0.2T,S}$	0.40 · $R_{p0.2T,S}$	α_S · 360 N/mm²

For loading level 2 the allowable stresses may be increased by 10 % and for loading level 3 by 25 %.

Here, the following is meant:

A_S : bolt stress section

F_V : bolt preload force

α_S = $R_{p0.2T,S}$ / $R_{p0.2RT,S}$

$R_{p0.2T,S}$: 0.2% proof stress $R_{p0,2T}$ or yield strength R_{eHT} of the bolt material at the pertinent governing temperature

$R_{p0.2RT,S}$: 0.2% proof stress $R_{p0,2T}$ or yield strength R_{eHT} of the bolt material at room temperature

Table 6.4-3: Allowable tensile stress for bolted connections

Annex A

Regulations referred to in this Safety Standard

(The references exclusively refer to the version given in this annex. Quotations of regulations referred to therein refer to the version available when the individual reference below was established or issued.)

AtG		Act on the Peaceful Utilization of Atomic Energy and the Protection against its Hazards (Atomic Energy Act) of July 15, 1985 (BGBl. I, p. 1565), last Amendment by article 1 of the law dated 26th July 2016 (BGBl. I 2016, no. 37, p. 1843)
StrlSchV		Ordinance on the Protection against Damage and Injuries Caused by Ionizing Radiation (Radiation Protection Ordinance) dated 20th July 2001 (BGBl. I 2001, No. 38, p. 1714), last Amendment by article 8 of the law dated 26th July 2016 (BGBl. I 2016, no. 37, p. 1843)
SiAnf	(2015-03)	Safety Requirements for Nuclear Power Plants (SiAnf) as Promulgated on March 3rd 2015 (BAnz AT 30.03.2015 B2)
Interpretations	(2015-03)	Interpretations of the Safety Requirements for Nuclear Power Plants of November 22nd 2012, as Amended on March 3rd 2015 (BAnz. AT 30.03.2015 B3)
KTA 3201.2	(2013-11)	Components of the Reactor Coolant Pressure Boundary of Light Water Reactors; Part 2: Design and Analysis
KTA 3401.1	(1988-09)	Steel Containment Vessels; Part 1: Materials
KTA 3401.3	(1986-11)	Steel Reactor Safety Containment; Part 3: Manufacture
KTA 3401.4	(1991-06)	Steel Containment Vessels; Part 4: Inservice Inspections
KTA 3402	(2014-11)	Airlocks on the Reactor Containment of Nuclear Power Plants - Personnel Airlocks
KTA 3403	(2015-11)	Cable Penetrations through the Reactor Containment Vessel
KTA 3404	(2013-11)	Isolation of Operating System Pipes Penetrating the Containment Vessel in the Case of a Release of Radioactive Substances into the Containment Vessel of Nuclear Power Plants
KTA 3405	(2015-11)	Leakage Test of the Containment Vessel
KTA 3407	(2014-11)	Pipe penetrations through the Reactor Containment Vessel
KTA 3409	(2009-11)	Airlocks on the Reactor Containment of Nuclear Power Plants - Equipment airlocks
KTA 3413	(2016-11)	Determination of Loads for the Design of a Full Pressure Containment Vessel against Plant-Internal Incidents
DIN 13-1	(1999-11)	ISO general purpose metric screw threads - Part 1: Nominal sizes for coarse pitch threads; nominal diameter from 1 mm to 68 mm
DIN EN 1090-2	(2011-10)	Execution of steel structures and aluminium structures - Part 2: Technical requirements for steel structures; German version EN 1090-2:2008+A1:2011
DIN EN 1993-1-6	(2010-12)	Eurocode 3: Design of steel structures - Part 1-6: Strength and stability of shell structures; German version EN 1993-1-6:2007 + AC:2009
DIN EN 1993-1-6/NA	(2010-12)	National Annex - Nationally determined parameters - Eurocode 3: Design of steel structures - Part 1-6: Strength and stability of shell structures
DIN 7968	(2007-07)	Hexagon fit bolts with hexagon nut for steel structures
DIN EN 14399-1	(2015-04)	High-strength structural bolting assemblies for preloading - Part 1: General requirements; German version EN 14399-1:2015
DIN EN 14399-2	(2015-04)	High-strength structural bolting assemblies for preloading - Part 2: Suitability for preloading; German version EN 14399-2:2015
DIN EN 14399-3	(2015-04)	High-strength structural bolting assemblies for preloading - Part 3: System HR - Hexagon bolt and nut assemblies; German version EN 14399-3:2015
DIN EN 14399-4	(2015-04)	High-strength structural bolting assemblies for preloading - Part 4: System HV - Hexagon bolt and nut assemblies; German version EN 14399-4:2015
DIN EN 14399-5	(2015-04)	High-strength structural bolting assemblies for preloading - Part 5: Plain washers; German version EN 14399-5:2015
DIN EN 14399-6	(2015-04)	High-strength structural bolting assemblies for preloading - Part 6: Plain chamfered washers; German version EN 14399-6:2015

DIN EN 14399-7	(2008-03)	High-strength structural bolting assemblies for preloading - Part 7: System HR - Countersunk head bolt and nut assemblies; German version EN 14399-7:2007
DIN EN 14399-8	(2008-03)	High-strength structural bolting assemblies for preloading - Part 8: System HV - Hexagon fit bolt and nut assemblies; German version EN 14399-8:2007
DIN EN 14399-9	(2009-07)	High-strength structural bolting assemblies for preloading - Part 9: System HR or HV - Direct tension indicators for bolt and nut assemblies; German version EN 14399-9:2009
DIN EN 14399-10	(2009-07)	High-strength structural bolting assemblies for preloading - Part 10: System HRC - Bolt and nut assemblies with calibrated preload; German version EN 14399-10:2009
DIN EN 15048-1	(2016-09)	Non-preloaded structural bolting assemblies - Part 1: General requirements; German version EN 15048-1:2016
AD 2000-Merkblatt B0	(2014-11)	Design of pressure vessels
AD 2000-Merkblatt B1	(2000-10)	Cylindrical and spherical shells subjected to internal overpressure