DIN 2413 Part1 Design of steel pressure pipes

1 Scope and field of application

This standard covers the design of straight steel pressure pipes with a circular cross-sectional shape and a ratio of outside to inside diameter, dx.dx, of up to 2,0, for the following service conditions (referred to here as load cases Ⅰ through Ⅲ).

Ⅰ Pipes subjected to predominantly loading and rated for a temperature up to 120°C¹) .

Ⅱ Pipes subjected to predominantly loading and rated for a temperature over 120°C.

Ⅲ Pipes subjected to fatigue loading and rated for a temperature up to 120°C¹), ²).

The design of pipe fittings (e.g. flanges, branches) shall be carried out in compliance with the relevant DIN Standards and codes of practice.

¹) Where the temperature of the pipe wall could fall below - 10°C, it shall be ensured that the steel exhibits adequate low temperature toughness (e.g. steel in compliance with DIN 17 173, din 17 174, din 17 178 or DIN 17 179).

For more information on pipes to be used at low temperatures, see AD-Merkblatt(AD Code of practice)W10.

²) For more information on pipes to be used at elevated temperature, see Technische Regel fur Dampfkessel (Code of practice for steam boilers) TRD 301 Suppliment 1 and AD-Merkblatt S2.

2 Quantities, symbols and units

2.1 Quantities and SI units

The quantities and SI units used in this standard are given in table 1.

Table 1: Quantities and SI units

Quantity	SI unit
Dimensions	
Diameter, wall thickness, radius	mm
Area	mm^2
Pipe length, length of pipe run	m
Pressure *)	N/mm^2
Stresses, characteristic strength values, modulus of elasticity	N/mm^2
Mass	kg
Density	kg/m^3
Time	s or h
Velocity	m/s

Temperature	˚C
Temperature difference	K
*) In the relevant literature, pressure is also expressed with the following units: 1N/mm²=1MPa=10bar.	

2.2 Quantities, symbols and units used in the design formulae

Table 3: Data required to determine wall thickness and test pressure

Load case	Design wall thickness, sx in mm	Characteristic strength value, K, in N/mm²	Safety factor, S, or degree of utilization, Y, for pipes supplied				
				with		without³)	
				a DIN 50 049 inspection certificate			
			A 5)	S	Y	S	Y
Ⅰ		Yield strength or 0.2% proof strength or 0.5% proof strength (specified minimum values at 20˚C) 4) 6) (see sub-clause 4.2 for exceptions)	≥25% =20% =15%	1.5 1.6 1.7	0.67 0.63 0.59	1.7 1.75 1.8	0.59 0.57 0.55
			For buried pipes not subjected to significant additional loading, the following shall apply:				
Ⅱ		1. 0.2% proof strength (specified minimum value) at the design temperature4)6)		1.5	-	1.7	-
		2. Minimum rupture strength, The lowest value of x shall be used in the calculation (see subclause 4.2.2 for exceptions).	-	1.0	-	-	-
Ⅲ The design is to account for deformation and fatigue failure at a specified number of cycles. Therefore, the larger wall	a) Equation (2) shall be used to account for deformation. b) Equation (4) shall be used to account for fatigue failure, at	As for load case Ⅰ, with x determined as in subclause 4.2.3. Minimum fatigue strength at a specified number of cycles, x	As for load case Ⅰ.				
			-	See subclauses 4.2 and 4.2.3. x shall be between 2 and 10.		-	-

thickness obtained is to be used in the analysis.	constant stress amplitude: In the case of varying amplitudes, see subclause 4.2.3.2.	Minimum fatigue strength, x	-	1.5	0.67	-	-
Test pressure, x, in N/mm^2	Applies to a single pipe (cf. subclause 4.7).						

3) Pipe not supplied with an inspection certificate shall only be made from unalloyed steel with a minimum tensile strength of up to 550 N/mm^2 or from austenitic steel with a strain at fracture, A, of not less than 40%

4) The yield strength shall either be taken from the relevant specifications (e.g. standards, codes of practice), intermediate values being obtained by interpolation. In the case of design temperatures below 20°C, the values specified for 20°C shall be used (cf. subclause 4.2.1).

5) Intermediate values of A may be obtained by interpolation or, where the strain is less than 15% by extrapolation.

6) In certain cases and only for austenitic steel, x may be used in the analysis instead of x, and x instead of x (cf. subclauses 4.2.1 and 4.2.2).

7) Equation (2b) yields the same result as equation (2a) where $x=x+2X$. The same applies to equation (3b) as compared to (3a), and (3d) as compared to (3c).

3 Design formulae

The required wall thickness shall be calculated from the following equation:

where x is the design wall thickness as specified in table 3, x is a factor to allow for the lower limit deviation for wall thickness (cf. subclause 4.6.1). Where the lower limit deviation for wall thickness is given as a percentage, x, the required wall thickness shall be calculated from the following;

The formulae required to determine the deign wall thick-ness, x, as a function of the load case, are given in table 3.

4 Information relevant to calculation procedures

The formulae included in the present standard are intended for use in the design of pipes under internal pressure (cf. [1] through [5]).

Equations (2a, b), (3a, b, c, d) and (4) given in table 3 are based on the maximum shear theory, which only accounts for the maximum and minimum values of primary stresses (in this case, x and x). Provided the value of longitudinal stress as a result of internal pressure, x, plus any additional stresses (cf. clause 5), lies between the values of x and x, i.e. provided that the following apply, the result will not be affected:

for equations (2a) and (2b),

for equations (3a) and (3b),

for equations (3c), (3d) and (4),

Where the stresses exceed the above values, clause 5 shall apply.

4.1 Design pressure

The design pressure, p, is understood to be the internal pres-sure to which a pipe run is subjected, account being taken of all service conditions involved.

The design pressure shall be taken as the greater of the values described under a) and b) below.

a) The maximum pressure at the pressure-relieving device, plus the pressure resulting from the difference in height between this device and the lowest point of the pipework.

b) The following components of peak pressure, x, which represent increases in pressure under the service conditions involved, as a result of difference in height, loss in pressure and pressure surges, are given as:

p=1.00, x when the duration of peak pressure exceeds 10% of the total operating time;

p=0.83, x when the duration of peak pressure does not exceed 1% of the total operating time.

Intermediate values shall be obtained by linear interpolation.

A reduction in peak pressure resulting from pressure surges shall only be allowed for when considering load cases Ⅰ and Ⅱ. In the case of fatigue loading (load case Ⅲ), the actual peak pressures as a result of pressure surges shall be used.

Pressure surges shall be given due consideration where liquid media are conveyed.

4.2 Maximum permissible stress

The maximum permissible stress, x, is equal to K/S or Y˙K (the latter being that used in international codes of practice for pipe design). The factor Y represents the degree of utilization which can be assigned to the characteristic strength value, K, under the given loading conditions. Values of S and Y are specified in table 3.

Where fatigue loading is involved, analysis may be based on load case Ⅰ where seamless pipes, or welded pipes with x equal to 1,0, are used, and where the number of cycles given in tables 4,5 and 6 is not exceeded in service (cf. [8]). These cycles are a function of both tensile strength and x, and they account for a safety factor, x, of 10. In the case of welded pipes supplied with an inspection certificate, and with x equal to 0,9 x shall be equal to 20. When determining x, only those pressure changes having a large amplitude (e.g. these as a result of opening and closing the valves) need to be taken into consideration. Where higher numbers of cycles are expected, analysis shall also be based on load case Ⅲ. Table 6 may also be used for high-frequency welded pipes complying with DIN 1630, DIN 17 172, or equivalent documents, provided their suitability has been verified by an accredited test house.

Table 4. Maximum number of load cycles for seamless steel pipes and for high-frequency welded pipes with x equal to 1 (determined with x equal to 10, as in figure 1)

Maximum permissible stress, x, in N/mm²	Maximum number of load cycles for a tensile strength, x, in N/mm², of				
	350 to 450	500	550	600	650
160	100 000	>100 000	>100 000	>100 000	>100 000
180	50 000	90 000	>100 000	>100 000	>100 000
200	30 000	50 000	80 000	>100 000	>100 000
150		17 000	26 000	40 000	56 000
300				16 000	22 000
350					10 000

Table 5. Maximum number of load cycles for submerged-arc welded pipes with x equal to 1 (determined with x equal to 10, as in figure 2)

Maximum permissible stress, x, in N/mm²	Maximum number of load cycles for a tensile strength, x, in N/mm², of				
	350 to 500	550	600	650	700

120	32 000	50 000	80 000	>100 000	>100 000
140	18 000	26 000	40 000	56 000	80 000
160	10 000	15 000	22 000	30 000	42 000
180	6 000	10 000	13 000	19 000	25 000
200		6 000	8 000	11 000	16 000
250			3 000	5 000	6 000
300				2 000	3 000

Table 6: Maximum number of load cycles for seamless steel pipes with an outside diameter not exceeding 114,3mm and complying with the quality requirements specified in DIN 1630, DIN 17172, or equivalent documents (determined with x equal to 10, as in figure 3)

Maximum permissible stress, x, in N/mm²	Maximum number of load cycles for a tensile strength, x, in N/mm², of			
	350	400	450	≥500
160	>100 000	>100 000	>100 000	>100 000
180		>100 000	>100 000	>100 000
200			>100 000	>100 000
250				70 000

4.2.1 Load case I

For pipes subjected to predominantly static loading and rated for a temperature up to 120°C, the characteristic strength value, K, shall be deemed to be the minimum yield strength at 20°C. However, in the case of fine grain steel pipes in accordance with DIN 17178 or DIN 17179 and of austenitic steel pipes, used at operating temperatures exceeding 50°C, K shall be the yield strength at the relevant operating temperature.

Where the operating temperature is below 20°C, K shall be the yield strength at 20°C.

In the case of steels having ratio of minimum yield strength to tensile strength, the following maximum values of K shall be applied:

0.7 x in the case of steel not designed for quenching and tempering;

0.8 x in the case of steel for quenching and tempering and of microalloyed, controlled rolled steel with a low carbon equivalent.

It may be permitted to deviate from these values where use of these materials has proved to be successful in practice, or where written proof of their suitability has been provided (cf. Explanatory notes).

Such proof shall be deemed furnished where the pipe maternal, under the intended conditions, exhibits an x ratio of more than 0.80 (or more than 0.70x)*). Such pipes shall have both a theoretical and an actual characteristic strength value, K, of more than 0.8 x (or more than 0.7 x), under the intended service conditions.

In the case of pipes made from 'new' steel grades (cf. Explanatory notes) or of pipes whose suitability in service cannot be sufficiently demonstrated, other proof of suitability shall be provided which indicates that they have a characteristic strength value, K, of more than 0.8 x (or more than 0.7 x).

The steel used shall be sufficiently ductile, the lower limit for ductility being a value of strain at fracture, A, of 14% (with x equal to 5.65 x), as determined on longitudinal test pieces at 20°C .

In the case of austenitic steel with an x ratio not exceeding 0.5 at 20°C, the pipes may be designed based on x.

The factors of safety specified are minimum values, the actual values being determined as a function of the strain at fracture of the material, as determined on longitudinal test pieces 8) at 20°C. Intermediate values may be obtained by interpolation or, where A is less than 15%, by extrapolation.

Pipes which gave not undergone acceptance inspection shall only be made from unalloyed steel with a minimum tensile strength of 550N/mm² or from austenitic steel with a minimum strain at fracture, A, of 40% or more (with x equal to 5.65 x).

4.2.2 Load case Ⅱ

For pipes subjected to predominantly static loading and rated for a temperature over 120°C, the maximum permissible stress, x, shall be taken as the lower of the two values described below for the characteristic strength value, K, which are to be divided by the factor of safety, S.

1. Where x is used as the bases for analysis, it shall be divided by a factor of safety, S, of 1.5 in the case of pipes supplied with a DIN 50 049 inspection certificate that is valid for the batch, or 1.7 in the case of pipes which have not been supplied with a DIN 50 049 inspection certificate.

In the case of austenitic steel with a ratio of yield strength to tensile strength not exceeding 0.5 at 20°C, it shall be permitted for the pipes to be designed based on x (instead of x).

Characteristic strength values for operating temperatures between 120°C and 200°C shall be obtained by interpolation, using minimum and maximum values of 100°C and 200°C, respectively, or, where K at 100°C is not known, with minimum and maximum values of 20°C and 200°C, respectively.

In the case of DIN 1626, DIN 1628, DIN 1629 or DIN 1630 pipes whose strength at elevated temperatures is not verified, the factors of safety specified above shall be increased by 20%.

2. A analysis based on rapture strength at the design temperature, x or x

Design based on rapture strength requires that the pipes be supplied with a DIN 50049 inspection certificate.

Either of the following two parameters may be considered:

a) the minimum rupture strength after 200 000h at the design temperature, x, which shall be equal to 0.8·x9) or, where such values are not avail-able;

b) he minimum rupture strength after 100 000h at the design temperature, x, which shall be divided by a factor of safety, S, of 1.5.

Where periods of operation are short (as is the case at testing facilities, for example), the reference times given above may be lower, provided the equipment undergoes regular inspection 9).

Welded pipes shall be designed based on a rupture strength value that is 20% lower than that specified for the basic material, unless verified values are available for the pipe (e.g. as specified in DIN 17177).

4.2.3 Load case Ⅲ

In the case of pipes subjected to fatigue loading, analysis as for load case Ⅰ shall be carried out (cf. subclause 4.2.12), along with an analysis for fatigue failure or for failure at a specified number of cycles, depending on the frequent and amplitude of the pressures (i.e. the number of cycles) to which a pipe run will be subjected. The larger value thus determined for wall thickness shall be used in the analysis.

The fatigue strength of seamless and welded pipes is given in figures 1 to 3, as a function of number of cycles, the information being based on pressure tests carried out at constant amplitude. (Cf. [9], [10], [11] and [12].)

These diagrams account for the surface finish, shape, material, and welding process used, i.e. these factors need not be accounted for separately. (For this reason, x no longer appears in equation (4).) They are based on the assumption that the pipes are of a high quality, i.e. that welded pipes are in accordance with DIN 1628, DIN 17172, or the like, with x equal to 1.0. The most important factor is that deviations of form at the weld must be minimal. The information given in figures 1 to 3 also assumes that the pipes are straight and that any such deviations are within the permissible limits.

Figure 1 applies to seamless pipes and high-frequency weld-ed pipes, with x equal to 1,0. In the case of seamless pipes with an outside diameter not exceeding 114.3mm and of a high quality (as specified in DIN 1630, DIN 17172, or the like), the higher values specified in figure 3 may be used.

These may also be used for high-frequency welded pipes of a high quality (as specified in DIN 1628, DIN 17172, or the like), if they have been issued a certificate documenting proof of their suitability, as verified by an accredited test house.

In the case of DIN 2391 (seamless) pipes made from St 35 NBK steel or of DIN 2393 (welded) pipes made from St 37-2 NBK steel (with x equal to 1.0), analysis may be based on a fatigue strength, x, of 225 N/mm² (cf. [13]).

It should be noted that the fatigue strength of pipes with a heavily corroded inner surface will be considerably lower than that of other pipes.

For further information on the service life of pipes in consideration of other factors (e.g. surface defects), see [14].

4.2.3.1 Cycles of constant stress amplitude

Pipes shall be designed to account for fatigue failure at a specified number of cycles and at a constant stress amplitude, with analysis being carried out using equation (4). The permissible stress under fatigue loading, x, shall be taken from figures 1to 3, with x being equal to x · n. (Cf. [15], [16],[17],[18].)

If loading models under service conditions are known, it shall be sufficient for x to be equal to 5. A higher value of x is recommended where corrosive environments or media or surface defects are involved.

For the purpose of analysis for fatigue failure, x shall be equal to

with S equal to 1.5.

4.2.3.2 Cycles of varying stress amplitude

Where pipes are subjected to fluctuating pressures, x cannot be determined by a direct method, but rather entails that the damage which can be expected over the service life of the pipes be checked (cf. [14] and [19] through [23]), which may be carried out on the basis of the linear damage accumulation theory. To this end, the most unfavorable combination of pressures shall be used for the various amplitudes involved,

and, from the results of equation (4), the fatigue strength, x, shall be obtained from the following equation:

the relevant number of cycles, x, being taken from figures 1 to 3.

Using the actual number of cycles, x, the following condition then results for the level of damage, D:

If loading models under service conditions are not known, and only information relating to the pressures resulting from the opening and closing of valves is available, x shall be equal to 10 or more.

9) Values for rupture strength after 200 000h are specified in DIN 17 175 and DIN 17 177. Use of such values assumes that the requirements specified in TRD 508 Supplement 1have been complied with.

4.3 Design temperature

The design temperature is considered to be the pipe wall temperature that is used to determine characteristic strength values. In the case of pipes that will not be heated, this temperature shall be the highest temperature that the medium conveyed may be expected to reach under any given service conditions.

Where determination of wall thickness is based on values of rupture strength, the design temperature shall be 5 K higher than the temperature of the medium conveyed.

Information regarding in accordance with subclause 4.2.2 (load case Ⅱ) is based on the assumption that the service temperature exceeds the design temperature for short periods by an maximum of 10 K, such periods being defined as less than 5% of the total operating time.

4.4 Degree of utilization of the design stress in the weld 10)

The degree of utilization of the design stress in the weld, x, is specified in the relevant standards and codes of practice (e.g. DIN 1626, DIN 1628, DIN 17172, DIN 17177 and DIN 17178). In the case of welded austenitic steel pipes, see DIN 17457 and AD-Merkblatt W2.

In the case of seamless pipes, x shall always be equal to 1.0 for design purposes.

4.5 Accounting for pressure surges

Dynamic changes in pressure ('pressure surges', for short) shall be accounted for in addition to the normal, static service pressure. In the case of pipework designed to operate at elevated temperatures over long periods, increases in pressure need only be accounted for when verifying their elevated temperature yield strength.

Pressure surges occur when the flow rate of the medium conveyed changes (e.g. when stop valves or control valves are opened or closed, or when pumps, turbines, compressors, etc. are turned on or off).

Water hammer is the result of a shock pressure wave due to a sudden change in the velocity f water in a pipe, this change usually being accompanied by a noise resembling hammering.

The most significant factors which affect the severity of a pressure surge are the length of the relevant pipe run, l, the closing (actuating) time, x, of the control valve, the flow rate, w, of the medium conveyed, and the propagation velocity, a, of the pressure wave in the medium conveyed.

The maximum pressure surge may be determined using equation (6) when the flow rate changes suddenly from x to zero (i.e. x = 0), 'suddenly' being regarded as a very short closing time (i.e. where x is less than x, x being equal to 1*//a*).

Disregarding friction, the maximum change in pressure, x, is equal to:

where x is equal to

In the case of control valves with a linear change in flow, extending the closing time over several response times can result in a marked decrease, s, in the severity of the pres-sure surge, i.e.

10) The degree of utilization of the design stress in the weld, regardless of the type of weld or process used, refers to such utilization normal to the weld axis.

The propagation velocity of a pressure wave, a, may be determined in accordance with [31].

In the case of hydraulic, relatively thick-walled pipework conveying water or low-viscosity oil, an approximate mean value of a of 133m/s may be assumed. For relatively thin-walled long-distance pipelines, a value of about 1000m/s may be assumed.

Equations (6) and (7) are suitable for guidance purposes only; therefore, in the case of pipework likely to be subjected to pressure surges (which includes those conveying highly compressed gases), a more accurate analysis is recommended in order to account for as many factors as possible and to determine whether and which protective measures are necessary.

Further information relating to this subclause is given in [6], [7][24] through [32][59] and[60].

4.6 Design factor c

See table 2 for the definition of c.

4.6.1 Factor x

The factor to allow for the lower limit deviation for wall thickness, x, is specified in the relevant technical delivery conditions, and shall be added to the value of the design wall thickness of the pipe, x. If the relevant literature specifies x as a percentage, this value shall be converted to x, in mm, as follows:

For the purposes of this standard, the lower limit deviation for wall thickness refers to that along the entire length of the pipe. Should the relevant literature specify stricter values for certain lengths of lile, these may be disregarded for the purpose of determining x.

4.6.2 Factor x

The factor x is intended to account for a possible reduction in wall thickness due to corrosion and/or wear and is a function of both the medium conveyed and the environment in which the pipework is laid. It is not intended to account for a reduction in fatigue strength due to corrosion (cf. subclause 4.2.3).

In the case of ferritic steel, 1mm is generally deemed to be a sufficient value for x. In the case of austenitic steel, allowance for corrosion generally need not be made, or in cases where suitable measures have been taken to prevent corrosion or wear, or where substantial wear is not likely.

The factor x does not account or the risk to materials from other occurrences, such as stress-corrosion cracking, these requiring separate analysis.

4.7 Test pressure for a single pipe

Single, straight pipes shall be tested by the manufacturer at his works, the test pressure used being specified in the relevant literature or agreed between purchaser and manufacturer.

Where the specified yield strength on the inside of the pipe is not to be exceeded, the test pressure, x, must not exceed:

The factor x (cf.[33]) shall be equal to 0.96 where x does not exceed 0.1 or 1.02-0.6 x where x is greater than 0.1(9).

The degree of utilization of the minimum yield strength (x or x) during pressure testing, x, is normally not to exceed 0.95, which accounts for fluctuations that occur as the upper yield strength is approached, as well as the permanent strain that occurs at the 0.2% proof strength.

Where it has been agreed between purchaser and manufacturer that x is to exceed 0.95, it may be assumed that creep will occur on one side of the pipe in the thinnest zone and that the tolerance on the diameter of a single pipe will not be satisfied.

5 General design principles

It is normally sufficient to design pipes for load cases Ⅰ and Ⅱ. Where the number of load cycles specified in tables 4,5 and 6 is exceeded, however, the pipes shall be designed, or their suitability checked, for load case Ⅲ, and account shall be taken of any additional or other variable stresses.

Based on the reference stress, x (cf. subclause 5.3.3), a factor of safety, x, of at least twice the minimum fatigue strength at a specified number of cycles, or at least 1.1 times the minimum fatigue strength, should be used in the analysis.

5.1 Additional stresses

The information given in subclauses 5.1.1through 5.1.6 describe the most significant stresses to which the pipes covered here will be subjected.

5.1.1 Bending moments from loading as a result of the self-weight of the pipework (including coating, lining, insulation, and medium conveyed), wind and snow loads, fitted elements, etc.

In the case of unburied pipework, bending moments from loads along the pipe run result in axial stresses which must be accounted for in the general analysis, as must stresses at pipe supports (cf. [34] through [38]).

5.1.2 Circumferential bending moments on buried pipes as a result of earth and imposed loads

Steel pipes with x equal to 0.01 or more are deemed to be suitable for typical burial parameters, these being defined as a cover of 1 to 6 m, imposed loads up to SLW 60, and compliance with the requirements specified in DIN 2460 and DIN 2470 Part 2. Additional analysis is only required where these conditions are not met.

An adequately leveled trench bottom and careful backfilling will significantly contribute to the resistance of pipes to stresses, particularly in the case of large-diameter pipes (cf. [39] to [40]).

Procedures to determine the stresses in and deformation properties of buried pipes are outlined in [45], [47] and [58].

5.1.3 Bending moments as a result of pipe curvature during laying

The longitudinal stresses which result from a curvature, with radius r, of the pipe axis during laying may be determined from the following equation:

5.1.4 Forces and moments due to obstructed thermal expansion and the resultant stresses

Forces and moments due to obstructed thermal expansion result in longitudinal stresses in the case of straight pipes laid in one plane and, in the case of pipework arranged in other configurations, in torsional stresses.

Increasing the wall thickness to prevent thermal expansion does not improve the construction, but rather increases the constraints involved.

The stresses that result from obstructed thermal expansion may be reduced in pipework that operates by gravity by the selection of appropriate types of pipe support and fixing points and by the provision of expansion loops. The forces prestressing the pipework during assembly. analysis in this regard need not be carried out for buried pipes used at a service temperature that does not deviate by more than ±30K from the temperature during laying.

5.1.5 Non-uniform temperature distribution across the pipe wall

The thermal stresses the pipe wall, in both the circumferential and longitudinal directions, that result from a difference in temperature between the inside and outside of the pipe wall, x, may be approximated using the following equation, provided u is equal to 1.2:

It should be noted that tensile stresses occur on the colder side. More specific information, particularly for thick-walled pipes, is given in [5] and [46].

The thermal stresses that occur in unalloyed and low-alloy steel pipes at a given rate of temperature change, x, when the valves are opened or closed may be approximatd using the following equation:

or, in the case of austenitic steel pipes:

Considerable thermal stresses result from sudden warming or cooling (also referred to as "thermal shock").

More specific information regarding thermal stresses as a function of rate of temperature change and as a result of thermal shock may be found in [5], [47], [48], and TRD 301 Supplement 1.

5.1.6 Circumferential bending stresses as a result of ovality

Oval pressure pipes will be subjected to bending stresses in the circumferential direction (cf. [50]), since the internal pres-sure tries to force the wall into a circular shape. Assuming the pipe has an approximately elliptical shape, with a given deviation of the radius from the circular form, x, the maxi-mum circumferential bending stresses will occur in the vertices of the ellipses, their value being calculated as :

with a design factor (cf. [50]) of

Pipes subjected to predominantly static loading generally need not be analyzed for stresses as a result of ovality.

For pipes subjected to fatigue loading, the strength values specified in figures 1 to 3 account for permissible ovality as covered in the relevant standards (e.g. DIN 1626, DIN 1628, DIN 1629, DIN 1630, DIN 17172). Where the ovality of pipes exceeds the values specified therein, the actual stresses as a result of internal pressure and any additional stresses shall be added to the bending stress as determined in accordance with equation (14). Reference values shall be taken from figures 1 to 3, and the factors of safety, from table 3 (for load case Ⅲ). An assessment of fatigue failure may be made in accordance with [49].

5.2 Pipes subjected to external pressure or to vacuum

Pipes subjected to external pressure or to vacuum shall be analyzed for their resistance to buckling. Where these are concurrent, their values shall be added.

The external pressure which causes a circular pipe to buckle ('critical external pressure') is calculated from the following equation:

Any deviations of form will considerably increase the thedency of pipes to buckle; therefore, a factor of safety, s, of at least 3 shall be used.

If only vacuum occurs, or if the external pressure (plus any vacuum) does not exceed a value of 0.1N/mm² (i.e. 1bar), then analysis for resistance to buckling is only necessary for pipes with x less than 0.01.

Buried pipes shall be analyzed for their resistance to buck-ling, account being taken of the earth pressure involved (cf.[45]).

5.3 Classification and assessment of stresses

All types of stress are classifiable with regard to their cause and effect, by means of either the classification system de-scribed in [51] to [54], or the method described in [55] and [56]. Both systems are equally valid from the safety standpoint.

5.3.1 Stress categories

A distinction is made among the following stress categories, as a function of the cause and effect of the particular type of stress on the component:

a) primary stresses;

b) secondary stresses;

c) peak stresses.

This classification system may be used for both static and fatigue loading conditions and assumes a perfectly elastic behavior of the material, but is not suitable for structural analysis.

5.3.1.1 Primary stresses

Primary stresses are considered to be uniformly distributed stresses or stress components which contribute to the establishment of equilibrium between the pipe and the external loads involved. Such loads continue to act even after permanent deformation of the pipe (i.e. they do not diminish). Primary stresses include:

a) internal and external pressure;

b) earth pressure and imposed loads in the case of buried pipework;

c) self-weight and snow and wind loads in the case of pipes laid outdoors.

5.3.1.2 Secondary stresses

Secondary stresses are considered to be uniformly distributed stresses or stress components which are caused by external loading and which result in obstructed thermal expansion or geometrical imperfections. Secondary stresses include:

a) obstructed thermal expansion;

b) a temperature gradient across the pipe wall;

c) different expansion behavior in zones of transition to other components, particularly to those of other shapes (e.g. pipes of different wall thickness, penetrations through floors);

d) ovality.

Where loading is excessive, secondary stresses may be diminished where the pipework is able to permanently deform. In other words, pipes subjected to predominantly static loading will not fail as a direct result of secondary stresses but, where deformation occurs frequently, they may lead to fatigue fracture.

5.3.1.3 Peak stresses

Peak stresses are not uniformly distributed and represent a combination of primary and secondary stresses which occur, briefly, at the same time. They cause localized strain, but not significant deformation of the pipework as a whole. Peak stresses are only relevant with regard to the fatigue behavior of the component, and include:

a) notch effects;

b) bearing stresses;

c) stresses resulting from thermal shock when the valves are opened or closed.

5.3.2 Plastic theory

When analyzing a component by the plastic theory, the component is considered in its entirety. In the case of components subjected to inhomogeneous loading, this theory accounts for the fact that, where localized hyperelastic loading occurs, the zones that had not previously been subjected to loading will have to accommodate more of the load, i.e. the components are used more efficiently.

This method may only be applied for pipes subjected to pre-dominantly static loading, and may also be used for the assessment of branches, bends and pipes subjected to localized loading.

5.3.3 To assess a multi-axial stress

To assess a multi-axial stress pattern, the maximum shear theory or the deformability energy hypothesis may be used. Reference stresses are calculated as follows:

a) according to the maximum shear theory:

b) according to the deformability energy hypothesis:

Both equations assume that the stresses concerned are primary stresses.

Depending on the type of stress involved, either the values of the stresses themselves or of the stress amplitudes shall be used in the above equations.

The information given in table 3 is based on the maximum thear theory (cf. clause 4).

Equations (17) and (18) may be applied regardless of whether the stresses are classified by means of the classification system or by the plastic theory (cf. [51] and TRD 301 Supplement 1).

5.3.4 Permissible stresses

Permissible stresses shall be specified as a function of the analysis method used and the safety requirements with which the pipework is expected to comply. See [45], [51],[52],[53],[54],[55],[56], TRD 301 Supplement 1, and AD-Merkblatt S2 for more information in this regard.

Standards and other documents referred to

DIN 1626		Welded, circular, unalloyed steel tubes subject to special requirements; technical delivery conditions
DIN 1628		Welded, circular, unalloyed steel pipes subject to special requirements; technical delivery conditions
DIN 1629		Seamless, circular, unalloyed steel tubes subject to special requirements; technical delivery conditions

DIN 1630		Seamless, circular, unalloyed steel pipes subject to special requirements; technical delivery conditions
DIN 2391	Part 1	Seamless precision steel tubes; dimensions
DIN 2391	Part 2	Seamless precision steel tubes; technical delivery conditions
DIN 2393	Part 1	Welded precision steel tubes; dimensions
DIN 2393	Part 2	Welded precision steel tubes; technical delivery conditions
DIN 2413	Part 2	Design of steel bends used in pressure pipelines
DIN 2460		Steel water pipes
DIN 2470	Part 2	Steel gas pipes rated for working pressures above 16 bar, requirements for pipe fittings
DIN 17172		Steel pipes for conveying combustible liquids and gases; technical delivery conditions
DIN 17173		Seamless circular tubes made from steel with low temperature properties; technical delivery conditions
DIN 17174		Welded circular tubes made from steel with low temperature properties; technical delivery conditions
DIN 17175		Seamless tubes with elevated temperature properties; technical delivery conditions
DIN 17177		Electric pressure-welded steel tubes with elevated temperature properties; technical delivery conditions
DIN 17178		Welded circular fine grain steel tubes subject to special requirements; technical delivery conditions
DIN 17179		Seamless circular fine grain steel tubes subject to special requirements; technical delivery conditions
DIN 17457		Welded circular austenitic stainless steel tubes subject to special requirements; technical delivery conditions
DIN 50049		Inspection documents for the delivery of metallic products
AD-Merkblatt	B0	Berechnung von Druckbehaltern (Design of pressure vessels)*)
AD-Merkblatt	S2	Berechnung auf Schwingbeanspruchung (Analysis for fatigue strength)*)
AD-Merkblatt	W2	Austenitische Stahle (A ustenitic steel)*)
AD-Merkblatt	W10	Werkstoffe fur tiefe Remperaturen; Eisenwerkstoffe (Ferrous materials for low service temperatures)*)
TRD 300		Festigkeitsberechnung von Dampfkesseln (Analysis of steam boilers)*)
TRD 301	Supplement 1	Berechnung auf Wechselbeanspruchung durch schwellenden Innendruck bzw. durch kombinierte Innen-druck- und Temperaturanderungen (Analysis of fatigue loading as a result of internal pressure or of coexistent internal pressure and temperature fluctuations)*)
TRD 508	Supplement 1	Zusatziche Prufungen an Vauteilen; Verfahren zur Berechnung von Vauteien mit zeitabhangigen Festigkeitskennwerten (Additional component testing; design of components having time-dependent strength parameters)*)