BRITISH STANDARD

BS EN 13941:2003
Incorporating corrigendum March 2008

Design and installation of preinsulated bonded pipe systems for district heating

ICS 91.140.10

British Standards

National foreword

This British Standard is the UK implementation of EN 13941:2003. It partially supersedes BS 7572:1992.

The UK participation in its preparation was entrusted by Technical Committee RHE/9, Thermal insulating materials, to Subcommittee RHE/9/3, Insulation of underground pipelines.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 2 April 2003

ISBN 978 0 580 61327 2

Amendments/corrigenda issued since publication

Date	Comments
31 March 2008	Correction to title on front cover

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 13941

March 2003

ICS 91.140.10

English version

Design and installation of preinsulated bonded pipe systems for district heating

Conception et installation des systèmes bloqués de tuyaux pré-isolés pour les réseaux enterrés d'eau chaude

Berechnung und Verlegung von werkmäßig gedämmten Verbundmantelrohren für die Fernwärme

This European Standard was approved by CEN on 27 December 2002.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Ref. No. EN 13941:2003 E

Contents

Foreword

This document (EN 13941:2003) has been prepared by Technical Committee CEN/TC 107 "Prefabricated district heating pipe systems", the secretariat of which is held by DS.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2003, and conflicting national standards shall be withdrawn at the latest by September 2003.

Annex A is normative. Annexes B, C and D are informative.

This document includes a Bibliography.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom.

Introduction

This standard has been prepared by JWG1, a joint working group with CEN/TC 267 "Industrial piping and pipelines"

According to the scope from CEN/TC 107

- The task of CEN/TC107/TC267/JWG1 is to specify rules for design, calculation and installation for preinsulated bonded pipe systems for underground hot water networks with pipe assemblies co-ordinated with EN 253, EN 448, EN 488 and EN 489.

- CEN/TC107/TC267/JWG1 can also specify rules for functional tests for preinsulated bonded pipe systems for underground hot water networks.

- The basic rules for design, calculation and installation should be based on functional requirements.

- The purpose of the work is to provide uniform basis for the design, construction and operation of district heating systems, to ensure that the system is reliable and efficient and safe for the surrounding area, the environment and public health.

- Joint assemblies for pipe systems dealt with should be co-ordinated with EN 489.

This standard takes account of experience acquired, of new knowledge available of the behaviour of material and of distribution of stresses and allowable deformations and also evolution in installation techniques.

When use is made of the standard, the different sections of which it is made up are interdependent and, because of this, cannot therefore be dissociated.

The standard consists of a main part and four annexes.

Depending on the character of the individual clauses, distinction is made in this standard between Principles and Application Rules.

The principles comprise:

- general statements, definitions and requirements, for which there is no alternative, as well as
- requirements and analytical models for which no alternative is permitted unless specifically stated.

The principles are printed in normal typeface (10 point font).

The application rules are generally recognised rules, which follow the principles and satisfy their requirements.

Application rule:

The application rules and comments to principles and application rules are printed in a 8 point font. This is an application rule.

Alternative design rules can be used instead of the application rules given in this standard, provided that it is shown that the alternative rule accords with the relevant principles and it is at least equivalent with regard to the resistance, serviceability and durability achieved by the system.

Annex A is part of the standard (principles). Annexes B, C and D have status as application rules.

This standard contains a number of requirements aimed at ensuring the sound execution of distribution networks for district heating. To the extent possible, the requirements specified in this standard are functional requirements.

The requirements and regulations contained in this standard should be assessed and applied in compliance with the intentions of the standard and in due consideration of the development taking place in the field it concerns. It is therefore assumed that the user of the standard has the requisite technical insight and that the user of the standard has adequate knowledge of legal and other external regulations that are of consequence to the practical application of the standard.

Special cases can occur within the scope of this standard in which its contents do not cover. An evaluation whether the contents cover should be made in any specific case where the standard is used.

Presently CEN/TC 107 "Pre-fabricated district heating pipe systems" is preparing standards for preinsulated flexible pipes and surveillance systems.

1 Scope

This European Standard specifies rules for design, calculation and installation for preinsulated bonded pipe systems for buried hot water distribution and transmission networks, see. Figure 2, with pipe assemblies in accordance with EN 253, for continuous operation with hot water at various temperatures up to 120 °C and occasionally with peak temperatures up to 140 °C and maximum internal pressure 25 bar (overpressure).

Application rule:

For larger pipe dimensions and pressures below 25 bar wall thickness bigger than specified in EN 253 can be required for straight pipes, bends and tees.

The principles of the standard can be applied to preinsulated pipe systems with pressures higher than 25 bar, provided that special attention is paid to the effects of pressure. Adjacent pipes belonging to the network (e.g. pipes in ducts, valve chambers, road crossings above ground etc.) can be designed and installed according to this standard.

The standard assumes use of treated water, which by softening, demineralisation, deaeration, adding of chemicals, or otherwise has been treated to prevent internal corrosion and deposits in the pipes.

This standard is not applicable for such units as

- pumps,
- exchangers,
- boiler installations, tank installations,
- consumer installations.

However, the full functional ability and durability of such units should be ensured in consideration of the impacts from the district heating system and other impacts occurring from the conditions under which they have been installed.

Guidelines for product quality inspection and in situ tests of joints are given in annex A of EN 448:2003, annex D of EN 253:2003, annex A of EN 488:2003 and annex B of EN 489:2003.

Guidelines for welding of polyethylene casing are given in annex B of EN 448:2003.

The estimation of expected life with continuous operation at various temperatures is outlined in annex B of EN 253:2003

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text, and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 253	2003	*District heating pipes – Preinsulated bonded pipe systems for directly buried hot water networks – Pipe assembly of steel service pipe, polyurethane thermal insulation and outer casing of polyethylene.*
EN 287-1		*Approval testing of welders – Fusion welding – Part 1: Steels.*
EN 288-1	1992	*Specification and qualification of welding procedures for metallic materials – Part 1: General rules for fusion welding.*
EN 288-2		*Specification and approval of welding procedures for metallic materials – Part 2: Welding procedure specification for arc welding.*
EN 288-3		*Specification and approval of welding procedures for metallic materials – Part 3: Welding procedure tests for the arc welding of steels.*
EN 444		*Non-destructive testing - General principles for radiographic examination of metallic materials by X- and gamma-rays.*

EN 448	2003	*District heating pipes – Preinsulated bonded pipe systems for directly buried hot water networks – Fitting assemblies of steel service pipes, polyurethane thermal insulation and outer casing of polyethylene.*
EN 488	2003	*District heating pipes – Preinsulated bonded pipe systems for directly buried hot water networks – Steel valve assembly for steel service pipes, polyurethane thermal insulation and outer casing of polyethylene.*
EN 489	2003	*District heating pipes – Preinsulated bonded pipe systems for directly buried hot water networks – Joint assembly for steel service pipes, polyurethane thermal insulation and outer casing of polyethylene.*
EN 571-1		*Non destructive testing - Penetrant testing - Part 1: General principles.*
EN 583-1		*Non-destructive testing - Ultrasonic examination - Part 1: General principles.*
EN 719	1994	*Welding coordination – Tasks and responsibilities.*
EN 729-1		*Quality requirements for welding – Fusion welding of metallic materials – Part 1: Guidelines for selection and use.*
EN 729-2		*Quality requirements for welding – Fusion welding of metallic materials – Part 2: Comprehensive quality requirements.*
EN 729-3		*Quality requirements for welding – Fusion welding of metallic materials – Part 3: Standard quality requirements.*
EN 729-4		*Quality requirements for welding - Fusion welding of metallic materials - Part 4: Elementary quality requirements.*
EN 970		*Non-destructive examination of fusion welds - Visual examination.*
EN 1289		*Non-destructive examination of welds - Penetrant testing of welds - Acceptance levels.*
EN 1290		*Non-destructive examination of welds - Magnetic particle examination of welds.*
EN 1291		*Non-destructive examination of welds - Magnetic particle testing of welds - Acceptance levels.*
EN 1418		*Welding personnel - Approval testing of welding operators for fusion welding and resistance weld setters for fully mechanized and automatic welding of metallic materials.*
EN 1435		*Non-destructive examination of welds - Radiographic examination of welded joints.*
EN 1594		*Gas supply systems - Pipelines for maximum operating pressure over 16 bar – Functional requirements.*
EN 1712		*Non-destructive examination of welds - Ultrasonic examination of welded joints - Acceptance levels.*
EN 1714		*Non-destructive examination of welds - Ultrasonic examination of welded joints.*
EN 10204		*Metallic products – Types of inspection documents.*
EN 10216-2		*Seamless steel tubes for pressure purposes - Technical delivery conditions - Part 2: Non-alloy and alloy steel tubes with specified elevated temperature properties.*

EN 10217-2		*Welded steel tubes for pressure purposes - Technical delivery conditions – Part 2: Electric welded non-alloy and alloy steel tubes with specified elevated temperature properties.*
EN 10217-5		*Welded steel tubes for pressure purposes - Technical delivery conditions – Part 5: Submerged arc welded non-alloy and alloy steel tubes with specified elevated temperature properties.*
EN 13018		*Non-destructive testing - Visual testing - General principles.*
EN 25817		*Arc-welded joints in steel – Guidance on quality levels for imperfections (ISO 5817:1992).*
EN 29692		*Metal-arc welding with covered electrode, gas-shielded metal-arc welding and gas welding – Joint preparations for steel (ISO 9692:1992).*
ISO 1000		*SI units and recommendations for the use of their multiples and of certain other units.*
ISO 3419		*Non-alloy and alloy steel butt-welding fittings.*
ISO/TR 15608	2000	*Welding - Guidelines for a metallic material grouping system (ISO/TR 15608:2000).*

3 Units and symbols

3.1 Units

The unit system applied in this standard is the SI system (Système International d'Unités), see ISO 1000 and others.

The following units and their multiples are used:

Length	m	(metre)
	mm	(millimetre)
Mass	kg	(kilogram)
Force	N	(Newton)
Stress	N/mm^2	(Newton per square millimetre)
Pressure	Pa	(Pascal = Newton per square metre)

Other units applied:

Temperature	°C	(degree centigrade)
Pressure	bar	(1 bar = 10^5 Pa = 0,1 N/mm^2)

3.2 Symbol

A	Area
c	Cohesion of the soil, fabrication tolerance
D	Diameter of casing
d	Diameter of service pipe
E	Modulus of elasticity
F	Friction force
f	Design stress, friction force per area unit, deflection
G	Selfweight
I	Momentum of inertia
i	Stress intensification factor
L	Friction length
l	Length
M	Bending moment
N	Normal force, number of full action cycles
n	Number
p	Internal pressure
R_e	Specified minimum upper yield strength
R_m	Tensile strength
R	Bend radius
r	Pipe radius
T	Temperature
t	Pipe wall thickness
W	Section modulus
Z	Depth of burial (measured to centreline of pipe)
α	Coefficient of thermal expansion
γ	Specific gravity, partial safety coefficient
δ	Friction angle between pipe and soil, displacement from thermal expansion
ε	Strain
θ	Angle
λ	Coefficient of thermal conductivity
μ	Coefficient of friction between pipe and soil
ρ	Density
σ	Normal stress
τ	Shear stress

ν	Poisson's ratio
φ	Internal friction angle of soil

Indices

a	Action
b	Branch pipe (at tee connections)
c	Casing
d	Design
fat	Fatigue
i	Inner, inside
j	Reference
m	Mean, membrane, material
min	Minimum
n	Nominal, number (of fatigue cycles)
o	Outer, outside
r	Run pipe (at tees)
res	Resulting
u	Fracture
v	Vertical

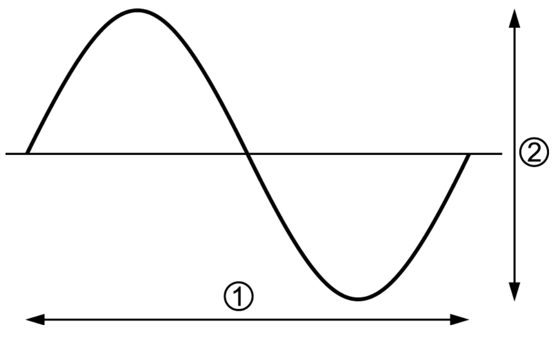
Separate symbol lists are found in annex A, B and C.

4 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in EN 253:2003 and the following apply.

4.1
action
set of concentrated or distributed forces acting on the pipe system (force-controlled action), or the cause of imposed or constrained deformations in the system (displacement-controlled action). Actions are often referred to as "loads"

4.2
action cycle
one action cycle is one impact with a given stress range. An action cycle comprises one full action course (which is twice the action amplitude calculated from an average value)



Key
1 One action cycle
2 Temperature or stress range

Figure 1 - **Action cycle**

4.3
bonded system
consisting of a service pipe, insulating material and casing, which are bonded by the insulating material

4.4
cold installed preinsulated bonded pipes
district heating systems where the pipes are installed and taken into operation without prior pre-stressing by pre-heating

4.5
creep
slow progressive strain under the influence of stresses

4.6
design pressure
internal pressure equal to or greater than the maximum operating pressure at any point of the pipeline acting in a component or pipe section multiplied by a partial safety factor

4.7
design temperature
maximum temperature used for the design of a component or pipe section

4.8
displacement-controlled action
action called forth by enforced deformation or movement, e.g. thermal expansion or settling

4.9
distribution pipeline
pipeline leading from place of production or transmission line to heating installations. Distribution mains are primarily main pipelines or house service connections, see Figure 2.

4.10
ductile materials
materials, which with good approximation are linearly elastic up to the yield stress or to the 0,2% proof stress, and which have a minimum elongation at rupture of 14 %

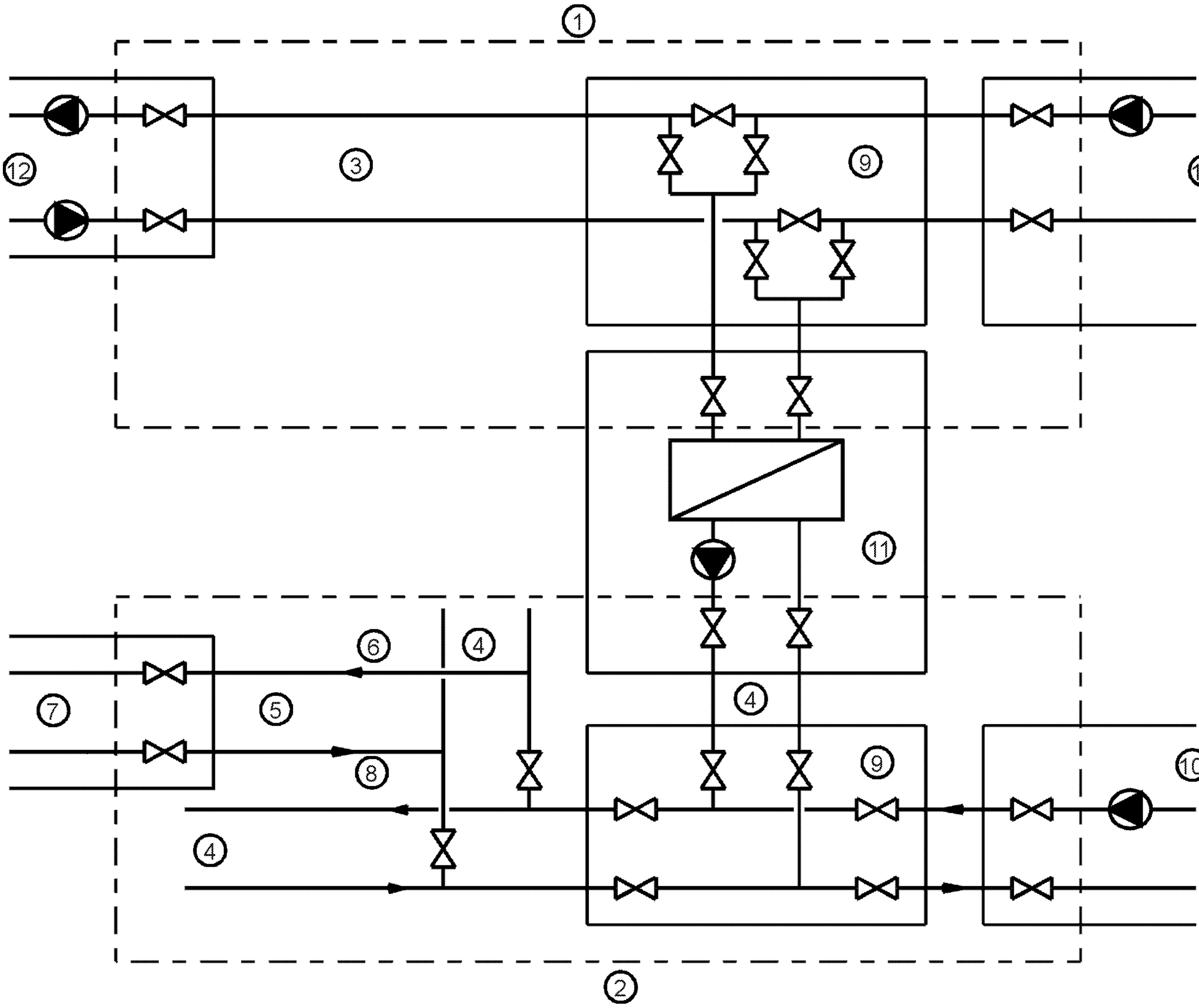
4.11
extruded tees
are manufactured by drawing a collar on which the branch pipe is welded. The collar is welded onto a transitional piece with increased wall thickness, so that the local stress intensification for the tee is reduced before the straight pipe with normal wall thickness.

4.12
fabricated tees
are manufactured by welding a branch pipe directly onto a run pipe

4.13
fatigue strength
stress range of constant magnitude which, under given circumstances, just causes fatigue failure

4.14
force-controlled action
action, which maintains its size irrespectively of the deformation of the structure, e.g. pressure and weight

4.15
house service connection
pipeline leading from main pipeline to one consumer installation, see Figure 2.



Key

1 TRANSMISSION SYSTEM
2 DISTRIBUTION SYSTEM
3 TRANSMISSION PIPE
4 MAIN PIPE
5 HOUSE SERVICE CONNECTION
6 SUPPLY PIPE
7 CONSUMER
8 RETURN PIPE
9 VALVE CHAMBER
10 HEAT PRODUCTION
11 HEAT EXCHANGER STATION
12 PUMP STATION

Figure 2 - Distribution and transmission systems

4.16
installation temperature
temperature arising from the ambient conditions during laying or installation, prevalent at the time when action is taken

4.17
main pipeline
pipeline supplying several heating installations. See Figure 2.

4.18
number of equivalent full action cycles
number of action cycles with constant full action range calculated from a known or presupposed temperature history using Palmgren-Miner's formula and the respective SN-curve

4.19
operating pressure
maximum internal pressure acting against the pipe wall at any point or in any section of the pipeline at a given operating temperature

Application rule:

This is generally the internal pressure needed to take account of the static head, friction losses and required outlet pressure.

4.20
operating temperature
water temperature in a component or pipe section during specified operating conditions

4.21
pre-heated system
system, which after being assembled, but before backfilling, is heated to a pre-heating temperature allowing the system to expand without introducing additional stresses

4.22
preinsulated systems
systems assembled at site consisting of prefabricated pipe elements and components with integrated protective casing, insulation and service pipe

4.23
pressure
over-pressure or sub-pressure as compared to normal atmospheric pressure. Unless otherwise indicated, pressure refers to gauge pressure.

4.24
pre-stressing temperature
temperature applied during pre-stressing of a pre-heated system
Application rule:

The pre-heating temperature is chosen such as approximately average axial stress is obtained, compared to the axial stress levels at ambient temperature and maximum operating temperature.

4.25
reference stress
is calculated (with sign) from the membrane or resulting stresses by Tresca or by von Mises' formula

Application rule:

The formulae are presented in 7.4.3

4.26
resulting stresses
all stress occurring in one point, i.e. membrane stresses plus stresses varying over the wall thickness

4.27
service life
span of time during which the network is expected to function without major replacements, given normal maintenance and operation conditions as described in the project

4.28
service pipe
steel pipe that contains the water

4.29
single action compensator
functioning during pre-heating. After pre-heating the compensator is locked

4.30
strain
unit deformation, e.g. elongation or reduction per unit of length

4.31
stress range
difference between maximum stress and minimum stress for one single load cycle, the stress being computed with preceding sign, see Figure 1

4.32
surge pressure (water hammer)
variation of pressure for relatively short period, resulting from a change in velocity of the circulating water. Such a change can be a consequence of valve closing, pump failure, boil over, impacts from non-return valves, blockage, fractures in the pipeline, etc.

4.33
system
complete pipeline installation including joints, branches, accessories, etc. and adjacent pipelines

4.34
temperature range
absolute value of the difference between the two extremes of temperature occurring during a cycle, taking account of operational and environmental influences, see Figure 1

4.35
test pressure
internal pressure occurring within the pipeline or a part of the pipeline during strength testing (strength test pressure) or leak tightness testing (leak tightness test pressure)

4.36
transmission pipelines
major pipelines leading from place of production to distribution pipelines, see Figure 2

4.37
valves and accessories
surveillance, operating and safety equipment directly fitted to a district heating pipeline

4.38
weld-in tees
are e.g. made by forging and are usually seamless

5 General considerations for system design

5.1 General requirements

Design and installation of district heating pipe systems shall ensure that the system is given

- sufficient durability, robustness and reliability in relation to the internal and external loads and impacts, to which it is likely to be subjected in normal operation.
- sufficient safety that unusual operating conditions or accidents do not jeopardise persons or the environment,
- good energy economy,
- good operating properties,
- safety of supply.

Application rule:

Installation expenses, maintenance expenses and operating expenses arising throughout the service life of the system should be included in the assessment of the system.

The assessment of operating properties should pay regard to the possibilities of inspection and maintenance.

5.2 Service life

When a system, designed according to this standard, is subject to temperatures exceeding 120 °C, for periods such that the requirement for a service life of 30 years at continuous operation at 120 °C, calculated in accordance with annex B of EN 253:2003, is exceeded, the service life of components subject to ageing shall be assessed.

Application rule:

The minimum requirements for the type test of EN 253 (based on the shear strength between PUR foam and steel pipe) is a service life of 30 years for continuous operation at 120 °C.

If the cumulative ageing requires a lifetime exceeding the equivalence of 30 years at 120 °C special documentation for the ageing properties are required.

5.3 Preliminary investigations

Preliminary investigations comprising an assessment of all conditions of importance to a district heating project shall be carried out.

These preliminary investigations shall elucidate matters in the planning, design, execution and operating stages as well as consequences of any kind of failure of the system.

The principal basis of the preliminary investigation is the main data for the current system, e.g.

- function,
- pressure and temperature,
- dimensions,
- depth of burial,
- materials,
- distances and heat transfer to other utility networks, buildings and trees,
- geotechnical and groundwater parameters, etc.

Application rule:

The preliminary investigations may include elucidation of the following matters:

- pipeline route,
- operating conditions of the system, e.g. variations in pressure and temperature and requirements for safety of supply,
- function mode of the system during operating and maintenance stage as well as resistance to relevant impacts such as:
  - loads due to installation and operation,
  - internal and external loads and deformations,
- consequences of possible kinds of failure of the system,
- authorities' requirements, environment and third party aspects,
- methods of execution.

5.4 Determination of project class

5.4.1 Risk assessment

Possible coincidences involving a risk of personal damage or consequences to the society or environment, shall be assessed.

Application rule:

When evaluating possible risk both the probability of a failure and the effects of a failure should be taken into account.

The **effect of failure** of a district heating pipeline system to its environment is related to temperature, pressure and diameter of the pipeline.

The **probability of a failure** is based on internal and external factors and the quality of design, installation and operation.

Possible risks are:

- escape of hot water due to bursting or leakage, involving a risk of scalding, flooding, tunnelling, etc.,
- damage to the installation, involving interruption of the heat supply,
- damage to the installation, involving a risk of further spread of the damage in the installation,
- loss of safety of supply.

The consequences of failure may be related to the entire system or to a section only.

The project class determines the level for design and installation of the pipeline system.

5.4.2 Project classes

The choice of project class is related to the level of safety and complexity of execution expressed as requirements with respect to design procedures and construction.

Based on preliminary investigations and risk assessment the pipeline system shall be classified in one of the following classes:

Table 1 - Project classes

Project class **A**	– Small and medium diameter pipes with low axial stresses – pipes with low risk of personal damage or damage to the surroundings – pipes with low risk of economic losses
Project class **B**	– High axial stresses, small and medium diameter pipes
Project class **C**	– Large diameters pipes and/or high pressures – pipes with higher risk of personal damage or damage to the surroundings – special or complex constructions

Application rule:

Special or complex constructions can be crossings with railways, major roads and waterways, which are normally designed in consultation with the owners and/or authorities. For crossings with dykes and flood defences extra measures may be required to prevent flooding of the hinterland.

System parts, which are not directly pressurised, but in which a failure may involve fracture or leakage in a pressurised section are referred to the same project class as the pressurised section.

Pipelines, which are accessible during operation shall, as a minimum, be classified in project class B.

Based on the expected effects the project classes A, B and C are determined by Figure 3.

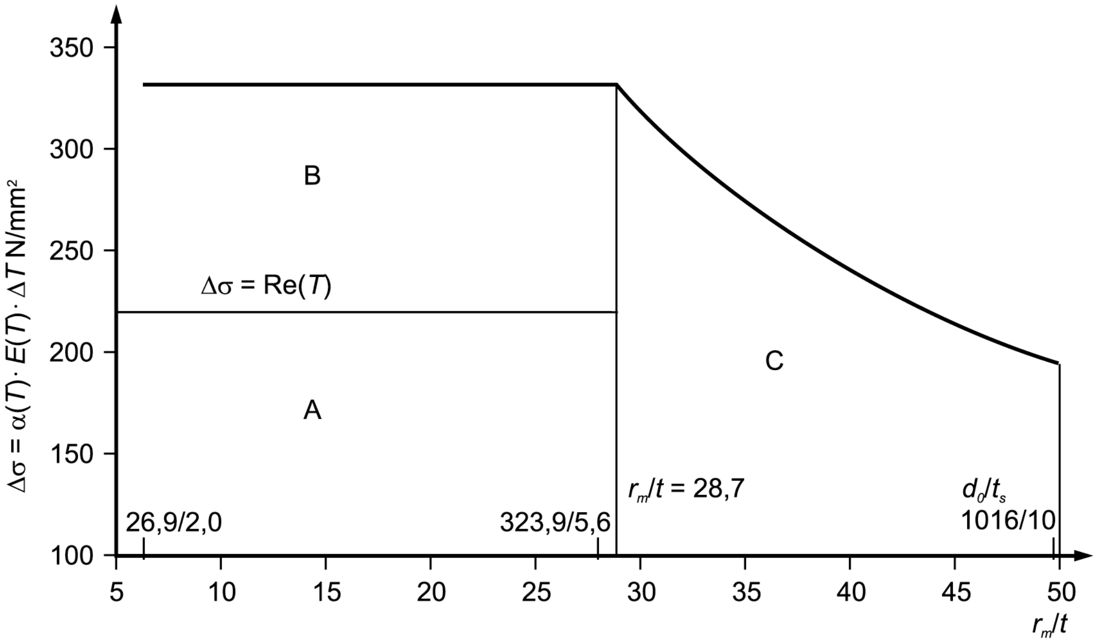


Figure 3 - Definition of project classes for a steel with a specified minimum yield strength, R_e(23 °C) = 235 N/mm²

Table 2 - Requirements for project classes

Project class Figure 3	Welding control 8.5.8	Fatigue analysis 7.4.2	Documentation
A	≥ 5%	$\gamma_{fat} = 5$	Generalised documentation, 7.2
B	≥ 10%	$\gamma_{fat} = 6,67$	Generalised documentation, 7.2
C	≥ 20%	$\gamma_{fat} = 10$	Specific documentation required

Application rule:

In relation to project class the following has to be considered:

- requirements for documentation,
- determination of γ_{fat} in Palmgren-Miner's formula,
- requirements for welding,
- scope of inspection of weld seams,
- quality management and scope of inspection.

An installation can always be classified in a higher project class than stated in Figure 3.

Application rule:

Following conditions can result in the choice of a higher project class:

- system design and complexity,
- soil and groundwater conditions,
- traffic conditions,
- position in relation to other structures and utility networks,
- experience with corresponding installations,
- new methods,
- location of the pipeline and possibilities for maintenance and replacement.

5.5 Design documentation

5.5.1 General

Any pipe installation shall be made on basis of design documentation that is sufficiently detailed to ensure execution of the project presupposed quality.

If the installation is changed during execution the design documentation shall be changed accordingly.

General design documentation in all project classes shall comprise :

- general operational data,
- data related to the pipeline,
- specifications for quality control.

5.5.2 Operational data

Operational data:

- design life, design pressure and design temperature,
- number of operating temperature and pressure cycles and their duration occurring during the life of the pipelines (estimated pipeline operating pattern over its life).

Application rule:

The relevant values for both summer and winter conditions as well as the expected number of full cycles should be specified.

5.5.3 Data related to the pipeline

Data on pipeline location, materials and special provisions.

a) Data on the pipeline route.

Drawings shall contain all information required for a safe and reliable design, such as:

- map of the planned route,
- the longitudinal profile,
- the location of the pipeline with respect to other structures, including intersecting or parallel pipelines or cables, buildings and other obstacles,
- locations of horizontal and vertical bends, tees and reducers, casings, fixpoints, concrete ducts, etc.,
- information on civil engineering works and special constructions.

Application rule:

Above data may be presented in the form of:

- a geographical map with, where applicable, an indication of the area covered by the individual route maps,
- route maps or similar drawings,
- detailled maps and drawings standard structures, indicating the route map(s) to which they apply and providing all information needed for assessment of the design and installation.

The following drawings can be required:

- drawings of pipeline elements, fixed points, casings, etc.,
- isometric calculation drawings for special structures,
- distances between the pipeline and buildings (survey distance) and project class, on a separate list or route map,
- drawings of sheet-piling structures (pile driving plan).

b) Data related to pipeline dimensions:

- outside diameters and tolerances,
- nominal wall thickness and tolerances,
- relevant data on fittings, including bend radii or other information relating to the pipeline element (reducers, tees, etc.),
- corrosion allowances if applied,
- data on abutting structures and supports which affect the distribution of forces acting on the medium-carrying pipeline.

c) Material data:

- material specifications and certificates.

d) Installation data.

Information may be required on the following aspects, among others:

- any pre-stressing applied to the pipeline, and the point at which and methods by which this pre-stressing is applied,
- small angular deviations and permitted elastic bending radii applied to the pipeline, both permanent and temporary,
- test pressure,
- installation temperature.

e) As built drawings:

- registration of location.

Application rule:

An installation plan should include the items a to d.

5.5.4 Specifications for quality control

Application rule:

A plan for quality control should be elaborated for each project.

Quality control can e.g. be divided into five stages:

- procurement,
- design,
- installation and approval
- setting into operation
- operation phase.

Quality control should be ensured for each stage covering the following domains:

- management and organisation of the quality control ,
- management and organisation of the inspection.

It is recommended to

- compare the draft project with the specified objectives and the conditions of the intended operation,
- check the design,
- check the preinsulated components,
- check each stage of the execution, paying special attention to the construction details,
- require the inspections, tests and certificates specified in the quality control plan for applied materials prior to setting into operation.

During each stage of execution the supplier, the manufacturer and the owner should keep the complete documentation updated:

- description of materials,
- quality control plan,
- design report,
- report on setting into operation,
- maintenance records,
- inspection certificates for the materials, works certificates, welding, tests etc. as specified in the quality control plan, report on transfer to the user.

6 Components and materials

6.1 Basic requirements

6.1.1 General

Preinsulated bonded pipe systems for district heating having a pipe assembly of steel service pipe, polyurethane thermal insulation and an outer casing of high density polyethylene shall as a minimum comply with the basic material requirements in EN 253, EN 448, EN 488 and EN 489.

All materials significant to the proper functioning of the system shall possess stable properties during the service life of the system, considering the temperatures and other actions to which the materials will be exposed. Fatigue, creep and ageing shall be considered in this context.

When designing the system the properties of the components shall be calculated in values, which are valid throughout the entire service life of the system.

Application rule:

Properties, which are not directly influencing the service life of the system such as thermal conductivity, should be calculated with weighted average values.

6.1.2 Non standardised components

To the extent to which preinsulated pipes, fittings and joints, not covered by the aforementioned standards, are used for the circulation of district heating water the necessary requirements for material properties, strength and durability shall be substantiated on basis of relevant European Standards, or it shall be otherwise documented that properties and system design comply with the functional requirements of this standard throughout the service life of the system.

Non standardised components shall fulfil the requirements for standardised components whenever applicable.

6.2 Steel pipe components

6.2.1 General

Steel pipe components under the scope of this standard are:

- straight pipe,
- bends,
- tees and branch connections,
- reducers and extensions,
- other steel components like wall penetrations and single action compensators.

6.2.2 Documentation

All steel pipes and components used for fabrication of pipe systems under the scope of this standard shall as a minimum be delivered with a 3.1.B certificate according to EN 10204.

The manufacturer shall keep documentation of the certificates.

6.2.3 Characteristic values for steel

6.2.3.1 General

Materials for steel service pipe shall be either welded pipe according to EN 10217-2 or EN 10217-5 or seamless pipe according to EN 10216-2 with diameter tolerances according to EN 253.

Application rule:

EN 253 specifies stricter tolerances on diameter than specified in the above mentioned steel standards.

As an alternative, equivalent European or national standards may be used.

6.2.3.2 Steels with specified elevated temperature properties

Values for the yield strength at design temperature shall be derived from the specified minimum yield strength or 0,2 %-proof stress at elevated temperature given by the relevant material standards. These specified minimum values guaranteed for the delivery condition can be used for design purposes, unless heat treatment is known leading to lower values. In such cases the values to be used shall be agreed upon by the parties involved.

In case steel pipe or pipe components are delivered without the required certificate according to 6.2.2 the specified minimum yield strength shall be divided by an extra safety factor $\gamma_{m,yield}$ = 1,2. (This factor is to be multiplied by the partial factor for yielding of base material, according to 7.4.2)

Application rule:

Tests performed by the steel pipe manufacturer at elevated temperatures to determine the yield strength values for a specific material delivery may lead to acceptance of a higher yield strength value at elevated temperatures compared with the values specified in the relevant standard.

6.2.3.3 Steels without specified elevated temperature properties

In those cases where the material standards for unalloyed and low alloy steels show no specified value for the yield strength at elevated temperatures, the following formula shall be used:

$$R_{p0.2} = R_m \frac{720 - T}{1.400} \qquad \text{for } 50\,^\circ\text{C} \leq T \leq 140\,^\circ\text{C}$$

6.2.3.4 Elasticity modulus (E) and linear thermal expansion coefficient (α) at elevated temperatures

Application rule:

The following formulas should be used for non alloy or low alloy steel with temperatures up to 140 °C:

$$E = \left(21{,}4 - \frac{T}{175}\right) \cdot 10^{4} \quad (\text{N/mm}^2)$$

$$\alpha = \left(11{,}4 + \frac{T}{129}\right) \cdot 10^{-6} \quad (1/\text{K})$$

For simple design and temperatures up to 100 °C the value of the product $E \cdot \alpha$ may be valued equal to 2,52 N/mm^2/K .

6.2.4 Specific requirements for bends and tees

The use of mitred bends made from straight pipe sections for the service pipe is normally not allowed.

Bends and tees shall normally be made of steel with the same (or higher) specified minimum yield strength than the adjacent straight pipes.

When installing a bend or a tee in a pipe system, the nominal wall thickness of the bend or tee at the welding ends shall normally not be less than the nominal wall thickness of the adjacent straight pipes.

Only set-on branches shall be used. The use of branches welded into the run pipe is not permitted.

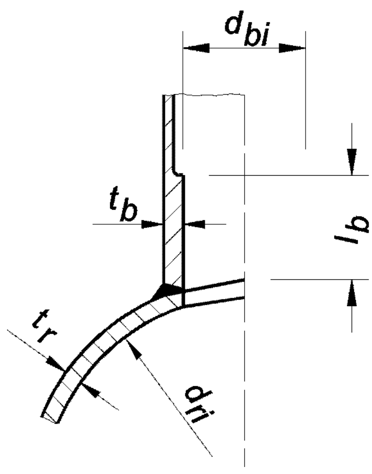


Figure 4 - Set-on branch

Tees may be reinforced by increasing the wall thickness of the run pipe and/or the branch pipe or by compensating plates to withstand the internal pressure, bending moments and axial compressive forces according to the requirements of annex A and C.

Application rule:

For extruded tees for project class C the nominal design stress should be generally reduced to 90 % of σ_d given in 6.2.3.

6.2.4.1 Compensating plates

Reinforcement of tees by compensating plates in project class C is limited to a diameter ratio of $d_{ob}/d_{or} \leq 0{,}8$ where d_{ob} and d_{or} are the outer diameter of the branch and the run pipe respectively.

6.2.5 Specific requirements for reducers and extensions

Reducer material shall have the same or higher yield strength as the adjacent straight pipes.

Annex A specifies additional requirements for non standardised components.

Application rule:

As an alternative to ISO 3419 an equivalent European or national standard may be used. See 4.1.5 of EN 448:2003.

6.2.6 Specific requirements for other components

Other components like wall penetrations and single action compensators shall be considered as non-standardised components for which the conditions of 6.1.2 apply.

6.3 Polyurethane foam insulation

The thermal insulation shall comply with the requirements of EN 253.

Application rule:

Characteristic values for PUR foam:

Elasticity modulus: E_{PUR} = 6,5 MPa (long term at 140 °C)

E_{PUR} = 10,0 MPa (at 23 °C)

Concerning insulation thickness, see annex D.

6.4 PE casing

The PE casing and welding of PE casing shall comply with the requirements EN 253, EN 448 and EN 489.

6.5 Expansion cushions

Materials selected for use in expansion cushions shall provide the required flexibility, be chemically stable and possess the required strength, during the entire service life of the pipe system, at the design range of temperatures.

The thickness of the cushion shall be selected so that the surface temperature at the PE casing pipe is not exceeding 50 °C.

Elasticity modulus as a function of the percentage of compression (secant modulus) shall be specified by the manufacturer based on tests.

Application rule:

Expansion cushions should be closed cell and of a type preventing the progressive compaction caused by sand backfill of the soil cavity occurring after pipe displacement.

When load-deformation curves made up from uni-axial tests are used it should be observed that the cushions in practice will be approximately twice as rigid due to Poisson's ratio.

6.6 Valves and accessories

6.6.1 General requirements

Preinsulated valves shall comply with EN 488.

The applied materials and the fabrication methods shall be such that the design conditions can be fulfilled throughout the entire service life.

Valves and accessories shall be dimensioned to withstand operational conditions and external actions in accordance with the relevant chapters and annexes of this standard. Special attention shall be paid to ensure that high axial compressive forces in restrained pipelines parts can be taken up.

Preinsulated valves for buried installation shall be designed in such a way that they require a minimum of maintenance.

Any preinsulated component shall be fully welded.

6.6.2 Marking and documentation

Valves and accessories shall be clearly and durably marked allowing identification of manufacturer, pressure class (if applicable), design temperature, etc.

The manufacturer shall keep documentation that the components have been designed according to this standard.

Application rule:

Each prefabricated component which is a part of a district heating pipe system, should by labelling be furnished with a declaration stating the conditions the component has been designed and manufactured for.

The declaration shall specify following design data:

- material and grade,
- max. operating pressure,
- max. axial stress for straight pipe parts or maximum axial force,
- max. bending moment (for valves, one time compensators),
- installation method:

  A: Conventional installation methods (e.g. pre-heating, single action compensators).

  B: Cold installation.

7 Actions and limit states

7.1 General

Design and calculation shall be performed in such a way that sufficient documentation is provided that the pipe system will be able to withstand all relevant actions and fulfil the safety and functional requirements during its entire service life.

Application rule:

For a given pipeline system the design and calculation procedure, as presented in Figure 5, can be followed. It includes the following steps:

I. Assessment of design data.

II. Classification of actions.

III. Sub-division of the pipeline, along the proposed route into sections for stress analysis.

IV. Determination of project class and options for simplified analysis.

V. Selection of the combinations of actions to be considered.

VI. Limit state design (and the safety factors to be applied).

VII. Determination of cross sectional forces and displacements due to the action combinations calculated.

VIII. Calculation of the stresses (and/or strains).

IX. Selection of assessment criteria (limit states and associated limit values).

X. Checking of the calculated stresses, strains and deformations with the limit values.

The depth of analysis for each of these steps depends on

- complexity of the pipe system in the section considered,
- physical pipe parameters,
- project class.

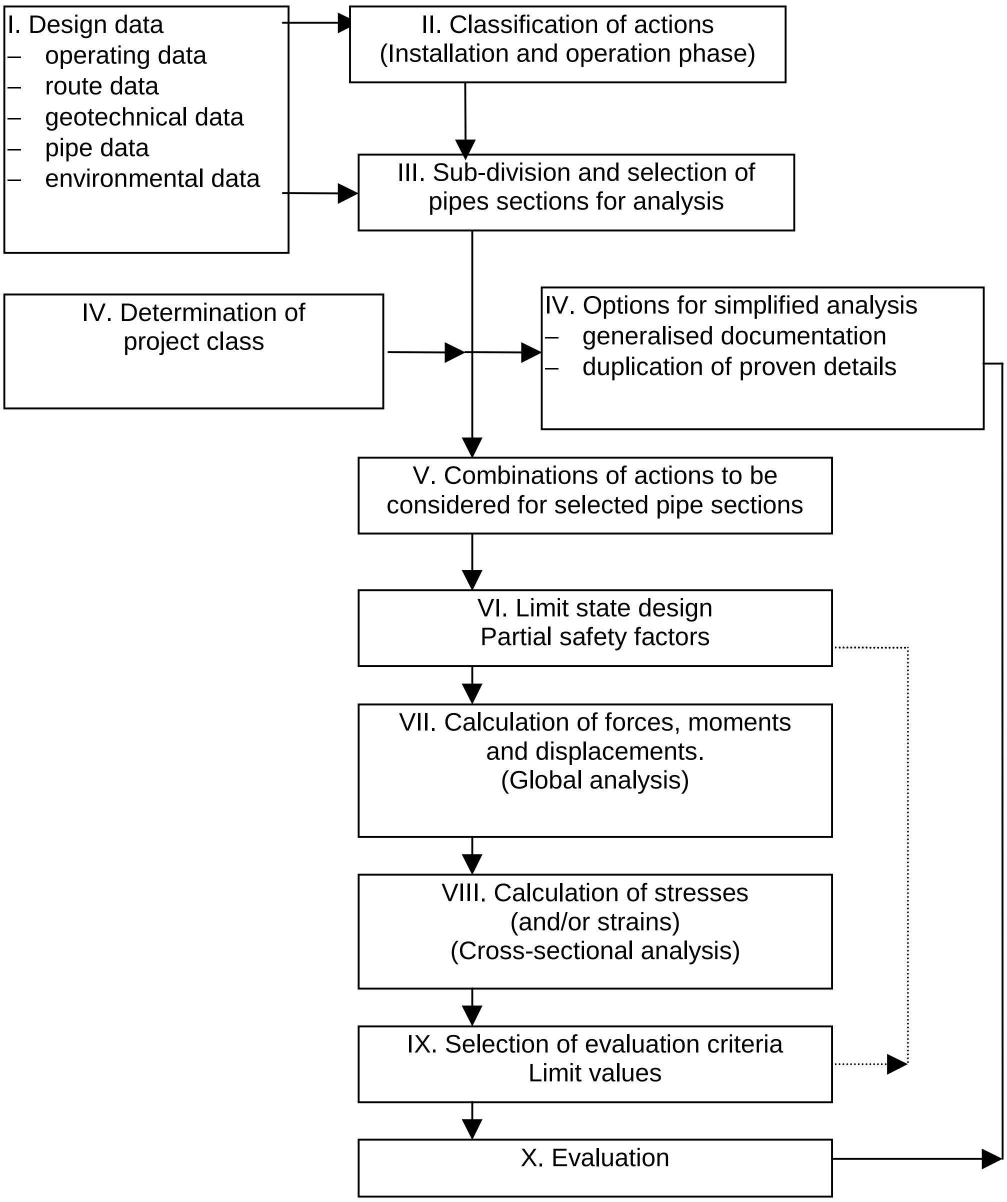


Figure 5 - Flow chart for the design of district heating systems

7.2 Simplified analysis procedure

In project classes A and B design and installation can be performed on the basis of generalised documentation, provided it is in compliance with the requirements of this standard and fulfil the prerequisites (pressure, temperature, traffic actions, etc.) corresponding to local conditions.

Application rule:

Generalised documentation can be e.g. company standards or manufacturers' manuals, provided that the company or manufacturer keeps documentation that the company standards or manufacturer's manuals are in compliance with this standard.

Proven construction details can be installed on the basis of available experience provided that the new construction is not subject to more severe actions.

Application rule:

Fatigue life should always be checked, by estimation of the equivalent number of full temperature cycles, for the pipe system considered, see C.5.2. The number of cycles shall be lower than the number of full temperature cycles presupposed in the generalised documentation (minimum values, see Table 4).

7.3 Actions

7.3.1 General

Actions shall be determined in such a way that the calculation models used provide sufficient documentation that the installation complies with given functional requirements.

Application rule:

The characteristic value of a stochastic variable action is in principle defined as the action value which, at a probability of 95%, will not be exceeded.

Selfweight may, in most cases, be calculated on the basis of the nominal dimensions and mean unit masses.

For the assessment of actions and possible combinations, installation phase and operating phase and any foreseen modification in the use of the current installation and areas shall be taken into consideration.

Application rule:

The installation phase includes transport, handling, welding, laying, backfilling, testing, commissioning (note that actions arising during the installation phase may persist during the operating phase, e.g. pre-stressing).

The operating phase includes the situation after completion of installation, whether the pipeline is in service or not.

Design actions are obtained by multiplying (or dividing) the characteristic values by partial safety factors, γ_a.

7.3.2 Classification of actions

The actions and partial safety factors that shall be taken into account in the design are presented in Table 3.

Actions can be divided into

- force-controlled actions and
- displacement-controlled actions.

Table 3 - Classification of actions and partial safety coefficients

FORCE-CONTROLLED ACTIONS	PARTIAL SAFETY FACTORS γ_a
PRESSURE	
- operating pressure	1,2
- pressure surges. Note 1	1,2
- external pressure	1,05
- internal vacuum. Note 2	1,2
- test pressure	1,0
PERMANENT ACTIONS	
Selfweight	
- pipe assembly	1,0
- water	1,0
- accessories (valves, etc.)	1,0
- buoyancy	1,2
- neutral/passive soil pressure (see NOTE 4)	1,0 - 1,5
- settlements. Note 3	1,2
VARIABLE ACTIONS (see NOTE 4)	1,0 - 1,5
- traffic	
- wind	
- snow	
DISPLACEMENT-CONTROLLED ACTIONS	
TEMPERATURE VARIATIONS	1,0
- variations during operation	
- start-up/shut-down cycles	
- lateral soil reactions	
- soil/pipe friction	
PERMANENT ACTIONS	
- pre-stressing	
thermal, electrical,	1,0
mechanical	1,5
- settlements. Note 4	1,0
- differential settlements	1,2
- deformations during installation	1,0

NOTE 1 Application rule:

Steps in design and operation should be taken to reduce the risk of harmful pressure surges. In project class C the possibility and consequences of pressure surges should be analysed.

NOTE 2 The design pressure for vacuum ≥ -1 bar.

NOTE 3 If it is not acceptable that the pipe follows soil settlement the weight of soil should be treated as a force-controlled action.

NOTE 4 Depending on the standard used for actions.

7.4 Limit states

7.4.1 General

Pipelines for district heating systems shall be designed and constructed such that the probability of an ultimate limit state or serviceability limit state being exceeded during the planned service life is sufficiently low.

Application rule:

The methodology described below is one method to prove that the functional requirement above is fulfilled.

The effect of the design actions in terms of stress, strain and deformation calculated shall not exceed the associated limit states for the pipe materials.

The required safety margin between 'service' condition of the pipeline and the limit state is expressed by the terms 'characteristic value', 'partial safety factor' and 'design action'.

Application rule:

The (residual) uncertainties for which partial safety factors are intended to compensate include:

- the possibility of the action being greater than the characteristic value,
- the possibility of the actual values for the strength of the pipeline being lower than the characteristic values employed,
- deviations from the physical reality, due to the calculation model used in the analysis process.

Ultimate limit states are those associated with collapse or other forms of structural failure:

- failure caused by plastic deformation (limit state A),
- rupture caused by (high and low cycle) fatigue (limit state B),
- instability of the pipeline system or part of it (limit state C),
- leakage (by other causes, e.g. corrosion or third party damage), which may affect safety.

Serviceability limit states corresponds to states beyond which specified service criteria are no longer met:

- deformations or deflections which adversely affect the effective use or maintenance of the pipeline system or cause damage to finishes or structural elements, not being part of the pipeline system, such as installed equipment and/or abutting structures (limit state D).

7.4.2 Limit states for service pipes of steel

7.4.2.1 General

For steel pipes the following limit states are derived from the ultimate and serviceability limit states.

7.4.2.2 Limit state A: Failure caused by plastic deformation

Limit state A1: Ultimate limit state reached by one severe action (load bearing capacity)

Limit state A2: Ultimate limit state reached by few actions (stepwise plastic deformation)

For actions, the partial safety factors γ_a are applied according to Table 3.

Limit state A1: Ultimate limit state reached by one severe action (load bearing capacity)

An equilibrium stress field is any stress field, which is necessary to satisfy the equilibrium equation for force-controlled actions.

The corresponding stress at each point of the structure is not to be greater than the characteristic material parameter divided by the partial safety factor.

The installation, inclusive of valves and accessories, is to be examined for one single elevated effect of the most unfavourable combination of force-controlled actions.

Application rule:

The action combinations comprise operating condition as well as condition during pressure testing.

In some special cases the axial membrane forces from displacement-controlled actions shall be included when calculating the equilibrium stress field (e.g. free spanning pipes with high axial forces from pre-stressing or heating).

For the design an elasto-plastic material model is used. In the calculations a purely linear elastic stress-strain relation is used, also for stresses exceeding the yield strength.

The design of solid component walls with membrane and bending stresses shall verify that the following is observed for the principal stresses, and in the case of composite stress conditions also for the reference stress:

$$\left.\begin{matrix}\sigma_{\mathrm{m}} \\ \sigma_{\mathrm{j,m}}\end{matrix}\right\} \leq \sigma_{\mathrm{d}} = \frac{R_{\mathrm{e}}(T)}{\gamma_{\mathrm{m}}}$$

$$\sigma_{\mathrm{res}} \leq \begin{cases} 1{,}5 \cdot \sigma_{\mathrm{d}} & \text{for } \sigma_{\mathrm{m}} \leq 0{,}67 \cdot \sigma_{\mathrm{d}} \\ 2{,}5 \cdot \sigma_{\mathrm{d}} - 1{,}5 \cdot \sigma_{\mathrm{m}} & \text{for } \sigma_{\mathrm{m}} > 0{,}67 \cdot \sigma_{\mathrm{d}} \end{cases}$$

$$\sigma_{\mathrm{j,res}} \leq \begin{cases} 1{,}5 \cdot \sigma_{\mathrm{d}} & \text{for } \sigma_{\mathrm{j,m}} \leq 0{,}67 \cdot \sigma_{\mathrm{d}} \\ 2{,}5 \cdot \sigma_{\mathrm{d}} - 1{,}5 \cdot \sigma_{\mathrm{j,m}} & \text{for } \sigma_{\mathrm{j,m}} > 0{,}67 \cdot \sigma_{\mathrm{d}} \end{cases}$$

where

σ_{d} is the design stress

σ_{m} is the design membrane stress

$\sigma_{j,\,m}$ is the design reference stress for the membrane stresses

σ_{res} is the design total stress of membrane stress and bending stress

$\sigma_{j,\,res}$ is the design reference stress for the total stresses of membrane stresses and bending stresses

γ_{m} is the partial safety factor for material

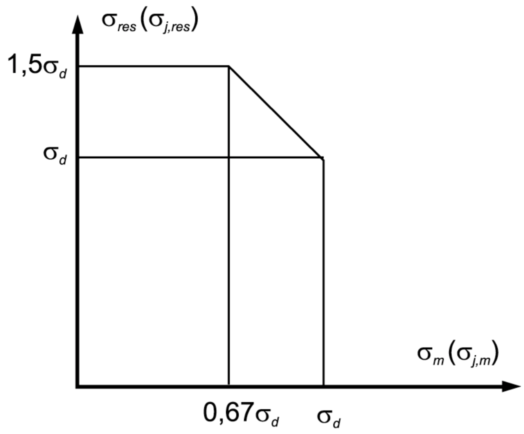


Figure 6 - Range for limit state A1

Application rule:

The requirements for σ_{res} and $\sigma_{j,res}$ will always be fulfilled if $\sigma_{j,res} \leq R_e(T)/\gamma_m$. However, the requirements above will allow higher ovalising stresses.

For straight pipes with $T \leq 140^oC$, the hoop stress from internal pressure shall be calculated from

$$\sigma_{pd} = \frac{p_d \cdot d_o}{2 \cdot t_{min} \cdot z}$$

where

- σ_{pd} is the design hoop stress
- z is the weld factor for longitudinal welds (normally = 1 for welds made by the steel pipe manufacturer)
- t_{min} is the nominal wall thickness minus thickness allowance and possible allowance for corrosion.

Application rule:

Limit state A1 concerns safety against failure from force-controlled action. Limit state A1 can be decisive for high pressures and in case of large moments from force-controlled action (e.g. selfweight on free spanning pipes) or ovalising stresses (e.g. traffic actions and selfweight of soil).

Partial safety factors for steel where the material standards for unalloyed and low alloyed steels show values for yield strength at elevated temperatures:

Yielding of base material, yielding of weld seam, γ_m = 1,25.

Partial safety factors for actions, see Table 3.

Application rule:

With the partial factor of 1,2 on pressure this gives a safety factor 1,2 · 1,25 = 1,5 on force-controlled actions.

Limit state A2: Ultimate limit state reached by few actions (stepwise plastic deformation)

Application rule:

Limit state A2 concerns incremental collapse and stress ratcheting.

Fracture resulting from repeated yielding or gradually increasing plastic deformation shall be prevented.

The installation, inclusive of valves and accessories, shall be examined for the most unfavourable combination of force and displacement actions.

The service fluid pressure may have a positive effect, e.g. lessen the risk of instability (balloon effect), and shall not be included in such cases.

Application rule:

Limit state for stress ratcheting for fully restrained sections:

$$\varepsilon_{\max} = \alpha \cdot \Delta T \leq \frac{R_e(T)}{E}\left(\sqrt{1-\frac{3}{4}\left(\frac{\sigma_p}{R_e(T)}\right)^2}+\sqrt{\gamma^2-\frac{3}{4}\left(\frac{\sigma_p}{R_e(T)}\right)^2}\right)$$

where:

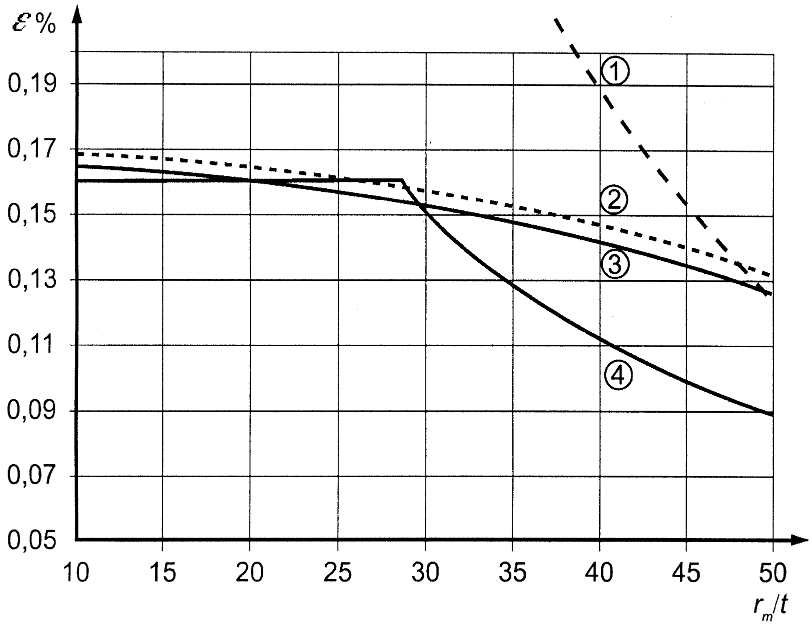
γ is a safety factor, γ = 0,7. The partial safety factor on p and ΔT is 1,0.

ΔT is the maximum positive temperature difference which will occur in the pipe section at any time

σ_p is the hoop stress, $\sigma_p = \dfrac{p \cdot d_i}{2 \cdot t}$

Stepwise plastic deformation (stress ratcheting) can only be caused by very high pressures and large pipe diameters. Stress ratcheting cannot occur if following requirements are fulfilled, see Figure 7:

1. Limit state A1 is fulfilled.
2. The limit state for strain in straight pipes in C1 is fulfilled.
3. $p \leq 20$ bar.



Key

1 Local buckling, uniform strain
2 Racheting 25 bar, 130°C
3 Racheting 25 bar, 140°C
4 Limit state C1, see Figure 3.

Figure 7 - Limit states for axial strain for steel qualities with $R_e \approx 235$ N/mm²

7.4.2.3 Limit state B: From "Rupture caused by fatigue"

Limit state B1: Low cycle fatigue (repeated yielding)

Limit state B2: High cycle fatigue

In safety evaluations of fatigue-affected installations, γ_a = 1,0 is used for actions, and γ_m = 1,0 is used for material parameters.

Limit state B1: Low cycle fatigue (repeated yielding)

Documentation of the safety against fatigue failure shall pay regard to the relevant actions in such combinations so that a realistic picture is obtained of the variations in size and frequency of the stress variations in the individual components.

Safety against fatigue failure shall be verified in consideration of the variations of impacts anticipated throughout the service life of the system.

Application rule:

The limit state low cycle fatigue will be important mainly for bends, tees and reducers but should also be checked for straight sections with high axial forces, where for example the fatigue life of circumferential welds can be decisive.

The number of full action cycles chosen for pipelines in normal operation shall not be lower than the number of equivalent full action cycles stated in Table 4, see C.5.2.

Table 4 - Equivalent full action cycles for *m* = 4 and ΔT_{ref} = 110 °C

Major pipelines	100
Main pipelines	250
House service connections	1000

Application rule:

Major pipelines can be e.g. transmission pipelines and pipelines adjacent to production plants.

Normal operation is e.g. supply temperature regulation according to ambient temperature (sliding respectively sliding/constant). Abnormal operation can be production from waste incineration or e.g. night set-back. The highest number of cycles are normally generated by the consumers in the return pipe. The lowest number of full cycles can be expected in e.g. low temperature networks.

Verification of sufficient safety against fatigue fracture is made using Palmgren-Miner's formula:

$$\sum_i \frac{n_i}{N_i} \leq \frac{1}{\gamma_{fat}}$$

where:

n_i is the number of cycles of stress range ΔS_i during the required design life

N_i is the number of cycles of stress range ΔS_i to cause failure

γ_{fat} is the safety factor for fatigue fracture

i is the number of different stress ranges

Application rule:

N_i can be calculated from $N_{\mathrm{i}} = \left(\frac{k}{S_{\mathrm{i}}}\right)^m = \left(\frac{5000}{S_{\mathrm{i}}}\right)^4$ where S_i is the design stress range in N/mm^2, see C.7.1,

The following values of γ_{fat} shall be applied:

Table 5 - Partial safety factor for fatigue

Project class	γ_{fat}
A	5
B	6,67
C	10

In states of multi-axis stress cases the overall impact of all stress components shall be taken into account. The reference stress can be calculated by Tresca or von Mises' formulas, or - if the location or direction of stress components are not known - by simple addition.

Regard shall be paid to the stress concentrations occurring at bends, tees, branch connections, and similar.

For welded components regard shall be paid to the weld quality and scope of inspection.

Limit state B2: High cycle fatigue.

Application rule:

Limit state B2: High cycle fatigue, is only of importance in the case of large diameter pipe, small soil cover and heavy traffic actions or pipes above ground subject to vibration, e.g. from wind. High cycle fatigue is not further dealt with, see Eurocode 3, Structural Use of Steel.

7.4.2.4 Limit state C: From "Instability of the system or part of it"

Limit state C1: Local buckling or folding

Limit state C2: Global instability (Flexural buckling and loss of equilibrium of the pipeline system)

The installation, inclusive of valves and accessories, shall be examined for the most unfavourable combination of force- and displacement-controlled actions.

For actions, the partial safety factors γ_a are applied according to Table 3.

The limit states local buckling, flexural buckling and wrinkling will be important mainly for straight pipelines sections with high forces, caused by soil friction preventing thermal expansion or for local settlement.

Limit state C1: Local buckling or folding

Local buckling or folding shall be prevented.

Provided that it can be demonstrated that local buckling or folding will not initiate fracture, and provided that the other requirements of the standard are met, the buried bonded preinsulated pipes can be utilised for compressive yielding over the entire cross section.

Application rule:

Concentration of plastic deformation, which may occur in pipe systems with elevated axial compressive stresses and weakened cross sections should be avoided.

Pipe systems with elevated axial stresses are, for instance, pipe systems in which the temperature movements are more or less obstructed by external friction forces, e.g. buried, bonded preinsulated pipes.

The service fluid pressure may have a positive effect, e.g. lessen the risk of folding (balloon effect), and shall not be included in such cases.

For a pipe with no risk of local accumulation of strain the limit value, ε_{cr}, for compressive strain in the longitudinal direction is:

$$\text{For} \quad \frac{r'}{t} \leq 60 \;:\; \varepsilon_{cr} = 0{,}25 \, \frac{t}{r'} - 0{,}0025$$

$$\varepsilon \leq \frac{\varepsilon_{cr}}{\gamma_s}, \qquad \gamma_s = 2$$

If a pipe has ovalised (due to vertical or horizontal earth pressure) the mean radius r_m is replaced by

$$r' = \frac{d_m}{2} \cdot \frac{1}{3 \cdot \frac{d'}{d_m} - 2}$$

where:

$\frac{d'}{d_m}$ is the ovality, see also limit state D

d' is the smallest diameter

Application rule:

The formulas above can be used when evaluating the stresses from bending (e.g. pre-bending of pipes or bending moments from settlements).

For straight pipes with elevated axial compressive stresses and normal variation in wall thickness and yield strength there will be a risk of strain accumulation, and the formulas above will give too high values. Furthermore, imperfections like misalignments of welds and other geometrical and material variations can result in considerable reduction in ε_{cr}.

The safety in limit state C1 can be verified by reference to substantiated tests/experience or by calculations.

If no special documentation is available, the following limits may be used for assessing the safety of buried bonded preinsulated pipes in state C1.

Limit state for strain in straight pipes based on local buckling:

$$\text{for} \ \frac{r_m}{t} \leq 28{,}7 \quad \Delta\varepsilon \leq 0{,}16\%$$

$$\text{for} \ \frac{r_m}{t} > 28{,}7 \quad \Delta\varepsilon \leq (4{,}58 \frac{t}{r_m} + 0{,}003)\%$$

For straight fully restrained pipes using the values for $E(T)$ and $\alpha(T)$ in chapter 3 the limit state for $\Delta\sigma$ and ΔT will be:

for $\frac{r_m}{t} \leq 28,7 \quad \Delta\sigma \leq 334\ \text{N/mm}^2$

for $\frac{r_m}{t} > 28,7 \quad \Delta\sigma \leq (9250\frac{t}{r_m} + 11,7)\ \text{N/mm}^2$

for $\frac{r_m}{t} \leq 28,7 \quad \Delta T \leq 130\text{K}$

for $\frac{r_m}{t} > 28,7 \quad \Delta T \leq (3500\frac{t}{r_m} + 8)\text{K}$

The formulas are valid with the following limitations:

1. All components (e.g. tees and valves) on the restrained part shall be designed to resist the large axial stresses.
2. The pipeline shall be constructed with uniform steel quality and nominal wall thickness.
3. No weak points shall be built in like small angular deviations and misalignment at welds.
4. Proper measures shall be taken to limit stresses at bends due to increased expansion.
5. The formulas are valid for steel grades with specified minimum yield of approximately 235 N/mm$^{2.}$ (For steels with R_e > 235 N/mm^2 other values may be derived in the future.)

As examples of weakened cross sections may be mentioned:

- circular seams with insufficient seam thickness as a consequence of misalignment or similar,
- local reduction of dimension or wall thickness (e.g. non-reinforced tees),
- local use of material with lower yield stress.

Limit state C2: Global instability (flexural buckling and loss of equilibrium of the pipeline system)

For parallel excavation, special precautions are to be taken for pipelines with large axial compressive forces, see annex B.

Application rule:

The limit state "loss of equilibrium, etc." may be important for pipelines installed with limited soil cover and/or below groundwater level, see annex B.

For systems above ground the stability shall be ascertained, see Eurocode 3, Structural use of steel.

7.4.2.5 Limit state D: Serviceability limit state

γ_a = 1 is used for actions. γ_m = 1 is used for material parameters.

Limit state D will usually not be of any consequence to the dimensioning of district heating systems. Examples in which limit state D may be of importance are the allowable deflection of pipe bridge, differential soil settling and allowable impacts on valves and accessories, anchors, building walls, etc.

Ovalisation

The limit value for the smallest diameter of the ovalised cross section is $d' > 0,94\ d$.

Application rule:

Due care shall be taken to other ovalisation limiting requirements such as through-pass of inspection equipment.

7.4.3 Composite stress conditions

In composite stress conditions with the principal stresses σ_1, σ_2 and σ_3 the reference stress can be calculated from "Tresca" or "von Mises" hypothesis:

Tresca:

$$\sigma_j = \max \begin{vmatrix} \sigma_1 - \sigma_2 \\ \sigma_2 - \sigma_3 \\ \sigma_3 - \sigma_1 \end{vmatrix}$$

Von Mises:

$$\sigma_j = \sqrt{½(\sigma_1 - \sigma_2)^2 + ½(\sigma_1 - \sigma_3)^2 + ½(\sigma_2 - \sigma_3)^2}$$

7.4.4 Limit states for PUR and PE

7.4.4.1 Limit state for PUR

Application rule:

For long term actions the design compressive stress $\sigma_{PUR,d} \leq 0,15$ N/mm^2 for PUR according to EN 253. Higher values can be used for temperatures below 130 °C or special reinforced foams.

For short term actions $\sigma_{PUR,d} \leq 0,3$ N/mm^2.

$\sigma_{PUR,d}$ is a combined stress and a result of lateral movement of the steel pipe into the PUR.

It depends on the temperature history whether an action is short term or long term. The true stresses in the PUR cannot easily be calculated. For design purposes $\sigma_{PUR,d}$ can therefore be used for lateral movements assuming long term action.

For small pipes ($d_o \leq 114$ mm) the PUR can fail due to large tensile stresses at the outside curve of the pipe when the pipe moves horizontal in the soil. For large pipes ($d_o \geq 610$ mm) the PUR can fail due to shear stresses at top and bottom of the pipe caused by the ovalising of the pipe.

Concerning shear strength before and after ageing, τ_{PUR} , see EN 253.

The partial safety factor for PUR $\gamma_m = 3$. For sections shorter than 20 m between two bends a partial safety factor $\gamma_m = 2$ can be used in project classes A and B.

7.4.4.2 Limit state for PE

Temperatures above 50 °C shall be avoided.

Application rule:

Elevated temperature on the casing (e.g. where foam cushions are applied) will reduce the service life of the casing.

Under normal conditions the stresses in the PE casing will not be decisive. Local impacts (e.g. especially in cold weather or from sharp objects) can cause rupture or puncture of the casing.

8 Installation

8.1 General

The installation shall be done

- in accordance with the installation plan and the system manufacturers instructions,
- in accordance with the design documentation so to ensure the adequate safety of fitters and other personnel on site as well as any third persons,
- so that installation and operation do not harm other structures or installations, e.g. roads. Conversely, those structures and installations shall not be able to cause damage to the pipe system.

According to 5.4, project classes have been determined, thus also the required design documentation.

For the installation and assembly of pipes and components only materials and methods, which meet the specified instructions, regulations, and standards shall be used.

Application rule:

Pipeline sections, which cannot be installed in compliance with this standard such as other than preinsulated pipe sections, e.g. bridge crossings, water course crossings, casing pipes should be installed by skilled personnel according to the project drawings and corresponding other standards, codes and regulations.

If changes are made during installation the design documentation shall be changed accordingly. The constructive and static consequences of any changes that may become necessary shall be examined.

8.2 Transportation and storage

Handling, transportation and storage of pipes and fittings, etc. shall take account of the properties of the different materials, the special instructions given by the manufacturer of this material and current external conditions, in order to avoid subjecting the components to harmful impacts and in order to avoid impurities, etc. in pipes and fittings.

Precautions shall be taken to avoid scratches and notches. The special conditions for PE casing pipes shall be taken into account during transportation and storage.

Adequately wide straps, according to the dimension in question, shall be used as lifting tools as well as adequate supports.

Application rule:

Steel pipe ends should remain sealed by means of end caps.

PUR foam should be protected against moisture e.g. by foam skin.

Due to the risk of brittle fracture, precautionary measures should be taken in the case of temperatures below 10 °C.

8.3 Excavation of pipe trench

The pipe trench shall be excavated in accordance with the specifications for line routing and depth.

The width of the excavation is, among other things, determined by the requirement for sufficient room during the installation phase, e.g. welding chambers, manholes but also the possibility of compacting the backfill material around the system.

In soft soil areas (organic material and the like) special attention shall be paid to adapting the pipe excavation to a possible need for additional foundation.

8.4 Installation of pipes and components

8.4.1 General

Prior to installation and during the installation stage the floor of the trench shall be made level and the trench shall also be checked on position, height, width. Impurities, stones etc. shall be removed.

Special attention shall be given to the installation of pipes and components room for movements in the trench enlargements shall be given to expansion legs, branches etc.

Whenever pipes and components are handled, precautions shall be taken to avoid damaging the PE casing.

The pipes shall be placed on a sand layer or corresponding foundation, see 8.8.

Application rule:

Sand sacks, styrene supports or sleepers can be used. If sleepers are used, attention shall be paid to any unallowable surface pressure on the PE casing pipe. Sleepers shall be removed prior to pre-stressing of the pipeline and backfilling.

If pipes are to be cut, this shall usually be done perpendicular to the pipe axis. Preinsulated fittings shall be shortened only according to manufacturer's instructions.

The distance between the casing pipes, of parallel laying pipes, shall be minimum 0,15 m or in accordance with the installation plans.

8.4.2 Steel pipes

Steel pipes shall be assembled and steel welds tested according to 8.5, and the pressure test and/or tightness test of the pipeline shall be performed according to 8.6.

8.4.3 PUR-PE Joints

The joint installation shall be performed in accordance with the specifications given in 8.7.

8.4.4 Accessories

Branches, compensators, valves, venting and draining arrangements and special components shall be installed according to their specifications.

8.4.5 Expansion zones

Expansion cushions, if specified, shall be installed as prescribed.

In case the pipe system is thermally pre-stressed, temperature and expansion movements shall be checked.

The pre-stressing temperature shall be maintained until the trench has been completely backfilled unless otherwise specified. The design temperature shall not be exceeded during pre-stressing in order to avoid damage to the PUR foam.

It shall be ensured that the mechanical forces do not damage the pipe parts during mechanical pre-stressing.

8.5 Welding of the steel pipe and testing of the steel welds

8.5.1 General

This clause defines the minimum requirements for welding and testing of steel pipe joints used in district heating systems related to the 3 project classes.

Application rule:

Additional requirements may be specified in the installation plan when any of the following are considered critical:

- the strain on pipelines and systems,
- the line routing,
- the design or the welding technique,
- the materials.

The steel pipe standards specified in EN 253 are EN 10216-2. EN 10217-2 and EN 10217-5. The steel grades in these standards are in group 1 of ISO/TR 15608:2000 for welding purposes. Other material groups may be used, but the requirements will need to be changed accordingly.

Fittings and other steel components should be made of steels grades that are compatible with the straight pipe and for welding should be in group 1 of ISO/TR 15608:2000.

The welding contractor as mentioned in 8.5.2 can be a contractor, a welder, the owner or any organisation or person responsible for the welding part of a project.

8.5.2 Quality system for the different project classes

The relation between project classes and quality demands is provided in Table 6, the table gives an overview, more details can be found in the text.

Application rule:

The quality requirements include the following aspects in the construction of the systems:

- The contractor's organisation/ personnel:
  - welder(s),
  - supervisor personnel,
  - testing personnel.
- Welding procedures:
  - specification,
  - welding method,
  - material,
  - consumables,
  - execution of the work.
- Level of testing:
  - percentage of non destructive testing,
  - destructive testing or other tests

8.5.2.1 Welding contractors

The quality requirements to be fulfilled by the contractors depend on project class applying to the project under construction. The quality level with specific areas of activity assigned to each class can be seen in Table 6 section 1. Each quality level category includes the requirements of the lower one(s), as applicable.

Table 6 - Relation project classes and quality

Requirements for the welding, welding tests and contractors	Project classes		
	A	B	C
Section 1 Quality:			
EN 729-1 and EN 729-3, Standard		X	X
EN 729-1 and EN 729-4, Elementary	X		
Section 2 Welding co-ordination personnel:			
According to EN 719:1994, annex A, the following personnel is required			
Welding technologist			X
Welding specialist.		R	
Foreman welder with a minimum of 2 years technical experience	X	X	
Section 3 Testing personnel:			
In accordance with EN 473	R	R	R
Section 4 Welding procedure specification (WPS) and WPS approval:			
Welding procedure shall be specified and approved in accordance with the appropriate Parts of EN 288	R	X	X
X Requirement			
R Recommended			

NOTE The use of particular method of a welding procedure is often a mandatory requirement of an application standard. In absence of such a requirement the method of approvalshould be agreed between the contracting parties at inquiry or at the order stage.

8.5.2.2 Welders

The welders shall be qualified in accordance with EN 287-1 for the techniques, material groups, dimension ranges and welding position concerned. Welding personnel operating mechanised welding equipment shall be qualified in accordance with EN 1418.

Application rule:

Welders should always have a valid certificate according to EN 287-1.

8.5.2.3 Welding co-ordination personnel

Welding co-ordination personnel shall be responsible for all welding and testing. Depending on the project class, these persons shall possess a qualification to EN 719 appropriate to the relevant quality requirement of EN 729 as shown in Table 6 section 1 and 2.

8.5.2.4 Testing personnel

Destructive testing and non-destructive examination personnel shall be employed either by the pipeline contractor or by the pipeline operator or by an independent testing company. It is assumed that all NDT testing are performed by qualified and capable personnel.

Application rule:

In order to prove this qualification, it is recommended to certify the personnel in accordance with EN 473.

8.5.3 Qualification of the welding procedures

Welding procedure shall be specified in accordance with clause 4 of EN 288-1:1992 and approved in accordance with 5.1.1 of EN 288-1:1992 and Table 6.

All types of fusion welding are acceptable, but for pipes with $t > 3$ mm arc welding with covered electrodes and gas shielded metal-arc welding are preferred.

8.5.4 Welding consumables

Welding consumables shall be of such a quality that the welds have mechanical characteristics at least equivalent with the parent metal.

Welding consumables have to fit the basic material, the welding procedure and welding conditions.

Electrodes shall be in accordance with the relevant European Standard and be accompanied by a document type 3.1.B in accordance with EN 10204.

After electrodes have been removed from their original package, they shall be protected or stored in accordance with the manufacturer's requirements so that their characteristics or welding properties are not affected.

8.5.5 Place and position of the weld

Weld joints, in particular tie-ins, shall be arranged and designed in a way suited to the planned welding and testing technique. The placement of tie-in welds is particularly important.

The choice of joint configuration shall take into account the welding technique, the welding position and the accessibility of the weld seam.

Application rule:

Attention should be paid to movement due to temperature changes during welding.

8.5.6 Performance of welding work

8.5.6.1 Joint edge preparation and different wall thickness

Joint edge preparations shall be selected from EN 29692 except that for joints between sections of different wall thickness Figure 8 shall apply.

For the different values of the possible misalignment and difference in wall thickness Table 7 shall apply.

Minor differences in pipe end measurements are to be distributed evenly over the entire circumference by centring of the pipes.

Table 7 - Adaptation of misalignment and difference in wall thickness

Misalignment Difference in wall thickness	Adaptation	Remark
Misalignment $h \leq 0{,}3\ t$, max. 1 mm	Figure 8 detail A	Adjust to outside diameter
Misalignment 1 mm < $h \leq$ 10 mm		Adaptation of pipe ends
Misalignment h > 10 mm	Extra fitting	Preinsulated reduction piece, Length ≥ 5 times misalignment
Differences in wall thickness $t' \leq 1{,}5\ t_n$	Figure 8 detail B	Adaptation of thicker wall t'
Differences in wall thickness $t' > 1{,}5 \cdot t_n$	Figure 8 detail C	Adaptation both sides

For small axial angular deviations in the welding joint between straight pipeline elements such as pipes, reducers and tees the maximum allowable values of Table C.4 apply.

Application rule:

These angular deviations can be necessary in the field, to adjust the pipe route, without the use of prefabricated smooth bends pipes.

Before tack welding the pipe ends are to be centred with tools, which at the same time correct ovalities.

During welding the pipes shall be guided to achieve the best possible alignment of the centre lines and inner surfaces.

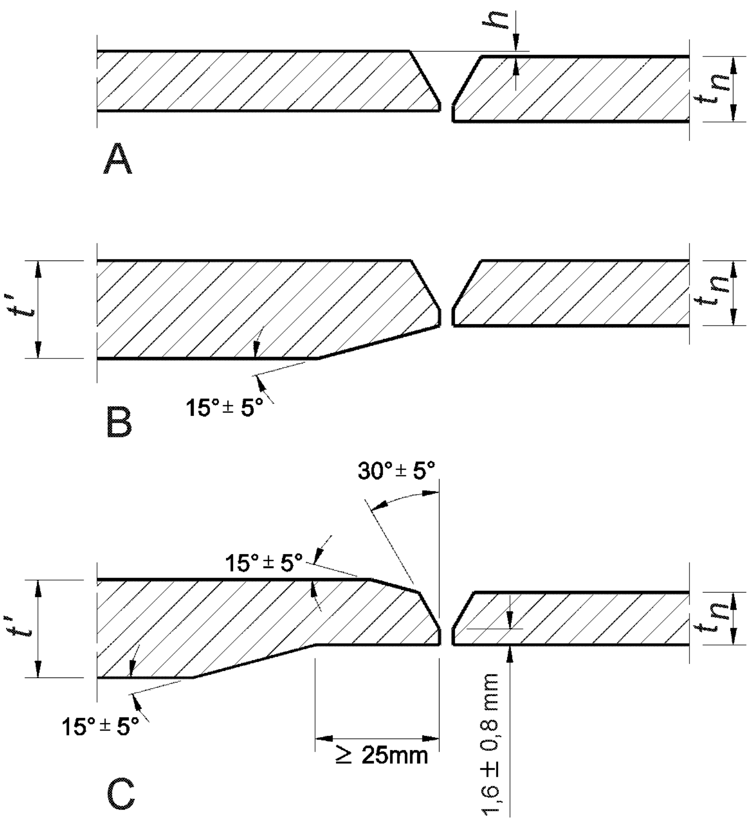


Figure 8 - Misalignment, difference in wall thickness and joint end preparation

8.5.6.2 Cutting and marking

Pipes, pipeline parts and other components, which require marking shall be re-stamped or remarked next to the cutting line prior to cutting.

Application rule:

Marking only applies to the higher project classes if full traceability is required.

8.5.6.3 Weld seam spacing

The seam spacing shall be such that the heat-affected zones do not overlap or interact, the absolute minimum spacing is 3,5 times the wall thickness.

Application rule:

A spacing of 100 mm or more is recommended.

8.5.6.4 Interaction of longitudinal seams

Longitudinal seams or spiral seams shall be staggered by a distance of 10 times the wall thickness with a minimum of 50 mm.

8.5.6.5 Welds with more than one pass

There shall be a minimum distance of 30 mm between the start and the stop positions of the passes.

8.5.6.6 Execution of the welding (welding action)

The area 50 mm back from the weld on both sides of the joint shall be kept free of dust, dirt, grease and water, and protected against wind and rain.

At temperatures below 5°C and in the event of high air humidity, the weld seam areas shall be heated to avoid condensation.

Arc strikes on the pipe surface shall be avoided. If arc strikes occur repair shall be removed by grinding.

Application rule:

To avoid potentially damaging air movements within the pipe, at least one end of the pipe should be sealed off during welding in the open air.

8.5.6.7 Actions after welding

After the weld is completed, weld spatter shall be removed. The weld surface shall be cleaned of slag. The cooling process shall not be accelerated.

Application rule:

At air temperatures below 5°C, and if the pipeline owner requires it, the weld seam should be protected against excessively rapid cooling.

8.5.6.8 Repair of weld failures (defects)

Weld seams, which do not meet the specified requirements, shall be repaired or cut out.

Repairs shall be carried out in accordance with an approved welding procedure.

When the defect is a crack this shall only be repaired if the cause of cracking is clearly established and can be shown to be repairable.

8.5.7 Special procedures

8.5.7.1 General

Before special procedures are carried out, the type and scope of the weld joint shall be specified. The testing technique used will depend on the type and accessibility of the weld joints.

8.5.7.2 Attachment of structural parts

Structural parts shall be attached using a continuous weld. Intermittent welds shall not be acceptable.

8.5.7.3 Welding on pipes under pressure

Welding work on pressurised pipelines and systems shall only be carried out according to safe and proven procedures to ensure the correct mechanical properties of the weld and the safety of the working crew.

8.5.8 Inspection of the weld joint

Seam weld quality shall be checked using the systems and personnel in accordance with Table 6 and the standards in Table 8 to show compliance with the requirements in Table 9 and if required Table 10.

Welded joints are divided into inspection section in such a way that for joints in the same section there will be no circumstances which may cause differences in quality.

Application rule:

Examples of welded joints, which should be referred to different inspection sections, are welds with difference in base material, welding process, welder or weather conditions during welding.

8.5.8.1 NDT of welds

NDT of welds in pipelines is generally done by radiography. Alternatively, when agreed by the owner and in particular cases where this method is unable to give adequate information on the quality of the weld, radiographic examination should be supplemented or replaced by ultrasonic examination.

Weld seam examination shall be carried out in accordance with one or more of the standards shown in Table 8 unless another NDT method is required dependent on the material, design and/or welding technique.

Table 8 - NDT weld seam examination

NDT Method	General principle /procedure	Acceptance criteria
Visual inspection	EN 970 and EN 13018	
Radiographic examination	EN 444 and EN 1435	
Ultrasonic examination	EN 1714 and EN 583-1	EN 1712
Dye penetrant examination	EN 571-1	EN 1289
Magnetic particle examination	EN 1290	EN 1291

Table 9 - Inspection and test requirements for seam weld quality of site welds

Quality requirement	Type and position of weld seam	Radiographic or ultrasonic examination [a] note 3	Assessment category EN 25817
Project class A	– Circumferential welds: – Branch nozzle, fillet welds: – Longitudinal seams: – Welds not included in tightness test:	**5%** note 1 note 1 **20%**	Assessment category **B**
Project class B	– Circumferential welds: – Branch nozzle, fillet welds: – Longitudinal seams: – Special constructions: – Welds not included in tightness test:	**10%** note 1 note 1 [b] **50%**	Assessment category **B** Defect number 18: $h \leq 0,3\ t$, max. 1 mm note 2
Project class C	– Circumferential welds: – Branch nozzle, fillet welds: – Longitudinal seams: – Special constructions: – Welds not included in tightness test:	**20%** note 1 note 1 [b] **100%**	Assessment category **B** Defect number 18: $h \leq 0,3\ t$, max. 1 mm note 2
Welds in project classes A, B and C shall be 100% visually inspected			
For welds project classes A, B and C, the defects 24 and 25 of EN 25817 are not allowed			

NOTE 1 Representative random sample on basis of total number of seams made by the welder during the course of one year.

NOTE 2 For project classes B and C the requirements concerning misalignment EN 25817, defect number 18, is tightened up to $h \leq 0,3\ t$ and maximum 1mm

NOTE 3 The extent of the radiographic inspection is stated as a percentage of the number of field welds of the project.

[a] The proportion of both techniques shall be agreed.

[b] The extent of non-destructive examination shall be specified, taking into account internal and external loads and purpose and place of the construction.

Application rule:

b of Table 9: The first inspection of pipelines in which repair causes particular difficulties, e.g. pipeline below watercourses dykes and railways, should be increased to 100%.

The initial inspection and test requirements for welds produced on site are shown in Table 9. If defects are found, the repaired section shall be inspected in accordance with Table 10.

In Table 10 the inspection level is progressively increased, if defects are detected at the previous level of testing, from level 1 up to level 4.

Table 10 - NDT inspection levels for inspection sections where welds have been repaired on site

Level 1	Level 2	Level 3	Level 4
5 %	20 %	50 %	100 %
10 %	20 %	50 %	100 %
20 %	50 %	100 %	100 %
100 %	100 %	100 %	100 %

8.5.9 Documentation

The test results shall be documented as specified in EN 729-2.

Application rule:

The documentation is intended to prove that the welding requirements and test provisions according to this standard are fulfilled and are traceable.

8.6 Strength pressure test and leak tightness test

During these tests, the tested system shall be visually inspected to ensure that the system components, welds and other joints are leak tight.

Welds shall be subject to leak tightness test by one of the following methods:

- Leak tightness test with air at 0,2 bar over-pressure or 0,65 bar below atmospheric pressure where the tightness of the weld is checked by application of a suitable indicator fluid.
- Leak tightness test with water applied at 1,3 times the design pressure with simultaneous leak inspection of the welds.
- 100% NDT inspection of steel service pipe when the weld seams made on site are made up of minimum 2 passes, and if starting/ ending positions of the two passes are mutually displaced.

Application rule:

The leak tightness test with water can be regarded as a strength test when a pressure test is demanded. The pressure can be increased to 1,5 times the design pressure for the required period of time. Following a leak tightness test the pressure test can be performed after the pipes are buried.

The leak tightness test is compulsory and the pressure test is optional and can be specified according to local authorities or the requirements of the owner.

In project class A the leak tightness test can be done with operation pressure and the pressure test may be omitted.

The duration of a leak tightness test should be sufficiently long in order that the water can penetrate small defects e.g. pinholes.

Any pressure test shall be performed on the completed pipe section; it shall be performed on pipe sections, as long as possible, on which no further work shall be done.

The test duration depends on the pipe volume and shall be agreed with the owner. A test report shall be made for each leak tightness and pressure test.

8.7 Assembly of casing pipes, joint installation and site insulation

Assembly of the PE casing pipe and the insulation of joints shall be performed in accordance with the requirements of EN 489.

All types of joints shall be installed by specially trained personnel according to the instructions given by the manufacturer.

The requirements depend on the type of joint involved.

If leak detection and/or surveillance systems are part of the system, wires and other components shall be installed in the joint according to the instructions given by the manufacturer.

All joints shall be subject to a leak tightness test according to 4.1.7 of EN 489:2003.

Leak tightness testing of joints shall be carried out with air or another suitable gas. The test pressure applied depends on the type of joint used.

Application rule:

The testing can normally be done by applying an internal over-pressure of 0,2 bar to the joint. During this test temperature changes have to be avoided.

The tightness is checked by means of a suitable indicator fluid or a leakage detector.

The indicator liquid shall be detrimental to neither casing and joint material nor to the surroundings.

8.8 Backfilling of trench

An inspection of the installed pipe shall be performed prior to backfilling of the pipe trench. This inspection involves a visual inspection of the pipe assembly, joints, expansion provisions and the registration of as-built data such as dimensions of pipes and components and their geographical placement for registration on maps and drawings.

The pipeline area (the room between trench floor and minimum 0,1 m above top of casing pipe) shall be backfilled with the materials as specified.

During the backfilling it shall be ensured that the materials are compacted carefully around the pipes, allowing the presupposed friction between outer casing and backfill.

The backfill shall be made up in a way that neither its properties nor the compaction cause damage to pipe and joints.

The backfill material shall possess sufficient carrying capacity and the mechanical and hydraulic properties required to comply with the design basis. The backfill material shall posses such qualities that it can be compacted with a reasonable effort of compacting equipment.

Application rule:

Example of ordinary sand:

Friable, round-edged medium- or gross-grained sand, 0-4 mm.

Fine grained sand max. 8%.

The following material specification can be used for normal circumstances:

Grading:	-	Maximum grain size	≤ 32 mm
	-	Maximum 10% by weight	≤ 0,075 mm
or		Maximum 3% by weight	≤ 0,020 mm

Coefficient of uniformity: $$\frac{d60}{d10} > 1{,}8$$

Purity: The material should not contain harmful quantities of plant residues, humus, clay or silt lumps.

Grain form: Large keen-edged grains, which may damage pipe and joints should be avoided.

Friction: The material composition should allow such coefficients of friction as required by the installation plan following careful compaction.

Compaction: The friction coefficients of the material are based on a standard proctor value, average 97-98%. No values below 94-95%. Careful and even compaction is required.

The subsequent backfilling of the pipe trench shall comply with the instructions for e.g. road building.

The compression zone, i.e. the room between pipeline zone and upper (e.g. road) construction shall be made from such a material and in such a manner (by layers) that the requirements made by the structures above the pipeline are fulfilled. Unsuitable material, e.g. stone and rocks, shall not be used. The upper construction zone, i.e. the room between compression zone and surface, shall be backfilled according to the instructions given by the authority responsible for the surface.

Application rule:

To reduce the risk of pipe damage by third parties it is recommended to use warning tapes, referring to the pipeline.

The warning tape shall be placed at a distance of approx. 0,2-0,5 m above the district heating pipeline.

8.9 Pipe bends and other components

8.9.1 Pipe bends

Un-insulated pipe bends shall be installed (fitted and insulated) as specified.

Application rule:

Examples of such bends are bend fittings and specially designed bends, e.g. bridges and chambers.

Special attention shall be paid to the dimensions, the installation and also the trench enlargement necessary to allow the bends (legs) to expand.

During the final inspection of the bend zone in particular, prior to backfilling, the pipeline position, thickness and length of expansion pads shall be checked to ensure that they conform to the installation plan.

The actual value of the expansions and other important pipeline measurements shall be determined prior to backfilling.

8.9.2 Branches

Un-insulated tees for branch lines and other types of branches shall be installed (fitted and insulated) according to the system instructions.

Application rule:

Examples of such branches are branch saddles with bend fittings and other special constructions.

In the case of branches, be especially aware that the expansion pads correspond to the specifications laid down in the installation plan.

Special attention shall be paid to the dimensions, the installation and also the trench enlargement to allow branches and or expansion legs to move as expected.

The actual value of the expansions and other important pipeline dimensions shall be determined prior to backfilling. The pipeline position, thickness and length of expansion pads shall be checked to ensure that they conform to the installation plan.

8.9.3 Valves and accessories

Un-insulated valves shall be installed (fitted and insulated) according to the system instructions and the installation plan.

Valves and accessories shall be installed within the stress range allowed for the specific component.

Installation of expansion pads, operating chambers, chamber covers and proper backfilling shall be performed and checked meticulously.

For the installation of chambers and covers, the instructions for road building according to installation plan shall be observed.

The proper function of the valves shall be checked before and after installation.

8.10 Setting into operation

8.10.1 General

Application rule:

Cleaning:

The pipeline should be cleaned before it is set into operation, e.g. by pigging and flushing or manual procedure.

Preservation:

If the pipelines are not set into operation immediately, preservation of the installation is recommended after a foreseeable time of standstill, e.g. using gas or liquid.

8.10.2 Filling with water for initial operation

For network operation, the pipeline shall be filled with the type of water specified by the owner, and in due consideration of venting facilities at the high points.

Before the network is set in operation the backfilling of the trenches shall be completed.

While taking the network in operation the temperature rise shall be carried out with care, temperature rise shall be done slowly to allow the system to settle without sudden movement.

8.10.3 Surveillance system

If leak detection and surveillance systems are installed, their function shall be checked during installation according to the manufacturer's instructions and finally after they have been set into operation.

8.11 Special constructions

8.11.1 Special components

Special components and non-standardised components shall be installed as specified.

Application rule:

Special components are, for instance

- compensators,
- reducers,
- wall penetrations,
- fixpoints, etc.

8.11.2 Above-ground pipelines with preinsulated pipes

In the existing standard the building elements (pipe, bends, accessories, sealings, valves) are intended for buried systems only. In special cases, the pipeline can be installed above ground.

The following precautionary measures shall be taken:

- support of the pipeline,
- protection against ultraviolet radiation.

For above-ground pipelines in particular, the static layout shall be observed.

8.11.3 Insertion into casing pipe

Special attention is required for

- support in the tunnel,
- avoiding damage when inserting the PE and steel pipe into the casing pipe,
- resistance of the sealing in places where the pipes are connected to buried pipes,
- special static conditions.

8.12 Construction work during the operation stage

During excavation, around and close to the PE casing pipe it shall be ensured that the pipes are not damaged.

Prior to parallel excavations, a corresponding calculation check shall be made, as the removal of the restraining soil will result in a risk of buckling, see annex B.

If the soil cover is increased/reduced or its load changed substantially, a check of the statics is imperative.

Additional precautions according to the static specifications shall be taken in case a preinsulated pipeline is cut or equipped with branch lines.

Special safety regulations and welding instructions shall be taken into account when installing branches on pressurised pipelines, e.g. hot tapping procedure.

Annex A
(normative)

Design of piping components under internal pressure

A.1 General

This annex gives rules for the determination of the required minimum wall thickness to withstand the design pressure.

When use is made of internationally standardised components designed for internal pressure according to the relevant standard recalculation according to this annex is not required.

Application rule:
As an alternative equivalent national standards may be used.

The following pipe components are considered in this annex:

- straight pipes and bends,
- tees and branch connections,
- reducers and extensions,
- dished ends.

Application rule:
Dished ends may occur as a temporary provision during hydrostatic pressure testing or as a permanent provision at the pipeline ends which will be extended in the future.

A.2 Symbols

d	Diameter of service pipe
R	Bend radius
t	Wall thickness
z	Joint efficiency factor.
σ_{pd}	Calculated stress from design pressure
σ_d	Design stress = $R_e(T)/\gamma_m = R_e(T)/1,25$
l	Reinforcing length
T	Design temperature

Indices:

b	Branch pipe
d	Design
i	Inner
m	Mean, metal
o	Outer
r	Run pipe
p	Compensating plate, pressure

A.3 Straight pipe and bends

A.3.1 Straight pipes

For straight pipes with $T \leq 140^{o}$ C the minimum wall thickness from internal design pressure shall be calculated from

$$t_{\min} = \frac{p_{\mathrm{d}} \cdot d_{\mathrm{o}}}{2 \cdot \sigma_{\mathrm{d}} \cdot z}$$

$$t_{\mathrm{n}} \geq t_{\min} + c_1 + c_2$$

where:

c_1 is addition for tolerance

c_2 is addition for corrosion

A.3.2 Bends

The minimum wall thickness for a bend shall be calculated as follows:

For the intrados (inside fibre of bend)

$$t_{\mathrm{i,min}} = t_{\min} \frac{R - 0{,}25 \cdot d_{\mathrm{i}}}{R - 0{,}5 \cdot d_{\mathrm{m}}}$$

For the extrados (outside fibre of bend)

$$t_{\mathrm{e,min}} = t_{\min} \frac{R + 0{,}25 \cdot d_{\mathrm{i}}}{R + 0{,}5 \cdot d_{\mathrm{m}}}$$

where $t_{\min}$ is the minimum wall thickness for a straight pipe according to A.3.1.

A.4 Tees and branch connections

A.4.1 General aspects and limitations

The design method specified in this paragraph shall apply to cylindrical tees and branch connections with following requirements

- circular openings,
- the axis of the branch pipe perpendicular to the axis of the run pipe,
- two adjacent openings shall have a minimum distance between their outer edges of three times the diameter of the run pipe,

the distance between any tee or branch connection and any other geometric discontinuity of the run pipe shall not be less than 1,0 d_{m} of the run pipe.

A.4.2 Reinforcement

A.4.2.1 General

Tees and branch connections may be reinforced to withstand the design pressure by

- an increased wall thickness of the run pipe,
- set-on welded compensating plates,
- an increased wall thickness of the branch,
- combination of the methods above.

If a reinforcement is provided it shall be the same in all planes through the axis of the openings or branch.

Reinforcement of openings by compensating plates is limited to a diameter ratio of $d_{bm}/d_{r\,m} \leq 0,8$.

Application rule:

Increasing the wall thickness of the branch as well as the use of compensating plates are less effective methods and should only be applied if it is not possible to increase the wall thickness of the run pipe.

A.4.2.2 Dissimilar material of shell and reinforcement

If the run pipe and the reinforcement consist of material with different allowable stresses and if the allowable stress of the run pipe is the lowest, this stress shall also be taken for the reinforcement.

Material for reinforcements shall be selected avoiding thermal stresses because of significant difference in thermal expansion coefficients.

A.4.2.3 Thickness ratio.

The thickness ratio t_b/t_r for calculation shall be not greater than the value depending by d_{bm}/d_{rm} as indicated in Table A.1.

Table A.1 - Thickness ratio for reinforcement

$d_{bm}/d_{r\,m}$	t_b/t_r
$\leq 0,3$	2,0
$0,3 < d_{bm}/d_{r\,m} \leq 0,8$	$2,6 - 2\ d_{bm}/d_{r\,m}$
>0,8	1,0

A.4.2.4 Calculation method for reinforcement area

Application rule:

The required reinforcement area is calculated by the method of force equilibrium between the pressure loaded area A_p and the stress loaded cross sectional area A_m, see Figure A.1,

After an initial estimate of the reinforcement area, the calculation may need to be repeated using a revised estimate of the reinforcement area.

A.4.2.5 Reinforcement by increased wall thickness

The reinforcement can be obtained by an increased wall thickness of the run pipe and/or branch, This reinforced wall thickness shall exist up to a maximum distance of l_r at the run pipe and l_b at the branch, measured from the edge of the opening, see Figure A.1,

Furthermore, the following condition shall be satisfied

$$\sigma_d \cdot A_m \geq A_p \cdot p_d$$

where

A_p is the pressure loading area

A_m is the cross sectional metal area effective for compensation of over-pressure

l is the reinforcing length as shown by the index

$$l_r = \sqrt{d_{rm} \cdot t_r}$$

$$l_b = \sqrt{d_{bm} \cdot t_b}$$

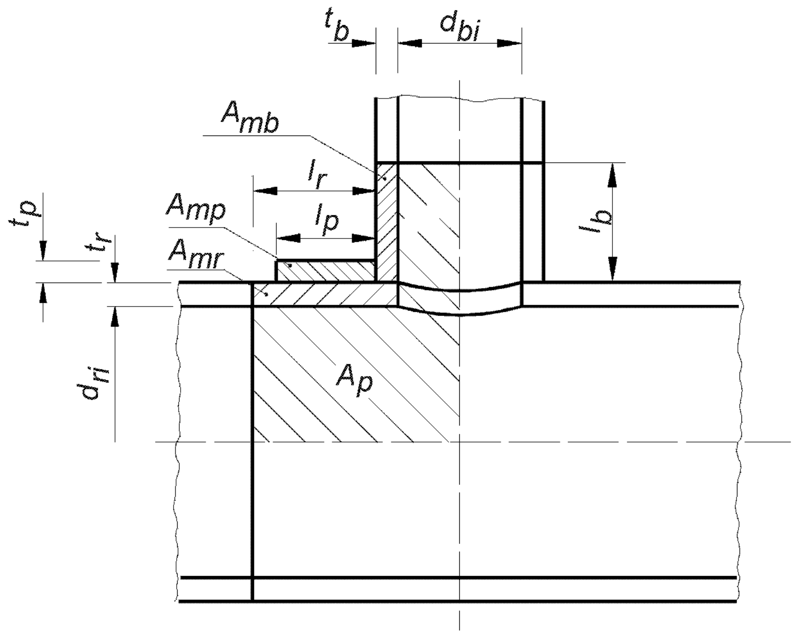


Figure A.1 - Reinforcement of tees

Application rule:

The actual wall thickness of the pipe is in many cases larger than t_{min} calculated according to A.3.1 presupposing $\sigma_{pd} = \sigma_d$. The difference can be considered to be reinforcement of the run pipe/branch.

An international or equivalent national standard may be used for selection of tees.

A.4.2.6 Reinforcement by compensating plates

Compensating plates shall have close contact with the shell. The width of compensating plate l_p considered as contributing to the reinforcement shall not exceed l_r, see Figure A.1.

The value of t_p used for the determination of A_{mp} shall not exceed the thickness t_r of the run pipe.

The following condition shall be satisfied

$$\sigma_d \cdot (A_{mr} + A_{mb} + A_{mp}) \geq p_d \cdot A_p$$

where A_{ms} and A_{mp} are the cross sectional areas of the run pipe and the compensating plate effective for reinforcement.

If the design stress of the compensating plate is less than the design stress of the run pipe the following condition shall be satisfied.

$$\sigma_d \cdot (A_{mr} + A_{mb}) + \sigma_{dp} \cdot A_{mp} \geq p_d \cdot A_p$$

where σ_{dp} is the design stress of the compensating plate material.

A.5 Reducers and extensions

Reducers and extensions are called reducers for simplicity.

This clause applies to welded or un-welded concentric reducers meant to withstand the same internal pressure as the connecting pipes where

– the reducer and the pipe axis are on same axis of rotation,

– the half angle, α, at the apex of the component does not exceed 30 °, see Figure A.2.

Application rule:

For selection of standardised reducers reference is made to ISO 3419 or a relevant national standard.

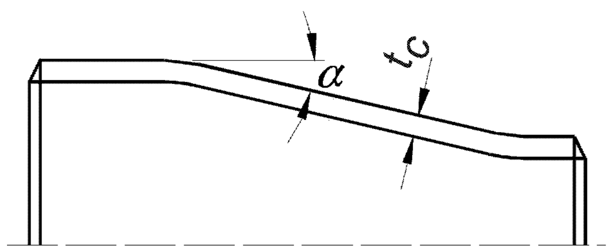


Figure A.2 - Reducer

A.5.1 Minimum wall thickness of the cone

The minimum wall thickness at any point along the length of the cone, $t_{c,min}$, is given by

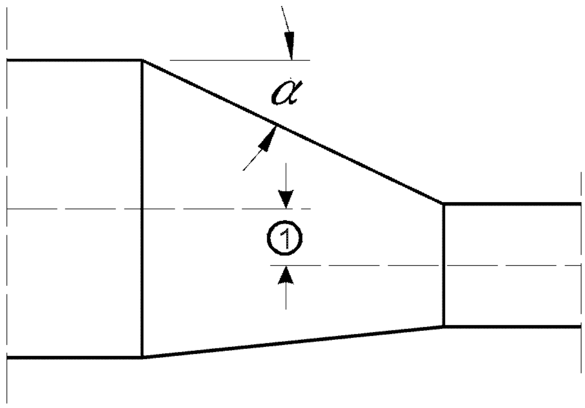
$$t_{c,min} = \frac{p_d \cdot d_{oc}}{2 \cdot \sigma_d \cdot z} \cdot \frac{1}{\cos \alpha}$$

where:

z	is the welding factor of the longitudinal weld, if any
d_{oc}	is the outer diameter at any point along the cone
α	is the semi angle of reducer at apex

A.5.2 Offset reducers

In case of offset reducers the connecting pipes shall have parallel centre lines offset from each other by a distance not greater than the difference of their radius. The angle α is taken as the greatest angle between conical and cylindrical part, see Figure A.3.



Key

1 Offset

Figure A.3 - Offset reducer

A.6 Dished ends

Dished ends shall be calculated according to relevant international or national standards.

Annex B
(informative)

Geotechnics and pipe-soil interaction

B.1 Scope

This annex has status as an application rule.

For hot buried pipelines subject to large deformations and axial forces, the calculated bending moments and forces are strongly dependent on the correct modelling of the pipe-soil interaction and the reliability of soil parameters used.

This annex provides guidance on

- the relevant parameters for pipe-soil interaction analysis (B.3),
- methods for obtaining characteristic values for soil parameters (B.4),
- requirements for specific areas of attention (B.5-B.7).

B.1.1 General requirements

The methods of analysis and soil parameters selected for design shall be appropriate for the intended pipeline system and the proposed route and facilities and shall be compatible with all potential actions and failure mechanisms. Methods of calculating the magnitude of deformation can be based upon numerical modelling, empirical relationships or combinations thereof.

B.2 Symbols and units

c	Soil cohesion, shear strength of soil
D_c	Outer diameter of casing pipe
d_o	Outer diameter of service pipe
E	Modulus of elasticity
F	Friction force per unit length of pipe
f	Axial soil reaction
k_h	Coefficient of horizontal soil reaction, plate bedding constant
k	Line bedding constant
P	Horizontal soil reaction per unit length of pipe
p	Horizontal soil reaction
Q	Vertical soil reaction per unit length of pipe
q	Vertical soil reaction
u	Axial displacement of pipe
v	Horizontal displacement pipe
Z	Depth of burial to centreline of pipe
w	Vertical displacement of pipe
γ	Effective density of soil
φ	Angle of internal friction of soil
μ	Coefficient of interface friction between soil and PE casing

B.3 Soil parameters for global analysis (pipe-soil interaction)

B.3.1 Modelling pipe-soil interaction

Reference is made to C.6.1.

For a static calculation of the system (global analysis) the forces due to pipe-soil interaction can be represented by a beam-element model comprising three components as shown in Figure B.1, The pipeline can be represented by a simple structural beam with the reactions from the soil *f, p* and *q* modelled as discrete soil springs k_x, k_y and k_z.

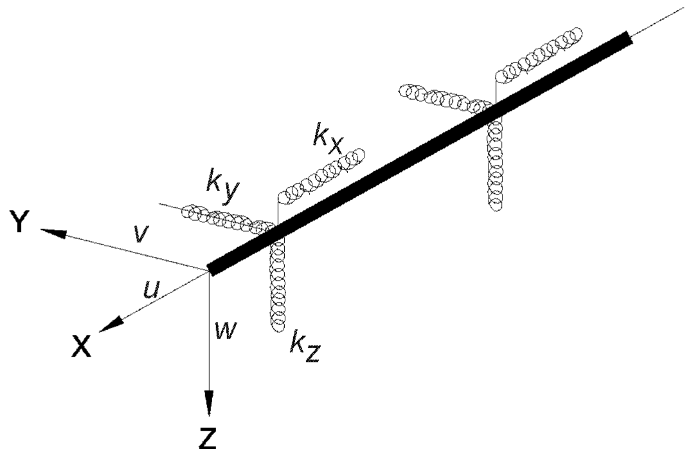


Figure B.1 - Modelling pipe-soil interaction

It is normally assumed that there are no shear stresses between two adjacent springs, along the pipe axis laying springs or bedding elements.

As an alternative for discrete springs, theories for beams on elastic foundation or finite element methods can be used.

The amount of restraint is usually a non-linear function of the relative motion between soil and pipe as illustrated in Figure B.2 where *f-u*, *p-v* and *q-w* refer to axial, horizontal and vertical reactions and displacements respectively.

If displacements greater than u_u, v_u and w_u occur the soil reactions can reach constant ultimate values of f_u, p_u and q_u respectively.

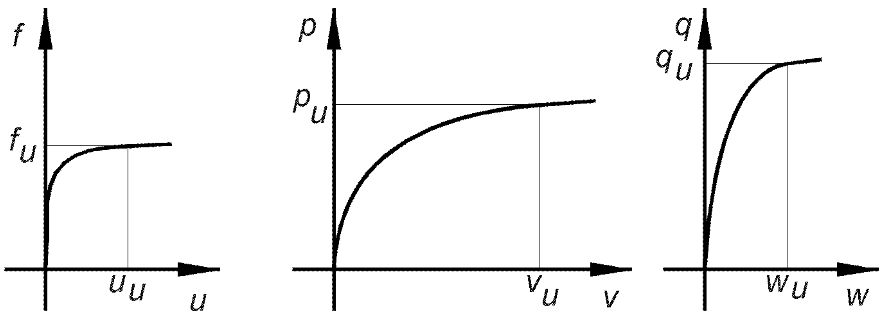


Figure B.2 - Load-deformation relationship

Normally the most important restraints are

– the axial restraint *f-u,* given by the pipe to soil friction, see B.3.2,
– the horizontal restraint *p-v,* given by the horizontal modulus of soil reaction, see B.3.3.

B.3.2 Pipe to soil friction (axial)

The relevant ultimate values of the friction f_u between PE casing and surrounding soil shall be determined in due consideration of the installation conditions such as

- type of backfill material and method and degree of soil compaction,
- maximum and minimum groundwater levels,
- presence of very stiff street covers preventing lateral soil displacements,
- influence of possible future parallel excavations nearby the pipes,
- "tunnel effect" due to possible increase in friction because of pipe diameter increase when heating up and friction reduction because of pipe diameter decrease when cooling down.

For sandy soils the relative displacement u_u between pipe and surrounding soil required to reach the maximum friction resistance f_u is approx. u_u = 1 - 3 mm.

The maximum friction resistance can be calculated as

$$f_u = \mu \, \sigma_n$$

where σ_n is the effective normal stress along the periphery of the PE casing.

For sandy soils the normal stress at a casing can be calculated on basis of a state of soil pressure at rest, giving the friction per unit length of pipe

$$F = \mu \left(\frac{1 + K_0}{2} \cdot \sigma_v \cdot \pi \cdot D_c + G - \gamma_s \cdot \pi \cdot \left(\frac{D_c}{2} \right)^2 \right)$$

where:

K_o is the coefficient of soil pressure at rest, $K_o = 1 - \sin\varphi$
For sandy soils K_o can normally be valued at 0,5.

G is the effective selfweight of pipe with water

σ_v is the effective soil stress at pipe centre level

For granular soils $\sigma_v = \gamma_s \cdot H_w + \gamma_{sw} (Z - H_w)$ for $H_w < Z$

$\sigma_v = \gamma_s \bullet Z$ for $H_w \geq Z$

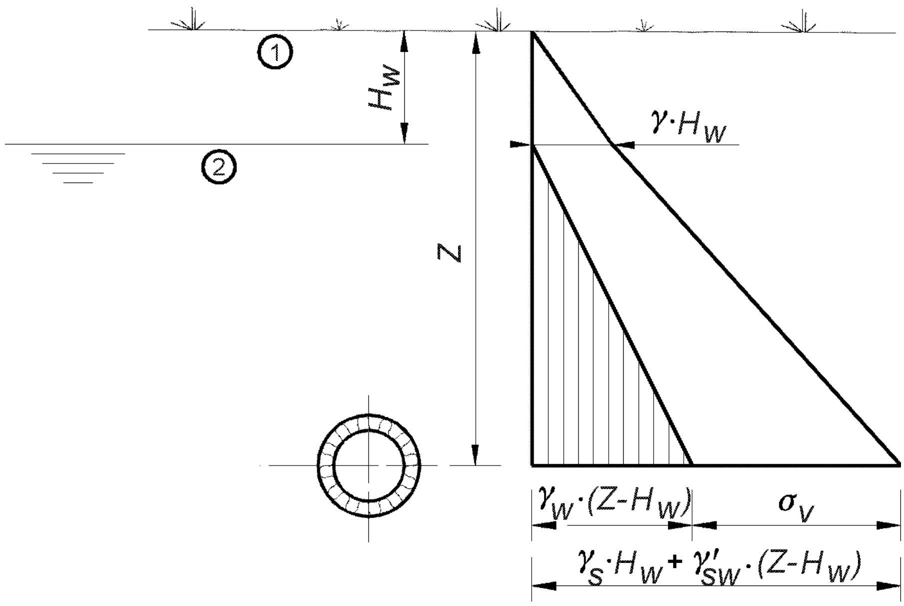
H_w is the depth of ground water table below grade, see Figure B.3

γ_s is the effective density of soil above ground water table

γ_{sw} is the effective density of soil below ground water table = $\gamma'_{sw} - \gamma_w$

γ'_{sw} is the density of saturated soil below ground water table

γ_w is the density of water



Key

1 Grade

2 Groundwater table

Figure B.3 - Calculation of effective soil stress

Friction coefficient

The friction coefficient μ should be determined with due consideration of the soil type, size and shape of the grains, compaction of soil backfill and deformation velocity.

For sandy soils μ can be calculated as

$$\mu = \tan \delta$$

where δ is the angle of interface friction between soil and pipe.

For sandy soils and PE casing δ may be taken as approximately equal to 2/3 φ, with a maximum value of δ approximately 20-22°.

For sandy soils, which are not settlement areas, typical design values for μ used for fatigue analysis and design of expansion provisions can be taken from Table B 1.

Table B.1 - Friction coefficients for sandy soils

Type of movement	Friction coefficient, μ, see note 3
Slow movement or movements in consideration of creep or hysterese (long term effects), see note 1.	0,2
Normal movement, see note 2.	0,3 – 0,4
Fast movements with short term actions, see note 2.	0,6

NOTE 1 For large diameter pipes in well-graded sand there is a risk for the so-called tunnel-effect when cooling down. The tunnel-effect can give expansions equivalent to $\mu = 0 – 0,2$. The low values should be used e.g. when designing expansion facilities.

NOTE 2 For low cycle fatigue analysis an average value should be used. In most cases $\mu = 0,4$ is considered appropriate.

NOTE 3 Specific local soil condition should be taken into account.

B.3.3 Coefficient of horizontal soil reaction (lateral)

The coefficient of horizontal soil reaction or horizontal bedding constant is defined as the ratio between horizontal soil pressure and horizontal movement of the pipe system.

$$k_h = \frac{p}{v} \left(\frac{\text{Force}}{\text{Length}^3}\right)$$

where:

- p is the horizontal soil reaction
- v is the relative horizontal movement between pipe and soil.

The value $k = k_h \cdot D_c$ (Force/Length^2) is defined as the line bedding constant.

For buried pipes without expansion cushions a fair relationship between horizontal pipe movement and corresponding soil restraint is given by

$$\frac{p}{p_u} = \frac{\frac{v}{v_u}}{0,15 + 0,85\frac{v}{v_u}}$$

where:

- p_u is the maximum soil pressure mobilised by deformation v_u .
- p is the soil pressure, $p < p_u$ and $v < v_u$ corresponding to the deformation v.

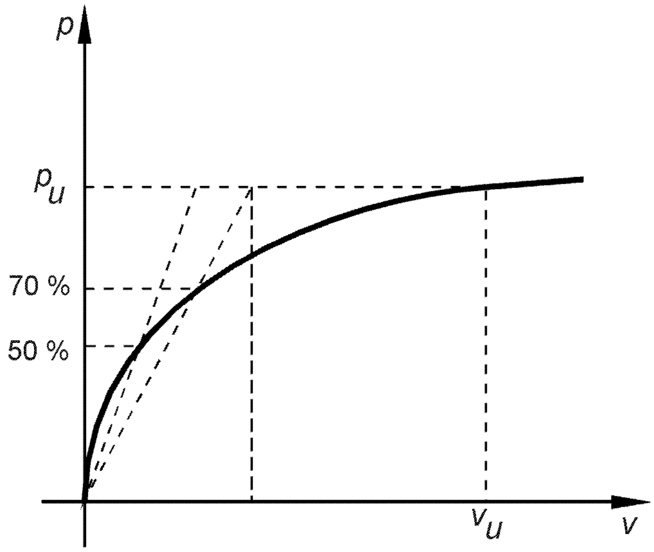


Figure B.4 - Relation between horizontal pipe displacement and soil restraint

The horizontal bedding constant, which is the secant modulus of the action-displacement diagram, can be deducted from the expressions above

$$k_h = \frac{p}{v} = \frac{p_u}{0{,}15 \cdot v_u + 0{,}85 \cdot v}$$

The *p* - *v* diagrams show elastic soil behaviour at smaller displacements represented by the bedding value and plastic soil behaviour at large displacements represented by the ultimate horizontal bearing capacity.

For modelling a bi-linear action-displacement diagram can be used where the bedding constant is chosen as 70% of p_u divided by the corresponding displacement, see Figure B.4.

For small displacements the k_h value referring to 50 % p_u can be used.

The ultimate horizontal soil resistance p_u can be assessed using the equivalent action capacity formula for side support (in cohesion-less soils)

$$p_u = \gamma \cdot Z \cdot K_q$$

where K_q is the soil pressure coefficient, see Figure B.5.

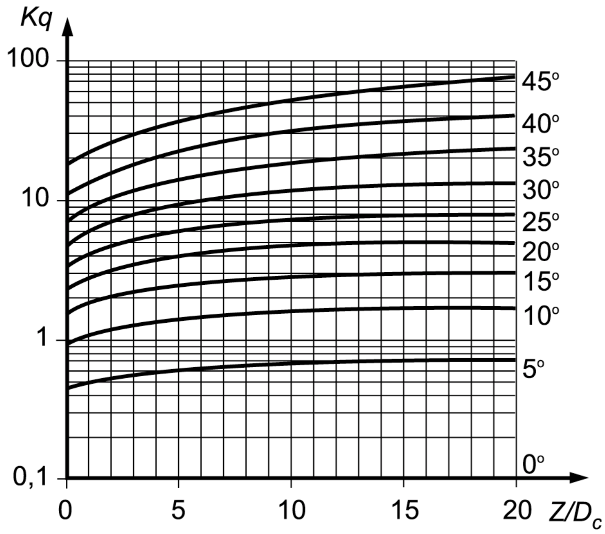


Figure B.5 - Soil pressure coefficient K_q for sandy soils

The ultimate horizontal displacement v_u is not defined precisely. The results of a number of tests with small diameter pipes are summarised in Table B.2.

Table B.2 - Ultimate horizontal displacement v_u

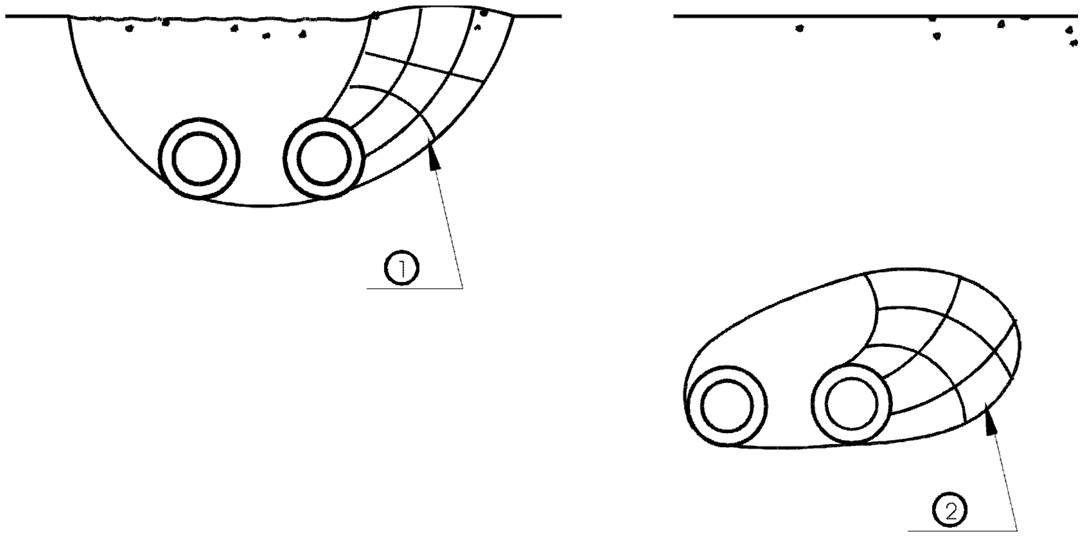
v_u/Z %		
Casing diameter D_c	Loose sand	Dense sand
75 mm, note 1	4,5	2,7
120 mm	3	2
≥ 300 mm	2	1,5

NOTE 1 Values obtained by interpolation.

Alternatively values derived from calculations or tests on anchor plates can be used.

B.3.3.1 Influence of large depths or stiff street cover

The failure mechanism at the plastic stage which strongly influences the ultimate value depends on the depth of burial. At shallow or intermediate depths the failure zone will be extended to the surface with a passive front wedge and an active wedge at the backside of the pipe. At burial depths greater than approximately 6 -10 · D_c. The plastic zone will develop as a limited flow zone in front of the pipe. The dimensions of this flow zone are dependent on the degree of soil compaction, see Figure B.6.



Key

1 Failure surface

2 Zone of flow of the soil

Figure B.6 - Failure mechanism of soil at horizontal pipe displacement

For pipes laid at shallow depths under a stiff street surface, e.g. concrete, the failure mechanism with the passive front wedge is prevented and a failure mechanism with a limited flow zone can occur. This leads to a much higher horizontal soil reaction than normally encountered at these depths.

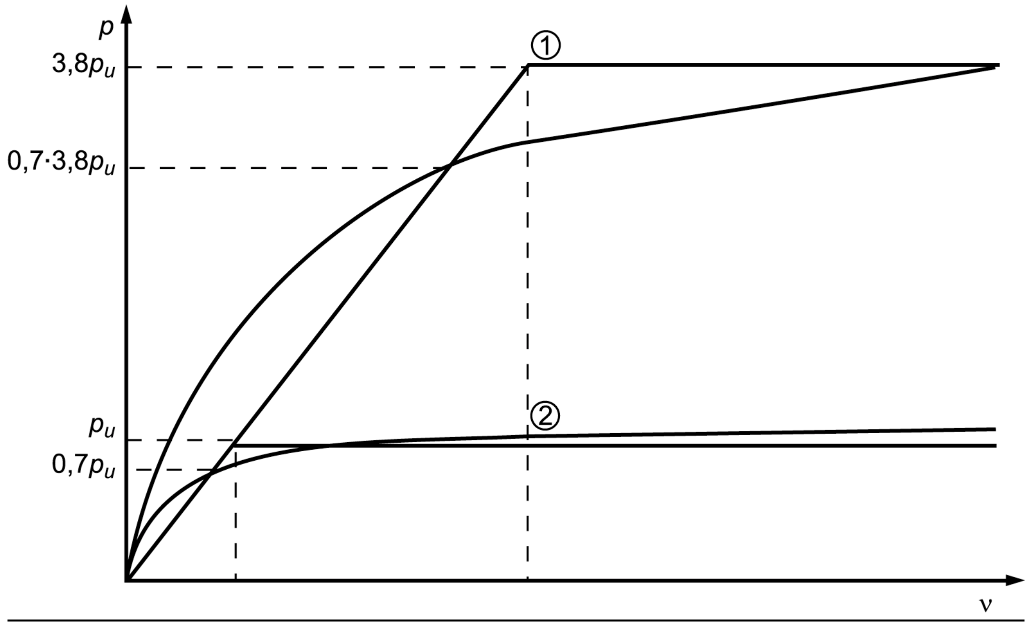
Actual stiffness of the cover as well as the pipe diameter influence on the result. For very stiff street cover (e.g. concrete slaps or pavement for heavy traffic) FEM analysis indicate that a relation between pipe displacement and soil restraint (see Figure B.4) for dense sand and a stiff road cover 0,4 m thick can be established as follows:

For $H \geq 1$ m v_u and p_u are multiplied by 3,8.

For $H < 1$ m the values for $H = 1$ m can be used.

Stiff street cover is e.g. concrete slaps and asphalted roads for heavy traffic. Higher horizontal soil reactions can also result from frozen soil around the pipes, to be taken into account with e.g. soils containing clay in northern climate.

For light street cover a factor < 3,8 can be chosen.



Key

1 With stiff street cover

2 Without stiff street cover

Figure B.7 - Soil reaction for stiff street cover

B.3.4 Combined stiffness of PUR foam, expansion cushions and soil

In expansion zones the combined stiffness of steel pipe, PUR foam, PE casing, expansion cushions and surrounding soil should be calculated to a combined value for the line bedding constant.

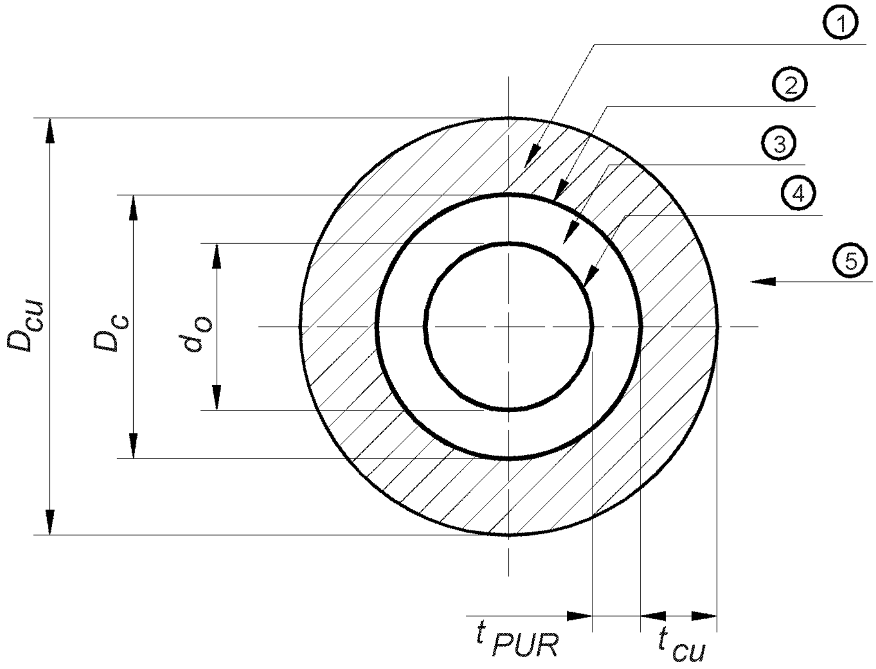
The combined line bedding constant can be derived from the bedding constants of the different components. However, in the following only PUR, expansion cushions and soil are considered, deformations from steel pipe and PE casing are left out due to their small size.

The total horizontal deformation is equal to the sum of the deformation of PUR foam (v_1), expansion cushion (v_2) and surrounding soil (v_3). This means that normally 3 serial springs have to be combined.

For practical calculations the stiffness of the PE casing can be deleted, as it has little influence on the result. The stiffness of the steel pipe can be taken into account only for large diameter pipes,

e.g. $d_o \geq 610$ mm.

Calculation of the bedding constant for the expansion cushions should take account for the non linear load- deformation curve of the cushions.



Key

1 Cushion

2 PE

3 PUR

4 Steel

5 Soil

Figure B.8 - Symbols for bedding constants

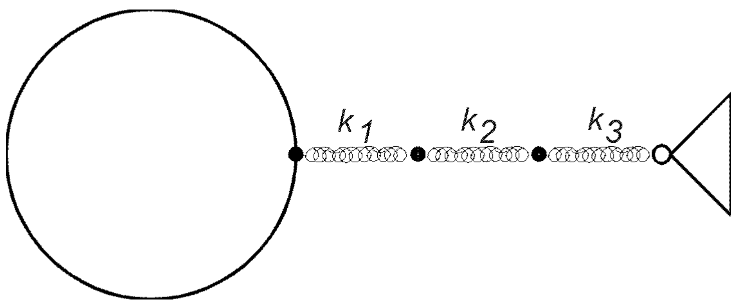


Figure B.9 - Combined soil spring constant

1) PUR foam:

$$k_{\mathrm{h},1} = \frac{E_{PUR}}{t_{PUR}}, \; k_1 = k_{\mathrm{h},1} \cdot d_{\mathrm{o}}$$

2) Expansion cushion:

The plate bedding constant for expansion cushions should be taken from the load-displacement curve based on the actual deformation, see 6.5.

$$k_{h,2} = \frac{E_{cu}}{t_{cu}},\ k_2 = k_{h,2} \cdot D_c$$

3) Surrounding soil:

$$k_{h,3} = \frac{0{,}7 \cdot p_u}{v(70\%)},\ k_3 = k_{h,3} \cdot D_{cu}$$ see B.3.3 and Figure B.4

where:

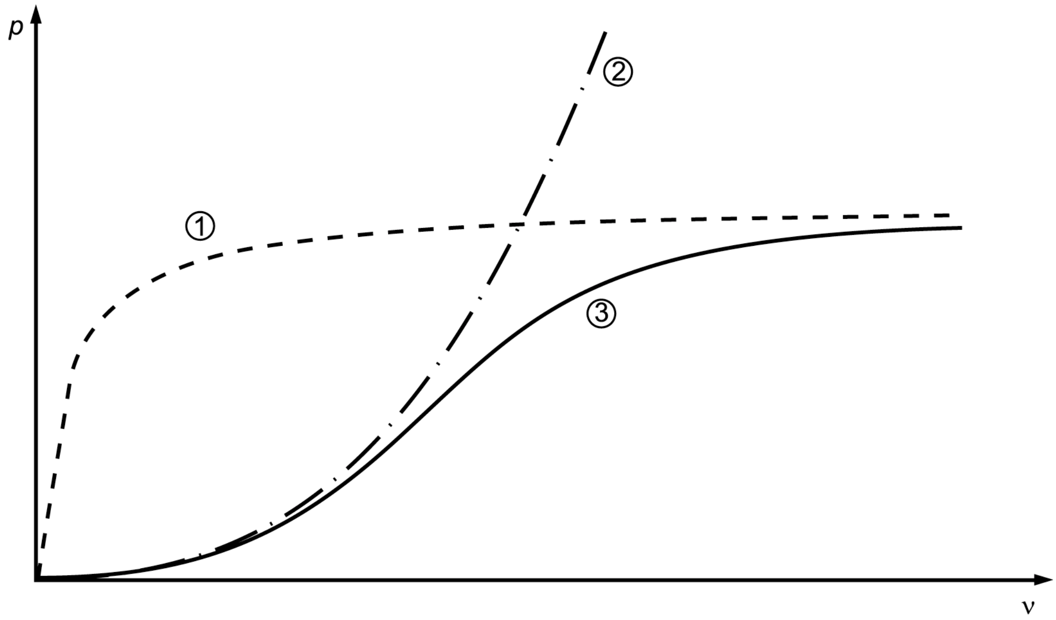
E_{cu} is the elasticity modulus of the cushions, see 6.5

t_{cu} is the equivalent thickness of the cushions

D_{cu} is the equivalent outside diameter of the cushions

The combined load-displacement curve can be calculated from

$$\frac{1}{k_h} = \sum \frac{1}{k_{h,i}}$$



Key

1 Soil

2 Cushion

3 Resulting curve

Figure B.10 - Combined load-displacement curve for foam cushion and soil

B.4 Characteristic values for soil loads and soil parameters

B.4.1 General

Geotechnical parameters for axial and transverse (lateral) stability and deformational analysis should be selected in accordance with good engineering practice taking due account of the stochastic variation of soil properties.

When the limits of variation of the soil properties are well known (i.e. granular sandy soils), use can be made of standard values and methods, as presented in B.3.

In other cases, especially when large variations in soil properties are to be expected, or when the pipeline system is installed in soft soils (containing clay and peat) and settlement areas, a local soil mechanics study can be required, according to B.4.2.

Excavation and backfill procedures should be performed and safeguarded such that the values for soil parameters, as used in the design calculations, are sufficiently guaranteed.

B.4.2 Soil mechanics study

In case a local soil mechanics study is required to define reliable values for pipe-soil interaction allowance should be made for various uncertainty sources

- Field examinations are carried out at a limited number of points along the pipeline axis and the soil properties in between these points can deviate.
- Difference in soil sampling procedures.
- Laboratory work deriving the parameters for pipe-soil interaction from the results of borings, cone penetration tests and soil samples, making use of theoretical models.

When mean values (having a probability of 50% to be exceeded) are presented, these should be multiplied or divided by contingency factors (load variation factors) to arrive at the characteristic upper or lower values required for pipeline analysis (having a probability of 5% to be exceeded).

The results of the soil mechanics study should therefore clearly be presented as ultimate values or as mean values.

The soil mechanics report shall further clearly state whether and which contingency factors have been taken into account.

Contingency factors for soil parameters, referred to mean value are presented in Table B.3. [ref EN 1594]

Table B.3 - Contingency factors for soil parameters referred to mean value

Parameter	Contingency factor
Neutral vertical soil load	1,1
Passive vertical soil load	1,1
Modulus of sub-grade reaction -for sand and clay -for peat	 1,3 1,4
Neutral horizontal soil load (contact angle =120^{o}) and ultimate horizontal soil resistance (contact angle180^{o}) -for sand -for clay -for peat	 1,2 1,4 1,5
Soil friction	1,4

B.5 Specific requirements for stability

B.5.1 General

In a state with large axial compressive forces in the pipes there can be a risk of buckling due to column effect (global instability). Therefore, the depth of burial shall be sufficient to allow the upper backfill to provide stability.

B.5.2 Vertical stability

Vertical stability should be examined in the case of

- little soil cover,
- high groundwater level,
- excavations over the pipes.

The remaining soil action shall be sufficient to withstand a vertical upward reaction equal to 2*Q* for pipe pairs and equal to *Q* for single pipes.

For an "infinitely" long, partly straight pipe section with equally distributed vertical load Q per unit length of pipe (from backfill and selfweight of pipe) buckling can be avoided if

$$Q \geq \frac{\gamma_s \cdot N^2}{E \cdot I} f_o$$

where:

I is the moment of inertia of one single pipe

N is the axial compressive force in the single pipe

$f_o \geq \frac{\pi}{200}\sqrt{\frac{EI}{|N|}}$, minimum 10 mm is the initial deflection

γ_s is a safety factor, $\gamma_s = 1,1$

For pipe sections entirely locked by friction

$$N = -\left\{A_s \cdot \left(E \cdot \alpha \cdot \Delta T - \nu \cdot \sigma_p\right) + p \cdot A_p\right\}$$

where:

A_s is the cross-sectional area of the steel pipe

α is the coefficient of thermal expansion of the steel

ΔT is the temperature increase from equilibrium temperature (where $N = 0$) to maximum temperature

ν is Poisson's ration (ν = 0,3 for steel)

σ_p is the hoop stress from internal pressure

p is the internal pressure (maximum operating pressure)

A_p is the area the pressure is acting on

Q can be calculated from $Q = G_W + G + 2 \cdot S_F$

Where:

G_W is the effective weight of soil stratum over the pipe per metre of pipe length

G is the effective selfweight of the preinsulated pipe per metre of pipe length

S_F is the shear force, which can result from the soil pressure at rest shown in the vertical cut in Figure B.11.

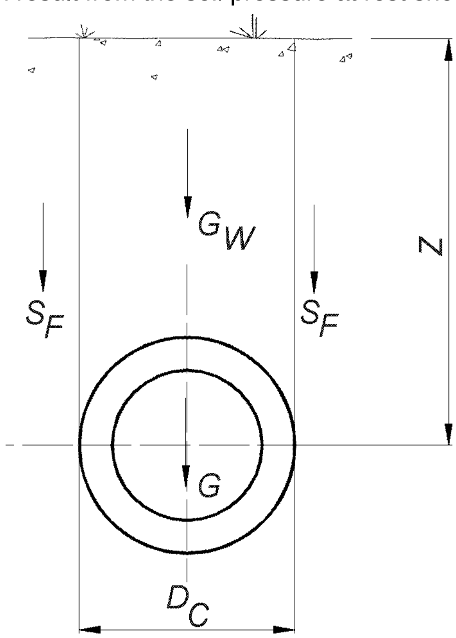


Figure B.11 - Stabilising vertical soil pressure

For ground-water table below the pipes

$$G_{\mathrm{w}} = \left(Z \cdot D_{\mathrm{c}} - \frac{\pi}{2}\left(\frac{D_{\mathrm{c}}}{2}\right)^{2} \right) \cdot \gamma \quad \text{and} \quad S_{\mathrm{F}} = \frac{1}{2} \cdot \gamma \cdot Z^{2} \cdot K_{\mathrm{o}} \cdot \tan \varphi$$

If the groundwater table is above the bottom of the pipe the effective density of the soil and the buoyancy of the pipe shall be taken into account.

Normal forces reduced due to resulting buckling are not taken into account in these calculations.

B.5.3 Horizontal stability

Securing sufficient side support is of particular importance when using curved pipes, small angular deviations or in the case of parallel excavation.

Parallel excavations at the side of the district heating pipes demand that the "local" stability of the slope is in order considering an outwards horizontal force towards the slope at the size *P* for single pipes and 2 *P* for pipe pairs.

Moreover, the overall stability of the slope shall be in order, as no stabilising effect from the pipes may be included in the calculations.

B.6 Specific requirements for parallel excavations

B.6.1 General

In case of parallel excavations above and /or beside buried district heating pipes, during the operating phase adequate provisions should be taken to ensure

– that the pipes are horizontal and vertical stable, according to B.5,in order to prevent flexural buckling,

– that the increased movements of the pipe system at the expansion zones caused by reduced pipe to soil friction are within allowable limits with regard to stresses and displacements.

B.6.2 Reduced friction

In situations with length-wise excavations, directly above the pipes, the friction force is calculated, corresponding to the reduced depth of burial.

Reduction of friction force as a consequence of excavating at one side of the district heating pipes can be assumed to be an approximate maximum of 35%. The reduction can be completely ignored if the distance between excavation side and district heating pipe exceeds 2 times the excavation depth.

B.7 Requirements for soft soils and settlement areas

B.7.1 General

When a district heating pipeline is laid in soft soils, and sand is used for backfill, the bedding constants for the sand should not be used in the calculations. The actual values will be lower and should be determined taking into account the lower stiffness of the surrounding soil.

Similarly there is no reason to make special effort to reach a high degree of compaction of the sand backfill. Because of the deformation of the softer soils around the sand backfill, the effective soil to pipe pressure (and thus the friction value) will show relaxation.

B.7.2 Differential settlements

Special attention should be paid to transition zones between pipes in a buried trench and pipes on fixed vertical support such as

- bored or jacked crossings under roads, etc. especially when an additional casing pipe is used,
- wall penetrations at house connections.

When sand backfill is applied in peat or soft clay soil settlement prediction should be based on a local soil mechanics study. The results should be clearly presented as ultimate values.

Annex C
(informative)

Global- and cross sectional analysis

C.1 General

Annex C has status as application rule.

Annex C describes a method for verifying the required resistance of a pipe system to force- and displacement-controlled actions.

The method and assessment specified in this standard presupposes that

- ductile materials are used for the system
- a bi-linear, elasto-plastic material model is used for the soil
- a pseudo-elastic material model is used for the steel assuming purely linear elastic material behaviour, also for stresses exceeding the yield strength.

Alternatively a plastic material model can be used. The calculation in this case is based on an elastic-plastic stress-strain relation of the material. In such case the assessment of stresses and strains are different from the specifications in this standard.

When calculating internal forces, stresses and deformations the rigidity of individual components and the stress concentrations occurring for different action combinations shall be taken into account.

C.2 Symbols

A	Cross section of service pipe
c_y, c_z	Spring factors for tees
d_o/d_i	Outside/inside diameter of service pipe
$d_{min.}/d_{max.}$	Minimum/maximum mean diameter of service pipe
$d_{o\ min.}/d_{o\ max.}$	Outside diameter of smallest/largest pipe
d_m	Mean diameter of service pipe
$d_{bo}/d_{bi}/d_{bm}$	Outside/inside/mean diameter of branch in tee
$d_{ro}/d_{ri}/d_{rm}$	Outside/inside/mean diameter of run pipe in tee
E	Modulus of elasticity
I	Moment of inertia of pipe cross section
i_{a1}	Stress concentration factor for axial stresses from normal force
i_{a2}	Stress concentration factor for axial stresses from bending moments
i_{a3}	Stress concentration factor for shear stresses from torsion
i_{a4}	Stress concentration factor for shear stresses from shear forces
i_{a5}	Stress concentration factor for tangential stresses from bending moments
i_{ap}	Stress concentration factor for hoop stresses from pressure
k_b	Flexibility factor for bending
k, k_1, k_2	Valuation constants for the calculation of stress concentration factors
l_b, l_r	Extent of increased wall thickness for branch and run pipe
M_z	Bending moment
M_x	Torsional moment
N_x	Axial force, including pressure contribution
NFP	Natural fixpoint
p	Internal pressure

r_b,r_m	Stress reduction factors for branch and run pipe
r,r_1,r_x	Radii of curvature
R	Bend radius
S	Stress range
t_n	Nominal wall thickness of service pipe
t	Nominal wall thickness of pipe less possible allowance for tolerance and corrosion
$t_{b,}$ t_r	Nominal wall thickness of branch and run pipe less possible allowance for tolerance and corrosion
V_y, V_z	Shear force
W	Section modulus of pipe cross section
α	Thermal expansion coefficient
α, Θ	Angle
ν	Poisson's ratio
σ_a, σ_x	Axial stress
σ_m	Membrane stress
σ_{res}	Resulting stress
$\sigma_{j,m}$	Reference stress for membrane stresses
$\sigma_{j,res}$	Reference stresses for resulting stresses
σ_p	Hoop stress
σ_t	Tangential stress
τ	Shear stress
$\Delta\sigma_o$	Ovalisation stress from soil pressure, traffic etc.

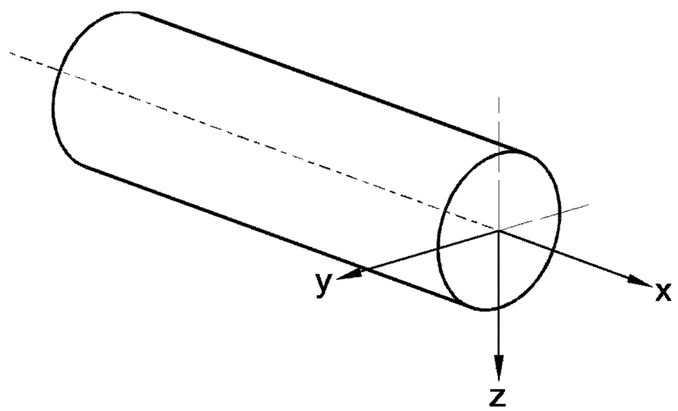


Figure C.1 - Local co-ordinate system

Stresses and axial forces are positive for tension.

C.3 Survey of limit states for steel

See chapter 7 for validity and limitations

Limit state A1 One severe action		**Limit state A2** Stepwise plastic deformation	**Limit state B1** Low cycle fatigue	**Limit state B2** High cycle fatigue	**Limit state C1** Local buckling	**Limit state C2** Global instability
Force-controlled action		Force- and deformation-controlled actions	Force- and deformation-controlled actions	Force- and deformation-controlled actions	Force- and deformation-controlled actions	Force and deformation controlled actions
Membrane stresses σ_m	Resulting stresses σ_{res}	Maximum strain ε_{max}	Resulting stress range spectrum	Resulting stress range spectrum		
Mean stress in component wall	Maximum stress in component wall		Maximum stress range *S*			
				See Eurocode 3		See annex B

A1 (membrane stresses):

$$\left.\begin{matrix}\sigma_m \\ \sigma_{j,m}\end{matrix}\right\} \le \sigma_d = \frac{R_e(T)}{\gamma_m}$$

A1 (resulting stresses):

$$\sigma_{res} \le \begin{cases} 1{,}5 \cdot \sigma_d & \text{for } \sigma_m \le 0{,}67 \cdot \sigma_d \\ 2{,}5 \quad \sigma_d - 1{,}5 \cdot \sigma_m & \text{for } \sigma_m > 0{,}67 \cdot \sigma_d \end{cases}$$

$$\sigma_{j,res} \le \begin{cases} 1{,}5 \cdot \sigma_d & \text{for } \sigma_{j,m} \le 0{,}67 \cdot \sigma_d \\ 2{,}5 \quad \sigma_d - 1{,}5 \cdot \sigma_{j,m} & \text{for } \sigma_{j,m} > 0{,}67 \cdot \sigma_d \end{cases}$$

A2:

$$\varepsilon_{max} \quad \alpha \; \Delta T \le \frac{R_e(T)}{E}\left(\sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(T)}\right)^2} + \sqrt{0.7^2 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(T)}\right)^2}\right)$$

B1:

$$\sum \frac{n_i}{N_i} \le \frac{1}{\gamma_{fat}}$$

C1:

$$\varepsilon \le \frac{1}{2}\left(0.25\frac{t}{r_m} - 0.0025\right)$$

For uniform ε

$$\text{for } r_m/t \le 28{,}7 \qquad \Delta\varepsilon \le 0{,}16\,\%$$

$$\text{for } r_m/t > 28{,}7 \qquad \Delta\varepsilon \le \left(4{,}58\frac{t}{r_m} + 0{,}003\right)\%$$

For pipes with imperfections

C2:

$$Q \ge \frac{\gamma_s \cdot N^2}{E \cdot I} f_0$$

Below the flow for fatigue analysis is exemplified being the most complex. Similar flow charts should be followed for other limit states.

Table C.1 - Methodology for fatigue analysis

Tasks	Comments	Clause
Identify locations to be assessed	Bends, tees, reducers, etc.	C.4
Define actions	Pressure and temperature variations.	C.5
Perform global analysis	Calculate cross-sectional forces, moments and deformations.	C.6
At each location, establish stress history and design stress range spectrum	Stresses are derived from structural principal stresses, calculated using elastic theory assuming linear elastic conditions. This applies for both elastic and elasto-plastic conditions. Hot-spot stresses are calculated by using analytical methods, by formula or by FEM. Fatigue actions are normally transformed into full action cycles. In this case the stress range spectrum is given directly Calculation of stress range. The reference stresses are calculated using von Mises or Tresca. Otherwise the stress range spectrum is calculated using for example the rain-flow method.	C.7
Identify fatigue strength data	A SN-curve applying to the particular construction detail is chosen. $S = k \cdot N^{-1/m}$; $N = (\frac{k}{S})^m$	C.8.1
Extract design fatigue lives from SN-curves and perform assessment	$\sum \frac{n_i}{N_i} \leq \frac{1}{\gamma_{fat}}$	C.8.2
Further action if location fails assessment	E.g. make system more flexible, increase wall thickness of tees, etc.	C.9

C.4 Locations to be assessed

C.4.1 Components to be considered

Components to be considered for analysis are

1. straight sections,
2. welds,
3. long bends (elastically laid or pre-manufactured),
4. small angular deviations and single mitred bends,
5. bends,
6. branch connections (tees),
7. reducers,
8. underground expansion joints. (one time compensators as well as permanent expansion joints),
9. valves and other accessories,
10. dished ends and flanged connections
11. interface with other systems.

Table C.2 - Limit states, see 7.4.2

Limit state	Component
A1: One severe action	All
A2: Stepwise plastic deformation	1 to 4
B1: Low cycle fatigue	2 to 8
B2: High cycle fatigue	All (when relevant)
C1: Local buckling or folding	1 to 4 and 7
C2: Flexural buckling (global instability)	1 and 3
C2: Loss of equilibrium	Whole system and parts thereof
D: Serviceability	All

In principle all the above mentioned combination should be examined. However, for normal buried systems the following combinations are decisive:

Table C.3 - Limit states

Component	Limit state
Straight pipes Curved pipes	Limit state C1: Local buckling or folding
Straight and curved pipes in settlement areas and/or with high pressures	Limit state A2: Stepwise plastic deformation
Bends Tees Small angular deviations Single and multiple mitre bends Welds with misalignment	Limit state B1: Low cycle fatigue
For pipes with limited soil cover High ground water table Parallel excavation	Limit state C2: Flexural buckling

Forces and moments near valves, reducers and compensators shall be analysed. The values obtained shall be compared with the design values of the relevant product standard or manufacturer's specifications.

Special attention should be paid to misalignment of welds due to variations in pipe diameter and wall thickness and poor fitting.

C.4.1.1 Small angular deviations

When using cold installation techniques, mitre bends and small angular deviations shall not be used.

In other cases multiple mitred bends should be avoided. Pre-manufactured smooth bends should be used in expansion zones.

In fixed pipe sections, small angular deviations (to follow the pipeline route) can be used as follows :

Table C.4 -Small angular deviations

Max. temperature difference	Max. angular deviation. See note 1
90 K	2^o
100 K	1^o
110 K	$0,5^o$
>110 K	0^o
NOTE 1 Maximum angular deviation excluding installation tolerance, which should be limited to $\pm$ $0,25^o$.	

C.4.2 Areas to be considered

Areas requiring specific analyses are

- areas of possible future parallel excavations near the district heating pipes,
- areas of specific requirements due to nearby building foundations in urban areas,
- areas subject to soil settlement or mining subsidence.

The analysis should take due account of the method of thermal expansion compensation.

The analysis shall include both the required constructive precautions during the installation phase, e.g. less soil cover, as well as the technical requirements in the operating phase, e.g. excavation requirements or buoyancy requirements.

Further due attention should be paid to:

- Interfaces with plant areas, substations or house installations, in particular
  - underground bends at the end of long, straight pipeline sections (thermal expansion and pressure expansion),
  - points of transition from an excavated trench to a rigid supported structure, whether above or below ground (for example pumping stations, fixpoints, house connections, pipe tunnels, etc.). Both the buried and aboveground sections should be incorporated into one single calculation model, taking due account of any settlement differences,
  - interfaces with installations, paying special attention to frequent changes in wall thickness in these situations,
  - pipe supports in transition zones,
  - intersection points to other connected piping and facilities (e.g. pump and heat exchanger units, heating centres and wall penetrations).
- Crossings
  - road, railway and waterway crossings,
  - other utility pipes and cables,
  - water barriers and dykes.
- Change in installation method
  - these can in weak soils give rise to differential settlement and/or subsidence (for example, at the transition between a pipeline section laid in a trench and a jacked or bored section.
  - special attention should also be paid to settlement differences between the pipe system and casing pipes, when applied (e.g. at crossings).
- Abrupt changes in soil conditions.

C.5 Actions

C.5.1 General

The number and size of temperature and pressure cycles throughout the service life of the system should be evaluated.

Safety against fatigue failure shall be verified in consideration of impacts anticipated throughout the service life of the system.

C.5.2 Action cycles

If the temperature history is known or can be presupposed, the history can be converted to equivalent full temperature cycles, N_o, by using Palmgren-Miner's formula, see 7.4.2.3. The same SN-curve as used in the subsequent fatigue analysis shall be used when calculating N_o.

For systems where the static system does not change due to variations in temperature, variation in stress will be proportional to the variation in temperature and the number of equivalent full temperature cycles can be calculated from

$$N_o = \frac{\sum n_i \cdot (\Delta T_i)^m}{(\Delta T_{ref})^m}$$

where

n_i	is the number of cycles with temperature range ΔT_i
ΔT_{ref}	is the reference temperature at which N_o is calculated
m	is the constant in the SN-curve, see C.8.1.

It should be noted that N_o not only depends on the temperature history but also on the factor m.

If the static system changes (e.g. if neutral fixpoints move) the relation will not be proportional. In these cases the stress history should be calculated first.

Normally the variation of temperature will be the predominant action. In a district heating system with normal operating conditions the variation will consist of a few full action cycles (start-up and shut-down cycles) and a large number of smaller cycles due to the daily temperature variations.

Special conditions like energy production from incineration plants, cold plugs, night-set-back at consumers, etc. can give many and/or large temperature variations.

Normally the largest number of full equivalent temperature cycles will occur in the supply pipe for main pipelines and in the return pipe for service connections.

In district heating systems with normal operation and a stable flow temperature, the following number of full action cycles, corresponding to a period of 30 years, may be presupposed for $m = 4$ and $\Delta T_{ref} = 110$ °C, see 7.4.2.3, limit state B:

-	Major pipelines	100-250 cycles
-	Main pipelines	250-500 cycles
-	Service connections	1000-2500 cycles

For major pipeline the maximum value can be reached e.g. close to incineration plants. For service connections maximum values are typically reached in case of e.g. night-set-back at the consumer.

The number of full action cycles shall not be chosen lower than the smallest values above according to 7.4.2.3, Table 4.

C.6 Global analysis

C.6.1 General

The following procedure can be used:

1. Calculation of bending moments, forces and deformations of the steel pipe as the action bearing structure.
2. Calculation of impacts on PUR foam and the PE casing pipe, which are assumed to follow the deformations of the steel pipe.

The calculation model used, shall take due account of the interaction between pipe and soil generally caused by temperature expansion of the pipe or by soil settlements.

The interaction of pipeline and soil can be characterised by using a soil spring model. In such a model the non-linear action-displacement behaviour of the soil in axial and horizontal directions can be outlined by a series of (discrete) multi-linear soil springs, see annex B.

These springs represent the amount of action or restraint exerted on the pipeline system for a given displacement. Account shall be taken of the variation in soil properties by considering a reasonable range of properties in the analysis.

Calculation of pipe-soil interaction can be done by means of the theory of beams on elastic foundation, by "beam-element" programmes or by application of finite element methods (FEM).

The axial reaction (soil friction) can be applied as a uniform axial action against the expansion of the pipe. The horizontal soil reaction is normally characterised as elastic or elasto-plastic soil springs.

When using "beam-element" programmes the pipeline is reduced to a system of beam elements for the pipeline and spring elements for the supports. In the case of buried pipelines, the surrounding soil is also reduced to a system of springs.

Near areas where foam cushions are applied or large soil deformations occur the use of linear spring characteristics can give unreliable results, and elasto-plastic soil springs should be used, see annex B.

C.6.2 Flexibility

C.6.2.1 General

The properties of components in respect of rigidity and stress concentration are assessed on the basis of the properties of an equivalent straight pipe. The rigidity of an individual component is obtained by dividing the rigidity of the equivalent straight pipe (expressed by *EI*) with the flexibility factor k_b of the component.

To be on the safe side the modules of elasticity of the materials should be set at the values they have at the lowest temperature occurring in the system.

Note that the nominal wall thickness can normally be used for calculating the flexibility, but for components of special significance to the rigidity of a pipe system, e.g. pipe bends, it can be necessary to consider the variation in k_b due to excess measures of the thickness.

C.6.2.2 Bends

For short radius 90° bends ($R = 1{,}5 \cdot d_o$) a flexibility factor $k_b = \frac{1{,}24 \cdot d_m^2}{4 \cdot t_n \cdot R} \geq 1$ can be used for in-plane and out-of-plane bending. The stiffening effect of adjacent straight pipes is included in this factor. For bend angles between 90° and 0 the flexibility factor can be reduced linearly.

For larger radii bends the stiffening effect is reduced. In this case k_b can be valued

$$\frac{1{,}24 \cdot d_m^2}{4 \cdot t_n \cdot R} \le k_b \le \frac{1{,}65 \cdot d_m^2}{4 \cdot t_n \cdot R} \text{ for } 1{,}5\ d_o \le R \le 2{,}5\ d_o$$

Intervening values are obtained by interpolation.

$$k_b = \frac{1{,}65 \cdot d_m^2}{4 \cdot t_n \cdot R} \text{ for } R > 2{,}5\ d_o$$

The flexibility factor for normal forces, shear forces and torque equals 1.

For pipe bends, an internal pressure will counteract ovalisation. This is considered by dividing k_b with

$$1 + 6\,\frac{p}{E}\left(\frac{d_m}{2t}\right)^{\frac{7}{3}}\left(\frac{2R}{d_m}\right)^{\frac{1}{3}}$$

The above stated condition is usually only of importance for the dimensioning of pipe guides and similar in connection with pipes in duct structures, buildings, etc.

When the more exact calculation for stresses in bends is used with $p > 0$ see. C.7.4 the effect of over-pressure shall be included when calculating the flexibility factor.

C.6.2.3 Tees

The flexibility factor for tees equals 1.

For $d_{bo}/d_{ro} \le 0{,}8$ the flexibility of the connection between branch pipe and run pipe can be taken into account by applying following spring factor to the branch pipes at the point where the axis of the branch intersects the outside of the run pipe:

For in-plane bending, M_{by}, see Figure C.8.

$$c_y = \frac{E \cdot I_b}{k_y \cdot d_{ro}}$$

$$k_y = 0{,}2 \cdot \left(\frac{d_{ro}}{t_r}\right) \cdot \left(\frac{t_r}{t_b} \cdot \frac{d_{bo}}{d_{ro}}\right)^{0{,}5} \cdot \frac{t_b}{t_r}$$

For out-of-plane bending, M_{bz} , see Figure C 8.

$$c_z = \frac{E \cdot I_b}{k_z \cdot d_{ro}}$$

$$k_z = 0{,}1 \cdot \left(\frac{d_{ro}}{t_r}\right)^{1{,}5} \cdot \left(\frac{t_r}{t_b} \cdot \frac{d_{bo}}{d_{ro}}\right)^{0{,}5} \cdot \frac{t_b}{t_r}$$

where

I_b is the moment of inertia of branch cross section

d_{ro} is the outside diameter of run pipe

d_{bo} is the outside diameter of branch pipe

t_r is the wall thickness of run pipe

t_b is the wall thickness of branch pipe

The spring factor for a branch pipe can be compared to a spring factor for an angular compensator.

C.6.2.4 Other components

For all other components $k_b = 1$.

C.6.3 Boundary conditions

Actions, displacements and restraints shall be considered as a whole for the entire pipeline system, considering both static and dynamic aspects.

This means that even in cases where the analysis considers the pipeline in sections, the requirements of equilibrium, including accommodation of actions imposed by abutting structures, shall be fulfilled satisfactorily in the entire pipeline system.

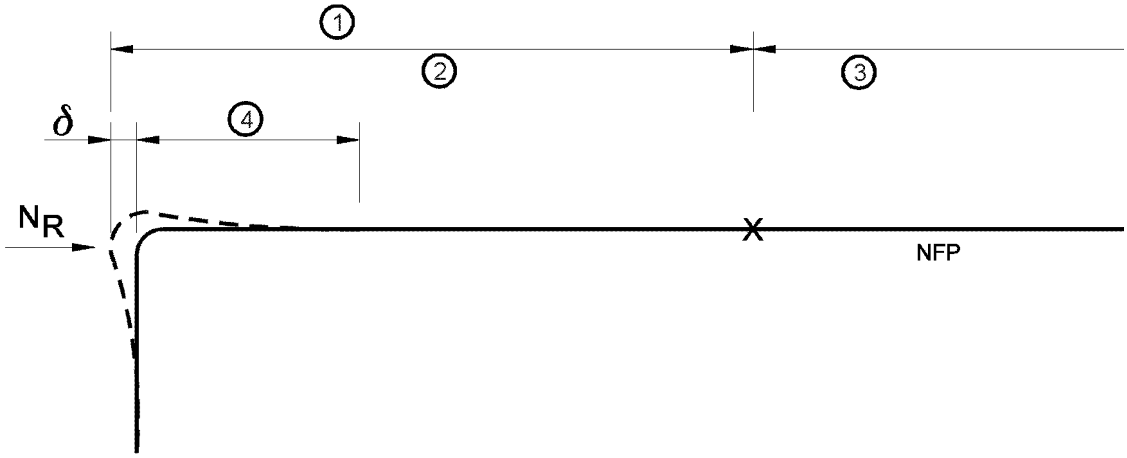
The section of the pipeline under consideration shall also be limited by points, in respect of which the following items shall be ascertained with sufficient accuracy:

- either the displacements (translation and rotations) or
- the forces and moments or
- the relationship between displacements on the one hand and forces and moments on the other.

In bonded systems the friction between protective casing and soil is entirely or partly fixing the pipes.

In sections where pipes are partly fixed, see Figure C.2, it should be ensured that the resulting movements at free pipe ends, bends and branch connections are allowable, as concerns deformations and stresses.

In a partly restrained pipe section the friction length L is the length which is required to provide a sufficient friction force between pipes and soil in order that the pipes do not move. Typically the friction length is the distance from an expansion provision (compensator or expansion loop) to a natural fixpoint (NFP).



Key

1 Friction length, *L*

2 Partly restrained

3 Fully restrained

4 Expansion zone

Figure C.2 - Partly and fully restrained pipe sections

At the other side of the NFP the pipe is fully restrained and does not move. However, the NFP can change position according to the stress history of the pipe and as a result of changes in the soil.

Forces and deformations can be calculated with the formulas below when the following conditions are fulfilled:

- uniform soil cover,
- uniform pipe to soil friction,
- the total length between two expansion zones exceeds twice the friction length, *L*.

For positive ΔT (heating) the deformations and forces are:

At the NFP:

$$\varepsilon = \frac{\sigma_x}{E} = -(\alpha \cdot \Delta T - \frac{\upsilon \cdot \sigma_p}{E}); \; N_x = -A(E \cdot \alpha \cdot \Delta T - \upsilon \cdot \sigma_p)$$

At the expansion:

$$N_x = N_p + N_R = A \cdot \frac{\sigma_p}{2} + N_R$$

The friction length is calculated as the numerical value of

$$L = \frac{A}{F}(E \cdot \alpha \cdot \Delta T + (0{,}5 - \upsilon)\sigma_{p}) + \frac{N_{R}}{F}$$

and the expansion is

$$\delta = \frac{L}{2} \cdot \varepsilon_{max} = \frac{F}{EA} \cdot \frac{L^2}{2}$$

where

- ΔT is the temperature difference related to the installation or pre-stressing temperature. ΔT is negative by cooling.
- F is the friction force per metre of pipe, see annex B.
- A is the sectional area of the steel pipe
- σ_p is the hoop stress from the over-pressure (positive by over-pressure)
- σ_x is the axial stress (positive for tension)
- N_x is the axial force (positive for tension)
- N_p is the axial force from pressure at expansion
- N_R is the axial force from lateral soil reaction at expansion (N_R is normally negative)

For systems with axial compensators, ½ is left out from the last link (½-ν) of the expressions for L and δ.

For axial compensators where the active area is larger than the area of the run pipe ½ can be replaced by

$$\frac{1}{2} \cdot \left(1 - \left(\frac{d_w}{d_i}\right)^2\right)$$

where

- d_w is the average diameter of the bellow
- d_i is the internal diameter of the steel pipe.

L can be calculated through iteration by first calculating the upper limit for L setting $N_R = 0$. A first estimate of N_R can then be calculated with the belonging value of δ. It should taken into account that N_R normally gives a considerable reduction of L and δ (75 - 80%).

For systems as Figure C.3 where fixpoints or other methods ensure that the distance l from the fixed point to an expansion facility is shorter than or equal to the friction length L, or where the distance between two expansion facilities is less than $2L$, the axial stresses in the steel pipe are calculated as

$$\sigma_x = -(\frac{F}{A} l - ½\sigma_p - \frac{N_R}{A})$$

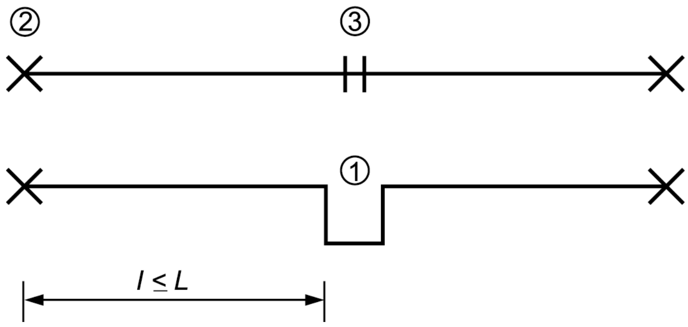
Expansion at the free pipe end from the partly restrained pipe (see Figure C.2) is calculated as

$$\delta = \frac{l}{E}(E \cdot \alpha \cdot \Delta T - \frac{F \cdot l}{2A} + (½ - \upsilon)\sigma_p + \frac{N_R}{A})$$

where

1st link is the movement from the temperature change ΔT.
2nd link is the "fixation" from the friction.
3rd link is the movement from the internal over-pressure.
4th link is the movement from the reaction from lateral soil pressure.

For systems with axial compensators the ½ in the link (½-ν) of the expressions for σ_x and δ is omitted.



Key
1 Expansion loop
2 Fix point
3 Compensator

Figure C.3 - Reduced friction length, *l*

When axial compensators do not have end-stops designed to take high axial forces, it should be ensured that the expansion conditions are well defined, for instance when installing fix points, in order to avoid overloading the compensators.

If expansion from the section partly restrained by friction is absorbed in L, Z or U bends expansion is ensured by means of foam or sand cushions, the resistance in the foam or sand cushions shall be taken into account when calculating the expansion loop.

Compensators and L, Z and U bends should not be mixed between two fix points.

Ageing of foam cushions throughout the service life of the pipeline should be taken into account.

See annex B concerning the transverse horizontal movement of the pipe underground.

C.7 Calculation of stresses

The size of the stress in the component is obtained by multiplying the maximum stress (membrane stress) in the equivalent straight pipe with the stress concentration factor i_a (for the current type of impact) of the component.

The methodology presupposes that hot-spot values for i_a are used in combination with SN-curves from uni-axial tests.

The stress history is established by calculating forces and deformation in an elastic model. Stresses are calculated assuming linear elastic conditions. Hot-spot stresses are calculated by applying i-factors (stress concentration factors according to C.7.3 - C.7.6) or by FEM analysis.

An alternative method is to use i-factors from “the experimental method” See Power Piping, ANSI B31.1. In this case the matching SN-curve shall be used.

C.7.1 Simplified procedure

In project classes A and B design and installation can be performed on basis of documented generalised calculations and instructions, see 7.2.

C.7.2 Cross section analyses, steel

Membrane stresses, σ_m, are mean stresses over the wall thickness, whereas resulting stresses, σ_{res}, are all occurring stresses, i.e. membrane stresses plus stresses varying over the wall thickness.

Membrane stresses are positive by tension and negative by compression.

The radial stresses from internal over-pressure have not been included in the following formulas due to their limited size.

The individual design stress components are determined from the following expressions. The expressions give an upper limit for the stresses. With simplified analysis it can safely presuppose that the maximum stresses occur in the same spot. It is recommended to refer to specialised literature concerning size and location of the actually occurring stresses.

Stresses and internal forces are illustrated in Figure C.4

For the calculation of areas and section modulus the wall thickness less possible allowance for corrosion shall be used. For district heating pipelines the allowance for corrosion can usually be valued at 0.

Area and section modulus are calculated by

$$A = \pi \cdot (d_0 - t) \cdot t$$

$$W = \frac{\pi}{32 \cdot d_0}\left[d_0^4 - (d_0 - 2t)^4\right]$$

For tees the outside diameters d_{ro} and d_{bo} and the thickness t_r and t_b for run pipe and branch, respectively, are inserted.

Table C.5 - Calculation of stresses

Maximum axial stress:	$\Delta\sigma_a = i_{a1}\frac{\Delta N_x}{A} \pm i_{a2}\frac{\sqrt{\Delta M_y^2 + \Delta M_z^2}}{W}$
Maximum shear stress:	$\Delta\tau = i_{a3}\frac{\Delta M_x}{2W} \pm i_{a4}\frac{2 \cdot \sqrt{\Delta V_y^2 + \Delta V_z^2}}{A}$
Maximum tangential stress:	$\Delta\sigma_t = i_{ap}\frac{p \cdot d_i}{2t} \pm i_{a5}\frac{\sqrt{\Delta M_y^2 + \Delta M_z^2}}{W} + \Delta\sigma_o$

p is positive for internal over-pressure.

The first link in the expression for σ_t represents the membrane stress from internal pressure, whereas the second link (ovalisation stress from external moments) is only included in the calculation of resulting stresses.

N_x is the resulting axial force including the contribution from pressure.

When calculating stresses for fatigue analysis, $\Delta\sigma_a$, $\Delta\tau$ and $\Delta\sigma_t$ the values for ΔN, ΔM, ΔV and Δp shall be used in the expressions in Table C.5. All changes of actions shall be considered (cold-warm, warm-cold).

$\Delta\sigma_o$ is the ovalisation stresses from for example soil pressure and traffic.

The effect of soil pressure and traffic actions can normally be ignored for pipe dimensions $d_n \leq 300$ mm.

For $d_n > 300$ mm the ovalising stresses from soil pressure and traffic action will normally not be decisive, but should be checked. Internal pressure will counteract ovalisation and thereby reduce the ovalising stresses. Therefore the ovalising stresses should not be added to the stresses from internal pressure.

Calculation of the stress concentration factors i_{ap} and i_{a1} - i_{a5} for a number of pipe components appears from C.7.3 to C.7.6.

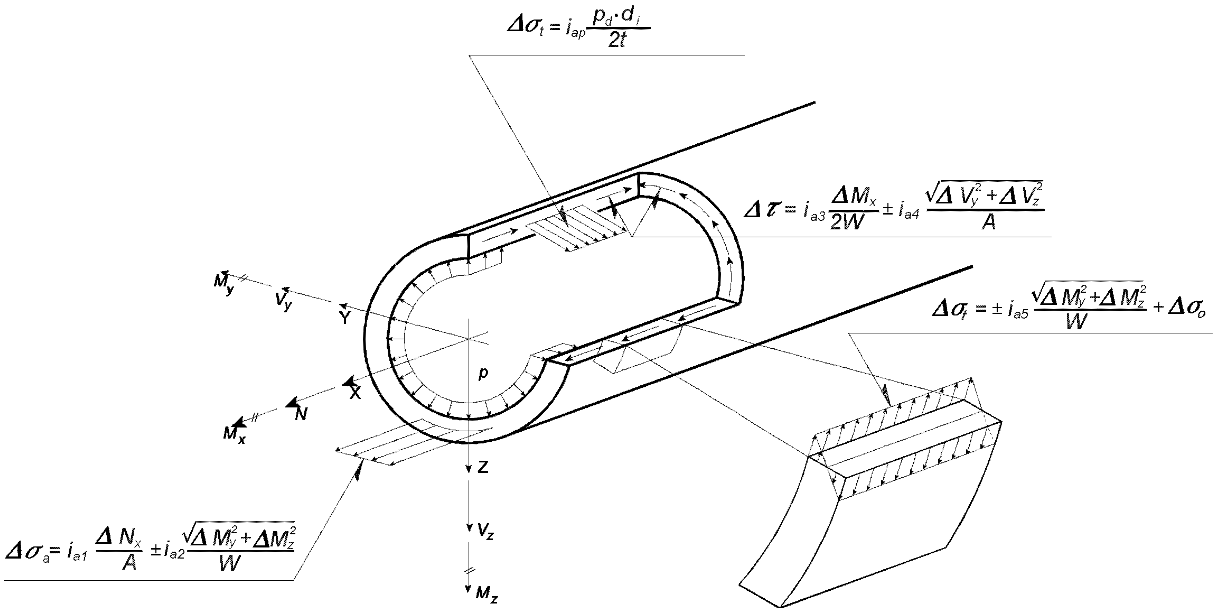


Figure C.4 - Stress components and internal forces

The reference stress is calculated from the above-mentioned stress components (calculated with sign) by Tresca or by von Mises' formula:

$$\sigma_j = \begin{vmatrix} \sigma_1 - \sigma_2 \\ \sigma_2 - \sigma_3 \\ \sigma_3 - \sigma_1 \end{vmatrix}$$

$$\sigma_j = \sqrt{½(\sigma_1 - \sigma_2)^2 + ½(\sigma_1 - \sigma_3)^2 + ½(\sigma_2 - \sigma_3)^2}$$

The above calculation method is approximate, as it presupposes that all peak stresses are referred to the same point and added although they are not necessarily located at the same point of the cross section.

Using the stresses in Table C.5, σ_j can be calculated from the following formula:

$$\sigma_j = \sqrt{\sigma_a^2 + \sigma_t^2 - \sigma_a \cdot \sigma_t + 3\tau^2}$$

C.7.3 Straight pipes

C.7.3.1 Straight pipes

σ_m (membrane stresses) and σ_{res} (resulting stresses):

Table C.6 - Stress intensification factors for straight pipes

	i_{a1} σ_a (ΔN_x)	i_{a2} σ_a (ΔM_y, ΔM_z)	i_{a3} τ (ΔM_x)	i_{ap} p
σ_m and σ_{res}	1	1	1	1

$i_{a4} = i_{a5} = 0$

C.7.3.2 Butt welds

Table C.7 - Stress intensification factors for butt welds, same actual wall thickness, see Figure C.5

	i_{a1} σ_a (ΔN_x)	i_{a2} σ_a (ΔM_y, ΔM_z)	i_{a3} τ (ΔM_x)	i_{ap} p
σ_m	1	1	1	1
σ_{res} note 1	1,3 · k	1,3 · k	1,3 · k	1,3 · k

$i_{a4} = i_{a5} = 0$

$k = 0{,}9 + 2{,}7 \dfrac{d_{max} - d_{min}}{2t_n}$ k is min. 1,4 and max. 1,9

NOTE 1:

Factor 1,3 is for normal weld control (5, 10 and 20% in project classes A, B and C). If weld control is extended to 10, 20 and 100% in project classes A, B and C the factor can be reduced to 1,1

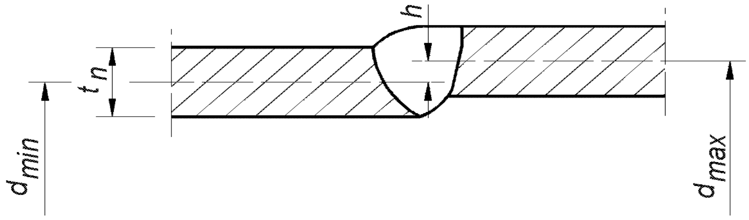


Figure C.5 - Butt weld misalignment

Butt welds at changes in wall thickness without after-welded root pass. The joint fulfils the requirement specified in 8.5.8.

Table C.8 - Stress intensification factors for butt welds, different wall thickness, see Figure C.6

	i_{a1} σ_a (ΔN_x)	i_{a2} σ_a $(\Delta M_y, \Delta M_z)$	i_{a3} τ (ΔM_x)	i_{ap} p
σ_m	1	1	1	1
σ_{res} note 1	$1{,}5 \cdot k$	$1{,}5 \cdot k$	$1{,}5 \cdot k$	$1{,}5 \cdot k$

$i_{a4} = i_{a5} = 0$

$$k = 1{,}3 + 0{,}0036\,\frac{d_0}{t_n} + 3{,}6\,\frac{d_{max} - d_{min}}{2t_n}$$ k is max. 1,9

NOTE 1:

Factor 1,5 is for normal weld control (5, 10 and 20% in project classes A, B and C). If weld control is extended to 10, 20 and 100% in project classes A, B and C the factor can be reduced to 1,3.

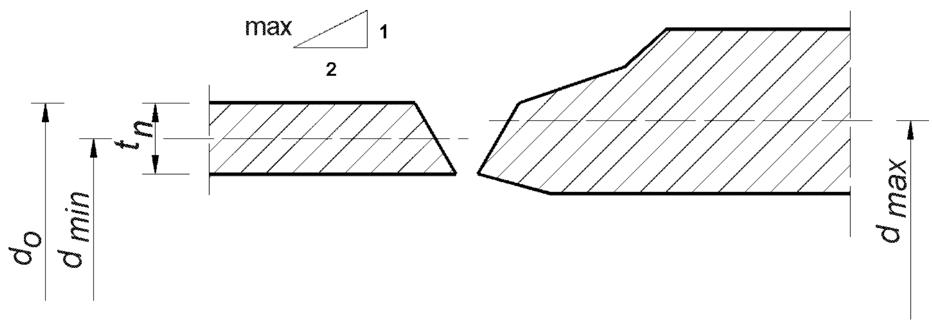


Figure C.6 - Butt weld at change in wall thickness

C.7.4 Bends

The methodology below for bends is based on present practice. Recent work shows that the plastic strain in larger diameter pipe bends is larger than in smaller diameter bends. The proposed limit state for low cycle fatigue does not take this into account.

The *i*-factors are valid for in-plane and out-of-plane bending.

Table C.9 - Stress intensification factors for bends

	i_{a1} σ_a (ΔN_x)	i_{a2} σ_a $(\Delta M_y, \Delta M_z)$	i_{a3} τ (ΔM_x)	i_{a4} τ $(\Delta V_y, \Delta V_z)$	i_{a5} σ_t $(\Delta M_y, \Delta M_z)$	i_{ap}
σ_m	1	$0{,}9 \cdot \left(\frac{d_m^2}{4 \cdot t_n \cdot R}\right)^{\frac{2}{3}}$	1	1	0	$\frac{R - 0{,}25 \cdot d_i}{R - 0{,}5 \cdot d_m}$
σ_{res}	1	$0{,}9 \cdot \left(\frac{d_m^2}{4 \cdot t_n \cdot R}\right)^{\frac{2}{3}}$	1	1	$1{,}8 \cdot \left(\frac{d_m^2}{4 \cdot t_n \cdot R}\right)^{\frac{2}{3}}$	$\frac{R - 0{,}25 \cdot d_i}{R - 0{,}5 \cdot d_m}$

The maximum stress is an ovalising stress, σ_t, and for in-plane bending it is at the side of the bend

($\Phi = 0^o$ and 180^o in Figure C.7).

For in-plane bending the maximum axial stress, σ_a, is found about 70^o from the symmetry plane of the bend ($\Phi \approx 20^o$, 160^o, 200^o and 340^o). The maximum axial stress at the side of the bend ($\Phi = 0^o$ and 180^o, where the maximum ovalising stress is found) can be evaluated by using the stress concentration factor $0{,}5 \cdot i_{a2}$.

For out-of-plane bending and combinations of in-plane and out-of-plane bending the maximum values of σ_a and σ_t shall be used when calculating the references stresses, or the more exact method below shall be used.

When a pipe bend is connected to a flange at the one end, k_b, i_{a2} and i_{a5} shall be multiplied by $h^{1/6}$. If there are flanges at both ends of a bend k_b, i_{a2} and i_{a5} shall be multiplied by $h^{1/3}$

where $$h = \frac{4 \cdot t_n \cdot r_b}{d_m^2}$$

i_{a2} and i_{a5} shall be valued at minimum 1,0 after the multiplication.

If the bracing effect of over-pressure has been considered when calculating the flexibility of the pipe bend, i_{a2} and i_{a5} shall be divided by

$$1 + 3{,}25 \frac{p}{E}\left(\frac{d_m}{2t}\right)^{\frac{5}{2}}\left(\frac{2R}{d_m}\right)^{\frac{2}{3}}$$

i_{a2} and i_{a5} shall be valued at minimum 1,0 after the division.

For more exact calculation of stresses and location of stresses the formulas below can be used.

These formulas include the effect of rerounding and shall only be used if the flexibility factor, k_b, is reduced due to over-pressure see C.6.2. Alternatively bending stresses shall be calculated for $p = 0$ in the formulas below.

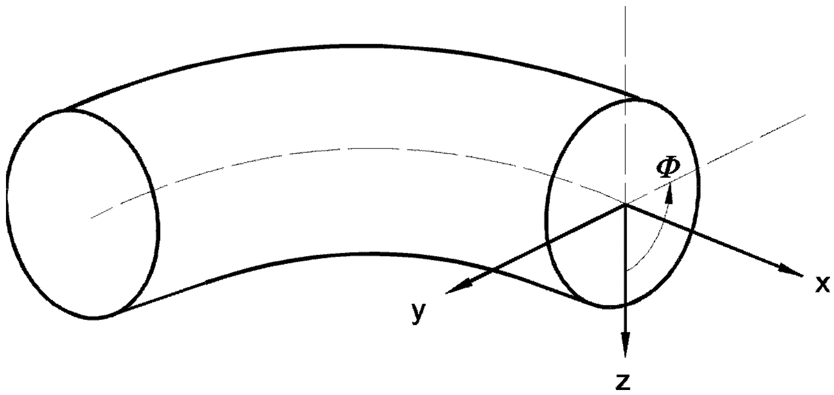


Figure C.7 - Local co-ordinate system for bends

Membrane stresses σ_m :

$$\Delta\sigma_a = \frac{\Delta N_x}{A} + i_{ay}\frac{\Delta M_y}{W} + i_{az}\frac{\Delta M_z}{W}$$

$$\Delta\sigma_t = i_{ap}\frac{p \cdot d_i}{2t}$$

$$\Delta\tau = i_{mx}\frac{\Delta M_x}{2W} + \frac{2 \cdot \sqrt{i_{vy} \cdot \Delta V_y^2 + i_{vz} \cdot \Delta V_z^2}}{A}$$

Resulting stresses σ_{res} :

$$\Delta\sigma_a = \frac{\Delta N_x}{A} + i_{ay}\frac{\Delta M_y}{W} + i_{az}\frac{\Delta M_z}{W}$$

$$\Delta\sigma_t = i_{ap}\frac{p \cdot d_i}{2t} + i_{ty}\frac{\Delta M_y}{W} + i_{tz}\frac{\Delta M_z}{W} + \Delta\sigma_t$$

$$\Delta\tau = i_{mx}\frac{\Delta M_x}{2W} + \frac{2 \cdot \sqrt{i_{vy} \cdot \Delta V_y^2 + i_{vz} \cdot \Delta V_z^2}}{A}$$

Stress intensification factors:

$$i_{ap} = \frac{R + 0{,}25 \cdot d_i \cdot \sin\Phi}{R + 0{,}5 \cdot d_m \cdot \sin\Phi}$$

$$i_{vy} = -\cos\Phi, i_{vz} = -\sin\Phi$$

$$i_{mx} = 1 \quad \text{for outside,} \qquad i_{mx} = \frac{d_i}{d_o} \quad \text{for inside}$$

Table C.10 - Stress intensification factors for bends

	Out-of-plane moment, ΔM_y	In-plane moment, ΔM_z
Outside	$i_{ay} = i_{amy} + \nu \cdot i_{tby}$ $i_{ty} = i_{tby}$	$i_{az} = i_{amz} + \nu \cdot i_{tbz}$ $i_{tz} = i_{tmz} + i_{tbz}$
Inside	$i_{ay} = i_{amy} - \nu \cdot i_{tby}$ $i_{ty} = - i_{tby}$	$i_{az} = i_{amz} - \nu \cdot i_{tbz}$ $i_{tz} = i_{tmz} - i_{tbz}$

For out-of-plane moments, ΔM_y:

$$i_{amy} = \cos\Phi + \frac{(1{,}5 \cdot x_2 - 18{,}75) \cdot \cos 3\Phi + 11{,}25 \cdot \cos 5\Phi}{x_4}$$

$$i_{tby} = -\lambda \cdot \frac{9 \cdot x_2 \cdot \sin 2\Phi + 225 \cdot \sin 4\Phi}{x_4}$$

For in-plane moments, M_z:

$$i_{amz} = \sin\Phi + \frac{(1{,}5 \cdot x_2 - 18{,}75) \sin 3\Phi + 11{,}25 \cdot \sin 5\Phi}{x_4}$$

$$i_{tbz} = \lambda \cdot \frac{9 \cdot x_2 \cdot \cos 2\Phi + 225 \cdot \cos 4\Phi}{x_4}$$

$$i_{tmz} = -0{,}5 \cdot \frac{d_m}{R} \cdot \cos\Phi \cdot (\cos\Phi + \frac{(0{,}5 \cdot x_2 - 6{,}25) \cdot \cos 3\Phi + 2{,}25 \cos 5\Phi}{x_4})$$

where

$x_1 = 5 + 6 \lambda^2 + 24 \psi$

$x_2 = 17 + 600 \lambda^2 + 480 \psi$

$x_3 = x_1 x_2 - 6{,}25$

$x_4 = (1-\nu^2) (x_3 - 4.5 x_2)$

$$\lambda = \frac{4 \cdot R \cdot t_n}{d_m^2 \cdot \sqrt{1-\nu^2}} \quad \text{and} \quad \Psi = \frac{2 \cdot p \cdot R^2}{E \cdot d_m \cdot t_n}$$

C.7.5 Tees

In tees the maximum membrane stresses from internal over-pressure will occur in point A (top point) in Figure C.8, whereas the impact from internal forces is limited at this point.

Maximum stresses from internal forces in run pipe and the branch (including normal force from pressure) usually occur in the vicinity of point B (saddle point) in Figure C.8, whereas internal over-pressure is of minor importance here. For large in-plane moments in the branch maximum stresses can occur at point A.

However, the simplified methodology described below presupposes that for fatigue analysis all stresses are referred to point B.

In most cases it is therefore sufficient to assess limit state A1 in point A and limit state B1 in point B.

Consequently the strength verification shall be carried out separately for both points. For pipelines with large normal forces, point B will normally be decisive for the dimensions.

Stress contributions are calculated from the formula expressions given in C.7.2, using the values for i_{ap}, i_{a1} - i_{a5}, d, t, W, and A valid for run pipe and branch, respectively.

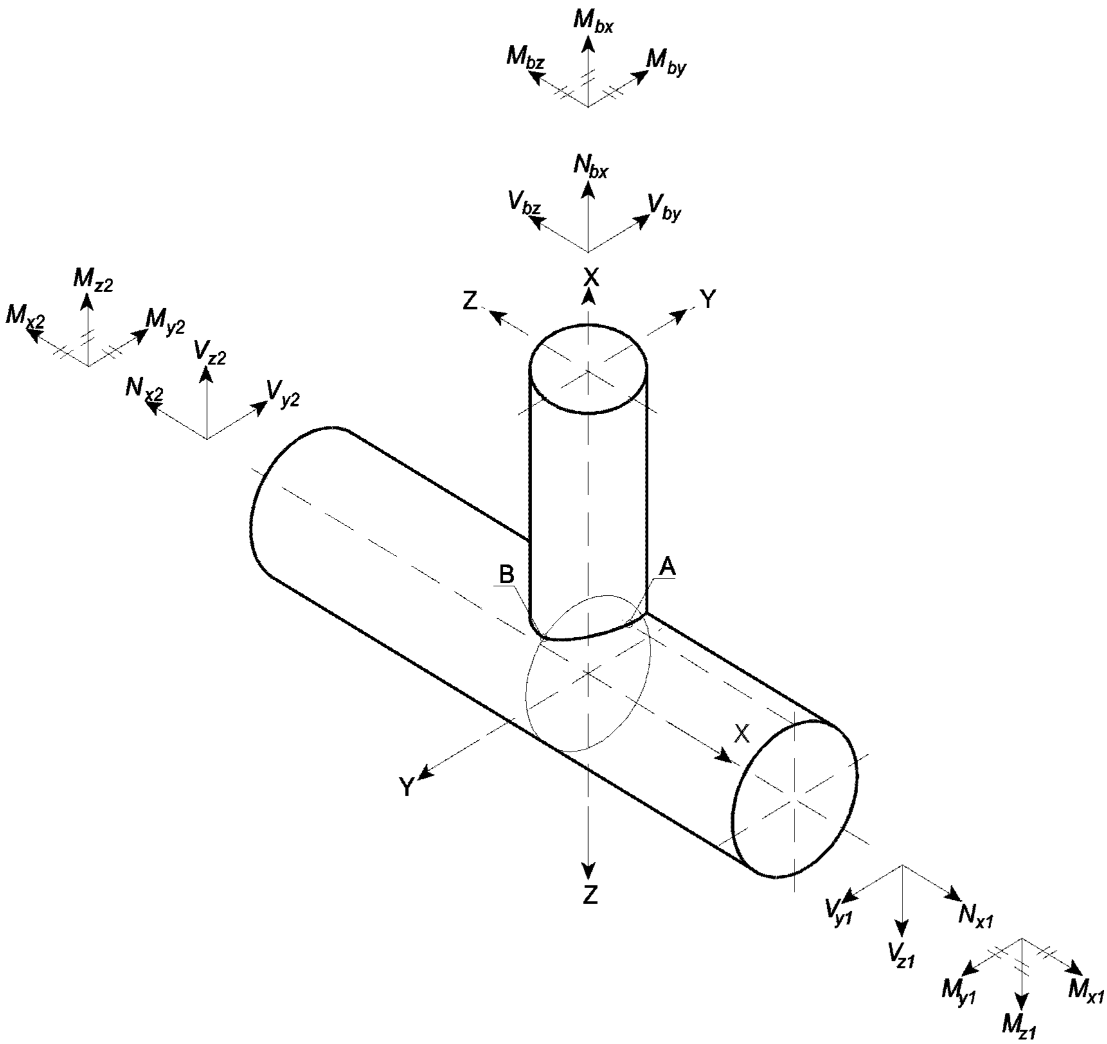


Figure C.8 - Symbols for tees

Stress intensification factors for tees in point A:

$i_{a1} = i_{a2} = i_{a3} = i_{a4} = i_{a5} \approx 0$

$$i_{ap} = \frac{1}{1 - 0{,}3084 \cdot \ln\left(\frac{d_{bo}}{\sqrt{d_{ro} \cdot t_b}}\right)}$$

Table C.11 - Stress intensification factors for membrane stresses in point B of tees (all types)

Membrane stresses σ_m	i_{a1} σ_a (ΔN_x)	i_{a2} σ_a $(\Delta M_y, \Delta M_z)$	i_{a3} τ (ΔM_x)	i_{a4} τ $(\Delta V_y, \Delta V_z)$
Run pipe	$r_r \cdot k_2$	$r_r \cdot k_1$	$2\, r_r \cdot k_1$	$r_r \cdot k_1$
Branch pipe	$r_b \cdot k$	$r_b \cdot k$	$r_b \cdot k$	$r_b \cdot k$

Table C.12 - Stress intensification factors for resulting stresses in point B

Resulting stresses σ_{res}	i_{a1} σ_a (ΔN_x)	i_{a2} σ_a $(\Delta M_y, \Delta M_z)$	i_{a3} τ (ΔM_x)	i_{a4} τ $(\Delta V_y, \Delta V_z)$
<u>Fabricated tee</u>				
Run pipe	1,2 k_2	k_1	2 k_1	k_1
Branch pipe (note 3)	k	k	k	k
<u>Weld-in tee (note 1)</u>				
Run pipe	0,7 k_2	0,6 k_1	1,2 k_1	0,6 k_1
Branch pipe (note 3)	0,4 k	0,4 k	0,4 k	0,4 k
<u>Extruded tee (note 2)</u>				
Run pipe	0,8 k_2	0,7 k_1	1,4 k_1	0,7 k_1
Branch pipe (note 3)	0,7 k	0,7 k	0,7 k	0,7 k

$i_{a5} = i_{ap} = 0$ in point B.

$$k_1 = 0{,}523 \cdot \left(\frac{1}{d_{rm}}\right)^{\frac{1}{3}} \cdot \left(\frac{1}{t_r}\right)^{\frac{2}{3}} \cdot d_{bm} + 2{,}5 \cdot \left(1 - \frac{d_{bm}}{d_{rm}}\right)^{\frac{3}{2}}$$

$$k_2 = 0{,}65 \cdot \left(\frac{1}{d_{rm}}\right)^{\frac{5}{6}} \cdot \left(\frac{1}{t_r}\right)^{\frac{2}{3}} \cdot \left(d_{bm}\right)^{\frac{3}{2}} + 2{,}5 \cdot \left(1 - \frac{d_{bm} \cdot t_b}{d_{rm} \cdot t_r}\right)^{\frac{9}{5}}$$

$$k = 0{,}567 \cdot \left(\frac{d_{rm}}{t_r}\right)^{\frac{2}{3}}$$

Reduction factors for membrane stresses:

$$r_r = 0{,}56\,\frac{t_b}{t_r}\left(2 - \frac{d_{bm}}{d_{rm}}\right)^{\frac{5}{3}}$$

$$r_b = \begin{cases} 0{,}83\sqrt{\dfrac{d_{bm}}{d_{rm}}} & for\ N_b \leq \dfrac{1}{d_{bm}}\sqrt{M_{by}^2 + M_{bz}^2} \\ 0{,}83 & for\ N_b > \dfrac{1}{d_{bm}}\sqrt{M_{by}^2 + M_{bz}^2} \end{cases}$$

NOTE 1

Weld-in tees are usually made in dimensions $d_h \leq 600$ mm. The formulas for weld-in tees are applicable for dimensions according to ISO 3419 and DIN 2615.

The stress concentrations i_{a1} and i_{a2} indicated for resulting stresses, σ_{res}, make up an upper limit value for i_{a1} and i_{a2} for membrane stresses σ_m.

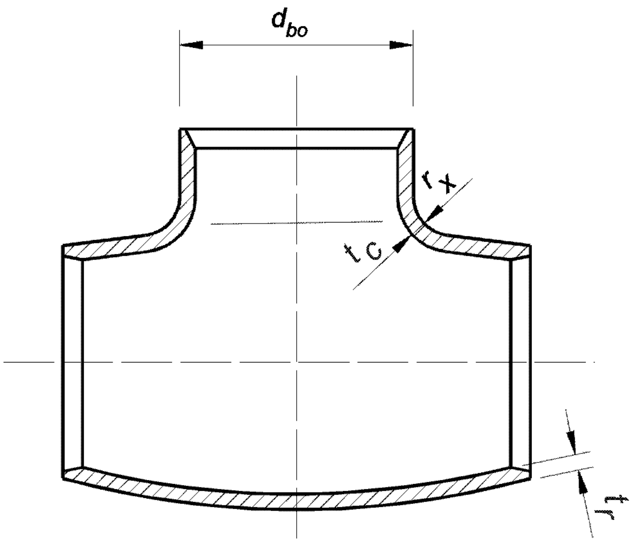


Figure C.9 - Extruded or forged tee

NOTE 2

The formulas for extruded tees are also applicable for tees made by welding two identically formed halves together.

The stress concentration factors i_{a1} and i_{a2} indicated for resulting stresses σ_{res} stated for welded tees give an upper limit value for i_{a1} and i_{a2} in respect of membrane stresses, σ_m, for extruded tees.

NOTE 3

Although FEM analyses show higher values for stress intensification factors for the branch pipe the values proposed are according to present experience. The lower values here are proposed under consideration, among other things, of the methodology that all stresses are referred to point B. In special cases (e.g. when the tee only is subject to actions from the branch giving maximum stresses in point A) the factors might be on the unsafe side. In this case k_a can be valued at

$$k = 0{,}75 \cdot \left(\frac{d_{rm}}{t_r}\right)^{\frac{2}{3}} \cdot \left(\frac{d_{bm}}{d_{rm}}\right)^{\frac{1}{8}}$$

For fatigue analyses all stresses are referred to point B, Figure C.8.

σ and τ are calculated separately for run pipe and branch pipe with sectional forces chosen as follows:

For the calculation of stresses in point B, normally the forces and moments determined in the intersection between the centrelines of the pipes are used. When $d_{bo} < 0,5\ d_{ro}$, the forces and moments from the branch pipe can be used, determined at the distance 0,5 d_{ro} from the centreline of the run pipe.

Reduced forces and moments are used for calculating the stresses from the forces and moments in the run pipe. If M_{y1} and M_{y2} have the same sign as in accordance with Figure C.8, M_y is equal to the smallest values of M_{y1} and M_{y2}. If M_{y1} and M_{y2} have different signs, $M_y = 0$. Reduced values of the other forces and moments in the run pipe are determined accordingly.

The stresses at point B are calculated as the sum of the stress contribution from internal forces in main pipe and branch pipe.

$$\Delta\sigma_a = i_{a1}\frac{\Delta N_x}{A} \pm i_{a2}\frac{\sqrt{\Delta M_y^2 + \Delta M_z^2}}{W}$$

$$\Delta\tau = i_{a3}\frac{\Delta M_x}{2W} \pm i_{a4}\frac{2\cdot\sqrt{\Delta V_y^2 + \Delta V_z^2}}{A}$$

$$\Delta\sigma_a = \Delta\sigma_a(\text{run}) + \Delta\sigma_a(\text{branch})$$
$$\Delta\tau = \Delta\tau(\text{run}) + \Delta\tau(\text{branch})$$

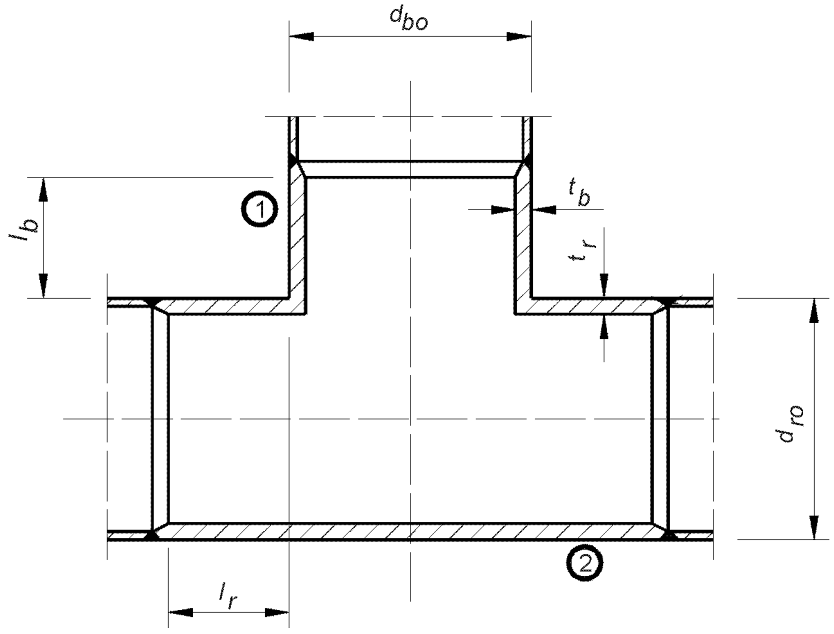
For tees with locally increased wall thickness the increased wall thickness can only be included in the calculations if the extent of the increased wall thickness in the run pipe is a minimum of

$$l_r = 1{,}8\sqrt{d_{rm}\cdot t_r}$$

measured at both sides of the branch.

The extent of an increased wall thickness in the branch pipe shall be a minimum of

$$l_b = \sqrt{d_{bm}\cdot t_b}$$



Key
1 Branch
2 Run pipe

Figure C.10 - Tee with increased wall thickness

C.7.6 Other components

C.7.6.1 Small angular deviations

Table C.13 - Stress intensification factors for small angular deviations

	i_{a1} σ_a (ΔN_x)	i_{a2} σ_a (ΔM_y, ΔM_z)	i_{a3} τ (ΔM_x)	i_{ap} p
σ_m	1	1	1	1
σ_{res}	k	k	1	1

$i_{a4} = i_{a5} = 0$

$k = 1 + 1{,}65 \cdot \sqrt{\frac{d_o}{t_n}} \cdot \tan \Theta$ k shall not be valued lower than the value for butt welds.

These stress intensification factors only apply if there is no risk of local buckling and the conditions in Table C.4 are fulfilled.

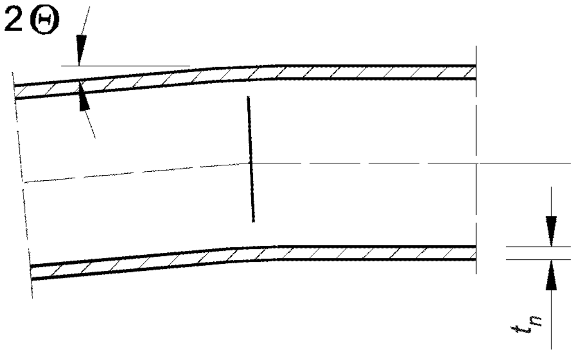


Figure C.11 - Small angular deviations

The stress intensification factor for small angular deviations and angular misalignment can be used for fatigue analysis. However, in combination with high axial stresses (cold installation) the limits in Table C.4 should be observed.

C.7.6.2 Reducers

Reducers with defined radii of curvature r and r_l:

Table C.14 - Stress intensification factors for reducers

	i_{a1} σ_a (ΔN_x)	i_{a2} σ_a (ΔM_y, ΔM_z)	i_{a3} τ (ΔM_x)	i_{ap} p Note 1
σ_m	1	1	1	1/cosα
σ_{res} note 1	k	k	1	1/cosα

NOTE1 See also A.5.

$i_{a4} = i_{a5} = 0$

$$k = 0{,}5 + 0{,}01 \cdot \alpha \cdot \sqrt{\frac{d_{0,\min}}{t_{\ln}}}$$

α is inserted in degrees.

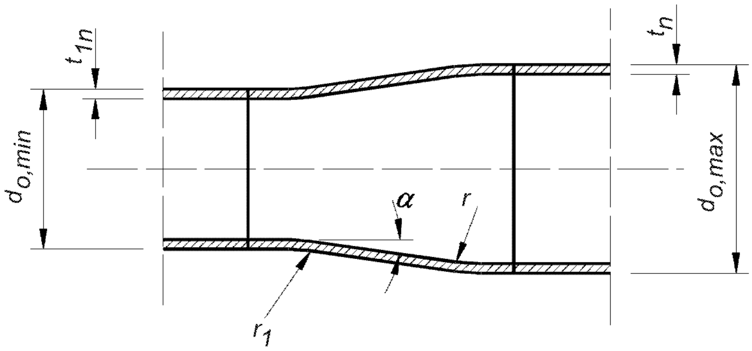


Figure C.12 - Reducer

The expression for *k* is only valid if the following requirements are met:

- the transitional part is concentric
- $\alpha \leq 30°$
- $d_{o,min.}/t_{l,n}$ and $d_{o,max.}/t_n$ are both smaller than 100

For pipes with larger axial forces (e.g. cold installed pipes) it should be assessed whether the redistribution of forces in larger and smaller pipes is acceptable, and the stresses in the reducer and the smaller pipe should be checked. In these cases it will be expected that reducers with $\alpha < 30^o$ are required.

C.7.6.3 Dished ends

Reference is made to relevant international or national standards.

C.7.7 PUR foam and PE casing

The shear force between PUR foam and casing pipe and steel pipe respectively should be calculated.

PUR foam /PE casing:

$$\tau = \frac{F}{D_c \cdot \pi}$$

PUR foam /steel pipe:

$$\tau = \frac{F}{d_o \cdot \pi}$$

where

F	is the friction force per unit length, see annex B
D_c	is the PE casing diameter
d_o	is the steel pipe diameter

In expansion zones the lateral soil pressure against PUR foam /PE casing from the steel pipe should be calculated.

$$\sigma_{PUR} = \frac{P}{d_o}$$

where P is the passive soil pressure per unit length calculated based on D_c.

Limit state: See 7.4.4.

σ_{PUR} is a formal stress. For small pipes the typical failure is tensile failure, and for large pipes it can be shear failure.

C.8 Fatigue analysis

C.8.1 Fatigue strength data

SN-curves in the low cycle fatigue range are established by strain-controlled cycling, and the strains are translated into formal stresses by $\sigma = E \cdot \varepsilon$.

Fatigue strength is expressed in terms of series of SN-curves, each applying to particular construction details. The curves have been derived from fatigue test data obtained from appropriate laboratory specimens tested under stress control or, for applied strains exceeding yield (low cycle fatigue), under strain control. Continuity from low to high cycle regime is achieved by expressing low cycle fatigue data in terms of the pseudo-elastic stress range (i.e. strain range multiplied by elastic modulus, if necessary corrected for plasticity).

$$S = k \cdot N^{-1/m} \; ; \quad N = \left(\frac{k}{S}\right)^m$$

For the steel types normally used for preinsulated pipes the factors k = 5000 N/mm^2 and m = 4 can be used giving:

$$S = 5000 \cdot N^{-1/4} \text{ N/mm}^2 \; ; \quad N = \left(\frac{5000}{S}\right)^4$$

The SN-curve shall be used with stress intensification factors calculated or measured as hot-spot values. The curve includes the effect of a butt weld. Reductions for rolled skin, temperature and plastic yield are included. The effect of the electro-chemical environment is not included. The low cycle fatigue life can be impaired by water with pH-values typical for district heating. The limit state for fatigue (the above mentioned SN-curve) in combination with the actions defined in clause 7 and methodology for modelling in annex B and C gives results within present practice for normal construction details in preinsulated district heating systems.

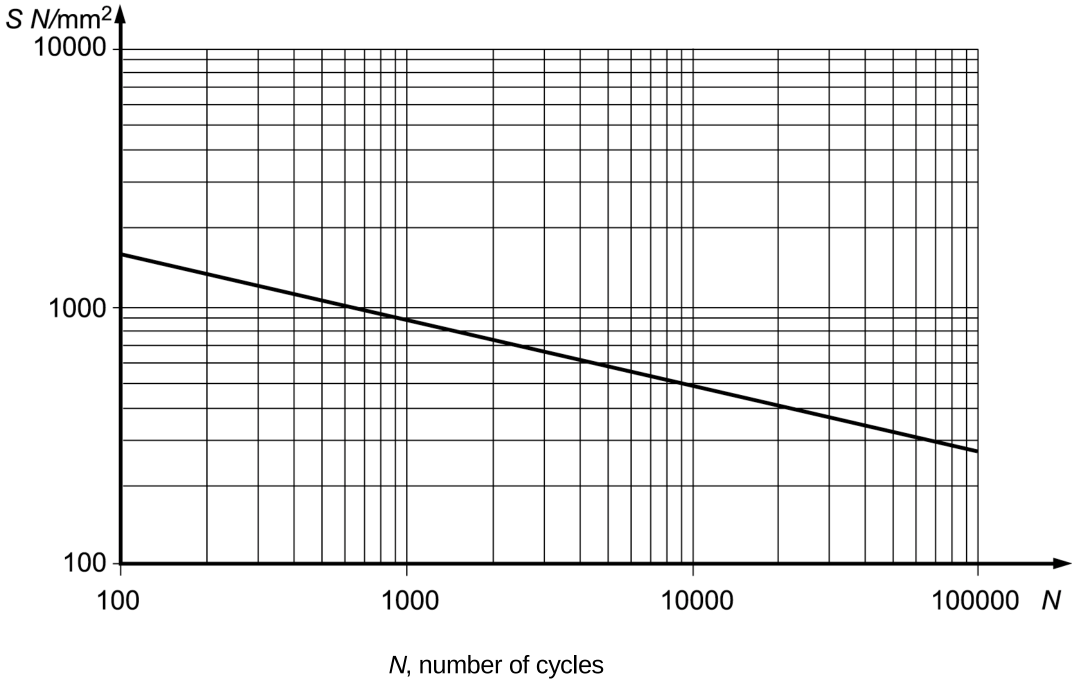


Figure C.13 - SN-curve

The fatigue strength design curves are approximately three standard deviations of logN below the mean curve, fitted to the original test data by regression analysis. Thus, they represent a probability of failure of approximately 0,1%.

The curve presupposes that the stress range is calculated assuming purely linear elastic material behaviour for the steel, also above yield.

If other SN-curves based on strain-controlled cycling are used (e.g. uni-axial tests on polished rods) suitable reductions for surface defect and welding details shall be included, and a suitable theorem to recalculate stresses higher than yield stress, back into strains shall be applied (e.g. the Neuber hyperbola to recalculate stresses back into plastic strains).

C.8.2 Fatigue strength data, detailed design

The method of calculation in EN 13445-3 can be used provided that

1. a detailed analysis of actions (size and distribution) is made e.g. pipe-soil interaction and the increase of soil reaction under road cover,

2. a detailed analysis of stresses and strains is made,

3. it is ensured that in multi-axial stress states (e.g. bends with large bending moment due to high lateral soil reactions) the applied transformation of calculated elastic stresses into plastic strain for the applied fatigue curve gives safe results. This can especially be important for larger d_o/t ratios and

4. it is considered that the low cycle fatigue life can be influenced by water with pH-values typical for district heating.

C.8.3 Design fatigue lives

The safety factor is applied by dividing the calculated number of cycles with γ_{fat}.

Table C.15 - Partial safety factor for action cycles

	Project class A	Project class B	Project class C
γ_{fat}	5	6,67	10

Or the failure criterion is expressed by the Palmgren-Miner hypothesis

$$\sum \frac{n_i}{N_i} \leq \frac{1}{\gamma_{fat}}$$

where

n_i is the number of cycles with stress range $\Delta\sigma_i$ during the required design life

N_i is the number of cycles of stress range S_i to cause failure.

C.9 Further actions

If the analysis show too high stresses or too short fatigue life the following steps can be taken:

- The system can be made more flexible in the expansion zones.
- Reduction of small angular deviations. Use curved pipes instead.
- Increase of wall thickness of tees. For other components increase of wall thickness normally give very little reduction of stresses.

The use of steel with higher yield strength only gives a marginal increase in fatigue life (limit state B1).

Annex D
(informative)

Calculation of heat losses

D.1 General

Annex D has status as application rule.

The insulation thickness can be chosen in consideration of operating economy and technical conditions. The following circumstances can be considered:

- pipe dimensions,
- temperature level,
- installation costs, price of lost heat and heat losses between heating station and place of consumption,
- risk of condensation,
- vicinity of power cables or other heat- sensitive utility networks,
- requirements for surface temperature and environmental impact,
- requirements for maximum ambient temperature in heating stations, etc.

The annex contains guidelines for the approximate calculation of heat loss per meter of buried pipe pair.

D.2 Heat loss per pipe pair

The heat loss for supply pipe Φ_f and for return pipe Φ_r are calculated from

$$\Phi_f = U_1 (t_f - t_s) - U_2 (t_r - t_s)$$

$$\Phi_r = U_1 (t_r - t_s) - U_2 (t_f - t_s)$$

The overall heat loss will be

$$\Phi_f + \Phi_r = 2(U_1 - U_2)(\frac{t_f + t_r}{2} - t_s)$$

where

U_1 and U_2	are the coefficients of heat loss
t_f and t_r	are the flow and return temperatures
t_s	is the undisturbed soil temperature at depth Z

For symmetric pipe structures the heat loss coefficients can be calculated from

$$U_1 = \frac{R_s + R_i}{(R_s + R_i)^2 - R_h^2}$$

$$U_2 = \frac{R_h}{(R_s + R_i)^2 - R_h^2}$$

where

R_s is the insulance of the soil

R_i is the insulance of the insulating material

R_h is the insulance of the heat exchange between flow and return pipe

The insulance is the specific insulation resistance.

The overall heat loss coefficient is

$$U_1 - U_2 = \frac{1}{R_s + R_i + R_h}$$

D.3 Insulance of the soil

$$R_s = \frac{1}{2\pi\lambda_s} \ln \frac{4Z_c}{D_c}$$

where

Z_c is a corrected value of depth Z, so that the surface transition insulance R_o at the soil surface is included. $Z_c = Z + R_o \cdot \lambda_s$

Z is the distance from the surface to the middle of the pipe

λ_s can usually be valued at 1,5 - 2 W/mK for wet soil.

For dry sand $\lambda_s \approx$ 1,0 W/mK

R_o can usually be valued at 0,0685 m²K/W.

D.4 Insulance of the insulation material

$$R_i = \frac{1}{2\pi\lambda_i} \ln \frac{D_{PUR}}{d_o}$$

where

D_{PUR} is the diameter of the insulation material

d_o is the outer diameter of the service pipe

λ_i is the coefficient of thermal conductivity for the PUR insulation.

The limit for λ_i in EN 253 is λ_i = 0,033 W/mK.

For practical calculations λ_i = 0,030 W/mK or according to the producer specification.

The coefficient of thermal conductivity is increasing during the course of time. In heat loss calculations the average value of λ throughout the service life of the pipe system should be used.

D.5 Insulance of the heat exchange between flow and return pipe

$$R_h = \frac{1}{4\pi \cdot \lambda_s} \ln\left(1 + \left(\frac{2Z_c}{C}\right)^2\right)$$

where C is the distance between the centre lines of the two pipes.

Bibliography

EN 473	*Non destructive testing - Qualification and certification of NDT personnel – General principles.*
EN 13445-3	*Unfired pressure vessels – Part 3: Design.*

blank

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover. Tel: +44 (0)20 8996 9000. Fax: +44 (0)20 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: +44 (0)20 8996 9001. Fax: +44 (0)20 8996 7001. Email: orders@bsi-global.com. Standards are also available from the BSI website at http://www.bsi-global.com.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre. Tel: +44 (0)20 8996 7111. Fax: +44 (0)20 8996 7048. Email: info@bsi-global.com.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration. Tel: +44 (0)20 8996 7002. Fax: +44 (0)20 8996 7001. Email: membership@bsi-global.com.

Information regarding online access to British Standards via British Standards Online can be found at http://www.bsi-global.com/bsonline.

Further information about BSI is available on the BSI website at http://www.bsi-global.com.

Copyright

BSI
389 Chiswick High Road
London
W4 4AL