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NATURAL GAS TRANSMISSION PIPELINE SYSTEM: ADDITIONAL REQUIREMENTS FOR STEEL PIPELINE

מערכת הולכת גז טבעי: דרישות נוספות לצנרת פלדה

Combined edition

The Standards Institution of Israel

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Notice of measure of compliance of Israeli Standards with foreign Standards or documents

This Standard excluding the modifications and additions indicated, is identical to the unofficial translation into the English language from November 2004 of the Dutch Standard NEN 3650-2 – 2003.

Descriptors: gas pipelines, gas supply, natural gas, pipelines, steels

מילות מפתח:

צנרת גז, הספקת גז, גז טבעי, צנרת, פלדות

Updating the Standard

Israel Standards are reviewed periodically at least every five years, in order to adapt them to scientific and technological developments. Users of Standards should ascertain that they are in possession of the latest editions of the Standard including its Amendments.

A document appearing in the "Reshumot" (The Israeli Official Journal) as an Amendment may be a separate Amendment, or an Amendment incorporated into the Standard.

Official Standard

Whether the document or parts of it are Official should be checked. An Official Standard or Amendment (in whole or in part) takes effect 60 days following publication of the notice in the "Reshumot", unless the notice states otherwise for the effective date.

Standards Mark

A manufacturer of a product complying with the requirements of the applicable Israel Standards is entitled, after being licensed by the Standards Institution of Israel, to mark it with the Standards Mark:

Introduction to the Israeli Standard

This Israel standard is the unofficial translation from November 2004 of the Dutch Standard NEN 3650-2 - 2003 approved in the English language as an Israel Standard with national deviations.

The national deviations are brought in this standard in a different font.

This Standard is part of a Standard series dealing with a natural gas transmission pipeline system, as follows:

SI 5664-1 - Natural gas transmission pipeline system – General

SI 5664-2 - Natural gas transmission pipeline system – Additional requirements for steel pipeline

Foreword

SI 5664-2 is a part of standard series SI 5664. SI 5664-2 contains specific requirements for a natural gas steel pipeline system. These requirements are in addition to the general requirements set forth in SI 5664-1.

Appendixes A, B, C, D and F are the normative components of this standard. Appendix E is an informative component of this standard.

Because the figures in this standard are in large part adopted from other standards, the standards and editing rules for technical drawings have not been completely followed, which can be seen from the editing and scripts of the figures. In the text part of the standard, however, the correct manner of writing and printing is utilized.

Purpose of the Standard

The purpose of the Standard series is to obtain pipeline systems that are safe for people, the environment and property, by specifying requirements for the design, installation, operation and termination that will guarantees a durable, effective, and efficient system.

This demands safety regulations. Deviation from the (fixed) regulations of this standard is only possible, if approved by the authority having jurisdiction and provides an equivalent or higher level of safety.

Interface EN and ISO standards

Application of the stipulations of this standard, including references to EN 1594: 2000 and ISO 13623: 2000 means that the pipeline system is also in compliance with the stipulations of EN 1594: 2000 and ISO 13623: 2000.

Note: In case of contradiction between SI 5664 and any other standard mentioned herein, the requirements of SI 5664 will prevail.

Use of Standard

The people applying the standard shall be familiar with the subject and be in possession of the relevant expertise.
The designer, builder or user of the pipeline system is reminded that this standard is neither a design specification nor a handbook.

1 Subject and Scope

This section of the standard includes requirements for steel pipelines, which shall satisfy the requirements set forth in SI 5664-1.

Figure 1 has been deleted and figure 2 has been modified and called Figure 1.

A schematic representation of which pipeline systems fall under the standard is depicted in Figure 1.

NOTE: Figure 1 is also found in SI 5664-1.

Informative note: For a pipeline system downstream of the PRMS (Pressure regulating and metering station) at the customer's premises, see SI 4489 (ANSI/ASME B31.3 with modifications and additions) or ANSI/ASME B31.1 or NEN 2078. In any case, the pressure safe control logic shall be compatible with SI 5664.

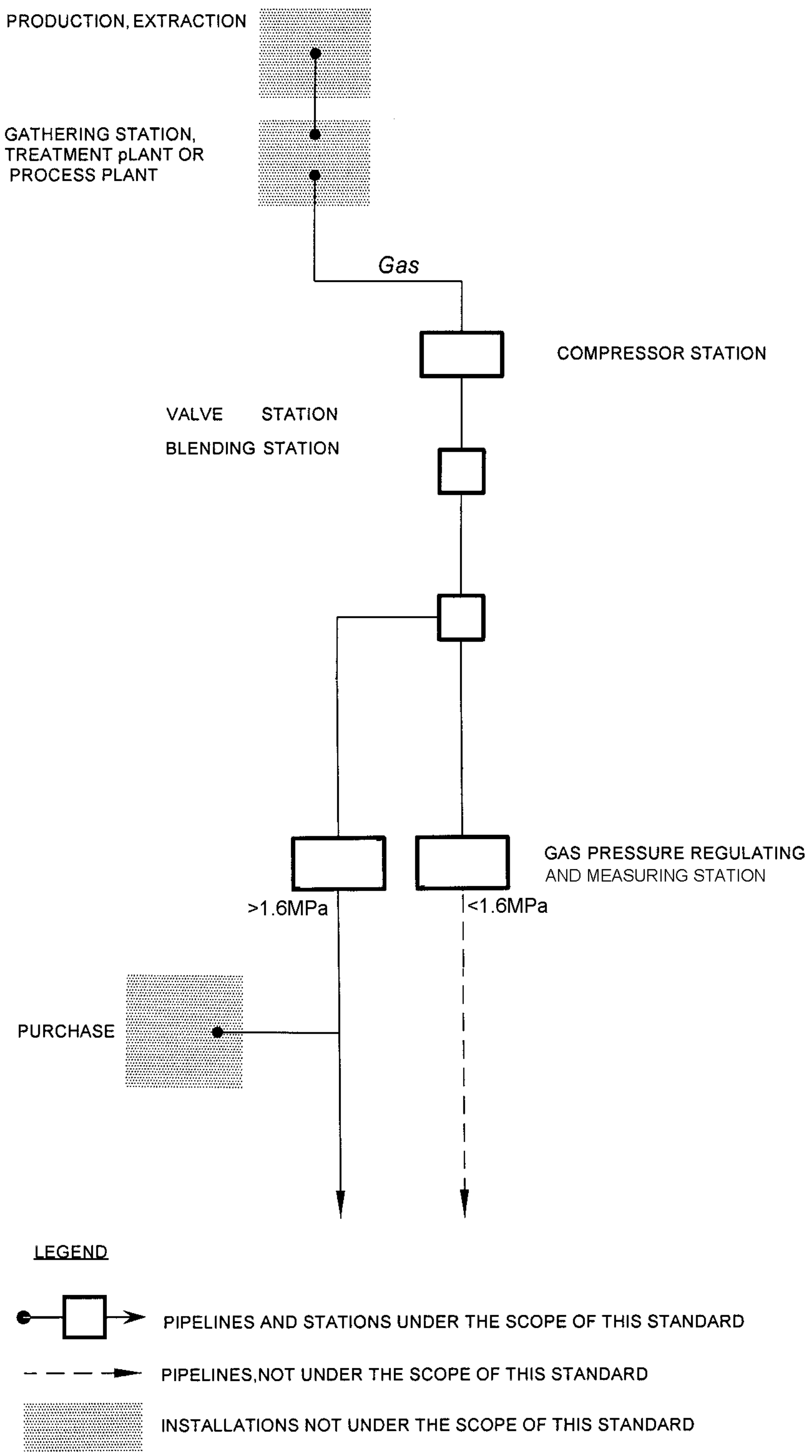


Figure 1 — Area of application of the standard

2 Normative References

The following normative documents include provisions which, since they are referenced, are likewise provisions of this standard. As this standard was printed, the cited versions were in force. All normative documents can however be modified; it is therefore recommended that parties which make agreements on the basis of this Standard, try to apply the most recent version of the standards documents cited below.

Israel Standards

SI 1340 - Carbon steel covered electrodes for shielded metal arc welding

SI 4489 - Process piping

SI 5664-1 – Natural gas transmission pipeline system – General

SI-ISO 9001: 2000 - Quality management systems – requirements

Israel Specification

SII 266 Part 5.2 - Steel pipes with protective coatings: External extruded polyethylene coatings – three layer coating

International Standards

ISO 898-1: 1999 - Mechanical properties of fasteners made of carbon steel and alloy steel – Part 1: Bolts, screws and studs.

ISO 898-2: 1992 - Mechanical properties of fasteners – Part 2: Nuts with specified proof load values – Coarse threads

ISO 2566-1: 1999 - Steel – Conversion of elongation values – Part 1: Carbon and low alloyed steels.

ISO 3183-1:1996 - Petroleum and natural gas industries – Steel pipe for pipelines – Technical delivery conditions – Part 1: Pipes of requirement class A

ISO 3183-2:1996 - Petroleum and natural gas industries – Steel pipe for pipelines – Technical delivery conditions – Part 2: Pipes of requirement class B

ISO 3183-3: 1999 - Petroleum and natural gas industries – Steel pipe for pipelines – Technical delivery conditions – Part 3: Pipes of requirement class C

ISO 3834-1: 1994 - Quality requirements for welding – Fusion welding of metallic materials – part 1: Guidelines for selection and use

ISO 5817: 2003 Welding – Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) – Quality levels for imperfections

ISO 7005-1:1992 - Metallic flanges – Part 1: Steel flanges

ISO 8501-1: 1998 - Pretreatment of steel for the application of paints and related products – Visual evaluation of surface cleanliness– Part 1: Pretreatment for rusting of uncoated steel and of steel following removal of previous layers

ISO 9606-1: 1994 + A1: 1998 – Approval testing of welders – fusion welding – part 1: Steels.

ISO 9692: 1992 - Metal arc welding with covered electrodes, gas shielded metal-arc welding and gas welding joint preparations for steel

ISO 13623:2000 - Petroleum and natural gas industries – Pipeline transportation systems

ISO 14313 - Petroleum and natural gas industries – pipeline transportation systems – pipeline valves

ISO 15589-1: 2003 - Petroleum and natural gas industries – Cathodic protection for pipeline transportation systems – Part 1: On-land pipelines

ISO 15590-1: 2001 - Petroleum and natural gas industries – Induction bends, fittings and flanges for pipeline transportation systems – Part 1: Induction bends

ISO 15590-2: 2003 - Petroleum and natural gas industries – Induction bends, fittings and flanges for pipeline transportation systems – Part 2: Fittings

ISO 15614-1: 2004 - Specification and qualification of welding procedures for metallic materials – Welding procedure test – part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys

ISO 15741 - Paints and varnishes – Friction-reduction coatings for the interior of on- and offshore pipelines for non-corrosive gases

ISO/IEC 17020: 1998 - General criteria for the operation of various types of bodies performing inspections

European Standards

EN 288-9: 1999 - Specification and approval of welding procedures for metallic materials. Welding procedure test for pipeline welding on land and offshore site butt welding of transmission pipelines

EN 473: 2000 - Non-destructive testing - Qualification and certification of NDT personnel - General principles

EN 1092-1: 2001 - Flanges and their joints. Circular flanges for pipes, valves, fittings and accessories, PN designated - Part 1: Steel flanges

EN 1591-1: 2001 - Flanges and their joints. Design rules for gasketed circular flange connections - Part 1: Calculation method

ENV 1591-2: 2001 - Flanges and their joints. Design rules for gasketed circular flange connections – Part 2: Gasket parameters

EN 1594: 2000 – Gas supply systems – Pipelines for maximum operating pressure over 16 bar – functional requirements

EN 1708-1: 1999 + A1: 2003 - Welding. Basic weld joint details in steel - Pressurized components

EN 1991-2: 2003 – Eurocode 1: Actions on structures – Part 2: Traffic loads on bridges

ENV 1993-1-1: 1995 - Eurocode 3: Design of steel structures – Part 1-1:General rules and rules for buildings

EN 10021: 1993 - General technical delivery requirements for steel and iron products

EN 10028-3: 2003 - Flat products made of steels for pressure purposes – Part 3: Weldable fine grain steels, normalized

EN 10113-2: 1993 - Hot-rolled products of weldable fine-grained construction steel – Part 2: Conditions of delivery for normally tempered / normalized rolled types of steel

EN 10168: 2004 – Iron and steel products – Inspection documents – List of information

EN 10204: 2004 - Metallic products– Types of inspection documents

EN 10208-1: 1997 - Steel pipes for pipelines for flammable liquid substances — Technica conditions of delivery – Part 1: Class A pipes

EN 10208-2: 1996 - Steel pipes for pipelines for flammable liquid substances — Technical conditions of delivery – Part 2: Class B pipes

EN 10216-2: 2002 + A1: 2004 – 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: 2002 – 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: 2002 – 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 10222-2: 1999 – Steel forgings for pressure purposes – Part 2: Ferritic and martensitic steels with specified elevated temperature properties

EN 10289: 2002 – Steel pipes and fittings for pipelines installed underground and offshore – External coating comprised of layers of epoxy and altered epoxy applied in a liquid form

EN 10290: 2002 – Steel tubes and fittings for onshore and offshore pipelines – External liquid applied polyurethane and polyurethane-modified coatings

prEN 10298: 2002 – Steel tubes and fittings for onshore and offshore pipelines – Internal lining with cement mortar

EN 10301: 2003 – Steel tubes and fittings for on and offshore pipelines – Internal coating for the reduction of friction for conveyance of non corrosive gas

prEN 10309: 1999 – Steel tubes and fittings for onshore and offshore pipelines – External epoxy powder coating

EN 10310: 2003 – Steel tubes and fittings for onshore and offshore pipelines – Internal and external polyamide powder based coatings

EN 12007-3: 2000 – Gas supply systems – Pipelines for maximum operating pressure up to and including 16 bar – Part 3: Specific functional recommendations for steel

EN 12068: 1998 – Cathodic protection – External organic coatings for the corrosion protection of buried or immersed steel pipelines used in conjunction with cathodic protection – Tapes and shrinkable materials

EN 12327: 2000 – Gas supply systems – Pressure testing, commissioning and decommissioning procedures – Functional requirements

EN 12474: 2001 – Cathodic protection of submarine pipelines

EN 12560-1: 2001 – Flanges and their joints – Gaskets for class-designated flanges – Part 1: Non-metallic flat gaskets with or without inserts

EN 12560-2: 2001 – Flanges and their joints – Gaskets for class–designated flanges – Part 2: Spiral wound gaskets for use with steel flanges

EN 12560-3: 2001 – Flanges and their joints – Gaskets for class–designated flanges – Part 3: Non-metallic PTFE envelope gaskets

EN 12560-4: 2001 - Flanges and their joints – Gaskets for class–designated flanges – Part 4: Corrugated, flat or grooved metallic and filled metallic gaskets for use with steel flanges

EN 12732: 2000	-	Gas supply systems – Welding of steel pipework – Functional requirements
EN 12954: 2001	-	Cathodic protection of buried or immersed metalic structures – General principles and applications of pipelines
EN 13480-3: 2002	-	Metal industrial piping – Part 3: Design and calculation
CR 13642: 1999	-	Flanges and their joints – Design rules for gasketed circular flange connections – Background information
EN 13941: 2003	-	Design and installation of preinsulated bonded pipe systems for district heating
EN 50162: 2004	-	Protection against corrosion by stray current from direct current systems

National Standards

AD Specification Sheet S2:1995	-	Calculations for alternating stress
ANSI/ASME B16.5-96	-	Pipe Flanges and Flanged Fittings
ANSI/ASME B16.20-98	-	Metallic Gaskets for Pipe Flanges – Ring Joint, Spiral-Wound, and Jacketed
ANSI/ASME B16.21-92	-	Nonmetallic Flat Gaskets for Pipe Flanges
ANSI/ASME B 31.1: 2001	-	Power piping
API RP 5L1	-	Recommended Practice for Railroad Transportation of Line Pipe (Fifth Edition)
API RP 5LW	-	Recommended Practice for Transportation of Line Pipe on Barges and Marine Vessels (Second Edition)
API SPEC 5L	-	Specification for Line Pipe Forty-Second Edition
ASME B&PVC 9		
ASNT TC 1A: 2001	-	Recommended practice, personnel qualification and certification in nondestructive testing
ASTM A105/A105M-00	-`	Standard Specification for Carbon Steel Forging for Piping Applications
ASTM A106-99e1	-	Standard Specification for Seamless Carbon Steal Pipe for High-Temperature Service
ASTM A182/A182M-00c	-	Standard Specification for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service
ASTM A193/A193M-00b	-	Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service
ASTM A194/A194M-00b	-	Standard Specification for Carbon and Alloy-Steel Nuts for Bolts for High-Pressure or High-Temperature Service, or Both
ASTM A216/A216M-93	-	Standard Specification for Steel Castings, Carbon, Suitable for Fusion Welding, for High-Temperature Service
ASTM A234/A234M-00a	-	Standard Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and High Temperature Service
ASTM A312/A312M-00c	-	Standard Specification for Seamless and Welded Austenitic Stainless Steel Pipes
ASTM A320/A320M-00b	-	Standard Specification for Alloy/Steel Bolting Materials for Low-Temperature Service
ASTM A333/A333M-99	-	Standard Specifications for Seamless and Welded Steel Pipe for Low-Temperature Service
ASTM A350/A350M-00c	-	Standard Specification for Carbon and Low-Alloy Steel Forging, Requiring Notch Toughness Testing for Piping Components

ASTM A352/A352M-93	-	Standard Specification for Steel Castings, Ferritic and Martensitic, for Pressure-Containing Parts, Suitable for Low-Temperature Service
ASTM A420/A420M-00b	-	Standard Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Low-Temperature Service
ASTM A487/A487M-93	-	Standard Specification for Steel Castings Suitable for Pressure Service
BS 7910: 1999 + A1: 2000	-	Guide on methods for assessing the acceptability on flaws in metallic structures
DIN 267-13, Edition: 1993-08	-	Mechanical connection components – Technical conditions of delivery –Parts for screw connections with special mechanical properties for use at temperatures from -200 °C to +700 °C
DIN 2628:1975	-	Welding neck flanges, Nominal pressure 250
DIN 2629:1975	-	Welding neck flanges, Nominal pressure 320
DIN 2638:1975	-	Welding neck flanges, Nominal pressure 160NEN 2078 - Requirements for industrial gas installations
DNV-OS-F101:2000	-	Submarine pipeline systems
MSS SP 44:1996	-	Steel, pipeline flanges
MSS SP-75	-	Specification for high test wrought butt welding fittings
NEN 2078	-	Requirements for industrial gas installations
NEN 6770: 1997 + A1: 2001	-	TGB 1990 – Steel structures – Basic requirements and basic rules for calculation of predominantly statically loaded structures

3 Terms and definitions

3.1 Safety

3.1.1
Group Risk (GR)
the yearly probability that a sizeable group of people will die in one occurrence as a result of some unusual event relating to the pipeline.

3.1.2
Local Risk (PR)
the yearly probability that a person, continuously in a certain locality, will die as a result of some unusual event relating to the pipeline

3.1.3
serviceability limit state
condition where the stated requirements are no longer satisfied in connection with the proper operation of the construction

NOTE Examples of the serviceability limit state are the pipeline's losing its rounded characteristic, the occurrence of annoying vibrations or noise, leakage of substances which do not cause unacceptable damage.

3.1.4
ultimate limit state
condition where rupture or another form of failure in construction occurs because the maximum load bearing capacity is exceeded

NOTE Examples of an ultimate limit state are the fracturing of the pipeline and/or leakage of substances which cause unacceptable damage.

3.2 Engineering

3.2.1
yield strength
the highest or lowest limit of yielding (“yield strength”) can be understood as:

— the yield strength for 0.2 % permanent elasticity;

— the yield strength for 0.2 % disproportionate elasticity;

— the yield strength for 0.5 % total elasticity under load

NOTE 1 How the yield strength is defined and determined should be described in the material specifications.

NOTE 2 The specified minimum value of the yield strength (R_e of $R_a(\theta)$) is given in the material specifications. The calculation value (R_{eb}) *is* determined by dividing the specified minimum value by the material factor.

3.2.2
heat treatment
treatment whereby metal in a solid state is subjected to one or more temperature cycles

3.2.3
work piece
the pipe, the piece of pipe or (with local heat treatment) the area which is subjected to the heat treatment

NOTE A sample is considered to be a separate work piece, even when the heat treatment takes place together with the pipe, etc.

3.2.4
UO manufactured pipe
designation (sketch) of the method in which the pipeline is manufactured: a smooth plate is shaped into a “U” and then made into a pipe

3.2.5
UOE manufactured pipe
same as UO manufactured pipe whereby the pipe is brought to the precise dimension by expansion

3.2.6
road
public structure for traffic and vehicles:

— primary road: road which forms a main connection for the passage of motor vehicle traffic throughout the nation (primary road scheme);

— secondary road: road which forms a major connection for the passage of motor vehicle traffic regionally (secondary road scheme);

— tertiary road: road which forms a major connection for the passage of intercity motor vehicle traffic;

— quaternary road: intercity road of lesser importance (such as agricultural roads and recreational roads);

— non plan -scheme road: for e.g. example, town and village roads usually used for mixed traffic between residential areas and industrial areas. Also roads for the through going traffic, such as beltways, belong to this group

4 Symbols

4.1 Mechanical variables

A	steel surface of the pipeline cross section	mm^2
D_e, D_u	external diameter of the pipe	mm

D_g	average diameter of the pipe	mm
D_i	internal diameter of the pipe	mm
$D_o = D_e + 2e$	external diameter, increased by the thickness of any possible coatings	mm
d	minimum wall thickness including manufacturing, corrosion and abrasion tolerances	mm
d_n	chosen from a table of dimensions or applicable nominal wall thicknesses	mm
d_1	corrosion or abrasion additive	mm
d_{min}	minimum allowable wall thickness because of installation requirements (weld-ability, manageability) $d_n > d_{min}$	mm
e	thickness of the coatings (corrosion coating, concrete casing, possible marine fouling)	mm
I of I_z	moment of inertia with respect to the neutral line	mm^4
I_p	polar moment of inertia	mm^4
I_w	moment of inertia of the pipeline wall	mm^4/mm
I_x	moment of inertia with respect to a chosen line	mm^4
R	bend radius	mm
r_e	external radius	mm
r_g	average radius	mm
r_i	internal radius	mm
W	section factor	mm^3
W_w	section factor of the pipeline wall	mm^3/mm
z	attenuation factor	–

4.2 Material variables

E	elasticity modulus of the pipeline material (20 °C)	N/mm^2
$E(\theta)$	elasticity modulus of the pipeline material at θ °C	N/mm^2
G	sliding modulus	N/mm^2
R_e	specified minimum yield strength at 20 °C	N/mm^2
$R_e(a)$	actual measured yield strength	N/mm^2
$R_e(\theta)$	Specified minimum yield strength at θ °C	N/mm^2
R_{eb}	value of R_e of $R_e(\theta)$ to be employed in the calculation	N/mm^2
R_m	Specified minimum tensile strength at 20 °C	N/mm^2
$R_m(a)$	actual measured tensile strength	N/mm^2
$R_m(\theta)$	guaranteed minimum value of the tensile strength at θ °C	N/mm^2
α_g	linear coefficient of expansion (averaged over the temperature incrase or decrease)	mm/mm·K
ρ_3	Specific weight per unit volume of the pipeline material	kg/m^3
ν	Poisson's ratio	–
θ, θ_t	temperature of the pipeline material	°C

4.3 Processing variables

p	internal overpressure	MPa
p_d	design pressure (gauge pressure)	MPa
p_{dv}	design pressure (gauge pressure) upstream of the pipeline system	MPa
p_{inc}	internal overpressure (incidental)	MPa
ΔH	difference in pressure	MPa
v	speed of flow of the medium	m/s
K	compression modulus of the medium	N/m^2
t	temperature	°C
dt, Δt	difference in temperature	K
p_v	weight per unit volume of the medium	kg/m^3

4.4 Stress technical variables

σ_v	resultant stress	N/mm^2
σ_x, σ_y, σ_z	normal stress	N/mm^2
τ, τ_x, τ_y, τ_z	shear stress	N/mm^2
σ_1, σ_2, σ_3	principal stresses	N/mm^2

4.5 Stochastic variables

α	is the probabilistic coefficient of influence	–
β	is the reliability index	–
μ	is the average value of a stochastic variable	–
σ	is the standard deviation of a stochastic variable	–
V	is the coefficient of variation	–
γ_M	is the model factor	–
γ_S	Is the load factor	–
γ_R	is the material factor	–

5 Abbreviations

LC	Load combination
	Global analyses (pipeline as a beam) Cross section analyses
E-E	Elastic beam calculation – Elastic calculation
E-P	Elastic beam calculation – Plastic calculation
P-P	Plastic beam calculation – Plastic calculation
MAOP (MOP)	Maximum Allowable Operating Pressure (MAOP according to ISO 13623); Maximum Operating Pressure (MOP according to EN 1594). Both terms are equivalent
MIP	Maximum allowable incidental pressure “Maximum Incidental Pressure”

6 Safety

6.1 General

The requirements for external (public) safety (safety of persons) with respect to the transport of natural gas are presented in Chapter 6 of SI 5664-1. These requirements are fully applicable for steel natural gas transmission pipeline systems.
The last sentence was deleted.

In this chapter, supplementary requirements are presented which are specific to on-shore steel pipelines. Supplementary requirements for offshore pipelines are included in 11.2.

6.2 Safety evaluation - External safety

The clause has been deleted.

6.3 Safety aspects in the development of a pipeline route and the design of the system

The following points shall be taken into consideration with steel pipelines:

— with regard to systems with operational temperatures that are higher that the installation temperature, the difference in temperature shall be taken into consideration with the choice of route. A change in temperature (possibly alternating) of the pipelines leads to expansion (whether hindered or not). Pipelines shall therefore be configured so that stresses and deformations remain within allowable ranges;

— installation of the pipeline parallel to high voltage cables, railways, and tramways with electrical traction shall be avoided or, if unavoidable, additional measures shall be undertaken to prevent detrimental effects from ground currents and possible induction currents as per clause 6.4. The last two sentences have been deleted.

6.4 Safety measures regarding Mutual influence of gas pipelines and (MV-HV-EHV) circuits

6.4.1 Terms and definitions

6.4.1.1 LV – Low voltage circuit (overhead lines and underground cables) /installation
a group of conductors and adjacent conductive structures for the distributrion of electric energy with a nominal voltage of less than 1 kV AC and 1.5 kV DC.

6.4.1.2 MV – Medium voltage circuit (overhead lines and underground cables) /installation
a group of conductors and adjacent conductive structures for the distributrion of electric energy with a nominal voltage less than 52 kV AC.

6.4.1.3 HV – High voltage circuit (overhead lines and underground cables) /installation
a group of conductors and adjacent conductive structures for the transmissionn of electric energy with a nominal voltage less than 245 kV AC (161 kV).

6.4.1.4 EHV – Extra high voltage circuit (overhead lines and underground cables) /installation
a group of conductors and adjacent conductive structures for the transmissionn of electric energy with a nominal voltage of more than 245 kV AC (400 kV).

6.4.2 Influence on pipelines by (MV-HV-EHV) circuits (see also Fig. 2A)

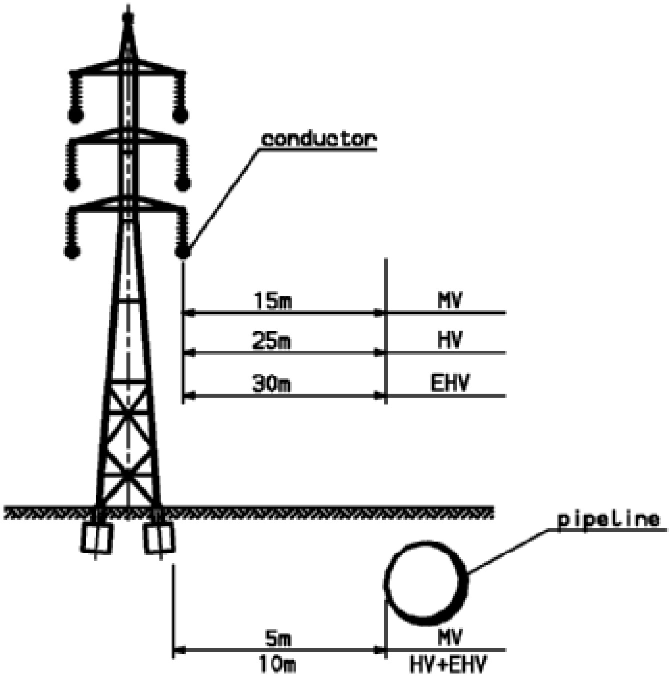


Figure 2A – Distance between pipe and electric installations

6.4.2.1 Close coordination between both MV-HV-EHV circuits and pipeline owners is required.

6.4.2.2 The horizontal distance between the overhead phase conductor (without blowout) and the pipeline shall be at least 15 m for Medium Voltage (MV) circuits, 25 m for High voltage (HV) circuits, and 30 m for Extra High Voltage (EHV) circuits.

6.4.2.3 The abovementioned distances can be reduced if:
- close consultation and coordination between both MV-HV-EHV circuits and pipeline owners is performed; and
- special calculations will be performed in order to avoid problems due to induction currents and electricity interferences between the circuits and pipelines.

6.4.2.4 The minimum distance between the pylon foundation and the pipeline shall be at least 5 m for Medium Voltage circuits and 10 m for High and Extra High Voltage circuits.

6.4.2.5 The abovementioned distances can be reduced if close consultation and coordination between both MV-HV-EHV circuits and pipeline owners is performed.

6.4.2.6 The minimum distance between the earthing of pylon and the earthing of the pipeline shall be at least 20 m.

6.4.2.7 To prevent ignitions of gas blow off, if relevant, the horizontal distance between the pipeline blow off orifice (manual actuated vent), with diameter not greater than 2", and the nearest insulator of the MV-HV-EHV circuits shall be at least twice the vertical distance between them but not less than 35 m. In case of vent-stack greater than 2", a safety evaluation (QRA) shall be performed.

6.4.2.8 The distance between the pipeline and MV-HV-EHV underground cables shall be at least 1.5 m. This distance may be reduced to a minimum of 0.50 m if special mechanical protection measures are taken to protect the electrical cable (i.e. short sheet concrete partitions between the cables and the pipelines, cable jackings or casings, pipelines and cables mounted in common corridors, etc.)

6.4.3 For other aspects about choice of route and pipeline alignment, refer to 8.1 of SI 5664-1.

7 Structural Design – Strength analyses

7.1 General

The technical design of the pipeline shall minimally comply with the stipulations of 8.2 from SI 5664-1 and with the supplementary requirements cited below.

SI 5664-1 gives a general description for reducing to an adequate level the probability of exceeding limit states.This is further elaborated for structural design, along with the calculations required to verify the same.

Testing beforehand the wall thickness to be used in the calculations, with the stipulations of 7.2 and those in [1] and [2], as per the information summarized in Appendix F.3.2.4, is recommended.

If a corrosion allowance is applied to the wall thickness, the influence of this on the strength calculation shall be analyzed (situation immediately after installation).

In doing the calculations, the selection of cross sections to be assessed shall take into account the most heavily loaded points or pipeline sections.

NOTE In general, this involves the cross sections at bends and T-fittings, as well as cross sections in straight pipe sections with the greatest bending moment (greatest curvature), the greatest support reactions, and/or greatest axial forces (e.g., the axial compression force with “hot” pipelines).

7.2 Minimal nominal wall thickness

7.2.1 Minimal nominal wall thickness relative to handling during shipping and storage

The minimum nominal thickness of pipelines to meet requirements for handling (except for cold bending) and transport, shall be equal to or greater than the dimensions given in Table 1.

Table 1 - Wall thickness relative to handling during shipping and storage

Outside Diameter D_e mm	Nominal wall thickness d_n mm
219.1	4.5
273	4.8
323.9-406.4	5.2
508-599	5.6
610-914	6.4
965-1016	7.9
1067-1219	8.7
1321-1626	9.5
1727	11.9
1829-1930	12.7
2032	14.3

7.2.2 Minimal nominal wall thickness relative to external force and corrosion

7.2.2.1 For pipes with nominal diameter up to 6", the minimum nominal wall thickness shall be Sch. 80.

7.2.2.2 For pipes with nominal diameter 8" or more, 3 mm corrosion allowance shall be applied. In any case, the nominal wall thickness shall be at least 9.52 mm (3/8").

7.3 Wall thickness for T's and other fittings

A separate wall thickness determination, relative to internal pressure, is required for Tees, fittings (elbows, adapters, convex bottoms, etc.) and flanges. See EN 13480-3.

For Tees, or convex bottoms in gas pipelines with a maximum operating pressure greater than 16 bar, the calculation method provided in EN 1594, Appendix L, or Appendix M may also be used.

7.4 Simplified calculation method

Based on the results of earlier research, for certain buried, drilled or jacked steel pipeline sections, it is sufficient (except when assessing fatigue) to assess only the hoop stress from internal pressure. For various pipeline configurations and crossings of less important public works, such research has been specified and grouped under the so-called “simplified calculation method”. Appendix A deals with the simplified calculation method and the conditions that have to be met.

If conditions do not allow the application of the simplified calculation method, an extensive strength calculation shall be carried out in accordance with the stipulations of 7.5.2
The Note was deleted

7.5 Extensive strength calculation

7.5.1 General

If conditions do not allow for the application of the simplified calculation method , an extensive strength calculation shall be carried out.

The representative values of loads, multiplied by the respective load factor γ_s given in, Table 2, shall be used in the calculations.

7.5.2 Ultimate limit states

There is a distinction to be made between fundamental ultimate limit states and derived ultimate limit states.
Fundamental ultimate limit states are:

– tearing of a pipe wall;

– deformations;

– loss of equilibrium or stability of the pipeline or of the supporting structure;

– leakage from other causes then tearing of the pipe wall.

Checking these fundamental ultimate limit states can be done by checking the following derived ultimate limit states:

1) **stresses**: the limit state in which the calculated stress exceeds the calculation value for the resistance (of the pipe material). When the stress limit state is exceeded, the pipe wall can tear open;

2) **strain**: the limit state in which the calculated strain exceeds the calculation value for the strain capacity . If this limit state is exceeded, the pipeline wall can also tear open. When determining the calculation value for strain capacity, the toughness of the pipe material shall be taken into account,as well as the factors influencing toughness, such as welds and the associated welding imperfections;

3) **deformation**: the limit state manifested by excessive deformation of the pipeline cross-section, such as to much out of roundness (ovalization), local buckling, flexural buckling, implosion and progressive plastic collapse. Even with such deformation, there may not yet be a danger of a pipeline product spill, however locally, large strains may occur exceeding the limit state of strain;

4) **alternating yield**: the limit state in which variations in the magnitude of load(s) cause strain variations in the steel to such a degree that the steel becomes plastically deformed in more than one direction (+ and -);

5) **fatigue**: the limit state in which fatigue creates a rupture. This could be “high cycle” –fatigue or “low cycle” -fatigue. ”Low cycle” fatigue is sometimes also called, alternating yield;

6) **resonance**: the limit state in which the pipeline gets into its natural frequency (resonance), for example caused by vortices past offshore pipelines in currents or by wind along above-ground pipelines, or by water hammer effects and cavitation in specifically above-ground liquid pipelines;

7) **displacements**: the limit state in which the pipeline is subject to impermissible large displacements, (for example, due to a longitudinal or cross current to an offshore pipeline on the sea bottom), and where the pipeline has no stable position anymore;

8) **dents and/or scratches**: the limit state where local loads cause unacceptable damage to the pipeline wall, e.g., dents and/or scratches caused by excavation equipment.

9) **leakage**: the limit state in which leakage occurs, other than caused by tearing open of the pipewall (for example, leaks caused by leaking couplings, corrosion, or damage by excavating equipment) giving rise to an unacceptable risk to the environment or safety.

7.5.3 Serviceability limit states

Serviceability limit states to be taken into account are the following:

1) **deformation**: the limit state in which deformation is limiting the use of the pipeline. For example, the pipeline shows to much out of roundness, so that pigs, measuring instruments and the like, can no longer pass through; the development of large bending deformations and displacements (sea bottom), in so far no ultimate limit state has yet been exceeded. Even minor folds which clearly do not threaten to violate a fundamental ultimate limit state, could still make the pipeline unfit for use;

   NOTE In general these kinds of large unacceptable deformations will occur in the plastic range (of the stress-strain diagram). These are cases of excessive plastic deformation. However also situations can occur in which excessive elastic deformations become a threat to safety.
   Examples of this occur when moving parts which have some play (valves) are seized up, or when deformation results, violating the tightness, due to the strain in non-prestressed bolts in flange connections.

2) **vibrations and noise**: the limit state in which vibrations might damage supporting structures and other contiguous structures or people in the area. This can include the sound that is produced by the flow of the product to be transported, compressors, etc.;

3) **leakage**: leakage other than that caused by rupture of the pipe wall, without causing unacceptable risk to the environment or safety.

7.5.4 Loads and load combinations to be calculated

For the loads to be included in the calculations, see 8.2.7 of SI 5664-1.

The load combinations to be assessed, and the load factors to be used in the same, are given in Table 2 (see also 8.2.8 of SI 5664-1).

In appendix D, Table D.1, more detailed information is given about the various load combinations.

7.5.5 Limit values and assessment

The results of the complete strength calculation for the relevant load combinations presented in Table 2, shall be tested to their corresponding ultimate limit states and the associated limit values.

For the ultimate limit states presented in 7.5.2, the method of assessment and the limit values are given in appendix D.

As a serviceability limit state, the limit state of ovalization is especially important for the passing through of an inspection apparatus. This also depends on the kind of inspection device used and differs per pipeline. As a rule of thumb the allowable ovalization during operations can be kept on 5%.

NOTE In [16] a value of 6% is cited for the allowable deformation during operation .

7.5.6 Summary of limit states, load combinations and ultimate limit values

Table 3 gives an overview of the following:

- the limit states to be assessed

- the load combinations to include in the calculation

- possible calculation models

- limit values for every limit state.

Table 2 – Load combinations and load factors for ultimate limit states

Loads	Load factors for load combinations (LC)[a]						
		Operational Phase					
	installation phase	only internal pressure, operating pressure, incidental pressure	external load with zero internal pressure	external load with internal pressure and temperature difference	variable load (primarily static load, e.g., temperate changes and pressure changes)	external pressure, external load and internal pressure	incidental load(other than internal pressure)
Load Combinations	LC 1	LC 2	LC 3	LC 4	LC 5	LC 6	LC 7
Internal Pressure (Design Pressure)		1.25	-	-	-	-	1.00
Internal Pressure (In combination with other loads)		-	1.15	1.15	1.15	-	-
Internal Pressure (Max. Incidental Pressure (MIP)		1.10	-	-	-	-	-
Temperature Differences			1.10	1.10	1.10		1.00
Soil Mechanical Parameters [b]			b	b	b		
Forced Deformation [c]			1.10	1.10	1.10	1.10	
Traffic Load	1.35		1.35	1.35	1.10		0.50
Own Weight	1.10		1.10	1.10	1.10	1.10	1.00
Possible coatings	1.20		1.20	1.20	1.20	1.20	1.00
Weight Of fluid	1.10		1.10	1.10	1.10	1.10	1.00
Installation Load [d]	1.10					1.10	
External Water Pressure	1.10		1.10	1.10	1.10	1.10	1.00
Marine Growths (Offshore)			1.20	1.20	1.10		1.00
Current Load (Offshore)	1.10		1.20	1.20	1.10	1.10	1.00

[a] If the load has a favorable influence on the limit state in question, it is not brought into the calculation, if it concerns a variable load; when it is a permanent load, it is brought into the calculation with a load factor of 0.9.

[b] For factors taking account for spatial variation of soil properties, and model factors to take into account when calculating soil mechanical parameters, see Appendix B.4 of SI 5664-1.

[c] Forced deformation can include the following: settling differences, uneven trench bottom, subsidence differences following installation, deformation caused by impeded thermal expansion, deformation during horizontal directional drilling (HDD) and with underwater steel pipe.

[d] Examples of installation load are: load as a result of tensile forces on underwater pipelines, load during directional horizontal drilling, pressure from pipe thrust jacking, and lifting forces from sidebooms, draglines and floating cranes.

Table 3 – Overview limit states, load combinations and limit values

Limit states **(reference article)**	Load combination to be assessed see Table 2	Possible calculation models	Load factors ($\gamma_{gi,}$)	Material factors (γ_{mi}) (resistance)	Model factors (γ_{Mi})	Limit value	Note's
stresses (D.3.1)	1,2,3,4 ,5,6	E-E	Table 2	1,1	1,0	$\sigma_v \le R_e/\gamma_m$	
stresses (D.3.1)	4,5	E-E	Table 2	1,1	1,0	$\sigma_v \le f(R_e + R_{e\theta})/\gamma_m$	including forced deformation
strain (D.3.2)	3,4,5	E-E; E-P P-P	Table 2	1,1	1,0	$R_e \le 340$ N/mm^2 : $\varepsilon \le 0{,}7$ % $R_e > 340$ N/mm^2 : $\varepsilon \le 0{,}5$ %	
deformations (D.3.3):							
— ovalization (D.3.3.1)	1,3	E-E; E-P P-P	Table 2	1,1	1,0	$\Delta D \le 15$ %	Use: $\Delta D \le 5$ % (recommended value)
— local buckling (D.3.3.2)	1,3,4	E-E E-P P-P	Table 2	1,1	1,0	$\varepsilon_{cr} = 0{,}25\frac{d_n}{r'} - 0{,}0025 + 3000\left(\frac{r'}{Ed_n}\right)^2 \cdot p \cdot \lvert p \rvert$ $\varepsilon_{cr} = 0{,}10\frac{d_n}{r'} + 3000\left(\frac{r'}{Ed_n}\right)^2 \cdot p \cdot \lvert p \rvert$	
— buckling (D.3.3.3)	1,3,4,5	E-E E-P P-P	Table 2	1,1	1,0	$Q \ge \frac{\gamma_s \cdot N^2}{EI} f_0$	straight sections of hot buried pipelines . See NEN 6770 (TGB Steel)
— implosion (D.3.3.4):	6	E-E E-P	(offshore pipelines, deep drillings)				
a) external pressure (D.3.3.4.1)	1,3,6		1,05	1,45	0,93	$\gamma_{g,p} \cdot p_L \le \frac{\gamma_M \cdot p_c}{\gamma_{m,p}}$	
b) bending moment (D.3.3.4.2)	1,3,6		1,1	1,3	1,0	$\gamma_{g,M} \cdot M_L \le \frac{\gamma_M \cdot M_c}{\gamma_{m,M}}$	
c) external pressure + bending moment (D.3.3.4.3)	1,3,6	ex. pres.	1,05	1,25	0,93	$\frac{\gamma_{g,p} \cdot p_L}{p_c/\gamma_{m,p}} + \left(\frac{\gamma_{g,M} \cdot M_L}{M_c/\gamma_{m,M}}\right)^n \le \gamma_M$ $n = 1 + 300\frac{d_n}{D_{nom}}$	
		ben-ding	1,55	1,15			
— progressive plastic failure (D.3.3.5)	4	E-E E-P	Table 2	1,1 f_1=0,95		$\varepsilon_{max} = \alpha \times \Delta T \le \left[\frac{R_e(\theta)}{E}\sqrt{1 - \frac{3}{4}\left(\frac{\sigma_y}{R_e(\theta)}\right)^2} + \frac{R_e}{E}\sqrt{0{,}9 - \frac{3}{4}\left(\frac{\sigma_y}{R_e}\right)^2}\right]$	

Table 3 (end)

Limit states (reference article)	Load combination to be assessed see Table 2	Possible calculation models	Load factors ($\gamma_{gi.}$)	Material factors (γ_{mi})	Model factors (γ_{Mi})	Limit value	Note's
alternating yield (D.3.4)	5	E-E	Table 2	1,1	1,0	$\sigma_v \leq f(R_e + R_{e\theta})/\gamma_m$	
fatigue (D.3.5):						$\sum \frac{n_i}{N_i} \leq \frac{1}{\gamma_{fat}}$	
a) elastic domain; membrane-stress through internal pressure	5		1.0				high pressure pipelines
a.1) seamless pipe	1,5	E-E	,,	γ_{at}= 10 (γ_{fat}= 5) [a]		$N = 5.3 \times 10^3 \left(\frac{R_m}{\Delta\sigma}\right)^{5,15}$	
a.2) welded pipe	1,5	E-E	,,	γ_{fat}= 10 (γ_{fat}= 5) [a]		$N \approx 700 \left(\frac{R_m}{\Delta\sigma}\right)^{4,35}$	
b) elastic and plastic domain; bending and peak stresses	5	E-E E-P	1,0	γ_{fat}= 10		$N = \left(\frac{5000}{\Delta\sigma}\right)^4$	elbows, T's at high operating temperatures
resonance/vortex shedding (D.3.6)	1,5	E	Table 2	see[29]	see[29]	system frequency outside band of hammer frequencies	offshore pipelines
large displacements(D.3.7)	1,5	E	Table 2	see [29]	see[29]	See [29]	See [29]
dents and/or scratches	'Fitness for purpose' calculations on the basis dents and/or scratches dimensions(see BS 7910)						
[a] If the actual operation is known with precision.							

8 Construction Design – Miscellaneous

8.1 General

The remaining technical aspects of design which specifically cover steel as a pipeline material include:
- material requirements: the material specifications;
- requirements regarding connecting of pipeline elements: welding and flange connections;
- requirements regarding internal or external coating for protecting the material against corrosion and/or abrasion and the application of cathodic protection in addition to the external coating.

8.2 Material specifications

The material specification requirements for pipeline components, as well as requirements related to approval of a manufacturers production process for delivery of pipeline components according to specifications referred to in this standard, have been stipulated in the model specifications in Appendix B.2.

By pipeline components is meant: pipes, fittings, flanges, weldolets, split-Tees, repair shells, bolts and nuts.

For all materials that are to be used, the requirement applies that the steel shall be “fully killed”.

The pipe components shall have good weldability under field conditions.

8.2.1 Delivery, inspection and inspection documents

The general conditions for delivering steel and steel products in conformity with EN 10021: 1994 shall be applied.

In general, pipeline elements for use in gas pipeline systems shall be delivered with a 3.2 inspection report in accordance with EN 10204: 2004. At stations, pipeline elements with diameter less than 10" can be delivered with a 3.1 inspection report in accordance with EN 10204: 2004, althugh a 3.2 inspection report is preferred.

Bolts, nuts and gaskets shall be delivered with a 3.1 inspection report in accordance with EN 10204: 2004.

An inspection report 3.2, means that approval has been granted by type A inspection – independent certification institution – (in accordance with ISO/IEC 17020: 1998) that is one of the following:

a) An inspection body, that is accredited (in accordance with ISO/IEC 17020: 1998) for the relevant inspection procedures;
b) In the US: Inspection body that is widely recognized (like by the leading insurance companies), for the relevant inspection procedures;
c) Authorized inspection agency for the relevant Standards;
d) Approved laboratory, according to the Israeli Standards Law.

An inspection report 3.1, means approval by the quality control department of the factory which is accredited as a Type C inspection institution (in accordance with ISO/IEC 17020: 1998).

Notes:
a) The inspection body will be qualified for the relevant Standards.
b) Lists of accredited institutions can be found on the internet.
c) All inspection institutions within the European Union should be acknowledged (non-discrimination).
d) The certification of pipe components is in line with the Pressure Equipment Directive (per member of the EU, there are lists of pressure equipment inspection institutions available).
e) Station components (e.g., valves), when they are for pressures > 0.05 MPa, are under the scope of the Pressure Equipment Directive, and shall be marked CE, or shall be certified by the client’s inspectors.

8.2.2 (Line)Pipe

Examples of pipe specifications which satisfy the model specification, are specifications for welded and seamless pipe with material in accordance with B.1, Table B.1, and the particulars of application given there.
Other steel grades than those mentioned in table B.1 can be used, provided their suitability can be demonstrated to the user and/or an autonomous inspection body (see 8.2.1).

NOTE 1 It should be shown that steel to be used in H_2S environments has sufficiently high resistance to rupture through high stress in the presence of sulfides “Sulfide Stress Cracking,” and to rupture due to the presence of hydrogen “Hydrogen Induced Cracking.”

NOTE 2 For information about corrosion resistant steel grades, see [30].

8.2.3 Induction bends

The same specifications as for pipe in 8.2.2, hold for induction bends. Induction bends shall moreover comply with ISO 15590-1.

8.2.4 Fittings, flanges, bolts and nuts

8.2.4.1 General

Fittings shall comply with ISO 15590-2.

NOTE A standard is now in preparation for flanges [31].

8.2.4.2 Welded fittings

Welded fittings are subject to the same specifications as welded pipe in 8.2.2.

Manufacturing methods for welded fittings:

1) Tees, elbows ($R < 3\ D_e$) or reducers made from a longitudinally welded pipe.
These fittings shall not be manufactured from pipe with a spiral weld seam.

2) Tees, elbows ($R < 3\ D_e$) or reducers made from plate shells with at most two longitudinal welds, which shall be placed diametrically opposite to each other.

Requirements for welded connection of fittings:

1) All weld filler material shall be approved by an accredited certification-institution, or:

2) the welding is carried out by a continuous electric resistance welding process and complies with the requirements given in B.2.2 regarding welded fittings.

Repair of welded fittings:

a) Parent material
Exclusively repair by grinding
Plate or welded pipe which has been repaired by welding is not permitted for use in making welded fittings.

b) Welded seam
Repair by grinding.
Repair by welding shall be exclusively carried out before heat treatment and in accordance with a repair procedure in consultation with the user.

If the dimensions deviate from those established in EN-, ISO-, ASTM-, API- or DIN-standards, stipulations shall be laid down about verifying the dimensions and the relevant tolerances. Moreover, they shall minimally satisfy these standards.

8.2.4.3 Seamless fittings

These fittings can be made in the following ways:

1) Tees, elbow ($R < 3\ D_e$) or reducer made from seamless pipe;

2) Dished heads formed from steel plate.

In addition to the material specifications in 8.2.2, also seamless fittings which conform to the following specifications and supplementary requirements, comply with the model specification (refer to B.2).

- ASTM A234/A234M Gr. WPB [a],[b];
- ASTM A420/A420M Gr. WPL6 [b];

In square brackets are the supplementary requirements to the specifications, described in 8.2.5.
Repair of fittings shall excusively be done by grinding.
Pipe which has been repaired by welding shall not be used to make fittings.

8.2.4.4 Forgings

Examples of specifications which, once the supplementary requirements are fulfilled, comply with the model specification include:

– ASTM A 105/A 105M[a], [b];

– ASTM A 182;

– ASTM A216 M Gr. WCB/WCC [a], [b];

– ASTM A350/A350 M Gr. LF2 [b];

– ASTM A352 Gr. LCC [a], [b];

– ASTM A487 Gr. 1B/1C [a], [b];

– MSS-SP-75.

In square brackets are the supplementary requirements to the specifications, described in 8.2.5.

Material specifications for forgings not referred to in this standard, shall satisfy the requirements of the model specification in accordance with B.2.2.

8.2.4.5 Cast fittings

Examples of specifications which, once the supplementary requirements are fulfilled, comply with the model specification, include:

– ASTM A216/A216M-93;

– ASTM A216 Gr. WCB [a],[b];

– ASTM A216 Gr. WCC [a],[b];

– ASTM A352/A 4352M-93;

– ASTM A352 Gr. WCB [b];

– ASTM A352 Gr. WCC [b].

In square brackets are the supplementary requirements to the specifications described in 8.2.5.

8.2.4.6 Bolts and nuts

Examples of material specifications which, once the supplementary requirements are fulfilled, comply with the model specifications are given in Table B.3.

8.2.5 Supplementary requirements to the specifications for pipe, fittings, flanges, bolts and nuts

8.2.5.1 Supplementary requirements relative to (Charpy V) notch-impact values [a]

For components that have a diameter greater than or equal to 150 mm, or bolts with a greater diameter than 25.4 mm (1 inch) the following minimum values shall be met:

- for fittings and components made from steel with a specified minimum yield strength up to 360 N/mm^2; average 27 Joule with the minimum individual value of 18.9 Joule;

- for fittings and components made from steel with a specified minimum yield strength above 360 N/mm^2; average 40 Joule with the minimum individual value of 28 Joule.

The temperature θ_t at which the notch-impact test shall be carried out, depends upon the lowest possible material temperature θ_c and the plate thickness d_c, determined in accordance with B.1.3. The following formula holds:

$$\theta_c = \theta_{min} + \Delta\theta_1 + 15\ \text{K}$$

where:

θ_{min} is the lowest temperature to be brought into the formula, at normal operating conditions;

$\Delta\theta_1$ is the temperature change caused by pressure expansion (for example caused by failure of cryogenic lines).

8.2.5.2 Supplementary requirements relative to chemical analysis (cast analysis) [b]

For fittings and components made from steel with a specified minimum yield strength:

- up to 360 N/mm^2 the following requirement holds: [C_{eq}] = maximum 0.45 (IIW-formula);

- above 360 N/mm^2 the following requirement holds: [C_{eq}] = maximum 0.48 (IIW-formula);

Furthermore, the carbon content of the steel used shall not be more than 0.23%. The sulfur content shall lie below 0.030% and the phosphorus content below 0.035%. The sum of the sulfur and phosphorus content shall not amount to more than 0.050% in accordance with the cast analysis.

If pipe material is being used as parent material for making fittings, then the mechanical and chemical values shall satisfy the requirements for pipe material contained in this standard.

8.2.5.3 Ratio yield strength to tensile strength

The ratio of the yield strength to the tensile strength as measured from the tensile test of the base material of the pipe shall not exceed 0.90.

8.2.5.4 Determination of notch-impact values of gas pipelines

As an alternative to using the values given in the tables of `EN 10208-1` and `EN 10208-2`, it is also permitted to use the following formulae to determine the notch-impact requirements for the pipe at 0 °C (average of three tests):

For pipe material with a yield point up to and including 450 N/mm^2:

$$CV = 3{,}05 \cdot 10^{-4} \cdot \sigma_p^{1,5} \cdot D_e^{0,5}$$

For pipe material with a yield point up to and including 450 N/mm^2

$$CV = 3{,}573 \cdot 10^{-5} \sigma_p^2 \cdot (0{,}5 \cdot D_e \cdot d_n)^{1/3}$$

where

σ_p is the circumferential membrane stress as a result of the design pressure.

8.2.5.5 Take-off inspection

Mechanical testing shall take place in delivery condition. If mechanical properties are established by testing a piece of test plate, then this test plate shall have undergone a heat treatment equivalent to that of the pipe segments. For interest of checking mechanical properties pipeline segments can be grouped into identical groups. Identical groups consist of materials, manufactured from the same cast of steel and being subject to the same heat treatment.

All pipes ready for shipping shall undergo complete and effective non-destructive testing.

NOTE: Pipe materials ordered in conformity with EN 10208-2, ISO 3183-2 and ISO 3183-3, are in compliance with the requirement above.

8.2.5.6 Identifying markings

All pipe components shall be marked in such a way that inspection documents, components and casts can be related to one another.

All pipe components shall be die stamped as follows:

- name or logo of the manufacturer;

- unique identification or series number;

- stamp of the inspection-institution;

- further identification that might be required on instructions of the client.

NOTE Pipe materials ordered in conformity with EN 10208-1, EN 10208-2, ISO 3183-2 and ISO 3183-3, are in compliance with the requirement above.

For small items manufactured in a series (e.g., bolts and nuts), a mark, applied to the item may substitute for a 3.1.B inspection report, provided all of the following conditions are satisfied:

- the stamp marks the article in an unambiguous way;

- the stamp shall be permanent and be indelibly applied to each article.

When a mark is used to substitute for an inspection document, then the inspection document reference stamps are no longer necessary.

The stamping of bolts and nuts shall also comply with B.2.3.6.

8.2.6 Valves

8.2.6.1 Valves shall conform to the requirements of ISO 14313: 1999 (identical to API 6D: 1994).

8.2.6.2 Valves, including control valves, with minimum body welds, are preferred.

8.3 Connections

8.3.1 General

Connections between segments of a pipeline system can be realized by:

- welding: a butt weld between two segments makes a flexure resistant connection equivalent in strength to the pipeline segment itself.
- mechanical connections: this includes "weld neck" flange connections only.

For more on welding, see 9.4.

8.3.2 Flange connections

Dimensions and boring patterns of all flanges shall comply with the relevant standards, and may only be applied, relative to operating temperatures and concomitant permissible operating pressures, when in agreement with the requirements cited in those standards. RTJ flange connections are preferred. Other flange types can be used if suitable tightening procedures are applied.

- EN 1092-1, EN 1591-1, ENV 1591-2, EN 12560-1, -2, -3, -4;
- ISO 7005-1;
- ANSI/ASME B16-5 (for Iron and Steel);
- DIN 2686; DIN 2629; DIN 2638;
- MSS SP 44

Flanges which do not comply with the above-cited standards shall be calculated separately.

The calculation can be carried out in accordance with EN 1591-1:2001 (see also CR 13642:1999) or the ANSI/ASME boiler and Pressure Vessel Code, Section VIII, Division 1, including the next supplement for forces from connecting parts.

If an external axial force (F_e) and/or an external bending moment (M_e) acts upon the flange connection, the force from the adjoining cylindrical part (for example, the pipeline) on the flange connection shall be increased by:

$$F_e + 4\ M_e/D_g$$

where:

D_g is the diameter of the effective circumferential seal.

8.3.2.1 Bolts and nuts

Bolts and nuts shall comply with ISO 898-1 and ISO 898-2 or ANSI/ASME B 16.5 or an equivalent standard. The nuts shall be so threaded upon the bolts or threaded ends that the thread protrudes beyond the nut. To prevent the stripping of the internal thread, the quality of the nuts shall match the quality of the bolts.

The yield strength of the material of the nut may be lower than that of the bolts, but shall be at least 0.6 times the yield strength of the bolt. Wherever vibrations may occur, the nuts shall be effectively held in place. For material specifications, see 8.2.2.

8.3.2.2 Gaskets

Gasket material shall not be affected by the fluid to be transported and shall be capable of withstanding operating temperature and pressure.

Gaskets shall be designed in coherence with the flange design. Gaskets which follow EN 1591-2, ANSI/ASME B16.20, ANSI/ASME B16.21 can be applied.

Gaskets which contain asbestos are not acceptable.

8.4 Coating

8.4.1 General

Internal corrosion of pipelines can result from the corrosiveness of- and abrasion by the fluid

Measures against internal corrosion can include the application of an internal coating, adding inhibitors to the product or a combination of the two.

It is also possible to add a corrosion allowance tothe wall thickness, in case the processes and rates of corrosion are known. Eventually a different material more resistant to corrosion than unalloyed or alloyed steel, may be selected,.

Internal linings, decreasing the friction between the pipeline wall and the fluid, may be applied to transport the fluid with reduced loss of pressure.

Above-ground pipelines may be subject to external corrosion from the atmosphere. Protection against this can be provided by an effective protective coating.

Underground pipelines may suffer external corrosion in moist soil by the formation of electro-chemical cells at the the steel /soil interface, the presence of stray DC current in the soil or in the influence of high-voltage alternating current.

Protection against these possible causes of corrosion can be obtained by applying an external coating (passive protection) and cathodic protection, including a managed grounding of stray currents (active protection).

8.4.2 Internal and external coatings

8.4.2.1 Internal coatings

Materials which can be factory-applied against internal corrosion are:

- mortar cement for steel pipe and fittings in accordance with prEN 10298:2002;
- epoxy resins with polyamide top layer (two layer system) as per EN 10310:2003;
- a line has been deleted.
- an internal coating with corrosion resistant steel (Clad steel).

Also applied, although to a lesser extent, PTFE, PUR and polyamides.

Tested and accepted methods of application shall be available for all materials. Untested and uncertified materials shall not be used.

Internal finishing of girder welds after welding is necessary, unless additional inhibitors are used to further protect these uncoated steel surfaces against corrosion.

For internal pipeline linings to lower frictional resistance for non-corrosive gases, the standards of EN 10301 or ISO 15741 can be used.

The use of inhibitors

If corrosion inhibitors are used, this shall be taken into account when designing the pipeline. Equipment shall be installed for detecting any corrosion process which may occur.

The choice of inhibitor shall be such that there will be no adverse effects from its coming into contact with any segment of the pipeline.

An adequate number of corrosion samples, or other means through which the corrosion process can be monitored, shall be installed at appropriate locations, in such a way that they do not interfere with pigging operations .

8.4.2.2 External coating

8.4.2.2.1 External coating of above-ground pipelines

Above-ground pipelines can be protected against external corrosion by using a suitable coating system.

Any paint system to be used shall have adequate mechanical strength, adequate resistance to atmospheric influences, and adequate resistance to ultraviolet radiation.

In selecting a coating system, the expected maximum temperature of the fluid shall be taken into account, as well as any condensation that might form on the outside surface as a result of a relatively low fluid temperature.

8.4.2.2.2 External coating of underground pipelines

External coatings for underground application shall have good mechanical and electrical properties relative to the pipe diameter, environment (soil type) and operation conditions. In selecting a coating system, the expected maximum temperature of the fluid shall be taken into account.

The coating shall adhere well to the steel. A careful pre-treatment of the steel up to SA 2.5 according to EN-ISO 8501-1 and the application of the coating under controlled conditions are essential in obtaining a good coating system. The coating shall have adequate resistance against disbonding adjacent to areas of coating damage Therefore. factory-applied coatings are preferred for all pipeline components,.

Criteria for mechanical and electrical properties, for adhesion and resistance against disbonding, and for temperature-related applications, are given for various coatings in the following standards:

– SII 266 Part 5.2, triple-layer system with extruded polyethylene as a top layer;

– SII 266 Part 5.2, triple-layer system with extruded polypropylene as a top layer;

– SII 266 Part 5.2, single, double or triple-layer system with molten polyethylene as a top layer;

– A line has been deleted.

– EN 10289, coating system with epoxy or modified epoxy material;

– EN 10290, coating system with polyurethane or modified polyurethane material;

– prEN 10309, coating system with epoxy powder.

8.4.2.2.3 Coating applications in the field

Field application of coatings (such as when finishing girder welds) shall, as much as possible, occur under controlled conditions.

For choice of materials and their application, see 9.5.

8.4.3 Cathodic protection

8.4.3.1 Pipelines

Damage to the coating can cause local corrosion of the pipeline.

This corrosion can be of a general nature, but there is also a risk of highly localized corrosion, (e.g., pit corrosion). Therefore, in addition to applying the coating, it is generally necessary to employ cathodic protection (C.P.). Only in exceptional cases, as defined in ISO 155819-1:2003, can C.P. be omitted.

Cathodic protection can be achieved by using sacrificial anodes or by impressed current. Design and installation of the C.P. system for underground pipelines shall be in accordance with EN 12954 and/or ISO 15589-1:2003.

The C.P. system shall be in operation as soon as possible after the installation of the underground pipeline. If this is not possible, the temporary use of sacrificial anodes is recommended, in particular in areas of aggressive soil conditions.

In areas with stray currents in the soil or high voltage alternating current present, adequate measures shall be taken to ensure the proper functioning of the cathodic protection system. In order to determine the mutual interference of pipelines and high-voltage lines, and measures which can be taken, see clause 6.4.

Application of cathodic protection to pipeline systems can give rise to adverse effects on other underground metal structures; similarly, the C.P. system may be adversely affected by third-party current sources. In the case of mutual influence (interference) the procedures to be followed are described in EN 50162.

The cathodic protection of pipelines shall be continuously maintained, in accordance with the procedures described in EN 12954.

8.4.3.2 Casing and cathodic protection

In the interests of effective cathodic protection the use of casing pipes at crossings shall be limited as much as possible. Possible casing materials are steel, concrete, or plastic (HPE, PVC, GVK).

If steel casing is used, it should preferably be uncoated, and steps should be taken to prevent metallic contact between the carrier pipe and the casing.

The ends of the casing shall be tightly sealed.

If an casing pipe of an isolating material is to be used, supplementary measures shall be taken to ensure cathodic protection within the casing in orderto protect the fluid carrying pipeline. See 9.7 for a practical implementation of such measures.

NOTE An uncoated steel pipeline casing does not interfere with the cathodic protection of the fluid carrying pipe . If the soil is too aggressive, the casing can be coated externally and grounded. The uncoated inside of the casing then functions as an anode. The protective current reaches the (steel) fluid carrying pipe ,via the grounding and the casing pipe.

8.5 Stations

8.5.1 Supports for above-ground pipelines

Supports and/or superstructure for pipelines shall not be welded directly to the pipeline if the hoop stress resulting from the design pressure is higher than 0.5 R_e. For such supports shells and/or brackets can be used which are put around the pipeline and for example, fastened with bolts.

If the pipeline is to be anchored, the anchor force shall come to bear on the shell which grips the pipeline. In that case, the shell can be welded to the pipeline with one single completely circumferential weld.

The note has been deleted.

8.5.2 Pipelines in stations

The minimum wall thickness of pipeline sections shall comply with the requirements of 7.2. The partia load factor when calculating the load case of internal pressure only (load combination 2 in accordance with Table 2) is 1.5/1.1.

9 Construction

9.1. General

In addition to the general construction acitivities, described in Chapter 9 of SI 5664-1, a number of specific construction activities are required for the installation of a steel pipeline. These are described hereafter for on-shore pipelines. Refer to Chapter 11 for offshore pipelines.

9.2 Transport and storage

In addition to the note in 9.4 of SI 5664 -1, the following points apply for steel pipelines:

— when using an electromagnet, take note of residual magnetism related to electrical welding;

— for transport see API RP 5L1 and API RP 5LW.

9.3 Bending of pipes

9.3.1 General

Changes in horizontal pipeline alignment and level differences in the vertical plane can be obtained by using elastically or plastically bent bends.

In those cases where the pipeline cannot follow the changes along the route through elastic bending , cold-formed bends (9.3.3) or hot-formed bends (9.3.4) are applied.

It is recommended to select the bending radius for smooth bends sufficiently large ($R \geq 3\ D$) to allow for pigging the pipeline.

9.3.2 Elastic bends

The minimum allowable bend radius shall be specified in the structural design.

9.3.3 Cold-formed bends

The minimum allowable bend radius for cold field bending of bends,made from the pipe material (unalloyed or low-alloyed steel), specified for the straight pipes, equals:

— 20 x *D* for pipes with a nominal diameter *D* of 200 mm or less;

— 30 x *D* for pipes with a nominal diameter *D* of 200 mm up to 400 mm;

— 40 x *D* for pipes with a nominal diameter *D* of 400 mm or more.

NOTE 1 Other dimensions may be applicable for high-alloyed types of steel.

The bending process shall not damage the pipe coating. If, after the cold-bending, small cracks occur in the pipe coating, they shall be repaired. The difference between the maximum and minimum value of the outside diameter in any cross-section of the bend shall not exceed 2.5 % of the pipe nominal outside diameter.

If wrinkling occurs , the allowable wrinkle depth amounts 0.01 times the distance between 2 successive peaks.

If necessary, a gauging plate made of soft metal can be pulled through the bend to check compliance with above requirements. Other methods can be applied. The dimensions of the gauging plate are determined by the properties of the pipe and allowable tolerances.

A bending test shall be conducted prior to commencement of the bending activities. The manufacturing procedures shall form a part of an integral quality system according to SI-ISO 9001:2000.

When present, a longitudinal weld seam in the bend shall nearly coincide with the neutral axis of the bend during bending.

No circumferential welds shall be present in the bending area . There shall be a straight length of pipe measuring at least one pipe diameter on each end of the bend, with a minimum of 0.5 meter. If necessary, a mandrel can be used.

Spirally welded pipes may be cold formed.

The increase in hardness of the pipeline material as a result of the bending process shall not exceed 50 % of the original hardness and the notch impact value shall satisfy the requirements from 8.2.5.1.

Certain fluids can give a lower limit (for example, the HIC-requirement).

NOTE 2 For diameters over 300 mm and for diameter / wall thickness ratios greater than 70:1, the use of a mandrel is recommended.

9.3.4 Hot-formed bends

Hot-formed bends can be manufactured from straight pipes by means of inductive heating. No heat treatment is necessary insofar as this method is applied with unalloyed or low-alloyed steel with [Mo] < 0.65 %. Hot-formed bends shall be supplied in conformity with ISO 15590-1:2001.

If other methods are applied, heat treatment following the bending of the pipes is required.

NOTE If a hot-formed bend has to be made from line pipe, this should be specified to the pipe manufacturer at the time of ordering so that they can take this into account when selectiing the (chemical) composition of the pipe material and the welding filler material.
When making hot-formed bends in cold-formed (expanded) pipes or pipeline sections which have undergone heat treatment, due account shall be taken of the possible change in material properties in comparison to the original pipe (also see 9.4.2).
It is recommended to determine per cast, diameter, wall thickness and bend radius, through mechanical testing, that the bends comply with the applicable material specifications (Appendix B). It is customary that a representative bend or an (additional) section of a bend of adequate length be manufactured during the production process and that 10% of the bends be tested.
The outside of the pipe may be (grit) blasted and can be protected against the formation of rust by an undercoat (“primer”).

9.3.5 Bends manufactured from half shells

Small radius bends can be manufactured through the welding of two half shells. These shells are manufactured from material specified in EN 10113-2:1993.

9.3.6 Miter bends

Miter bends (also called segment or joint bends) are manufactured by cutting through a pipe at an angle, rotating one section and welding the sections back together again.

This type of bend shall not be used.

9.4 (Field) weld connections, examination of welds and acceptance criteria

9.4.1 General

Weld connections in pipelines made of low-alloyed carbon steel in conformity with material groups 1 to 3, inclusive, of ISO 15614-1:2004 shall be made according to EN 12732:2000 and the supplementary stipulations according to C.1 and C.2.

NOTE For pipe material grades outside the scope of these material groups, agreements have to be made on a project-by-project basis, given the specific properties of the materials (e.g. Duplex, X-80, 13Cr)

For preparation of weld seams and construction details, refer to lSO 9692:1992 and EN 1708-1:1999+ A1:2003.

For weld connections in pre-manufactured insulated bonded pipe systems for the transport of hot water (district heating), EN 13941:2003 is applicable .

9.4.2 Heat treatment

Following the welding of steel, heat treatment may be necessary.

Heat treatment of longitudinal welds shall take place according to the product standard or material standard. In case those standards do not include requirements on this , the requirements according to C.3,.shall be followed.

9.4.3 Welding filler materials

All filler materials shall be approved by an independent inspection institution (see 8.2.1).

9.4.4 Non-destructive testing and acceptance criteria

Non-destructive testing of welds (NDT) shall be done in accordance with EN 12732:2000 and the additional requirements stated in C.1.2.

Guidelines for the determination of acceptance criteria for NDT techniques are presented in C.2.1.

For weld testing, conducted with TOFD (“Time Of Flight Diffraction”) techniques, the acceptance criteria is stated in C.2.2.

9.5 Coating of field welds

9.5.1 Types of coating

Field coatings shall be applied, dependent on the type, according to the standards mentioned in 8.4.2.2.2, according to the specifications of the coating supplier or the designer. Field applied coatings shall be compatible with the factory coating and have sufficient overlap with it. The last three words hae been deleted.

For weld connections in pipeline sections which are constructed, using boring, jacking, or horizontal drilling techniques, it is permissible, in addition to the relevant standards, that a fiberglass-reinforced epoxy coating or a shrinkable sleeve specially developed for this purpose (fiberglass-reinforced heat shrinking coating) be applied. The requirements of the supplier shall be satisfied for the application of this coating. The coating shall be able to resist the shearing forces occurring during drilling or jacking. The functionality of the coating shall not be affected as a result of the drilling or jacking.

For requirements with respect to the pre-treatment of the welded pipe sections and coating control, refer to the standards mentioned in 8.4.2.2.2. For requirements with respect to wrapping tapes and heat shrinkable sleeves, refer to EN 12068:1998.

NOTE The application of heat shrinkable sleeves for drilling is not advised because of the possibility of sliding (tearing) off.

9.5.2 Preparation

The sections that are to be coated, including the required overlap shall be dry and free of grease and dust/dirt and at a temperature above the freezing point. Further preparations shall take place in conformity with the factory specifications for relevant types of coating.

9.5.3 Application, control and repair

The application of the field coating shall be performed by qualified personnel who are thoroughly instructed and are equipped with all tools, materials and equipment necessary to be able to perform their tasks properly. Repairs to and replacements of damaged factory coating shall be performed according to the applicable standards (see 9.5.1).

Connection points for cathodic protection shall be protected with a coating that is compatible with the original coating.

The coating control (spark test) shall take place (once again) over the entire length of the pipe immediately after the pipeline has been lifted from the temporary supports. If necessary, any damage shall be repaired. The repair coating shall be compatible with the original coating and shall have comparable properties. Each repair shall be spark tested.

NOTE It is recommended that the coating be checked for density following the filling and compaction of the trench through an aboveground coating integrity test.

9.5.4 Other

It is possible that a special pipeline coating has to be applied for additional resistance against external damage (e.g. in rocky areas) or with a weight coating against buoyancy (e.g. in peat areas and marshes). This shall be specified in the design.

A sentence has been deleted.

NOTE The design may also prescribe local measures against buoyancy such as: anchor rods with one auger blade, concrete saddles, sandbags or clay-filled bags with or without geo-textile or an equivalent.

9.6 Trenchless techniques for steel pipelines

In principle, all trenchless technique ,discussed in Appendix G of NEN 3550-1:2003 can be utilized with steel pipelines.

A boring employed according to the “impact ramming” (PBT) technique (with a bare steel casing or with a fluid carrying steel pipe coated with sintered PE) is not controllable. For pipelines with a small diameter, the risk arises that the pipeline leaves the projected direction.

Horizontal directional drillings (HDD’s) are very feasible with steel pipelines.

9.7 Cathodically-protected pipeline in a casing

9.7.1 General

This paragraph applies to the insertion of steel pipelines into casings where the length of the material of the casing forms an obstruction for the cathodic protection currents and as a consequence produces an additional risk.

9.7.2 Diameter casing

It is important to select a large (oversized) casing diameter whenconstructing a new crossing in order to ensure the following:

— the simple insertion of the pipeline;

— adequate space for the subsequent application of anode ribbons;

— the subsidence and settlement differences between the casing and the fluid carrying pipeline can be better absorbed;

— the replacement of an existing pipeline with a new one is simpler.

9.7.3 Insertion of the pipeline

9.7.3.1 General

The interior of the casing shall be cleaned before the fluid carrying pipeline is brought into position. The insertion of the pipeline shall be done in such a way that the coating is not damaged and the thinsulators (spacers) are not moved.

The casing end seals shall be positioned at the ends of the casing, immediately after the positioning of the fluid-carrying pipeline.

9.7.3.2 Soil subsidence / soil settlements

When positioning the carrier pipe in the casing pipe, possible differences in settlement of the surrounding soil with respect to the casing shall be taken into account. If a geotechnical investigation indicates that the casing will settle more quickly than the surrounding soil, the pipeline shall be situated on the bottom of the casing pipe. In case it appears that the casing will stay back with respect to the surrounding soil, the carrier pipe shall be situated against the inner top side of the casing pipe (see figure 3).

9.7.3.3 Positioning of thinsulators (spacers)

The positioning of the thinsulators shall be done such that the carrier pipe remains free from the casing pipe permanently. In order to absorb settlement of the surrounding soil it is advisable to place additional thinsulators at the ends of the casing pipe.

The following aspects shall as well be taken into account when selecting the thinsulator type :

— electrically isolating (made entirely of plastic materials, without any metal components);

— absorption of the forces which occur during the insertion into the casing;

— weight of the fluid to be transported and pipe weight;

— diameter of the casing:

— type of pipeline coating,

9.7.3.4 Filling a casing with corrosion-inhibiting material

In order to minimize the risk of penetration of groundwater into a casing pipe, the annular space between the casing and the pipeline shall be filled with material that will continuously protect the pipeline against corrosion over a long period of time (see figure 3). If a casing is filled with corrosion-inhibiting material, it is no longer necessary to apply anode ribbons in the casing. Before the corrosion-inhibiting material is applied, the casing pipe shall be free of water. It shall be demonstrated through measurements and calculations that the filling of the (annular space by) corrosion-inhibiting material is such that the pipeline is completely encased by the corrosion-inhibiting material..

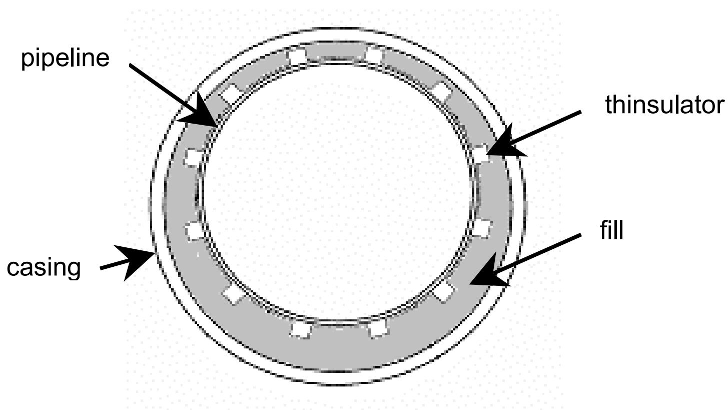


Figure 3 — Pipeline in casing with filling

9.7.3.5 Application of anode ribbons

Situations may occur where there is no possibility of applying corrosion-inhibiting material into the casing. In such cases, the pipeline shall be protected with anode ribbons. When the steel (carrier) pipeline is being inserted it is recommended to connect perforated auxiliary guide pipes (Ø 30 mm) to it, for easy insertion of new anode ribbons in the future. (see figure 4). Plastic-coated steel cables (minimum Ø 2 mm) shall be placed in the auxiliary guide pipes.

The number of anode ribbons to be applied depends on:

— the pipe diameter:

— the length of the pipeline in the casing;

— the capacity of the anode ribbon;

— environmental conditions in the casing (acid degree of the groundwater in the annular space);

— ability of the rubber end-seals to remain waterproof, even with axial or radial movement of the fluid carrying pipe relative to the casing pipe.

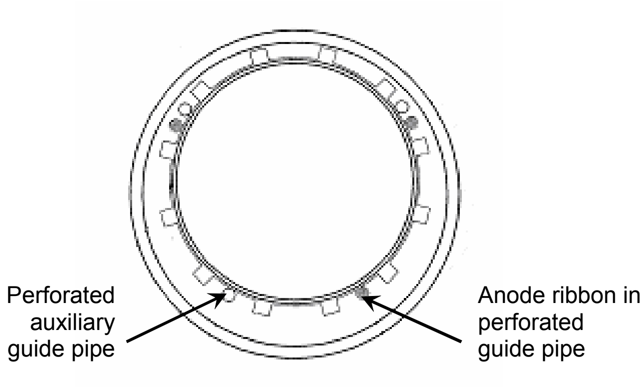


Figure 4 — Pipeline in casing with additional guide pipes for anode ribbon

The guide pipes shall be mounted on the plastic thinsulators. In addition, the rubber end-seals shall be mounted free of tension. This shall be installed in such a way that the soil load has as little influence as possible (S-form). The isolation sleeve of the cathodic protection cable should not be removed to such an extent that the non-insulated cable sticks out of the rubber seals.

9.8 Pressure testing

9.8.1 General

Pressure testing shall be conducted as indicated in 9.9 of SI 5664-1. In addition to this, the requirements given in this chapter and up to 9.8.5 shall be met.

In the case of buried pipelines, testing is generally carried out after the pipeline has been buried.

Some transport pipelines may be too long to permit testing of the entire pipeline. In this case, the pipeline is tested in sections. The subsequent joints made between these sections (girth welds, flanges) are not usually subjected to testing and the quality of these joints is evaluated after visual and nondestructive examination.

Testing may take one of two forms, depending on whether it is possible to make a visual examination during the test. Either:

- no visual examination of the pipeline or pipeline section is possible during testing (see 9.8.1.1); or
- visual inspection is possible throughout testing (see 9.8.1.2).

If the test reveals a leak or the presence of some other defect, this must be repaired. After repair, the test must be repeated to demonstrate that the repair has been effective.

The pipeline is approved if any pressure rises or falls occurring during the test can be satisfactorily explained in terms of temperature variations, variations in air pressure or other physical phenomena taking place during the test.

With regard to the equipment, joints and other ancillaries connected to the pipeline section under test, the materials, dimensions and method of attachment must be capable of withstanding the test pressure.

A test procedure and a test schedule must be drawn up for each test.

9.8.1.1 Testing of pipelines which do not permit full visual examination

Testing is generally carried out on the pipeline after the trench has been backfilled, pipeline sections which are difficult or impossible to reach after installation (sections constructed by directional horizontal drilling, prefabricated waterway crossings, etc.) are also tested before installation.

The test procedure must cover the following aspects, as a minimum:

a) The pressure prevailing in the pipeline during temperature equalization, stabilization, strength testing and tightness testing and the duration of these tests:
   - Temperature equalization
     'temperature equalization' is understood as the equalization of the temperature of the liquid in the pipeline and that of the soil surrounding the pipeline. Depending on the difference in initial temperatures, the pipeline diameter and the insulation applied to the pipeline may take several weeks. If the temperature equalization is not possible, for example where the pipeline incorporates thermal insulation, this must be taken into account in the procedure.

   - Stabilization
     'stabilization' is understood as the absorption by water of the air which is present in the pipeline. A pressure in excess of around 50 bar is needed to ensure that the water takes up all the air. Therefore, transport pipelines with a test pressure below this value cannot be fully stabilized.
     Stabilization is only possible if the tansport pipeline has no side branches and a filler plug is used when filling the pipeline to reduce the volume of entrapped air to a minimum.
   - In the case of transport pipelines which do not satisfy these requirements, such as those forming part of district heating systems, the welds are subjected to air pressure or vacuum heating to check for tightness before the welds are coated and before the strength test is carried out. The strength test is carried out after the welds have been coated and the trench has been backfilled. Depending on the volume, stabilization may take several days.
     To monitor the pressure during the test, at least two pressure measuring devices shall be installed, one at each end of the pipe.

b) The pressure gauge shall be with a measurement accuracy of at least 0.1% and read-out accuracy of at least 0.05 bar.

9.8.1.2 Testing of pipelines which permit full visual examination

For transmission pipelines or part of, which permit full visual examination during testing, the following requirements also apply:

a) The welds under test must not be covered with nonmetallic coatings, such as paint, insulation, etc. either internally or externally.

b) The external surface of the welds under test must by dry, clean and grease-free.

c) The pipeline section under test must be vented, as far as possible, during filling.

d) The temperature of the test liquid must be at least 50 °C and at least 10 °C above the minimum design temperature.

To monitor the pressure during the test, at least two pressure measuring devices shall be installed, one at each end of the pipe.

9.8.2 Strength test

During the strength test a pressure p_t ,,which shall be equal to the design pressure p_d multiplied by C_p, is prevalent in the pipeline (or a portion thereof). A higher value of p_t is permissible, provided, the hoop stress σ_{pt} shall not exceed the value R_e. The duration of the strength test is 15 minutes.

The hoop stress shall be calculated according to the following formula:

$$\sigma_{pt} = p_t \cdot D_g / 2 \cdot d$$

where:

σ_{pt} is the hoop or circumferential stress, in N/mm^2;

p_t is the test pressure, in MPa;

D_g is the average pipe diameter, in mm:

d is the minimum wall thickness after deducting mill tolerances and without corrosion or abrasion allowance, in mm;

R_e is the specified minimum yield strength, in N/mm^2.

If the design temperature is higher than the ambient temperature, the strength test pressure changes as follows:

— with a design temperature of $\theta > 50$ °C $p_t > C_p\, p_d\, R_e/R_e(\theta)$ is applicable;

The factor C_p in the equation above is dependent on the fluid carried. For natural gas pipelines C_p = 1.30 in accordance with EN 1594:2000. The last sentence has been deleted.

NOTE 1 If C_p = 1.3 is also used for the other Group I pipelines, a MIP = 1.15 MAOP is allowable according to ISO 13623:2000 (6.7.3).

NOTE 2 ISO 13623:2000 specifies 1.1 MAOP and 8 hours for the tightness test and duration, respectively (6.7.3).

NOTE 3 For the above notes, MAOP is equal to p_d.

9.8.3 Tightness test

After the strength test, the tightness test shall be conducted, which will last not less than 24 hours. For this test, it is recommended to select a pressure equal to or greater than the design pressure. The pipeline can be approved (considered leaktight) if changes in pressure can be explained from the recorded temperature measurements within acceptable limits, taking into account those points discussed in 9.8.1 such as stabilization and temperature equalization.

For volumes smaller than 20 m^3 or for sections which can be completely inspected visually, a shorter test period can be selected.

9.8.4 Pre testing

Pipeline sections and components shall be pretested in following circumstances:

— if they cannot be tested following assembly in an existing installation;

— if they are to be installed near in an existing station that cannot be protected against possible consequences of a rupture during the testing;

— if the consequences of a possible test failure justify testing prior to installation, such as in the case of a long sag pipe or horizontal directional drilling.

9.8.5 Testing “tie-in” welds

Welds connecting tested pipeline sections to the pipeline system – so-called “tie-in welds” — are not tested by means of the strength or tightness test and therefore require extra consideration and care during construction.

The location of the welds shall be chosen such that the welds are easily accessible from all directions.

Two different methods of non-destructive testing of welds shall be applied. Both methods shall demonstrate satisfactory results for the weld. (Also see C.1 Ad. Chapter 11 supplement 3) in 11.7.)

9.8.6 Miscellaneous

The parts can be tested for strength with air or an inert gas. Furthermore, the entire unit can be tested for its tightness following assembly with air or an inert gas at least at the design pressure. *(The subject of this stipulation is not clear !!)*

Those components or constructions from which it is demonstrated by means of material specifications, testing documentation and/or calculations that they have sufficient strength to resist the applied test pressure do not need to be retested for strength.

Machine directive for rotating components

In addition to the verification and inspection activities, described in 9.11 of SI 5664-1, a practical guideline is included in Appendix J of SI 5664-1on how to comply with the current legislation and rules (such as the Machine directive) for rotating components such as shut-off and actuator combinations, safety shut-offs, compressor and pump units, etc.

9.9 Completion

In addition to the stipulations of section 9.10 of SI 5664-1 the following standards can be taken into consideration for commissioning and decommissioning activities:

— for natural gas pipelines EN 12327:2000;

A line has been deleted.

— for cathodic protection EN 12954:2001 or ISO 15589-1:2003.

10 Operation and termination of operations

10.1 Corrosion management

Within the framework of integrity management presented in Chapter 10 of SI 5664-1, monitoring and management of possible corrosion shall be included in the quality control cycle for steel pipelines.

NOTE In Chapter 9 of ISO 13623:2000 many aspects of corrosion management are discussed on a practical level.

10.2 Fitness ("fitness for purpose")

Pipelines can be damaged by different causes. Examples are local damage from pitting corrosion and damage resulting from excavation activities by third parties. The damage may not lead to pipeline leakage immediately, but could also result in a dent in the pipeline wall, or in local reduction of wall thickness of the impacted bare wall as a result of corrosion. An investigation shall be conducted as to whether it is necessary to correct the abnormality which has occurred, respectively to establish whether the pipeline is still suited for its purpose ("fitness for purpose"). BS 7910 can be used during the investigation; [6] and [7] are informative as well.

NOTE The "fitness for purpose" assessment requires, in addition to knowledge of fracture mechanics, specific knowledge about materials (brittle/ductile behavior, material lto fluid interaction at relevant temperatures, external interactions with soil or C.P. etc., as well as knowledge of structural design). The determination of the extent and dimensions (of the damaged area) as well as the evaluation is an inspection operation. These activities are often performed by an inspection institution referred to in 8.2.1, which is competent for the specified operation(s) etc.

11 Offshore pipelines

11.1 General

This chapter gives, in addition to SI 5664-1, specific requirements for steel offshore pipelines.

11.2 Design

11.2.1 Structural design

11.2.1.1 Limit states

Research shall be conducted as to whether compressive stresses in the pipeline can give rise to:

— implosion as a result of external (hydrostatic) pressure (see E.3.3.4);

— local buckling resulting from a combination of compressive stresses in axial and circumferential direction;

— propagation of local buckling (see same);

— (upward) flexural buckling (upheaval buckling) with hot pipelines with no or little lateral support;

— flexural buckling ("global buckling") as a result of bending and normal forces, especially with risers and free spans.

11.2.1.2 Cathodic protection

The design and the installation of the C.P. system of offshore pipelines shall be done according to EN 12474:2001.

11.3 Laying

11.3.1 Reel lay method

For pipelines that are installed with the reel lay ("reel barge") method, it shall be demonstrated that the permanent plastic strain in the pipeline material is less than or equal to 2 %. The demonstration can be performed according to DNV-OS-F101:2000, clause E of section 9.

Appendix A
(normative)

Reduced analyses procedure

A.1 General

On the basis of results from earlier research, when making strength calculations for certain classified underground steel pipeline sections it is sufficient (except for fatigue assessment) to test the hoop stress from internal pressure according to the formula:

$$\sigma_{\mathrm{p}} = \gamma_{\mathrm{P}} \cdot p_{\mathrm{d}} \cdot D_{\mathrm{g}} \big/ 2 \cdot d \ \leq \frac{R_{\mathrm{eb}}}{\gamma_{\mathrm{m}}}$$

where:

σ_{p} is the hoop stress or circumferential stress caused by internal pressure in N/mm^2;

γ_{p} is the (modified) partial factor applied to internal pressure according to Table A.1;

γ_{m} is the partial material factor from Table A.1;

p_{d} is the design pressure, in MPa;

D_{g} is the average diameter, in mm;

d is the minimum wall thickness, in mm;

R_{eb} is the limit value for stresses, in N/mm^2.

The pipeline sections in question are classified into categories a) to e) inclusive:

a) 1) pipelines or pipelines laid in the open field or in pipeline corridors and laid in open trenches;

2) crossings of watercourses without flood defenses, less than 30 m wide and laid in open trenches (for the purposes of calculation, these are regarded as field sections);

b) pipelines in the shoulder of secondary, tertiary, and quaternary roads and laid in open trenches;

c) pipeline crossings with tertiary, quaternary and uncategorized roads and laid in open trenches;

d) pipeline crossings with tertiary, quaternary and uncategorized roads and watercourses whose width is less than 30 m, without flood defenses, and the pipeline is installed by boring or jacking at the crossing, and open excavation in the adjacent field sections;

e) railway crossings

If the reduced analyses procedure is to be allowed, these pipeline sections shall satisfy with a number of criteria. These criteria are described in A.2.

A line has been deleted.

Figures illustrating the situations for the various categories of pipeline sections are included in A.3. How to incorporate differences in construction subsidence is covered in Tables C.3 and C.5 of SI 5664-1.

A.2 Criteria for applying the reduced analyses procedure

A.2.1 Category a) (fieldsection, watercourse)

Pipeline sections in (open) field or pipeline corridors (a1) and crossings with watercourses having a width of less than 30 m without flood defense (a2), and laid in open trenches.

The following criteria shall be complied with:

- *The section shall be made of straight pipe or cold-formed field bends with a bend radius of* R $\geq$ *40* D*;*

- D_e/d ratio(straight pipe):
  R_e = 480 N/mm$^2 \rightarrow D_e/d \leq$ 106;
  R_e = 415 N/mm$^2 \rightarrow D_e/d \leq$ 92;
  R_e = 360 N/mm$^2 \rightarrow D_e/d \leq$ 80;
  R_e = 240 N/mm$^2 \rightarrow D_e/d \leq$ 70;

- *soil cover on top of the pipeline: between 0.8 m and 2.5 m.*

- *maximum difference in construction subsidence after installation:*
  see Table C.3 of SI 5664-1 *(dry trench),*
  see Table C.5 of SI 5664-1 *(underwater trench),*
  This difference in construction subsidence gradually goes from zero to a maximum value and back again to zero over a distance of at least 2 x 20 m;

- *the maximum difference between the installation temperature and the maximum, or minimum operating temperature is not greater than 35 K. The total temperature range remains between –20 °C and + 50 °C with the stipulation that the pipeline shall not be subject to frost heave;*

- *traffic load class: load model in conformity with "Fatigue Load Model 2, Lorry 4" from Table 4.6 of* EN 1991-2:2003*, (see* SI 5664-1*, Figure C.17), multiplied by a factor of 0.5;*

- *there will be no crossings with potentially active fault planes or areas of mining subsidence;*

- *the expected settlement difference (e.g. due to lowering the water level of polders) shall not exceed 100 mm minus the difference in construction subsidence after installation, as in Table C.3 of* SI 5664-1*;*

- *the minimum nominal wall thickness* d_n *is 4.78 mm;*

- γ_p *to be applied according to Table A.1.*

The criteria regarding soil cover and the traffic load class can be disregarded if it can be demonstrated that the total intergranular stress at top level of the pipe (exclusive load factors) does not exceed 55 kN/m^2.

*If vertical or horizontal factory-made bends with a small bend radius (*R ≥ *3* D*) are used, the following supplementary requirements shall be complied with:*

- *the wall thickness of the bends shall be greater than for those used in adjacent field sections, and shall be calculated using the so-called torus formula (see D.1.2 in* SI 5664-1*). If the bend is fabricated from material which has a higher specified minimum yield strength, the bend shall have at least the same wall thickness as applied in the adjacent field sections;*

- *maximum temperature difference for pipe with* D_e ≤ *324 mm (12") is 20 K, in case horizontal bends are used;*

- *the minimum center to center distance between two horizontal bends (*R ≥ *3* D*) is 2.0 m., unless the pipe diameter* D_e ≥ *457 mm (18").*

A.2.2 Category b) (road shoulder)

Pipe sections which are laid in open trench in the shoulder of secondary, tertiary and quaternary roads.

These shall satisfy the criteria for category a) (field sections), as well as:

- *traffic load class: load model in conformity with "Fatigue Load Model 2, Lorry 4" from Table 4.6 of* EN 1991-2:2003*, where the axle loads according to this load model,are divided, by the (incorporated) impact coefficient of 1.2 (see* SI 5664-1*, Figure C.17);*

- *apply* γ_ρ *from Table A.1;*

- *settlement difference from c) (road crossing in open excavation).*

The criteria related to soil cover and traffic load class can be disregarded if it can be demonstrated that the total intergranular stress at top level of the pipe (exclusive load factors) does not exceed 65 kN/m^2.

A.2.3 Category c) (crossing in open trenches)

Pipeline sections in crossings with tertiary, quaternary and uncategorized roads, and laid in open trenches.

These shall satisfy the criteria of category a) (field sections), except for of the stipulations regarding factory-bends, and also:

- γ_ρ *is to be applied using Table A.1;*

- *there shall be no crossing of a dike (primary flood defence, secondary flood defence, inland flood defence and enclosing dyke of a high-level-drainage-canal);*

- *for quaternary roads:Traffic load model in conformity with "Fatigue Load Model 2, Lorry 4" from Table 4.6 of* EN 1991-2:2003 *(see* SI 5664-1*, Figure C.17);*

- *for tertiary roads: Traffic load model in conformity with "Fatigue Load Model 3, from* EN 1991-2:2003 *(see* SI 5664-1*, Figure C.17);*

- *for uncategorized roads: load model as in tertiary roads;*

- *the (rest-) settlement differences resulting from past embankments (roadbed, re-asphalting), and the embankments from maintenance to be expected during the service life of the pipeline, as per information obtained from the road administrator, shall not exceed 100 mm, sloping gradually over at least 2 x 20 m;*

- *the pipe wall thickness at the crossing shall be at least equal to the pipe wall thickness of the adjacent field sections, regardless of possible differences in material quality.*

The criteria related to soil cover and traffic load class can be disregarded, if it can be demonstrated that the total intergranular stress at top level of the pipe (exclusive load factors) does not exceed 65 kN/m^2 (for quaternary roads), or 85 kN/m^2 (for tertiary and uncategorized roads).

A.2.4 Category d) (drilled crossings)

Pipeline sections crossing tertiary, quaternary and uncategorized roads and watercourses with a width less than 30 m and without flood defenses, where the pipe is drilled or jacked, and the abutting field sections are laid in open trenches;

These shall satisfy the following criteria :

- *settlement differences, as per A.2.3, shall not exceed 200 mm;*

- *only valid for straight pipe and cold-formed bends* R ≥ *40* D*;*

- γ_ρ *is to be applied using Table A.1;*

- *maximum construction subsidence difference after installation: see Table C.5 of* SI 5664-1 *(loosely compacted pit);*

- *no casing is to be used on the pipeline;*

- *there shall be compliance with the criteria of A.2.1, A.2.2 and A.2.3, except for the stipulations under A.2.1 regarding factory-made bends.*

*If vertical factory-made bends with a small bend radius (*R ≥ *3* D*) are used in a jacking and/or receiving pit, the following supplementary stipulations shall be complied with:*

- *the wall thickness of the bends with* R = *3*D *shall be at least 10% greater than the wall thickness of the straight pipe in the crossing, respectively 5.5% greater for* R = *5*D *bends and 2.6% greater for* R = *10*D *bends;*

- D_e/d ratio(straight pipe in the crossing):
  R_e = 480 N/mm$^2 \rightarrow D_e/d \leq 81$;
  R_e = 415 N/mm$^2 \rightarrow D_e/d \leq 70$;
  R_e = 360 N/mm$^2 \rightarrow D_e/d \leq 61$;
  R_e = 240 N/mm$^2 \rightarrow D_e/d \leq 57$;

- *vertical bends* R ≥ *3* D *shall be mounted at the back of the pit (see Figures A.5 and A.6) unless* D_e ≥ *457 mm (18"). If* D_e ≤ *457 mm (18") then bends* R ≥ *40* D *may also be mounted in the front of the pit, provided that the backfill of the pit is well compacted;*

- *settlement differences as per A.2.3, shall not amount to more than 100 mm.*

NOTE If the method described here for drilled or jacked crossings cannot be applied, a calculation method according to C.4.7.3 of SI 5664-1 *is allowed.*

A.2.5 Category e) (railway)

Pipeline sections crossing railroads

These shall satisfy the following criteria:

- *maximum construction subsidence difference after installation; see Table C.5 of* SI 5664-1 *(well compacted pit);*

- *compliance with the boundary conditions a) through d), insofar as these are applicable for the chosen configuration (straight pipe with field bends or straight pipe with factory-made bends);*

- *the pipeline is installed in a casing pipe;*

- *the diameter of the casing pipe shall be large enough to allow after installation, the fluid-carrying pipeline, including spacers, to follow without obstruction a discontinuous construction subsidence difference of 10 cm;*

- γ_ρ *is to be applied using Table A.1);*

- *the fluid-carrying pipeline shall be bedded over an angle of least 60º at the entry to and exit from the casing.*

NOTE This can be done, for example, by mounting 3 spacers close together, and spiraled relative to one other, so that one is always carrying on 2 ribs (or more as a result of the ovalization of both pipes).

Table A.1 – Partial factors reduced strength calculation

Category	***Pipelines in, or crossing with***	***Partial Factor Internal Pressure*** γ_p	***Partial Material Factor*** γ_m
a)	*field sections and pipeline corridors* *crossings with ditches, canals and natural waterways with a width of less than 30 m, without water retaining structures and laid in open excavation*	*1.39/1.1*	*1.1*
b)	*in the shoulder of paved secondary, tertiary or quaternary roads (within 20 m from the edge of the pavement)*	*1.5/1.1*	*1.1*
c)	*under the road surface of paved tertiary, quaternary and uncategorized roads (open excavation)*	*1.5/1.1*	*1.1*
d)	*drilled or jacked crossings of ditches, canals and natural watercourses with a width smaller than 30 m without flood defences* *drilled or jacked crossings with tertiary or quaternary roads*	*1.82/1.1*	*1.1*
e)	*along or under railroads within 10 m from the outer rail, and in crossings where the pipeline is encased in a casing.*	*1.82/1.1*	*1.1*

In Table A.2, the application criteria of the reduced strength calculation for the various categories are tabulated.

Table A.2 – Summary of application criteria for the reduced analyses procedure

Category of Pipeline Section	**a1 field**	**a2 water-course**	**b shoulder**	**c road**	**d boring**	**e railway**
straight pipe with:						
- bends R ≥ 40 D	+	+	+	+	I	+
- bends 3 D ≤ R ≤ 10 D	+	+	+	0	I	I
installed:						
- in open excavation	x	x	x	x	-	-
- crossing using drilling or jacking	-	-	-	-	x	x[II]
soil cover between 0.8 m and 2.5 m	x	x	x	x	x	x
Traffic load class (max. soil + traffic load on top)[III]						
- "Lorry 4":1.2 *factor: 0.5[XI] (55 kN/m²)	+	+	-	-	+	-
- "Lorry 4":1.2 *factor: 1.0[XI] (65 kN/m²)	-	-	+	+	+	-
- "Load Model 3" [XII] (85 kN/m²)	-	-	-	+	+	-
difference in construction subsidence over at least 2x20 m						
- according to Table C.3 of SI 5664-1	+	-	+	+	-	-
- according to Table C.5 of SI 5664-1	-	+	-	-	+	+
maximum difference in settlement in mm	IV	100	100	100	200	200
- for the case of 3 *D* ≤ *R* ≤ 10 *D*	IV	100	100	-	100	100
maximum temperature difference in K	35	35	35	35	35	35
- for the case *D* ≤ 323 mm and 3 *D* ≤ *R* ≤ 10 *D* [IX]	20	-	20	-	-	-
dimensions of the pipeline						
- wall thickness d_n ≤ 4.78 mm	x	x	x	x[X]	x[X]	x[X]
- D_e/ *d* ratio [V]	x	x	x	x	x	x
- D_e/ *d* ratio [VI]	-	-	-	-	x[VII]	x[VII]
wall thickness increase increment in bends per [VIII]	x	x	x	x	x	x
design factor internal pressure	1.39	1.39	1.50	1.50	1.82	1.82

Legend: x = requirement; + = permissible; 0 = not permitted in a crossing; - = n.a.

I Bends to be installed on the field side of the pit, unless D_e ≤ 457 mm.

II With casing, bedding angle near the end of the casing greater than 60°, 100 mm clearance and well compacted pit

III If it can be demonstrated that the soil- and traffic load does not exceed limit values given in brackets, the requirement regarding soil cover and traffic load class can be waived.

IV 100 mm minus f_v from Table C.3 in SI 5664-1.

V R_e = 480 N/mm²; D_e/d ≤ 106;
R_e = 415 N/mm²; D_e/d ≤ 92;
R_e = 360 N/mm²; D_e/d ≤ 80;
R_e = 240 N/mm²; D_e/d ≤ 70;

VI R_e = 480 N/mm²; D_e/d ≤ 81;
R_e = 415 N/mm²; D_e/d ≤ 70;
R_e = 360 N/mm²; D_e/d ≤ 61;
R_e = 240 N/mm²; D_e/d ≤ 57;

VII If 3*D* ≤ *R* ≤ 10*D* bends are being used

VIII *R* = 3*D* + 10%, *R* = 5*D* + 5.5%, *R* = 10*D* + 2.6% increment relative to the straight pipe in the crossing.

IX When using 2 horizontal bends, the center-to-center distance between bends shall be 2.0 m or more.

X d_n crossing ≥ d_n field section

XI For traffic load model, in conformity with "Fatigue Load Model 2, lorry 4" from Table 4.6 of EN 1991-2:2003, Graphic I, Figure C.17 from SI 5664-1.

XII For traffic load model as per "Load model 3" (special transport) of EN 1991-2:2003, Graphic II, Figure C.17 from SI 5664-1.

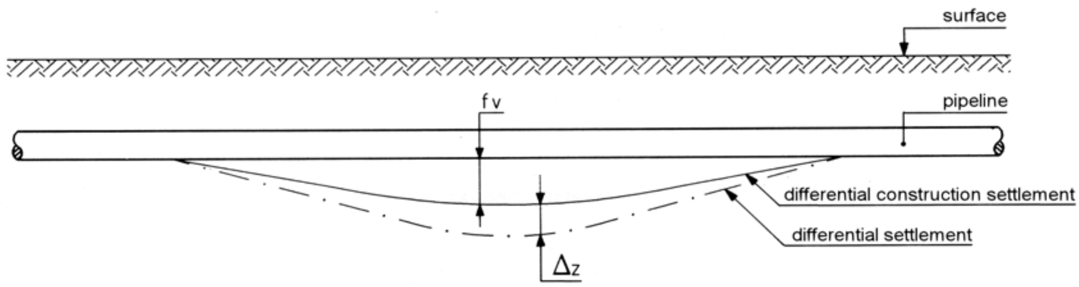
A.3 Figures for reduced strength calculation

These figures pertain to various categories of pipeline segments which are included in the reduced strength calculation, drawn below (not to scale).

Legend:

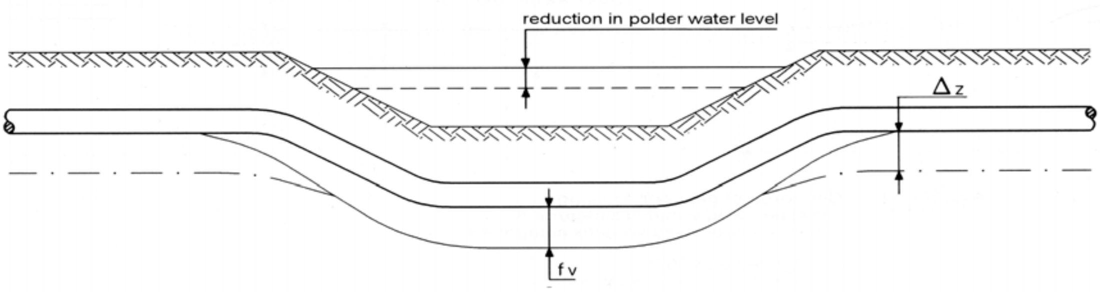
f_v *is the maximum difference construction subsidence*

Δz *is the maximum difference in settlement* *(words in parentheses have been deleted)*



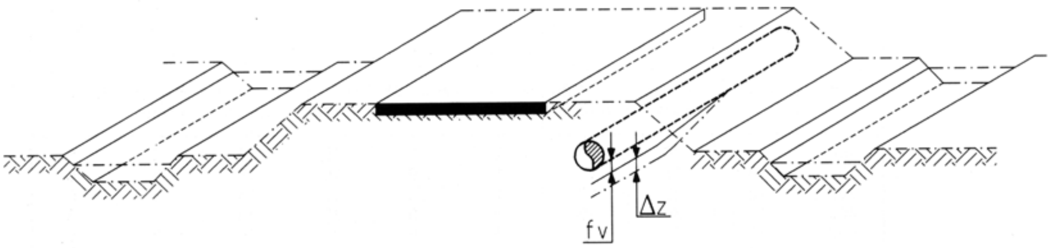
f_v *as per Table C.3 of* SI 5664-1
Δz *= 100 mm –* f_v

Figure A.1 – Field section according to Category a1



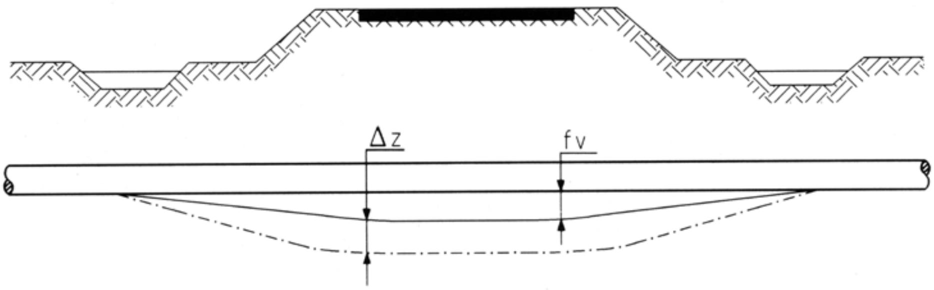
f_v *as per Table C.3 of* SI 5664-1
Δz *= 100 mm*

Figure A.2 – Crossing watercourse as per Category a2



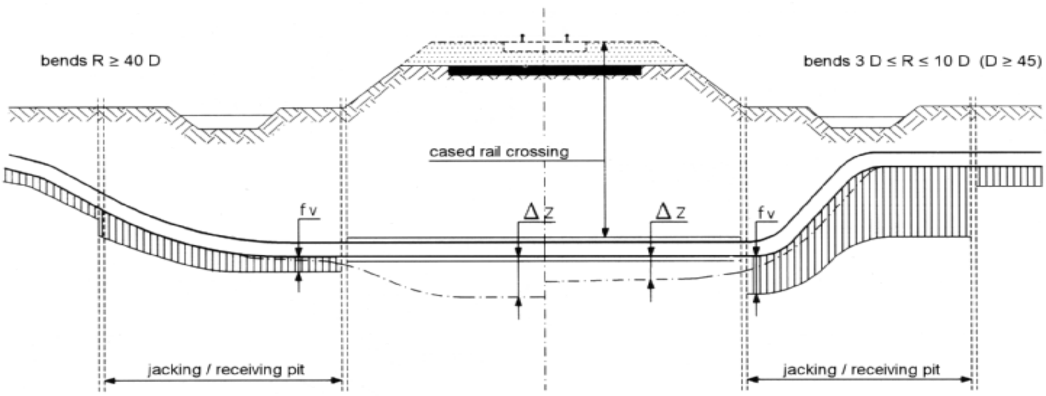
f_v *as per Table C.3 of* SI 5664-1
Δ z = 100 mm

Figure A.3 – shoulder of road as per Category b



f_v *as per Table C.3 of* SI 5664-1
Δ z = 100 mm

Figure A.4 –Crossing of road as per Category c *(words within the parentheses have been deleted)*

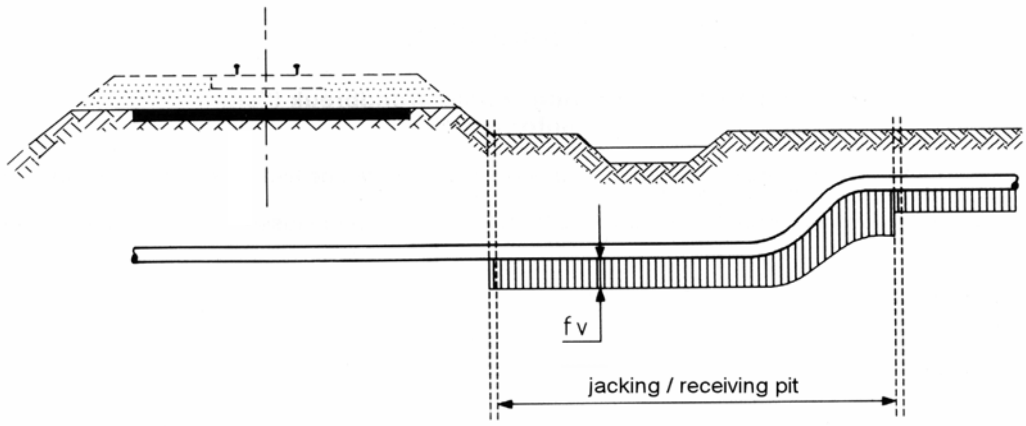


f_v *as per Table C.5 of* SI 5664-1*:* *pit loosely compacted for category d),*
pit well-compacted for category e),

Δ z = 200 mm for bends R *≥ 40* D,

Δ z = 100 mm for bends 3 D *≤* R *≤ 10* D

Figure A.5 Drilled, or jacked crossing of a road as per category d)



When applying D $\leq$ *457 mm and 3*D $\leq$ R $\leq$ *10*D

Figure A.6 – Alternative to Figure A.5

Appendix B
(normative)

Material Specifications

B.1 Overview specifications and hot yield strengths

B.1.1 Introduction

The tables of this appendix are listing a number of material specifications which are in effect, in combination with with any supplementary stipulations and particulars.

All of the materials shall only be used within the scope of application of the relevant specification or standard.

NOTE For example, materials corform EN 10208-1:1997 *AND ISO 3183-1:1996 standards are, according to the foreword of these standards, not meant to be used for transportation pipelines.*

The tables also specify the hot yield strength (R_e (θ) for a number of materials. However, if hot yield strengths are specified in an EN- or ISO standard, referred to in this standard as a material specification, such values may be used instead of the values from the tables of this appendix.

These tables are not exhaustive. In addition to the cited materials, there are still a great number of specific materials ("specials"), having limited scopes of application. These materials shall comply with the model specifications of B.2.

Supplementary requirements relative to notch toughness testing are described in B.1.3.

If a material – according to a specification that is part of a national standard – is produced in another nation, it will not necessarily comply with the specified hot yield strength. When in doubt, further data or supplementary proof may be needed. This is true as well for specifications in regional or international standards (e.g., EN- or ISO standards) if the country which produced the material has not accepted such standard as a national standard.

Note:
In order to meet the requirements of the Standard, when purchasing materials, the requisitioner shall specify all the relevant requirements stated in this Standard. The supplier shall meet all of the requirements stated in the purchase order and shall certify that he has met the purchase order requirements. Stamping of materials shall be in accordance with the specified international accepted standard only. No SI 5664 stammping is required.

B.1.2 Specifications and hot yield strength

B.1.2.1 Pipe (seamless and welded)

For hot yield strengths from Table B.1 and Table B.2 the following conditions shall be met:

a) for material thickness $d_n \leq 35$ mm, the values of R_e (θ) from the tables can be used in the calculations, provided that one hot yield strength test is carried out at 150°C for each cast and each thickness of material; the result of this test shall be reported in the inspection certificate, and shall not be lower than the value in the table;

b) any higher value that might be found, shall not be brought into the calculation;

c) for material thickness 35 mm < $d_n \leq 40$ mm, other conditions being equal, the table values for R_e (θ) shall be lowered by 10 N/mm^2;

d) if the hot yield strength test as per a) is not carried out, then R_e (θ) shall be determined as follows:

$$R_e(\theta) = \frac{R_m(720 - \theta/^\circ C)}{1400}$$

NOTE The material specifications give the specified minimum yield strength (R_e or R_e (θ)). The calculation value of the yield strength (R_{eb}) is determined by dividing the specified minimum yield strenght by the material (resistance) factor.

Table B.1 – Linepipe: EN-, ISO-, API-, ASTM- specifications and hot yield strength

Name			Supplementary requirements and particulars for application	$R_e(\theta)$ [N/mm^2] θ [°C] ($d_n \leq 40$ mm)			
Specification	**Material/ type of steel**	**Material No.**	a, b	**≤ 50°C**	**100°C**	**150°C**	**200°C**
EN 10208-1	L210	1.0307		210	182	163	
EN 10208-2 ISO 3183-2	L245NB	1.0457	LT	245	208	187	
	L290NB	1.0484	LT	290	255	235	
	L360NB	1.0582	LT	360	304	284	
	L415NB	1.8972	LT	415	363	343	
	L290MB	1.0429	LT	290	255	235	
	L360MB	1.0578	c,LT	360	304	284	
	L415MB	1.8973	c,LT	415	363	343	208
	L450MB	1.8975	c,LT	450	402	373	
	L485MB	1.8977	c,LT	485	422	392	
ISO 3183-3	L245NC L290NC L360NC L290MC L330MC L415MC L450MC L485MC						
EN 10216-2	P235GH	1.0345	f	225	198	187	170
EN 10217-2	P265GH	1.0425	f	225	226	213	192
EN 10217-5	16Mo3	1.5415	f	270	243	237	224
EN 10216-2	13CrMo45	1.7335	$d_n \leq 40$ mm	290	264	253	245
EN 10028-3	P355NH	1.0565	$d_n \leq 35$ mm	355	304	284	255
	P355NL1	1.0566	$d_n \leq 35$ mm	355	217	199	182
API Spec. 5L PSL2 only	Gr. A		[a],[b]	207	182	163	
	Gr. B		[a],[b]	241	208	187	
	Gr. X42		[a],[b]	289	255	235	
	Gr. X46		[a],[b]	317	275	255	
	Gr. X52		[a],[b]	358	304	284	
	Gr. X56		[a],[b] c, [C] ≤ 0,23 %	386	333	314	
	Gr. X60		[a],[b] c, [Ceq] ≤ 0,45 %	413	363	343	
	Gr. X65		[a],[b] c, [Ceq] ≤ 0,45 %	448	402	373	
	Gr. X70		[a],[b] c	482	422	392	
ASTM A 106	Gr. B		[a],[b] c, d, e	241	215	198	182
ASTM A 333M	Gr. 6		d, e, LT, [C] ≤ 0,23 %	241	215	198	182
AISI 304							
AISI 316							
ASTM A 312M	TP304	S30400		170	145	132	122
	TP304L	S30403		205	170	132	122
	TP316L	S31603		170	144	131	120
	-	S31254		300	235	215	195
VDTÜV 418 SAF 2205	X2 CrNiMoN 22 5 3	1.4462		450	360	335	310
		S31803		450	360	335	310

[a] The pipelines shall also be marked with the cast number.

[b] Ratio between the yield strength and tensile strength (as given by the tensile test of the parent material) ≤ 0.90.

[c] For the given materials, the actual (measured) yield strength $R_{e\ (a)}$ and the actual hot yield strength shall not exceed the guaranteed minimum yield strength or the hot yield strength respectively with more then: for L360MB and L385M: 130 N/mm^2, for L415MB and L450MB: 120 N/mm^2: for L485MB: 100 N/mm^2. For API material this is: for X52 and X56: 130 N/mm^2, for X60 and X65: 120 N/mm^2, for X70: 100 N/mm^2. The maximum allowable yield strength thus defined, is called $R_{e\ (a,\ max)}$.

[d] Transverse notch impact test for d_n > 20 mm.

[e] Hot yield strength tested at 300 °C.

[f] Can be applied for district heating pipelines per EN 13941:2003, supplementary diameter and wall thickness tolerances. Not applicable for intrinsically dangerous substances per A.1.2.1 of SI 5664-1.

LT: Steel with specified notch-impact value at temperatures ≤ 0 °C;

[a] Supplementary requirement to notch impact value per 8.2.5.1.

[b] Supplementary requirement to chemical composition per 8.2.5.2

B.1.2.2 Flanges (Forgings)

Supplementary to 8.2.4.4, Table B.2 provides specifications with supplementary requirements, particulars regarding application and hot yield strength.

Table B.2 – Flanges: Specifications and hot yield strengths

Name		**Supplementary requirements and particulars for application**		***$R_e(\theta)$* [N/mm²] θ [°C] ($d_n \le 40$ mm)**			
Specification	**Material/Type of steel**			**≤ 50**	**100**	**150**	**200**
EN 10222-2	P245GH	Inspection	[b]				
	P280GH	per	[b], LT				
ASTM A 105M	P305GH	batch	[b], LT				
ASTM 350M		[C] ≤ 0.23 %	[a], [b], [a], [c]		226	220	214
	Gr. LF 2	[C] ≤ 0.23 %	[b], LT		226	220	213

[a] Heat treatment and mechanical testing is required for all dimensions.
[b] ≤ 300 °C. Application of non-standard flanges limited to $p_a D_l \le 20{,}000$ bar.mm.
[c] The type with [C] ≤ 0.23 % in normal annealing condition is in conformity with C21, VdtÜV, Werkstoffblatt 399.
LT: Steel with specified notch-impact value at temperatures ≤ 0 °C.

[a] Supplementary requirement for notch impact value per 8.2.5.1.
[b] Supplementary requirement for chemical composition per 8.2.5.2.

The values for hot yield strengths from Table B.2 shall only be applied, when the following conditions are met:

a) for material thickness $d_n \le 100$ mm, the values of $R_e(\theta)$ from the table can be used into the calculation, provided if $\theta > 100$ °C, a hot yield strength test at 300 °C shall be carried out for each cast of the thickest semi-manufactured goods; the results of this test shall be reported in the inspection certificate, and may not be lower than the value in the table. Any higher result that might be found, shall not be brought into the calculation;

b) *For material thicknesses 100 mm* < $d_n \le$ *200 mm, other requirements being equal, the table values for* $R_e(\theta)$ *shall be lowered by 10 N/mm²;*

c) for material thickness above 200 mm, the $R_e(\theta)$ to be brought into the calculation shall be determined separately;

d) in case the hot yield strength test as per a) is not carried out, $R_e(\theta)$ shall be calculated as follows:

$$R_e(\theta) = \frac{R_m(720 - \theta/^{o}C)}{1400}$$

B.1.2.3 Bolts and nuts

B.1.2.3.1 Specifications, required inspection certificate and hot yield strength test

Table B.3 states the (material) specifications with the supplementary requirements and particulars for application, and with (for some specifications), the hot yield strength.

The values of $R_e(\theta)$ can be brought into the calculation without further testing.

Table B.3 - Bolts and nuts: Specifications, required inspection certificate and hot yield strength

Name			Supplementary stipulations and particulars for application	Requirement inspection certificate bolts/ nuts per EN 10204	Required inspection certificate for rod material	$R_e(\theta)$ [N/mm²] θ [°C] ($d_n \le 40$ mm)			
	Specification	**Material/type of steel**	[b, e]			**≤50**	**100**	**150**	**200**
Bolts	ISO 898-1	4.6-2	[f], W	m [h]	3.2				
	DIN 267 part 13	5.6	[f], W	m [h]	3.2				
		8.8	[f, g]	3.1	3.1				
	ASTM A193	Gr. B7	[c, d]	3.2, 3.1, [a]	3.2, 3.1 [a]		470	453	442
		Gr.B7M	[c, d]	3.2, 3.1, [a]	3.2, 3.1, [a]		357	344	336
	ASTM A 320	Gr.L7	[c, d], LT	3.2, 3.1, [a]	3.2, 3.1, [a]				
		Gr. L43	[c, d], LT	3.2, 3.1, [a]	3.2, 3.1, [a]				
Nuts	ISO 898-2	5-2	[f]	m [h]	m [h]				
	DIN 267 part 13	8	[f,g]	m [h]	m [h]				
	ASTM A 194	Gr.2	[d]	3.1	3.1				
		Gr.2 H	[d]	3.1	3.1				
		Gr. 4		3.1	3.1				
		Gr. 7		3.1	3.1				

[a] An inspection certificate 3.1 is sufficient for standard bar bolts with $D \le 51$ mm.
[b] Notch impact test and requirements per 8.2.5.1.
[c] Checking surface faults for bolts with $D > 51$ mm.
[d] At the end phase, products shall be checked for material changement.
[e] Identifying markings as per Appendix B.2.3.6.
[f] ≤ M30, $\theta \le 300$ °C: $p_a \le 4$ MPa.
[g] Application limited to connections with an internal diameter up to and including 500 mm.
[h] No inspection certificates required, but identifying markings are, per B.2.3.6.
LT: Steel with the specified notch impact value at temperatures ≤ 0 °C.
W: Steel with specified mechanical properties at temperatures above room temperature.

The determination of the required inspection certificate 3.2, 3.1 or mark 'm' is based on Table B.4. An inspection certificate of the bar stock material is required if the mechanical testing was carried out on the bar stock material and, subsequently the bolts and nuts were made by machining only In all cases the bolts and nuts shall be supplied with the required inspection certificate or mark.

If inspection certificate 3.2 or 3.1 is cited in Table B.3, then inspection certificate 3.1 will be accepted for bolts, nuts, and bar stock material with D ≤ 51 mm.

Table B.4 – Required inspection certificate per EN 10204:1995 for bolts and nuts

R_m		Rod material for		Bolts	Nuts
		Bolts	Nuts		
≤ 600 N/mm²		3.2	m[a]	m[a]	m[a]
> 600 N/mm²	D ≤ 51 mm	3.2	3.1	3.1	3.1
	D > 51 mm	3.2		3.2	

[a] No inspection certificate required, but identifying markings are required as per B.2.3.6

B.1.3 Notch ductility testing

Determining plate thickness d_c

The determining plate thickness d_c is derived from the thickness d_n per construction drawing or dimension table.

a) for welding neck flanges, d_c equals the greater of the two following values:

- d_n of the welding end;

- 0.25 d_n of the flange (plate) at the bolt circle.

b) for welded components of with unequal thickness, where (slope of) the taper does not exceed 1:4, d_c shall be no more than equal to the thickness on the weld side. (see figure B.1).

c) for welding, d_c is equal to the greatest adjacent welding-edge thickness

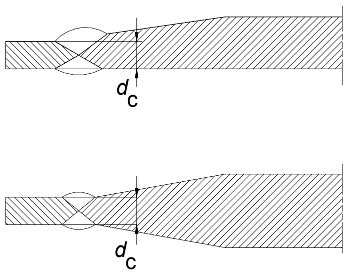


Figure B.1 – Welded parts with different thickness

Sampling

The position and orientation of notch impact test samples of rolled steel for pipes, shall satisfy EN 10208-2:1996, ISO 3183-2:1996 and ISO 3183-3:2000. Table B.5 states requirements for the other components.

Table B.5 Position and orientation for notch impact test samples

Component	d_n mm	**notch impact test samples** [a] site	direction long. axis
plate, forged cylinders, spheres or cones	≤ 40	-	
	> 40	centerline ≤ 0.25 d_n of the surface area	transverse [b]
other forgings	≤ 40	-	
	> 40	centerline ≤ 0.25 d_n of the surface area	-
cast fittings	each	-	-
Bar (rod) material	each	Distance of center line at least 0.17 times from the diameter or the diagonal of the surface away	-

[a] **If not filled in: there is no requirement for position or orientation of the test sample.**

[b] Transverse: perpendicular to the direction of the last rolling, or to the direction of the maximum forging.

Test temperature

The test temperature for the notch impact test with Charpy-V test samples, if required according to the model specification in B.2, shall comply with Figures B.2 – B.5 incl.

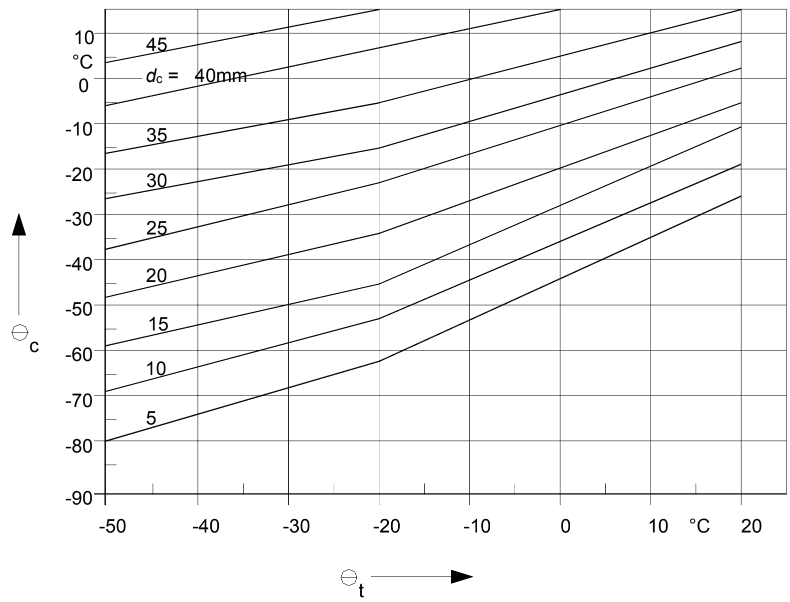


Figure B.2 – Test temperature θ_t for the notch impact ductility test of ferritic material with Ni < 1.5% and $R_m \leq$ 450 N/mm², where non-heat treated welds are present in or onto the pressurized section Extrapolation is not permitted.

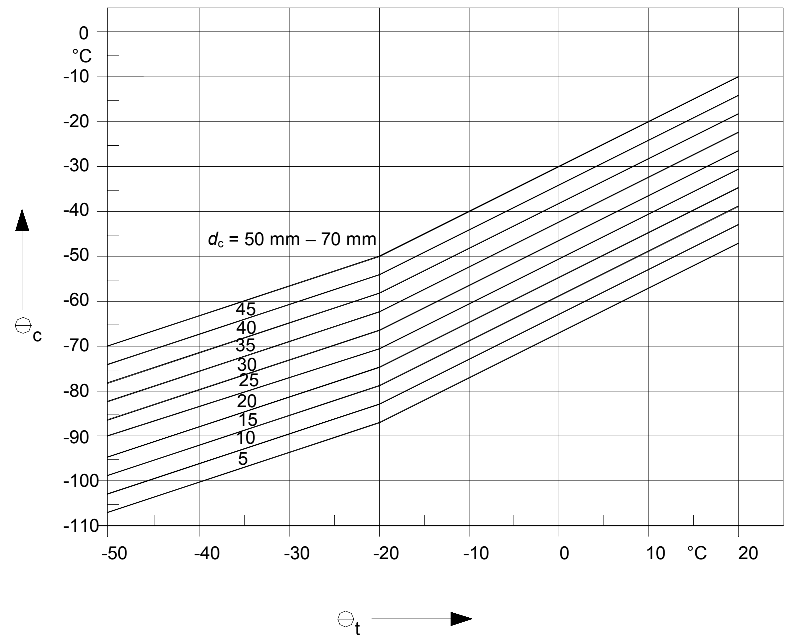


Figure B.3 - Test temperature θ_t for the notch impact ductility test of ferritic material with Ni < 1.5% and $R_m \leq$ 450 N/mm², where any weld present in or onto the pressurized section have been heat-treated. Extrapolation is not permitted.

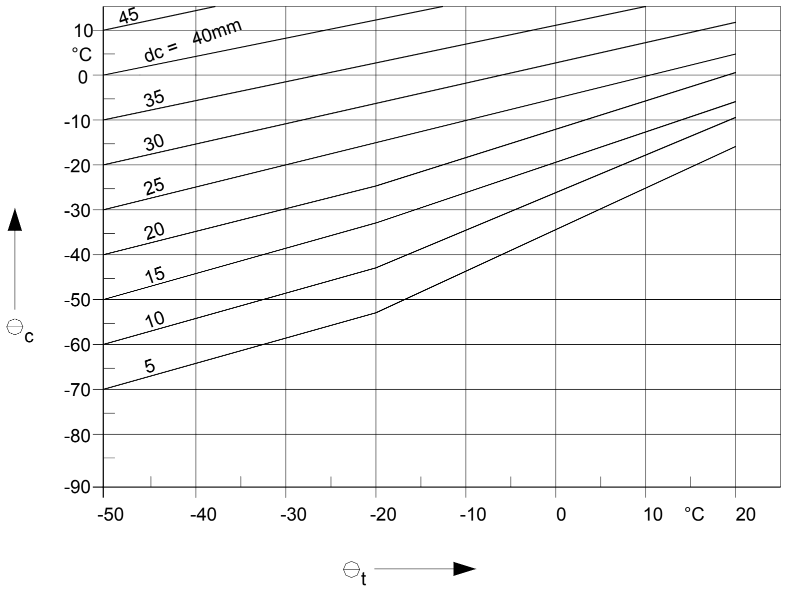


Figure B.4 – The test temperature θ_t for the notch impact ductility test of ferritic material with Ni < 1.5% and $R_m > 450$ N/mm², where non-heat treated welds are present in or onto the pressurized section. Extrapolation is not permitted.

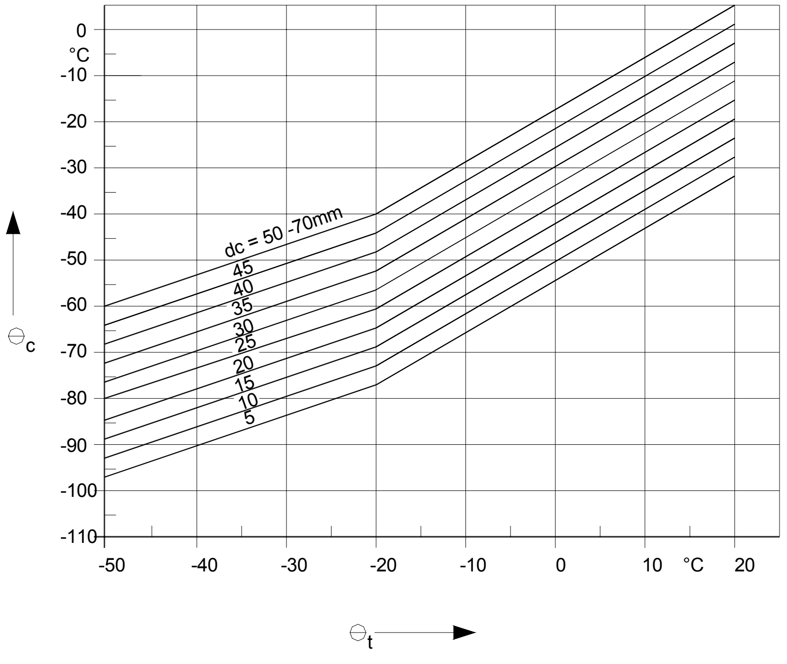


Figure B.5 - The test temperature θ_t for the notch impact ductility test of ferritic material with Ni < 1.5% and $R_m > 450$ N/mm², where any welds present in or onto the pressurized section have been heat-treated. Extrapolation is not permitted.

B.2 Model specification and Order Specifications

B.2.1 Acceptance of a material specification

B.2.1.1 Requests

The following types of requests:

- request for acceptance of a material specification not cited in this standard, submitted by a manufacturer;

- acceptance of a material specification cited in this standard, submitted by a new manufacturer;

shall be directed to a for these services accredited inspection institution type A or B, as per ISO/IEC 17020:1998.

The following information shall be submitted along with the request:

- the complete material specifications including:

- characteristic designation;

- revision number and date;

- scope;

- (compliance ??);

- the results of the materials testing (for use by the inspection institution);

- the required inspection certificate.

NOTE In principle the only specifications which can be accepted, are those which comply with EN standards and/or ISO standards, cited in this standard.

B.2.1.2 Material specifications

The material specifications shall always include the following elements:

Characteristic designation of the material

- the name or trade name of the pipe manufacturer (X);

- the number of the (European) standard and steel grade;

- the type of pipe (seamless S or welded pipe W);

- in case an inspection certificate is submitted, the type of certificate shall be specified (e.g., EN 10204*:2004* 3.2 *or* 3.1*).*

- the mark of the inspector or the inspection institution (Y);

- an identification number correlating the product delivered with its inspection certificate (Z).

EXAMPLE X EN 10208-1 L360GA S Y Z

Edition

The specification shall unambiguously indicate the revision, by issue date, revision number, etc.

Scope

The specification shall include information about the dimensional range within which the specified material properties are valid.

Dimensional tolerances

The specification shall stipulate the checking of dimensions, and the tolerances to be considered in case the dimensions deviate from the relevant EN standards. Apart from that, these dimensions shall, as a minimum, comply with these standards.

Chemical composition

The specification shall include requirements regarding chemical composition. The cast analysis shall be equivalent to the ISO 3183 series . The end of the sentence has been deleted.

Steel manufacture.

The steel shall be fully killed. Unkilled steel is not acceptable.

Product manufacture

Heat treatment

Mechanical properties

- *Yield strength; the specification shall state the minimum required yield strength at room temperature. "Yield strength" means either the stress for 0.2 % permanent strain, the stress for 0.2% non-proportional strain, the stress for 0.5% of the total elongation under load, as well as the upper or lower yield point. The specification shall clearly state the used definition for the yield strength .*

- *Strain; the specification shall state the minimum required elongation at break of a tensile test bar, with a length of* l_o *in mm equal to 5.65* $\sqrt{A}$*; this requirement shall fit with the type of steel considered, but shall amount to at least 18%, in which* A *is the surface area of the perpendicular cross-section of the tensile test bar in* mm^2.

Scope and requirements of non-destructive testing

A specification is acceptable if it requires that all pipe ready for delivery be subjected to complete and effective non-destructive testing (see also C.2); (for seamless pipe with a diameter less than 200 mm, this testing may be carried out before hydrostatic testing).

Markings

The specification shall require that products ready for delivery be effectively marked with the casting number.

Checking for materials substitution

The specification shall require that alloyed steel, nickel and nickel alloys products ready for delivery, be duly tested for materials substitution (e.g., by microscopic testing).

B.2.1.3 Materials Testing Results

The results of the materials testing shall minimally include the following:

1) *(If mentioned in the model description) tensile strength, yield strength, elongation after fracture, and reduction of cross-section at room temperature, and at temperatures at least 50 K higher than the specified maximum metal temperature (if the material is to be used where metal temperatures will be > 50 °C);*

NOTE If a tension test sample of another length is used, then the elongation measured after fracture shall be referred to a standard measure of 5.65 √A, as per ISO 2566-1:1999.

2) notch impact toughness (transverse if so prescribed in Table B.5) at room temperature;

3) data about physical properties such as elasticity modulus, coefficient of expansion, heat conductivity coefficient, etc. insofar as significant for the application;

4) (only if notch toughness test at temperatures < 20 °C are specified) sufficient data to be able to determine the transition temperature of the notch toughness (longitudinal). The results shall relate to condition of the material that is ready for delivery, and any condition it might be in following heat treatment which can occur during the processing of the material;

5) (only if the weldability of the material is specified) the results of the notch-impact toughness- and hardness testing of the fused weld metal and the heat-affected zone. Batches, whose chemical composition might have an – expected - negative influence on the results, shall be used for welding tests;

6) data about the technological properties such as weldability, suitability for cold and hot forming, fracture sensitivity.

B.2.1.4 Required inspection certificate (for acceptance of a material specification)

General

*The inspection certificates shall be prepared and validated certifying agreement with the requirements of this standard, based on inspection and testing carried out by or under the supervision of an accredited inspection body cited in B.2.1.1. For approval of a new material specification or a new manufacturer, an inspection certificate 3.1.A as per EN 10204:*2004 *is required.*

Content of the inspection certificate

The inspection certificate shall be prepared according to EN 10168*. It shall include at least the following data:*

1) information provided by the steel manufacturer:

- the steel preparation process;

- the chemical composition, with the results of the cast analysis for the specified elements;

2) information from the product manufacturer:

- the heat treatment undergone, including the temperature cycles that were run through, and the methods of cooling;

3) from a technical expert associated to the product manufacturer, being independent from the production departments involved;

- the results of the materials substitution check (if applicable);

4) verified by the person issuing the inspection certificate;

- the nature, scope and results of the mechanical investigation;

- the results of visual inspection and the dimensions check;

5) a declaration that the shipment complies with the specification requirements cited in the inspection certificate. (E.g., EN 10208-2:1996 *or equivalent ISO.)*

B.2.1.5 Supplementary stipulations for acceptance of a material specification (pipe)

Scope and requirements of mechanical testing:

Sampling

1) a specification can be accepted if the required mechanical testing relates to at least:

- *1% of the number of pipes, if* $D_e \leq 500$ *mm;*

- *2 % of the number of pipes, if* $D_e > 500$ *mm.*

2) A batch means a quantity of pipes that comply with the following conditions:

- *the same diameter and wall thickness;*

- *the same cast;*

- *the same steel quality;*

- *the same tunnel oven run or annealing furnace batch (if no heat treatment takes place);*

- *hot formed in the same way. If it appears from the temperature record that the temperature of a number of annealing furnace batches do not differ from one another by more than 15 K, then these can be treated as a unit.*

3) the testing shall take place on pipe that is ready for delivery.

4) a sample shall be taken from each pipe that is designated.

Required testing.

The scope and requirements of the mechanical testing are in conformity with ISO 3183 series. The end of the sentence has been deleted.

Production

For cold formed steel, permanent strain shall not exceed 5 %.

With HFW welded pipe, the weld shall be subjected to heat treatment (when a pipe has been thermo-mechanically treated, treat only the weld!).

Maximum wall thickness

For a plate thickness ≥ 40 mm, a post-welding heat treatment may be necessary, for application within the scope of this standard.

B.2.2 Flanges (forgings), unalloyed and low-alloyed steel (model description for specifications)

B.2.2.1 Product manufacture

Acceptable forging methods are:

- *forging by hammering or intermittent pressure forging;*

- *pressing;*

- *extrusion.*

During the forging, the steel of the entire cross-section of the forging shall be re-formed.

B.2.2.2 Heat treatment

Depending on the type of steel, the material shall be delivered in a normalized or tempered *condition. This need not be adhered to if the material will undergo the required heat treatment afterwards.*

B.2.2.3 Mechanical testing

Sampling

The number of samples per forging or batch of forgings , which shall be taken for mechanical testing, shall be at least:

1) for forgings with a mass > 3,500 kg and for hollow forgings with a length > 3 m:

- *one sample from each end;*
- *for forgings where the diameter is greater than the length: two samples on the outer surface, diametrically opposite at the greatest distance from each other;*

2) for forgings with a mass > 1000 kg but ≤ 3500 kg, with the exception of hollow fittings with a length > 3 m:

- *one sample from one end*
- *for forgings made by reducing the length of a bar : one sample from one location on the outside surface;*

3) for forgings with a mass ≤ 1000 kg:

- *one sample per batch of identical forgings which were made from the same melt and belong to the same annealing oven batch, or to the same heat treatment sequence in a tunnel oven;*
- *one sample per batch of identical forgings which were made from one piece with a mass > 1000 kg, and were separated only after the last heat treatment.*

Heat treatment of the samples

The samples shall be selected in ready for delivery condition after the last heat treatment of the forging.
For closed hollow forgings, the required samples may be selected before the forging is closed.
In such case the test samples shall undergo the remaining heat treatment together with the forging from which they were taken.
For material which is delivered without having undergone the required heat treatment, the samples shall be subjected to the remaining heat treatment according to the specifications.

Test pieces

If the forging is a cylinder, sphere, cone or plate, or forms a part of such component, the test samples have to be taken perpendicular to the greatest stress.(largest dimension?) For all other forgings, there is no preference regarding the removal of the test pieces.

Position of samples:

- *for a forging thicker than 40 mm. which is cylindrical, spherical, conical or a plate or a part of one of these, the distance between the outer surface and the axis of the test piece shall be at least ¼ of the wall thickness of the forging;*

- *in all other cases, the axis of the test piece shall be at least 12.5 mm away from the outer surface.*

The specification shall require for each sample the selection of the following test pieces:

- *tensile test: a cylindrical tensile test piece;*

- *notch impact test piece: in those cases where a notch impact test is required, three Charpy-V notch impact test pieces. The specification can also require DVM.*

A notch impact test is required in the following cases:

a) for flanges, flat flange-covers, bars, bolts and nuts with wall thickness > 50 mm;

b) for other forgings;

- *unalloyed steel with $R_m \leq 450$ N/mm^2 and wall thickness > 20 mm.*
  If the specification specifies notch impact values, this thickness limit is increased to 50 mm;

- *other unalloyed and low-alloyed types of steel with wall thickness > 10 mm.*

The selection of test pieces shall comply with Table B.5.

B.2.2.4 Non-destructive testing

The specification shall prescribe ultrasonic testing for each forging with d_n > 100 mm.

B.2.2.5 Mechanical Properties Requirements

Tensile Strength

The specification shall give the minimum required and the maximum allowable tensile strength at room temperature. The required minimum value shall not be less than 320 N/mm^2 and the allowable difference between the two values may not amount to more than:

- 140 N/mm^2 for unalloyed steel;

- 150 N/mm^2 for low-alloy steel.

Yield strength

The specification shall give the minimum required yield strength at room temperature.

Elongation

The specification shall give the minimal required elongation after fracture for a tensile test piece with a measured length l_o equal to 5 D_o (D_o is the diameter of the test piece) This value shall be at least:

- 16 % for unalloyed steel;

- 14 % for low-alloyed steel.

If a tensile test piece with a different length is used, then the measured elongation after fracture according to ISO 2566-1:1999 shall be recalculated to the standard length 5 D_o.

Notch impact value

The specification shall state the following requirements regarding the results of the notch impact test:
These requirements hold for notch impact test with Charpy-V test pieces:

- for unalloyed steel with $R_m \geq 450$ N/mm^2; average of three tests 27 J, minimum individual value 18.9 J;

- for all other unalloyed and low-alloyed steels: average of three tests 31 J, minimum individual value 21.7 J.

B.2.2.6 Surface testing and tests for internal faults

The specification shall include stipulations for testing for surface- and internal faults, and what kinds of results are required to meet the specifications.

B.2.2.7 Markings

Marks to be affixed

Each forging shall be marked with the following:

- a mark identifying the type of steel;

- a manufacturer's mark: this shall be a specific mark and not a combination of standard characters;

- markings which makes it possible to correlate inspection certificates, forgings, and batches to one another;

- (if applicable) mark of the inspection body.

The marks shall be chosen such that confusion with other forgings is not possible.

Means of affixing

The stamp shall be affixed in a durable manner.

For flanges with $D_e \leq 61$ mm, the marks may be duly applied on a sticker on the packaging.

B.2.3 Bolts and nuts (model description for specifications)

B.2.3.1 Manufacture of the product

The material, from which the bolts and nuts are manufactured, can be forged, rolled, or drawn.

Bolts and nuts can be manufactured by cold-forming, hot-forming, machining process, or by a combination of these.

Threading bolts by cold rolling does not require a follow-up heat treatment.

B.2.3.2 Heat treatment

Bolts and nuts shall be supplied in heat treated condition.

The heat treatment shall be appropriate for the type of steel and method of manufacture.

The heat treatment may be applied to the bar stock, or to the bolts and nuts, depending on the method of manufacture.

B.2.3.3 Scope of mechanical testing
Sampling

To be a batch, the bar stock, bolts and nuts shall comply with all the conditions below:

- the same dimensions;

- the same batch from the (s)melting oven;

- the same annealing furnace charge, or the same heat treatment run in a tunnel oven.

The specification shall indicate how the homogeneity of the batch is established.

For material to be used for bolts and nuts, which do not have to undergo another heat treatment, two test samples per batch, are required. If the starting material consists of bar stock, the two samples shall be selected from different bars.

If according to the inspection certificate, the rod material has undergone heat treatment, and has the required mechanical properties, the nuts and bolts machined from it (including threading the bolts by rolling) require no further testing.

For bolts and nuts which have not been tested in accordance with the above, one sample shall be taken per batch as per Table B.6. In this table, *1 + n* represents a unit sample of bolts, in which *n* is the number of bolts needed for the required notch impact tests.

The samples shall be taken after the last heat treatment.

Table B.6 – Scope of the sample taking

Batch Size	**Sample Size**	
	Bolts	Nuts
≤ 800	1 + n	7
801 ... 8000	2 (1+n)	14
8001 … 22000	3 (1 + n)	21
> 22000	5 (1 + n)	35

Test bars and test pieces

1) Bar material and bolts
The specification shall prescribe the method for selecting from each sample (or sample unit) the following test pieces:

- tensile test piece
A cylindrical tensile test piece, of which the length l_o and diameter D_o satisfy $l_o = 5D_o$;

- notch impact test piece:
If a notch impact test is required, three Charpy-V- test pieces.

If the specification prescribes Charpy-U- test bars or DVM, these are also acceptable.

A notch impact test is required for ferritic steel with a diameter > 50 mm.

The test bars shall be taken in compliance with Table B.5

2) Nuts
For each nut to be tested, the specification shall prescribe the following tests:

- hardness test, unless the mechanical properties have been determined in some other way;

- proof load test with the load prescribed in the specification.

The following cases do not require a load test:

- test load > 350 kN;

- nut diameter > 39 mm, or 1.5 inches.

B.2.3.4 Requirements for mechanical properties
Tensile strength

The specification for the rod material for bolts shall state the minimally required and the maximally allowable tensile strength at room temperature.

The required minimum values shall not be less than 400 N/mm^2.

Yield strength

The specification for the bar stock or bolt material shall state the required yield strength at room temperature.

Strain

The specification for the bar stock or bolt material shall state the required strain after fracture, which shall be at least:

- 16% for $R_m \leq 600$ N/mm^2;

- 14% for $R_m > 600$ N/mm^2.

Notch Impact values

The specification shall state the following requirements regarding the results of the notch impact testing:

- for all the unalloyed and low-alloy types of steel: average of three tests 27 J, lowest value minimum individual 18.9 J;

- for 1.5% to 9% Ni-steel: average of three tests 39 J; minimum individual, value 27.3 J.

Up to 70 mm thickness, a test temperature of 0 °C for a design temperature of –20 °C is sufficient.
Hardness

The specification for nuts shall state the minimally required and maximally permissible hardness at room temperature.

The required value shall match the type of steel.
Proof load

The specification for nuts shall demonstrate the minimum demands for load at room temperature. The required value shall fit with the type of steel in question and the dimensions of the nut.

B.2.3.5 Surface testing

The specification shall include stipulations about the surface test, and about the resulting requirements. Such a check shall be required for all steel bolts with a diameter > 51 mm with $R_m \leq 600$ N/mm^2.

B.2.3.6 Markings

Markings to be affixed.

The markings cited below shall be affixed to bolts, nuts and the rod material for manufacturing them:

- a mark identifying the type of steel;

- a manufacturer’s mark: this shall be a specific mark and not a combination of standard characters.

And if $R_m \geq 600$ N/mm^2, on bolts with a diameter > 51 mm as well as on the rod material:

- markings which relate the inspection certificates, batches, and product to each another;

- (if applicable), mark of the inspection body.

The marks shall be chosen such that the bolts, nuts and rods cannot be mistaken for others.

Means of affixing.

The marks shall be affixed in a durable manner.

Stock bar material with a diameter of ≤ 26 mm shall have the marks duly made on a sticker and attached to the bundle or package containing the bar material.

Appendix C
(Normative)

Welding and weld examination

C.1 Supplementary and/or deviating requirements in comparison to EN 12732:2000

C.1.1 General

EN 12732:2000 is applicable, together with the supplemental requirements to each chapter, paragraph or appendix as specified in C.1.2.

C.1.2. Supplementary and/or deviating requirements to EN 12732:2000

In Chapter 4:

- Replace "If required by the pipeline operator, a quality system shall be applied to the pipeline welding" by "A quality system shall be applied to pipeline welding".
- Replace EN 729 with ISO 3834 including all its parts, respectively.
- The quality requirements contained in "Table 2" are not "recommended" but normative.
- In table 2 after "according to EN 719:1994", add: or welding inspector according to AWS (American Welding Society).
- In table 2 after "EN 473:2000" add or ASNT TC 1A:2001, level 2.
- In table 2 add after EN 288-3: or ISO 15614-1.
- In section 4.4: The last sentence is changed as follows: "All non-destructive examination personnel shall be qualified for the duties they are to perform, in accordance with EN 473:2000, level 2, or ASNT-TC-1A:2001: level; 2.
- In section 4.2, 4.3 and 4.4, replace "should" by "shall" (the requirements are a normative).

In Chapter 5:

- At the end of the first sentence, add:... the following, or equivalent as approved by the pipeline owner.
- In welding consumable list: Shielded metal arc welding: add "...or SI 1340".
- In the paragraph beginning with: "Batch testing...", replace the two first sentences with: Filler materials shall be tested and approved by a type A inspection body (see 8.2.1). The certificate shall be in accordance with EN 10204: 2004, type 3.2.
- Table 3 is normative.

In Chapter 8:

- 8.2; the scope of the non-destructive examination (radiographic and ultrasonic examination) for circumferential welds:

- NDE shall be carried out on all circumferential welds over the complete circumference.

- 8.3, paragraph 4: delete "if not otherwise agreed by the pipeline operator". And at the end: "...EN 45001:1997 or SI-ISO 17025".

- add new paragraph after paragraph 4;
  An X-ray shall be used.
  Gamma radiation may be used on circumferential pipe welds if the use of an X-ray is not possible for technical reasons, under the pipeline owner's approval and in full compliance with the Standard's requirements.

- 8.5; paragraph 4; the ultrasonic examination only refers to ultrasonic pulse-echo examination method.

  100% of all circumferential welds shall be examined by NDE methods.

In Chapter 11:

- 11.2, replace EN 287-1 with ISO 9606-1. add: or ASME B&PVC 9.

- 11.4 add: The welding procedures and consumables shall be such that they provide low hydrogen weld metal.

- 11.4.1; 2nd paragraph, Replace: "For grades L 485 and L 555 ..... and the use of Table 3 is recommended" by "For grades L 485 and L 555 ..... and Table 3 shall be used".

- 11.4.4; in addition to the documented requirements, two all-weld-metal tensile tests shall be carried out for weld connections of the above pipelines DN 500 mm. The results of every test rod shall fulfill the requirements in Table C.2 for tensile strength, in the perpendicular direction to the weld ($R_{m\perp}$), and in a parallel direction (R_{mII}) to the weld.

- 11.5.3 (Repair of weld defects): 2nd paragraph, replace "pipeline operator" with "the relevant authority".

- 11.6 EN 288-3 shall be deleted. The sentence shall be: "...Welds shall be tested in accordance with EN 288-9."

Table C.2 - Additional requirements for weld connections of pipelines

Specification of base material	Requirement melt down material
$R_e \leq 320$ N/mm^2	$R_{m\perp}$ and $R_{m//} \geq R_{m,\text{ base material}}$
$R_e \geq 320$ N/mm^2	$R_{m\perp}$ and $R_{m//} \geq 1.1 \times R_{m,\text{ base material}}$ $R_{e//} \geq 1.13 \times R_{e,\text{ base material}}$

- 11.7; Paragraph 1, 2 and 4 have been cancelled. As a supplement the following is applicable:

  1) Circumferential welding of field sections.

     For materials with a high yield strength (steel grade equivalent to L 480 or higher) and with a nominal wall thickness ≥ 6 mm, half-mechanized TOFD examinations are recommended.

The TOFD images shall be coherent. For wall thicknesses > 10 mm, the TOFD examination shall be extended with pulse-echo inspections. Circumferential welds in the base material L 480 or higher (or equivalent), welded with cellulose electrodes, shall be examined with TOFD and pulse-echo techniques, irrespective of the pipeline length.

The zone height shall, after deduction of 10 % of the wall thickness, amount to 3 mm or 4 mm. The acceptance criteria for TOFD examinations, documented in C.2.2, are applicable.

2) Other circumferential welds

For other cases, whereby a radiographic examination of the circumferential welds is carried out, Tier 1 in Table G.2.1 and Table G.2.2 are applicable for the acceptance of welding defects.

3) Welds that are not pressure tested for strength.

In supplement to Paragraph 3 of Chapter 11.7, of EN 12732:2000, it is applicable that for weld connections in (Quality) category D, with material groups 2 and 3 of ISO 15614-1:2004, and with a wall thickness of more than 8 mm, a second and different type of volumetric NDE examination shall take place.

4) Manual ultrasonic pulse-echo examination.

A manual pulse-echo examination is permitted as a supplement to radiographic or TOFD examinations. Table G.3 is applicable for those weld imperfections that are detected.

5) Combined installation of pipelines in category D.

The requirements under 1) shall be applied to circumferential welds in pipeline sections, which are installed in combination with other pipelines in one trench, regardless of the length.

6) Acceptance criteria for NDE

For the selection of acceptance criteria for welding defects with non-destructive examinations is referred to C.2.

NOTE Pipe material of a high strength, such as L 485, is more sensitive to the occurrence of welding defects than lower quality steel in a TM implementation. The use of inspection techniques with a higher "probability of detection", such as TOFD, for transport pipelines can increase the reliability of welded connections. These inspection techniques should be taken into account for critical welds showing severe consequences in case of failure. Examples are crossings, pipesections to be pulled through bore holes and welds subject to addition al stresses from deformation restrictions.

In Chapter 12:

- Chapter 12 is normative.

In the appendixes:

- Appendix A is normative.

- A.2; Summary c is only applicable for welders that shall create tie-in welds in a trench. The welder's certificate shall be amended with the certifying identification "T" (Tie-in welding). The specified dimensions are not applicable for automated welding. A clearance of 40 cm, between the pipebottom and the trench bottom, remains applicable for all welders qualifications for manual welding.

- A.3; If one single qualification weld is carried out, then the approval range for plates, respectively the pipe wall thickness. shall be in conformity with Table C.3

Table C.3 - Approval range for plate

Welding process	Thickness d_1 of the welding sample mm	Applicable range for wall thickness d mm
Arc welding with coated electrodes	< 12	$0.75\ d_1 \leq d \leq 2\ d_1$
	≥ 12	> 9
Arc welding with other electrodes	all	$0.75\ d_1 \leq d \leq 2\ d_1$

Furthermore, Table C.4 is applicable for pipes.

Table C.4 - Approval range for pipes

Welding process	Outside diameter D_e of the welding sample mm	Applicable range for outside diameter D_e mm
Arc welding	< 80	< 80
	$80 \leq D_e \leq 500$	$80 \leq D_e \leq 500$
	≥ 500	≥ 325

- Appendix B is in informative.
- Appendix C is a normative.
- Appendix D is informative.
- Appendix E is informative.
- Appendix F is informative.
- Appendix G is normative. See also C.2.1.
- Appendix H is informative.

In Chapter 6:

- 6.7: First paragraph, delete: "unless otherwise agreed by the pipeline owner".

C.2 NDE acceptance criteria

C.2.1 Acceptance criteria

Acceptance criteria shall be in accordance with ISO 5817.

Defects acceptance level shall be according to Table 1 – Quality level B.

Clauses C.2.1.1 and C.2.1.2 have been deleted.

C.2.2 Acceptance criteria TOFD

C.2.2.1 Acceptance criteria of relevant indications

NOTE See [10] for background information over the development of acceptance criteria on defects in transport pipelines.

All relevant indications shall be evaluated in accordance with Table C.5. If wall thicknesses differ, then the lowest wall thickness shall be decisive .

Table C.5 - Maximum allowable length and depth of defects, in mm.

Nominal wall thickness d_n mm	**Maximum permitted length (l_{max}) and height (h) of defects,** mm			
	Exposed defects		Enclosed defects	
	l_{max}	h_3	l_{max}	h_2
$6.0 < d_n \leq 9.0$	2 *d*	1.5	4 *d*	2.0
$9.0 < d_n \leq 15.0$	2 *d*	2.0	4 *d*	3.0
$15.0 < d_n \leq 27.0$	2 *d*	2.5	4 *d*	4.0

Fault indications are acceptable if:

- the height is ≤ 1 mm for exposed defects, up to a length of ½ *D* and up to a maximum of 300 mm;
- the height is ≤ 1 mm for enclosed defects, regardless of the length;
- 1 mm < $h \leq h_2$ and $l \leq l_{max}$ for enclosed defects;
- 1 mm < $h \leq h_3$ and $l \leq l_{max}$ for exposed defects.

With the values for h_2, h_3 and l_{max} as given in the table.

A group of fault indications, for which the individual indications are acceptable, is only acceptable if all of the following conditions are fulfilled:

1) the distance between the successive indications, paralle to the weld direction, is greater than the length of the average length of the indications;

2) if the distance between two successive indications, in the direction of the thickness of the weld, is greater than the height of the highest indication;

3) if the sum of the lengths of the individual indications is ≤ 7 x *d*, measured over any length of ½ *D*, up to a maximum distance of 300 mm from the weld.

Indications that do not fulfill the above-mentioned conditions 1 and 2 shall be treated as one single indication. The defect dimensions "*h*" and "*l*" shall then be measured under inclusion of the distance between the indications, and Table C.5 shall be utilized for the evaluation.

C.2.2.2 Single diffraction signals

Whenever single diffraction signals are visible in a TOFD scan, then the maximum number of acceptable and relevant indications shall not exceed the values from Table C.6 for each edge zone over a length of ½ *D* and up to a maximum distance of 300 mm.

Table C.6 - Maximum permitted number of single diffraction signals per edge zone of ¼ *D*

Nominal wall thickness d_n mm	Maximum allowable number of single diffraction signals per edge zone of ¼ *D*
$6 < d_n \leq 9$	20
$9 < d_n \leq 15$	30
$15 < d_n \leq 27$	40

C.3 Post –weld heat treatment

C.3.1 Scope

The data in Table C.3 is applicable for field welding in pipes, which are made of alloyed or unalloyed steel, in conformity with section 9.4 (this is not applicable for components manufactured in a factory).

For each heat treatment, which may or may not be required according to C.3.2, the provisions of C.3.3 are applicable. Incorrectly executed heat treatments can have a negative influence.

Symbols and units

D_u	outside diameter	mm
d_d	wall thickness; according to the design drawing or size table with regard to C.3.3, this is the greatest thickness of the welding edge.	mm
C_{eq}	carbon equivalent	%
R_e	specified minimum yield strength, at 20 °C	N/mm^2
r	bending radius	mm
t_e	cooling time	s(h)
t_n	residence period	s(h)
φ	(angle at the center)	°
θ	temperature (in general)	°C
q_m	metal temperature	°C
q_n	temperature at the point of measurement *n*	°C

[Symbol for chemical element] is the maximum content in % of the corresponding element, as shown by the specified cast analysis.

{ } around the symbol for a magnitude indicates that the numerical value (expressed in the above-mentioned unit) is meant; temperature differences are indicated in Kelvin (K).

C.3.2 Classification of materials with regard to heat treatment after welding

The following group classification is used (Table C.7):

Table C.7 - Group classification of materials for post-weld heat treatment

Group	Steel type [a]
1	Steel with a specified minimum yield strength $R_e \leq 360$ N/mm^2 and with a chemical composition that does not exceed the following values in %: [C] = 0.24, [Si] = 0.60, [Mn] = 1.70, [Mo] = 0.70, [S] = 0.045, [P] = 0.045, and each other element separate = 0.3, all other elements together = 0.8.
2	Normally annealed/normalized or thermo-mechanically rolled fine-grained steel with a specified minimum yield strength of $R_e > 360$ N/mm^2
3	Quenched and tempered steel, and precipitation hardened steel, with the exception of corrosion resistant steel
4	Ferritic and Martin-processed corrosion resistant steel with 10.5% ≤ [Cr] ≤ 30%
5	Austenitic corrosion resistant steel
6	Austenitic ferritic corrosion resistant steel (duplex)
[a] For the groups 1,2 and 3, no heat treatment is required after welding. For the remaining groups 4, 5 and 6, the principal shall specify whether a post-weld heat treatment is required. If the welding thickness is greater than 40 mm, then a post-weld heat treatment is required for all groups.	

C.3.3 Type and scope of post-weld heat treatment

If a heat treatment can adversely affect the properties of the coating or the protective layer, measures can be taken to prevent or to repair these damages.

From case to case a decision shall be made, whether the corresponding welding works shall be subjected once more to a heat treatment.

If required according to C3.2., and after all welding on a certain work piece have been completed, the welds shall be subjected to a heat treatment according to the requirements of the material specification.

If such requirements are incomplete or missing, then the following conditions shall be met:

- if the temperature is not specified, then 600 °C will be taken for the materials (no fine-grained steel);
- if the allowable emperature deviations are not specified, then a tolerance of +20 K or -20 K will be used instead;
- if the residence time is not specified then a value of 120 $\{d_d\}$ s shall be applied, with a minimum of 1800 s (0.5 h); the residence time need not be more than 7200 s (2 h). The application of arbitrarily long residence periods can have a negative influence and shall preferably be avoided;
- If the cooling rate is not specified, it shal not exceed the smallest value of 2/$\{d_d\}$ K/s and 0.08 K/s. However,the cooling rate needs not to be less than 0.015 K/s.

NOTE For cases in which a heat treatment is not foreseen, or in which a deviation from these regulations can lead to a more effective heat treatment procedure, special regulations may be established. Such special regulations should not only be approved by the accredited expert, but also by the manufacturer of the material, the pipe manufacturer, the designer and the operator.

C.3.4 Realization

The realization shall conform both to the following requirements and to the material specification.

If the material has to be tempered, then eventual hot forming may be considered part of the required heat treatment, if the final temperature reached during hot forming lies within the temperature range that is indicated in the material specification for hardening.

C.3.4.1 Equivalent standards of post-weld heat treatment

Two workpieces are viewed as having been subjected to an equivalent post-weld heat treatment, if, in addition to the requirements that are applicable to each of these workpieces, the requirements of C.3.4.1.1 and C.3.4.1.2 are also fulfilled.

The method used for heat treatment of the two workpieces need not therefore be the same. This is relevant for example, in case of a separate heat treatment of test pieces and samples.

C.3.4.1.1 Determination of allowable distribution range

The temperature-time diagram for the residence- and cooling period for one of the two workpieces is used to plot the distribution range according to Figure C.1 and the related instructions.

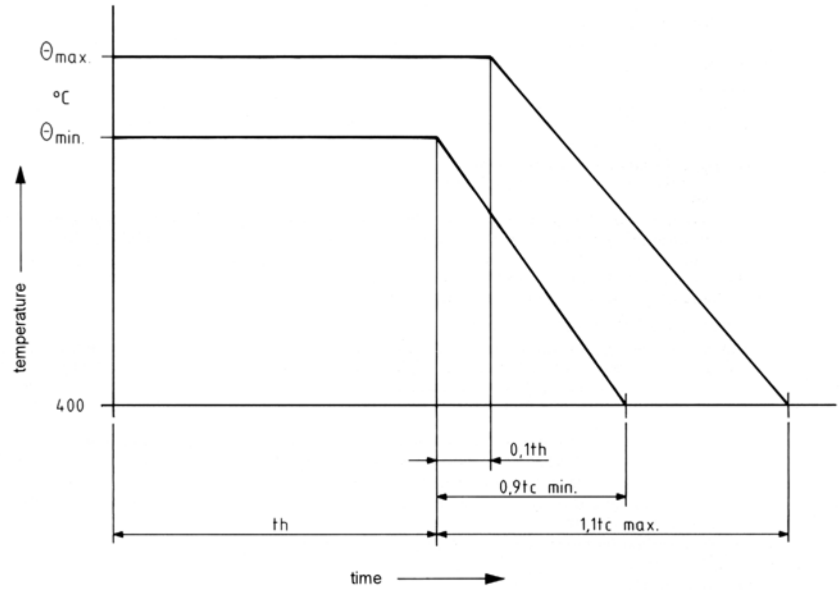


Figure C.1 - Distribution range in the temperature-time diagram for residence and cooling periods

Permissible temperature distribution range, according to C.3.3: $\theta_{max} - \theta_{min}$

Actual lingering period t_n

Cooling period to 400 °C (at point recording most rapid cooling) t_{min}

Cooling period to 400 °C (at point recording slowest cooling) t_{cmax}

C.3.4.1.2 Assessment value

The temperature-time diagrams for the residence- and cooling periods of the other workpieces shall lie entirelywithin the distribution range that has been determined in the previous paragraph.

C.3.4.2 Heat treatment in a furnace

In case of a heat treatment in a furnace, the following aspects shall be taken into account:

- The workpiece shall not be heated through a direct contact with flames;
- (for pipes with D_e ≤ 170 mm). The heat treatment process shall be monitored; the annealing report shall show that the workpiece has been subjected to the required heat treatment;

- (for pipes with D_e > 170 mm). The heat treatment process shall be continuously recorded in a temperature-time diagram, by means of an automatic recording device. This diagram shall show that the required heat treatment have been effectuated at all measuring points ..
- (post-weld heat treatment). The workpiece shall remain in the furnace during cooling, until the temperature of all parts with d_d > 20 mm has declined to 400 °C. After this, the workpiece may be removed from the oven for further cooling in standing air.
- (post-weld heat treatment). During cooling to 400 °C, the temperature gradient shall not exceed the following values:
  - in the axial direction: 100 K/m;
  - in circumferential direction: 40 K/m;
- number and location of the temperature sensors shall be such that the recorded temperature is representative for the temperature gradient in the entire workpiece. The following minimum number of measuring points is required:
  - 1 for samples;
  - 2 for pipes with $D_e \leq$ 170 mm;
  - 3 in all other cases
- the temperature sensors shall be in contact with the workpiece;
- the temperature sensors shall be calibrated.

C.3.4.3 Local heat treatment

Stress-free annealing or tempering may be used as a local heat treatment, if all requirements of C.3.4.3.1 and also all requirements of C.3.4.3.2 and C.3.4.3.3 are satisfied.

C.3.4.3.1 General

The zone to be heated (workpiece) shall satisfy one of the following descriptions, as illustrated in Figure C.2:

- bend;
- branch or T-piece
- a circular ring, which is a part of one of the following surfaces:
  - a circular cylinder;
  - a circular cone, with a half top angle < 30 °;
  - a spherical segment, bounded by a central angle: 120 ° ≤ φ ≤ 240 °
    This is also fulfilled, if the ring lies within a spherical element and both of the cut-off sphere segments fulfill this requirement. The thus described spherical segment shows a tangent cone at the edge, with a half top angle ≤ 30°;
  - a transition area between two of the above-mentioned surfaces, with or without a torus, or a torus-shaped ring.

C.3.4.3.2 Inductive annealing or resistance annealing

The heat treatment process shall be continuously and automatically recorded in a temperature-time diagram. This diagram shall show that the required heat treatment procedure has been fulfilled at all the measuring points. The temperature registration may be discontinued, after the temperature has declined to ≤ 400 °C at all measuring points.

In the following cases, the temperature-time diagram does not have to be submitted to the accredited inspection institution and it will be sufficient to supply an annealing report:

- (for all materials) $D_e \le 170$ mm;
- (for unalloyed or low-alloy content steel with [Cr] ≤ 1.5% and [Mo] ≤ 0.65%) $D_e \le 325$ mm and also $d_d \le 25$ mm.

The required number of temperature measuring points shall be at least:

- 1 if $D_e \le 170$ mm and $d_d \le 70$ mm;
- 2 if 170 mm < $D_e \le 460$ mm and $d_d \le 25$ mm;
- 4 in all other cases.

If the zone to be heated includes changes in cross-section, additional measuring points are required. In these cases, a programme shall be defined in advance for the execution of the heat treatment procedure.

- the temperature sensors shall be distributed evenly over the zone to be heated.
- (if $d_d \le 70$ mm). The temperature profile recorded by additional measuring points shall demonstrate that the required procedure for heat treatment has been fulfilled both on the internal and external surfaces of the workpiece. These extra measuring points are not required if the heat treatment of a sample, which can be regarded as an equivalent to the workpiece in accordance with C.3.4.1, demonstrates that during the cooling process to 400° C the temperature gradient over the wall remains at ≤ 50 K.
- the temperature sensors shall be in contact with the workpiece.
- the temperature sensors shall be calibrated.
- the pipe shall be insulated over the entire zone to be heated, and over a length of at least $3.5\sqrt{D_e \times d_d}$ on both sides thereof.

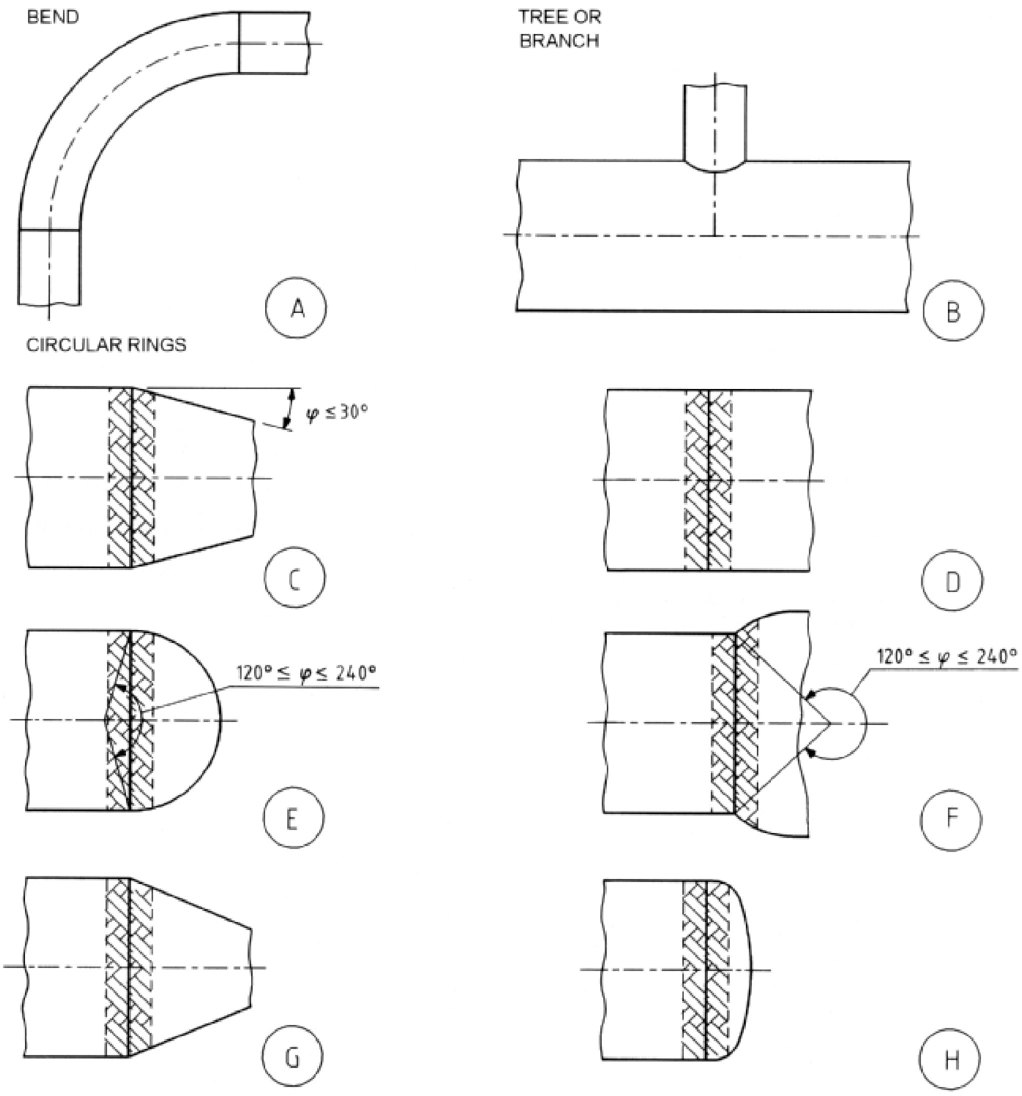


Figure C.2 - Zones to be locally heated

C.3.4.3.3 Annealing with ring-type burners

- [Cr] < 2.5% and/or [Mo] < 1.2%;
- D_u < 800 mm and $d_d \leq$ 32 mm;
- The zone to be heated does not contain any transitions in cross-section and only includes circumferential welds;
- The treatment is carried out by an annealing technician holding a valid certificate of competence with regard to annealing skills
- The progress of the heat treatment shall be monitored; and the annealing report shall state that the corresponding workpiece has been subjected to the required heat treatment. The annealing report shall document the name of the person carrying out the annealing process, as well as the observed residence period and the highest and lowest temperature recorded during that period.

C.3.5 Critical thickness

The thickness d_c is to be deduced for each component from it's dimensions and can be decisive for the need to carry out post-weld heat treatment.

The following is not taken into account, in the determination of d_c:

- overfill of welds, and additional fillet weld or mitres, applied over a weld (see Figure C.3);
- the thickness of the pipe plates, flanges and flat walls, except as stated belowl;
- the thickness of forged branches;
- the thickness of welded in rings around apertures.

The critical thickness d_c is equal to the greatest value of:

- the weld thickness. For double-sided welds with less than full penetration this is the combined thickness of the two sections of the weld. For a fillet weld this is the throat thickness ("*a*-measure").
- (only for flanges, with fillet welds between the flange and the pipe or wall) two times the thickness d_d of the wall or pipe welded to the flange;
- the thickness d_d of any component directly connected next to the weld. If at a butt weld, in cylinders, spheres, heads or cones (but not in a branched pipe), the connected component is merged into a greater thickness at a gradient than 14° (= 1:4) then this greater thickness is taken into account;
- (only for apertures with an flat reinforcing ring inside and outside) 0.5 times the combined thickness of the wall and both reinforcing rings;
- (only for apertures) the thickness d_d of the connecting part of a set-on branch directly abutting to the weld;
- (only for tube plates, flanges and flat walls, including full-penetration welds) the thickness d_d of the pipe plates, flange or flat wall. In this case, welds and weld preparations on pipe plates are not taken into consideration.
-

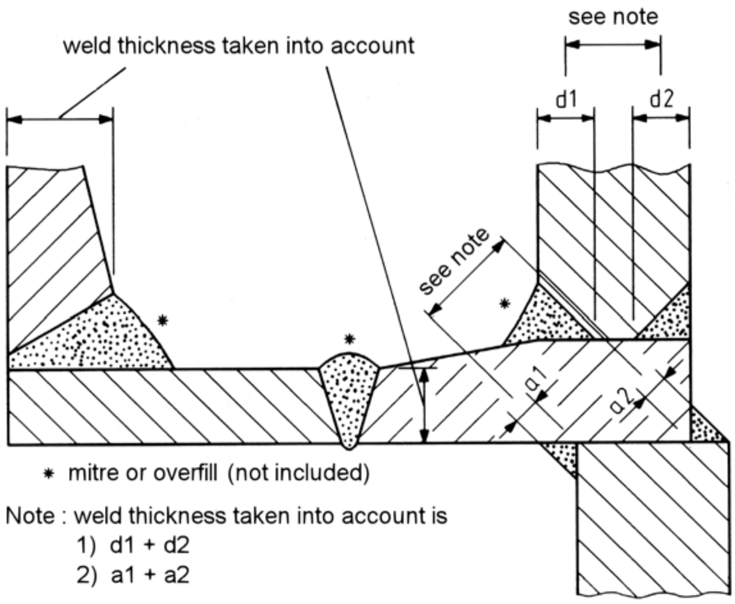


Figure C.3: Determining critical thickness

Appendix D
(normative)

Complete Analysis procedure

D.1 Load combinations

The ultimate limit states that shall be tested are documented for each load combination (LC) in Table D.1, including the motivation for the choice of the LC and the calculations that shall be carried out, for the benefit of a complete strength calculation.

Table D.1: Calculations to be carried out for each load combination

LC 1: Construction phase for pipelines and stations	
Limit states to be assessed	Stresses, strains, deformations
Motivation	It shall be shown that the loads that occur in the construction phase do not lead to any damages on the pipeline. The loads that occur during that phase are generally quite different from those in the definition phase. NOTE Since this concerns a temporary situation, and since the consequences of exceeding a limit state will on the whole be limited, it is justified to use lower load factors than during the operational phase.
Calculations to be carried out	Static beam and cross-section calculation, depending on the loads that occur.
LC 2: Internal pressure only	
Limit states to be assessed	Stresses
Motivation	The calculation for internal pressure only is often decisive for the final wall thickness. NOTE In the assessment of the fundamental ultimate limit state of rupture, caused by excessive internal pressure, other loads do not have to be taken into account in the case of buried pipelines, provided the following conditions are fulfilled: - ductile material behavior of the pipe wall; - limitation of the occurring bending deformations, that is limitation of the occurring settlement differences; - primarily static loads, therefore no danger of fatigue. These conditions are verified in the other load combinations.
Calculations to be carried out	A calculation according to the "*boiler formula*" is sufficient: $\sigma_p = \frac{\gamma_p \cdot p_d \cdot D_g}{2 \cdot d}$ γ_p is the partial load factor for internal pressure, see Table 2.
LC 3: External loads, with internal pressure zero	
Limit states to be assessed	Stresses, strains, deformations
Motivation	In the case of external loads, such as soil loads and settlement differences, the situation with the lowest internal pressure is often decisive for the magnitude of the occurring stresses and deformations, such as ovalization and the occurrence of local buckling. Occurring strain shall of course be verified.
Calculations to be carried out	Static global analyses (beam analyses, including pipe-soil interaction)(s) and cross-section analyses.

See continuation

Table D.1 (continued)

LC 4: External loads with internal pressure and (maximum) temperature fluctuations	
Limit states to be assessed	Stresses, strains, deformations
Motivation	In a plasticity calculation and in case of (high) internal pressure, the resistance against bending deformations (the plastic moment M_p) declines. This means that in case of occurring settlement differences, the bending deformations will be larger than in the case LC 3, and with that the strains will also be larger than in LC 3. Temperature fluctuations, like settlement differences, contribute to bending deformations (in bends), as well as axial forces and displacements. NOTE Deformations, such as ovalization and local buckling, will not be decisive in case of minor temperature fluctuations. In the case of pipelines, with a high operating temperature, large local deformations can however occur in bends, as well as large normal forces in long and straight pipeline sections, which make assessments for flexural buckling and local buckling necessary.
Calculations to be carried out	Static global (beam) analyses(s) and cross-section analyses.
LC 5: Cyclic, largely static, loads, (temperature fluctuations, pressure fluctuations)in combination with other loads	
Limit states to be assessed	Stresses, strains, fatigue. In the corresponding cases, an assessment shall also be made on stepwise plastic deformation (ratcheting).
Motivation	Fluctuations in operating pressure and operating temperature,will introduce variations in stresses and strains.. This can lead to fatigue damage (cracks). NOTE 1 A differentiation can be made between load cycles with corresponding strain fluctuations within the elastic range, and load cycles with strain fluctuations, leading to local yield with each cycle NOTE 2: Traffic loads too,can, in principle, introduce stress fluctuations. The "stress wrinkle" that can occur as a consequence of this, will usually be limited in the case of high-pressure pipelines and not lead to fatigue damages. This may be a point of attention in the case of low-pressure pipelines with limited soil cover, and in case the pipeline system is supported on piles.
Calculations to be carried out	These concerns the strain variations, as a consequence of load fluctuations. Calculations models, which can determine the strain history as a function of the load history, are therefore to be recommended, especially when plastic deformation occurs. The resulting strain fluctuations shall be assessed in a fatigue calculation that shall be carried out, Common fatigue analyses however frequently introduce a (fictive) elastic stress variation obtained from strain based fatigue tests (see D.3.5). NOTE 1: In the case of elastic material behavior, use can be made of the superposition principle, whereby two situations are compared with one another, namely one with a low value for the temperature and one with a high value for the temperature. The difference gives an estimate of the occurring strain fluctuation. This result is less precise, to the extent that the response of the pipeline is less linear (geometrically and physically). NOTE 2: Large strain variations are likely to occur, above all in and near T-pieces and bends.
LC 6: External pressure, external loads and internal pressure zero	
Limit states to be assessed	Stresses, strains, deformations (implosion, local buckling, flexural buckling), large displacements

See continuation

Table D.1 (end)

Motivation	External pressure can cause collapse in deeply buried pipelines (for instance at crossings), or in pipe-in-pipe systems with a pressurized annular space, and in the case of offshore pipelines. Especially during the installation of offshore pipelines, critical load combinations of external pressure, bending moment and normal forces may occur.
Calculations to be carried out	The calculations to be performed follow from the above described physical phenomena and load situations. The relevant limit states shall be assessed
LC 7: Incidental and special loads	
Limit states to be assessed	Leakage, resonance, large displacements, fatigue, local supports
Motivation	Resonance can result from water and air flows along respectively offshore pipelines and above ground pipelines.. Resonance can also occur through pumps and water hammer. Resonance can lead to uncontrolled stress and strain variations, as well as occurrence of damages through fatigue. NOTE: Offshore pipelines may be buried or not. Buried pipelines can as a result from erosion (sea currents). subsequently come to lie on or above the seabed In the case of freely suspended pipelines (present from the time of construction or as a consequence of erosion) it shall be assessed whether there is a danger of resonance (for instance caused by vortex shedding) and of large strains, local buckling and similar hazards. Large displacements (unstable positioning) can occur in offshore pipelines due to currents, and for instance in above ground pipelines, due to insufficient anchoring. In case of unstable positioning, uncontrolled deformations can occur, which may lead to, for nstance, exceeding a fundamental limit state, such as rupture. Damages to the pipewall can occur through dents and scratches, caused by excavation tools, passing fishing gear, etc. In due time, these can lead to pipeline rupture.
Calculations to be carried out	Suitable calculations shall be carried out for incidental and special loads. NOTE 1: In case of scratches or dents, caused to the pipewall by excavating machines etc., the wall thickness and toughness of material (and of course the shape and the dimensions of the excavator bucket (tooth)), as well as the power that the excavating machine can exert, are of crucial importance. Strictly seen one can speak of an incidental load here, and such a load cannot (yet) be included in the common strength analyses models. If, in the relevant cases, the scratch dimensions are known, then a "fitness for purpose" approach can be applied on the basis of BS 7910. NOTE 2: BS 7910 does not give any information for an assessment of dents. To a certain extent, this concerns a serviceability limit state, in which the opinion of the pipeline manager is decisive. However , internal pressure variations may cause additional stresses in a circumferential direction, which may possibly influence the result of the fatigue calculation. Also see [17].

D.2 Calculation models

D.2.1 Schematization

D.2.1.1 Geometry

See Chapter 8 of SI 5664-1 and the related appendices. The pipeline (beam) elements and the spring elements for the soil shall be selected such that the behavior of the pipeline can be modelled with adequate accuracy.

D.2.1.2 Material properties

The values for material variables that are documented in Table D.2, such as the yield strength, tensile strength, transverse contraction coefficient, maximum strain, the development of the stress-strain-diagram etc., are always calculation values, unless indicated to the contrary. Calculation values are generally the characteristic values, which are divided by a corresponding material factor γ_m (see Table D.2).

Table D.2: Material factors γ_m

Material variable (characteristic values)	Material factor γ_m
Yield strength	1.1
Rupture strength	1.1
E modulus	1.0
Transverse contraction coefficient	1.0

The stress-strain diagram that shall be applied is dependent on the calculation model that is used. The diagram in Figure D.1a) is applicable to a calculation in accordance with the elasticity theory, and Figure D.1b) for a calculation according to the plasticity theory. The diagram in Figure D.1c) may also be used.

NOTE Other schematizations may also be used, such as for instance that of Ramberg-Osgood, under the condition these lead to the same safety, at a minimum.

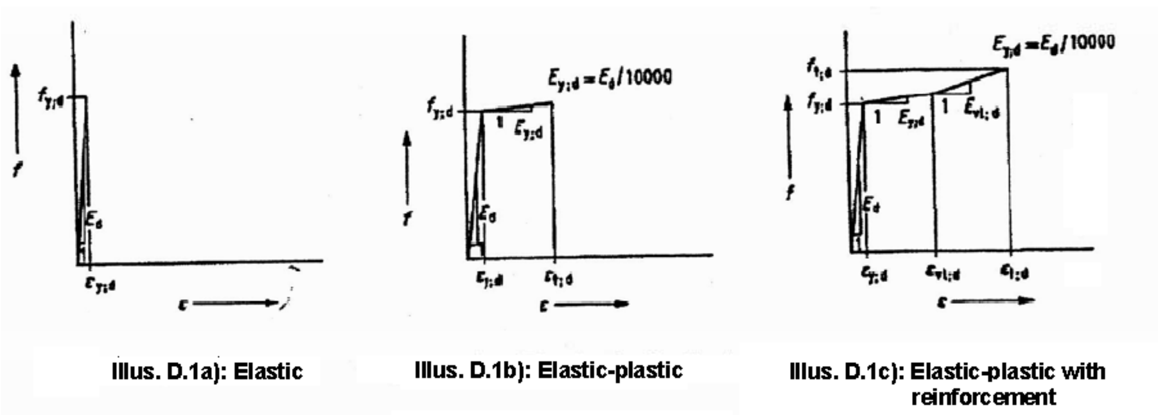


Figure D.1 - Schematization of the stress-strain diagram for calculations.

Variables mentioned in figure are:

$f_{y:d}$ is the calculation value for the yield strength ($f_{y:d} = R_e/\gamma_m$);

$f_{t:d}$ is the calculation value for the tensile strength ($f_{t:d} = R_m/\gamma_m$);

E_d is the calculation value of the elasticity modulus;

$\varepsilon_{y:d}$ is the calculation value for the strain, on reaching the yield strength. (strain at yield)

D.2.2 Calculation models under static load

For carrying out calculations, the following calculation models can be used.

D.2.2.1 Elasticity theory for beam calculation - elasticity theory for cross-section calculation (E-E)

A beam calculation is carried out, whereby the pipeline is reduced to a system of linear elastic beam elements. The soil is modelled to a system of soil springs (physically linear or physically non-linear).

Subsequently a cross-section calculation is carried out, whereby:

- the material behavior can be assumed to be physically linear or physically non-linear (elastic or elastic-plastic material behavior);
- either geometrically linear behaviour or geometrically non-linear behavior (taking into account, the influence of occurring deformations on the load distribution, or the inclusion of second order phenomena, such as "rerounding") is assumed;
- the stiffness ratio between the pipe cross-section and the surrounding soil is taken into account.

The results (forces acting on the cross-section and stresses, deformations such as curvature from bending and ovalization) shall be checked against the relevant limit states in D.3.

D.2.2.2 Elasticity theory for beam calculation - plasticity theory for cross-section calculation (E-P)

A beam calculation is carried out, whereby the pipeline is schematized with linear elastic beam elements. The soil is schematized with soil springs (physically linear or physically non-linear).

The result of these calculations are forces acting on the cross-section, such as bending moments, transverse forces, normal forces, soil loads resulting from overhead burdens and soil support reactions.

Subsequently, a set of interaction formulas used for verifying, whether the pipe cross-section is able to carry the forces that act on it. A check is also made, whether the bending moments that are a result of the beam calculation fulfill the boundary conditions for the application of the elasticity theory. See [23] and Attachment E.

NOTE If the series of interaction formulas and also the conditions of E.5.2 are met, then the verification of the limit state "stresses" is also fulfilled (since, in the derivation of the interaction formulas, one of the boundary conditions states that the stresses shall not be higher than the yield stress).

A cross-section calculation shall be carried out for verifying the ovalization limit state.

The results of the various calculations, in the form of deformations such as curvature from bending and ovalization, shall be checked against the relevant limit states in D.3.

D.2.2.3 Plasticity theory for beam calculation - plasticity theory for cross-section calculation (P-P)

A beam calculation is carried out, whereby the pipeline is schematized with linear beam elements, which can describe the non-linear behavior. The soil is schematized with soil springs (physically linear or physically non-linear).

The result of these calculations are forces acting on the cross-section, such as bending moments, transverse forces, normal forces, soil loads due to overhead burdens and through soil support reactions.

Subsequently, a series of interaction formulas [23] for straight pipeline sections (see Attachment E) are used to verify that the pipe cross-section is capable of handling the forces that act on it.

NOTE A check that the bending moment of the beam calculation fulfills the conditions that shall be met is discounted in the calculation, in accordance with the plasticity theory. The limit state "stresses" is automatically met.

The necessary calculations, for checking that the other limit states are met, shall be carried out, such as a cross-section calculation for the verification of the ovalization limit state, and a calculation of the strains, for a check of the limit state "strains". In [20], [21] and [23], descriptions and formulas have been included for the determination of ovalization.

The results of the various calculations, in the form of deformations such as curvature from bending and ovalization, shall be checked against the relevant limit states in D.3.

D.2.2.4 Integrated calculation for pipeline – soil interaction

Finite element models, schematizing both the behavior of the pipeline and that of the surrounding soil in one single model, will be used for generating calculations, which should provide resulting values for stresses, strains and deformations that are "ready for assessment".

NOTE 1: A distinction is usually made between a beam model and a ring (cross section) model in the computer programs, presently available for calculation of elastic or plastic pipeline behaviour. In the beam calculation, the pipeline is modelled with beam elements in two or three dimensions, in order tp calculate the normal forces, the transverse forces, torsional moments and longitudinal bending moments, resulting from the various loads that influence the pipeline. The entire cross-section of a pipe element is subsequently looked at in detail with a ring calculation, including the active of forces and bending moments in axial direction as well as the loads and reactions in circumferential direction. Subsequently the stresses and strains as well as a resultant stress are determined in a number of points along the cross sectional circumference.

NOTE 2: Validated models, which conform to the above, are not yet available at the time of publication of this standard.

D.2.3 Calculation models for cyclic loads

In this, a distinction can be made between models that are based on superposition and models that follow the load history.

D.2.3.1 Superposition

Strictly seen, calculation models based on superposition may only be applied in cases of geometrical and physically linear behavior, that is, in cases where the elasticity theory is applied, whereby effects of a secondary order do not have to be taken into account. If these conditions are not met, then their use is nevertheless permitted by this standard, under the condition that the scope of the geometrical and physical linear behavior remains within certain predefined (still to be defined) limits.

The following calculation models may be used:

- Elasticity theory for beam calculation - Elasticity theory for cross-section calculation (E-E);
- Elasticity theory for beam calculation - Plasticity theory for cross-section calculation (E-P).

NOTE An example of superposition is the check of alternating yield under fluctuating internal pressure, whereby the stress fluctuation is determined through the differences in the calculated stresses, which are arrived at through a calculation with low internal pressure and with high internal pressure. If the second calculation model is used, including the application of the plasticity theory for the cross-sectional calculation, then the conditions of geometrical and physically linear behavior are not met.

D.2.3.2 Load history

For the application of this, a computer program is required, which can include the load history over time in the calculation.

NOTE Such computer programs are available, but they are only used to a limited extent.

D.3 Limit states and corresponding assessments

D.3.1 Limit state “stress”

The possibilities for checking this limit state depend on the model selected for calculating the response of the pipeline. Two assess methods are available, namely assessment on the basis of cross-sectional forces and assessment on the basis of resultant stresses:

a) Assessing on the basis of cross-sectional forces;

In this, use is made of the interaction formulas, which are documented in Attachment E. This assessment method may be used for all calculation models.

b) Assessment on the basis of a resultant stress σ_v.

This assessment method is only used for the following calculation model:

- Elasticity theory for beam calculation - Elasticity theory for cross-section calculation (E-E).

This assessment method is described in detail below.

After the beam and cross-sectional calculations have been prepared, under application of the calculation values of the loads, the calculated stresses in the representative points of the representative cross-sections shall be combined
After the determination respectively of the axial and the tangential stresses, in relevant points along the circumference of pipeline cross-sections with the heaviest load, these stresses shall be combined into the equivalent stress σ_v. The equivalent stress σ_v is a parameter, which characterizes the stress condition at a certain point.

The equivalent stress can be calculated both with the minimum distortion energy hypothesis (Von Mises), or with the shear-stress hypothesis (Tresca):

- According to the “minimum distortion energy” hypothesis, the resultant stress is:

$$\sigma_v = \sqrt{\left(\sigma_x^2 + \sigma_y^2 + \sigma_z^2 - \sigma_x\sigma_y - \sigma_z\sigma_x - \sigma_y\sigma_z + 3\tau_x^2 + 3\tau_y^2 + 3\tau_z^2\right)}$$

In the analyses a plane (bi-axial) stress condition may generally be assumed, instead of a three-axial one, if the third principal stress is relatively small in absolute terms (for example, the radial internal pressure component for (thin-walled) pipeline components, without fittings, T-pieces etc.).

The following formula then applies for a plane stress condition:

$$\sigma_v = \sqrt{\left(\sigma_x^2 + \sigma_y^2 - \sigma_x\sigma_y + 3\tau^2\right)}$$

- The following applies in accordance with the shear-stress hypothesis (Tresca):

$$\sigma_v = \sigma_{max} - \sigma_{min}$$

where:

σ_{max} is the maximum principal stress in 1 of the three directions;

σ_{min} is the minimum principal stress in 1 of the other two directions.

NOTE In the determination of the values for the limit state of stresses in Table D.2, the possible redistribution of stresses, due to the plastic deformation capacity of steel, and the self-limiting character of certain loads, such as temperature, have been taken into account. As an alternative, a assessment in accordance with the fully elasticity analyses of section 6.4.1 and 6.4.2 of ISO 13623:2000 can be carried out.

In case of alternating loads, the relevant pipe elements shall also be assessed for fatigue.

Table D.2: Assessment stress limit states and alternating yield, in calculations according to the calculating model: E-E

Load combination		Resultant stresses from load combination		limit stress
LC 2	→	σ_p	≤	$R_e(\theta) / \gamma_m$
LC 3[a]; (LC 3 + LC 2)[a]		σ_v: pm [a]		1.1 x R_e / γ_m
LC 3, LC 4		σ_v		0.85 x $(R_e + R_e(\theta))/\gamma_m$
[a] This assessment concerns situations, in which the pipeline is loaded primarily as a supporting beam and the occurring stresses are largely membrane stresses, for instance a pipeline section on piles with circumferential stresses through internal pressure and longitudinal bending stresses through beam-behavior..				

D.3.2 Limit state "strain"

The calculation value of the strain (total strain under load) shall not amount to more than 0.50%, if no more detailed information is available. In case it, is demonstrated for a specific material in combination with specific requirements regarding the welding and the welding process, that the corresponding pipe material including welds have a greater strain capacity than 0.5%, then this greater capacity may be utilized.

For steel types with $R_e \leq 360$ N/mm^2 and within the framework of this standard, a calculation value for strain of 0.7% can be applied.

NOTE The value of 0.5% was established in the middle of the 1980 s, when plastic calculation was introduced. The strain capacity of the plate material is actually much larger, and the welds, including the imperfections in it, are the limiting factor. In Table C.2, a new requirement with regard to "overmatching" of the welding material has been included. A check of the strain capacity of "old" pipelines appears to show a strain capacity in the order of several %. Strains of up to 2.5% appeared to 'be possible for welded steel pipelines, during the installation of offshore pipelines with the "reel" method. In [16], a maximum strain of 0.75% is specified, in combination with a material factor of 1 or 0.7, if no further information is available. A limitation of the R_e/R_m ratio is also important in this instance. For steel types with a high yield strength, a higher safety margin should be applied.

D.3.3 Limit state deformations

Ovalization, local buckling, flexural buckling, implosion and progressive plastic failure shall be checked with the limit state for deformations.

D.3.3.1 Ovalization

<u>*Ultimate limit state*</u>

The limit value for the smallest diameter of the ovalized cross-section is 0.85 D, or $D' > 0.85\,D$ (see Figure D.2).

NOTE In tests carried out by Spangler, it appears that at $D' < 0.80\,D$ there is a risk of colapse. Here $D' = 0.85D$ is indicated as the value for the smallest permissible diameter.

Serviceability limit state

The limit value for ovalizationmay also be affectedby the deformation capacity of the corrosion coating or insulation, or requirements related to efficient operations, such as the possibility of the passage of measuring and detection equipment ("intelligent pigs"). The allowable ovalization is dependent on the equipment that shall pass through the pipeline.

NOTE 1 For the benefit of passing of such equipment through the pipeline, the ovality is generally set at not more than 5%. Requirements of the operator of the pipeline may influence this limit, as long as the limit value for instability of the cross-section is not exceeded.

NOTE 2 When assessming serviceability limit states, a lower reliability index and, with that, lower partial factors are in principle applicable. The practical difference with the partial factors presented in this standard for the ultimate limit states is however rather small, which is why the latter factors are recommended for use.

D.3.3.2 Local buckling

With regard to deformations through local buckling, the following limit values are applicable for pipelines where $p = p_i - p_u > -0.2$ MPa (most pipelines on land):

1) Compressive strain under bending and normal force:

The limit value ε_{cr} for compressive strain in the longitudinal direction is:

— where $2\dfrac{r'}{d_n} \leq 120$: $\varepsilon_{cr} = 0{,}25\dfrac{d_n}{r'} - 0{,}0025 + 3000\left(\dfrac{r'}{Ed_n}\right)^2 \cdot p \cdot |p|$

— where $2\dfrac{r'}{d_n} > 120$: $\varepsilon_{cr} = 0{,}10\dfrac{d_n}{r'} + 3000\left(\dfrac{r'}{Ed_n}\right)^2 \cdot p \cdot |p|$

2) Torsional deformation:

The limit values for torsion θ_{cr} is:

$$\theta_{cr} = 0{,}66\frac{d_n}{(r')^2}\sqrt{\frac{d_n}{r'}} + \frac{3000}{r'}\left(\frac{r'}{Ed_n}\right)^2 \cdot p_d \cdot |p_d|$$

The limit value for $\varepsilon_{compression}$ and $\theta_{torsion}$ is given by:

$$\left(\frac{\varepsilon_{compression}}{\varepsilon_{cr}}\right)^{1.5} + \left(\frac{\theta_{torsion}}{\theta_{cr}}\right)^2 \leq 1$$

The critical radius r', which shall be used in the above-mentioned formulas, is given by:

$$r' = r/(1 - 3w/r)$$

where:

r' is the critical radius;

r is the radius of the pipeline without load;

w is the change in the radius, at the area of the occurring compressive strain or torsional deformation (see Figure D.2).

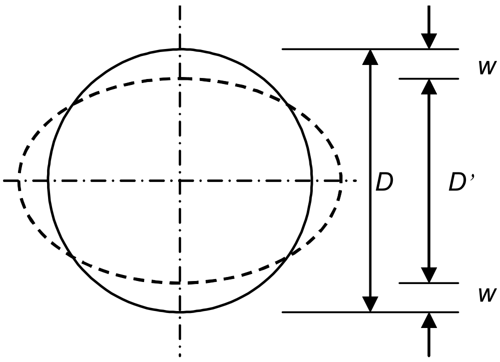


Figure D.2 - Change in cross-section

NOTE 1 Whether local buckling occurs or not is largely dependent on the radius of the curvature of the pipe wall, at the location of the compressed fibers, or where the torsional deformations occur. By bending, or by soil loads, the cross-section becomes oval. Comparing the the formulas for the limit values, using $r' = r$, with test results on pipes loaded by bending and normal forces, shows that these formulas provide safe values.
Tests carried out show that if r' is used when soil loads are acting, the influence of greater ovalization can be taken into account.

NOTE 2 If $D/t < 55$ an assessment on local buckling can generally be omitted

D.3.3.3 Flexural Buckling

Flexural buckling of the pipeline

Criteria for a determination of the critical buckling stress shall be derived from NEN 6770:1997/A1:2001 (Dutch TGB standard Steel).

If ε_{cr} is less than $\varepsilon_e = R_e/E$, in the case of compressive strain from bending and normal forces, then, for the determination of the critical buckling stress, one shall proceed from material with a fictitious yield stress of $R'_e = \varepsilon_e \times E$. The buckling curvature, which shall be used with $R'_e < R_e$ is givenin Figure D.3.

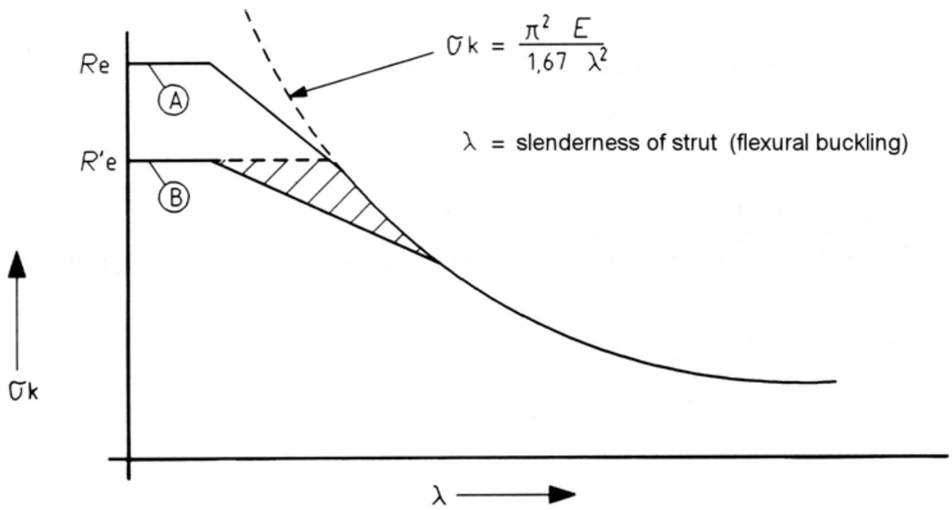


Figure D.3 - Buckling curvature

NOTE 1 Fexural buckling and local buckling may interact, resulting in collapse at a lower load than the lowest value indicated by the local buckling and buckling criteria, if these were considered in isolation. This effect is allowed for by selecting the buckling curve B in Figure D.3 (that is a material with $R_e = R'_e$) instead of the buckling curve A, where R'_e is smaller than R_e.
The hatched area in Figure D.3 represents the effect for interaction between flexural buckling and local buckling.

NOTE 2 In practice, the flexural buckling of pipelines is especially a problem with high-temperature underground pipelines. This problem can be prevented by setting requirements with regard to the maximum excavation length, or on the desirable minimum lateral or vertical soil load, for instance by using formulas of the following type:

$$Q \geq \frac{\gamma_s \times N^2}{EI} f_0$$

where:

Q is the required lateral force (ultimate horizontal bearing capacity or passive soil load) per unit of length (N/mm[1]);

N is the calculated axial compression force (calculation value) in the pipe;

f_o is the initial eccentricity of the pipe (as a beam), for instance $f_o = l_o / 200$, with a minimum of 10 mm;

EI is the bending stiffness of the pipe;

l_o is the initial buckling length: $l_o = \sqrt{\frac{EI}{|N|}}$

γ_s is the safety factor for stability, (for instance $\gamma_s = 1.25$)

NOTE 3 γ_s can be seen as the product of a spatial variation factor and a calculation model factor, analogous to SI 5664-1, Table B.3, but with the introduction of a larger length effect. This concerns the average available lateral soil load over the initial buckling length. In relevant cases it is recommended to calibrate this factor to the actual circumstances.

D.3.3.4 Implosion

In case of omnidirectional external pressure, possible implosion (radial instability) shall be checked for the following load cases:

1) external pressure only ;

2) bending moments only ;

3) combination of external pressure and bending moments.

The utilized symbols are:

D_{nom} is the nominal diameter of the pipe;

D_{max} is the largest diameter of the ovalized pipe cross-section;

D_{min} is the smallest diameter of the ovalized pipe cross-section

M_c is the characteristic bending moment for local buckling;

M_L is the maximum allowable bending moment for local buckling;

p_c is the omnidirectional external pressure, whereby the pipe collapses through implosion;

p_e is the omnidirectional external pressure, whereby the pipe collapses elastically;

p_p is the omnidirectional external pressure, whereby the pipe collapses plastically;

p_L is the maximum allowable omnidirectional external pressure on the pipe;

ε_o is the initial ovalization of the pipe.

D.3.3.4.1 External pressure only

If only external (gauge) pressure is acting on the pipeline as a load, then the collapse pressure p_c causing implosion (radial instability) can be determined with the formula:

$$(p_c - p_e)(p_c^2 - p_p^2) = p_c p_e p_p 2\delta_0 \frac{D_{nom}}{d_n}$$

where:

$$p_p = \frac{2R_e d_n}{D_{nom}}$$

$$p_e = \frac{2E}{1-\nu^2}\left(\frac{d_n}{D_{nom}}\right)^3$$

$$\delta_0 = \frac{D_{max} - D_{min}}{D_{max} + D_{min}}$$

The value for R_e in the formula for p_p shall be reduced by 15% for pipes produced according to the UOE manufacturing process, and with 7.5% for pipes produced according to the UO manufacturing process.

Under application of the load factor ($\gamma_{g,p}$), the material factor ($\gamma_{m,p}$) and a modeling factor (γ_m) from Table 3 for this load combination, it shall be valid that:

$$\gamma_{g,p} \cdot p_L \le \frac{\gamma_M \cdot p_c}{\gamma_{m,p}}$$

D.3.3.4.2 Bending moment only

If only a bending moment is acting on the pipeline, the characteristic bending moment M_c, initiating local buckling, can be taken equal to to the fully plastic bending moment of the pipeline cross-section:

$$M_c = D_{nom}^2 d_n R_e$$

Under application of the load factor ($\gamma_{g.M}$), material factor ($\gamma_{m.M}$) and modeling factor (γ_m) from Table 3 for this load combination, it shall be valid that:

$$\gamma_{g,M} \cdot M_L \le \frac{\gamma_M \cdot M_c}{\gamma_{m,M}}$$

D.3.3.4.3 Combination of external pressure and bending moment

If combinations of loads can occur, then, in addition to the separate assessments of the external pressure and the bending moment as given in D.3.3.4.1 and D.3.3.4.2 the assessment below shall also be carried out.

Under application of the load factor, material factor and modeling factor from Table 3 for this load combination, it shall be valid that:

$$\frac{\gamma_{g,p} \cdot p_L}{p_c / \gamma_{m,p}} + \left(\frac{\gamma_{g,M} \cdot M_L}{M_c / \gamma_{m,M}}\right)^n \le \gamma_M$$

where:

$$: \quad n = 1 + 300\frac{d_{\mathrm{n}}}{D_{\mathrm{nom}}}$$

NOTE 1 For background information is referred to DNV-OS-F101, [9] and [32].

NOTE 2 The corresponding load factors, material factors and modeling factors are derived in [9], for *D/d* ratios that vary between 20 and 50. Further research may show whether the applied models are also applicable to larger *D/d* ratios.

D.3.3.5 Progressive plastic collapse

Progressivel plastic deformation with each load cycle leading to excessive deformation or failure.

NOTE 1 A characteristic of this limit state is that the stress, required to satisfy the state of equilibrium and which is of constant magnitude, is relatively high. The stress, resulting from satisfying continuously the deformation (angular rotation) conditions is, ,moreover, of a such substantial magnitude that, with every stress cycle , aggregated with the forementioned equilibrium stresses, a plastic strain occurs in one direction. After only a few cycles, failure can already occur. On the basis of [8], assessment of this limit state is important for an axially restrained pipe section, in which a high circumferential tensile membrane stress from internal pressure occurs in combination with a high axial membrane compressive stress (for instance from restricted thermal expansion).

The limit value is not exceeded if the following relationship is fulfilled:

$$\varepsilon_{\mathrm{max}} = \alpha \times \Delta T \leq \left[\frac{R_{\mathrm{e}}(\theta)}{E}\sqrt{1-\frac{3}{4}\left(\frac{\sigma_{\mathrm{y}}}{R_{\mathrm{e}}(\theta)}\right)^{2}} + \frac{R_{\mathrm{e}}}{E}\sqrt{0{,}9-\frac{3}{4}\left(\frac{\sigma_{\mathrm{y}}}{R_{\mathrm{e}}}\right)^{2}}\right]$$

NOTE 2 The partial factors that shall be applied to temperature and internal pressure (acting in combination) shall conform to Table 2.

NOTE 3 In case of a ’restrained’ section of a hot buried pipeline, for the given load combination and with the fulfillment of the above-mentioned requirements, the Von Mises criterion for alternating yield is also met.

D.3.4 Limit state with alternating yield

D.3.4.1 Background

If, through variations in the size of the loads, the strain in the steel varies to such an extent that plastic deformations occur in the steel in more than 1 direction (+ and -), alternating yield occurs.

The number of cycles, which are needed to reach crack initiation, is dependant on the magnitude of the strains that occur during yielding.
Relative to crack formation through strain variations in the elastic range, the number of cycles needed to cause cracking is lower with alternating yield.
Characteristic in this is the loop in the stress-strain diagram of the material at that point (see Figure D.4).

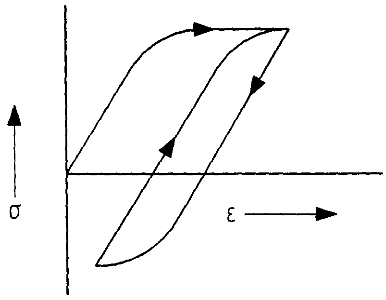


Figure D.4 - Stress-strain diagram during alternating yield

The limit state for alternating yield aims to limit the maximum strain and strain variations from cyclic loads, to ensure that at a certain point of the structure plastic yield can only occur one time, and that during the following load cycle the strain fluctuations stay within the elastic range.

The limit value for alternating yield is dictated by the condition that the stress fluctuations shall fit within the yield ellipse of Figure D.5 (maximum distortion energy hypothesis by Huber, Hencky and Von Mises).

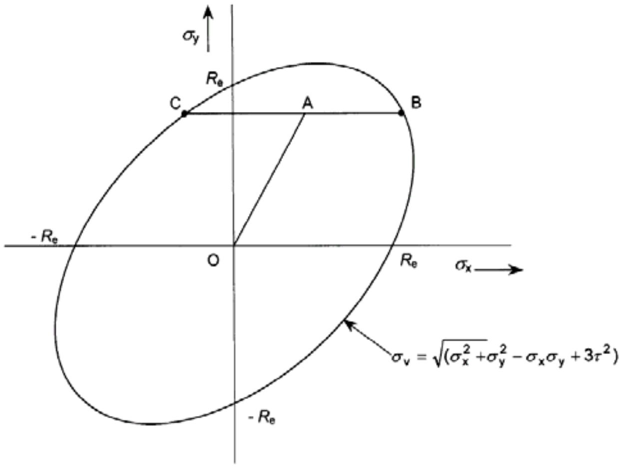


Figure D.5: Yield ellipse

NOTE 1 The deformations are elastic, as long as the stress points are within the yield envelope. Trough variation of the pressure and/or temperature, after imposing a certain bending and/or axial deformation a point on the circumference of the yield ellipse can be reached at the first cycle. This generally leads to some redistribution of stresses, accompanied with yielding. One time yielding is considered acceptable, as long as the limit state for strain is fulfilled. Everything has to develop elastically after the first cycle of load and during subsequent cycles, that is the stress ranges (such as OA - CB in Figure D.5) should be within the ellipse. If this is not the case, then alternating yield occurs.
In a majority of the assessment cases it is possible to easily examine which stresses are or are not relevant, and a plane stress condition will apply.

The shear-stress hypothesis may also be applied to assess alternating yield. It shall be shown that half of the variance of the greatest difference between each pair of the three principal stresses during a load cycle is less than .

D.3.4.2 Procedure for assessing straight pipelines and bends

In principle, separate calculations shall be carried out for the load combinations LC 3 up to and including LC 5 of table D.1. In the calculation, the load factors from Table 2 shall be applied.

The representative range of stresses or strains, between the different stress conditions, shall be determined.

NOTE 1 In general, in the case of pipelines under high-pressure and with substantial temperature fluctuations, the difference between the load combinations LC 4 and LC 5 will be representative.

NOTE 2 The maximum variations of the resultant stresses, from operationally varying load components (pressure and temperature) are considered. It is to be checked whether the design pressure and the design temperature will occur in combination with one another, or whether the maximum operating temperature can only occur in combination with a lower operating pressure than the design pressure.

NOTE 3 The pressure and/or temperature changes can also be varied through the simulation of time steps. During a load cycle, the maximum difference between the stresses or strains is determined.

D.3.4.3 Generally applicable procedure

If it is not clear, whether the principal stress shows a change in direction direction during load fluctuations, then the generally applicable procedure described below, shall be followed:

1) Calculate the stresses σ_x, σ_y and ι for each stress condition;

2) Select a (representative) stress condition as a reference condition (with the subscript $_i$), which is the extreme stress condition during the load cycle. In some cases it is necessary to select different stress conditions as a reference condition, so as to be able to determine the representative stress range or strain range;

3) Calculate the difference between the stresses σ_x, σ_y and ι of a stress condition with the reference condition, during a load cycle;

4) Calculate the principal stresses for these stress ranges;

5) Determine the differences between each pair of the principal stresses;

6) Determine the representative difference (absolute value) between each pair of the principal stresses.

If necessary, repeat the above procedure (steps 2) up to and including step 6)) for finding the representative reference condition.

The limit value for assessment for alternating yield is $R_e + R_e(\theta)$.

D.3.4.4 Simplified procedure, if primary stresses do not change direction

If the principal stresses do not or only barely fluctuate in direction during load fluctuations, then the following procedure, which is only applicable to a limited extent, may be followed:

1) Determine the principal stresses σ_x, σ_y and ι for each stress condition;

2) Determine the differences between each pair of the three principal stresses for each stress condition;

3) Determine the absolute value of representative stress range, during the load cycle.

The limit value for assessment for alternating yield is $R_e + R_e(\theta)$.

D.3.4.5 Stress ellipse for straight field sections

Assessment for alternating yield in a straight pipeline section (no bend) may also be carried out with the help of the Von Mises stress ellipse. The limit value for alternating yield is determined through the condition that the stress fluctuations shall fit within the yield ellipse of Figure D.5 (distortion energy hypothesis by Huber, Hencky and Von Mises).

NOTE The yield ellipse cannot be applied for assessing alternating yield of bends, since the stress condition can fluctuate in an axial and a tangential direction due to fluctuations in the load. As a consequence the stress condition is no longer clearly defined in case of yield.

One can also apply the shear-stress hypothesis for alternating yield, that is, the limit value is R_e/γ_m for half of the variation of the greatest difference between each pair of the three principal stresses, during a load cycle.

D.3.4.6 Simplified assessments for bends

By applying the shear-stress hypothesis (Mohr, Tresca), a simplified assessment for bends has also been defined. The basic assumption in this is in that the representative stress range is found by applying all loads in one go. The limit value for assessment for alternating yield is $R_e + R_e(\theta)$, if the representative stress range is defined as the difference between the principal stresses.

D.3.5 Limit state fatigue

D.3.5.1 Assessment procedure

Table D.3 lists the step-by-step measures that shall be carried out. (Also see ENV 1993-1-1:1995, Chapter 9 additional words have been deleted).

Table D.3 - Methodology for fatigue analysis

Step	Explanation	Reference
Identity the construction details to be assessed.	straight pipe, bends, T-pieces, reducers, etc.	
Identity the loads that shall be taken into account.	pressure and temperature fluctuations; traffic load.	8.2.7 from SI 5664-1
perform globa l(beam) analyses.	calculate the forces and moments on the cross-section.	SI 5664-1and 7.4 and 7.5
carrie out cross-section analyses	calculate the forces and moments acting on the pipe wall.	
establish stress history and design stressrange spectrumfor the relevant details and locations. determine the design 'stress range' spectrum.	calculate the stress range. determine the principal stresses, calculated according to the elasticity theory, proceeding from linear elastic material behavior (both in the elastic and in the plastic range). determine the peak stresses (hot-spot stresses) in the representative components of the structure, by analytical methods (stress intensification factors) or finite element analysis. determine the equivalent (reference) stresses (von Mises or Tresca). the spectrum of load cycles during the operating life of the pipeline shall be translated by way of a suitable method (the words in parentheses have been deleted) into a few full-load cycles.	D4
Identify fatigue strength data.	select a σ-N curve for the relevant construction detail $\sigma = k \times N^{-1/m} \quad ; N = \left(\frac{k}{\sigma}\right)^m$	D.3.5.2.2 and D.3.5.2.3
Identify fatigue endurance (number of full load cycles) for the design 'stress range'	$\sum \frac{n_i}{N_i} \leq \frac{1}{\gamma_{fat}}$	D.3.5.3

D.3.5.2 Limit value for fatigue

D.3.5.2.1 General

The fatigue strength of specific construction parts is expressed in σ-N curves, each of which is applicable for classified construction details.

σ-N curves are determined through tests on representative pipe components, or through stress or (in the plastic range) strain-oriented fatigue tests, under laboratory circumstances.

The fatigue strength (σ-N) curves are defined by using the equation:

$$\sigma = k \times N^{-1/m} \quad ; N = \left(\frac{k}{\sigma}\right)^m$$

D.3.5.2.2 Limit values (σ-*N*-curve) for fatigue caused by variations in membrane stress by internal pressure

In those pipes, which are primarily loaded by internal pressure, (for instance high-pressure gas and oil pipelines with operating temperatures ≤ 50° C), the stress cycles, from internal pressure variations resulting from operations, are often decisive when assessing the risk of fatigue damages. The resulting stress distribution is an elastic membrane stress evenly distributed over the entire pipe wall. For such transport pipeline systems, a fatigue analysis shall be carried out and assessed on the basis of the $\Delta\sigma$-*N* curves according to Figure D.6 and Figure D.7:

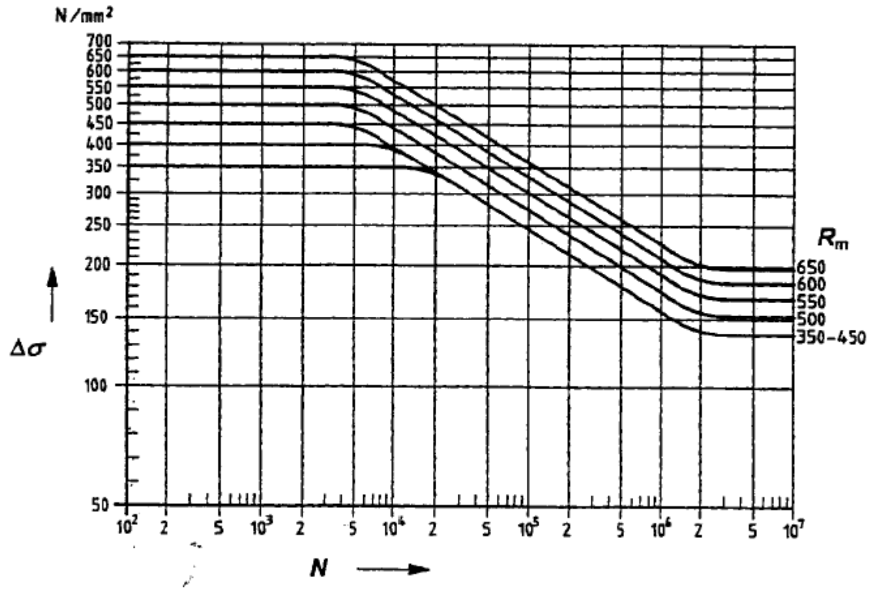


Figure D.6 - $\Delta\sigma$-*N* lines for seamless pipelines, and for pipelines in which the direction of the stresses is parallel to the direction of the weld ($\Delta\sigma$ and R_m in N/mm^2)

In the range between 5.10^3 and 2.10^6 cycles the curve of fig D.6 is approximated by [see14],:

$$N = 5.3 \times 10^3 \left(\frac{R_m}{\Delta\sigma} \right)^{5,15}$$

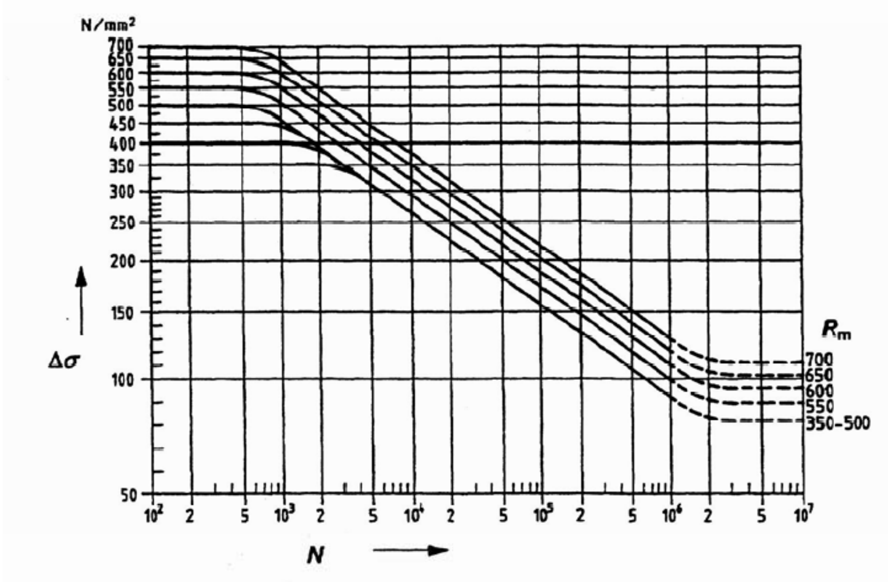


Figure D.7 - $\Delta\sigma$-N lines for submerged arc welded steel pipes ($\Delta\sigma$ and R_m in N/mm^2)

In the range between 5.10^3 and 2.10^6 load cycles, the curve of fig D.7 is approximated by [see 14],:

$$N \approx 700\left(\frac{R_m}{\Delta\sigma}\right)^{4,35}$$

NOTE 1 In case of high frequency induction welded (HFW) pipelines it is recommended not to use figure D.6 for, but rather to use the curves that are provided in Figure D.7, for pipelines welded with longitudinal seams.

The value of $\Delta\sigma$ is calculated according to load combination 2 (‘hoop stress formula'), under application of a partial load factor γ_p = 1.0.

The number of load cycles that are calculated according to the chart shall be divided by a safety factor (model and material factor) $\gamma_{M.fat}$ = 10.

NOTE 2 The $\Delta\sigma$-N curves according to Figure D.6 and D.7 are based on field tests that were carried out in the '70s on straight pipes. These curves have included the influence of standard surface defects, welding imperfections and form deviations in manufacturing. The influence of corrosive surroundings has not been included. The curves furthermore do not take into account the influence of the mean stress level on the operating life. Recent full scale field tests, by the European Pipeline Research Group carried out on pipe sections manufactured according to up to date production methods, indicate that a correction for the influence of the mean stress level may possibly be necessary [see 13], especially for spirally welded pipes and induction (HFW) welded pipes. For HFW welded pipes it is recommended to utilize the chart for submerged arc pipes welded. Both the Gerber and the Goodman models can be taken into consideration for this correction. Both models are described in [13].

D.3.5.2.3 Limit values (σ-N-curve) for fatigue caused by local stress as result of temperature and pressure cycles

Fatigue due to local stresses, or by temperature or pressure cycles, is primarily important for the assessment of local stress peaks in such components as bends, T-pieces, reducers, etc., whereby deformation-oriented loads, such as temperature, play an important role. Arithmetically, such stresses can exceed the yield strength.

For steel grades that are documented in this standard, one can proceed from the factors: k = 5000 N/mm^2 and m = 4. This results in the curve according to Figure D.8. This curve is also based on the AD (Arbeitsgemeinschaft Druckbehälter = German Pressure Container Association) data sheet S2:1995, and it also includes fatigue by local variation of plastic strains. Continuity from the elastic to the plastic range is achieved by expressing the strain, as measured in the plastic range, into a pseudo- elastic 'stress range', for instance through $\sigma = E\,\varepsilon$.

The stress amplitude is recorded in a vertical direction in Figure D.8 (pseudo-elastic).

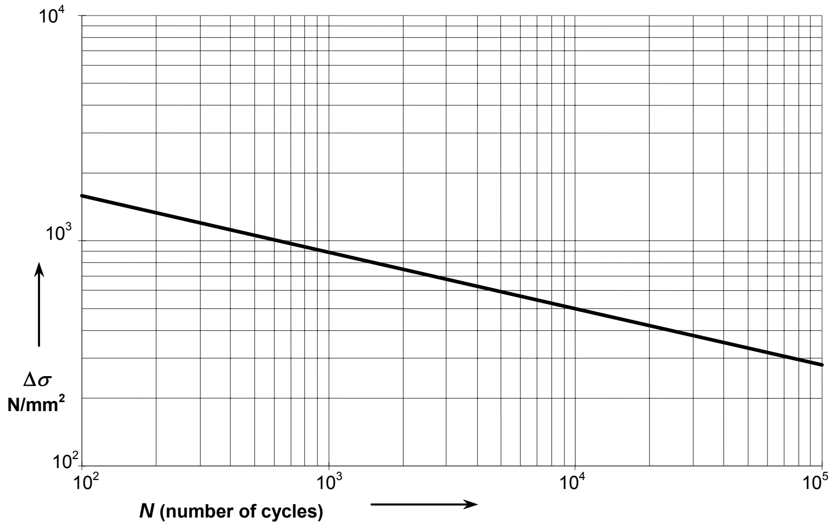


Figure D.8 - $\Delta\sigma$-N curve

NOTE 1 The curve , used in the above figure for the design fatigue strength, is based on the AD data sheet S2:1995 and [14], is estimated to lie at approximately three times the standard deviation of log *N* under the average curve, which was obtained through "curve-fitting" from the original test results for welded test rods. The probability of having a fatigue material strength under the curve values then amounts to approx. 0.1%. The values in the plastic range have been obtained through extrapolation from data in the elastic range.

NOTE 2 Reduction factors for a butt weld, mill scale imperfections and temperatures of up to approx. 140 °C have been included in the calculation of the curve. The effect of the electro-chemical surroundings has not been included in the curve.

NOTE 3 If other σ-N-curves are used, which are based on strain-oriented fatigue tests (for instance uni-axial tests on polished test rods), then reduction factors for surface defects and welded details shall be applied, as well as a suitable theorem for calculating the fictitious elastic stress and relating this to the plastic strain.

NOTE 4 The method with fictitious elastic stresses, as it has been covered here, is valid when the area in which plastic strain occurs is relatively small with regard to the total cross-section. If large parts of the cross-section are subject to plastic deformation, then the implicitly applied relationship between calculated elastic stresses and the occurring strain is no longer guaranteed.

NOTE 5 Stress intensication factors, according to SI 5664-1, should be taken into account in determining the fictitious elastic stresses in a curve.

NOTE 6 The influence of the fluid that is to be transported on the design fatigue curve should be examined.

NOTE 7 Reference is made to EN 13480-3:2002 for more information about fatigue calculations with regard to steel constructions.

NOTE 8 The use of steel, with a higher yield strength, only leads to a marginal improvement of the fatigue endurance .

NOTE 9 For fatigue assessment of stress variations from internal pressure. fatigue curves, different from the curve in Figure D.8, were used in the past These curves formed the basis for a simplified fatigue calculation, according to D.3.5.4.

The material and modeling factors are discounted, by dividing the calculated number of permissible cycles according to the σ-N-curve by $\gamma_{\mathrm{m.fat}}$ (see Table 3).

D.3.5.3 Fatigue damage from changing stress intervals

To assess fatigue damage from variable stress intervals, the concept of "cumulative damages", as formulated by Palmgren-Miner is used:

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

where:

n_i is the number of cycles for each stress range σ_i

N_i is the maximum number of cycles with a stress range σ_i, $N_i = \left(\frac{k}{\sigma_i}\right)^m$

D.3.5.4 Simplified fatigue analyses

If it can be shown that the number of cycles (N) from temperature and pressure fluctuations, resulting in a variation in the calculated stresses (calculation value) that is greater than 0.5 R_e (but less than R_e), conform to:

$$N \le 10^7 \left\{\frac{60}{R_e}\right\}^{4,25} \quad (R_e \text{ in N/mm}^2)$$

then no detailed fatigue analyses is required.

If this condition is not fulfilled, then a complete fatigue analysis shall be carried out.

D.3.5.5 Fatigue through traffic load

For possible fatigue through traffic loads, at crossings of pipelines with roads, reference is made to clause 6.5 SI 5664-1.

D.3.6 Limit state for resonance and "vortex shedding" / excessive lateral movements

NOTE These movements occur, whenever the impact frequencies of for instance wind, waves or currents, correspond with the natural frequency of the corresponding pipeline section. The impact frequencies can, amongst others, be a consequence of turbulences of the internal or external (liquid) currents ("vortex shedding"), acoustic vibrations, or a source of vibration located in the neighborhood of the pipeline, for instance a machine.

No limit values for such vibrations are directly available. The designapproach is to prevent vibrations from resonance and "vortex shedding".
The natural frequency of the pipeline system is assessed against a range of impact frequencies. An amplification of these frequencies can be avoided by designing the pipeline system in such a way that the natural frequency of the pipeline remains outside the range of impact frequencies (also see F.2.2.4 of SI 5664-1).

D.3.7 Limit state: displacements (stable position)

Inadmissibly large displacements in comparison to the desired position

The most unfavorable combination of simultaneously active horizontal and vertical loads acting on the pipeline shall be taken into account.

The pipeline shall be supported, anchored or buried such, that no displacements will occur under all possible conditions, with the exception of allowable displacements from pressure, temperature, expected settlements, and possible effects due to self-burial.

If a offshore pipeline is not buried, covered or anchored, then the dead weight of the pipeline, both empty, filled with product or filled with a testing medium and own weight of the pipeline, shall be such that a stable horizontal and vertical positioning in the construction phase is guaranteed.

Appendix E
(informational)

Application of the theory of plasticity

E.1 Introduction

After the yield strength has been reached, deformations in steel pipelines can still increase considerably before collapse occurs. In addition, the load bearing capacity (strength) is frequently considerably greater than the load at reaching yield strength.

The behavior (stress strain relationship) of the pipeline until the yield strength is reached can be described with the elasticity theory. Formulae (calculation models) for this are given in manuals as well as in this standard.

A proper description of the behavior after yield occurs is only possible with the application of the theory of plasticity in which the non-linear behavior of steel, namely yielding, has been taken into account. The available formulae (calculation models) for the application of the theory of plasticity are complicated and more consuming than the 'elastic' models.

Calculation models are presented in [23] and in [19], among others, for the calculation of the elastic and plastic behavior until collapse. A summary of these calculation models is presented in [18].

A series of interaction formulae has been included in this appendix in order to assess the limit state of stresses in the plastic area in straight pipes. For the calculation of the deformations which occur such as bending and ovalization, and for the calculation of the strains, simplified formulae for approximation have been provided. For more precise calculations and for the calculation of bends, please see [20], [21], [22], [23] and [18].

Demarcation of the area where the theory of elasticity can be applied in beam calculations can be found in E.2 and E.3 (calculation model E-P, see D.2.2.2). The calculation procedure to be followed, is reported in E.4.

Interaction formulae with which the different variables, which determine the behavior of straight pipelines,as a beam can be calculated, are included in E.5.

NOTE All forces and stresses in this appendix are calculation values, i.e. prior to calculation, the loads were multiplied with the partial load factors according to table 2.

E.2 Load bearing capacity of the pipeline as a beam

The mechanism of yield in a longitudinal direction is generally representative for the determination of the load bearing capacity for bending in a longitudinal direction. The load bearing capacity and the bending-stiffness of a pipe which is loaded by a bending moment in a longitudinal direction, however, change under the influence of the other loads (soil load, internal pressure, etc.). The influence of these other loads shall be taken into consideration when performing the global(beam)analyses

Appearing in figure E.1 are:

M_p the (full) plastic bending moment when the pipeline is loaded only by bending in a longitudinal direction;

M_e the elastic bending moment at which the yield strength is reached in the ultimate fiber;

M_m the maximum absorbable bending moment in case the pipeline is also loaded by other loads;

M^*_e the elastic bending moment in combination with other loads at which the yield strength is reached in the ultimate fiber;

C_e the curvature of the pipe as a beam when the yield strength is reached in the ultimate fiber;

C^*_e the curvature of the pipe as a beam in combination with other loads, atwhich the yield strength is reached in the ultimate fiber.

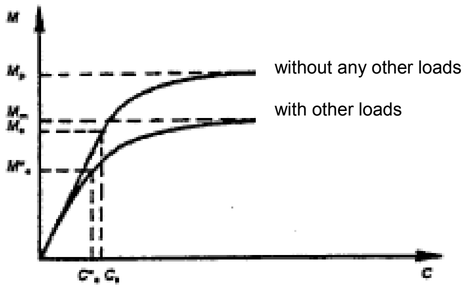


Figure E.1 — The influence of soil loads and other loads on the moment-curvature diagram in the elastic-plastic area

Before reaching M_e, the behavior is elastic. Afterwards, a gradual plastification of the cross-section occurs (elastic-plastic behavior) until the entire cross-section is yielding and M_p is reached. As a result of the soil loads present, which cause the ovalization of the pipe's cross-section, , M_e, C_e, and M_p however transform into M_e^*, C_e^* *and* M_m, respectively, and the situation in figure E.2 arises:

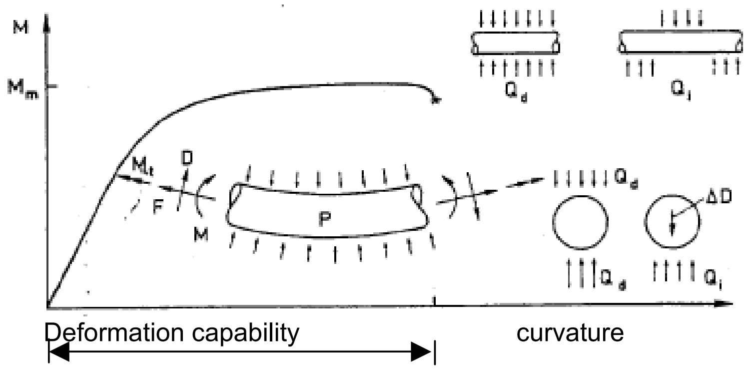


Figure E.2 — Moment-curvature diagram of the pipeline with different loads

E.3 Demarcation of the elastic area

If the results from analyses of the pipeline as a beam, according to the theory of elasticity (calculation model E-P) are used, M_e is used as the limit value for the calculated bending moment:

Straight pipelines:

$$M_e^* = \frac{M_e}{M_p} \cdot M_m \approx \frac{\pi}{4} \cdot M_m \approx \pi \cdot r_g^2 \cdot d_n \cdot \sigma_e^*$$

The corresponding curvature is:

$$C_e^* = \frac{M_e^*}{EI} = 2\frac{\varepsilon_y}{D}\frac{M_m}{M_p}$$

Bends:

$$M^{*}_{\text{e-bend}} = \frac{\pi}{4} M_{\text{m-bend}}$$

The corresponding curvature is:

$$C^{*}_{\text{e-bend}} = \frac{M_{\text{e-bend}}}{EI_{\text{bend}}} = 2\frac{\varepsilon_{\text{y}}}{D}\frac{M_{\text{m}}}{M_{\text{p}}} \cdot k_{\text{bend}}$$

Here, M_m is the maximum bending moment that the pipe cross-section can transmit, see figure E.2. For the determination of M_m, M_p, $M_{m\text{-bend}}$ and k-bend, please refer to the interaction formulae in E.3 and [19], [21], [23] and [24].

If these conditions are satisfied and likewise the series of interaction formulae in E.3 (and the conditions in the references [19], [20], [21], [22] and [23]) are satisfied, then it is also demonstrated that the limit state "stresses" has not been exceeded (as, the requirement that the stresses cannot be higher than the yield strength is one of the conditions in the derivation of the interaction formulae).

E.4 Calculation procedure

A 'best guess" of the load bearing capacity on bending moment and torsional moment shall be made, providing "input" for the beam calculation. This load bearing capacity is, as is shown in figure E.1 and E.2, influenced by the other loads. For this reason, a provisional calculation of the cross-section is first conducted in order to determine this load bearing capacity for the relevant cross-sections. The result of this cross-section calculation is the ovalization which shall be imported into the formulae for bending stiffness.

Calculation model E-P:

After the beam-calculation has been performed, the stresses and deformations in the representative cross-sections are calculated with the help of the interaction formulae from E.3. If the ovalization introduced into the beam-calculation (ΔD $=2a$) deviates more than $0.02D$ from the final calculated value, the calculations shall be repeated with a better initial estimate of the ovalization.

Calculation model P-P:

If the results of the beam-calculation show that the resulting calculated soil loads, normal forces and shear forces are deviating too much from the initially introduced values, the calculations shall be repeated.

NOTE A difference of 10 % between the introduced and the resullting calculated forces in the plastic range (load bearing capacity, soil loads, N_p, D_p) will still produce acceptable small deviations in the size of the load bearing capacity on bending and torsion.

E.5 Interaction formulae for straight pipelines

E.5.1 General

A moment curvature-diagram is given in figure E.2 for a straight pipe which, aside from bending, is also loaded by other loads such as direct soil load Q_d, indirect soil load Q_i, normal force F, shear force V, torsion moment M_t and pressure p (p is the difference between the internal pressure p_i, and the external pressure p_u).

The maximum absorbable bending moment (M_m) for a straight pipe loaded with a combination of bending moment, torsion moment, normal force, shear force, internal pressure, external pressure and soil load, can be calculated with the interaction formulae from E.5.2 and E.5.3. The strains that occur are calculated according to E.5.4.

NOTE 1 For the derivation and background of the series of interaction formulae that follow, refer to [18], [10], [20] and [23].

NOTE 2 In general, the influence of the shear force and the normal force on M_m is relatively small. Soil loads and the pressure p have the major influence.

NOTE 3 Performing the necessary calculations manually is very laborious. Use can be made of dedicated computer programs

E.5.2 Interaction formulae for a straight pipe

The following formula is applicable for the cross-section being considered:

$$\frac{M}{M_{\mathrm{pdtr}}}+\left(\frac{|N|}{N_{\mathrm{pdtr}}}\right)^{1.7}\leq 1$$

where:

M is the bending moment occurring (calculation value) in the given load situation, in Nmm;

N is the effective normal force occurring (calculation value), $N=F-p\pi r_{\mathrm{g}}^{2}$, in N;

where:

F is the normal force which comes from the beam-calculation, in N;

r_{g} is the average radius, $r_{\mathrm{g}}=(D_{\mathrm{u}}-d_{\mathrm{n}})/2$, in mm;

p is the internal or external pressure (the pressure difference), whereby internal pressure shall be indicated with a positive sign and external pressure shall be indicated with a negative sign, in N/mm^2;

M_{pdtr} is the maximum absorbable bending moment if there is no normal force N acting on the relevant cross-section, but other loads such as internal pressure, shear force, torsion moment, soil loads etc.are in effect, in Nmm;

$$M_{\mathrm{pdtr}}=M_{\mathrm{pr}}\sqrt{1-\left(\frac{V}{V_{\mathrm{pr}}}+\frac{M_{\mathrm{t}}}{M_{\mathrm{tpr}}}\right)^{2}}$$

N_{pdtr} is the maximum absorbable effective normal force if there is no bending moment M acting on the relevant cross-section, but other loads such as internal pressure, shear force, torsion moment, soil loads etc. are in effect, in N;

$$N_{\mathrm{pdtr}}=N_{\mathrm{pr}}\sqrt{1-\left(\frac{V}{V_{\mathrm{pr}}}+\frac{M_{\mathrm{t}}}{M_{\mathrm{tpr}}}\right)^{2}}$$

where:

M_{pr} is the absorbable plastic bending moment (pipe as beam) for a straight pipe, taking into account the influences of the ovalization of the cross-section, the internal pressure repectively external pressure, and the soil loads (directly and indirectly transmitted overhead loads Q_{d} and Q_{l}), in Nmm;

M_{t} is the torsion moment in the considered cross-section (beam effect), in Nmm;

M_{tpr} is the absorbable plastic torsion moment for a straight pipe, taking into account the influences of the ovalization of the cross-section, the internal pressure respectively external pressure, and the soil loads (directly and indirectly transmitted overhead loads Q_{d} and Q_{i}), in Nmm;

V is the shear force in the considered cross-section (pipe as a beam), in N;

V_{pr} is the absorbable shear force, taking in account the influences of the ovalization of the cross-section, the internal pressure with respect to external pressure, and the soil loads (directly and indirectly transmitted overhead loads Q_{d} and Q_{i}), in N;

N_{pr} is the absorbable normal force, taking in account the influences of the ovalization of the cross-section, the internal pressure with respect to external pressure, and the soil loads (direct and indirect transmitted overhead loads Q_d and Q_i), in N;

$M_{pr} = g\, h\, M_p$

$M_{tpr} = g\, M_{tp}$

$N_{pr} = g\, N_p$

$V_{pr} = g\, V_p$

where:

M_p is the plastic bending moment (pipe as beam) for a straight pipe, in Nmm;

M_{tp} is the plastic torsion moment for a straight pipe, in Nmm;

N_p is the normal force at yield for a straight pipe, in N;

V_p is the shear force at yield for a straight pipe, in N;

g is a factor used to count for the influence of the arising forces and moments in the pipe wall in circumferential direction;

h is a factor used to count for the influence of the ovalization of the pipe on the absorbable plastic bending moment;

a is the ovalization of the pipe cross-section in the bending plane (a is half of the change in the diameter ΔD), in mm (for the calculation of a, see E.5.3);

$$M_p = 4 r_g^2 d_n R_{eb}$$

$$M_{tp} = \frac{2}{\sqrt{3}} \pi\, r_g^2 d_n R_{eb}$$

$$N_p = 2\pi\, r_g\, d_n\, R_{eb}$$

$$V_p = \frac{4}{\sqrt{3}} r_g\, d_n\, R_{eb}$$

$$h = 1 - \frac{2}{3}\frac{a}{r_g}$$

$$g = \frac{c_1}{6} + \frac{c_2}{3}$$

$$c_1 = \sqrt{4 - 3\left(\frac{n_y}{n_p}\right)^2 - 2\sqrt{3}\left|\frac{m_y}{m_p}\right|}$$

$$c_2 = \sqrt{4 - 3\left(\frac{n_y}{n_p}\right)^2}$$

where:

n_y is the force occurring in the pipe wall per unit of plate width as a result of soil load (n_{yq}), the curvature of the pipe as a beam (n_{yk}) and the difference between the internal and the external pressure (n_{yp}), in N/mm;

m_y is the bending moment occurring in the pipe wall in circumferential direction, per unit of plate width as a result of soil load (m_{yq}), the curvature of the pipe as a beam (m_{yk}) and the difference between internal and external pressure (m_{yp}), in Nmm/mm;

n_p is the force at yield in the pipe wall per unit of plate width, in N/mm;

m_p is the plastic bending moment in the pipe wall in circumferential direction, per unit of plate width, in Nmm/mm;

$$n_y = n_{yq} + n_{yk} + n_{yp}$$

$$m_y = m_{yq} + m_{yk} + m_{yp}$$

$$n_p = d_n \cdot R_{eb}$$

$$m_p = 0.25 \cdot d_n^2 \cdot R_{eb}$$

with:

$$n_{yq} = 0.25\, Q_d + 0.125\, Q_i$$

$$n_{yk} = 0.20 \frac{M_m\, C}{r_g}$$

$$n_{yp} = p\, r_g$$

$$m_{yq} = m_{yqd} + m_{yqi}$$

$$m_{yqd} = 0.25 Q_d\, r_g \left(1 - 0.25\left(\sin\frac{\alpha}{2} + \sin\frac{\beta}{2}\right)\right) f_0$$

$$m_{yqi} = 0.25 Q_i\, r_g \left(0.5 - 0.25 \sin\frac{\gamma}{2}\right) f_0$$

$$f_0 = 1 + \frac{a}{r_g}$$

$$m_{yk} = 0.071 \cdot M_m \cdot C \cdot f_0$$

$$m_{yp} = -p \cdot r_g \cdot a$$

where:

Q_d is the directly transmitted overhead load, in N/mm;

Q_i is the indirectly transmitted overhead load, in N/mm;

C is the curvature of the pipe as a beam, in mm^{-1};

α is the load angle for directly transmitted overhead load;

β is the angle of support;

γ is the angle of load for indirectly transmitted overhead load (γ may be considered to be equal to α = 180°).

E.5.3 Calculation of the ovalization

The ovalization a is primarily caused by the soil loads. In addition to this, the bending in longitudinal direction is also a contributing factor. The internal pressure produces a reduction of the ovalization ("rerounding"). The ovalization a is the result of an elastic component a_{el} and a plastic component a_{pl}.

$$a = a_{el} + a_{pl}$$

NOTE In deviation from the rest of this standard in this appendix , the notation a is used for the vertical deflection of the pipe cross-section (the ovalization) , instead of δ or δ_y. This is done in order to guarantee conformity with the background literature ([20], [21] and [23]).

a) *Elastic range*

$$a_{el} = a_{gd\text{-}el} + a_{qi\text{-}el} + a_{c\text{-}el}$$

where:

$a_{qd\text{-}el}$ is the ovalization caused by the directly transmitted soil load, including rerounding;

$a_{qi\text{-}el}$ is the ovalization caused by the indirectly transmitted soil load, including rerounding;

$a_{c\text{-}el}$ is the ovalization caused by curvature from Bending Moment including rerounding;

$$a_{qd-el} = 0.5\,k_{yd}\frac{Q_d \cdot r_g^{\,3}}{EI_w}(1+\frac{3a}{r_g})\cdot f_{rr}$$

$$a_{qi-el} = 0.5\,k_{yi}\frac{Q_i \cdot r_g^{\,3}}{EI_w}(1+\frac{3a}{r_g})\cdot f_{rr}$$

$$a_{c-el} = C^2\,\frac{r_g^{\,5}}{d_n^{\,2}}(1+\frac{3a}{r_g})\cdot f_{rr}$$

where:

k_{yd} is the ovalization (deflection) coefficient dependent on the way in which the direct soil loads affect the cross-section, see SI 5664-1. table D.1;

k_{yi} is the ovalization (deflection) coefficient dependent on the way in which the indirect soil loads are acting on the cross-section, see SI 5664-1, table D.2;

f_{rr} is the rerounding factor;

EI_w is the bending stiffness of the pipe wall per unit of plate width, in Nmm^2/mm;

$$EI_w = \frac{E\,d_n^{\,3}}{12\,(1-\nu^2)}$$

For the rerounding factor f_{rr}, please consult D.3.1 from SI 5664-1.

$$C = \frac{M}{EI} = \frac{M}{E \cdot \pi \, r_g^3 d_n}$$

The abovementioned formulae for $a_{qd\text{-}el}$ and $a_{qd\text{-}pi}$ can be used till the maximum circumferential bending moment in the pipe wall where m_{yq} has become equal to m_p is reached. The formula for $a_{c\text{-}el}$ is applicable up to reaching C_e

b) Plastic range

$$a_{pl} = \left(a_{qd-pl} + a_{qi-pl} + a_{c-pl}\right) \cdot \left(1 + \frac{3a}{r_g}\right)$$

where:

$a_{qd\text{-}pl}$ is the ovalization caused by the direct soil load, including rerounding (plastic);

$a_{qi\text{-}pl}$ is the ovalization caused by the indirect soil load, including rerounding (plastic);

$a_{c\text{-}pl}$ is the ovalization caused by curvature, including rerounding (plastic).

In general, the soil loads will not be that large to cause ovalizations exceeding the elastic range. In those cases , $a_{qd\text{-}pl}$ and $a_{qd\text{-}pi}$ will be equal to 0. In other cases, a non-linear cross-sectional analyses shall be conducted to determine the total of a resulting from the soil load. See [19], [20] and [23] for this purpose.

The following approximation formula may be used for $a_{c\text{-}pl}$ in case a more precise calculation is not necessary.

$$a_{c-pl} = -2 \frac{r_g^3}{d_n} \cdot \psi \cdot (C - C_e^*)$$

with:

$$\psi = 1 - \left(\frac{0.5 \times c_2}{g}\right)^2$$

NOTE Because c_2 and g are dependent on, among others, curvature and ovalization, iteration will be necessary.

E.5.4 Calculation of the strains

E.5.4.1 In longitudinal direction

$$\varepsilon_x = \varepsilon_{xC} + \varepsilon_{xN}$$

with:

$$\varepsilon_{xC} = \pm C \times r_g$$

$$\varepsilon_{xN} = \frac{N}{AE}$$

where:

A is the cross-sectional area on which the normal force is acting, in mm^2.

E.5.4.2 In circumferential direction

The following approximation formulae may be used for the maximum circumferenial strain $\varepsilon_{y\text{-}max}$ if a more precise calculation is not necessary.

a) Elastic range

The following formula applies in the elastic ($\varepsilon_{y\text{-el}} \geq \varepsilon_{yield} = R_{eb} / E$)range:

$$\varepsilon_{y-max} = \varepsilon_{y-el} = \pm \frac{k_{max}}{k_{yd}} \cdot \frac{d_n}{r_g^{\,2}} \cdot a + \frac{p \cdot r_g}{E \cdot d_n}$$

where:

k_{max} is the maximum value for the moment coefficient when calculating the circumferential bending moments from soil loads (in general, this will be k_{bottom}), see SI 5664-1, tables D.1 and D.2;

k_{yd} is the ovalization coefficient dependent on the manner in which the direct soil loads are acting on the cross-section, see SI 5664-1, table D.1.

The ovalization corresponding with ε_{yield} is named a_{yield}.

b) Plastic range

The following formula applies in the plastic area:

$$\varepsilon_{y-max} = \varepsilon_{y-pl} = \pm \left(\frac{a}{a_{yield}} \right)^2 \cdot \varepsilon_{yield} + \frac{p \cdot r_g}{E \cdot d_n}$$

E.6 Moment-curvature diagram

The following formula applies for the elastic range of the moment-curvature diagram (see figures E.1 and E.2):

$$M = EI_{red} \cdot C \quad \text{with} \qquad EI_{red} = E \pi r_g^{\,3} d_n \left(1 - 1.5 \frac{a'}{r_g} \right)$$

In this equation, a' is the ovalization when C_e^* is reached.

The following formula applies for the moment-curvature diagram in the plastic range:

$$M = M_m 0.5 \left(\frac{\phi}{\sin \phi} + \cos \phi \right) \cdot \left(1 - 1.5 \frac{a}{r_g} \right) \quad \text{with} \qquad \phi = \arcsin \frac{C_e^*}{C}$$

E.7 Interaction formulae for bends

There are two mechanisms that can determine the magnitude of the load bearing capacity on bending moment in bends. These mechanisms are:

a) the occurrence of plastic hinges along the circumference of the cross section. This mechanism will become all the more representative the more the bends are curved (small bend radius), the lower the internal pressure is, the greater the soil loads are, and, moreover , are giving rise to an ovalization that has the same direction as the ovalization from longitudinal bending;

b) the occurrence of yielding in a longitudinal direction. This mechanism will become all the more governing the less the bends are curved (greater bend radius), at higher internal pressure, the greater the soil loads are and moreover are giving rise to ovalization contrary to the ovalization produced by longitudinal bending. This mechanism matches with the behavior dealt with in E.5.2 in the case of straight pipes.

For calculation methods and interaction formulae for bends, refer to [19], [21], [22], [23], [24] and [25]. Due to the physically and geometrically non-linear character of the interactions, manual calculations are not really possible. Therefore,finite element computer program is generally necessary to deal with both non-linear phenomena.

Appendix F
(informativel)

Public Safety

F.1 Assessing local and group risk

F.1.1 Purple book

A "Quantitative Risk Assessment", (abbreviated: QRA) shall be performed for natural gas station.

A "Quantitative Risk Assessment", (abbreviated: QRA) shall be performed for natural gas pipelines in case the safety distances as stipulated in Table F.6 are not maintained.

CPR 18^E "Guidelines for QRA" (the "Purple book") [3] shall be used in order to complete the QRA. The text from F.2 is a translation into Dutch of 3.5 "Pipeline transport" from section 2 'Transport' of the CPR 18^E. In case of discrepancies, CPR 18^E shall prevail.

The results of a QRA are iso risk contour lines of local (individual) risk(PR), presented in the form of a graph, and graphics from which the group risks (GR) emerges. For evaluation of the results of the calculation of PR and GR, see F.2.5.

F.1.2 VROM circulars

The text from F.3 is a summary from the Circular "*Safety zones along high pressure natural gas transportation pipelines "*[1], from the Circular "Safety *zones along transportation pipelines for category K1, K2 and K3 flammable liquids"* [2] and from *Assistance regarding external safety in the transport of dangerous substances* [28]. The text from these circulars and the safety distances stated in these circulars have been determined and compiled under the aegis of the ministry of VROM , The safety distances are summarized in table F.4 and table F.6 of this standard.

The distances are valid as long as the Dutch government does not issue an amendment through a new Circular. Please consult the original documents for the correct application of the current regulations.

NOTE 1 Establishing the safety distances under regulation and their enforcement is primarily the task of the government.

NOTE 2 At the time of the first edition of this standard, a revision of CPR 18^E and of the abovementioned circulars were in preparation. (A few points under discussion are included under F.4). As soon as the results of the revision have been made available, a revised version of appendix F will be included in this standard.

F.2 QRA according to CPR 18^E

F.2.1 General

CPR 18^E contains a description of a detailed external safety evaluation ("Quantitative Risk Assessment", abbreviated: QRA) for hazardous substances that are transported via underground pipelines. Indicated in CPR 18^E are those events where a quantity of substance escapes ("Loss of Containment Events", abbreviated: LOC's) which shall be included in the QRA, as well as the respective frequencies of failure and the various events (and the probability thereof) which can arise following the release of the substances. No detailed description is provided on medeling the types of discharge, dispersion, exposure and injury, or the wayin which the results are calculated and reproduced,. Only the differences with the modeling of stationary installations is explained (see section 1 "Establishments" of CPR 18^E for this).

The data which are necessary to perform for a QRA are:

— a description of the transportation system (diameter, location of the safety (check) valves);

— a description of the transport stream (fluid, flow);

— a description of the sources of ignition;

— properties of the hazardous substance to be transported;

— classification of the area in the vincinity of the pipeline route;

— meteorological data;

— population density in the vicinity of the pipeline route.

F.2.2 Leakage or rupture of pipeline or “Loss of Containment Events”

Two types of LOC’s (“Loss of Containment Events”) can occur with underground pipelines:

— leakage from a 20 mm hole in the pipeline;

— rupture of the pipeline.

F.2.3 Frequencies, probabilities and results of incidents with leakage

The frequency of LOC is given per kilometer per year. Table F.1 shows the LOC frequency for the different types of underground pipelines.

Table F.1 — LOC frequencies for the various types of pipelines

Type of pipeline	LOC frequency (1/km year)
pipeline in a “pipeline corridor”	7.0×10^{-5}
pipeline not in a "pipeline corridor"	6.1×10^{-4}
The last line has been deleted	

NOTE 1 What is meant by a pipeline in a “pipeline corridor” is a pipeline which is a part of a group of pipelines ,located in a route that has been specially designated and designed for pipelines. The LOC frequencies are lower because extra safety measures have been included.

NOTE 2 Other frequencies can also be used for specific pipelines, for example, in case extra safety measures are included to lower the probability of a LOC. (This has been applied, for example, to a chlorine pipeline in the” Rotterdam Harbour” area).

NOTE 3 Discussions regarding failure frequencies were still ongoing between pipeline operators and the government at the time of issuing of this standard. The results of these discussions may be included in a revision of CPR 18[E]. [11] provides an inventory of the available failure casuistics in Europe and the U.S.A. over the period of 1970-1998.

Table F.2 provides the probability of a leakage of a rupture given an LOC.

Table F.2 — Probability of a leakage or rupture in case of LOC

Type of pipeline	Probability of leakage	Probability of rupture
pipeline in a “pipe corridor”	0.9	0.1
all other pipelines	0.75	0.25

The dangerous events which can occur following an LOC are:

— exposure to toxic substances;

— flares;

— fireballs;

— pool fire;

— flash fires;

— explosions.

The probability of instant ignition following a LOC are presented in table F.3.

Table F.3 — Probabilities of immediately ignition following an LOC

Type of liquid	Probability of instant ignition	
	Leakage	Rupture
flammable gas	0.04	0.09
liquid flammable gas	0.14	0.30

The probability of delayed ignition is maximum: (1 minus probability of immediate ignition) because there is a possibility that no ignition will occur.

NOTE 4 A higher probability of instant ignition shall be taken into account with hydrogen, because of the very low minimal energy needed for ignition.

F.2.4 Modelling of discharge, dispersion, exposure and fatal injury

After the LOCs have been determined, the discharge is calculated. When doing this, a distinction shall be made between a leakage and a rupture.

F.2.4.1 Leakage

If the LOC is not immediately noticed and the valves are not immediately closed, the leakage is considered to be a continuous source from which a discharge lasting 30 minutes occurs.

If the valves are closed, the following is applicable:

— gas: the discharge will continue until the pressure in the pipeline is equal to the atmospheric pressure;

— liquid: due to expansion of the liquid the discharge will continue until the vapor pressure in the pipeline is equal to the atmospheric pressure. If the pipeline does not run horizontally, consideration shall be made with a discharge , caused by gravity;

— gas compressed to a liquid: a two-phase discharge occurs.

NOTE A comparison of the flow going into the pipeline versus that leaving the pipeline gives an indication of the leak flow and the possibility for the operator to notice the leakage.

F.2.4.2 Pipeline rupture

With a pipeline rupture the calculated discharge shall be doubled, because of discharge from both sides. Furthermore, the discharge shall be increased by the pump discharge, until the pump is stopped or the valves are closed. In the case of liquid transport pipelines, running through accidented terrain, gravity shall also be taken into consideration.

Starting points used and important related aspects are :

1) a check shall be made whether the pump speed increases as a result of the drop in pressure ,caused by the rupture of the pipeline;

2) no consideration is made for crater formation and the location of the hole (direction of discharge), because insufficient reliable data available for this are not i trustworthy;

3) the pool has a maximum dimension of 3000 m^2 and is 0.1 m deep;

4) with the rupture of a ethene pipeline, the discharge is dependent on the temperature of the air and the soil: this is because of the critical temperature of ethene. For leakage, there is hardly any difference in risk between a discharge of gas or a two-phase discharge.

5) the evaporation factor for soil is equal to 1800 W/K.$s^{1/2}$;

6) the meteorological data that are used in a QRA shall come from a weather station that is representative for the transport route being considered. If applicable, data from different weather stations shall be used for the different sections of the pipeline;

7) a representative value shall be used for the aerodynamic length of roughness z_0 of the terrain along the transport route (see 4.6.2 from section 1 of [3]). If applicable, different values shall be used for the different sections of the pipeline. Standard value z_0 = 1.0 m;

8) when modelling the dispersion of the gas cloud, no chemical processes or dry or wet deposition processes need to be taken into consideration;

9) exposure and injury shall be modeled in conformity to chapter 5 in section 1 of [3];

10) An inventory shall be made of the presence of population along a transport route conform 5.3 in section 1 of [3].

After the size of the discharge has been determined, the modeling can be continued in the same manner as for stationary installations.

F.2.5 Calculation and reproduction of the results

The results of a QRA are presented as iso-risk contour lines for local risk and graphs from which the group risk emerges. Group risk shall be calculated and reproduced per kilometer of the respective transport route.

NOTE Chapter 6 of CPR 18[E] provides a description of a frequently applied methodology for the calculation of risk and how the results can be reproduced graphically. The following aspects regarding this are important:

— the size of the grid should be sufficiently small in order to obtain sufficiently precise calculation results;

— in order to obtain consistent iso-risk lines, the accident locations should be situated at regular distances from each other and accident locations which lie outside of the regions of the pipeline route that is being considered should also be taken into consideration. There should also be an adequate number of accident locations so that the risk contour does not change substantially if the number of locations increases;

— The beginning and the end of the section of a pipeline route that is considered for calculation of group risk, can be chosen . previously and arbitrarily. However, the sections should be chosen in such a way that the maximum group risk will be calculated

F.3 Safety zones for natural gas pipelines

F.3.1 General

In deciding upon an acceptable route, the determination of the iso-risk contour lines for the local (individual) risk(PR) , by means of a QRA, can be omitted for natural gas transport pipelines if compliance with Tables F.5 and F.7 are met.

With regard to group risk (GR), rules of thumb have been developed for natural gas transport, through which a quick insight can be obtained if more detailed GR research is necessary. See F.3.3.

F.3.2 Local risk

F.3.2.1 Safety zoning

In the determination of an acceptable route from the viewpoint of local risk, the following terms are employed:

a) Survey distance

Distance measured from the core of the pipeline (for stations, the edge of the station) within which the location classification shall be determined on both sides of the pipeline (for stations, the edge of the station). For land planning purposes, unless otherwise agreed upon by the authorities, the area classification shall be determined by surveying a strip whose width is determined in the statutory regulations.

b) Building proximity distance

The shorter horizontal distance between the core of the pipeline (for stations, the edge of the station) and the outer edge of a building intended for human occupancy, buildings of considerable infrastructure value such as computer centers, telephone exchanges, or buildings containing air traffic control equipment, or special objects which shall be taken into consideration.

c) Location classification

The classification of an area based on the density of buildings intended for human occupancy, the presence of special objects and the use of the area.

F.3.2.2 Objects determining the location classification

The design of gas pipelines must consider the factors and consequence of failure due to the presence and activities of people along the pipeline route where damage is likely to be more prevalent in locations with larger concentrations of human occupancy. To address this, the route of pipelines must be given a location classification based on population occupancy which in turn will limit the design of the pipeline to the appropriate design factor.
The area class will comply with the following table – Area classification.

Area classification

Area class	Description
1 See note c	Any 0.5 km. section along the pipeline that has 3 or fewer buildings intended for human occupancy. It may include farmland, agricultural structures and storage facilities.
2	Any 0.5 km section along the pipeline having more than 3 but fewer than 8 buildings intended for human occupancy. It may include public assembly facilities such as open-air markets, sports facilities, permanent houses of worship and other public and industrial buildings not included in classes 3 and 4, that accommodate less than 50 people at one time.
3	Areas intended for continued occupation for part of the year, such as camping sites. Areas occupied for short periods by large groups of people for part of the day, such as playgrounds, allotments, sports fields or open-air swimming pools. Groups of adjacent dwellings where the shortest distance between the dwellings do not generally exceed 10m. Industrial areas and engineering facilities. Area where there is frequent excavation work including quarries. Main or secondary road with heavy traffic. Areas in the close vicinity to several pipelines, cables etc.
4	• Buildings of more than three stories • Residential homes for the elderly and nursing homes\ including hospitals and sanatoria. • Schools and commercial centers. • Hotels , office buildings and facilities accommodating more than 50 people. • Buildings of considerable infrastructure value such as computer centers, telephone exchanges, or buildings containing air traffic control equipment. • Buildings, which present an increased risk due to secondary effects such as above ground installations or aboveground storage tanks (>5m³) for flammable, explosive and or toxic materials.
Notes	a. The area classification shall be determined by surveying any 500 m long strip with a width of the assessment distance, (see SI 5664-2 Table F.4). b. Each separate dwelling unit in a multiple dwelling building is to be counted as separate building. c. For wall thickness calculations, the design factor associated with area class 1 shall not be used.

Remark: Once a section is defined based on the occupation density, the distance of the beginning and the end of such a section to the outermost dwelling shall be the minimal survey distance, given below.

F.3.2.3 Survey distances

Table F4 —Summary survey distances (in m)

Nominal diameter		**Natural gas transport pipelines operational pressure in MPa**		
inch	mm	2-5	5-8	8-11
2	50	20	20	20
4	100	20	20	25
6	150	20	25	30
8	200	20	30	40
10	250	25	35	45
12	300	30	40	50
14	350	35	50	60
16	400	40	55	70
18	450	45	60	75
24	600	60	80	95
30	750	75	95	120
36	900	90	115	140
42	1050	105	130	160
48	1200	120	150	180

Note: For land planning purposes, refer to statutory regulations.

F.3.2.4 Wall thickness

The minimum wall thickness of the pipeline to be used is dependent on the location classification. Because the wall thickness of the pipeline is calculated in the structural design, however, the wall thickness calculated, using the method described below shall always be taken as mandatory minimal wall thickness. The pipe’s wall thickness shall also conform to the requirements of chapter 7.2. The hoop stress and the wall thickness shall be calculated with the following formula:

$\sigma_p = p \cdot D_g / 2 \cdot d$ and shall be assessed by: $\sigma_p \leq R_e / f_d$

where:

σ_p is the tensile circumferential hoop stress, in N/mm^2;

p is the design pressure, in N/mm^2;

D_g is the average pipeline diameter, in mm;

d is the minimum wall thickness after subtraction of manufacturing tolerance and without any corrosion or abrasion allowances, in mm;

R_e is the specified minimum yield strength, in N/mm^2;

f_d is the wall thickness factor (see table F.5).

The representative values for design pressure and yield strength shall be used in the calculation, without applying a load factor or a resistance factor.

Table F.5 — Wall thickness factor

Location classification	1	2	3	4
pipelines in a “pipe corridor”	1/0.72 (1.39)	1/0.72 (1.39)	1/0.65 (1.54)	1/0.65 (1.54)
all other pipelines	1/0.72 (1.39)	1/0.65 (1.54)	1/0.55 (1.82)	1/0.45 (2.22)

NOTE The factor determines the minimum pipe wall thickness and provides a greater wall thickness in case of higher location-classification (more densely populated areas).

F.3.2.5 Building proximity distances

Table F.6 sets forth the building proximity distances for transmission pipelines.

Table F.6 — Summary of building proximity distances (in m)

Nominal diameter		Natural gas transport pipelines with operating pressure in MPa		
inch	mm	2-5	5-8	8-11
2	50	4	5	5
4	100	4	5	7
6	150	4	5	7
8	200	7	8	10
10	250	9	10	14
12	300	14	17	20
14	350	17	20	25
16	400	20	20	25
18	450	c	20	25
24	600	c	25	25
30	750	c	30	35
36	900	c	35	45
42	1050	c	45	55
48	1200	c	50	60
c	Distance to be determined in consultations between the parties involved in a project.			

F.3.2.6 Requirements related to the reduction of building proximity distances

F.3.2.6.1 General

The routing of a new pipeline or planning changes in the vicinity of an existing pipeline can cause conflicts with the system of area classification.
In this case, the adoption of supplementary measures may be considered. The object of these measures is to link risk-reduction techniques more specifically to the needs of the area classification system. This is discussed in greater detail below for transmission pipelines conveying (non-toxic) natural gas.

F.3.2.6.2 Measures

Measure 1) is mandatory.

1) Increasing the design factor for wall thickness allowance (see table F.5) for natural gas pipelines by reducing the reciprocal value by 0,1;

The measures which may be considered include:

2a) Providing additional protection over the pipeline, for example in the form of concrete slabs;

2b) Providing additional protection on both sides of the pipeline, for example with sheet piling;

2c) Providing depth of cover of at least 2 m and marking the pipeline on the surface.

At least one additional measure chosen from 2a), 2b) or 2c) must be chosen for pipelines with a diameter of 300 mm and larger.

F.3.2.7 Effect of additional measures

The proximity distance for natural gas pipelines can be halved provided the above conditions are met.

F.3.2.8 Reduced wall thickness allowance for natural gas pipelines

For existing pipelines only, if one or more of the measures referred to under 2a, b or c is adopted, a reduced design factor for wall thickness (Table F.5) may be applied. This factor is the factor for the area classification one level lower than the area classification for which the pipeline is designed (with a minimum of 1/0.65).

F.3.3 Group risk

F.3.3.1 Rules of thumb for natural gas transport

In order to judge whether the requirements for group risk have been satisfied, a supplementary assessment shall be conducted for natural gas transport pipelines. For this purpose, rules of thumb can be used through which (quick) insight can be obtained with regard to the group risk into the actual risks and the possibilities for spatial development.

The rules of thumb indicate the lower limits with regard to the group risk. If a rule of thumb indicates that, given the size of the pipeline (mass of the gas), the risk assesment criteria cannot be exceeded, additional assessment of the group risk is not necessary. If the rule of thumb indicates that exceeding the requirements is possible, then an additional assessment shall be conducted with the risk pattern (see F.3.3.2).

Rule of thumb 1: whenever there are residential buildings and/or special objects within the minimum building proximity distance (see table F.6), the risk pattern shall be applied.

Rule of thumb 2: if all of the requirements in table F.7 are satisfied, the risk pattern shall be applied.

Table F.7 — Rule of thumb 2 for natural gas transport pipeline

Parameter	Requirements	
	buildings at one side(of the pipeline	buildings at both sides
diameter in inches	> 42	> 24
population density per ha (determined up to a max. of 175 m of the pipeline)	> 120	> 60
distance from buildings to pipeline, in m	< 100	< 100

F.3.3.2 Risk pattern

Risk pattern is a simple aide for calculation to quantify risks in a more detailed fashion. If, on the basis of the rules of thumb such as are given under F.3.3.1, it appears that there is potentially an unacceptable risk present, the risk pattern shall be applied.

NOTE 1 An accepted risk pattern is the IPO risk pattern. This risk pattern was developed under the authority of the ministries of VROM and of V&W, the IPO and the Netherlands Railroads, and is also known by the name of IPO Risk Calculation Methodology (IPORBM). The program can be consulted in the provinces and the regional offices of the Ministry of Waterways and Public Works.

The input for the risk pattern is made up by the transport stream and data on the number of people present along the route. The surrounding area is mapped in order to calculate the group risk. A characteristic of the group risk is that the presence of persons close to the axis of transport weighs much more heavily on the calculation results than persons at a greater distance. In theory, the group risk is influenced by all persons present withinin the greatest possible effect area (“worst case scenario”); the size of that area is determined by the 1 % limit of lethality. When using the Risk Pattern, special attention shall be paid to the inventory of persons present close to the pipeline (up to a distance of approximately 300 meters), whereas at greater distances the estimates may be rougher.

If additional constructive measures are taken to lower the probability of damages, this can be conducted through a correction on the standard failure frequency (see F.2.3). Whenever the results of the risk pattern indicate that the requirements for the group risk have been exceeded or parameter(s) for the case to be calculated deviate strongly from the standard parameter(s) in the risk pattern, a specific risk analysis (QRA) is necessary (see F.2).

NOTE 2 A specific risk analysis is an extensive risk analysis whereby a quantitative calculation of the risk tied to a particular area and the group risk is made in a manner that is as realistic as possible. A QRA is frequently very detailed and contains many starting points and assumptions. When drafting a QRA it is furthermore recommend to conduct interviews with all parties in advance regarding the calculation models, level of detail, the scenarios to be used for calculations and the starting points that are to be utilized.

F.4 Measures for limiting the probability of failure

Measures for limiting the probability of failure for steel pipelines are given below. The measures are also dealt with in table 2 of SI 5664-1. Additionally, various measures are also applicable for other pipeline materials.

The degree to which the probability of failure is limited by the respective measures shall be established in consultation with appropriate authorities.

NOTE One of the most important causes of pipeline failure (if not the most important at the current state of the art of pipeline engineering, excluding internal corrosion resulting from the medium) results from external mechanical damage caused by excavation work by third parties. Effective measures for limiting failure rates of the pipeline shall therefore in particular be oriented towards the prevention of these mechanical damages.

Applicable measures for limiting the probability of failure are:

— increased wall thickness;

— a barrier above the pipeline, for example, concrete plates or slabs (tyles);

— an additional barrier on each side of the pipeline, for example, a short sheet piling or buried curb stones or concrete piles laid at grade level;

— laying the pipeline deeper with identification tape placed above it. Please consult [4] and [5] for the effects of laying a pipeline deeper;

— the application of an extra soil cover which will prevent damage from agricultural activities (deep plowing, drainage), whether or not in combination with additional pipeline markings placed aboveground;

— the application of a casing pipe;

— additional controls, monitoring and inspection during the construction phase;

— the application of an external corrosion resistant cover with a high mechanical strength (for example, sintered polythene has a higher resistance against mechanical damage than asphaltic bitumen or epoxy paint);

— a stringent system for reporting and permits;

— KLIC reporting; prior to the excavation work there is the possibility of entering into contact with the KLIC (Cable and Pipeline Information Center), where it is known who operates the pipelines and cables in the affected area. The pipeline operators supply information on the exact location of the pipeline or cable.

— “tough” (high notch toughness) material;

— crack arrestors (limiting the propagation of cracks), especially in crossings with important public works.

For additional information concerning measures for limiting risk for transport pipelines, refer to [4], [5], [11] and [12].

NOTE In [4] and [5], reductions of the probability of failure were reported for a few (combinations of) constructive measures based on field tests with excavating machines.

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