Gas supply systems — Pipelines for maximum operating pressure over 16 bar — Functional requirements

The European Standard EN 1594:2000 has the status of a British Standard

ICS 75.200;

National foreword

This British Standard is the official English language version of EN 1594:2000.

EN 1594 recognises the need for more detailed national standards and codes of practice in the CEN member countries. For the UK additional guidance of this nature can be found in BS 8010-1 and BS 8010-2-2.8. In due course BS 8010-2-2.8 will be revised and reissued.

The UK participation in its preparation was entrusted by Technical Committee GSE/33, Gas Supply, to Subcommittee GSE/33/3, Gas Supply: Transmission, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

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

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled “International Standards Correspondence Index”, or by using the “Find” facility of the BSI Standards Electronic Catalogue.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 98, an inside back cover and a back cover.

The BSI copyright notice displayed in this document indicates when the document was last issued.

This British Standard, having been prepared under the direction of the Engineering Sector Committee, was published under the authority of the Standards Committee and comes into effect on 15 June 2000

ISBN 0 580 35871 2

Amendments issued since publication

Amd. No.	Date	Comments

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 1594

March 2000

ICS 23.040.01; 75.200

English version

Gas supply systems - Pipelines for maximum operating pressure over 16 bar - Functional requirements

Système d'alimentation en gaz - Canalisations pour pression maximale de service supérieure à 16 bar - Prescriptions fonctionelles

Gasversorgungssysteme - Rohrleitungen mit einen maximal zulässigen Betriebsdruck über 16 bar - Funktionale Anforderungen

This European Standard was approved by CEN on 21 October 1999.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

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

Central Secretariat: rue de Stassart, 36 B-1050 Brussels

Ref. No. EN 1594:2000 E

Contents

Foreword

This European Standard has been prepared by Technical Committee CEN/TC 234, Gas supply, the Secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2000, and conflicting national standards shall be withdrawn at the latest by September 2000.

There is a complete suite of functional standards prepared by CEN/TC 234, Gas supply, to cover all parts of the gas supply system from the input of gas to the transmission system up to the inlet connection of the gas appliances, whether for domestic, commercial or industrial purposes.

A list of the relevant functional standards prepared by CEN/TC 234 is included in clause 2 and Annex A to this document.

CEN/TC 234 will continue its work updating this standard to the latest developments at regular intervals.

In preparing this standard a basic understanding of gas supply by the user has been assumed.

Gas supply systems are complex and the importance on safety of their construction and use has led to the development of very detailed codes of practice and operating manuals in the member countries. These detailed statements embrace recognized standards of gas engineering and the specific requirements imposed by the legal structures of the member countries.

This European Standard has been prepared under mandate M/017 given to CEN by the Commission of the European Communities and the European Free Trade Association.

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

Introduction

This European Standard describes the general functional requirements for gas supply through pipe systems and covers the pressure range greater than 16 bar maximum operating pressure (MOP) for steel systems. It gives normative and informative references for safe and secure gas supply systems. It applies to their design, construction, operation and the related aspects of safety, environment and public health, all in order to provide a safe and secure supply of gas.

The requirements of this standard are based on safe gas engineering practice under conditions normally encountered in the gas industry. Requirements for all unusual conditions cannot be specifically provided for, nor are all engineering and construction details prescribed.

Existing industrial safety regulations applying to work areas, safety devices, and safe work practices are not intended to be supplanted by this standard.

Managers with responsibilities for the design, construction and operation of gas supply systems should have regard to the guidance given in this document and to other relevant standards. It is the responsibility of these managers and engineers to apply these functional requirements, supplemented with other proven good practice to the particular circumstances of each gas supply system.

The designer, constructor or operator of pipeline systems is cautioned that this standard is not a design handbook or code of practice. Additional national or company standards describing the details are needed. These detailed standards should be in line with the basic principles of this standard.

In preparing the standard it was recognized that the suite of relevant European standards is incomplete. Reference may be made where appropriate to international, national or other standards until relevant European Standards are available.

1 Scope

This European Standard is applicable to pipelines with a maximum operating pressure (MOP) over 16 bar for the carriage of processed, non-toxic and non-corrosive natural gas according to ISO 13686 in onland gas supply systems, where:

- the pipeline elements are made of unalloyed or low-alloyed carbon steel;
- the pipeline elements are joined by welds, flanges or mechanical couplings;
- the pipeline is not located within commercial or industrial premises as an integral part of the industrial process on these premises except for any pipelines and facilities supplying such premises;
- the design temperature of the system is between -40 °C and 120 °C inclusive.

This European Standard does not apply to existing pipelines, in use prior to the publication of this standard, nor to modifications to existing pipelines.

Gas supply systems covered by this standard begin after the gas producer's metering station. The functional demarcation of the pipeline system within a plant area will be determined from case to case. Generally speaking, this will be directly after the first isolating valve of the installation.

This standard also describes the mechanical requirements for pipework in stations with a maximum operating pressure greater than 16 bar. Welding requirements are described in a special application standard on welding for gas supply systems, EN 12732. Functional requirements for stations are given in:

EN 1776, *Gas supply systems - Natural gas measuring stations - Functional requirements*
EN 1918-5, *Gas supply systems - Underground gas storage - Part 5: Functional recommendations for surface facilities*
EN 12186, *Gas supply systems - Gas pressure regulating stations for transmission and distribution - Functional requirements*
EN 12583, *Gas supply systems - Compressor stations - Functional requirements.*

This European Standard specifies common basic principles for gas supply systems. Users of this European Standard should be aware that there may exist more detailed national standards and codes of practice in the CEN member countries.

This European Standard is intended to be applied in association with these national standards and/or codes of practice setting out the above mentioned principles.

In the event of conflicts in terms of more restrictive requirements in the national legislation/regulation with the requirements of this standard, the national legislation/regulation shall take precedence.

Reference is made in this standard to relevant European and other recognized standards for products used to construct and operate gas supply systems.

A schematic representation of pipelines for gas transmission is given in Figure 1.

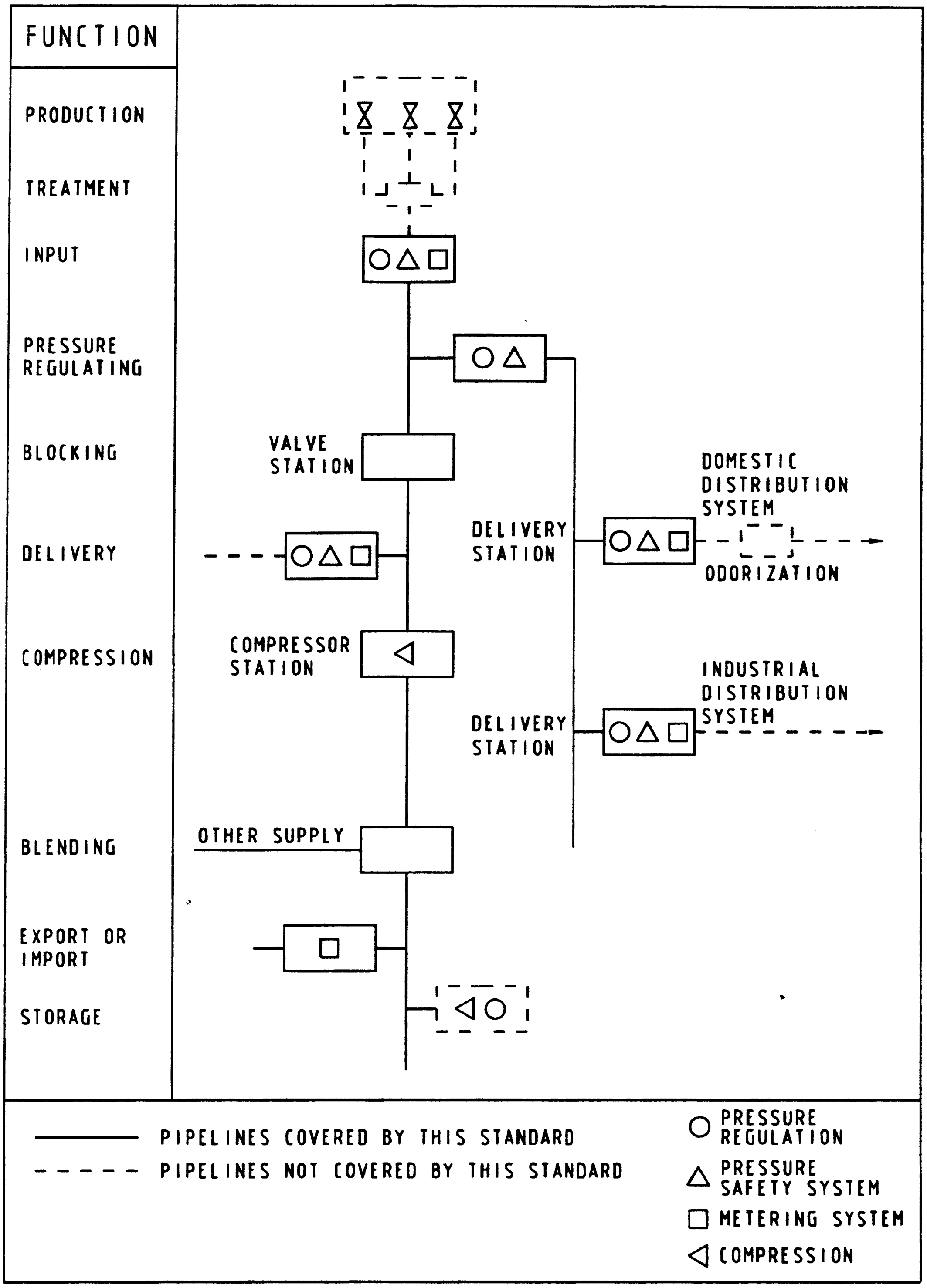

Figure 1 - Schematic representation of pipelines for gas supply over 16 bar

2 Normative references

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

EN 10002-1, *Metallic materials - Tensile testing - Part 1: Method of test*

EN 10204, *Metallic products - Types of inspection documents*

EN 10208-2, *Steel pipes for pipelines for combustible fluids - Technical delivery conditions - Part 2: Pipes of requirement class B*

prEN 10216-1, *Seamless steel tubes for pressure purposes - Technical delivery conditions - Part 1: Non-alloy steel tubes with specified room temperature properties*

prEN 10216-2, *Seamless steel tubes for pressure purposes - Technical delivery conditions - Part 2: Non-alloy and alloy steel tubes with specified elevated temperature properties*

prEN 10216-3, *Seamless steel tubes for pressure purposes - Technical delivery conditions - Part 3: Non-alloy and alloy fine grain steel tubes*

prEN 10216-4, *Seamless steel tubes for pressure purposes - Technical delivery conditions - Part 4: Non-alloy and alloy steel tubes with specified low temperature properties*

prEN 10217-1, *Welded steel tubes for pressure purposes - Technical delivery conditions - Part 1: Non-alloy steel tubes with specified room temperature properties*

prEN 10217-2, *Welded steel tubes for pressure purposes - Technical delivery conditions - Part 2: Electric welded non-alloy and alloy steel tubes with specified elevated temperature properties*

prEN 10217-3, *Welded steel tubes for pressure purposes - Technical delivery conditions - Part 3: Non-alloy and alloy fine grain steel tubes*

prEN 10217-4, *Welded steel tubes for pressure purposes - Technical delivery conditions - Part 4: Electric welded non-alloy and alloy steel tubes with specified low temperature properties*

prEN 10217-5, *Welded steel tubes for pressure purposes - Technical delivery conditions - Part 5: Submerged arc welded non-alloy and alloy steel tubes with specified elevated temperature properties*

prEN 10217-6, *Welded steel tubes for pressure purposes - Technical delivery conditions - Part 6: Submerged arc non-alloy and alloy steel tubes with specified low temperature properties*

prEN 10285, *Steel tubes and fittings for on and offshore pipelines - External three layer extruded polyethylene based coatings*

prEN 10286, *Steel tubes and fittings for on and offshore pipelines - External three layer extruded polypropylene based coatings*

prEN 10287, *Steel tubes and fittings for on and offshore pipelines - External fused polyethylene based coatings*

prEN 10288, *Steel tubes and fittings for on and offshore pipelines - External two layer extruded polyethylene based coatings*

prEN 10289, *Steel tubes and fittings for on and offshore pipelines - External liquid applied epoxy and epoxy-modified coatings*

prEN 10290, *Steel tubes and fittings for on and offshore pipelines - External liquid applied polyurethane and polyurethane-modified coatings*

EN 12007-1, *Gas supply systems - Pipelines for maximum operating pressure up to and including 16 bar - Part 1: General functional recommendations*

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

EN 12068, *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 12186, *Gas pressure regulating stations for transmission and distribution*

EN 12327, *Pressure testing, commissioning and decommissioning procedures for gas supply systems*

EN 12583, *Gas supply systems - Compressor stations - Functional requirements*

prEN 12560-1, *Flanges and their joints - Dimensions of gaskets for Class-designated flanges - Part 1: Non-metallic flat gaskets with or without inserts*

prEN 12560-2, *Flanges and their joints - Dimensions of gaskets for Class-designated flanges - Part 2: Spiral wound gaskets for use with steel flanges*

prEN 12560-3, *Flanges and their joints - Dimensions of gaskets for Class-designated flanges - Part 3: Non-metallic PTFE envelope gaskets*

prEN 12560-4, *Flanges and their joints - Dimensions of gaskets for Class-designated flanges - Part 4: Corrugated flat or grooved metallic and filled metallic gaskets for use with steel flanges*

EN 12732, *Gas supply systems - Welding steel pipework - Functional requirements*

EN 45004, *General criteria for the operation of various types of bodies performing inspection*

EN 45011, *General requirements for bodies operating product certification systems (ISO/IEC Guide 65:1996).*

3 Definitions, symbols and abbreviations

For the purposes of this standard, the following definitions apply. Symbols used in formulae are defined where they occur.

3.1
commissioning
the activities required to pressurize pipework, stations, equipment and assemblies with gas and to put them into operation

3.2
control zone
the strip of land over which the pipeline operator has a right to control activities

3.3
decommissioning
the activities required to take out of service any pipework, station, equipment or assemblies filled with gas and to disconnect them from the system

3.4
design factor
f_o
a factor applied when calculating the wall thickness or pressure

3.5
design pressure
DP
the pressure on which design calculations are based

3.6
design temperature
the temperature on which design calculations are based

3.7
emergency
a situation which could affect the safe operation of the gas supply system and/or the safety of the surrounding area, requiring urgent action

3.8
gas
the gaseous fuel which is in gaseous state at a temperature of 15 °C under atmospheric pressure (1,013 25 bar absolute)

3.9
gas distribution system
the pipeline system including piping above and below ground and all other equipment necessary to supply the gas to the consumers

3.10
gas distributor
the private or public organization authorized to distribute gas to consumers through a gas distribution system

3.11
gas transmission
the activity intended to convey gas from one place to another through pipelines in order to supply gas to distribution systems or to industrial consumers

3.12
incident
an unexpected occurrence, which could lead to an emergency situation.

This includes a leakage of gas or plant failure

3.13
incidental pressure
IP
the pressure which occurs incidentally within a system at which a safety device becomes operative

3.14
inspection
the process of measuring, examining, testing, gauging or otherwise determining the status of items of the pipeline system or installation and comparing it with the applicable requirements

3.15
installation
equipment and facilities for the extraction, production, chemical treatment, measurement, control, storage or offtake of the transported gas

3.16
installation temperature
the temperature arising from ambient or installation conditions during laying or during construction

3.17
maintenance
the combination of all technical and associated administrative actions intended to keep an item in, or restore it to, a state in which it can perform its required function

3.18
maximum incidental pressure
MIP
the maximum pressure which a gas system can experience during a short time, limited by the safety devices

3.19
maximum operating pressure
MOP
the maximum pressure at which a system can be operated continuously under normal conditions

NOTE Normal conditions are: no fault in any device or stream.

3.20
national requirements
requirements following from national legislation or more detailed or stringent national standards

3.21
onshore pipeline
a buried and/or above ground pipeline including those sections laid in or across inland lakes or water courses

3.22
operating pressure
OP
the pressure which occurs within a system under normal operating conditions

3.23
operating temperature
OT
the temperature which occurs within a system under normal operating conditions

3.24
pig
a device which is driven through a pipeline by the flow of fluid, for performing various internal activities (depending on pig type), such as separating fluids, cleaning or inspecting the pipeline

3.25
pipeline
a system of pipework with all associated equipment and stations up to the point of delivery. This pipework is mainly below ground but also includes above ground parts

3.26
pipeline components
the elements from which the pipeline is constructed. The following are distinct pipeline elements:

– pipe including cold-formed bends;

– fittings;

EXAMPLE 1 Reducers, tees, factory-made elbows and bends, flanges, caps, welding stubs, mechanical joints.

– fabrications, manufactured from the elements referred to above;

EXAMPLE 2 Manifolds, slug catchers, pig launching/receiving stations, metering and control runs.

– equipment;

EXAMPLE 3 Valves, expansion joints, insulation joints, pressure regulators, pumps, compressors.

– pressure vessels

3.27
pipeline operator
the private or public organization authorized to design, construct and/or operate and maintain the gas supply system.

3.28
pipework
an assembly of pipes and fittings

3.29
point of delivery
the point of transfer of ownership of gas from supplier to the customer

NOTE This can be at a valve or at the meter outlet connection.

3.30
precommissioning
a series of activities, including cleaning and possible drying, executed prior to pipeline commissioning

3.31
pressure
the gauge pressure of the fluid inside the system, measured in static conditions

3.32
pressure control system
a combined system including pressure regulating, pressure safety and eventually pressure recording and alarm systems

3.33
pressure regulating system
the system which ensures that a pressure is maintained at the outlet system within required limits

3.34
pressure safety system
a system which, independent of the pressure regulating system, ensures that the outlet pressure of the regulator does not exceed the preset value

3.35
recommissioning
the activities required to put a decommissioned pipeline, associated stations and equipment into service again

3.36
special crossing
a point at which the pipeline has to pass a special feature

EXAMPLE Major road, railway, river, canal, dyke.

3.37
station
a plant or facility for the operation and/or processing of gas supply systems

3.38
strength test
a specific procedure to verify that the pipework and/or station meets the requirements for mechanical strength

3.39
strength test pressure
STP
the pressure applied to a system during strength testing

3.40
test pressure
TP
the pressure to which the gas supply system is subjected to ensure that it can operate safely

3.41
tightness test
a specific procedure to verify that the pipework and/or station meets the requirements for leak tightness

3.42
tightness test pressure
The pressure applied to a system during tightness testing

3.43
volume under normal conditions
a quantity of gas which in the dry state occupies a volume of 1 m^3 at atmospheric pressure (1,013 25 bar absolute) at a temperature of 0 °C

3.44
volume under standard conditions
a quantity of gas which in the dry state occupies a volume of 1 m^3 at atmospheric pressure (1,013 25 bar absolute) at a temperature of 15 °C

4 Quality system

The life of a pipeline for transmission of gas can be divided into three phases:

- the design;
- the construction and testing;
- the operation and maintenance.

A quality system should be applied to the design, construction, testing, operation and maintenance activities in accordance with this standard.

Reference may be made to the EN ISO 9000 series of standards or to equivalent quality assurance systems.

After the pipeline has been commissioned, the integrity should be maintained by a precisely defined programme of operation, maintenance and condition monitoring (a pipeline integrity management system).

Competent personnel capable of assessing the quality of the work within the scope of this standard shall be employed in all activities in the design, construction, testing and operating phases.

5 Safety and the environment

5.1 Introduction

Various safety measures are required to ensure a safe pipeline. Measures that are appropriate to the specific circumstances shall be adopted.

5.2 Appropriate safety measures

Possible measures to ensure safety in design, construction and operation are listed below. The list is not intended to be exhaustive nor will it be necessary to incorporate all the measures on each occasion.

When selecting measures, consideration shall be given to the safety and environmental conditions existing at the time of construction for which firm details are known:

- A control zone should be established to control all third-party activities in order to safeguard the pipeline against interference.
- If a system of area classification is used, design factors should be chosen relevant to the classification levels.

  This design factor may be increased if additional measures are taken against third-party interference (for limitation on the design factor reference is made to 7.2).
- The route of the pipeline should be at an appropriate distance from buildings. The distance should be fixed by the particular parameters and/or national requirements.
- For high-strength pipe steels, appropriate toughness properties for fracture-arrest capability should be selected.
- The minimum depth for the pipeline shall be greater than that of normal agricultural/horticultural activities expected in the area. The probability of third-party interference to the pipeline will decrease if a depth greater than the minimum specified in 7.7 is adopted.
- Additional forms of mechanical protection can reduce interference by third-party activity. Designers shall carefully select the forms of the additional protection to minimize any adverse effects on the efficiency of the cathodic protection.
- The route of the pipeline should be identified by a locating system such as markers.
- Pipeline safety can further be increased by ensuring an adequate frequency of surveillance.

5.3 Routing considerations

5.3.1 Introduction

Safety, environmental and technical considerations are the primary factors governing the pipeline route.

The shortest route need not to be the most suitable. Physical and environmental obstacles, high voltage cables and installations and other factors shall be considered.

The factors can be broadly separated into above-ground (topographical) and below-ground (subterranean) factors. It is usually convenient to consider both natural and man-made features under these two headings.

5.3.2 Surveys

An essential prelude to pipeline projects is to acquire from records, maps and physical survey a set of data that is relevant for the design, construction and safe and reliable operation of the pipeline. The adoption of a preliminary route shall be preceded by a desk study, making use of all available information.

Before a route is finally adopted for construction, a physical survey shall be made, aided as necessary by aerial photography, soil surveys, underwater observation and a review of geographical, geotechnical, topographical and environmental features, as well as safety-related aspects in connection with other activities along the pipeline route. The route survey shall cover a sufficient width and be sufficiently accurate to identify features that could adversely influence the installation and operation of the pipeline.

5.3.3 Environmental impact

The planning of any proposed pipeline route shall be approached systematically to identify and record environmental issues which could be affected. Detailed assessments may need to be undertaken to ascertain the impact of the pipeline on environmentally sensitive areas. Among environmental factors to be considered in selecting route and station locations, care shall be taken to identify the possible effects on the following:

- areas of outstanding natural beauty;
- ancient monuments, archaeological and ornamental sites;
- natural resources, such as water catchment areas, forestry;
- flora and fauna.

Also the following aspects shall be considered:

- the reduction of noise and vibration;
- the avoidance of odour and dust and deterioration of air quality.

Other considerations applying to pipelines laid under inland water courses include:

- the underwater environment;
- underwater development;
- bed conditions.

5.3.4 Ground conditions

The following ground conditions shall be considered and carefully investigated during the route planning stage:

- areas of geotechnical instability, including faults and fissuring;
- soft or waterlogged ground;
- corrosive nature of the soil;
- rock and hard ground;
- flood plains;
- areas with high seismic risk;
- mountainous areas;
- existing or potential areas of land slippage, subsidence and differential settlement;

– mining areas and quarrying;

– infill land and waste disposal sites, including those contaminated by disease or radioactivity.

If any of these conditions are expected during the lifetime of the pipeline, monitoring of these aspects shall be incorporated into the regular surveillance procedures. This can include measurement of local ground movements and changes in pipeline stresses.

5.4 Linevalve spacing

Pipeline systems should be sectionalized using linevalves.

In determining the spacing of linevalves, consideration should be given to operating pressure, pipeline diameter, time taken to arrive at the valve site, the need for linevalves for operational purposes, the position of the nearest offtakes and other existing valves.

6 Pressure safety

6.1 Pressure levels

Stress and strain calculations on the pipeline during the design phase shall be based on the design pressure (DP) of the pipeline.

The pipeline shall be pressure-tested after construction and prior to operation. The test pressure (TP) shall be chosen in accordance with 9.5.

The maximum operating pressure (MOP) shall not exceed the design pressure (DP).

6.2 Normal operation

A pressure control system shall be provided to ensure that, during normal operation, the sustained operating pressure does not exceed the maximum operating pressure (MOP) at any point in the pipeline. The pressure regulators shall be sized for the normal operating conditions expected.

The sustained operating pressure is the maximum set pressure for the pressure regulation devices. However, when operating at or near the maximum operating pressure, this pressure may be exceeded by no more than +2,5 % of its value due to the variations of pressure regulation devices.

6.3 Requirements for installation of pressure safety devices

Throughout a gas supply system, pressure can be reduced or increased at one or more stations.

Apart from pressure regulation devices, consideration shall be given to safety devices which protect the downstream pipeline section against failure of the pressure regulation system. If installed, the safety device shall operate independently of the active pressure regulation device.

An incidental pressure rise is acceptable provided systems exist to automatically limit the extent of the excess to 15 % above the maximum operating pressure (a lower value may be selected for this pressure, which is the maximum incidental pressure or MIP). The maximum operating pressure shall not be exceeded for longer than is strictly necessary to check the malfunction and to reset the normal operating conditions. The safety device(s) shall be set such that the maximum incidental pressure is not exceeded (see Figure 2).

The installation of pressure safety devices for pressure regulating systems shall be in accordance with EN 12186 and for compressor stations in accordance with EN 12583.

6.4 Pipeline with DP equal to or less than 40 bar and hoop stress equal to or less than $0,45R_{t\,0,5}$

For pipelines with a design pressure equal to or less than 40 bar and a hoop stress level at the design pressure, calculated according to the formula in 7.2, equal to or less than 0,45 specified minimum yield strength ($R_{t\,0,5}$), the incidental pressure rise referred to in 6.3 may be increased to +20 % above the maximum operating pressure.

6.5 Pipeline with DP equal to or less than 24 bar and hoop stress equal to or less than 0,30$R_{t\,0,5}$

Pipelines with a design pressure equal to or less than 24 bar and a hoop stress level at the design pressure, calculated according to the formula in 7.2, equal to or less than 0,30 specified minimum yield strength ($R_{t\,0,5}$), may be designed and operated in accordance with EN 12007-1 and EN 12007-3. However, construction and testing shall be carried out in accordance with this standard.

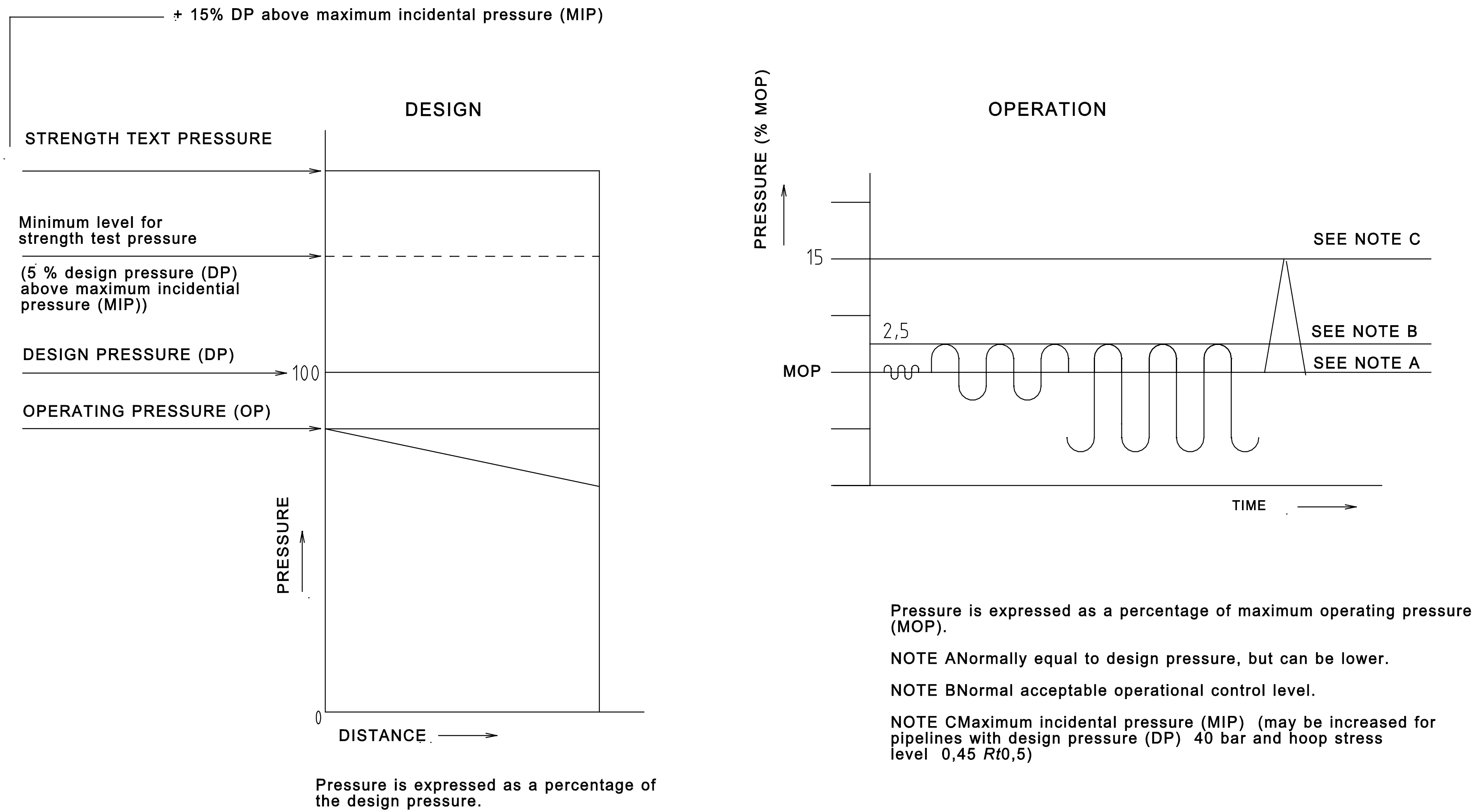

Figure 2 - Guide to pressure limiting systems

7 Design

7.1 General

7.1.1 Design principles

The design of the pipeline shall lead to a safe system for transmission of gas.

The design shall consider all technical issues together with the environmental and safety aspects.

The design shall take into account the controlled release of gas or other materials during construction, operation or maintenance of the pipeline.

The design principles shall be documented together with procedures in the design report (see 7.5).

7.1.2 Basis of design

7.1.2.1 Pipeline

The pipeline shall be leak-tight and shall have the necessary resistance to safely withstand all the forces to which it is expected to be exposed during construction, testing and operation.

The pipeline consists of pipeline sections (see example 1) and stations (see example 2). During the design phase these parts of the pipeline can be considered separately, as long as the interaction of forces between the connected parts is also considered.

EXAMPLES 1 Buried, submerged, above ground, trenchless.

EXAMPLES 2 Compression, pressure regulating, metering.

Crossings with railways, major roads and waterways shall be designed in consultation with the owners and/or authorities.

For crossings with dykes and flood defences extra measures can be required to prevent possible flooding of the hinterland.

7.1.2.2 Pipeline sections

Pipeline sections shall be supported, anchored or buried such that, during its lifetime, the pipeline section will not move with respect to its installed position, except for permitted displacement due to pressure loads, thermal loads and displacements expected after installation.

If a submerged pipeline section is not buried, covered or anchored, the pipework's own weight under all conditions, whether empty, filled with medium or filled with test medium, shall be such as to guarantee horizontal and vertical stability during both the construction and operating phases.

NOTE The design pressure and diameter required for a pipeline are determined by gasflow requirements and economics and this determination falls outside the scope of this standard.

Initial design to determine the wall thickness of the pipeline section is based on internal pressure and a design factor. Additional measures can be required to provide protection against third-party interference as referred to in 5.2.

Where a section of the pipeline passes through areas which can impose significant external loads, it is necessary for a more comprehensive design process to be followed as set out in 7.3. To decide whether these additional requirements are necessary, an analysis of all expected forces shall be undertaken or reference made to a previous analysis undertaken for a similar pipeline.

7.1.2.3 Station pipework

The pressure strength of station pipework should be achieved by selecting suitable pipe and components from a limited range of pressure ratings.

Because station pipework, either buried or above ground, is often subject to greater external forces due to temperature, vibration and restraint forces than the transmission pipeline, it can be necessary to impose additional requirements.

7.2 Wall thickness determination

If no additional requirements are imposed, for straight pipe the minimum wall thickness to withstand the internal pressure is calculated as follows:

$$T_{min} = \frac{DP \times D}{20\sigma_p}$$

with the requirement:

$$\sigma_p \leq f_o R_{t0,5}(\theta)$$

where:

- T_{min} is the calculated minimum wall thickness, in millimetres (mm);
- DP is the design pressure, in bar;
- D is the outside diameter of the pipe in accordance with EN 10208-2, in millimetres (mm). If D_i is preset, D shall equal $D_i + 2T_{min}$, D_i being the inside diameter in millimetres (mm);
- σ_p is the hoop stress, in newtons per square millimetre (N/mm^2);
- f_o is the design factor;
- $R_{t\,0,5}(\theta)$ is the specified minimum yield strength at the design temperature, in newtons per square millimetre (N/mm^2);
  - Temperature less than or equal to 60 °C: $R_{t\,0,5}(\theta) = R_{t\,0,5}$
  - Temperature over 60 °C: the value of the specified minimum yield strength has to be corrected for the temperature
- $R_{t\,0,5}$ is the specified minimum yield strength at ambient temperature, in newtons per square millimetre (N/mm^2) (ref. EN 10002-1).

The maximum design factor (f_o) for internal pressure to be used for the pipeline section in question is as follows:

– underground sections, except stations ≤ 0,72

– pipelines in tunnels continuously supported ≤ 0,72

– stations ≤ 0,67 [a]

[a] with the further wall thickness requirements in 7.9.2

NOTE The wall thickness to be specified according to EN 10208-2 is the calculated minimum wall thickness plus the specified under wall thickness tolerance.

For bends and elbows the minimum wall thickness to withstand the internal pressure is calculated according to 7.10.2.

7.3 Additional design requirements

7.3.1 Forces

A pipeline shall be designed so that it can withstand the effects of the predictable forces on it resulting from:

– internal pressure;

– the anchoring or backfilling of the pipeline, road and rail traffic and loads necessary for the installation and pressure testing of the pipeline;

– the weight loading imposed during hydrostatic testing;

– the attachment of branch connections;

– the attachment of non-pressure containing components;

– the attachment of non-pressure containing components;
– buoyancy;
– any other buried structure such as a pipeline, gas main or service pipework;
– environmental loads such as flooding, ice, snow, wind;
– settlement;
– mining subsidence;
– frost heave;
– landslide;
– areas with high seismic risk;
– areas of future planned increases in soil cover, local embankments, etc.;
– soil erosion;
– above-ground sections.

The designer shall take into account all other circumstances that can require calculations to be carried out for the pipeline section or the station pipework, such as:

– higher pipe temperature and/or large temperature differences in relation to special pipe configurations;
– any circumstances that can lead to excessive construction settlement differences as a result of the construction techniques employed;
– above-ground pipeline sections locally supported.

The calculations comprise of an analysis of the loads and displacements and an analysis of the stresses and strains which can occur. The degree to which each of these stages is involved in the analysis depends on the complexity of the design and the physical parameters of the pipeline section.

Where the assessment shows that additional design requirements should be imposed on the section under consideration, an established method of analysis shall be used to determine the stresses and strains and effects of all loadings on the pipeline section.

7.3.2 Soil engineering data required

If sufficient information is available on the nature of the soil, the analysis for certain pipeline sections can be based on typical soil parameters, where necessary in combination with additional soil mechanical investigation, such as soil sampling or cone penetration tests.

In the case of special structures and/or widely varying soil properties or in situations where substantial permanent soil displacements are expected, these parameters shall be established on the basis of a soil analysis.

7.3.3 Structural models for pipeline sections

Three different models can be used to analyze both supported (above-ground) pipeline sections subjected to typical operating loads and buried pipeline sections in the context of pipe/soil interaction problems:

a) **pipe considered as a ring:** This model is used for calculating the circumferential stresses and strains in the cross-section of the pipe.

b) **pipe considered as a beam:** This model is used for calculating the longitudinal stresses and strains in the pipeline sections. Using this model, the reaction forces perpendicular to the pipe can be used in the calculation of stress and strain in the cross-section of the pipe.

c) **pipe considered as a shell:** Pipe behaviour can be modelled precisely using shell elements in finite element analysis. This model can be used to solve problems of stress concentration to components, such as tees, bends, nozzles, supports, or local behaviour of the pipe wall (wrinkling, ovality, etc.)

For buried pipeline sections, the pipe/soil interaction can be modelled either by finite elements or by simplified methods.

7.4 Analysis of stress and strain

7.4.1 Elastic and extended elastic design

7.4.1.1 General

The calculation method is based on determination of stresses caused by loads during the construction and operation phases. The stresses are combined to resultant stresses (σ_v). No resultant stress shall exceed the relevant allowable stress.

7.4.1.2 Resultant stress (σ_v)

The state of stress at any point is completely described by the normal stresses σ_x, σ_y and σ_z and the shear stresses τ_x, τ_y and τ_z in a tri-axial system with mutually perpendicular axes *x*, *y* and *z* or by the principal stresses σ_1, σ_2 and σ_3 and their directions.

The resultant stress is a parameter which is considered to be characteristic of the state of stress at a point. The resultant stress can be calculated either by the shear stress hypothesis or the yield criterion.

According to the shear stress hypothesis, this is: $\sigma_v = \sigma_{max} - \sigma_{min}$
where:

σ_{max}	is the maximum principal stress in one of the three directions;
σ_{min}	is the minimum principal stress in one of the other two directions.

According to the Von Mises/Huber Hencky yield criterion, the resultant stress is given by:

$$\sigma_v = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2 - \sigma_x\sigma_y - \sigma_z\sigma_x - \sigma_y\sigma_z + 3\,(\tau_x^2 + \tau_y^2 + \tau_z^2)}$$

In a bi-axial system:

$$\sigma_v = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x\sigma_y + 3\,\tau^2}$$

Here, either $\sigma_z = 0$ or may be disregarded in terms of absolute value compared with σ_x and σ_y.

This also applies to the two shear stresses compared with the shear stress under consideration.

A bi-axial state of stress can be assumed in pipeline sections which contain no ancillaries, branches, etc.

7.4.1.3 Allowable stress

Under loading conditions where all stresses are considered as primary stresses and the calculation is carried out with characteristic values for the loads, the maximum resultant stress shall not exceed the allowable stress.

The allowable stress is $0{,}72R_{t\,0,5}(\theta)$

Temperature less than or equal to 60 °C	$R_{t\,0,5}(\theta) = R_{t\,0,5}$
Temperature over 60 °C	the value of the specified minimum yield strength has to be corrected for the temperature.

A higher allowable stress can be used where the stresses are divided into primary (e.g. direct equilibrium) and secondary (e.g. displacement controlled).

An example of this method (“extended elastic design”) is given in Annex G, but other established methods may be used.

7.4.2 Limit state design

7.4.2.1 General

The calculation procedure is based on the method of (partial) load factors and calculation loads. The calculation loads are obtained by multiplying the relevant (characteristic) loads arising during the construction and operating phases by the relevant load factor.

The load factor takes account of uncertainty as to the magnitude of the loads, the strength of the material and the construction.

The effect of the calculation loads shall not exceed the limit value associated with the relevant limit state.

In the limit state design, a clear distinction shall be made between load-controlled strains and deformation-controlled strains.

7.4.2.2 Relevant limit states

The relevant limit states are:

a) **stress:** The limit state in which the limit stress is exceeded.

b) **strain:** The limit state in which the limit strain is exceeded.

In evaluating this limit strain, the presence of imperfections in the pipe material and the joints shall be taken into account.

c) **alternating yield:** The limit state in which the variations in the strains due to cyclic loads are so great that plastic deformation occurs on each load reversal (plastic fatigue).

d) **fatigue:** The limit state for failure due to cyclic loading over time.

e) **resonance and vortex shedding:** The limit state for excessive excursions by the pipeline or its component parts.

These excursions arise when the frequency of excitation coincides with the pipeline's natural frequency.

For pipeline sections which are locally unsupported by soil and exposed to waves and currents, a study should be made of the possibilities of vibration due to vortex shedding and other instability phenomena.

f) **deformation:** The limit state for excessive deformation, taking the form for example of excessive ovality, local buckling, implosion or overall flexural buckling of the pipeline.

Generally speaking, excessive deformations of this kind will occur in the plastic range and therefore consist chiefly of plastic deformations. Situations can arise, however, in which excessive elastic deformations occur that have a deleterious effect on safety.

EXAMPLE Include seizure of close-tolerance moving parts (valves) and distortion of flanges which impairs their integrity.

g) **Displacement/lateral stability.**

7.5 Design report

On completion of the design, a comprehensive design report shall be produced containing the following information:

a) a description of the pipeline:

1) general data relating to the project, description of the pressure containment system, demarcation of the boundaries of the transmission pipeline, safety devices;
2) data relating to the gas and design conditions, the design pressure and design temperature, the values at critical design conditions of:
   - mass flow rate;
   - density;
   - viscosity (dynamic).

b) drawings:

1) geographical maps with, where applicable, an indication of the area covered by the individual route maps;
2) route maps or similar drawings;
3) detail and standard maps, indicating the route maps to which they apply and providing all information needed for evaluation of the design and construction.

c) data of pipeline components and structures:

1) outside or inside diameter(s);
2) wall thickness(es);
3) wall thickness tolerances;
4) relevant data on fittings, including bend radii or other information relating to the pipeline elements;

   EXAMPLE Reducers, tees.

5) data on abutting structures and supports which affect the forces and moments acting on the carrier pipework;
6) steel grade and specification;
7) thickness and type of coating;
8) thickness and density of weight coating, if required.

d) construction information, if required:

1) elastic bending radii to be applied to the pipeline section, both permanent and temporary;
2) test pressure, including the nature and weight of the test medium;
3) installation temperature;
4) specification of procedures to be employed in the installation of the pipeline sections, together with relevant data, design details and construction specifications;

EXAMPLE 1

- Installation specifications for pipeline sections: open trench (dry/wet), jacking, boring, horizontal directional drilling, tunnelling;
- data, design details and construction specifications: preparation of the trench bottom, method of backfilling and compacting the trench.

5) land management and soil engineering data.

EXAMPLE 2

- Soil handling, wellpoint drainage, surface reinstatement.

7.6 Land management and geotechnical studies

The purpose of the land management study is to gather data needed for reporting on land and water management and agricultural/horticultural aspects of the pipeline route.

These data are used to provide appropriate support in land management and agricultural/horticultural matters relating to the construction of the pipeline and to limit damage.

The purpose of the geotechnical study is to gather data for a report on geohydrological water management and geomechanical aspects relating to the pipeline route. (See also 5.3.4.)

7.7 Depth of cover

Buried pipework and casings shall in general have a minimum depth of cover of 0,80 m. A reduced depth of cover may be applied. Examples of cases of reduced depth are:

- rocky terrain;
- where the pipe crosses ditches or water courses.

NOTE Appropriate protective measures can be required.

An increased depth of cover shall be applied in the following cases:

- situations where frost heave can occur;
- areas where agricultural or horticultural practices require a greater depth;
- areas which can be subject to erosion;
- waterways. The lowest expected bed profile of the crossing should be determined. If the waterway is navigable, consideration shall be given to protection of the pipeline against damage from ships' anchors.

7.8 Casing pipes

The use of cased crossings should be minimized as they can cause adverse effects on cathodic protection systems.

When casings are used, they shall be designed such that:

- they are capable of withstanding all external loads;
- the carrier pipe is easily installed;
- cathodic protection of the carrier pipe can be provided if necessary;
- they can be sealed effectively or can be filled with a suitable material to minimize water circulation and thus reduce the oxygen supply to a minimum;
- the carrier pipe is provided with an adequate number of suitable supports at regular intervals and provision is made, especially at the extremities of the casing, to avoid the possibility of contact between the carrier pipe and the casing;
- the support rings are spaced and calculated on the basis of the weight of the pipe filled with water and additional cross-sectional forces caused by construction settlement at the extremities which mark a transition between two methods of installation.

7.9 Station design

7.9.1 Layout

The point of demarcation between the pipeline section and the station should be immediately upstream of the first inlet valve and immediately downstream of the last outlet valve. Alternatively, the station fence or the isolating valves can be taken as the point of demarcation.

The requirements applicable to the layout of the station depend on the surrounding area and the type of station.

However, each station shall be designed such that:

– the station or parts of the station can be taken out of service by operating a number of valves. This is not required for valve stations;

– efficient long-term operation is guaranteed under all weather conditions;

– the station suffers no adverse effects due to subsidence, settlement, corrosion or any other cause;

– maintenance can be carried out without interrupting the gas flow;

– unauthorized operation of components is prevented.

Within stations, certain requirements shall be imposed with respect to the minimum spacing between components, for example to facilitate maintenance and firefighting.

If circumstances require, stations shall be fenced to prevent unauthorized entry. Consideration shall be given to provisions to facilitate the evacuation of personnel from the station in case of emergency.

Depending on the size of the station, gates shall be dimensioned and constructed to permit easy access to firefighting equipment and ambulances.

If the station is installed in a building, the building shall be subject to the evacuation requirements.

The electrical installation shall be in accordance with the requirements of the relevant EN standards.

The electric lighting system, where fitted, shall be designed so that exits and critical areas inside and outside the station are clearly visible at night and in fog.

The construction of electrical installations in areas where there are potential gas atmospheres shall comply with the relevant EN standards.

Consideration shall be given to measures for the protection against lightning strikes. These measures shall satisfy relevant standards.

For pressure regulating systems the station layout shall be in accordance with EN 12186 and for compressor stations in accordance with EN 12583.

7.9.2 Components

Each individual component of a station shall be capable of performing the function required of it and shall satisfy the standards to which the component in question has been designed.

These include mechanical components (see example 1), electrical components (see example 2), and pipework and pipeline components (see example 3). The requirements relating to flanges, gaskets, bolts, nuts, valves and other fittings are specified in 7.10 and clause 8.

EXAMPLE 1 Compressors and pumps.

EXAMPLE 2 Generators, batteries.

EXAMPLE 3 Fittings, flanges, gaskets, valves.

The specified wall thickness *T* of pipework shall not be less than the values stated in Table 1 and shall be sufficient for the loads imposed, including internal pressure with a design factor $f_o \leq 0,67$.

Table 1 - Smallest wall thickness to be specified

D (mm)	≤114,3	168,3	219,1	273	323,9	355,6	406,4	508	610	> 610
T (mm)	3,2	4,0	4,5	5,0	5,6	5,6	6,3	6,3	6,3	1 % *D*

Components within stations are generally connected by pipework, including oil, gas, compressed air and water piping and instrumentation, control, power gas and sampling pipework. This pipework and the associated valves, flanges, reducers, bends and other components shall be made of suitable material and shall be capable of withstanding the maximum and minimum pressures and temperatures.

The installation as a whole shall satisfy safety and reliability requirements for the station in question.

7.9.3 Interaction with onland pipeline section

In the design of the connections between the onland section of the pipeline and the station, due account shall be taken of their interaction.

An expansion calculation is required for outlet lines from compressor stations laid in soft peat or clay soils.

Due account shall be taken of pulsations.

EXAMPLE Flow-induced pulsations.

Expansion and contraction of the pipeline due to temperature and pressure changes shall be taken into account in the design of the station. If necessary, the pipeline shall be anchored or suitably configured so that temperature and pressure variations do not give rise to stresses within components which exceed permitted levels.

Components of stations and adjacent pipeline sections shall be designed such that stresses due to non-uniform settlement remain within acceptable limits.

7.10 Pipeline components

7.10.1 General

Rules relating to the design of pipeline components are set out in 7.10.2 to 7.10.8 inclusive. Specifications for the material of the pipeline components are given in clause 8.

Components shall be of the same or equivalent material as required for the pipes.

7.10.2 Bends and elbows

Changes in pipeline direction can be achieved either by bending the pipe (see 9.2.8) or by installing a factory-made bend or elbow in the pipeline.

In the case of bends with a bend radius smaller than 20*D*, the maximum hoop stress requirement in accordance with 7.2 shall become:

Inside of the bend:

$$\frac{2R - 0{,}5D}{2R - D}\sigma_{\mathrm{p}} \leq f_{\mathrm{o}} R_{t0,5}(\theta)$$

Outside of the bend:

$$\frac{2R + 0{,}5D}{2R + D}\sigma_{\mathrm{p}} \leq f_{\mathrm{o}} R_{t0,5}(\theta)$$

where:

R	is the bend radius along the centreline of bend, in millimetres (mm);
D	is the outside diameter, in millimetres (mm);
σ_p	is the hoop stress, in newtons per square millimetre (N/mm^2)[a];
$R_{t\,0,5}(\theta)$	is the specified minimum yield strength at the design temperature, in newtons per square millimetre (N/mm^2). Temperature less than or equal to 60 °C: $R_{t\,0,5}(\theta) = R_{t\,0,5}$ Temperature over 60 °C: the value of the specified minimum yield strength has to be corrected for the temperature
$R_{t\,0,5}$	is the specified minimum yield strength at ambient temperature, in newtons per square millimetre (N/mm^2) (ref. EN 10002-1).
f_o	is the design factor.
a	in the calculation of the hoop stress, the minimum wall thickness after bending shall be considered.

7.10.3 Tees

Tees shall have sufficient strength against internal pressure. An example of a wall thickness calculation method is described in Annex L. Equivalent calculation methods may be used.

7.10.4 Flanges

Flanges shall be designed to accommodate the operating and climatic conditions and the associated permissible operating pressures. The dimensions and drilling pattern for all flanges shall satisfy the requirements of the applicable standards.

7.10.5 Caps

Caps shall have sufficient strength against internal pressure. An example of a wall thickness calculation method is described in Annex M. Equivalent calculation methods may be used.

7.10.6 Bolts and nuts

Bolts and nuts shall be designed in accordance with the relevant standard. Nuts shall be tightened onto bolts or studs sufficiently for the thread to project above the nut.

At points where vibration can occur, the nuts shall be effectively secured.

7.10.7 Gaskets

Gaskets shall be made of a material which is compatible with the gas conveyed by the pipeline and shall be capable of withstanding the operating temperature and pressure. Gaskets shall be designed in conjunction with the design of the flange and in accordance with the relevant part of prEN 12560. Gaskets containing asbestos shall not be used.

7.10.8 Other fittings

Other fittings shall be designed in accordance with the relevant standard. The level of stress at fittings shall be lower than or equal to that of the adjacent pipes at the same pressure and temperature.

EXAMPLE Other fittings can be reducers, insulating joints.

Insulating couplings are considered preferable to insulating flanges.

7.11 Pigging suitability

A pipeline should be designed to allow for initial and periodic pigging. Consideration shall be given to the maximum allowable variation of the pipe inside diameter, permitted ovality, minimum bend radius and the selection of bends, tees (with guide bars fitted, if necessary) and other components to permit safe and effective pigging. Pig launch and receiving stations are required at intervals with the appropriate equipment for loading, unloading, dust catching and collection of water or condensate (see also Figure 3).

7.12 Arrangements for venting

To permit depressurization of a pipeline section, facilities shall be provided for removing the gas from the section. An example of a pipeline with the appropriate facilities is given in Figure 3.

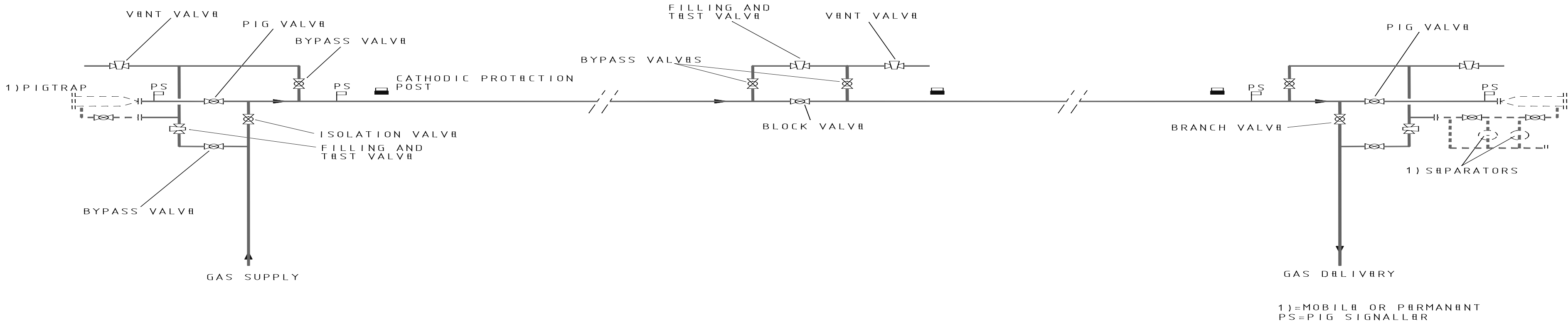

Figure 3 – Example of a valve station layout in piggable pipeline

7.13 Corrosion protection

7.13.1 General

Above-ground sections of pipelines shall be protected against atmospheric corrosion by means of a suitable coating system.

Buried or submerged pipeline sections shall be protected by means of a suitable external coating and an effective cathodic protection system. If cathodic protection will not be effective on or is not applicable to minor parts of the pipeline section, extra care shall be taken to exclude coating defects on these parts.

Consideration shall be given during the design and construction of the pipeline to the relevant EN standards for external coatings and cathodic protection when selecting an appropriate corrosion protection system. Wherever possible, all components of the pipeline shall be factory-coated before delivery to site.

7.13.2 External coating

7.13.2.1 External coating for above-ground pipeline sections

The external coating of above-ground pipeline sections and the method of application shall be selected in accordance with the appropriate EN standards.

7.13.2.2 External coating for buried pipeline sections

The external coating of buried pipeline sections and the method of application shall be selected in accordance with the appropriate EN standards.

EXAMPLE prEN 10285, prEN 10286, prEN 10287, prEN 10288, prEN 10289 and prEN10290.

a) **Properties and bonding**
External coatings for underground applications shall have good mechanical and electrical properties in relation to the environment (for example, type of soil) and operating conditions. The coating shall bond strongly to the steel surface and shall possess adequate resistance to disbonding adjacent to areas of coating damage and adequate resistance to cathodic disbonding.

b) **Selection**
In selecting the coating system, account shall be taken of the likely maximum temperature of the medium, the minimum climatic temperatures and the method of construction.

c) **Preparation of steel surface and application**
The steel surface shall be prepared and the coating applied under controlled conditions in order to ensure optimum results.

d) **"Trenchless" crossings**
Resistance to mechanical damage and abrasion shall be taken into account when selecting the coating for "trenchless" pipeline crossings of features.

EXAMPLE Crossings of roads and waterways.

e) **Field-applied coating**
The field-applied coating shall give a durable bond both with the factory-applied coating, where present, and the steel surface. The aspects described in a) to d) shall be considered regarding choice of material and application method, together with the requirements of the appropriate EN standards.

7.13.3 Cathodic protection

7.13.3.1 Basic requirement

The pipeline section to be cathodically protected shall be electrically continuous and shall have adequate longitudinal conductivity.

Cathodic protection shall be by means of an impressed-current system or sacrificial anodes.

7.13.3.2 Electrical interference

The pipework shall be protected against effects of stray currents by appropriate measures.

EXAMPLE 1 Stray currents caused by railways.

Influences associated with the proximity of high-voltage power transmission cables shall be taken into account because of safety reasons.

EXAMPLE 2 For the protection of the pipeline and the safety of individuals.

7.13.3.3 Adverse effects on other buried structures

The cathodic protection system shall be designed and the pipework installed in such a way as to reduce adverse effects on other buried metal structures.

7.13.3.4 Insulation joints

Insulation joints should be installed at suitable locations to confine cathodic protection to the pipeline system.

7.13.3.5 Putting into operation

The cathodic protection system shall be brought into operation as soon as possible following pipeline construction and where delays are unavoidable the use of temporary cathodic protection systems such as sacrificial anodes should be considered, particularly in areas with corrosive ground conditions.

8 Materials

8.1 General requirements

Pipes and pipeline components shall conform to the relevant EN standards.

In the absence of such standards or where such standards are incomplete, their characteristics shall be subject of agreement between purchaser and manufacturer.

EXAMPLE Characteristics such as chemical and mechanical properties or dimensions of the final product or manufacturing or test procedures.

8.1.1 Base material

Pipe and pipeline components shall be manufactured from fully killed steel.

Steel made by the Martin process shall not be used for pipes.

8.1.2 Manufacturing

The manufacturing procedure shall be approved by the purchaser or his representative.

If any changes are made to the approved manufacturing procedure, reapproval shall be required.

8.1.3 Weldability

8.1.3.1 General

Pipe and other pipeline components intended for welding shall be capable of being welded reliably under site conditions.

The manufacturer shall provide data on the weldability of the material. The purchaser may specify a weldability test if he/she considers the data inadequate.

8.1.3.2 Pipe

To meet the conditions given in 8.1.3.1, the maximum carbon equivalent CEV_{max} shall be in accordance with EN 10208-2.

8.1.3.3 Other pipeline components

To meet the conditions given in 8.1.3.1, the maximum carbon equivalent CEV_{max} shall not exceed:

CEV_{max} = 0,45 for grades with specified minimum yield strength not exceeding 360 N/mm^2;

CEV_{max} = 0,48 for grades with specified minimum yield strength above 360 N/mm^2;

unless otherwise agreed between purchaser and manufacturer.

$$CEV = C\,\% + \frac{Mn\,\%}{6} + \frac{Cr\,\% + Mo\,\% + V\,\%}{5} + \frac{Cu\,\% + Ni\,\%}{15}$$

where % is the percentage by weight of the ladle content of:

C Carbon;
Mn Manganese:
Cr Chromium;
Mo Molybdenum;
V Vanadium;
Cu Copper;
Ni Nickel.

Furthermore, unless otherwise agreed between manufacturer and purchaser, the carbon content shall not exceed 0,21 %.

The sulfur content shall not exceed 0,030 %, and the phosphorus content shall not exceed 0,035 %. The sum of sulfur and phosphorus as a total of the ladle analysis shall be smaller than or equal to 0,050 %.

If pipe is used for manufacturing pipeline components, the chemical composition of the pipe shall comply with the relevant EN standards.

8.1.4 Mechanical properties

8.1.4.1 Impact energy

Pipe shall at least meet the requirements for impact resistance given in EN 10208-2. For other pipeline components above nominal size DN 150, the following minimum impact energy values for full-size Charpy-V specimens shall be obtained for finished material and production welds as follows:

– **27 Joule** (average) **20 Joule** (individual)
for bends and fittings from steel grades with specified minimum yield strength not exceeding 360 N/mm^2 and all other components;

EXAMPLE Valves, flanges.

– **40 Joule** (average) **30 Joule** (individual)
for bends and fittings from steel grades with specified minimum yield strength above 360 N/mm^2.

Where full-size specimens cannot be obtained, the impact values shall be assessed in accordance with the following formula:

$$KV = \frac{8 \times 10 \times KV_{\mathrm{p}}}{S_{\mathrm{p}}}$$

where:

KV is the impact energy requirement for a full-size specimen, in joule (J);
KV_{P} is the measured impact energy, in joule (J);
S_{P} is the test piece cross-section measured under the notch, in square millimetres (mm^2).

Sub-size specimens shall be taken with a thickness greater than or equal to 5 mm without flattening.

8.1.4.2 Impact test temperature

The standard impact test temperature for pipe and pipeline components is 0 °C. When required by the design an impact test temperature below 0 °C shall be agreed between purchaser and manufacturer.

8.1.4.3 Tensile properties

Pipes shall meet the requirements for tensile properties given in EN 10208-2.

For other pipeline components, other than cast steel, the elongation at rupture of the proportional tensile specimen in accordance with EN 10002-1 shall be at least 18 %. For cast steel components the minimum elongation shall be at least 15 %.

The ratio between the yield strength and the rupture strength shall not exceed 0,90.

8.1.4.4 Hardness of welds

The hardness of production welds in pipeline components shall not exceed 350 points Vickers hardness (HV) 10 at any point including the heat-affected zone (HAZ).

8.1.5 Inspection documents

8.1.5.1 Manufacturing under a comprehensive quality system

Pipe and other pipeline components of all sizes manufactured under a comprehensive quality system, for example EN ISO 9002, approved by, and subject to, regular supervision by competent authorities, shall be supplied with inspection certificate 3.1.B in accordance with EN 10204, unless 3.1.A or 3.1.C or 3.2 is specified by the purchaser.

The manufacturer shall on request present documentation that demonstrates to the satisfaction of the purchaser that an approved quality system is in use.

8.1.5.2 Manufacturing not under a comprehensive quality system

Pipe and other pipeline components greater than DN 200 or made from grades with specified minimum yield strength greater than 360 N/mm^2 which are not manufactured in accordance with 8.1.5.1 shall be supplied with an inspection certificate 3.1.C in accordance with EN 10204, unless 3.2 is specified by the purchaser. Smaller pipes and pipeline components and lower specified minimum yield strength may be supplied with inspection certificate 3.1.B.

8.1.5.3 Small components

Instrument pipework, instruments, weld fittings, and similar components produced as bulk materials, where it is impracticable to be marked with product identification numbers, may be supplied with a test report conforming to level 2.2 of EN 10204.

8.1.6 Other steel types or grades

Steel types or grades other than those listed in the standards referred to in this clause 8 can also be used when their suitability has been approved by demonstration to an inspection body which has been accredited for this purpose according to EN 45004 or EN 45011. The requirements of these relevant standards referred to should be used for guidance in establishing material properties.

The requirements of 8.1.1 to 8.1.5 shall be observed.

8.2 Pipes

Pipe shall be in accordance with EN 10208-2.

For dimensions not covered by EN 10208-2, agreement shall be reached between purchaser and manufacturer concerning requirements.

EXAMPLE 1 Requirements such as minimum values for impact energy.

For facilities where smaller amounts of pipe materials are needed, pipes conforming to any relevant part of prEN 10216 or prEN 10217 may be specified by the purchaser.

EXAMPLE 2 Facilities such as pressure control stations.

8.3 Fittings

8.3.1 General

Fittings are understood as factory-made:

- bends and elbows;
- tees and Y-connections;
- reducers;
- caps;
- set-on and set-in branch connections;
- related items.

Where the tensile properties of a fitting do not meet the minimum requirements for the relevant grade, the conditions are also fulfilled if the term “actual yield times measured wall thickness” is equal to or greater than the term calculated with the specified minimum values. This term has to be obtained by testing.

The minimum required impact energy values according to 8.1.4.1 shall be met.

The manufacturing process shall be subject to a manufacturing procedure qualification test.

8.3.2 Manufacturing

8.3.2.1 Bending of pipes

Where longitudinally welded pipe (SAW) is used, the seam should be placed close to the neutral axis.

The manufacturing process shall be agreed between the manufacturer and the purchaser. Where the process employs heat treatment, the effect of the process on the material properties should be given due consideration.

8.3.2.2 Branch connections

Tees and Y-connections are manufactured:

- from pipe with welded-on nozzles or pipe with extruded outlet;
- if using welded pipe, care shall be taken to ensure that the outlet does not interfere with the pipe seam;
- by welding pressed or rolled shells with extruded or welded outlet.

8.3.2.3 Reducers

Reducers are manufactured:

- by expanding and/or reducing of pipe;
- by welding pressed shells or rolled plate;
- by extruding an outlet in a cap.

8.3.2.4 Caps

Caps are manufactured by pressing.

8.3.3 Dimensions and tolerances

Dimensions and tolerances shall conform to the relevant EN standard, unless otherwise specified by the purchaser.

8.3.4 End preparation

End preparation including bevelling shall conform to the relevant EN standard, unless otherwise specified by the purchaser.

8.3.5 Testing

Testing of physical properties shall be conducted after all forming and heat treatment operations have been completed. Test specimen shall be removed from additional fittings or from excess length. Test welds, made using the welding procedure approved for the manufacturing process, jointing separate plate, may be used to demonstrate the properties of longitudinal seams. The plate has to be submitted to the same heat treatment as the fitting.

For testing purposes, the fittings shall be divided up into test units. A test unit shall consist of fittings from the same heat, the same size and equivalent heat treatment.

The conformity of heat treatment has to be demonstrated by hardness tests.

8.3.6 Marking

All fittings shall be marked externally with low-stress die stamps as follows:

- manufacturer's name or symbol;
- unique identification or serial number;
- inspector's stamp.

8.4 Flanged connections

Flanges shall be class-designated. Flanges, gaskets, and bolting shall conform to the relevant EN standards.

8.5 Insulating connections

8.5.1 Type test

Insulating couplings and flanged connections shall be type-tested.

8.5.2 Strength test

Each insulating coupling shall be hydrostatically pressure tested for at least five minutes and a minimum of 1,5*DP*. End-sealing methods which subject the coupling to axial compression shall not be used for this test.

The hydrostatic test sequence shall be agreed between purchaser and manufacturer.

8.5.3 Electrical test

Each insulating coupling shall be tested in dry condition for one minute at a minimum voltage of 2 000 V AC (50 Hz). This shall not give rise to any corona effects or insulation property breakdown.

After the hydrostatic pressure test, the resistance in the dry condition shall be not less than 0,1 MΩ when tested with a minimum voltage of 500 V DC.

8.6 Valves

Valves shall be type-tested and conform to the appropriate EN standards.

8.7 External and internal coatings

Coatings on pipe and, where applicable, other pipeline components shall conform to the relevant EN standards.

9 Construction

9.1 General

The work on the pipeline structures shall be carried out in compliance with the legislation in force in the country concerned and the region in which the structure is built.

Work shall be carried out in such a way as to ensure the safety of the workforce and third parties and protection of property.

Competent personnel, capable of assessing the quality of the work within the scope of this standard, shall be employed on the supervision and execution of the construction project. Contractors appointed by the operator shall possess the qualifications necessary for the execution of the work. The operator shall satisfy itself that the necessary qualifications are held.

9.2 Execution of work

The easements relating to the working strip shall be obtained before work commences.

9.2.1 Marking out the site

The working strip shall be marked out and the projected pipeline route staked out; buried or overhead structures shall be marked giving the location, type, depth and characteristics of the structure.

EXAMPLE By signs or ground marking.

Overhead barriers or warnings should be installed 10 m minimum either side of overhead power lines where the working strip passes under.

The marking system shall be maintained in good condition during the construction period.

9.2.2 Initial site inspections

Initial site inspections shall be carried out before any actual work commences. Inspection reports shall be drawn up with the mutual agreement of all parties concerned.

The inspection reports shall state the requirements of the users/owners of the land during construction and set out the procedures for reinstatement of the site on completion of the work and compensation to the users/owners.

9.2.3 Working strip

The width of the working strip shall be determined before work begins, based on the extent of the work, the type of terrain crossed, the type of crops and any local constraints due to the environment.

The working strip shall be fenced if necessary, particularly on grazing land to prevent animals from straying.

Any felling of trees on the working strip shall be carried out in compliance with agreements drawn up with the owners, operators and others concerned.

If required by the bearing capacity of the ground, a road shall be constructed within the working strip for the movement of materials and equipment along the pipeline route.

9.2.4 Separation of topsoil

Before digging the trenches, the topsoil shall be carefully removed and separated to enable the original topsoil to be reinstated when backfilling.

Topsoil shall not be mixed with subsoil extracted from the trenches.

The width and the depth of topsoil removed shall be determined, on the basis of the type of terrain.

9.2.5 Trenches

The depth of the trench shall be determined such that the pipe cover complies with the drawings and documents established at the design and survey stage, taking into consideration the addition of any protection.

EXAMPLE 1 Protection by the use of a protective material, the installation of a ballast system, any drainage networks.

The width of the trench shall be determined as a function of depth, in order to avoid any instability. It shall enable easy installation of the pipe without damaging the external coating.

The trench walls can be vertical, sloping or battered depending on the depth, width and type of terrain and soil. The walls shall be shored if necessary, particularly if the workforce is to descend into the trench.

The trench bottom should be flat and free of any sharp edges or objects liable to damage the pipeline or its external coating. If necessary, the pipe shall be protected by suitable means as appropriate.

EXAMPLE 2 Protection by sand and/or mechanical means.

Where welds are to be made in the bottom of the trench, the trench shall be widened, deepened and kept free of water to facilitate welding and ensure safety of the workforce.

Precautions shall be taken to ensure the safety of and avoid damage to buried structures during trench work.

All excavation work, other earthmoving work and backfilling should, if possible, be carried out in dry trenches, if necessary by employing wellpoint dewatering.

A study shall be made to determine the dewatering procedure and the quantity and quality of the water removed.

Precautions shall be taken to prevent the pipe trench acting as a drain in inclined sections.

Where excavations pass under a road or footpath, the damaged area shall be kept to a minimum and any requirements of the local authorities shall be complied with.

Where explosives are used they shall be used and stored in accordance with local legislation and can be subject to prior authorizations. A detailed blasting plan shall be drawn up for this purpose.

Crossings through drained and irrigated areas shall cause as little nuisance as possible to the users of the drainage and irrigation networks.

The selection of equipment and associated working methods shall take into consideration the nature of ground conditions with respect to safety codes.

9.2.6 Crossing and proximity of buried structures (cables and pipes)

The method of excavation close to an underground structure shall be defined subject to the approval of the owner of the structure. Special precautions shall be taken to prevent damage to the structure. If necessary, the trench shall be excavated by hand.

Where the pipeline is to be constructed near power cables or other metallic structures, steps shall be taken to minimize any interference caused by the cathodic protection system. The distance between existing structures and the pipeline under construction shall, however, be in accordance with prevailing regulations, the design report and the owner's requirements.

Reduced distances may be permitted provided extra measures are taken to avoid damage to the existing structure and the pipeline under construction.

9.2.7 Handling and stringing

Handling, transport, storage, distribution and stringing of the pipes and accessories shall be performed with the utmost care in order not to damage the pipe, the external coatings and the bevels. The equipment used shall be of a flexible material of sufficient strength and shall be available in sufficient number. If an electromagnet is used, the residual magnetism shall be verified. If residual magnetism exists it shall be considered that problems can occur when arc welding is used.

EXAMPLE 1 Equipment such as slings and caps.

During storage the pipes shall be protected against corrosion, supported off the ground and, where required, separated from one another by suitable means.

EXAMPLE 2 Suitable means can be brackets or sandbags.

Measures shall be taken to prevent rolling and ensure stability of pipe storage.

9.2.8 Bends

9.2.8.1 Elastic bends

The permitted radius of curvature on bends obtained by deflection depends on the material grade and size of the pipes and shall be specified in the design phase.

9.2.8.2 Field bends

Pipes can be bent cold in the field to suit the line drawings and topographical survey. This work shall only be undertaken by experienced operators using suitable equipment.

The minimum radius for field bends should be:

– 20 X pipe outside diameters for pipes with nominal size DN 200 or less;
– 30 X pipe outside diameters for pipes with nominal size over DN 200 up to 400;
– 40 X pipe outside diameters for pipes with nominal size DN 400 or greater.

Bending shall cause no damage to the pipe or the coating. The ovality tolerance of bends shall be 2,5 % of the pipe outside diameter. If wrinkling occurs, the permissible fault depths shall be less than 0,01 times the distance between two consecutive peaks.

If necessary a gauging plate of soft steel should be pulled through the field bends to check compliance with the above requirements. The plate dimensions will depend on the characteristics of the pipe and the different permissible tolerances. Another appropriate measurement method may be used.

For cold bent pipes, a bending test shall be performed before the start of the work.

Welds on longitudinally welded pipes shall be positioned near the neutral zone. Circumferential welds are not permitted in the bending area. A straight length of at least one pipe diameter, with a minimum of 0,5 m, shall be left at either end of the bend. If necessary a mandrel should be used.

Spiral welded pipes may be used for field bending.

9.2.8.3 Factory bends

For factory bends, see clauses 7 and 8.

9.2.9 Welding and weld examination

Welding of pipeline systems shall be carried out in accordance with EN 12732 and approved procedures. It shall be performed by suitably trained and qualified operators.

Circumferential welds examination in pipeline systems shall be performed in accordance with the requirements of the standard selected for the welding and, except as allowed for test sections tie-in welds, be carried out before pressure-testing.

The minimum percentage of welds to examine is defined in EN 12732. In cases of built up areas, special constructions, pipeline sections above ground or test section tie-in welds, all welds shall be examined by an appropriate non-destructive method.

Welds shall meet the acceptance criteria specified in EN 12732 applied for welding for the selected inspection method. Welds not meeting these criteria shall either be repaired and reinspected, if permitted, or removed.

9.2.10 External coating

For coating of pipes and components, see also clauses 7 and 8.

The choice of system and method of application shall be in accordance with one of the following standards:

- prEN 10285;
- prEN 10286;
- prEN 10287;
- prEN 10288;
- prEN 10289;
- prEN 10290;
- EN 12068;
- and other appropriate EN standards.

9.2.10.1 Surface preparation, application conditions

When the surface of field joints and coating repair areas is dry and free of all deposits, it shall be cleaned in accordance with the specification.

The ends of the factory applied coating shall be bevelled before the field coating is applied.

The field coating shall be applied in accordance with the specification and/or manufacturer's instructions.

9.2.10.2 Coating welded joints and uncoated parts of pipes

Various techniques can be used to suit factory applied or existing coatings, such as:

- **tape wrapping:**
  The tapes shall be wrapped with the specified lap and shall overlap the pipe factory coating. If a machine is used, it shall not damage the coating.
- **heat-shrinkable sleeve:**
  This type is fitted after heating the pipe and the adjacent coating.
- **liquid or fusion-bonded epoxy resin coating:**
  For pipes with a factory epoxy coating, the area to be coated and the adjacent coating shall be heated before application.
- **hydrocarbon-based coating for pipes factory-coated with a hydrocarbon binding product**.

In all cases, compatibility between the products used and the pipe coating shall be verified. There shall be a sufficient overlap with the original coating.

9.2.10.3 Repairing the coating

After removal of the damaged coating, faults shall be repaired using a system compatible with the original and having identical characteristics.

9.2.10.4 Coating valves, fittings and cathodic protection connection points

The coating material for buried valves, fittings and cathodic protection connection points shall be suitable for this purpose.

This coating can be applied in the workshop or on site. In the workshop the fittings can be coated by, e.g.:

– moulding hydrocarbon-based products or epoxy resins;

– spraying coats of epoxy resin-based or polyurethane products with a high coal tar enamel content;

– dipping in a fluidized epoxy resin or powdered polyamide bath.

Site coating requires materials that conform easily to the geometry of the fittings. The following may be used:

– hydrocarbon-based binder materials which are applied either by moulding or by coating using an impregnated glassfibre surface mat;

– wrapping in combination with a filler product. The rate of overlap shall be a minimum of 50 % to give double wrapping at all points;

– cold polymerizable resin-based (epoxy) processes.

Fixing points for cathodic protection cables shall be protected using hydrocarbon-based products, bitumen wrapping applied hot, preformed polyethylene and adhesive-based systems or protective wrapping systems with filler products.

9.2.10.5 Inspections

The integrity of the pipe coating and the coating of joints shall be checked by a detector or electric scanner, the voltage of which is set to suit the characteristics of the coating. The detector shall be used after lifting the pipe and before lowering into the trench. The pass speed shall enable easy detection of faults. Faults detected shall be repaired immediately in compliance with 9.2.10.3. Each repair shall be retested with the detector.

Tests on field-coated components shall be carried out in accordance with the appropriate standards or the specifications.

9.2.10.6 Mechanical protection

At certain points on the line as determined in the design, as a result of the survey or during the work, the coating shall be protected mechanically from external interference. The type of protection chosen shall take into consideration the coating of the pipes and welded joints. It shall not disturb the functioning of the cathodic protection system.

EXAMPLE As protection sand, felt or concrete casing can be used.

9.2.10.7 Rocky ground

In rocky ground, the pipe coating shall be adequately protected by a backfill composed of sand, soft earth or crushed materials and/or the installation of mechanical protection.

Sharp-edged crushings, slag or clinker shall not be used. Saline sands should only be used if precautions are taken.

9.2.11 Lowering into the trench

The trench bottom shall be constructed in such a way as to provide uniform support to the pipeline.

Care shall be taken to ensure that the trench walls and bottom are free from protrusions or any object likely to cause damage to the pipe coating.

Immediately before lowering the pipeline into the trench, the whole of the pipe coating shall be inspected and any defects repaired.

Equipment used for lifting and lowering the pipeline shall not damage the pipe or its coating. The pipe shall be inspected where such equipment has been in contact with the pipeline.

Care shall be taken to ensure that overstressing of the pipeline does not occur during lifting or lowering operations and that, after lowering, the pipeline is not left in a stressed condition.

Wet installation (floating and sinking the pipeline section) should be considered in areas with very soft soils and/or areas where dewatering is not practicable.

9.2.12 Ballasting, anchoring

The pipe shall be ballasted or anchored, if necessary, in areas where the pipe tends to float because of the high ground water table.

The ballasting devices includes anchors, a continuous concrete coating applied on site or in the workshop, concrete set-on weights, sand and clay backfill with or without a geofabric, or any other equivalent system.

In sloping ground, the trench backfill shall be stabilized with erosion barriers to prevent washout.

EXAMPLE Sandbags or walling.

9.2.13 Tie-ins

Tie-ins shall be made so that, after welding, the pipe is as free as possible of any stresses.

Before coating, the joint welds shall be inspected according to prEN 12732. The coating shall be checked with a detector before the pipe is buried.

9.2.14 Backfill

The position of the pipe in the trench shall be surveyed to establish the as-built location before the backfill.

To avoid any damage to the pipe and the coating a prebackfill should be placed over the pipe immediately after the pipe is laid in the trench. This prebackfill should contain no materials likely to damage the pipe coating.

EXAMPLE Damage by stones or concrete.

Backfilling shall be carried out as soon as possible after lowering, either wholly or partly, to prevent damage.

If required, the pipe location should be marked by a standard yellow warning marker strip laid at a minimum of 0,30 m above the pipe.

Backfilling is generally performed mechanically. Special precautions shall be adopted in drained areas.

Roads, footpaths, shoulders, banks, etc. shall be backfilled with materials which ensure the stability of these structures.

If compaction is necessary, in particular for pipelines laid in built-up areas and pipelines routed on public roads or footpaths, it shall be performed with the appropriate equipment which does not cause damage to the pipe

9.2.15 Reinstatement

The ground occupied during the work shall be reinstated to its original condition as quickly as possible after backfilling the trench.

Accesses to property, fences, ditches, retaining walls, irrigation systems and other structures shall be reinstated in compliance with the agreements drawn up at the time of initial survey.

Land register marks moved for the work shall be replaced by an authorized surveyor.

Where necessary, devices to prevent erosion of the backfill materials shall be installed when reinstating embankments and slopes.

Reinstatement of footpaths, road surfaces, banks, shoulders, etc. shall be performed with the agreement of the authorities concerned.

9.2.16 Markings

The location of the pipe shall be clearly marked by suitable means.

EXAMPLE Yellow warning markers, overhead markers, signs.

These marker systems shall be firmly anchored to ensure permanent fixture. Where aerial surveillance is intended, sufficient markers shall be visible from the air to indicate the pipeline route.

9.2.17 Final site inspection with owners and users

When reinstatement and marking is completed, the site affected by the work shall be subjected to a final inspection attended by the parties concerned.

9.3 Special crossings

9.3.1 General

Special crossings shall be subject to the approval of the authorities concerned.

Special crossings shall be in compliance with technical provisions regarding public property, current legislation and normal design practices.

Crossings can be open trench, if necessary with a protective casing or slab, or they can be “trenchless”.

9.3.2 Open-trench road or path crossings

Open trench crossings of tarred roads or paths shall be made by cutting the surface over the full width or in sections, subject to the approval of the authorities concerned. Casings if required shall be laid on a stable bed.

9.3.3 “Trenchless” crossings

There are several techniques available for crossing features such as railways, roads, and waterways without excavating an open trench.

Depending on soil conditions and geohydrology, the appropriate technique can be selected from the following:

- excavation, either mechanical or manual;
- jetting;
- driving by displacing;
- ramming;
- microtunnelling;
- directional drilling (see 9.3.6).

When deciding which of the different techniques to use, the following aspects shall be considered:

– the process of excavating the hole;
– the support necessary for the face of the bore;
– the support required to maintain the hole;
– insertion of the pipe;
– removal of the soil;
– directional control.

The different parameters for these "trenchless" techniques are given in Table 2.

Table 2 - Overall process parameters in "trenchless" techniques

1 **Process of excavating hole**	**2** **Support forface of bore** ***options***	**3** **Support tomaintain bore** ***options***	**4** **Insertion of pipe** ***options***	**5** **Removal of soil** ***options***	**6** **Directional control** ***options***
A Excavation mechanical or manual	– No support – Hydraulic – Pneumatic – Mechanical	– No support – Hydraulic – Mechanical	– Static – Dynamic	– Through the pipe	– Yes
B Jetting	– Hydraulic	– Hydraulic	– Dynamic	– Through the pipe	– Yes
C Driving and displacing	– Mechanical	– Mechanical	– Dynamic	– To the surrounding soil	– Yes
D Ramming	– None	– Mechanical	– Dynamic	– Through the pipe	– No
E Microtunnelling	– Mechanical – Hydraulic	– Mechanical – Hydraulic	– Dynamic	– Through the pipe with transport system	– Yes

The effect on the surrounding soil and the crossed feature depends largely on the method selected. A combination of process and control method should be chosen which is most appropriate to the installed pipe, the crossed feature and the surrounding area.

The basic techniques are shown in Figure 4.

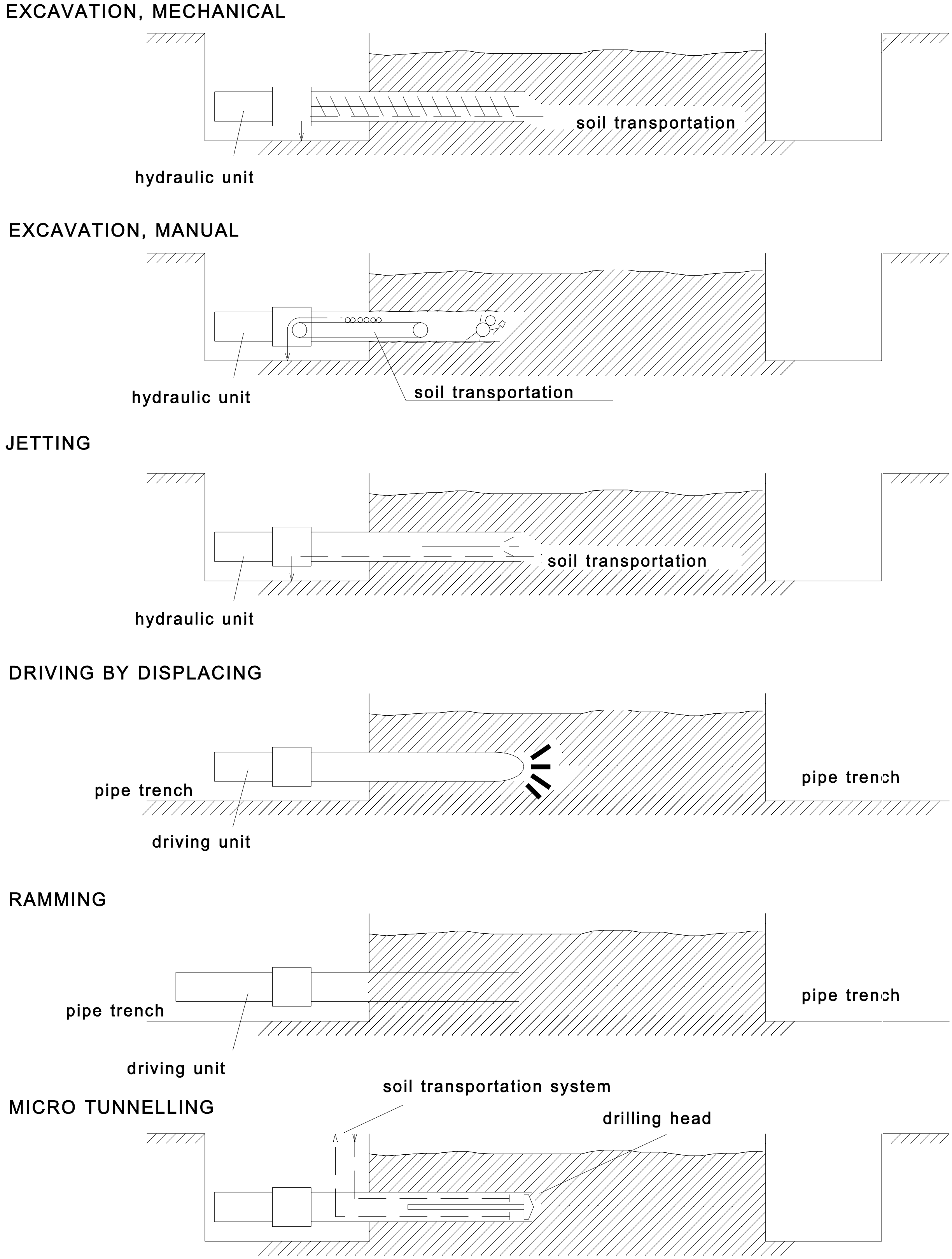

Figure 4 - Overview of some of the techniques for crossings

9.3.4 Requirements for casings

Casings can be of various materials and shall be in accordance with 7.8.

All casings shall be straight. Welded steel casings shall have no internal burrs. Their ends shall have no sharp edges.

Before inserting the carrier pipe section into the casing, it shall be fitted with insulating support rings. For support rings, see 7.8.

The condition of the carrier pipe coating shall be inspected and the inside of the casing pipe shall be cleaned before the insertion operation commences. The pipe shall be inserted gradually and in a controlled manner and kept perfectly in line with the casing in order to avoid any contact during the insertion. Extra precautions shall be taken, if necessary.

EXAMPLE Use of piled-up bags of sand or cement, or concrete blocks.

Correct execution of the work can be checked by visual inspection and by electrical insulation measurements.

9.3.5 Open-trench major water crossings

If the characteristics of the trench are likely to cause indentations, any unevenness shall be eliminated by filling the trench bottom. Additional protection to the pipeline, for example concrete coating, should be considered. The filler material shall be tipped in and dredged level immediately before laying the pipe in the trench. The depth of the trench shall take the additional fill into account in order to maintain the minimum cover depth.

The pipe shall be lowered into the trench gradually and evenly, so as to avoid any impacts, abnormal stresses or distortion of the pipe.

As soon as the pipe has been lowered in, it shall be checked for depth and alignment.

After laying, the pipe shall not be subjected to any unacceptable permanent stress.

Before placing and tieing-in the pipe, a leak-tight blanking device shall be fitted to each end.

After removal of the various pipe-laying devices, the trench and excavations shall be backfilled completely and the profiles of the bed, banks and surrounding terrain reinstated.

Backfilling with different materials shall be in compliance with the instructions given for the longitudinal and lateral profile in the design.

Bank slopes shall be consolidated by any appropriate device.

The impermeability of the banks shall be reinstated. The terrain and all structures located within the site limits shall be restored to a state identical to that reported prior to the work.

The pipe shall be subjected to the tests set out in 9.5.

9.3.6 Directional drilling

Before work commences, a report shall be drawn up setting out:

- the total extent of the work site;
- the profile of the launching stand, including the position of supports and the distance between lifting machinery;
- the pulling force on the pipe at the beginning, during and at the end of the process and the rate of progress of the pipe;
- the theoretical drilling profile.

An initial site inspection report shall be drawn up for all the land occupied for the drilling operation and construction and laying of the pipeline.

The topsoil should be removed from the area occupied by the work and stored separately.

This plot and the drilling start and end points shall be staked out.

All welds shall be inspected non-destructively in accordance with EN 12732.

The pipeline section shall be placed on supports to enable it to move during the pulling operation. The supports shall be designed so as not to damage the pipe coating.
The minimum radius should be 1000 DN unless otherwise required.

In addition, longitudinal stresses shall be lower than those permitted by the design.

Before installation of the pipeline, an insulation test shall be carried out on the coating using a holiday detector.

The predetermined theoretical profile shall be adhered to closely when drilling the pilot hole. The permitted deviation shall be 2 m laterally and 1 m vertically from the approved theoretical profile.

All precautions shall be taken to prevent drilling mud spreading over the area.

The parameters used to calculate the pulling load and the mud pressure during installation shall be continuously recorded.

During the operation, the pipe shall be sealed on both ends until tie-in.

After the work, the site shall be reinstated in compliance with 9.2.15. In particular, the drilling mud shall be removed before reinstatement of the topsoil.

A report shall be produced upon completion which includes:

- the longitudinal profile of the pipe with relevant dimensions of the curve and radius;
- the measurements of mud pressure, mud flow rate, pulling force, *x*-*y*-*z* coordinates of the drill head recorded during drilling and any other relevant statistics.

9.4 Cleaning

Before testing and commissioning, the pipeline section shall be checked for cleanliness and, if necessary, for ovality.

The pipeline section shall be cleaned with a pig or foam sphere.

To clean the pipe and, if necessary, check for ovality, a pig or a sphere shall be run several times through each backfilled section.

The pig travel speed shall be controlled and monitored on a pressure gauge.

To prevent ingress of foreign matter, the sections shall be capped before and after the tests.

9.5 Testing

9.5.1 General

The pressure tests shall prove the strength and tightness of the pipeline. Testing shall be performed in accordance with applicable sections of EN 12327.

9.5.2 Test preparation

The fluid used for the tests should normally be water.

The water shall be clean, with a corrosion inhibitor added, if necessary.

The pipe shall be filled using pigs to prevent the formation of air pockets.

The tests should normally be carried out with the trench adequately backfilled to avoid the influence of temperature changes. If the ground temperature in the immediate vicinity of the pipes is less than 2 °C, antifreeze shall be added.

On completion of filling operations, time should be allowed for the water in the sections to stabilize. The water pressures to be maintained and the location and characteristics of the measuring apparatus shall be defined before testing commences.

EXAMPLE Measuring apparatus such as thermometers, deadweight pressure gauges.

The measuring instruments shall have undergone certified periodic calibration. Pressure-recording instruments shall be installed in a sheltered place.

9.5.3 Strength test

The minimum duration for strength testing shall be 15 minutes.

Strength testing shall be carried out, starting at an actual pressure of at least 0,15 times the design pressure (DP) above the maximum incidental pressure (MIP) at the lowest point of the tested pipeline section.

At no point in the tested pipeline section shall the actual pressure for strength testing be less than 0,05 times DP above MIP at the start of the test.

The strength test pressure shall not exceed the pressure that causes extensive yielding.

The monitored pressure shall not show any significant drop during the test.

The test can be performed during the stabilization period prior to the tightness test.

Hydrostatic testing is recommended. Air or inert gas is acceptable as a test medium, provided appropriate safety precautions are taken and pressure times volume is limited.

EXAMPLE Actual pressure for strength testing at the start of the test:

a) if MIP = 1,15 MOP and MOP = DP then:
   - in flat areas the actual pressure shall be greater than or equal to 1,30 DP
   - in mountainous areas the actual pressure shall be at one point greater than or equal to 1,30 DP and at no point smaller than or equal to 1,20 DP

b) if MIP = 1,10 MOP and MOP = DP then:
   - in mountainous areas the actual pressure shall be at one point greater than or equal to 1,25 DP and at no point smaller than or equal to 1,15 DP

9.5.4 Tightness test

The tightness test may be combined with the strength test.

The tightness test pressure shall not be higher than the strength test pressure. The pressure shall not be less than DP at the start of the tightness test.

The test duration shall be determined on the basis of the characteristics of the structure and the accuracy of the measuring instruments. It shall not be less than 24 hours. For volumes of less than 20 m^3 or for uncovered sections which can be fully inspected visually, this duration may be reduced.

Hydrostatic testing is recommended. Air or inert gas is acceptable as a test medium, provided appropriate safety precautions are taken and pressure times volume is limited. In such case an appropriate test pressure shall be used.

Before carrying out the tightness test, it shall be ascertained that the quantity of air in the pipe is sufficiently small not to affect the test results.

The pipe is considered leak-tight if the temperature and pressure measurements show that the volume of test medium is maintained throughout the test.

9.5.5 Pretesting

Pipe and fittings shall be pretested in following circumstances:

- when they cannot be tested after installation in subassemblies to be incorporated into an existing installation;
- when they are to be installed in close proximity to operating plant which cannot be protected against test failure;
- when it is considered that the consequences of a test failure justify pretesting.

9.5.6 Dewatering

Once the test results have been declared satisfactory, the pipeline shall be dewatered.

The pigging equipment shall be run through the pipeline as many times as necessary to dewater it satisfactorily.

9.6 Acceptance

9.6.1 As-built records

As work advances, the position of the pipe shall be surveyed and plotted on the drawings.

An archive containing all documents (drawings, design calculations, welding log, etc.) which enable location and description of the pipe shall be compiled on completion of the work.

9.6.2 Precommissioning

Precommissioning shall take place prior to the introduction of gas for normal operating purposes.

The system shall only be commissioned when it is completely installed, tested and cleaned and, where applicable, connected to a main network.

If necessary, drying can be completed by vacuum drying, blasting with dry air or any other suitable method in addition to drying by pigging.

If operation of the pipeline is not to commence soon after precommissioning, it shall be filled with a fluid to protect against internal corrosion.

9.6.3 Handover and documentation

The pipeline system shall be handed over after precommissioning on final and countersigned inspection of the site and on submission of the construction completion report, including archives, construction drawings, specifications and all documents related to the design and construction, which shall be transferred to the pipeline operator.

10 Operation and maintenance

10.1 General

10.1.1 Policy

The pipeline operator is responsible for formulating the policy with regard to pipeline operation and maintenance activities. The object of the policy is to ensure that the system carries the gas safely, economically and without interruption.

The status of the pipeline system can, however, be influenced by the reliability of the individual items of equipment and/or by the operation and the maintenance of the pipelines. In order to meet good performance standards, all necessary precautions and provisions shall be taken to:

- ensure safe operation of the pipeline system;
- monitor its condition;
- carry out maintenance safely and effectively;
- deal effectively and responsibly with incidents and emergencies.

These precautions and provisions shall be incorporated into the management system.

10.1.2 Safety and environment

All operations and maintenance shall be carried out safely, in such a way as to minimize the impact on the environment as far as reasonably practicable, and shall be consistent with the requirements of national legislations or relevant rules.

All reasonable precautions shall be taken to ensure the safety of the personnel and the public at large and to protect property, plant and the environment.

10.2 Organization

One of the primary tasks of a maintenance and operating organization is to match resources to the workload. The objective of such matching is to achieve the agreed pipeline performance at optimum resource costs. This objective can be achieved in many ways and depends on the policy of the pipeline operator. As regards the organization of operation and maintenance of a pipeline system, the minimum requirements are:

- **organization chart:**
  The pipeline operator shall keep an up-to-date chart of its management and maintenance organization.
- **responsible persons:**
  The pipeline operator shall identify the responsible persons and their deputy or deputies for specific fields of activity including, if applicable, authorization of permits to work.
- **personnel and training:**
  The relevant personnel shall be familiarized with and have access to the operating instructions. The pipeline operator shall provide adequate training for it to ensure the safe operation and maintenance of the pipeline.
- **standby organization:**
  The pipeline operator shall have a standby organization which is ready at all times to rectify breakdowns and to deal effectively and responsibly with incidents and emergencies.

  This organization shall be provided with the necessary materials, equipment and tools to respond to emergency situations effectively.

  An effective communication system shall be provided to the personnel at the location where the work is being carried out.

10.3 Operating and maintenance instructions

The pipeline operator shall provide the information needed for safe operation and management of the pipeline system in the form of rules, guidelines and procedures embodied in operating instructions. These instructions form part of the management system and shall be checked at regular intervals to ensure maximum effectiveness and amended as necessary.

This information shall comprise as a minimum:

- the operating conditions

  EXAMPLE Pressure, temperature, gas quality

- limits and permitted departures from limits;
- instructions for the control centre(s);
- requirements for permits to work;
- procedures for, and frequency of, all inspection and maintenance activities;
- equipment descriptions, drawings, maps and all other general arrangements;
- requirements of relevant legislation or recommendations of regulatory bodies.

Separate procedures shall be laid down for special activities.

10.4 Emergency plan

In the event of an emergency, all necessary measures shall be taken without delay to rectify the fault or restore the pipeline and/or surrounding area to a safe condition. Potential faults and the procedures to be followed in the event of their occurrence shall be included in an emergency plan.

To this end, each pipeline operator shall have a written emergency plan which provides the basis for procedures and instructions to appropriate operating and maintenance personnel. The plan shall, as a minimum, contain the following information:

- a list of internal and external individuals who, and services and agencies which, have to be notified in the event of an incident;
- procedures defining responsibilities in the event of an incident;
- procedures for limiting the effect of leaks, dealing with hazardous situations and rectifying any damage caused;
- procedures for alerting the standby organization or emergency contractor and mobilizing emergency equipment and materials;
- a list of emergency equipment and materials available for use in damage limitation and when undertaking repairs.

The emergency plan shall be checked on a regular basis and amended as necessary.

If the existence of a leak from the pipeline is suspected or confirmed, action shall be taken without delay to prevent or limit the damage or effects to the surrounding area from any leakage.

Leaks shall be notified without delay to the appropriate agencies listed in the emergency plan if there is a danger to the public at large.

The cause of the incident shall be investigated and any precautions which need to be taken to prevent recurrence shall be identified and implemented without delay. The causes identified, the conclusions drawn and the method of repair shall be recorded in an incident report.

10.5 Records and documentation

The plans and documentation required for the pipeline system shall, in each case, be kept up to date.

The records of all maintenance and emergency activities shall be retained for a fixed period of time to be determined by the pipeline operator or as required by legislation.

10.6 Commissioning

Commissioning shall be carried out in accordance with EN 12327. In addition, special consideration shall be given to the need to dry the pipeline prior to or as part of commissioning.

The commissioning operation shall be conducted in such a way that any gas/air mixtures produced are removed safely and no air remains in the pipeline. The pipeline pressure shall then be increased to operating level in a controlled manner.

After construction and after sufficient time has elapsed to allow polarization of the pipeline, the effectiveness of the cathodic protection system on the pipeline shall be tested to ensure acceptability.

10.7 Decommissioning

Decommissioning shall be carried out in accordance with EN 12327. Pipeline sections which are taken out of service for an extended period shall, if necessary, be decommissioned.

10.8 Recommissioning

Recommissioning shall be carried out in accordance with EN 12327. Before or during the recommissioning of a pipeline, it is essential to verify that the work has been correctly executed and tested. Special attention shall be paid to welding work, tightness, coating integrity and cathodic protection.

The pressure shall not be allowed to exceed permitted limits during refilling of the pipeline.

During refilling, valves shall be operated in accordance with an approved procedure and in coordination with the appropriate control centre or the local supervisor.

10.9 Maintenance, modification and repair

10.9.1 General

The pipeline operator shall lay down procedures for maintenance, repair and modification work carried out on the pipeline system.

Work shall only be carried out on the pipeline system by, or under the supervision of, personnel authorized by permits to work.

The maintenance intervals/frequencies shall be determined by the owner or operator based on its experience of the pipeline conditions and particular circumstances and bearing in mind the legislative requirements. The maintenance intervals/frequencies shall also be determined with reference to the particular local situations and damage probabilities.

All components which are essential to the safe operation of the pipeline system shall be inspected, maintained, checked and operated in a way that safeguards their condition and ensures proper functioning.

EXAMPLE Block valves, check valves and safety devices.

During the course of the work, due account shall be taken of any third party services in the vicinity.

10.9.2 Pipeline monitoring and surveillance of third-party activities

The pipeline shall be continuously monitored and the data recorded where appropriate and necessary.

a) **pipeline route inspection:**
Pipeline routes shall be inspected at regular intervals, e.g. to check on the condition of the pipeline easement and the condition of the route markings. Any third-party activity on or adjacent to the pipeline easement which could affect the integrity of the pipeline shall be investigated.
Pipelines shall be physically inspected if the pipeline route inspection detects construction or other activity which can have jeopardized the safety of the pipeline or the surface equipment, or detects leakage from or damage to the pipeline and the equipment. The appropriate action shall be taken without delay.

b) **tightness of the pipeline:**
The pipeline system shall be checked for gas leaks at regular intervals.

c) **pipeline components:**
Pipeline components and associated control systems which are essential to the safe operation of the pipeline system shall be checked regularly and any problems which are identified shall be rectified without delay.

d) **corrosion prevention:**
Regular checks shall be carried out to ensure that the corrosion prevention systems for buried and above-ground pipework are functioning satisfactorily. Special attention shall be paid to pipelines which are subject to interference or stray currents. Any faults in the cathodic protection system shall be rectified once their cause has been determined.

e) **pressure monitoring:**
For safety reasons, the pipeline pressure shall be recorded at representative points on the pipeline.

10.9.3 Execution of repairs and modifications

Care shall be taken while the work is in progress to ensure that no hazardous gas mixtures are formed. If this cannot be guaranteed, appropriate precautions shall be taken to prevent hazard to persons and the surrounding area.

Welding, cutting, grinding and similar works may be performed on an in-service pipeline provided the pipeline design, the pipe material and the established techniques permit such work to be carried out safely.

On completion of the work, the corrosion protection (coating, cathodic protection) shall be carefully reinstated.

10.9.4 Work involving cutting of the pipeline

Before cutting the pipeline, appropriate technical precautions shall be taken to ensure that there is no possibility of an uncontrolled gas ignition.

Before work commences, the section of pipeline shall be isolated, depressurized and, if necessary, purged. Care shall be taken to ensure that no gas can enter any section of pipeline which has been purged.

10.9.5 Work on in-service pipelines

When working on in-service pipelines, including work involving the generation of heat, suitable precautions shall be taken to prevent the escape of gas and other hazards.

If the chosen procedure cannot be carried out on the pipeline at its normal operating pressure, the pressure in the pipeline section in question shall be reduced in a controlled manner to the required level and shall be maintained in that state while the work proceeds.

10.9.6 Other and special maintenance activities

Pipeline systems can have sections which require special maintenance at certain points. Often further points are identified in terms of the local environment which imposes special design requirements.

These special points include, among others:

- overhead crossings;
- water crossings;
- casing pipes;

  EXAMPLE Under roads, railways or other features.

- settlement areas/landslides;
- pipelines in mining subsidence areas.

a) **Overhead crossings:**
The purpose of this inspection activity is to verify:
- the condition of the mechanical protection of the crossing;
- the condition of the painting or coating of the pipeline;
- the condition of the pipe-support system.

EXAMPLE 1 Stability, integrity, protective painting.

Maintenance activities and their frequency shall be carried out in such a way that all overhead parts of the pipeline are inspected. Special attention shall be given to the transition area between atmosphere and ground, which can be subject to corrosion.

The inspection activities and their frequency shall take into account the prevailing atmospheric conditions.

EXAMPLE 2 In coastal or industrial areas.

b) **Water crossings:**
The purpose of this inspection activity is to verify:
- the stability of the bed and banks;
- bank erosion or deposition of material;
- the condition of the pipeline and its covering.

The inspection shall include monitoring the water depth and recording such events as flooding and its effects on the banks.

Inspection and maintenance work should be defined in consultation with the national/local agencies or the licensing authority.

c) **Casing pipes:**
The purpose of this inspection activity is to verify:
- the condition of the casing pipe (ground movement) and where relevant the internal pipe;
- the absence of electrical contact between the casing and pipe.

d) **Settlement/landslide areas:**
Special care shall be taken at points where the pipeline routing reports indicate, or it is subsequently determined, that increased loads can occur because of settlement or movements of ground. This movement can be detected by surveying the pipeline route and, if necessary, by instrument-based monitoring of the pipeline and/or the ground. Suitable precautions shall be taken to ensure that permitted limits are not exceeded.

e) **Pipelines in mining subsidence areas:**
In the case of pipelines in mining subsidence areas, the pipeline operator shall make regular checks to identify any detrimental effects on pipeline operation. If any detrimental effect is expected, the pipeline operator shall determine the action required after taking the opinion of a competent engineer.

10.10 Abandonment

To prevent an abandoned pipeline (or section) becoming a source of danger or nuisance, it shall be decommissioned and isolated from the pipeline system. The abandoned pipeline or section can be filled with an inert gas or other appropriate substance.

Annex A (informative)

Bibliography

EN 1776, *Gas supply systems - Natural gas measuring stations - Functional requirements*

EN 1918-5, *Gas supply systems – Underground gas storage - Part 5: Functional recommendations for surface facilities*

EN ISO 9001, *Quality systems - Model for quality assurance in design/development, production, installation and servicing*

EN ISO 9002, *Quality systems - Model for quality assurance in production, installation and servicing*

EN ISO 9003, *Quality systems - Model for quality assurance in final inspection and test*

EN ISO 9004-1, *Quality management and quality system elements - Part 1: Guidelines*

EN 12007-2, *Gas supply systems - Pipelines for a maximum operating pressure up to and including 16 bar - Part 2: Specific functional recommendations for polyethylene (MOP up to and including 10 bar)*

EN 12007-4, *Gas supply systems - Pipelines for maximum operating pressure up to and including 16 bar- Part 4: Renovation*

EN 12279, *Gas supply systems - Gas pressure regulating installations on service lines - Functional requirements*

ISO 13686, *Natural gas - Quality designation*.

Annex B (informative)

Settlement areas

B.1 General

Settlement areas are characterized by the occurrence of holocene strata beneath the pipeline.

A pipeline can be subject to settlement where it crosses an elevated section which has underlying layers of soft soil. The amount of settlement depends upon the thickness, depth and type of the soft soil layers, together with the height and age of the elevated section. The consolidation process can take many years.

EXAMPLE An elevated section can be a dyke or road.

Further raising and/or extension of the elevated section or lowering of the groundwater level initiates a new consolidation process.

Settlement in the case of elevated sections, with soft soil layers beneath, leads to high stresses at the transition to the elevated section or at the transition from fixed support (for example at stations) to a field section.

B.2 Procedure

Pipeline sections where differential settlement can be expected, should be identified.

EXAMPLE Crossings with dykes and elevated areas.

The following information should be available:

- general geotechnics data and occurrence, nature, properties, depth and thickness of soft soil layers;
- general geohydrological and piëzometric data;
- information from local agencies/authorities on settlement.

The differential settlement for the crossing should be assessed on the basis of the available data. In case of doubt, consolidation tests should be performed on representative soil samples.

The settlement of the soil layers can be calculated using conventional formulae (literature [1], [2] and [3]).

B.3 Construction settlement

In addition to settlement due to consolidation, allowance should also be made for settlement due to construction, as a result of both disturbance of the soil and the use of different construction methods:

- In the case of bored/jacked crossings, an abrupt difference in settlement at the point of transition from boring to open trench can be assumed. The pipe laid in the trench will be subject to greater construction settlement than the bored/jacked pipe. The difference in settlement is designated as X.
- In the case of pipelines laid in open trenches, it can be assumed that differences in construction settlement will occur due to non-uniform soil handling along the trench. For calculation purposes, it is assumed that this construction settlement increases gradually from 0 to X mm over a distance L and back to 0. The distance covered by the calculation is therefore equal to $2L$.
- The values for X depend on soil type (clay/peat or sand, degree of consolidation/ compaction), construction method (dry, wet) and pipeline diameter.

  Values for X can be taken from literature [4].

  If considerable swelling occurs during excavation, the values of X given for construction settlement are increased by the amount of swelling.

  EXAMPLE In the case of a bored/jacked crossing.

– Length L should not be less than 20 m or more than 50 m. Between these values, L (in mm) can be calculated by means of the formula:

$$L = 10 \times \sqrt[4]{\frac{4EI}{Dk_v}}$$

where:

D is the outside diameter, in millimetres (mm);
I is the moment of inertia of the pipeline, in millimetres to the power of four (mm^4);
E is the modulus of elasticity for the pipe material, in newtons per square millimetre (N/mm^2);
k_v is the vertical modulus of subgrade reaction, in newtons per cubic millimetre (N/mm^3).

$$\sigma_b = 0{,}02X\sqrt{\frac{E\,k_v}{T_{nom}}}$$

$$Q_r = 0{,}03XD\,k_v$$

$$Q_z = 0{,}000\,4XD\,k_v$$

where:

σ_b is the longitudinal bending stress, in newtons per square millimetre (N/mm^2);
Q_r is the soil reaction, in newtons per millimetre (N/mm) (Figure B.2);
Q_z is the settlement load, in newtons per millimetre (N/mm) (Figure B.2);
T_{nom} is the nominal wall thickness, in millimetres (mm).

B.4 Strength calculation

The analysis carried out on buried pipeline sections can take one of two forms:

– strength calculation in accordance with the beam model (B.4.1);
– simplified strength calculation (B.4.2).

B.4.1 Interaction between pipe and soil: pipeline considered as beam

The pipeline behaves as a beam if the soil is subject to differential settlement or settlement as a result of construction activity (Figure B.1).

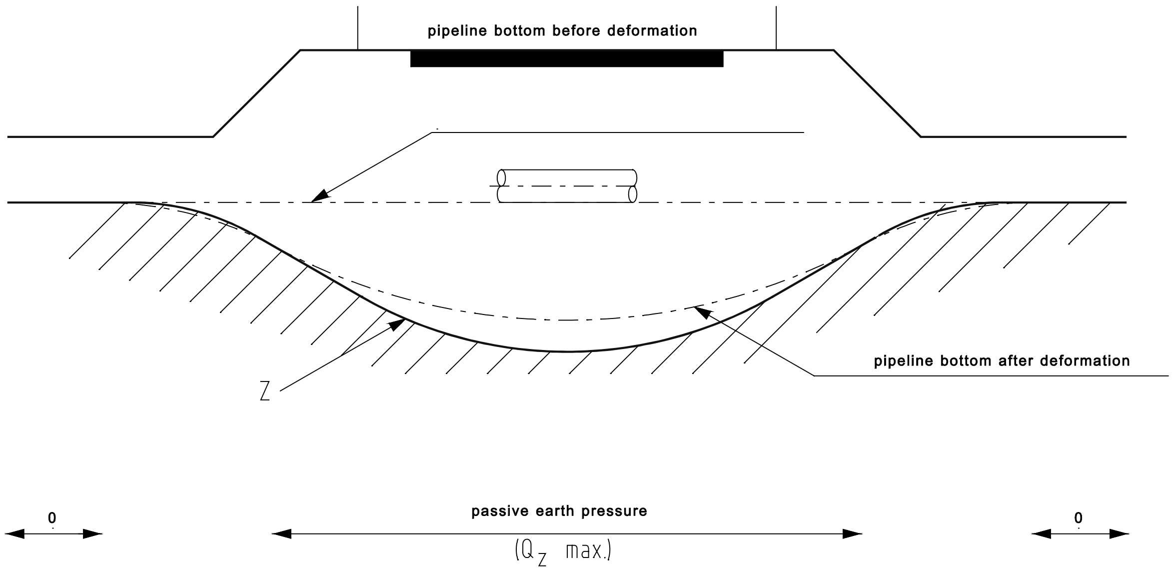

Figure B.1 - Pipeline considered as beam

As a result of settlement of the soil beneath the pipeline, the soil above the pipeline will force it to follow the soil movement fully or partially, depending on the stiffness of the pipeline section.

The load required to achieve this is designated as ”settlement load” (Q_z); it is not transmitted directly (by tangential moments and forces in the pipe wall) to the subsoil, but is instead transmitted to bedding zones to left and right of the settlement zone.

In the pipe, this creates axial bending moments and transverse forces. It can also give rise to tensile forces in the axial direction (catenary effect).

In the bedding zones, this gives rise to higher soil reactions to accommodate the settlement load.

The magnitude of the settlement load and soil reactions is limited by the amount of settlement, the stiffness of the pipeline and the stiffness of the soil.

The upper limit for the settlement load Q_z is equal to the sum of the upper limits of the earth pressure acting on the pipe (passive earth pressure) and the weight of the pipeline (Q_p + Q_w).

As long as Q_z is below the neutral earth pressure Q_n, then, in addition to the indirect transfer of Q_z (as shown in Figure B.2) to the bedding zones (Q_r in Figure B.2), the remainder of the load (Q_n + Q_w - Q_z) is transmitted directly to the soil beneath the pipeline.

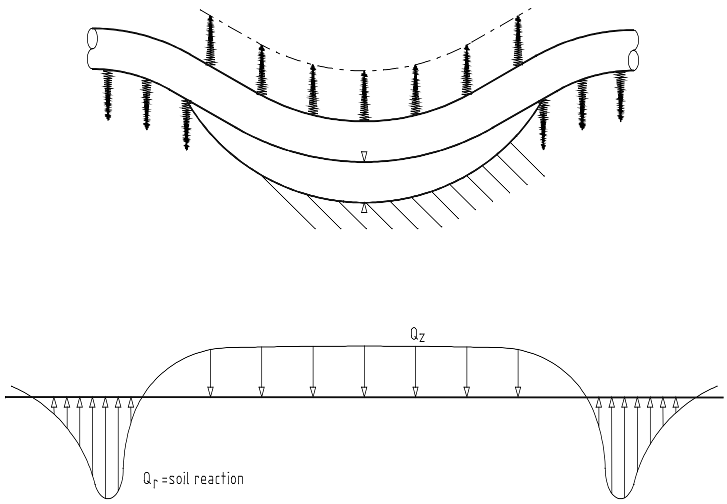

Figure B.2 - Settlement load and soil reaction

Strength calculations should be carried out in accordance with 7.3 and 7.4 using the relevant soil data, including the contingency factors according to Table G.1.

The contingency factor for consolidation settlement (mean value) is 1,5 if the predicted settlement is based on two representative samples. If it is based on three representative samples of each compressible soil layer, the contingency factor is 1,3. If the rate of settlement is monitored with reference to fixed markers, the contingency factor may be adjusted to 1,1. If the geotechnics of the area and the variation of the soil mechanics properties are well known, it is not necessary to base the contingency factor on the number of samples taken. It should be clearly stated whether the predicted settlements are mean values or characteristic values (see also Annex G, clause G.1).

B.4.2 Simplified calculation method

On the basis of the results of earlier research, full calculation can be dispensed with for certain pipeline sections (provided a number of conditions are met) and it is sufficient to calculate the hoop stress due to internal pressure, in accordance with 7.2; with:

a) for cross-country sections f_o = 0,72

b) for crossings with roads, ditches, canals and natural watercourses without flood defences:
   - open excavation f_o = 0,67
   - boring/jacking f_o = 0,55

The simplified calculation method can be used if the following conditions are met:

- D/T_{min} ratio
  $R_{t\,0,5}$ = 480 N/mm^2 $D/T_{min} \leq 106$
  $R_{t\,0,5}$ = 415 N/mm^2 $D/T_{min} \leq 92$
  $R_{t\,0,5}$ = 360 N/mm^2 $D/T_{min} \leq 80$
  $R_{t\,0,5}$ = 240 N/mm^2 $D/T_{min} \leq 70$
- Depth of cover over top of pipeline: maximum 2,5 m. The requirements relating to depth of cover are not applicable if it can be demonstrated that the effective stress at the depth of the top of the pipe does not exceed 65 kN/m^2.
- The specified wall thickness used in the section is equal to or greater than 4,78 mm.
- Differential settlement from consolidation does not exceed 100 mm. This differential settlement should increase gradually from zero to the maximum value and back to zero over a distance of at least 2 × 20 m and the construction settlement does not exceed the values that can be expected in normal pipeline construction practice, where no special measures are taken.
- The pipeline does not cross potential fracture planes or areas of mining subsidence.
- The pipeline section involved does not include bends smaller than 20D.

– The maximum difference between installation temperature and maximum or minimum temperature, as applicable, should not exceed 35 °C.

The overall temperature range lies between –40 °C and +60 °C. With regard to frost heave reference is made to Annex D.

Where bends of less than 20*D* are used, the following additional or alternative criteria apply:

– The maximum difference between installation temperature and maximum or minimum temperature when horizontal bends are present does not exceed 20 °C (instead of 35 °C) for diameters smaller than or equal to 300 mm.
– The minimum distance between horizontal bends *D* smaller than 450 mm is 2,0 m.

For bored/jacked crossings installed from working pits and where bends of less than 20*D* will be installed in the working pit, the following additional or alternative criteria apply:

– Wall thickness calculation for bends as described in 7.10.2, with f_o = 0,55 as for the crossing.
– D/T_{min} ratio (straight pipe)
  $R_{t\,0,5}$ = 480 N/mm^2 $D/T_{min} \leq 81$
  $R_{t\,0,5}$ = 415 N/mm^2 $D/T_{min} \leq 70$
  $R_{t\,0,5}$ = 360 N/mm^2 $D/T_{min} \leq 61$
  $R_{t\,0,5}$ = 240 N/mm^2 $D/T_{min} \leq 57$
– Where *D* smaller than 450 mm, the bend is located on the field side of the working pit.

B.5 Monitoring

The pipeline should be periodically checked for settlement in areas where settlement necessitates the raising of dykes or the reduction in groundwater levels and at road or other crossings. The results should be compared against those predicted in the original geotechnical study.

B.6 Action in the event of the allowable/limit values being exceeded

If the allowable/limit values are exceeded, the following action is possible:

– during design:
  • preload the strip/area under consideration before construction, to give presettlement;
  • in the case of raised areas, avoid piled supports if possible.
– during/after installation:
  • excavate the pipeline section under consideration, lift it, place soil underneath the pipeline and compact it;
  • replace the soil in the excavation with a lightweight material to reduce settlement.

B.7 Literature

[1] K. Terzaghi, R.B. Peck: “Soil Mechanics in Engineering Practice”, John Wiley & Sons Inc., New York, 1948.
[2] H.F. Winterkorn, Hsai-Yang: “Foundation Engineering Handbook”, Van Nostrand Reinhold, New York, London, 1975.
[3] A.W. Koppejan: “A Formula combining the Terzaghi Load - Compression Relationship and the Buisman Secular Time Effect”, Proc. Second Congress of the International Society for Soil Mechanics and Foundation Engineering, 1948.
[4] H.J.A.M. Hergarden: “Enkele geotechnische aspecten bij de aanleg van leidingen - Some geotechnical aspects of pipeline construction” (in Dutch), Report CO-322680/7, Delft Geotechnics, March 1992.
[5] D. Poulus: “Elastic solutions for soil and rock mechanics”, John Wiley & Sons Inc., New York, 1974.
[6] C. Desai: “Numerical methods in geotechnical engineering”, McGraw-Hill, Book Company, New York, 1976.

Annex C (informative)

Mining subsidence

C.1 General

Land surface subsidence occurs when material is removed from the underlying strata, as during longwall mining.

The maximum subsidence is less than the planned seam height because:

– the overlying rock fractures as it subsides, creating voids which reduce the volume of material required to replace the excavated minerals;
– material is “drawn” from outside the mined area. This “draw” extends the area affected by subsidence.

Buried pipelines follow these movements within limits, as overburden pressure changes and friction between the pipe surface and the backfill transfers lateral earth pressure.

C.2 Procedure

Projected mining operations along the general route of the pipeline should be identified.

The following information should become available:

– panel dimensions (width, depth and thickness) and orientation in relation to the pipeline;
– geological details;
– period covered by mining programme;
– old workings. Consideration should be given to assessing residual stress levels from previous ground movements.

Based on the information available, the effect of all projected mining operations (land surface subsidence and horizontal ground displacement) should be assessed.

All restraints which restrict relative movement between the pipe and the ground should be determined.

C.3 Strength calculation

Design calculations should be carried out in accordance with 7.3 and 7.4, using the relevant data.

Residual stresses from previous loading or previous subsidence should be assessed and may need to be added. The determination of the resultant stress should be carried out for the whole section of pipeline to a point beyond the mined area, covering both compressive and tensile stresses.

C.4 Action in the event of the allowable/limit values being exceeded

If the allowable/limit values are exceeded or if there is a possibility of their being exceeded during the mining operations, the following action is possible:

– replacement of backfill with selected low-friction material;
– use of expansion bends or sliding joints;
– refinement of pipe geometry;
– excavation of long lengths of pipeline, leaving them open for the duration of mining operations to isolate the pipe from the ground movements causing the problem. This action should only be regarded as a short-term measure, bearing in mind the environmental and security problems and the effects of changes in pipeline operating temperature;
– revision of the operating data;
– strain measurement and cutting to release stress.

C.5 Monitoring

Where mining activities are known to affect pipelines or stations, there should be frequent contact with the mining company.

It is important to have precise information on the as-built position of the pipeline section in relation to the stresses already present in the pipeline section.

If high stresses are predicted, and given the uncertainties inherent in mining operation, stress measurements should be performed at points of high stress and ground movements should be monitored to assess the effects as mining proceeds.

C.6 Literature

[1] B.N. Whittaker, D.J. Reddish: “Subsidence - Occurrence, Prediction and Control”, Development in Geotechnical Engineering 56, Elsevier, 1989.

[2] Subsidence Engineer's Handbook, National Coal Board, Second (Revised) Edition Mining Department (U.K.), 1975.

[3] D.R. Cole, N.C. Rogers: “Mining operational experience”, presented to the Midlands Gas Association, 1985.

[4] G. Drasdo: “Auswirkungen des untertägigen Bergbaus auf Wasserleitung”, 3 R International, 30 (1991), Heft 4, April.

[5] R. Hüning, H. Geissmann: “Uberlegungen zum Einsatz von Gasdruckleitungen aus PE-hart in Bergsenkungsgebieten”, gwf-gas/erdgas 120 (1979), Nr. 4, S. 197/200.

[6] H. Geilenkeuser: “Untersuchungen über die Bewegung von Rohrleitungen in der Erde unter dem Einfluß von äußeren Kräften”, Gesammelte Berichte aus Betrieb und Forschung der Ruhrgas Aktiengesellschaft, Nr. 11, 1962.

[7] W. Kiwitt: “Über das Verhalten von erdverlegten Rohrleitungen unter akuter Bergbaueinwirkung”. Dissertation, Technische Universität Clausthal, 1973.

Annex D (informative)

Frost heave

D.1 General

Frost heave occurs if the temperature of the soil at the depth of the pipeline section under consideration falls below 0 °C or if the soil is otherwise susceptible to frost heave.

EXAMPLE 1 Gas temperature is below 0 °C or frost penetration depth exceeds the depth of cover.

Differential heave along the pipeline results in stresses, among others:

- at crossings where frost penetration is deepest as at small forest paths where uneven frost heave could occur during snow clearing;
- where there are widely varying soil properties;
- at the transition from a fixed support to a field section.

EXAMPLE 2 In front of and behind stations.

The load is imposed by the increase in volume and by the rigidity of the frozen soil. This volume increase can be simulated by determining a frost heave profile.

D.2 Procedure

The susceptibility to frost heave should be determined from the geotechnical investigation. The frost heave at the level of the pipe should be determined using an appropriate frost heave model.

EXAMPLE Literature [2].

The soil properties should be indicated for the non-frozen and frozen condition.

It should be clearly stated whether the calculated frost heave is a characteristic value or a mean value.

D.3 Strength calculation

The analysis should be carried out in accordance with 7.3 and 7.4. The moduli of subgrade reaction along the pipeline section in the calculation model should represent the situation with non-frozen and frozen soil.

D.4 Other possible measures

If the strength of the pipeline section under consideration cannot meet the criteria, other techniques should be used to counter the effect of frost action or to overcome the mechanism that promotes it:

- (selective) soil replacement;
- modification of the soil with additives;
- drainage;
- insulation to alleviate frost heave or to shift it to a less critical location.

NOTE Other associated frost action mechanisms can be taken into account, such as thaw weakening and frost-grip.

D.5 Literature

[1] "Soil mechanics for road engineers", Department of the Environment, Transport and Road Research Laboratory, Her Majesty's Stationary Office, London 1952, Tenth impression 1974.

[2] J.F. Nixon: "Pipeline frost heave predictions using the segregation potential frost heave method", Proceedings 6th International Conference on Subsea Mechanics and Arctic Engineering, Houston, 1987.

[3] L.E. Carlson, J.F. Nixon: "Subsoil investigation of ice lensing at the Calgary, Canada, frost heave test facility", Can. Geotech. J., pp. 307-319, vol. 25, 1988.

[4] "A ground freezing test facility", 1992, Geotechnical Science Laboratories, Carleton University, Ottawa, Canada.

[5] Nymann: "Thaw settlement analysis for buried pipelines in permafrost", Pipelines in adverse environments 2.

Annex E (informative)

Landslide areas

E.1 General

Landslides are mass movements of the ground that can be triggered by reduction of shear strength of the soil or by seismic shaking.

It is unlikely that pipelines can survive the large deformations associated with deep translational and rotational slides, but it is possible to design for it if instability involves slumps and shallow slides.

Landslides are characterized by the extension and depth of the sliding area and the rate and direction of movement. The classification by Varnes (literature [1]) is the current reference for gravitational movements.

Some configurations can be particularly dangerous, due to the presence of fixed points at which the strains are concentrated by pipeline displacements imposed by landslide movement. Bends and other constraints in the pipeline give rise to different levels of flexibility, causing the bends to close and eventually collapse.

EXAMPLE If the pipeline is parallel to the direction of slip, the bend downhill (often adjacent to a river or road crossing) is the main potential danger point.

E.2 Procedure

Programmes for quantifying landslide hazards should include identification and investigation of zones displaying signs of movement and slopes which are potentially unstable.

Aerial photographs are of great assistance in identifying zones of recent displacement and infrared imagery is often a valuable supplement.

Apart from typical geomorphological signs of soil movement, all other not strictly geological elements which can indicate sliding activity should be considered with the geotechnical survey to obtain the following information:

– depth and extension of the landslide;
– displacement vector (rate and direction of movement);
– variation in stratum level;
– water table level;
– geotechnical parameters of the soil.

EXAMPLE 1 Cracks in buildings or roads, bent poles and trees.

The position of the pipe axis referred to the movement and the position of the pipe in the landslide and geometrical parameters, especially horizontal and vertical bends, should be determined. Slope stability analyses should be performed when there is potential instability in seismic zones.

EXAMPLE 2 Disjunction area, an intermediate area or a stack area.

E.3 Strength calculation

The magnitude of the stress in the pipe depends on the width of the sliding soil mass, the magnitude and direction of soil movement, the soil shear strength, the friction between soil and pipe and the depth of burial.

The angle of incidence between pipe and soil movement is very important because it can also lead to different failure modes for the pipe and possibly to different types of analyses.

Dynamic effects during the slide may be ignored.

In order to obtain the stress and strain of the pipeline, the pipe and its surrounding soil may be idealized through a structural model, either for specific analysis sections or for the entire pipeline system.

Inside the sliding soil mass, the effects of the soil can be described by distributed loads, by imposed displacements or by intermediate conditions.

Outside the slide, the soil restrains the movement of the pipe (see literature [3]).

In this situation pipe/soil interaction plays a determining role.

In the analysis of pipe/soil interaction, it should be selected a formula for the calculation of the forces and the restraints exerted by the soil on the pipe system.

The amount of restraint and load exerted on the pipeline is a non-linear function of the amount of relative displacement between the soil and the pipeline. In a transverse landslide, soil loading will induce lateral displacements, i.e. displacements transverse to the pipeline axis, that can become quite large (see literature [4]).

In these cases, conventional small-displacement beam bending theory is generally inappropriate.

An accurate analysis of the effects of large transverse ground displacements relies on the use of procedures that can account for non-linear behaviour of the pipeline, non-linear behaviour of the soil and large-displacement theory.

Finite-element techniques with simplified models for interaction can be employed for these analyses.

In longitudinal landslides, that means when the pipeline is parallel to the direction of slip, a field of axial strain is generated by the frictional force between soil and pipe.

In this case the pipeline can be severely compressed. Two modes of deformation are possible:

– the pipeline can break free of the soil and buckle upward as a beam;
– the pipeline can buckle as a shell with local warping and wrinkling of its wall.

Strength calculations should be carried out in accordance with 7.4, using the relevant soil data.

E.4 Possible action to prevent the allowable/limit values being exceeded

In the pipeline design process, it should be appreciated that the chance of survival of the pipeline is greatest if the failure mode is one of tension; when the pipeline is severely compressed, the chance of survival is significantly lessened (see literature [5]).

In either case, the following actions can be taken to reduce the state of stress of the pipeline:

– minimize lateral soil forces on the pipeline by controlling the type of backfill material, degree of compaction and depth of cover;
– minimize longitudinal friction force as above, paying particular attention to pipeline coatings;
– maximize the slide movement capacity of the pipeline by eliminating potential anchoring elements within the anchoring area either side of the sliding soil;

EXAMPLE 1 Anchoring elements can be, amongst others, bends, tee, valves.

– avoid particular geometry of the pipeline that can cause high stress concentrations.

When monitoring indicates that stresses are nearing the allowable/limit values or are following a steady trend, the following mitigating actions are possible:

– digging a trench around the pipeline section to relax it;
– cutting the pipe to eliminate the stress;
– stabilizing soil with suitable works and/or installation of a drainage system (see literature [3]).

EXAMPLE 2 By reinforcement of the slope by walls, reinforced concrete ties, reinforced embankments.

E.5 Monitoring

Depending on how critical the crossed area is, monitoring can range from simple, periodical surveying techniques to instrument-based monitoring of both the area and the pipeline.

Two fundamental problems are inherent in methods of monitoring the pipeline in unstable areas:

- strategic positioning of instrumentation (strain gauges). Sections where high stresses are predicted and points with high stress concentrations in particular should be monitored;
- determination of allowable limit values that, when exceeded, indicate the need for mitigating measures. In this case it is important to know in detail the as-built position of the pipeline in relation to the stresses already present in the pipeline.

Inclinometers should be used to measure the displacements and directions and piëzometers to monitor the water level.

E.6 Literature

[1] D.J. Varnes: “Slope movement types and processes - Landslide analysis and control”, Special report 176, Nat. Acad. of Sciences, Washington, 1978.
[2] Venzi, Mallardi: “Control of pipelines subject to landslides”, 15th World Gas Conference, Lausanne, Switzerland, June 1982.
[3] Kennedy, Nymann, Audibert: “Analysis of buried pipelines for seismic-induced ground distortions”, ASME 4th National Congress on Pressure Vessel and Piping Technology; Portland, Oregon, June 1983.
[4] Yeh: “Landslide effects to buried pipelines”, Numerical methods in geomechanics, Innsbruck, 1988.
[5] Bea, Aurora: “Design of pipelines in mudslide areas”, Journal of Petroleum Technology, November 1983.
[6] J.H. Greenwood, M.B. Bukovansky, G. Major: “Line-monitoring instruments prove effective for Western U.S. areas subject to landslides”, Oil & Gas Journal, pp. 68-73, Feb. 17, 1986.
[7] A. Olcese, C. Vescovo, M. Badaline, P. Baldelli, G. Palloni: “Monitoring of risk areas along pipelines in Italy”, Interpraevent, Bern, 1992.
[8] G. Stella, A. Olcese: “The Italian experience in crossing the Alps and Apennines”, 18th World Gas Conference, Berlin, 1991, IGU/C3-91.
[9] Cuscunà, Dallatorre, Bolzoni: “Controllo di metanodotti in aree instabili per mezzo di estensimetri a corde vibranti: influenza della geometria della tubazione” 6° Congresso Nazionale del Associazione Italiana Prove Non Distruttive, Milan, 1990 (Italian version).

Annex F (informative)

Areas with high seismic risk

F.1 General

On land, seismic hazards that affect pipelines are:

– vibratory ground motion due to travelling seismic waves (shaking);
– permanent ground movements, which include faulting, liquefaction and landslides.

Ground shaking is a major design consideration for above-ground sections of pipelines.

The seismic response of buried pipelines is strongly influenced by large, permanent soil displacements. Shaking does not cause serious stresses in straight buried pipelines except near the epicentre or in zones of strong seismic amplification. Bends and tees are more vulnerable.

F.2 Procedure

If justified by the seismic activity in the area, it can be necessary to quantify seismic hazards.

The principal phases of a seismic hazard analysis are illustrated in Figure F.1.

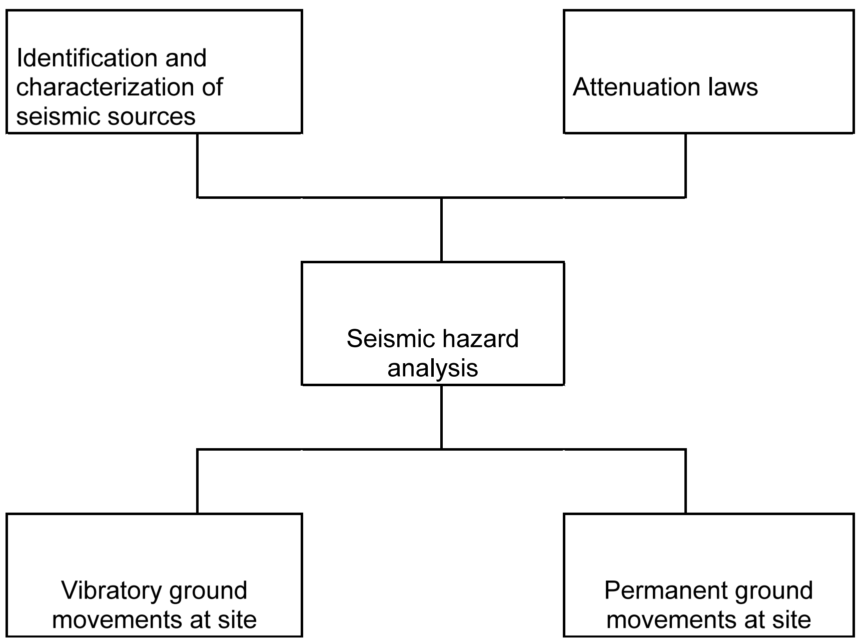

Figure F.1 - Seismic hazard analysis

The identification and characterization of potential seismic sources in the neighbourhood of a site involve both geological and seismological investigations and historical seismic data analysis.

Information on the characteristics of seismic sources, the geological and geotechnical conditions and site-to-source attenuation should be integrated into probabilistic or deterministic models to obtain the measures of seismic intensity at site (see literature [1]).

F.3 Strength calculation

F.3.1 Vibratory ground motion (shaking)

Depending on the type of analysis, the following approaches can be used for defining seismic input criteria (see literature [2] and [3]):

– **response spectra:** These give the probability of various levels of ground motion being exceeded in given periods of time.
– **seismic regionalization maps:** These provide representative intensities of shaking for the response under consideration, based on their seismological and geological characteristics.
– **ground motion time histories:** These are used for the analysis. More than one time history should be used, whether real or synthetic. They should be representative of the shaking expected to occur at the site and should have the same overall intensity and frequency contents.

Three basic methods are available for seismic response analysis of above-ground pipelines and related facilities (see literature [2]):

– a quasistatic (code type) load approach;
– a modal response spectrum approach;
– a time history analysis.

If an above-ground pipeline extends over relatively long distances, the spatial variation of incident seismic waves should be considered. Different support points along the pipeline will be subjected to excitations that differ both in amplitude and phase.

Two analyses should be carried out for pipeline bridges:

– design of bridges to resist the effects of earthquake;
– design of the pipeline in a manner similar to that for above-ground supported pipelines.

For a buried pipeline, the restraint and damping characteristics of the surrounding soil mean that dynamic amplification does not play an important role in the seismic response of the pipe. The seismic loading can therefore be considered as a pseudostatic load.

The effects induced on a buried pipeline by the seismic elastic deformation wave can be evaluated using simplified analytical approaches or numerical methods (see literature [2], [3] and [4]). The selection of appropriate modelling should be made on the basis of the type and importance of the pipeline being designed and the quality of the available and obtainable geotechnical data. Simplified methods are generally adequate in preliminary design. Where the results of this evaluation suggest that special precautions will be required to ensure acceptable performance or where the pipeline is too important or too complex, the more rigorous analyses should be considered.

Straight buried pipelines can be considered as rigidly bonded to the surrounding soil; there is no relative displacement between the pipe and soil so that both have the same strains, i.e. the “free field” deformations of the soil (see literature [3]). In soft soil, where the pipe is very stiff in relation to it, the above approach can lead to a very conservative design and an analysis of pipe/soil interaction is important. Pipe/soil interaction should also be considered in the analysis of buried pipelines with bends and tees. In no case should the stresses/strains in accordance with 7.4 be exceeded.

F.3.2 Permanent ground movement

Permanent ground effects on buried pipelines are evaluated by:

– locating areas of geotechnical hazard;
– estimating the likely soil displacement patterns;
– determining pipeline stresses and strains by means of models of pipe/soil interaction.

The analysis of pipe/soil interaction requires a procedure that can account for the non-linear behaviour of the surrounding soil mass, large displacement effects and inelastic pipe behaviour.

Analytical procedures for straight geometry of pipes are presented in literature [2], [4] and [5]. Where the pipeline configuration is complex (for example, three-dimensional), finite-element computer analysis is a useful technique. The pipeline is idealized as a beam (see literature [2]) or as a shell (see literature [6]). Pipe/soil interaction is modelled by simplified methods.

The predicted displacement should not lead to stresses/strains in the pipe which exceed the values in accordance with 7.4.

F.3.3 Possible action to prevent the allowable/limit values being exceeded

During the design process, the engineer should consider the following recommendations to prevent the allowable/limit values being exceeded:

For above-ground pipelines:

– provide ductility at the joints and connections.

For buried pipelines:

– avoid crossing soils which could cause strong amplification of seismic waves and horizontal discontinuity from firm to soft soil;
– place the pipeline in an oversized trench surrounded by loose to medium-dense cohesionless granular backfill;
– reduce the interface frictional resistance between soil and pipe;
– select a pipe alignment at a fault crossing such that compression is avoided;
– do not locate potential anchoring elements (tees, sharp bends, flanges) within the anchoring areas on either side of the fault zones.

F.4 Literature

[1] Cornell: “Engineering seismic risk analysis”, Bulletin of the Seismological Society of America, vol. 58, 1968.
[2] Committee on Gas and Liquid Fuel Pipelines: “Guidelines for the seismic design of oil and gas systems”, ASCE, New York, 1984.
[3] St. John, Zahrah: “A seismic design of underground structures”, Tunnelling and Underground Space Technology, vol. 2, no. 2, 1987.
[4] O'Rourke, Grigoriu, Khater: “Seismic response of buried pipelines”, Pressure vessel and piping technology, A decade of progress, 1985.
[5] L.R.L. Wang, Y.H. Yeh: “A refined seismic analysis and design of buried pipeline for fault movement”, EESD, vol. 12, pp. 75-96, January/February 1985.
[6] Tawfik, O'Rourke: “Analysis of pipelines under large soil deformation”, Cornell Geotechnical Engineering, Ithaca, New York, 1986.
[7] M. Aiqbal, E.D. Goodling Jr.: “Seismic design of buried piping”, 2nd ASCE Special Conference on Structural Design of Nuclear Plant Facilities, New Orleans, December 1974.
[8] N.M. Newmark: “Pipeline design to resist large fault displacements”, Proceedings of the 1st USNCEE, EERJ, Oakland, California, 1975.
[9] R.P. Kennedy, Chow, Williamson: “Fault movement effects on buried oil pipelines”, Transportation Eng. Journal of ASCE, vol. 103, no. TE5, 1977.
[10] R.P. Kennedy, A.C. Darrow, S.A. Short: “General considerations for seismic design of oil pipeline systems”, ASCE, CSKLEG, Los Angeles, 1977.
[11] Toki, Fukumori, Sako, Tsubakimoto: “Recommended practice for earthquake-resistant design of high-pressure gas pipelines”, International Symposium on Pipeline Earthquake Engineering. 4th Congress on Pressure Vessel and Piping Technology, Portland, Oregon, June 19-24, 1983, edited by Teoman Ariman, University of Tulsa, ASME.
[12] Saito, Nishio, Katayama: “Recommended practice for earthquake-resistant design of medium and low-pressure gas pipelines”, Earthquake behaviour and safety of oil and gas storage facilities, buried pipelines and equipment, vol. 77, 1983.
[13] C.L. Taylor, L.S. Cluff: “Fault displacement and ground deformation associated with surface faulting”, ASCE, CSKLEG, Los Angeles, 1977.

[14] S. Takada: “Earthquake-resistant design of underground pipelines”, New Delhi, 1977.
[15] J.B. Berril: “Building over faults: a procedure for evaluating risk”, EESD, vol. 11, no. 3, pp. 427-436, May/June 1983.
[16] A.S. Kiremidjian: “Reliability of structures subjected to differential fault slip”, EESD, vol. 12, no. 5, pp. 603-618, September/October 1984.
[17] J.A. Whitelaw, D.W. Reppond: “Design for buried pipeline can reduce seismic hazards”, Oil & Gas Journal, pp. 62-70, October 17, 1988.
[18] Hindy, Novak: “Earthquake response of underground pipelines”, Earthquake Engineering and Structural Dynamics, vol. 7, 1979.
[19] N. Nishio, A. Hamura, T. Sase: “Effect of ground conditions on seismic deformation in buried pipelines”, 1989 International Gas Research Conference.

Annex G (informative)

Extended elastic and limit state design

G.1 Procedure

Generally speaking, only the limit state of stress and alternating yield are taken into account in the extended elastic design. In the limit state design all limit states have to be considered.

In the stress and strain calculations in extended elastic and limit state design, calculation loads are used which are based on the characteristic loads.

Characteristic values for the loads are values for which the probability of their being exceeded is less than about 5 %.

EXAMPLE 1 Internal pressure, soil loads, differential settlement, thermal loads.

Characteristic values for the material properties of the pipeline are values for which the probability of the actual values being less than the characteristic values is less than about 5 %.

EXAMPLE 2 Yield strength, tensile strength.

Characteristic values for soil engineering parameters are obtained by multiplying or dividing the mean values by the contingency factors given in Table G.1.

The characteristic loads are then be multiplied by the load factors given in Table G.2 to obtain the calculation loads.

G.2 Limit states, limit values and assessment

G.2.1 General

The calculation loads are used to calculate stresses, strains and other values for the various limit states. These calculated values should not exceed the limit values associated with the relevant limit states given in G.2.4. For pipelines the term “limit state” can be defined as: “a limit state is a condition in which the pipeline can be considered unserviceable or unsafe”.

The following fundamental limit states can be distinguished:

– limit state for fracture;
– limit state for deformation.

For practical and design considerations, the fundamental limit state for fracture has been broken down into related limit states (in G.2.4 a), b), c), d) and e)). The limit state for deformation is discussed in G.2.4 f) and g).

G.2.2 Assessment criteria for analysis based on elasticity theory

Where the analysis is based on elasticity theory, the limit state for stress is generally the deciding factor in the assessment. The specified minimum yield stress at the design temperature ($R_{t\,0,5}(\theta)$) is taken as the limit value for stress.

In certain cases, however, the other limit states can also play a role and in principle all the limit states referred to in G.2.4 should be included in the assessment.

G.2.3 Assessment criteria for analysis based on limit state theory

Where the analysis is based on the limit state theory, the stresses, strains and other values should be calculated for all the limit states referred to in G.2.4. These calculated values should not exceed the limit values set forth in G.2.5.

G.2.4 Relevant limit states

The relevant limit states are (see also 7.4.2.2):

a) **stress:** The limit state in which the limit stress is exceeded.
b) **strain:** The limit state in which the limit strain is exceeded.
c) **alternating yield:** The limit state in which the variations in the strains due to cyclic loads are so great that plastic deformation occurs on each load reversal (plastic fatigue).
d) **fatigue:** The limit state for fracture due to cyclic loading over time.
e) **resonance and vortex shedding:** The limit state for excessive excursions by the pipeline or its component parts.

These excursions arise when the frequency of excitation coincides with the pipeline's natural frequency.

For pipeline sections which are locally unsupported by soil and exposed to waves and currents, a study should be made of the possibilities of vibration due to vortex shedding and other instability phenomena.

f) **deformation:** The limit state for excessive deformation, taking the form for example of excessive ovality, local buckling, implosion or overall flexural buckling of the pipeline.
Generally speaking, excessive deformations of this kind will occur in the plastic range and therefore consist chiefly of plastic deformations. Situations can arise, however, in which excessive elastic deformations occur that have a deleterious effect on safety.

EXAMPLE The seizure of close-tolerance moving parts (valves) and distortion of flanges which impairs their integrity.

g) **displacement/lateral stability.**

G.2.5 Limit values

The limit values given in the following apply to the assessment of results obtained with elasticity theory, assuming that the steel can undergo some plastic deformation, and results given by limit state theory. In cases where a limit value depends on the theoretical approach employed, this is indicated.

a) **stress:** The limit value for hoop stress is equal to $R_{t\,0,5}(\theta)$. The formula for the hoop stress is given below:

$$\sigma = \frac{p_c D_g}{20 T_{min}}$$

where:

σ	is the hoop stress, in newtons per square millimetre (N/mm^2);
p_c	is the calculation pressure (design pressure times load factor), in bar;
D_g	is the mean diameter of pipe, in millimetres (mm);
D_g	is $D - T_{min}$ if D is preset;
D_g	is $D_i + T_{min}$ if D_i is preset;
D	is the outside diameter in accordance with EN 10208-2, in millimetres (mm);
D_i	is the inside diameter, in millimetres (mm);
T_{min}	is the minimum wall thickness, in millimetres (mm)

NOTE The wall thickness to be specified in accordance with EN 10208-2 is the calculated minimum wall thickness plus the specified under wall thickness tolerance.

In bi-axial or tri-axial systems, the limit value for the resultant stress, calculated in accordance with Huber-Hencky and Von Mises or the shear stress hypothesis, is also equal to $R_{t\,0,5}(\theta)$.

At elevated operating temperatures, the following yield strength values apply:

up to 60 °C	$R_{t\,0,5}(\theta) = R_{t\,0,5}$
over 60 °C	the value of the specified minimum yield strength has to be corrected for the temperature.

To allow for the effect of plastic reserve where the analysis is based on elasticity theory, the stress correction factors in accordance with Table G.5 can be applied in the assessment of the limit state for stress.

b) **strain:** If the transmission pipeline analysis is based on elasticity theory or uses the stress correction factors (extended elastic method), strain need not be considered.

If it can be demonstrated that the actual strain capacity is greater than 0,5 %, this higher value may be used as the limit value. In determining strain capacity, due account should be taken of the ductility of the plate material and welds and any imperfections which they can contain.

NOTE For the assessment of the limit state for fracture, reference is made to the following literature:

General:

[1] PD 6493: 1991 “Guidance on methods for assessing the acceptability of flaws in fusion-welded structures”, British Standards Institution.

Pipeline-orientated literature:

[2] S.J. Garwood, A.A. Willoughby, P. Rietjens: “The application of CTOD methods for safety assessment in ductile pipeline steels”, Conference on Fitness-for-Purpose Validation of Welded Constructions, November 1981, London.

[3] J. Spiekhout: “Fitness-for-Purpose Assessment of Weld Flaws - Application of Various Fracture Mechanics Codes”, Welding Journal, September 1988.

The results of recent research can be used in the assessment.

c) **alternating yield:** The limit value for alternating yield is dictated by the condition that the stress variations should fit within the yield ellipse (Huber-Hencky and Von Mises yield criterion).

The shear stress hypothesis can also be used for alternating yield, as follows: the limit value for half of the variation of the maximum difference between any two of the three principal stresses during a load cycle is $R_{t\,0,5}(\theta)$.

d) **fatigue:** Results of recent research should be applied for fatigue analysis.

e) **resonance and vortex shedding:** The natural frequency of the pipeline is compared against the range of excitation frequencies.

Oscillation can be avoided by designing the pipeline so that the fundamental frequency lies outside the band of excitation frequencies and higher order vibrations (harmonics) are avoided.

f) **deformation:** Four types of deformation can be distinguished: ovality, flexural buckling, implosion and local buckling.

NOTE For the limit values, reference is made to:

A.M. Gresnigt: “Plastic design of buried steel pipelines in settlement areas”, HERON, Volume 31, no. 4, 1986.

g) **displacement/lateral stability:** The pipeline should be supported, anchored or buried such that, under all possible conditions, the pipeline will not move with respect to its installed position except for permitted displacement due to pressure loads, thermal loads and displacements expected after installation.

If an underwater pipeline is not buried, covered or anchored, the pipeline's own weight under all conditions, whether empty, filled with medium or filled with test medium, should be such as to guarantee horizontal and vertical stability, both during construction and in the operating phase.

G.2.6 Contingency, load and stress correction factors

For the contingency factors for soil engineering parameters, see Table G.1.

Table G.1 - Contingency factors for soil engineering parameters referred to mean value

Parameter	Factors
Neutral earth pressure	1,1
Passive earth pressure	1,1
Lateral modulus of subgrade reaction (k_l) – for sand and clay – for peat	 1,3 1,4
Ultimate bearing capacity – for sand and clay – for peat	 1,2 1,5
Horizontal passive earth pressure (contact angle = 180 °) and horizontal neutral soil resistance (contact angle = 120 °) – for sand – for clay – for peat	 1,2[a] 1,4 1,5
Soil friction	1,4
Relative displacement required for maximum soil friction (frictional elasticity)	1,4
Frictional bedding constant (k_w)	1,7[b]

[a] These contingency factors are partly based on current pipelaying practice.

[b] Soil friction (w) and displacement δ together give the frictional bedding constant $k_w = w/\delta$ for which the contingency factor is 1,7.

The soil engineering parameters refer to mean values. Depending on the situation, the soil engineering parameters are multiplied or divided by the factor. Essentially, this means that the critical combinations high/high, high/low, low/high and low/low of k_l and k_w are determined. In most cases, it is only necessary to calculate the high/high combination, except for small diameters. The combinations high/low or low/high are physical impossibilities.

For load factors as a function of load type, see Table G.2.

Table G.2 - Loads, partial load factors

Characteristic loads	**Load factors**		
	Construction phase	**Operational phase**	
	pipeline sections stations	pipeline sections	stations
Internal pressure			
– permanent		1,39	1,50
– incidental		1,21	1,30
External pressure	1,10	1,39	1,50
Self weight – pipeline components – coating (for corrosion, weight, insulation) – contents – buoyancy	1,10	1,50	
Soil loads[1) 2)]	1,50	1,50	
Traffic loads	1,50	1,50	
Temperature variations	1,25	1,25	
Imposed deformation			
– differential settlement – trench floor irregularities – deformation during horizontal directional drilling – towing-out crossings	1,10	1,50	
– elastic bends	1,10	1,50	
Meteorological loads			
– wind – snow – icing, thawing, ice break-up frost heave	1,10	1,20	
Construction loads	1,10		
NOTE 1 Soil loads determined in advance, applying contingency factors in accordance with Table G.1. NOTE 2 The load factor for the modulus of subgrade reaction and frictional bedding constant is 1,0.			

Table G.3 – Combining stresses to obtain resultant stress for extended elastic design

Stress category	State of stress	Associated resultant stress to be assessed (see Table G.5)
Primary membrane stress	Σpm	σ_{v1}
Primary bending stress	Σpb	[a]
Secondary membrane stress	Σsm	[a]
Secondary bending stress	Σsb	[a]
Total primary stress	Σpm + Σpb	σ_{v2}
Total membrane stress	Σpm + Σsm	σ_{v3}
Resultant of primary and secondary stresses, excl. peak stress	Σr = Σpm + Σpb + Σsm + Σsb	σ_{v4}
Secondary peak stress	Σsa	[b]
Total stress	Σt = Σr + Σsa	[b]

[a] These states of stress have no individual significance in assessment under elasticity theory.

[b] These states of stress are relevant only to assessment of the limit state for fatigue.

For straight pipe and smooth bends, they need not be investigated separately if the fatigue check according to G.2.5d is carried out.

Table G.4 indicates the categories which play a dominant role in the evaluation process for a number of commonly occurring situations.

Table G.5 outlines the procedure for assessing the extended elastic design.

Stresses acting on the same point at the same time and in the same direction can generally be combined.

The composite stresses and the resultant stress σ_v derived from them are obtained by combining the stress categories (Table G.3).

In order to take account of the possible redistribution of stresses due to the plastic reserve of the material, the resultant stresses calculated by elasticity theory are divided by stress correction factors when assessing them against the limit state values (Table G.5).

Table G.4 - Categorization and qualification of stresses related to originating load component and criteria

Load	**Criteria and pipe/soil interaction**	**Pipeline section**	**Stresses**		
			cat.	axial	tang.
Internal/external pressure		straight bend	p p	m m+b	m m+b[a]
Self-weight pressure	Does not follow soil settlement or trench profile or free span	straight bend	p p	m+(b) m+b	b b[a]
	Follows soil settlement or trench profile	straight bend	s s	m+(b) m+b	b b[a]
Soil loads (directly transmitted)	Follows soil settlement or trench profile	straight bend	p p	(b) (b)	b b
Traffic loads (directly transmitted)		straight bend	p p	(b) (b)	b b
Temperature variations		straight bend	s s	m m+b	n/a b[a]
Imposed deformation: – diff. settlement – trench irregularities	Does not follow soil settlement or trench profile or free span	straight bend	p p	m+(b) m+b	b b[a]
	Follows soil settlement or trench profile	straight bend	s s	m+(b) m+(b)	b b
– elastic bends		straight	s	m+(b)	b
Meteorological loads	Follows trench profile	straight bend	s s	m+(b) m+b	b b[a]
	Free span	straight bend	p p	m+(b) m+b	b b[a]

NOTE 1 The components between brackets under the heading “axial” are components generated by the restraint of lateral contraction by tangential bending.

NOTE 2 Stress concentrations at discrete supports are not included in the above table.

[a] This table refers only to the relevant stresses. For detailed explanation and analysis of stresses at bends, reference is made to ASME Boiler and Pressure Vessel Code, section III, division I, subsection NB.

Table G.5 - Assessment of limit states for extended elastic analysis, stress correction factors

Calculation loads	= Characteristic load x partial load factor (see Table G.2)
Calculation	- Ring calculation --> hoop stress (σ_p) - Beam calculation[a] --> forces and moments
Calculation stresses	Stress combinations and resultant stresses (see Table G.3)

Assessment

Resultant stress	**Stress correction factor**	**Limit stress**
σ_p (hoop stress)	1,0	$R_{t\,0,5}(\theta)$
σ_{v1} (pm)	1,0	
σ_{v2} (pm + pb)	1,5	
σ_{v3} (pm + sm)	1,5	
σ_{v4} (pm + pb + sm + sb)	1,5	

[a] Beam calculation can be based on the specified wall thickness according to EN 10208-2 instead of minimum wall thickness.

$R_{t\,0,5}$ specified minimum yield strength at 20 °C

$R_{t\,0,5}(\theta)$ minimum yield strength at θ °C

Annex H (informative)

Soil mechanics parameters

H.1 Parameters

Depending on the scope of the analysis, different soil engineering parameters can be relevant:

a) analysis of loads on the pipeline due to ground (at rest conditions):
   - neutral vertical earth pressure;
   - neutral horizontal earth pressure.

   These loads act upon the pipe when there is no movement between the pipe and the surrounding soil or when the movements in vertical and horizontal directions are disregarded.

b) analysis of interaction between pipe and surrounding soil:
   - passive vertical earth pressure;
   - ultimate vertical bearing capacity;
   - ultimate horizontal bearing capacity;
   - active horizontal earth pressure;
   - maximum friction resistance;
   - soil stiffness.

   There is interaction (exchange of actions) between the pipeline and the surrounding soil when the pipeline offers resistance, even if only slight, to ground movements or when the pipeline moves due to the effects of the loads imposed on it.

Neutral vertical earth pressure: This is equal to the weight of the vertical column of soil above the pipe (see literature [1]).

Neutral horizontal earth pressure: This is equal to the neutral vertical earth pressure multiplied by the coefficient of earth pressure at rest (see literature [1]).

Passive vertical earth pressure: This load acts on the top of the pipeline if it is unable to follow vertical downward movements of the surrounding mass of soil or is only able to follow such movements partially.

This is also the upper limit of resistance for upward movement of the pipeline (see literature [2], [3] and [4] for sands and literature [5] for clays).

Ultimate vertical bearing capacity: This is the upper limit of resistance to downward pipeline movement and is the load needed to cause the soil under the pipeline to fail over the full pipeline width (see literature [6]).

Ultimate horizontal bearing capacity: As soon as the pipeline moves horizontally, at right angles to its axis, the lateral earth pressure changes from the neutral earth pressure to the upper limit of lateral horizontal soil resistance. This is the load needed to cause the soil lateral to the pipeline to fail over the full pipeline width (see literature [7] for sands and literature [5] for clays).

Consolidated sand will give this reaction, but with compressible soils the increase in horizontal stress in the soil will initiate a consolidation process which will virtually cancel out the initial action/reaction. The upper limit of horizontal earth pressure is determined by the horizontal ultimate bearing capacity.

EXAMPLE Clay and peat

Active horizontal earth pressure: This is the minimum earth pressure when the buried pipeline moves away from the earth pressure (see literature [1]).

Maximum frictional resistance: This is the upper limit resistance for axial displacement or rotation of the pipeline in the soil (see literature [5], [8] and [9]).

Soil stiffness: This is the reaction of the soil to displacement of the pipeline (modulus of subgrade reaction). It can be regarded as the tangent modulus of the force displacement diagram (see literature [10] and [11]). (The modulus of subgrade reaction is a function principally of the modulus of elasticity of the soil and the pipeline diameter.)

H.2 Soil engineering study

The purpose of the soil engineering study is to determine the properties of the soil which are relevant to the strength analysis. Allowance should be made for various sources of uncertainty.

Two principal sources of uncertainty are:

– The fact that the examinations are carried out at a limited number of points along the pipeline axis and the soil properties between these points can be different;
– The fact that soil analysis involves deriving the soil mechanics parameters required for pipeline analysis from the results of penetration tests and soil samples. The sampling procedure and the models used for this purpose should make allowance for the uncertainties which are introduced.

The results of the soil engineering study should therefore be regarded as mean values. In reality, the soil engineering parameters can be greater or smaller than those obtained from the soil engineering study. Since the pipeline analysis has to be based on characteristic values for loads and material properties, the mean soil engineering parameters should be multiplied or divided by contingency factors to arrive at these characteristic values (see Table G.1).

The soil engineering report should clearly state whether these contingency factors have been taken into account.

H.3 Literature

[1] Terzaghi:“Fundamentals of soil mechanics”, John Wiley and Sons, New York, 1966.
[2] Clarke: “Buried pipelines”, McLaren and Sons, London, 1967.
[3] M.G. Spangler: “Soil Engineering”, International Textbook Company, Scranton, 1951.
[4] Trautmann, O'Rourke, Kulhawy: “Uplift force-displacement response of buried pipe”, Journal of Geotechnical Engineering, vol. III, no. 9, September 1985.
[5] ASCE: “Guidelines for the seismic design of oil and gas pipelines”, New York, 1984.
[6] J. Brinch Hansen “A revised and extended formula for bearing capacity”, Bulletin No. 28, Danish Geotechnical Institute, pp. 5-11, Copenhagen, 1970.
[7] Trautmann, O'Rourke: “Lateral force-displacement response of buried pipe”, Journal of Geotechnical Engineering, vol. III, no. 9, September 1985.
[8] J.G. Potyondy: “Skin friction between various soils and construction materials”, Géotechnique X1, no. 4.
[9] I. Littleton: “An experimental study of the adhesion between clay and steel”, Journal of Terramechanics, vol. 13, no. 4.
[10] Audibert, Nymann: “Soil restraint against horizontal motion of pipes”, Journal of the Geotechnical Engineering Division, ASCE, vol. 103, no. GT10, October 1977.
[11] Thomas: “Discussion of soil restraint against horizontal motion of pipes”, Journal of the Geotechnical Engineering Division, ASCE, vol. 10, no. GT 9, September 1978.
[12] S. Timoshenko and J.N. Goodier: “Theory of elasticity”, McGraw-Hill.
[13] B.B. Broms: “Coefficient of lateral subgrade reaction”, Journal of the Soil Mechanics and Foundation Division, ASCE, September 1963 and March 1964.
[14] J. Brinch Hansen: “The ultimate resistance of rigid piles against transversal forces”, Danish Geotechnical Institute, Bulletin 12, Copenhagen, 1961.
[15] A. Kêzdi: “Erddrucktheorien”, Springer Verlag, 1962.
[16] Vesic: “Breakout resistance of objects embedded in ocean bottom”, Journal of the Soil Mechanics and Foundations Division, ASCE, vol. 97, no. SM9, September 1971.
[17] Rowe, Davis: “The behaviour of anchor plates in sand”, Géotechnique, vol. 32, no. 1, March 1982.
[18] Ovesen: “Anchor slab calculation methods and model tests”, Danish Geotechnical Institute, Bulletin 16, Copenhagen, 1964.
[19] Matyas, Davis: “Prediction of the vertical earth loads on rigid pipes”, Journal of the Geotechnical Engineering Division, ASCE, vol. 109, no. 2, February 1983.
[20] H.J.A.M. Hergarden, A.H. Rol: “Grondonderzoek gedrag buisleiding in klei - Onderzoek uitgevoerd te Kesteren in 1984 (Behaviour of pipelines in clay - tests carried out in Kesteren 1984)” (in Dutch), Report CO-272040/75, Delft Geotechnics.
[21] Selvadurai, Lee, Todeschini, Somes: “Lateral soil resistance in pipe/soil interaction”, Proceedings of the Conference on Pipelines in Adverse Environments II, ASCE, edited by M.B. Pickell, San Diego, California, 1983.

Annex I (informative)

Bored/jacked crossings

I.1 General

Important aspects to be considered when selecting the boring method (for boring methods, see "Trenchless crossings" in clause 9; further information can be found in literature [1]) are:

- the excavation of the working pits;
- well pointing for dewatering;
- possible seepage along the pipeline section;
- geotechnical situation at the location of the crossing;
- the required accuracy of installation;
- allowable surface settlement or heave from construction of the crossing;
- environmental aspects.

The allowable mud pressure in relation to cover for boring methods which use drilling mud for jetting the soil and removing and transporting the cuttings should be calculated in accordance with literature [2].

I.2 Strength calculation

I.2.1 Horizontal directional drilling

The following phases should be analyzed in the pipeline design process:

a) **predisposition of the launching catenary:** Before the pulling operation, the pipeline is outside the borehole and has a configuration which allows it to enter the hole. During this phase, the only bending moment is due to the curvature of the catenary and the weight.
The pipeline should be designed so that it behaves elastically.

b) **pull-back operation:** In this phase the pipeline will be pulled back through the borehole.
The following forces should be considered:
- bending moment due to curvature of the hole;
- friction force between the pipe and drilling mud;
- friction force inside the hole, at the location where the soil reaction occurs;
- stress due to soil reaction.

The resultant stress should be calculated and the pipeline designed to behave elastically.

c) **operating conditions:** In this phase the loads acting on the pipeline are:
- bending moment due to curvature of the hole;
- internal pressure of the gas;
- temperature difference of the line between the pipelaying and operating conditions;
- dead loads (see 7.3.1);
  Vertical soil load at the top of the pipe can be calculated for different pipe laying conditions (see literature [3] and [4]);
- live loads (see 7.3.1);
  Vertical soil load at the top of the pipe can be computed by means of Boussinesq and Newmark analysis (see literature [5]). Impact factors should be included.

The following effects should be combined for the purposes of calculating the resultant stress:

- calculated longitudinal effects on the entire pipeline system;
- calculated effects on the cross-section of the pipeline.

The stress/strain values given in 7.4 should not be exceeded.

The effects of soil load on the cross-section of the pipe can be obtained by means of the following analysis. This analysis should be carried out at the deepest point reached in drilling.

The maximum bending moment on the pipe wall (bottom) due to vertical soil load is:

$$M_Q = 0{,}069qD^2$$

where:

M_Q	is a bending moment, in newton millimetres (N mm);
q	is the vertical load at the top of the pipe due to dead and live loads, in newtons per square millimetre (N/mm^2);
D	is the outside pipe diameter in accordance with EN 10208-2, in millimetres (mm).

The elastic bending of the pipe inside the hole causes a reaction by the soil q_r. The maximum bending moment on the pipe wall (bottom) due to soil is:

$$M_{Qr} = 0{,}041\, q_r\, D^2$$

$$q_r = yK_o$$

in which:

$$y = \frac{0{,}322M\lambda^2}{K_o D}$$

$$M = \frac{EI}{R}$$

$$\lambda^4 = \frac{K_o D}{4EI} (\text{mm}^{-4})$$

where:

q_r	is the soil reaction, in newtons per square millimetre (N/mm^2);
K_o	is the modulus of subgrade reaction, in newtons per cubic millimetre (N/mm^3);
R	is the bending radius, in millimetres (mm);
I	is the moment of inertia, in millimetres to the power of four (mm^4);
E	is the modulus of elasticity, in newtons per square millimetre (N/mm^2).

If arching plays a part (in general for soil depths greater than 8B_1, but this can also be the case at lesser depths), the assumption of neutral soil load is conservative. In such cases, the vertical soil load can be reduced as follows (see literature [4], [6], [7] and [8]):

$$q = \frac{B_1(\gamma' - c / B_1)}{K \tan\phi}\left(1 - \mathrm{e}^{-Kh \tan\phi / B_1}\right)$$

where:

$$B_1 = 0{,}5D + D \tan(45° - 0{,}5\phi) \geq r$$

where:

q	is the reduced vertical soil load on the pipe, in newtons per square millimetre (N/mm^2);
D	is the outside pipe diameter, in millimetres (mm);
r	is the hole radius, in millimetres (mm);
K	is the coefficient of horizontal earth pressure (K = 1 - sin φ);
h	is the depth of the hole below the surface, in millimetres (mm);
c	is the cohesion, in newtons per square millimetre (if $c > B_1\gamma'$, use $c = B_1\gamma'$);
φ	is the angle of shearing resistance, in degrees;
γ'	is the effective unit weight of the soil, in newtons per cubic millimetre (N/mm^3).

In compressible soils such as peat and soft clay, the formula is valid only for the situation immediately after construction. The initially vertical shear stresses (positive friction), which reduce the vertical soil load on the pipe, decrease due to settlement (consolidation) of the adjacent soil columns, caused by the same (here negative) friction.

The maximum mobilizable positive/negative friction follows from:

$$F_{max} = (h\gamma' - q)2B_1$$

The uncorrected actually mobilized friction is:

$$F_{ru} = \frac{F_{max}}{1 + \dfrac{B_1(3H - 2h)\alpha}{2CH\left(\dfrac{F_{max}}{2B_1 k_v} + \delta_d\right)}}$$

where:

H	is the thickness of the compressible soil stratum, in millimetres (mm);
α	is a dimensionless factor: $\alpha = \ln (h/h_{ref})$ with $h_{ref} = 1$ m;
C	is the compression index;
k_v	is the modulus of subgrade reaction of the bentonite/soil mixture after stiffening, in newtons per cubic millimetre (N/mm^3);
δ_d	is the relative displacement between soil columns required for full development of friction, in millimeters (mm)

The correction factor is: $f_c = 0,9$.

The corrected (actually) mobilized friction follows from: $F_r = F_{ru} f_c$.

The resulting soil load after consolidation is:

$$q = \frac{(h\gamma' 2B_1 - F_r)}{2B_1}$$

The horizontal support pressure is:

$$q_h = \left[\tan^2(45° - 0,5\,\phi)q - 2c\,\tan(45° - 0,5\,\phi)\right]\sin 60°$$

where:

q_h is the horizontal support pressure, in newtons per square millimetre (Nmm^2).

This horizontal support pressure is relevant only for the situation without internal pressure.

Other methods for reducing the vertical soil load can be derived from literature [6].

I.2.2 Jacked/bored crossings

The following phases should be analyzed in the design process:

a) **pushing operations:** During this phase, the pipe (or casing) is pushed into the ground.
The loads acting are:
- pushing force;
- any bending moment due to curvature of the hole.

b) **laying conditions:** The pipe (casing) should be designed to withstand the superimposed loads:
- design pressure and design temperature;
- dead loads;
- live loads;
- any bending moment due to curvature of the hole.

If the criteria for settlement areas given in Annex B (under B.4.2) are not met, the calculation should be performed taking into account the construction settlements at the ends of the boring as referred to in Annex B under B.3. The angle of support for borings can be taken as 120°. For casings, see also 7.8.

I.3 Literature

[1] D. Stein, K. Möllers, R. Bielecki: “Microtunnelling”, Erst & Sohn, Berlin, 1989.
[2] H.J. Luger, H.J.A.M. Hergarden: “Directional drilling in soft soil: Influence of mud pressures”, No-Dig 88.
[3] Clarke: “Buried pipelines”, McLaren and Sons, London, 1967.
[4] K. Terzaghi: “Theoretical soil mechanics”, pp. 194-202, 2nd edition 1944.
[5] Taylor: “Fundamentals of soil mechanics”, John Wiley and Sons, New York, 1948.
[6] Giovanni Falchi Delitala: “Calcolo dei rivestimenti delle gallerie (Calcul des revêtements de tunnels)”, Vitali & Ghianda, Genova, 1982.
[7] P. Meyers: “Review of a calculation method for earth pressure on pipelines installed by directional drilling”, Report CO-341850/4, Delft Geotechnics, March 1993.
[8] P. Meyers, R.A.J. de Kock: “A calculation method for earth pressure on directionally drilled pipelines”, Pipeline technology conference, Ostend, 1995.

Annex J (informative)

Allowable pulsation and vibration levels

J.1 Introduction

Pipeline damage is often due to cyclic stresses caused by gas pressure pulsations and vibrations. During the design phase the pulsation and vibration sources should be taken into account in order to investigate and calculate or predict the pulsation and vibration levels. These investigations and calculations are in general very complicated, but nowadays computer programs and simulation techniques are available to solve this problem. There are also some generally accepted rules that can help the engineer to avoid the occurrence of the most severe pulsation and vibration phenomena.

J.2 Pulsations

J.2.1 General

Pulsations are caused by turbulent flow phenomena, compressors and pressure-reduction devices.

A very important dynamic flow phenomenon is the “flow-induced pulsation”. Design rules for pipeline systems to avoid these types of pulsation should be derived from literature [1], [2] and [3].

Compressors (especially reciprocating compressors) should be designed such that the pulsation levels are kept below a certain limit. To this end, dynamic simulation studies are usually carried out.

J.2.2 Allowable pulsation levels

J.2.2.1 Safety

Formulae for allowable pulsation levels are given in literature [4] and [8].

J.2.2.2 Gas flow metering

Formulae for orifice meter errors due to flow pulsations are given in, for example, literature [9] and [10].

Formulae for turbine meter errors due to flow pulsations can be derived from literature [11], [12] and [13].

J.3 Pipe vibrations

J.3.1 General

Severe problems arise when the mechanical “eigen” frequency of a pipe system is equal or very close to the excitation frequency, caused for example by reciprocating compressors and flow-induced pulsations. The “self-sustained” frequencies of simple pipe systems with simple supports should be calculated from standard formulae (literature [7]). For more complex systems, computer programs, usually based on finite-element methods, can be used to determine the “self-sustained” frequencies and the vibration levels.

J.3.2 Criteria for vibration levels

Vibration criteria derived from field measurements are given in literature [4]. Literature [5] and [6] should also be consulted.

J.4 Induced effects

In the case of buried pipelines, possible side-effects are liquefaction or compaction of sandy soils.

J.5 Literature

[1] J.C. Bruggeman, A. Hirschberg, M.E.H. van Dongen, A.P.J. Wijnands, J. Gorter: “Self-sustained aero-acoustic pulsations in gas transport systems: experimental study of the influence of closed side branches”, Journal of Sound and Vibration (1991), 1503, pp. 371-393.
[2] J. Gorter: “Flow-induced pulsations in gas transport systems”, International Gas Research Conference, Tokyo, Japan, 6-9 November 1989.
[3] J.C. Bruggeman: “Flow-induced pulsations in pipe systems”, Thesis, Eindhoven University, Netherlands, 26 June 1987.
[4] W.W. von Nimitz: “Reliability and performance assurance in the design of reciprocating compressor and pump installations”, Proceedings of the 1974 Purdue Compressor Technology Conference.
[5] J.A. Wachel and W.W. von Nimitz: “Ensuring the reliability of subsea gas compression systems”, Journal of Petroleum Technology, November 1981.
[6] J.C. Wachel and C.L. Bates: “Techniques for controlling piping vibrations and failures”, ASME publication 76-Pet-18.
[7] J.P. den Hartog: “Mechanical vibrations”, McGraw-Hill Book Company, 1956.
[8] “Reciprocating compressors for general refinery services”, API Standard 618; third edition, February 1986.
[9] C.R. Sparks: “A study of pulsation effects on orifice metering of compressible flow”, Proceedings of ASME Flow Measurement Symposium, September 1966.
[10] V.P. Head: “A practical pulsation threshold for flowmeters”, Transactions of ASME, vol. 1472, October 1956.
[11] J.A. Bonner: “Pulsation effects on turbine meters”, Pipe Line Industry, March 1977.
[12] A. Haalman: “Pulsation errors in turbine flowmeters”, Control Engineering, May 1965.
[13] R.J. Mckee: “Detection of pulsation effects in turbine meter gas flow measurements”, International Gas Research Conference, Orlando, Florida, November 1992.

Annex K (informative)

Allowable vibration levels from construction work - blasting

K.1 General

Work in the vicinity can have effects on the pipeline due to ground vibrations.

This work includes:

– piledriving;
– installation or extraction of sheetpile walls;
– use of explosives;
– use of vibrators for seismic survey.
– soil compaction by vibration (sand) or stamping (clay);
– blasting.

The effects can be:

– direct effects due to ground vibration;
– induced effects such as liquefaction or compaction of sandy soils or settlement of clay soils.

K.2 Procedure

Data on the type of work should be obtained which can be used in the analysis.

Geotechnical aspects should be considered.

NOTE In the case of loose fills with high water content liquefaction can be induced.

K.3 Strength calculation

The increase in longitudinal and circumferential stress due to the effects of vibration should be added to the stresses calculated in accordance with 7.4 (at the operating pressure). The condition of pipeline section should be given proper consideration in determining the allowable increase in stresses.

For explosives, the stresses can be calculated in accordance with literature [1].

For blasting in rock, see literature [2] and [3].

A specific criterion for a particular site can be developed on the basis of tests.

When conducting seismic surveys using shakers, low frequencies should be avoided (≤ 18 Hz).

If a detailed analysis is not made, the minimum distance between shakers and pipeline is 10 m. In the case of frozen soil or rock, a minimum distance of 10 m can be insufficient and should be determined by analysis (for example, the type of analysis referred to in Annex F) or by means of site tests (see, for example, literature [4]).

For piledriving, Figure K.1 should be used. The maximum allowable amplitude for the pipeline section under consideration is derived with the aid of Annex J, “Allowable pulsation and vibration levels”. Where smaller allowable distances are required, a site-specific criterion should be developed which takes into account the different soil layers and the difference in vibration amplitude between the soil itself and the pipeline section.

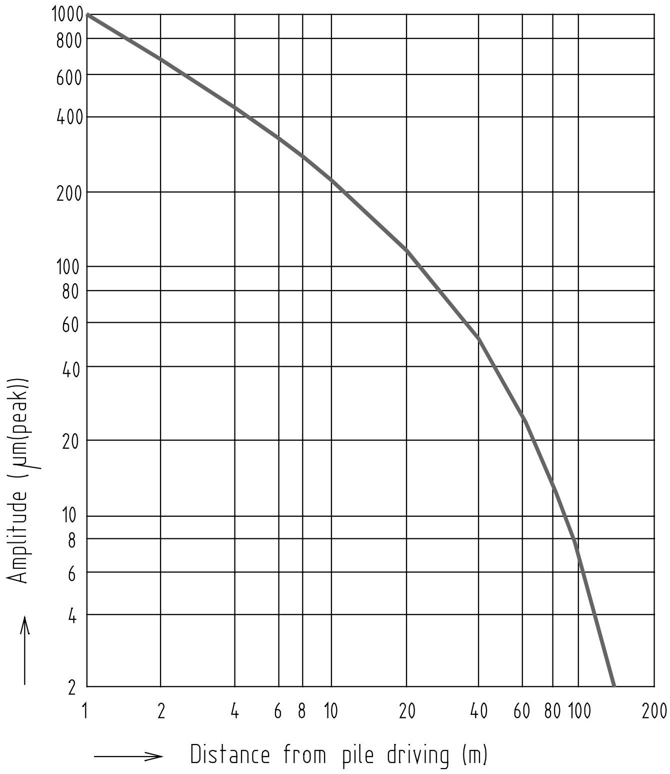

Figure K.1 – Allowable distance for pile driving

K.4 Literature

[1] E.D. Esparza, P.S. Westine, A.B. Wenzel: "Pipeline response to buried explosive detonations - Vol. 1 and Vol. 2", American Gas Association, Arlington (Va), USA, August 1981.

[2] E.D. Esparza: "Pipeline response to blasting in rock", AGA Project PR 15-712, American Gas Association, Arlington (VA), USA, September 1991.

[3] D.A. Clark: "Relationships between pipe stress, ground particle velocity and scale factors in blasting dolomite", 2nd Conference on Explos., Soc. Expl. Eng. - 1976, Louisville, USA

[4] G.P. Tschebotarioff: "Foundations, retaining and earth structures", Second Edition, McGraw-Hill Kogakuska (clause 15 "Soil vibrations and foundation design. Vibratory piledriving").

Annex L (informative)

Wall thickness calculation for tees and other openings

L.1 Introduction

This annex presents a method for calculating tees and other openings.

Other methods may be used provided there is a safety factor of at least 1,5 against significant general plastic strain.

EXAMPLE:

- Experimental determination of the design pressure from hydraulic proof test results.
- Finite-element computer modelling to calculate stresses and strains.

L.2 Wall thickness

The following equation should be used to calculate minimum wall thickness T_{min}:

$$T_{min} = \frac{DP \times D}{20 z \sigma}$$

where:

T_{min} is the minimum calculated wall thickness in millimeter (mm);
DP is the design pressure, in bar;
D is the outside diameter of the run, in millimetres (mm);
σ is the nominal design stress, in newtons per square millimetre (N/mm^2);
z is the strength reduction factor according to the equation:

$$z = \frac{D}{T_{min}} \times \frac{A}{2A_p + A}$$

where:

A_p is the area on which the pressure acts, in square millimetres (mm^2);
A is the reinforcement area according to the equation, in square millimetres (mm^2):

$$A = A_o + \frac{\sigma_1}{\sigma} A_1 + k \frac{\sigma_2}{\sigma} A_2$$

where:

A_o is the cross-sectional area of the material with a design stress at least equal to that of the run wall, in square millimetres (mm^2);
A_1 is the cross-sectional area of the material with a design stress σ_1 less than the design stress σ of the run wall, in square millimetres (mm^2);
A_2 is the cross-sectional area of additional reinforcing material with a reinforcement efficiency factor *k* and a design stress σ_2 (mm^2).

EXAMPLE For factor *k* see S. Schwaigerer: “Rohrleitungen - Theorie und Praxis”, Springer-Verlag 1967, page 330.

L.3 Stress limits

The stress limits should be as follows:

– σ, σ_1 and σ_2 should not exceed $0{,}67R_{t\,0,5}$ for the material under consideration (run wall, branch wall, reinforcement), where $R_{t\,0,5}$ is the specified minimum yield strength, in newtons per square millimetre (N/mm^2)
– σ_2/σ should be smaller than or equal to 1. The areas A_p and A are shown in Figure L.1. A can be calculated within the boundary lines indicated in this figure.

NOTE For irregular shapes, the areas can be determined by measurement (for example, planimetry). As the figure shows, the location of the boundary lines is determined by the diameter and wall thickness at the boundary lines.

Where wall thickness decreases, precise location of the boundary lines in Figure L.1 is possible only by trial and error. For the sake of simplicity, however, it will also suffice to determine the boundary lines on the basis of the minimum diameters and thicknesses of the wall and branch.

H and L mentioned in Figure L.1b) can be calculated with the following formulas:

$$H = 1{,}25\sqrt{T_2^*\left(D_{i2}^* + T_2^*\right)}$$

$$L = \sqrt{T^*\left(D_i^* + T^*\right)}$$

where:

H is the height for calculation purposes in millimetres (mm);
L is the length for calculation purposes in millimetres(mm);
T_2^* is the wall thickness of the branch in millimetres (mm);
$D_{i\,2}^*$ is the internal diameter of the branch in millimetres (mm);
T^* is the wall thickness of the run-pipe in millimetres (mm);
D_i^* is the internal diameter of the run-pipe in millimetres (mm).

L.4 Reinforcement

All the dimensions used for walls and reinforcements are “formula sizes”, i.e. dimensions in accordance with drawings or dimension tables less any fabrication allowances. The material of the reinforcement should be effectively bonded to the wall.

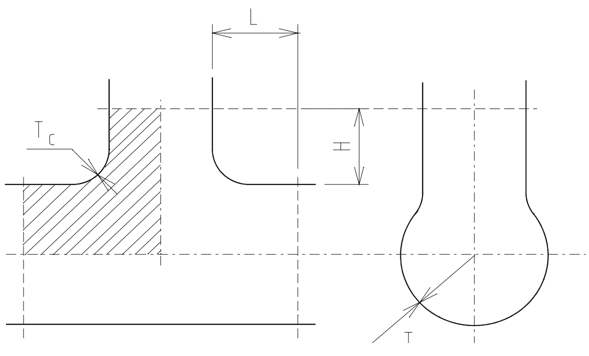

Figure L.1a)

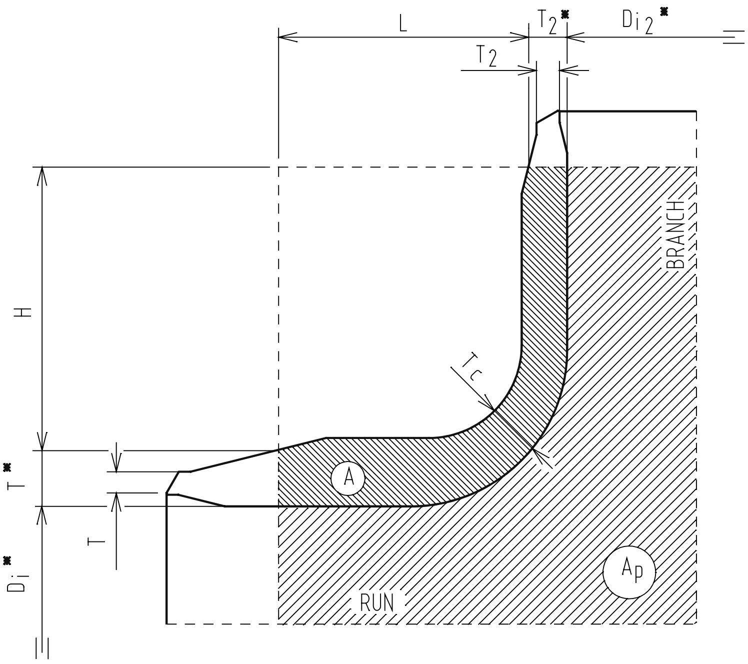

Figure L.1b)

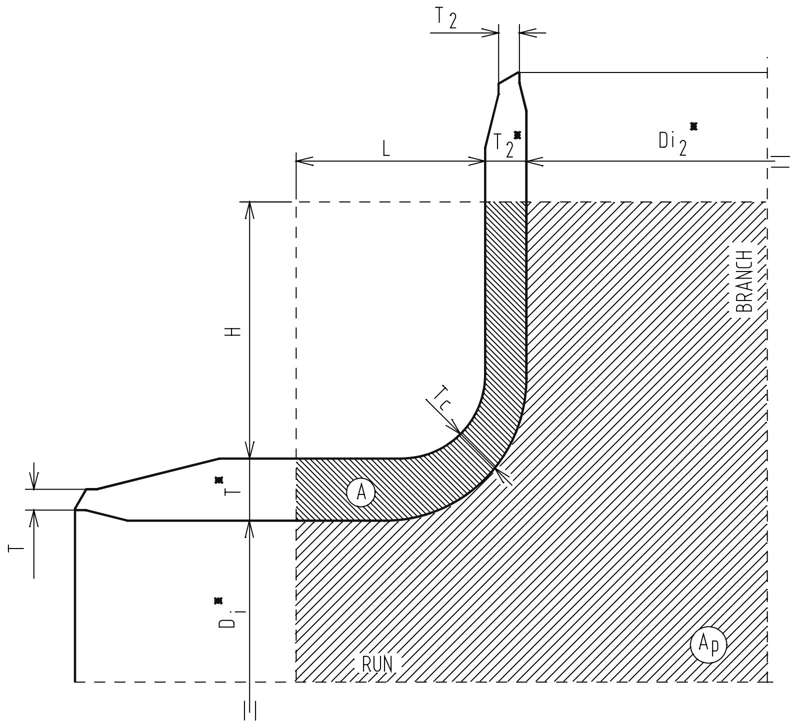

Figure L.1c)

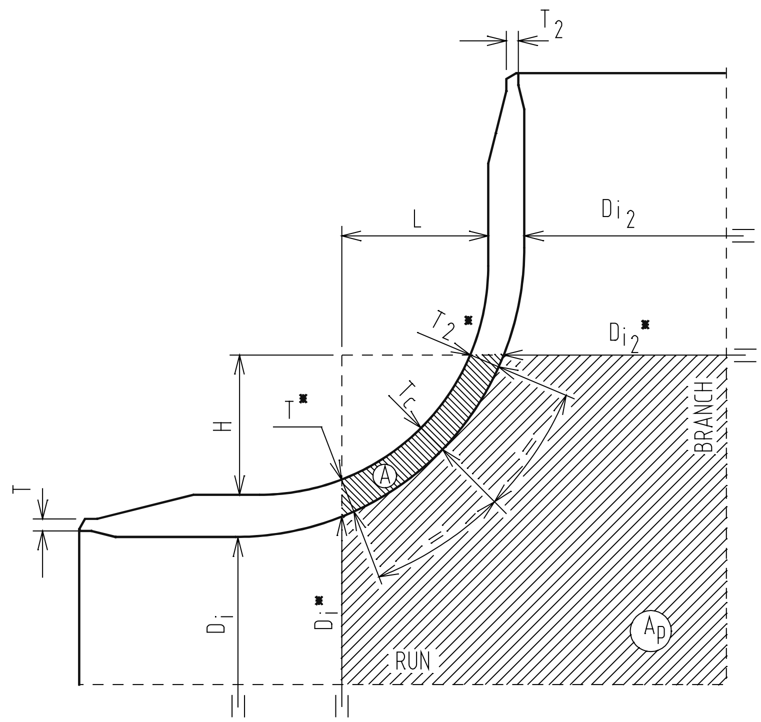

Figure L.1d)

Figure L.1 - Determination of *A* and A_p

Annex M (informative)

Wall thickness calculation for caps (domed ends)

M.1 Introduction

This annex presents a method for the calculation of caps (domed ends). Other methods may be used provided there is a safety factor of at least 1,5 against significant general strain

EXAMPLE:

- Experimental determination of the design pressure from hydraulic proof test results.
- Finite-element computer modelling to calculate stresses and strains.

For the determination of the wall thickness *T* of a semi-ellipsoidal end (hemispherical, torispherical and ellipsoidal ends with *T* smaller than or equal to 0,2*D* and r_{i1} greater than or equal to 0,05r_{i2}), the shape of an ellipsoidal cap is approximated by a torispherical end. The following inside diameter of knuckle is therefore used in the wall thickness equations for the knuckle and dish:

$$r_{i1} = \frac{1}{4}\left(D - 2T_{min}\right)\left[1 + k_1^2 - \left(1 - k_1\right)\sqrt{1 + k_1^2}\right]$$

where:

T_{min}	is the minimum calculated thickness after dishing, in millimetres;
D	is the outside diameter of the end, in millimetres;
r_{i1}	is the inside diameter of the knuckle, in millimetres.

$$r_{i2} = \frac{1}{4k_1}\left(D - 2T_{min}\right)\left[1 + k_1^2 - \left(1 - k_1\right)\sqrt{1 + k_1^2}\right]$$

where:

r_{i2} is the inside diameter of the dished central part, in millimetres in which (see Figure M.1):

$$k_1 = \frac{2\left(h_e - T_{min}\right)}{D - 2T_{min}}$$

where:

h_e is the outside head height, in millimetres.

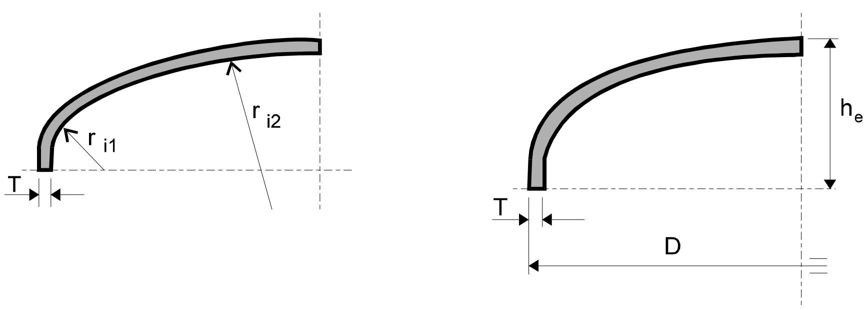

Figure M.1 - Knuckle and dish

M.2 Minimum wall thickness

The wall thickness at the knuckle and the dished central part should not be less than 4 mm. The dished central part should not be thinner than the required thickness of the knuckle, but may be thicker.

M.2.1 Calculation of wall thickness in the knuckle region for pressure loading

The minimum wall thickness T_{min} is calculated in accordance with the expression below:

$$T_{\min} = \frac{DP \times D \times C_1 \times C_2}{20 C_3 \sigma}$$

in which:

DP	is the design pressure, in bar;
σ	is the nominal design stress, in newtons per square millimetre (N/mm^2);
C_1	see the following;
C_2	see the following;
C_3	is the lower of $\sqrt{C_1}$ and 2: using for the design stress σ = $R_{t\,0,5}$ where: $R_{t\,0,5}$ is the specified minimum yield strength, in newtons per square millimetre (N/mm^2).

Factors C_1 and C_2 depend on the wall thickness (*T* is determined by trial and error).

$$\text{for } 0{,}05 \leq \frac{r_{i1}}{r_{i2}} \leq 0{,}30 : C_1 = 10^{1{,}125\left(1{,}6 - \lg 100 r_{i1}/r_{i2}\right)\left(1 - T/1{,}1 r_{i1}\right)}$$

EXAMPLE 1

$$\left.\begin{aligned} \frac{T}{r_{i1}} &= 0{,}30 \\ \frac{r_{i1}}{r_{i2}} &= 0{,}10 \end{aligned}\right] C_1 = 3{,}1$$

$$\text{for } 0{,}3 < \frac{r_{i1}}{r_{i2}} \leq 1 : C_1 = 10^{-0{,}264\left(0{,}68 + \left(2{,}3 - T/1{,}1 r_{i1}\right)\lg r_{i1}/r_{i2}\right)}$$

EXAMPLE 2

$$\left.\begin{aligned} \frac{T}{r_{i1}} &= 0{,}20 \\ \frac{r_{i1}}{r_{i2}} &= 0{,}50 \end{aligned}\right] C_1 = 0{,}975$$

$$C_2 = 1 + 0{,}306 \ \ln\left(1 + \frac{T}{r_{i1}}\right) + 0{,}1574 \ \ln^2\left(1 + \frac{T}{r_{i1}}\right)$$

M.2.2 Calculation of the wall thickness in the dished central part for pressure loading

The minimum wall thickness *T* is calculated in accordance with the following expression:

$$T_{\min} = \frac{2DP \times r_{i2}}{40\sigma - DP}$$

using for the design stress $\sigma = 0{,}67 R_{t\,0{,}5}$.

M.3 Explanation strength of the knuckle

Bending and peak stresses occur at and near the knuckle of a head, in addition to membrane stresses. The following conditions apply:

- the membrane stresses should be limited to prevent overall plastic deformation;
- it is acceptable for the combined membrane and bending stresses to exceed the yield stress once; this causes no overall deformation of the vessel and, by relieving stresses, produces a compensating residual stress system; the criterion is not therefore the absolute magnitude of the stress, but the stress range. If this is restricted to twice the yield stress, (local) plastic deformation will not occur more than once.

The stress range σ_e is determined by:

$$\sigma_e = \frac{DP \times D \times C_1 \times C_2}{20T}$$

Here membrane and bending stresses have been incorporated into C_1; the local peak stress has been incorporated into C_2.

At a low C_1, the membrane stress predominates and the first design condition is therefore decisive. At a high C_1, the bending stress predominates and the second condition is therefore decisive.

Combined, the design stress *f* is taken as follows:

$$\sigma = R_{t0{,}5}\sqrt{C_1} \leq 2R_{t0{,}5}$$

The values for C_1 in the above equation for the range indicated are based on the results of stress measurements on dished caps published in:

W.B. Carlson, J.D. McKean: “Cylindrical pressure vessels: stress systems in plain cylindrical shells and in plain and pierced drumheads”. Proceedings of the Institute of Mechanical Engineers, 169 (1955): 12, pp. 269-294.

In this range, the knuckle to dish transition is decisive.

For:

$$\frac{r_{i1}}{r_{i2}} = 1\left(\text{hemisphere}\right)$$

C_1 can be derived theoretically; here the transition to the adjoining (equally thick) part of the shell is decisive.

In the intermediate area:

$$0,30 < \frac{r_{i1}}{r_{i2}} < 1$$

no reliable values are known; it is clear that the course of C_1 will show a discontinuity where the transitions from knuckle to shell are equally decisive. As a safe approach, if no further data are known, this discontinuity is put at:

$$\frac{r_{i1}}{r_{i2}} = 0,30$$

The approximation of a semi-elliptical head by a dished head with knuckle is also based on stress measurements for axis ratio 2:2:1. It can also be assumed for other axis ratios that the approximation in the range *T*/*D* greater than 0,005 agrees sufficiently with fundamental stress calculations based on elasticity theory.

The stress concentration factor C_2 has been derived from the theory of sharply curved bars.

blank

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover. Tel: 020 8996 9000. Fax: 020 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: 020 8996 9001. Fax: 020 8996 7001.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre. Tel: 020 8996 7111. Fax: 020 8996 7048.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration. Tel: 020 8996 7002. Fax: 020 8996 7001.

Copyright

BSI
389 Chiswick High Road
London
W4 4AL