ISRAEL STANDARD SI 5664 PART 1 **תקן ישראלי ת"י 5664 חלק 1**

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NATURAL GAS TRANSMISSION PIPELINE SYSTEM: GENERAL

מערכת הולכת גז טבעי: כללי

Combined edition

The Standards Institution of Israel

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

This Standard excluding the modifications and additions indicated, is identical to the unofficial translation into the English language from November 2004 of the Dutch Standard NEN 3650-1 – 2003.

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

מילות מפתח:

צנרת גז, הספקת גז, גז טבעי, צנרת

Updating the Standard

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

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

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

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

Introduction to the Israeli Standard

This Israel Standard is the unofficial translation from November 2004 of the Dutch Standard NEN 3650-1-2003 approved in the English language as an Israel Standard with national deviations.

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

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

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

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

Foreword

The standard is divided into two parts. The first part includes general requirements for pipeline systems. The second part includes requirements specific to a steel pipeline.
Appendix A is not applicable. Appendices B, C, D, E, F and G are normative components of this standard. Appendices H, I, J, K and L are informative components of this standard.

Purpose of the Standard

The purpose of this Standard series is to obtain pipeline systems that are safe for people, the environment and property, by specifying requirements for the design, installation, operation and abandonment, for a durable, effective, and efficient system.
Deviation from the requirements of this standard is only possible, if it is approved by the authority having jurisdiction and provides an equivalent or higher level of safety.

Interface EN and ISO standards

Relative to the relevant EN standards for the pipeline-technical domain, this standard adds additional details for conditions in Israel.
Application of the stipulations of this standard, including references to EN 1594:2000 and ISO 13623:2000 means that the pipeline system is also in compliance with the stipulations of EN 1594:2000 and ISO 13623:2000.
Note: In case of contradiction between SI 5664 and any other standard mentioned herein, the requirements of SI 5664 will prevail.

Use of Standard

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

1 Subject and Scope

This standard specifies the safety requirements related to the safety of people, the environment and property, which are requirements for the design, installation, operation and abandonment of natural gas pipeline systems.

The requirements relate to pipeline systems for transport of natural gas both by land and by sea, and hold for newly built systems and for the modification of existing systems.

All work involving design, installation, operation, and termination shall be carried out by qualified persons. Application of a quality guarantee system, as per SI-ISO 9001 or SI-IS0 14001, is strongly recommended.

The Standard is applicable to transmission pipeline systems (see 3.2.16 and Figure 1):

Subclause a) and b) have been deleted.

The three notes hae been deleted and replaced by part of Note 1 only as follows:

NOTE Pipeline systems consist of pipelines and stations.

This Standard is also applicable for existing pipelines or systems with regard to:

- management of transmission pipeline systems;
- modification of design conditions (temperature, pressure).

This Standard has no requirements for:

- pipework of industrial installations connected to transmission pipeline systems, except for equipment which forms part of the (pressure) containment of the system.

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

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

Figure 1 provides a schematic of pipeline-(system)s subject to the standard.

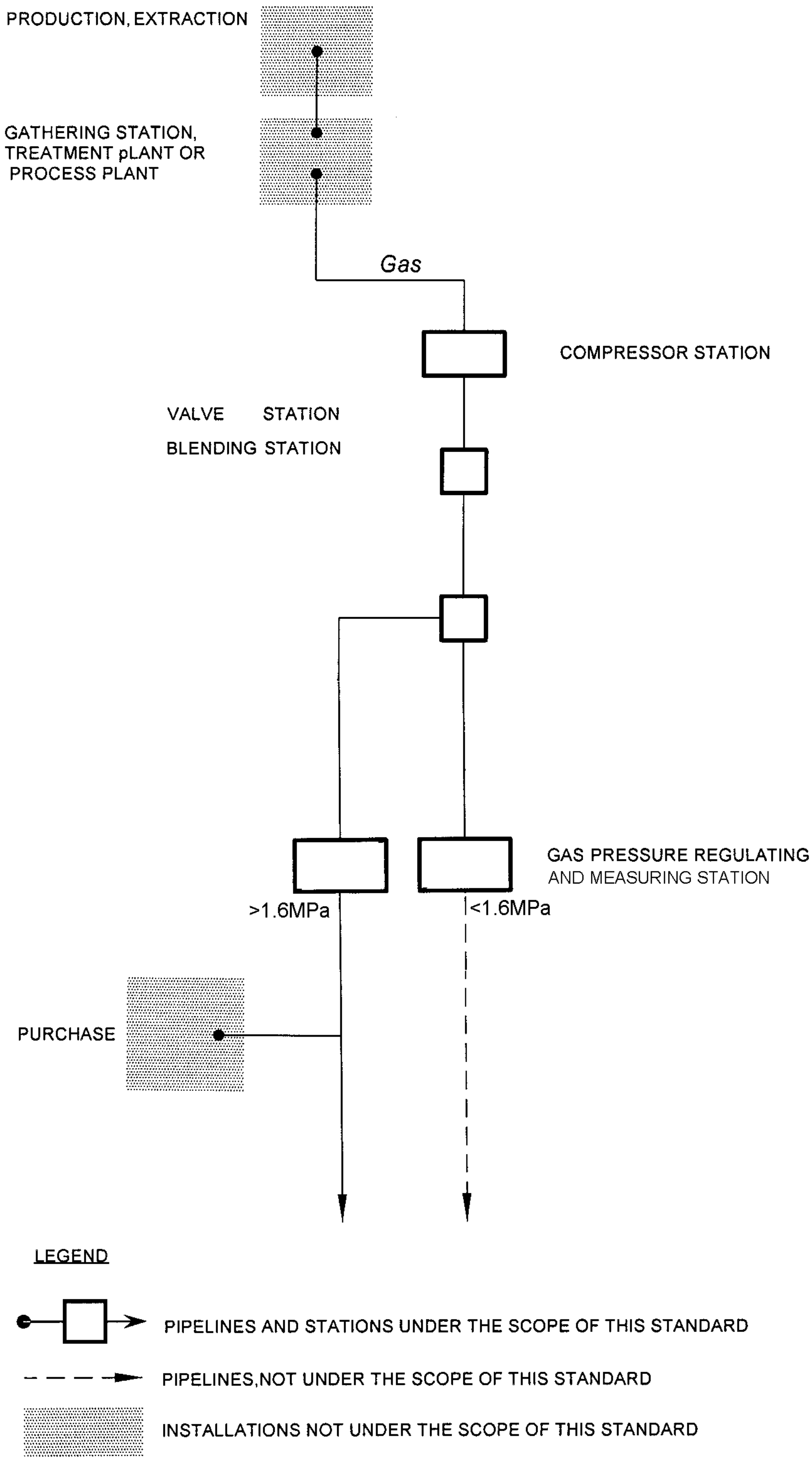


Figure 1 – Scope of Application of this Standard

2 Normative References

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

Israel Standards

SI 413-2	- Design provisions for earthquake resistance of structures[(1)]
SI 1173	– Lightning protection systems for buildings and installations
SI 3864-1	– Graphical symbols – Safety colors and safety signs[(2)]
SI 4489	- Process piping
SI 5664-2	– Natural gas transmission pipeline system – Additional requirements for steel pipeline
SI-ISO 9001: 2000	- Quality management systems – requirements
SI-ISO 14001: 2005	- Environmental management systems – Requirements with guidance for use
SI-ISO 14004: 2005	- Environmental management systems – General guidelines on the principles, systems and support techniques
SI 60079 (all parts)	- Electrical apparatus for explosive gas atmospheres

Israeli Laws

Israeli Electric Law – Code of Laws 164, 1.9.1954

International Standards

ISO 2394: 1998	– General principles of reliability for structures
ISO 3864-1	– Graphical symbols – Safety colours and safety signs – Part 1: Design principles for safety signs in workplaces and public areas
ISO 13623: 2000	– Petroleum and natural gas industries – Pipeline transportation systems
ISO 13686: 1998	- Natural gas – Quality designation

Regional Standards

EN 1594: 2000	– Gas supply systems – Pipelines for maximum operating pressure over 16 bar – functional requirements
EN 1991-2: 2003	– Eurocode 1: Actions on structures – Part 2: Traffic loads on bridges
EN 12186: 2000	– Gas supply systems – gas pressure regulating stations for gas transmission and distribution – Functional requirements
EN 12583: 2000	– Gas supply systems – Compressor Station – Functional requirements
EN 12889: 2000	- Trenchless construction and testing of drains and sewers

(1) SI 413-2 is currently being prepared. Until it is published, refer to the relevant requirements of the relevant statutory regulations.

(2) SI 3864-1 is currently being prepared. Until it is published, ISO 3864-1 applies.

EN 50110-1: 1996 – Operation of electrical installations

EN-IEC 61508-5: 2002 - Operating safety of electrically/electronically programmable electronic systems related to safety – Section 5: Examples of methods for determining levels of safety

National Standards

NEN 1059:1994 – Requirements for gas pressure regulating and measuring stations with an inlet pressure lower than 100 bar, along with the page of revisions NEN 1059/A1:1999

NEN 1059:2002 Draft – National explanatory note and supplement to NEN-EN 12186 and NEN-EN 12279 – Gas provision systems – gas pressure regulating stations for transport and distribution

NEN 2078 – Requirements for industrial gas installations

NPR 3659:1996/A1:2003 – Underground pipelines – Basis principles for strength calculations

NEN 6740:1991 – Geotechnical – TGB 1990 – Basic requirements and load

ANSI/ASME B 31.1: 2001 - Power piping

3 Terms and definitions

3.1 General

3.1.1
Installation Phase Pipeline System
the phase in which the delivery, transport, processing, connecting of pipes, laying, burying, testing and commissioning takes place

3.1.2
ALARA (As Low as Reasonably Achievable) principle
principle through which the best available technology is applied, and where all relevant (technical, economic, and social) concerns are taken into account and weighed against environmental concerns and external safety

3.1.3
Pipeline Corridor
a strip of land which is primarily used for installation of pipelines, if necessary provided with collective civil engineering work under government aegis

3.1.4
Pipeline Strip
a strip of land reserved for installation of pipelines, and as such included in the regional and municipal zone use plans.

3.1.5
Operational Phase of a Pipeline System
the phase after completion of the installation phase, regardless of whether the system is operational or not

3.1.6
External Safety
safety of persons in the vicinity of activities with hazardous substances

3.1.7 Hazardous Substances For The Environment (Pollution)
substances which, for example, pollute a ground-water protection zone, or brings about indirect damage as a result of causing dysfunction of a major public work

3.1.8 Substances Hazardous to People
substances when exposed to people can lead to injury or death

3.1.9
Group risk (GR)
the yearly probability that a sizeable group of people will die in one occurrence as a result of some unusual event relating to the pipeline

3.1.10
Incident
an unplanned, uncontrolled event which might have resulted, but did not result in fatalities, illness, wounding or other lesion
(EN 1594:Unexpected occurrence which could lead to an emergency situation)

3.1.11
Local Risk (PR)
the yearly probability that a person, continuously present at a certain locality, will die as a result of some unusual event relating to the pipeline

3.1.12
Pipeline Risk
combination of the probability and the consequences of release of the substance being transported

3.1.13
Environmental Protection
minimal probability of disturbing ecosystems, plants, animals, nature zones within the environment, and agricultural areas, aquifers and surface water for drinking water preparation, etc. but also the human experience of the natural environment

3.1.14
Safety of public works
safety of a public work relating to the consequences of system failure for groups of people and/or animals and damage to property

3.1.15
Natural gas
a mixture of gases, hydrocarbons or others, mainly methane (CH_4), in the gaseous state at a temperature of 15 °C and at atmospheric pressure (1.013 bar).

3.2 Pipeline Systems

3.2.1
Pipeline
string of pipes for the flow of gases, liquids or capsules, whose purpose is to transport a gas, a liquid or capsules, or a liquid used as a means to transport of heat or a dissolved or pulverized substance
EN 1594: System of pipe work, with all associated equipment and stations up to the point of deleivery. The pipe work is mainly below ground but includes also above ground parts
ISO 13623:Those facilities, through which fluids are conveyed, including pipe, pig traps, components and appurtenances, up to and including the isolating valves.

3.2.2
Above-Ground Pipeline
pipeline whose placement or configuration, except at a defined number of points, is not hindered by pipe or conduit and/or by structural units, or by the terrain around it.

3.2.3
Pipeline System
pipeline with all the parts of physical facilities through which gas is transported, including pipe, valves, fittings, flanges, regulators, pressure vessels, pulsation dampers, relief valves, flow meters, compressor/pumping

stations and other appurtenances attached to the pipe and fabricated assemblies and any other equipment or facility used in the transportation of gas.

3.2.4
Pipeline characteristics
pipeline flexibility characteristics :

- axially rigid: pipeline elements are longitudinally inflexibly connected; bending and torsional moment, axial force and cross-sectional force are transferred;

- articulated: elements of pipe are connected with flexible couplings which allow some translation and/or rotation;

- articulated, tension-resistant: elements of pipe are connected with flexible couplings resistant to tension; axial force is transferred;

- tangentially rigid: elements of pipe with high tangential rigidity (the effect of ovalization of the cross section on horizontal soil resistance is negligible);

- tangentially flexible: elements of pipe with low tangential rigidity (resulting in extra horizontal soil resistance through ovalization of the cross section).

3.2.5
Pipeline Elements
components of a pipeline system:

- straight pipe and bends made of this pipe by cold bending or induction bending;

- fittings (reducers, Tee's, factory made elbows, flanges, convex bottoms, welding studs, mechanical couplers, etc.);

- ancillary equipment (valves, expansion joints, transition piece with flexible joints, insulating couplings, safety apparatus, pressure regulators, pumps, compressors, filters, separators, etc.);

- structures (ISO: fabrications) (e.g., manifolds, "finger type" slug catchers, pigging stations, valve stations, gas measuring stations, control section, etc.)

3.2.6
Installation
arrangements and facilities for the extraction, production, (chemical) treatment, storage or intake of the substance to be transported
EN 1594: Equipment and facilities for extraction, production, chemical treatment, measurement , control, storage or take off of the transported gas

3.2.7
Pipeline Alignment
three dimensional configuration of the pipeline

NOTE The projection of the configuration can be both horizontal and vertical.

3.2.8
Location
the area, fenced in or not fenced in, in which one or more installations or stations are located

3.2.9
Casing
protective pipe around the pipe transporting the medium

3.2.10
Medium
the substance which is transported by the pipeline

3.2.11
Underground Pipeline
pipeline surrounded by soil.

3.2.12
Platform
structure for extraction and/or processing and/or transport of minerals including hydrocarbons and other related substances at sea

Note: Platform and riser for production or processing are not within the scope of this standard.

3.2.13
Station
facility, possibly including housing, for management of pipeline operations, such as:

- valve stations: containing valves;

- compressor- or pumping station; increasing the pressure of the medium (gas or liquid) in the pipeline;

- pigging station; launching and receiving “pigs’;

- measuring and/or regulating station; measuring and/or regulating the flow rate and/or the pressure in the pipeline;

- blending station; mixing the various streams of fluid;

- reducing station; lowering the pressure of the fluid in the pipeline

3.2.14
Riser
vertical section of the offshore pipeline between the section lying on the seabottom and the connection to the platform

Note: See note in 3.2.12.

3.2.15
Offshore Pipeline
pipeline lying in maritime waters and estuaries, seaward of the average high-water line

3.2.16
Pipeline transmission system

pipeline system for transmission of natural gas at a pressure of more than 16 bar, on land and off-shore and all related gas installations, up to the first isolation valve downstream of the PRMS connecting the distribution system or the customer’s system inside its premises.

3.3 Process and operation: Definitions and Concepts

3.3.1
Installation Temperature
temperature of the pipe (section) during installation, after which it can no longer be deformed without stress.
EN 1594:Temperature, arising from ambient or installation conditions during laying or during construction

NOTE The installation temperature is in some cases artificially increased (pre-tensioned) for pipe that will have to operate at high temperature.

3.3.2
Operating Pressure
internal pressure in a pipeline system, in order to bring about a certain throughput or buffer, or to maintain the same.
EN 1594: Pressure which occurs within a system under normal operating conditions

NOTE In general, this is internal pressure, necessary for the static pressure head, friction- and local losses, and eventual desired end-pressure.

3.3.3
Operating Temperature
temperature inside a pipeline system that is the result of the system's operation
EN 1594: Temperature which occurs within a systemunder normal operating conditions

3.3.4
Test Pressure
internal pressure in a pipeline system or a part of it, during a strength test or a tightness test
EN 1594:Pressute to which the gas supply system is subjected to ensure that it can be operated safely

3.3.5
Pressure
unless otherwise specified, pressure means gauge pressure
EN 1594:Gauge pressure of the fluid inside the system, measured in static conditions

3.3.6
Incidental Pressure
incidental increase of pressure above the design pressure, limited to the maximum allowable incidental pressure
EN 1594:Pressure which occurs incidentally within asystem at which a safety device becomes operative

3.3.7
Design Pressure and Design Temperature
internal pressure and temperature (high or low) which in combination determine the strength calculations
EN 1594: The pressure on which design calculations are based

NOTE The design pressure shall be greater than or equal to the maximum operating pressure.

3.3.8
Temperature range
the absolute value of the difference between the two extremes of temperature, occurring during a cycle, taking into account operational and environmental influences.

3.3.9
Cycle
transition from an arbitrary initial condition via the maximal (minimal) possible condition to the minimal (maximal) possible condition, and back again to the initial condition.

3.3.10
Maximum operating pressure
the maximum pressure at which the system can be operated continuously under normal conditions.
Note Normal conditions are: no fault in any device or stream.

4. Symbols

4.1 Mechanical variables

A	surface area of the pipeline cross-section	mm^2
D_e	outside diameter of the pipeline	mm
D_g	average diameter of the pipeline	mm

D_i	inside diameter of the pipeline	mm
$D_o = D_e + 2\,e$	outside diameter, plus the thickness of any eventual coating	mm
d	minimum wall thickness taking into account factory tolerances	mm
d_n	nominal thickness to be chosen or applied from the table of measurements	mm
e	thickness of the coating (corrosion coating, concrete wrapping, eventual marine accretions	mm
I or I_2	moment of inertia with respect to the neutral line	mm^4
I_p	polar moment of inertia	mm^4
I_w	moment of inertia of the pipeline wall	mm^4/mm
I_x	moment of inertia with respect to an arbitrary line	mm^4
R	radius of bend	mm
r_e	outside radius	mm
f_g	average radius	mm
r_i	inside radius	mm
W	resistance moment	mm^3
W_w	moment of resistance of the pipeline wall	mm^3/mm

4.2 Material variables

E	modulus of elasticity of the pipeline material (20 °C)	N/mm^2
$E\,(\theta)$	modulus of elasticity of the pipeline material at θ °C	N/mm^2
G	modulus of elasticity in shear	N/mm^2
α_g	linear expansion coefficient (average over temperature range)	mm/mm·K
θ, θ_t	temperature of the pipeline material	° C
υ	Poisson constant	-
ρ	weight per unit volume	kg/m^3

4.3 Process variables

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

4.4 Stress Variables

a	acceleration due to wave motion	m/s^2
C_m, C_d, C_1	mass-, drag- or lift- coefficient	-
f	load factor	-
f_{rr}	reduction factor following "rerounding" (straight pipe)	-
g	acceleration due to gravity	m/s^2
h	flexibility characteristic	-
i_x, i_j	stress intensification factor	-
i_{xp}, i_{yp}	stress intensification factor, including internal pressure	-
k, k_p	flexibility factor	-
K	tangential moment coefficient	-
$K\,(\alpha,\beta)$b of K_b	moment coefficient, bottom	-
$K\,(\alpha,\beta)$t of K_t	moment coefficient, top	-
$K\,(\alpha,\beta)$s of K_s	moment coefficient, side	-
$k\,(\alpha,\beta)$y of k_y	deflection coefficient, vertical	-
$k\,(\alpha,\beta)$x	deflection coefficient, horizontal	

M	moment	Nm
M_w	torsion moment	Nm
M_Q	tangential moment	Nm/mm^1
p_a	assess pressure	MPa
p_e	collapse pressure (limit value) related to the radial elastic stability	MPa
p_u	external hydrostatic pressure	MPa
p_p	collapse pressure (limit value) related to the radial plastic stability	MPa
p_t	strength test pressure	MPa
P_v	traffic load pressure on top of pipe	N/mm^2
Q_{dir}	top load, directly transmitted	N/mm^1
Q_{eg}	weight of the pipeline	N/mm^1
Q_{indir}	top load, indirectly transmitted	N/mm^1
Q_{op}	upward load (under water)	N/mm^1
Q_{vul}	load of the substance carried (fluid)	N/mm^1
Q_v	traffic load	N/mm^1
v	water velocity perpendicular to the pipeline, from waves and current.	m/s
α	loading angle	degrees
β	support angle	degrees
δ_y	vertical deflection	mm
σ_a	peak stress	N/mm^2
σ_b	bending stress	N/mm^2
σ_m	membrane stress	N/mm^2
σ_{ax}	axial membrane stress caused by temperature and/or internal pressure in case of prevented axial displacement	N/mm^2
σ_p	tangential stress caused by internal pressure (hoop stress)	N/mm^2
$\sigma_{p(bi)}$	hoop stress in the pipe wall at the inside of the bend	N/mm^2
$\sigma_{p(bu)}$	hoop stress in the pipe wall at the outside of the bend	N/mm^2
σ_{pi}	longitudinal stress caused by internal pressure	N/mm^2
σ_Q	tangential bending stress caused by top load	N/mm^2
σ_{tang}	total circumferential stress	N/mm^2

4.5 Soil parameters

B	bedding width of the pipeline	m
c	cohesion	N/m^2
c_u	undrained shear strength	N/m^2
dp, Δp	increase in vertical intergranular stress by increase or decrease of the water table	N/m^2
f_m	coefficient for calculating the soil load according to Marston	-
f_v	incremental subsidence due to installation activities	mm
H	soil cover	m
H_j	thickness of layer	m
K_q	load coefficient	-
$k_1(k_h, k_v)$	lateral modulus of sub grade reaction (horizontal or vertical)	N/mm^3
k_w	frictional modulus of sub grade reaction	N/mm^3
L	radius over which the subsidence increment reaches (field reach)	m
Q_n, q_n	neutral vertical earth pressure	N/mm^1, N/mm^2
Q_h, q_h	soil reaction horizontal	N/mm^1, N/mm^2
Q_k, q_k	actual soil load (during the consolidation process)	N/mm^1, N/mm^2
Q_r	soil reaction vertical	N/m^1
Q_z	settling load	N/m^1
Q_p, q_p	passive earth resistance (limit value)	N/mm^1, N/mm^2
w	soil friction	N/m^2
W	soil friction (per unit of length)	N/m^1
x	axial coordinate	m
y	lateral coordinate (horizontal)	m
z	lateral coordinate (vertical)	m

γ	contact angle horizontal soil resistance	degrees
γ	unit weight (density)of soil	N/m^3
γ_n	unit weight (density)of wet soil	N/m^3
γ_d	unit weight(density) of dry soil	N/m^3
γ_k	effective weight per unit volume of soil (corrected for groundwater table)	N/m^3
$\gamma_{k,j}$	effective weight per unit volume of soil layer (corrected for groundwater table	N/m^3
δ	friction angle between pipe coating and soil	degrees
φ	angle of internal friction	degrees
λ	pipe-soil stiffness characteristic	m^{-1}
λ_a	coefficient representing the relation between horizontal and vertical intergranular stress in active condition (soil moves towards the pipe)	-
λ_n	coefficient representing the relation between horizontal and vertical intergranular stress in neutral condition	-
λ_p	coefficient representing the relation between horizontal and vertical intergranular stress in passive condition (pipe is pressed against the soil, e.g., around bends)	-
ρ_w	unit weight of the water surrounding the pipe, or of the suspension in which the pipe is installed	kg/m^3
σ_h	horizontal intergranular stress at pipe level (centre of pipe)	N/m^2
σ_k	vertical intergranular stress at the top of pipe	N/m^2

5 Abbreviations

ALARA	"As Low as Reasonably Achievable"
CPR	Committee for Disaster Prevention
EV	External Safety
GFT	Closed Front Technique
GR	Group Risk
HDD	Horizontal Directional Drilling
HPSD	High Pressure Shut Down
LOC	Loss of Containment
MAOP	Maximal Allowable Operating Pressure of a system. ISO 13623:Maximum pressure at which a pipeline system or parts thereof, is allowed to be operated
MIP	Maximum Incidental Pressure
MOP	Maximum Operating Pressure of a system
OFT	Open Front Technique
PBT	Pneumatic Drilling Technique
PR	Local risk
ROW	Right of Way
SIL	Safety Integrity Level

6 Safety

6.1 General

6.1.1 Scope

This chapter deals with the requirements for the safety of onshore transmission pipeline systems. Requirements for offshore pipelines are listed in 11.2.

For operational safety, see also chapter 10.

6.1.2 Basic Principles

Each pipeline shall be so designed, installed and operated that, with regard to external safety, pollution of the environment and devaluation of property, and the safety of public works, the additional risk to the environment where the pipeline is placed, is considered acceptable.

The additional risk resulting from the presence of the pipeline shall comply with the safety level formulated in Section 6.2.

6.1.3 Safety aspects to be considered

The safety aspects which shall be considered are:

- external safety;

- preventing pollution of the environment;

- safety of public works.

6.1.4 Hazardous substances

Appendix A.1 deals with the classification of hazardous substances.

6.1.5 Safety requirements concerning minimum pipeline depth

Unless this Standard stipulates otherwise, underground pipe shall have a minimal soil cover on top of the pipe of 120 cm. See also 8.1.4.
If this minimal soil covering is not practically achievable, the pipe shall have additional protection against mechanical damage, e.g., by a casing or covering structure providing an equivalent degree of protection. Any form of additional protection shall be subjected to the client's approval.

6.2 Required Safety Level

6.2.1 External safety

The required safety level for external safety is formulated by means of the conceptions Local (individual) Risk and Group Risk and the set acceptance levels thereof.

Two sentences have been deleted.

6.2.2 Environment

All the relevant laws and regulations regarding environmental protection shall be taken into account.

6.2.3 Safety of public works

The required safety level is based upon the added probability of the dysfunction of relevant major public works caused by the presence of the pipeline. See also 6.5.

6.3 Safety Evaluation - External Safety

6.3.1 Scope and Purpose

It is mandatory to do a quantitative risk assessment (QRA) for stations in natural gas pipeline systems.
(QRA) is also required for "pipe only" sections of the pipeline, if:

- The safety requirements set forth in this standard or in SI 5664-2 are not achievable, or;
- changes in the environment immediately contiguous to the pipeline causes non-compliance with the safety requirements.

QRA consists of provisional selection and evaluation of route alternatives to find the safest possible route, and serves as a basis for the final choice of the route and, if necessary, for application of additional risk-reducing measures. For other aspects about choice of route and pipeline alignment, refer to 8.1 of this standard, and also chapter 6 and App. F in SI 5664-2.

6.3.2 Content of a quantitative risk assessment

The safety evaluation for external safety consists of the following components (see also Figure 3):

a) Determination the local iso-risk contours and the group risk curve, based upon:
   - (an analysis of) possible causes of failure and the probability of failure;
   - (an analysis of) the effect of the loss of containment on the environment where the station or pipeline is being installed or has been installed;

b) confronting the calculated risk contours with the environment where the station or pipeline is being installed or has been installed and assessing this against PR and GR criteria;

c) if necessary, revising the location of the station or its design, or the route of the pipeline, adopting risk-reduction measures and running another risk assessment.

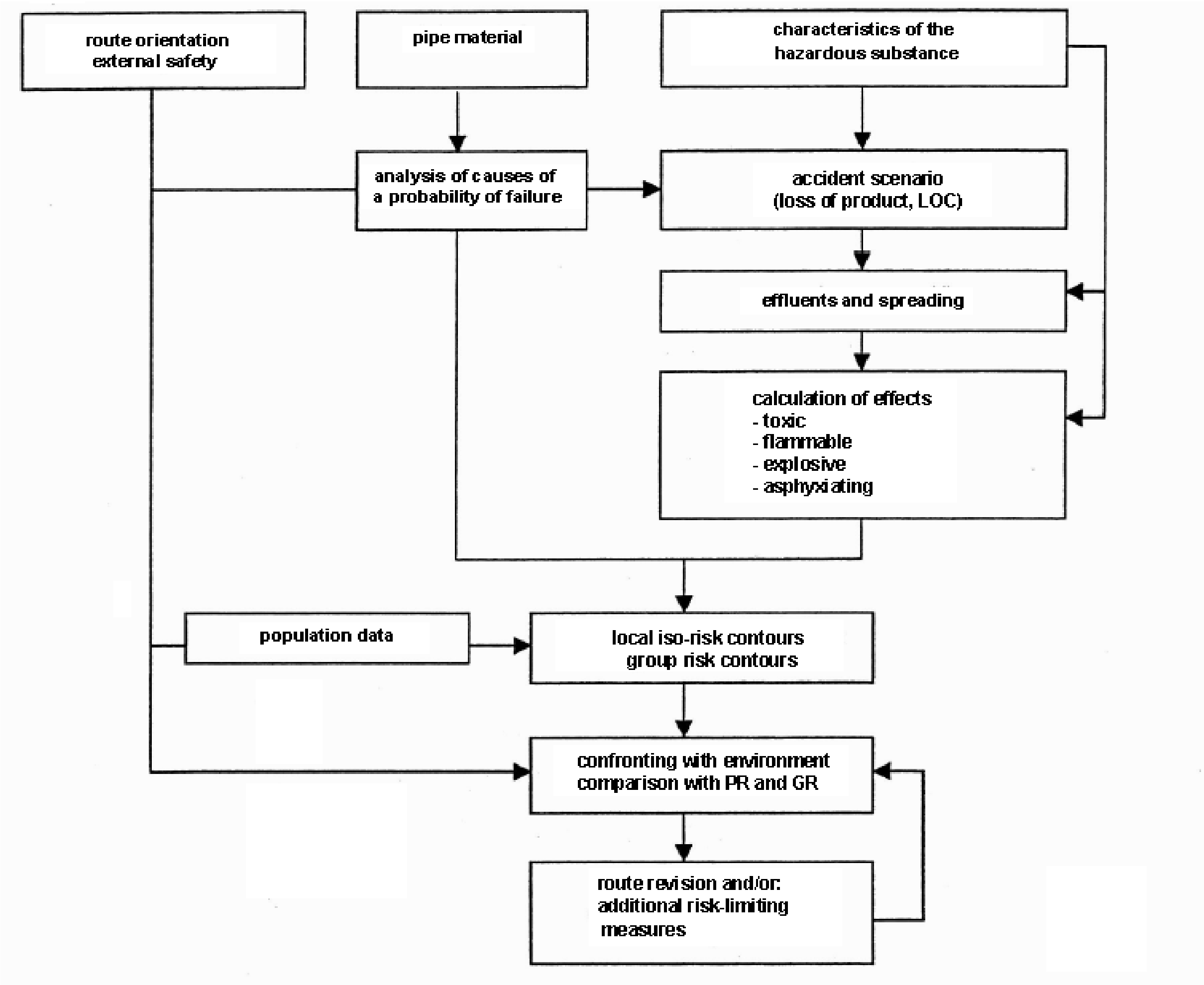


Figure 3 - Content And Scope Of Quantitative Risk Assessment

6.3.3 Causes of failure and determining the probability of failure

6.3.3.1 Causes of Failure

Potential causes of failure which shall be looked at are (in arbitrary order):

- structural faults (design and installation);

- operator faults (exceeding design specifications for pressure, temperature, and cycles);

- soil settlement - and subsidence differences;

- management faults (inspection, supervision and maintenance);

- damage by third parties (hitting the pipeline by mistake);

- time-dependent degradation of the material by surrounding influences (e.g., corrosion of metallic pipes, aging of plastic pipes, etc.);

- material faults (pipe material, connections, fittings, coating).

6.3.3.2 Quantifying the Probability of Failure

The analysis of the determination of the probability of failure shall be based upon statistical data that is as complete as possible, regarding comparable pipes and if possible, categorized into different causes of failure. Combined causes of failure, such as third party hits in corroded areas, need to be considered. When the data is being collected, the judgment and interpretation shall not merely take into consideration the incidents with loss of containment, but all incidents concerning hitting of the pipeline.

Failure probabilities for various categories of pipe can be taken from part 1 of CPR 18E [14].

The note has been deleted.

6.3.4 Quantifying the Effects of Loss of Containment

6.3.4.1 General

Hazards can occur from fire, explosion, poison, asphyxiation or a shock wave.

The amount of substance released is dependent upon, among other things, the internal pressure, the diameter, the properties of the hazardous substance, and the size of the rupture; the extent of the spread also depends upon meteorological circumstances. These parameters shall be taken into account (see Figure 3).

The calculation shall include at least the following:

- accident scenarios;

- rmode of escape of liquid or gas;

- the manner in which the released substance is dispersed;

- ignition mechanisms (direct or delayed) and probability of ignition;

- the consequences of exposure;

- criteria related to the injury of human beings.

This calculation shall be carried out with the help of recognized physical models, which describe and quantify, with the aid of the relevant parameters, the possible effects of the release. A sentence has been deleted.

For useful calculation methods, see also Part 1 of CPR 18E, Chapter 6. [14]

6.3.4.2 Accident Scenarios with Loss of Containment

CPR 18E [14] specifies (accident) scenarios for underground steel pipelines.

NOTE CPR 18E specifies the following scenarios:

- a leak from a hole with a diameter of 20 mm;

- pipeline rupture.

6.3.5 Determining Risk Contours

Local risk contours and group risk curves shall be determined, with the help of validated models and on the basis of risk probability analysis according to 6.3.3, and the calculation of the effect according to 6.3.4.

For calculating the Group Risk curve, the population density, expressed in persons per hectare, shall be available up to the 1% mortality-contour.

6.3.6 The environment - identifying problem areas.

6.3.6.1 General

The results of the risk calculations, presented as iso-risk lines on a topographical background, shall be compared with the results of the provisional route or site selection.

The pipeline or station satisfies the requirements of external safety if throughout the chosen route it satisfies the PR and GR requirements, or (if applicable) the condition that for that specific fluid, pipe material, process conditions and diameter of the pipe, the specified safety distances are satisfied (see SI 5664-2, Annex F).

For other conditions (group risks and/or local risks greater than the safety level established in 6.2) the route, site or station design shall be revised, or supplementary risk-reducing measures (compared to a pipeline which satisfies the technical requirements of this standard) shall be taken in accordance with 6.3.7.

These supplementary risk-reducing measures shall be adopted in the design and secured in the management- and maintenance procedures (see Chapter 10).

6.3.7 Risk-reducing measures

6.3.7.1 General

A risk-reducing measure is based upon one of two aspects of risk:

- the probability of failure; measures which limit the probability of pipe failure (leaks and release of the medium) ;

- the result or effect; measures which limit the consequences of release subsequent to a leak; also called mitigating measures.

These measures can be of a technical-structural, organizational or land-use-planning nature.

Table 1 gives an overview of measures for reducing the probability of failure and limiting the effects. The probability limiting measures, based upon the causes of failure which are applicable to every pipeline system, thus independently of the type of material, are dealt with here. Material-specific measures are dealt with in the relevant material parts of this standard.

Table 1 – Risk reducing and effect diminishing measures

Risk Reduction							
Probability Reduction (preventive)			**Effect Reduction (repressive)**				
Land-use planning	organizational	structural	Land-use planning	organizational	structural		
					structural provisions	quantitative reduction	reduce source strength
'safe' route or site choice distance to other pipes and objects	personnel training inspections preventive and/or situation-dependent maintenance stringent reporting and permit structure (e.g., lying in the pipeline corridors) To make pipeline location known via cable and pipeline information centers (KLIC)	increase in wall thickness for limiting mechanical damage by third parties make the pipe difficult to reach: - increase the depth - markers - relief plates/covering plates, concrete tiles; - screening off the sides (raised curbs, short sheet wall, hedge poles at grade); - casing application of high-strength external coating location in pipeline corridors advanced instrumentation, monitoring (pigging) coatings with high mechanical resistance (sintered PE); welding control by means of two independent methods of inspection; "tough" (high notch toughness) material; crack arrestors (reduction of crack propagation).	distance to dwellings (zoning)	alarm procedures emergency plan disaster fighting plan	shatterproof glass buildings pressure resistant (shockwave resistant) "tough" (high notch toughness) material; crack arrestors (reduction of crack propagation).	advanced instrumentation e.g., throughput or pressure measurements with fast closing valves. acoustic volumetric or optical leak detectors separation/ compartmentalization (shut off valves) thicker wall for limitation of crack initiation & propagation casing (removing, limiting or allocating of loss of containment)	low pressure transport
For the effect of deeper placement, see [29], [30] and [31].							

6.3.7.2 Risk reduction by limiting probability of failure

Structural measures

The most major structural measures to limit failure for a pipeline, are the prevention of, or limiting of the results of, mechanical damage caused by third parties (e.g., deep- plowing or drainage work) through:

- making the pipe wall of sufficient thickness, so that a scratch or dent will not rupture it;

- making it more difficult to reach the pipe, by burying it further down, protecting it, and/or placing warning signs.

Organizational measures

NOTE 1 Regarding organizational probability-lowering measures, it has been found that within a pipeline corridor or strip (the phrase in parentheses has been deleted) a stringent permit system, combined with a complex of management measures, has significantly reduced the probability of failure from mechanical damage by third parties.

In this situation a point of concern is the possible negative mutual affect of pipelines in a pipeline corridor, e.g., flooding by a failed water pipe or the effect of radiant heat from an oil or gas fire on the coating of adjacent pipelines.

NOTE 2 Another example of an organizational measure is the notification by pipeline owners or operators, via Cables and Pipelines Information Centers, of the location of their pipelines to parties intending to dig..

6.3.7.3 Risk reduction by limiting effects

6.3.7.3.1 Sectioning off the pipelines with valves

The quantity of medium released can in some cases be limited by applying extra valves in the pipeliness, or by using a material (e.g., liquid nitrogen) with which the medium is driven out of the problem segment. The application of extra valves, however, also creates new potential sources of faults (the valves themselves).

The effectiveness of sectioning off by valves has to be demonstrated in relation to the direct environmental risks. The potential increase on the probability of failure, that such valves would have as well as the achievable effect reduction, shall be closely examined.

Valves for sectioning off the pipeline will in any case be placed at the beginning and at the end of the pipeline. It shall be possible to bring the valves into action quickly. Moreover, for maintenance purposes they shall be easily accessible.

The beginning of the sentence has been deleted. The level differences of the terrain and the route of the pipeline shall be taken into account. Also to be taken into account is the speed of valve closing with respect to pressure surges

NOTE For further information on, in particular organizational, effect-limiting measures, see [32].

6.4 Environmental Impact Evaluation (land)

The clause has been deleted.

6.5 Safety of public works

6.5.1 General

This chapter outlines requirements for a better interaction between pipeline and major public works and other major infrastructure.
Special care shall be taken where installation and operation are being done in the vicinity of public works and other infrastructure [47].
When carrying out a risk evaluation of a major public work, risk (R) is defined as the product of the probability of failure (P) and the effects of the failure (E) where both (failure and effect) are brought linearly into the calculation (R = P x E).

6.5.2 Major public works

The following civil engineering structures are considered major public works:

- Primary road (e.g., highway, suburban highway and main road, as specified in the relevant statutory regulations);
- Secondary road (e.g., provincial road and local road, as specified in the relevant statutory regulations);
- Railway;
- Underground structures;
- High Tension Electricity (HTE) Installations.

6.5.3 Intersections with Major Public Works

A pipeline crossing a major public work should, except where opposed on technical, economic or urban planning grounds, run at right-angles to the longitudinal axis of the public work and cross it at a point where there are no ancillary structures, junctions or special features incorporated in it.

Varying degrees of additional protection from third party damage to a buried pipeline crossing within (or parallel to) the right-of-way of road or railroad may be achieved using the following techniques, or variants thereof, singly or in combination:

a) A physical barrier or marker may be installed above or around the pipe. Physical barrier or marker methods include:
   (1) a concrete or steel barrier placed above the pipe;
   (2) a concrete slab placed vertically adjacent to the pipe on each side and extending above the top of the pipe elevation;
   (3) damage-resistant coating material, such as concrete;
   (4) extra depth of the cover;
   (5) buried high-visibility warning tape placed parallel to and above the pipe;
   (6) pipe casing.
b) A heavier wall thickness than is required by the pipe design factor (see SI 5664-2 App. F).

Appropriate safety separation distances and other precautions must be maintained between the pipeline and existing cables or pipelines, to assure protection against damage during construction and operation.

6.5.4 Primary and Secondary Roads

The safe distance to be maintained while running in parallel to main and secondary roads is a minimum of 5 meters from the edge of the asphalt or the carriageway to the center of the pipeline.
In the case of secondary roads, the above mentioned distance may be reduced to a minimum of 1 meter in consultation with the body responsible for the road.
The safe vertical distance to be maintained while crossing or running under roads is a minimum of 0.8 meter measured from the bottom edge of the asphalt or the carriageway to the top of the pipeline, and 1.25 meters from the surface of the asphalt or the carriageway to the same.
When using concrete slab, a minimum distance of 0.1 meters shall be maintained between the slab and the surface of the pipeline.

6.5.5 Railways

The minimum distance to be maintained while running in parallel to above ground railways is 8 meters from the center line of the nearest railway to the center of the pipeline, and 6 meters from the toe of the embankment to the same.
In railway crossings, extra measures (e.g. casing, sleeves or concrete slab) are required.
The minimum vertical distance to be maintained while crossing a railway is 1.5 meters measured from the bottom edge of the railway to the top surface of the extra measure.

6.5.6 Underground Buried Structures

The minimum clearance to be maintained while running in parallel to other buried pipe laid simultaneously, pipe OD to pipe OD, is 0.4 meters.

In the case where the adjacent pipes are not laid simultaneously and the distance between them (pipe OD to pipe OD) is less than 5 m, then:

a) Coordination with the other pipe’s (or other underground structure) owner is required;

b) Appropriate protection measures regarding erosion, corrosion or other probable failure shall be applied.

In any case, the clearance between adjacent pipes shall not be less than 1 m. The minimum distance to be maintained from underground storage structures containing hazardous material is 5 meters.

6.5.7 High Voltage (HV) Installations

Refer to 6.4 in SI 5664-2.

7 Safeguarding of Process Conditions

7.1 General

7.1.1 System Requirements

The pipeline system shall be so designed, installed, operated and managed that during its life-cycle, it will comply with the required safety standards.

The system requirements shall be explicit, and documented in writing.

The intended life-cycle of system operation shall be firmly established.

7.1.2 Design conditions

When specifying design conditions, all normal and extreme process conditions and the relevant array of throughput velocities, pressures, temperatures, product composition and quality, shall be identified and taken into account.

7.1.3 Hydraulic calculation

For the fluid, to be transported through the system, hydraulic calculations shall be made to determine the outer limits (under- and overpressure) of the design. These calculations shall include both static and dynamic (transient) flow conditions.

NOTE All possible deviations from the normal static flow condition should be carefully considered. Examples are: formation of wax onto the pipeline wall, hydrate forming in wet gas, changes in viscosity caused by temperature changes, slugs of liquid caused by condensation in natural gas, air bubbles or air collection in a pipeline for liquids, two-phase flow etc., but also fast-closing valves, pump breakdowns, ruptures in the line, pressure shock waves and cavitations (imploding vapor bubbles) for example in elevated sections of pipelines for liquids etc., In above-ground pipelines, slugs of liquid in gas lines or air collection in liquid pipelines can cause shockwave loads, and are co-factors in determining the methods used for supporting above ground pipe sections.

7.2 Control of Process Conditions

An important activity within operations is control of process conditions. The pressure and the temperature of the fluid to be transported shall remain within design conditions. The throughput velocity, the flow and also the composition shall remain within the preset limits. Specific ancillary equipment along with the relevant control device (instrumentation) is necessary for monitoring.

It is recommended that both the ancillary equipment to be installed and the related instumentation, be subjected to a fault analysis during the design phase, so that the design can be revised if necessary, and the results of the analysis can be used as a baseline for the operating system (see Chapter 10).

7.3 Pressure Control

7.3.1 General

The internal pressure in a pipeline system shall be kept within the design limits by a pressure control system.

The pressure control system consists of a pressure regulating system, a pressure alarm system and a pressure safety system.

Five lines have been deleted.

The pressure control system can be designed deterministically. Its requirements are in agreement with those which hold for natural gas transport in EN 12186:2000, NEN 1059:1994 and Draft NEN 1059:2002
The pressure control system can also be designed according to the so-called SIL-methodology, from EN-IEC 61508-5:2002; a probabilistic approach.

NOTE 2 A disadvantage of the deterministic method is that there is no quality control required for the components used. SIL-methodology design has the advantage of forcing greater insight into the structure and behavior of the safety system. The SIL-methodology is a quality system which comprehends the entire life-cycle of the safety system. This system requires detailed registration of performance, which might mean that the system can be tested less frequently.

NOTE 3 SIL is an abbreviation for “Safety Integrity Level”. The SIL-methodology is especially important when designing electrical and electronic pressure control systems. Important preconditions for the application of the SIL-method are:

- sufficient knowledge of the pipeline system to be safeguarded, in order to determine the right SIL;
- sufficient numerical data about the failure causes and failure frequency of components used in the pressure control system;
- ability to show by calculation that the chosen design leads to the required risk reduction, respectively SIL level.

7.3.2 Pressure regulating system

The pressure regulating system shall be calibrated for the design pressure of the pipeline. The probability of undesirable excess pressure levels is primarily determined by the probability of failure of the pressure regulating system.

7.3.3 Pressure alarm system

The pressure alarm system shall bring attention to a hazardous situation. Timely intervention can make the intervention of the pressure safety system unnecessary.

A pressure alarm system is not necessary if the pressure safety system has a maximum trigger pressure equal to the design pressure. In all other cases a pressure alarm system is required. When the safety system is triggered, a (high priority) automatic alarm shall go off.

The pressure alarm system shall be installed in such a way that pressure in excess of 102% of the design pressure of the system, as well as its duration, are recorded. In order to prevent the triggering of the pressure alarm system within the bandwidth of the pressure regulating system, the alarm pressure trigger may be a maximum of 102% of design pressure.

NOTE For natural gas transmission pipelines (operating pressure > 1.6 MPa) this 102% may be revised to 102.5% (see Table 1 from EN 12186:2000 and 6.2 in EN 1594:2000).

The pressure alarm input signal may not be part of the pressure regulating system’s sensors (whose failure shall be signaled), but shall be a dedicated pressure transmitter installed for this purpose, or a pressure transmitter of the pressure safety system.

7.3.4 Pressure safety system

The necessity and degree of safeguarding pressure is determined by the relationship of the design pressures of the upstream and the downstream pipeline system and by the strength test pressure of the downstream system(Table 2).

The pressure safety system shall take automatic action, to prevent the maximum allowable incidental pressure in the pipeline system to be exceeded, in case of failure of the pressure regulating system. When designing and installing the pressure safety system, the dynamics of the pipeline system and the setting tolerance and the inertia of the pressure safety system (for example, the intervention time of the blocking valve), shall be taken into account.

The safety principles as per 7.4.1 (venting, repressive), and 7.4.2 (non-venting, preventive), can be applied separately or in combination for pressure safeguarding.

When the medium is a gas, the preferred choice is to protect the environment using a non-venting, preventive technology.

NOTE 1 For example, incidental pressures can be caused by the following: start-up or shutdown of a pipeline system, slow response of pressure regulating system, safety system intervention, pumps or compressors switching on- or off, valves opening and closing.

NOTE 2 In principle it is possible to combine at the beginning of a pipeline's operational life, a relatively low operating pressure with relatively greater incidental pressure changes, while in due course incidental pressure changes can be kept down by installing relevant provisions, thus making it possible to increase operating pressure.

Note 3 The pressure safety system prevents exceeding the MIP ("Maximum Incidental Pressure"). The magnitude of MIP is 110% or 115% of the design pressure, when the system is strength - tested at 125% or 130% of the design pressure. For high pressure pipeline systems, the design pressure is normally chosen as equal to the Maximum Operating pressure (MOP).

A schematic overview of the pressure levels in a pipeline is given in Figure 4. The relation between the triggering of the pressure control system components (regulating, alarming and securing) and the permissible pressure levels are given in Figure 5.

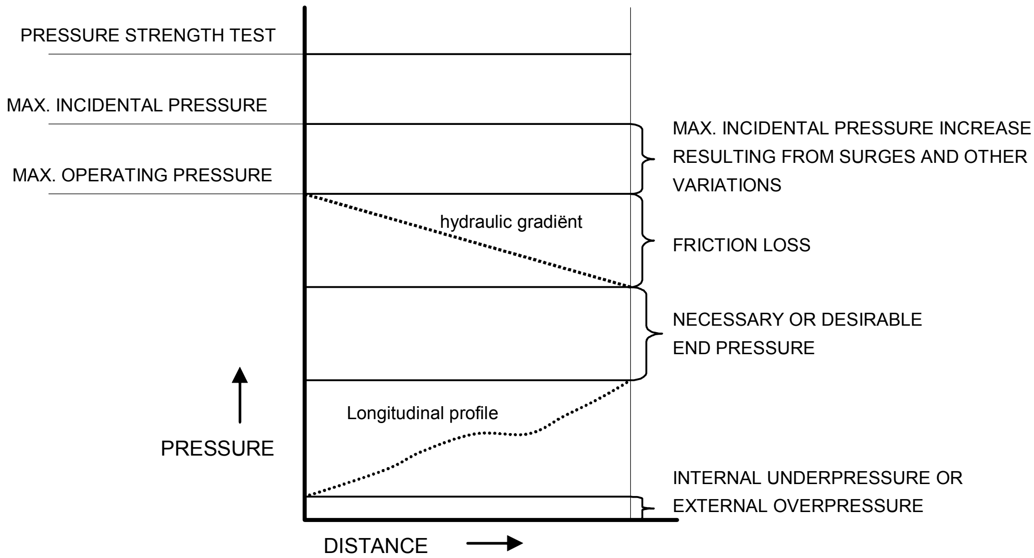


Figure 4 – Pressure levels

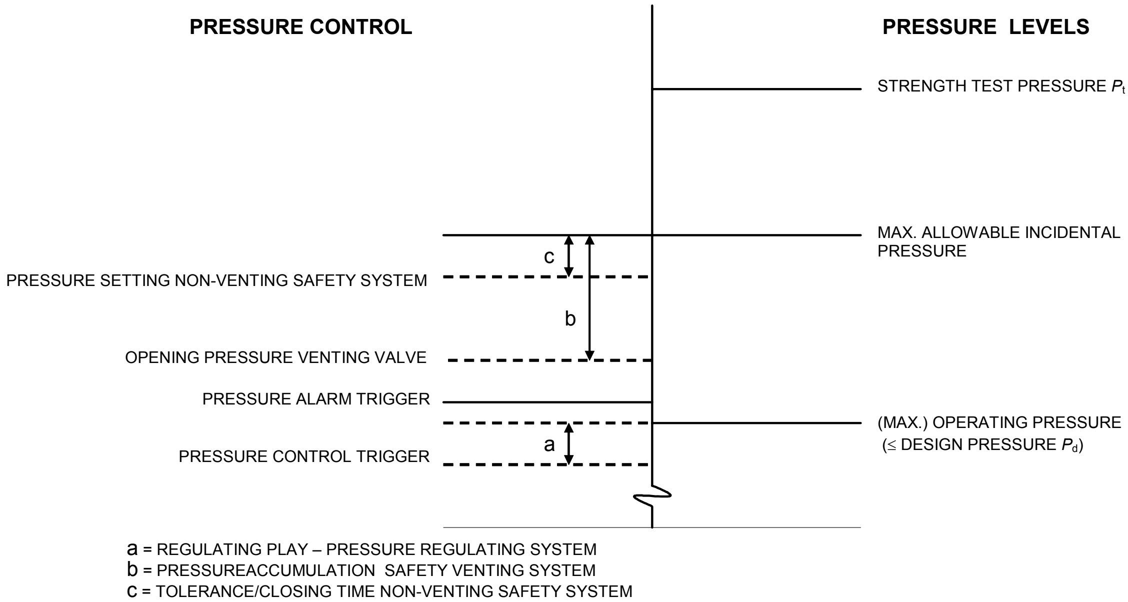


Figure 5 – Pressure Control

The degree of pressure safety for the system depends upon the design chosen, with the following consequences:

- *deterministic design,* leading to no system at all, or one or two pressure safety systems (Table 2);
- *probabilistic design,* leading to an SIL-pressure safety system in accordance with EN-IEC 61508-5:2002.

Table 2 – Components of Deterministically Designed Pressure Control System

pressure ratio	pressure regulation	pressure alarm	pressure safety system
$p_{bo} \leq p_{ibe}$	yes	yes	0
$p_{bo} > p_{ibe}$	yes	yes	1
$p_{bo} - p_{ibe}$ >1.6 MPa and $p_{bo} > p_{tbe}$	yes	yes	2[a]
p_{bo} is the maximum operating pressure upstream, p_{be} is the maximum operating pressure downstream, p_{ibe} is the maximum allowable incidental pressure downstream and p_{tbe} is the strength test pressure downstream of the pressure regulator (= the system to be safeguarded). [a] two pressure safety systems working independently			
The pressure ratio of the limits are in agreement with the stipulations of 8.3.3 of EN 12186:2000			

7.3.5 Pressure safety for pipeline grids

In the case of a meshed pipeline network fed by two or more stations, with one or two pressure safety systems, a fault analysis shall show that the structure of the pressure safety system complies with the same level of safety as that for the single system in accordance with 7.3.4.

7.4 Pressure Safety Design

Each pressure safety system shall separately satisfy the minimum requirements stipulated in 7.4.1 and/or 7.4.2 and 7.4.3. Moreover, the periodic controls stipulated in 7.4.4 shall be made to check that the system is available when needed.

For gas pressure regulating stations, the stipulations of EN 12186:2000 and NEN 1059:1994 and Draft NEN 1059:2002 are in force.

NOTE Depending upon the nature of the medium in the pipeline, and the circumstances outside the pipeline, a choice of safety principles can be made in accordance with 7.4.1 or 7.4.2. When two safety systems are required, two dissimilar systems are recommended, in the light of “common cause failures”. Safety systems that shut off the source are to be preferred over venting safety systems.

7.4.1 Pressure Safety by Venting

A venting pressure safety system can be implemented as:

- directly working safety valve (relief valve)

- indirectly working safety valve, which may or may not use ancillary equipment;

- indirectly working safety shut-down valve, which may or may not use an ancillary equipment;

- bursting safety device.

The maximum allowable incidental pressure in the pipeline to be safeguarded may not be exceeded. In the design of the safeguarding system, therefore, the following shall be taken into account:

- the total capacity of the system

- the opening pressure of the safety valves

- the trigger value for the indirectly operating safety shutdown valve;

- the bursting pressure for the bursting safety device.

The kind of construction and choice of materials for the safety valve, the safety shut-down valve, or the bursting safety device shall be demonstrably suitable.

The safety valves and safety shutdown valves, or bursting safety devices, shall be installed in such a way, that their action cannot be hindered by the medium to be safeguarded. Escaping substances shall be safely carried away via a dedicated system.

7.4.2 Pressure Safety without Venting

The operation of a non-venting pressure safety system can be based upon:

- shutting a valve (shut-off valve) upstream of the pipeline to be safeguarded so that the supply is shut off;

- shutting down the pressure increasing device;

The trigger value of the pressure sensor shall be such that the maximum incidental pressure in the pipeline is not exceeded (see 7.3.4).

The shut-off valve(s) shall be designed to adopt a safe condition.in the event of failure of auxiliary power (spring-loaded, air pressure, gas pressure etc.)

Safety Devices for Small Volumes

If, after safety interventions, relatively small volumes are blocked in, a small safety vent shall be installed to prevent a further increase of pressure caused by leakage of the blocking valve.

7.4.3 Instrumentation

The instrumentation used with venting- and non-venting pressure safety systems shall comply with the following regulations:

Safety Chain

The entire instrumental safety chain shall work according to the de-energize-to-trip principle.

The pressure transmittors shall operate in such a way, that loss of signal, results in a safety intervention..

The switching logic and ancillary controls shall be failsafe.

The safety chain shall be installed completely independent of the regulation- and control system.

Two serial mounted safety systems, safeguarding the same pipeline, shall be installed completely independently from each other.

Installation

Instrumentation wiring and pipe-work shall be dimensioned and installed in such a manner that they are suitable for their purpose.

The instrumentation of a pressure safety system shall be separate from the other instrumentation.The pressure sensor of each pressure safety system shall be redundant (e.g., one out of two, or two out of three).

The set points for the control system and the technical facilities forming part of non-venting pressure safety system shall be fixed (locked), where necessary.

NOTE Two out of three, means that two of the three pressure sensors shall be addressed before the safety system is activated.

Isolation or Disconnection

The pressure safety system's sensor shall be connected to the pipeline to be safeguarded, in such a way that it cannot be isolated or disconnected.

It is permissible to deviate from this if a changeover system is installed, with interlocked shut-off valves or switches ensurng that the pressure sensor systems of the required number of pressure safety systems are continuously connected to the pipeline to be safeguarded.

If a transmitter is disconnected from the electrical supply, or is being removed, then it shall be made to emit the trip signal, so that the tripping of one of the remaining sensors activates the safety system.

7.4.4 Start-up and periodic inspections

Before pressure safety systems are brought online, they shall be calibrated and tested using an approved testing procedure. “In situ” testing provides the most reliable data about the actual response of the safety system. It is important to record the outcome of testing because it will determine adjustment of the testing intervals.

NOTE 1 It is the responsibility of the owner or manager of the safety system, to determine when certain components have to be replaced or disassembled and cleaned, if necessary in consultation with the manufacturer or a certified maintenance firm.

Safety systems shall be tested periodically, according to dedicated procedures for the type of safety device installed. If there is no data that can be used to determine the test intervals for the specific type of safety device at the specific location in the system, Table 3 shall be used.

Table 3 – Testing intervals for different types of pressure safety systems

Component	Testing interval
a spring laded or weight loaded safety valve	4 years
relief valve ancillary instrumentation	1 year 1 year
shut-off valve (HPSD-syst.) ancillary instrumentation	1 year 0.5 year

When statistically, sufficient data has been gathered regarding a specific type of safety device the testing intervals may or shall be revised.

NOTE 2 It is advisable to increase the testing interval for mechanical components in increments of no more than half a year. When components are replaced by other types, the testing interval ought to be shortened, until sufficient data has been generated from experience which might justify an increase in the interval.

Changes in the safety systems shall be documented in detail.

NOTE 3 In order to better predict the behavior of specific safety equipment, it is recommended that the number of variations in design and construction should be limited to a smaller number than is usual for components that do not have a safety function.

Every maintenance cycle, or modification of the safety system, shall end with a test to demonstrate that the start-up and shut-down devices are in good working order. The test results shall be recorded.

During maintenance work and testing, where the safety system is bypassed, and the pipeline system to be safeguarded is in operation, pressure control shall be guaranteed in some other manner.

7.4.5 Test Reporting

With each periodic testing, the relevant data such as pipe element number, production year, test method applied, testing interval, time of tests, test results, as well as any measures that might have been taken in response to the test results, shall be recorded.

Test results shall be documented and kept in file for at least five years.

7.4.6 Pressure Control System Documentation

Documentation of the original design fundamentals and calculations shall be available for each pressure control system. Every revision in the system shall be documented in detail, and will be compared to the design fundamentals.

The results of the periodic tests and other relevant aspects shall be entered and maintained in a logbook.
Unusual events shall be logged. Undesirable addresses to the pressure safety system or its failure shall minimally be regarded as unusual events.

7.5 Temperature control

For the transport of substances at a higher or lower than ambient temperature, provisions shall be made to prevent the increase or decrease of temperature within the pipeline exceeding the design temperature trajectory envelope(range).

Temperatures and temperature variations during the operations phase shall be determined, based on the operations plan,. The number of cycles and the amplitudes shall be taken into account, when judging the safety margins on the limit state of material fatigue.

7.5.1 Temperature regulation of heat transport systems

The clause has been deleted.

7.6 Fluid

The composition of the fluid shall be monitored during operations. The allowable margins of deviation from the specifications for that fluid shall be known, as well as what shall be done to prevent undesirable conditions. These procedures shall be specified, and the documents made available to the operations management.

In case of pipeline systems carrying batchwise different products, rules for monitoring and tracking the batches including recording time of its arrival and the operation in the receiving installation.shall be specified,

For pipeline systems with multi-phase product transport, rules shall be specified for monitoring any liquid that might remain behind in the pipeline (“liquid hold-up”) and the free volume in the slugcatcher .

7.7 Critical parameters control

All control indications for critical parameters as temperature (high and low), liquid levels at separators, pressure etc., shall be "two out of three voting system protection".

8. Structural Design

8.1 Pipeline Configuration

8.1.1 General

The design, installation, operational management and temporary and/or final decommissioning of the pipeline(s) should be taken into consideration when selecting the route. Future urban and industrial developments near the route shall be considered in order to ensure that the number of adjustments, rerouting or limitations continue to be kept at a minimum in the future.

8.1.2 Route Definition

The activities that shall be performed before a pipeline route can be defined as final and before a pipeline can be installed along that route are given step by step. H.1 contains extensive descriptions of the activities.

1) Provisional route determination;
2) Obtaining planning approval;
3) Detailed route proposal ;
4) Obtaining the required (Public) licenses and permits, discretionary permits and approvals;
5) Obtaining the required property rights and private licenses;
6) Obtaining and arranging the required working strips for installation;
7) Paying and arranging, respectively, all compensations, damages, value appraisals, etc., including crop damage and cultivations;
8) Recommendations and reports in relation to agriculture-technical data;
9) Collecting specific information, recommendations and construction specifications for tendering and the execution of the work.

8.1.3. Aspects related to the choice of pipeline alignment

The pipeline configuration shall be designed in the chosen route strip in view of the risks involved and, where possible, these shall be limited. The following shall,as a minimum be taken into consideration:

- present and future underground infrastructure works;
- present underground obstacles and contamination (foundations that have not been removed, left behind piles, ditches filled with waste, land contamination, old landfill sites, tree stumps in boggy subsoil's, asbestos cement in rubble hardening, war residues, etc.; see also I.4);
- local changes in the nature of the soil (creeks and streams grown over by stumps of vegetation, domes and dunes);
- accessibility of the pipeline during installation, management and removal;
- possibilities to deal with expansion from internal pressure and from temperature changes;
- bends and corner radiuses in rigid or articulated (tension-resistant or not) pipelines in connection with thrust effect and/or thermal expansion;
- sand piles or vertical plastic drains for HDD's or GFT drillings (at least 2.0 m free space is recommended between the bottom of the pile or drain and the top drill passage);
- flexibility in the connection to structures on pile foundations, because of possible subsidence differences (transition piece with flexible joints, bellows, loops);
- high-voltage cables and induction on steel pipelines or pipe sections.

8.1.4 Pipeline Depth Position

The minimum required soil cover of 1.2 m should be increased in the following cases whereby soil cover shall be applied that has been adjusted to the circumstances:

- in areas where it may be expected that deep ploughing, drainage or depth excavation will occur or where the installation of drainage pipes can be expected;
- at locations where soil excavations can be expected;
- in areas that may be liable to erosion;
- in situations where the pipeline may rise due to freezing;
- at crossings with waterways related to the risk of pipe damage from ship anchors.

In those cases where the minimum soil cover of 1.2 m cannot be maintained, and protecting the pipeline against external mechanical damage is required, the pipeline shall be protected by a covering construction.

At crossings withes ditch or watercourses the pipeline may have to meet certain requirements set by, among others, the owner of the ditch or the water course. In liason with these owners . the soil cover of sag pipes at those locations may be increased to compensate for example,for soil erosion and anchor risk from, ship traffic (the words in parentheses have been deleted).

8.1.5. Parallel Pipelines

Between parallel underground pipelines a minimum of 0.4 m clearance shall be maintained. This distance may be set at a larger value as a consequence of safety considerations (chain reaction when one of the pipelines fails).

NOTE 1: The 0.4 m clearance size may be deviated from after mutual consultation between the parties involved. EN-1594:2000 specifies a clearance of 0.3 m. This is deemed to be too small in connection with accessibility for making connections, their inspection and management. Different criteria apply to drillings, sag pipes and crossings with public works.

NOTE 2: It is advisable to allow the clearance between the pipelines to amount to at least 0.4 m and a practical minimum for the space next to the pipeline would be 0.5 m for pipelines for which the trench backfill will be compacted.

8.1.6 Pipeline corridor

Pipelines in a pipeline corridor shall be configured in consultation with and according to the requirements of the manager of the pipeline corridor. The corridor is provided with the necessary engineering structures to safeguard a separation of interests with other land use (for example, water-retaining structures).

Pipelines in a pipeline corridor show a smaller failure probability of than comparable pipelines in the field as a result of the undertaken measures and the degree of management and monitoring of the corridor.

The note has been deleted.

8.1.7. Casing Pipe

The use of casing pipes may be required in the following cases:

a) with horizontal (the word "directional" has been deleted) drilling (the word "HDD" has been deleted) crossings of pipelines carrying environmental contaminating fluids (for example, hydrocarbons which are liquid at atmospheric circumstances) are transported:

- in groundwater protection areas;

- in other areas should the Pleistocene be approached up to less than 2 m and/or be drilled.into. This also applies to Holocene sand courses or domes that have an open connection to the Pleistocene.

b) With horizontal (the word "directional" has been deleted) drilling (the word "HDD" has been deleted)crossings:

  - of liquid pipelines with high-level-drainage-canal dikes (see also NEN 3651:2003);
  - of pipelines as a result of which corrosive substances are transported before the pipeline material;

c) crossings with railways, see 6.5.5;

d) road crossing when jacking or drilling of the pipeline itself is not possible;

The casing pipe shall fulfil thefollowing requirements: (see also 9.6.2):

- the casing pipe shall be suitable to absorb all external loads and, in those cases in which this is specified in the design,the internal design pressure of the fluid carrying pipeline;
- the casing pipe shall be put together in such a way that corrosion protection of the fluid carrying pipeline can be ensured;
- the casing pipe shall be flexibly sealed at both ends to limit the groundwater circulation to a minimum within the annular space and, thus, also the supply of oxygen.

8.1.8 Pigging Facilities

In general, all gas pipelines shall be piggable. Buried pipeline with a diameter greater than 10” and longer than 1 km shall be piggable. (Under unique circumstances, an alternative plan shall be developed).
The following provisions should be considered:

- location and orientation of the receiving and launching stations;
- temporary or permanent set-up, accessibility and hoisting provisions;
- shutoff valves, bypass pipes and blow-off and drainage provisions;
- minimum bend radius, maximum internal diameter variations, Tees with guiding bars;
- intelligent pig equipment to be used;
- pig position signaling;
- internal coating.

8.1.9. Axially Rigid and Non-rigid Pipes

The clause has been deleted.

8.1.10 Protection of the system from ground movements

The design of the system shall be with conformance to the Israeli Standard SI 413 part 2[1].

8.2 Pipeline Design

8.2.1 General and Field of Application

This paragraph deals with the general provisions for the structural design of pipelines on land (straight pipe, bends, connections and branch pipes). A distinction is made between underground (buried or trenchless installations) pipelines and aboveground (usually only locally supported) pipelines.

Specific requirements for offshore pipelines are dealt with in chapter 11.

Landfall pipelines shall be dealt with as would land pipelines. In addition to the crossing with the primary water-retaining structure (typically pipeline on land design), there is an overlap with offshore pipelines for the section in the shallow water just before the coast. The installation method used for the section has an important role in the design of the pipelines. Knowledge of pipelines on land and of offshore pipelines shall be combined for this issue.

8.2.2 Basic Requirements for Pipeline Design

Pipelines shall be designed and constructed in such a way that the probability of exceeding a limit state is acceptably low for the design service life.

Measures shall be taken when it is reasonable and possible to limit any potential damage to the pipeline by avoiding, undoing and/or reducing hazards that threaten the pipeline and/or it should be designed in such a way that the related hazards can be resisted properly (see also Table 2).

8.2.3 Safety Level

The required safety level is determined by the consequences in case of pipeline failure. A more serious consequence demands a lower level of risk of failure. A pipeline that is designed, installed and managed based on the requirements of this standard complies with the required risk of failure level which is achieved through a combination of (a) external measures, (b) structural design requirements and (c) installation requirements.

The structural design is further specified in 8.2, especially, the loads and load combinations to be taken into account, the load factors to be applied, the calculations to be performed, the (material) resistance functions to be used and the tests to be performed.

Differentiations in structural pipeline design are achieved by the following among other elements:

- the quality of the pipeline design. This not only refers to the strength and the deformation capacity but also the possibilities of achieving correct installation, avoiding potentially dangerous situations, building in resilience, making inspections possible during construction and operation, etc.;
- the magnitude of the load factors to be applied and the load combinations to be assessed. The magnitude is partly determined by the pipeline position (pipeline in the field, pipeline in crossings with major public works, area-classification in relation to, for example, natural gas transport);
- number, depth and quality of the calculations to be performed to determine the response of the pipeline under the expected loads;
- the reliability of the resistance functions based on which the results of the calculations shall be assessed;
- the requirements for the pipeline materials to be applied (such as for steel: strength and toughness of the parent material and welds, admissible geometry deviations such as wall thickness tolerances, out-of-roundness, welding imperfections, etc.);

Refer to SI 5664-2 for further details on the above where the load factors and load combinations which are to be taken into account are given per material, pipeline type and position.

8.2.4 Ultimate Limit State and Serviceability Limit State

A limit state is a state where the set performance requirements are no longer complied with according to ISO 2394:1998. A distinction is made between ultimate limit states and serviceability limit states:

- ultimate limit states are limit states in which the collapse or other forms of structure failure occur or the maximum strength is exceeded (for example pipe rupture and leakage of fluids causing unacceptable damage);
- serviceability limit states are limit states in which the set requirements are not complied with any longer in relation to the correct operation of the (pipeline)structure (for example, too much out-of-roundness, the occurrence of annoying vibrations or noise, leakage of fluids, not causing unacceptable damages).

Limit states and related strength functions are included in the sections which refer to each type of used material.

8.2.5. Calculation Method

Design values for the loads (so-called calculation loads) are used in the calculations. These are obtained by multiplying the representative values of the loads with the corresponding load factors. Next, relevant load combinations are determined.

Design values for material properties are obtained by dividing the characteristic values for the resistance properties by the corresponding material factors.

NOTE 1 When the load, settlement, strain limit and tensile strength variables and such are mentioned in this standard, the design value for the variable involved is referred to unless otherwise stated.

The effects of these load combinations on the construction are determined through calculations, such as section forces, deformations of the pipeline, stresses, strains and any varieties thereof. Finally, it shall be shown that no limit state has been reached. The effects shall be assessed in relation to the relevant strength functions for this purpose. See also 8.2.8 and 8.2.9.

NOTE 2 The strength functions may involve material properties but may also relate to a calculation formula that describes the course of a certain failure mechanism (for example, implosion or buckling).

The calculation includes the following detailed steps; see also the flow chart in Figure 8.

a) The collection of design data.
The design data required for the design and the calculation are dependent on the nature and dimensions of the pipeline system. These are further described in the paragraphs below, in Appendix B and, for the various materials, in SI 5664-2.

b) Outline and classification into calculation sections.
The pipelines and their loads shall be outlined and divided into sections which are then calculated. See 8.2.10.

c) A simplified calculation can be utilized or assessed to.

d) Under certain conditions it is admissible to utilize a simplified calculation whereby usually only the internal pressure is taken into account. Such a simplified calculation has been elaborated further in SI 5664-2.

e) Determining the load combinations, loads and related load factors to be taken into account as well as determining the limit states to be assessed. Every section of a pipeline system shall be examined for the influences of the loads given in 8.2.7. Based on this, the loads and load combinations that are relevant to that section shall be determined. The calculation loads are assumed for the calculation. Section 8.2.8 provides information on the load factors to be applied.

f) Calculation of displacements, deformations, force and moment distribution and reactions.
This calculation depends on the actual length of the pipeline configuration and, where it is required, the time relation. The trajectory and the size of the forces (axial force, shear force, bending moment, torque moment,

soil loads and bearing reactions), the deformations (bending deformation and axial force deformation) and the (relative) displacements and deflections shall be determined for the relevant combinations of loads. This applies to both the pipeline and also to the effects the pipeline has on its environment (soil and support, fixed point and guiding structures, etc.).

g) Calculation of the variables to be assessed such as section forces, section deformations, stresses, strains and variations therein.
The positive and negative values of the stresses and strains that can occur in the wall of the pipeline system sections shall be determined and, where necessary, also the range or the amplitudes and frequencies of stress and/or strain variations.
As a stress increase occurs in the pipeline elements as a consequence of geometry, it shall be taken into consideration (for example, for bends in rigid pipelines). Variables that are not relevant or variables, in relation to which there is no doubt about the subordinated and/or favorably active character, do not have to be included in the calculations.

h) Determination of the limit values from the strength functions, taking material factors into consideration that relate to the relevant limit states. These are material-specific and are further described in the material section concerned.

i) Assessment
The section forces, sectional deformations, stresses, strains and other values as a result from the calculation loads may not exceed the limit values.

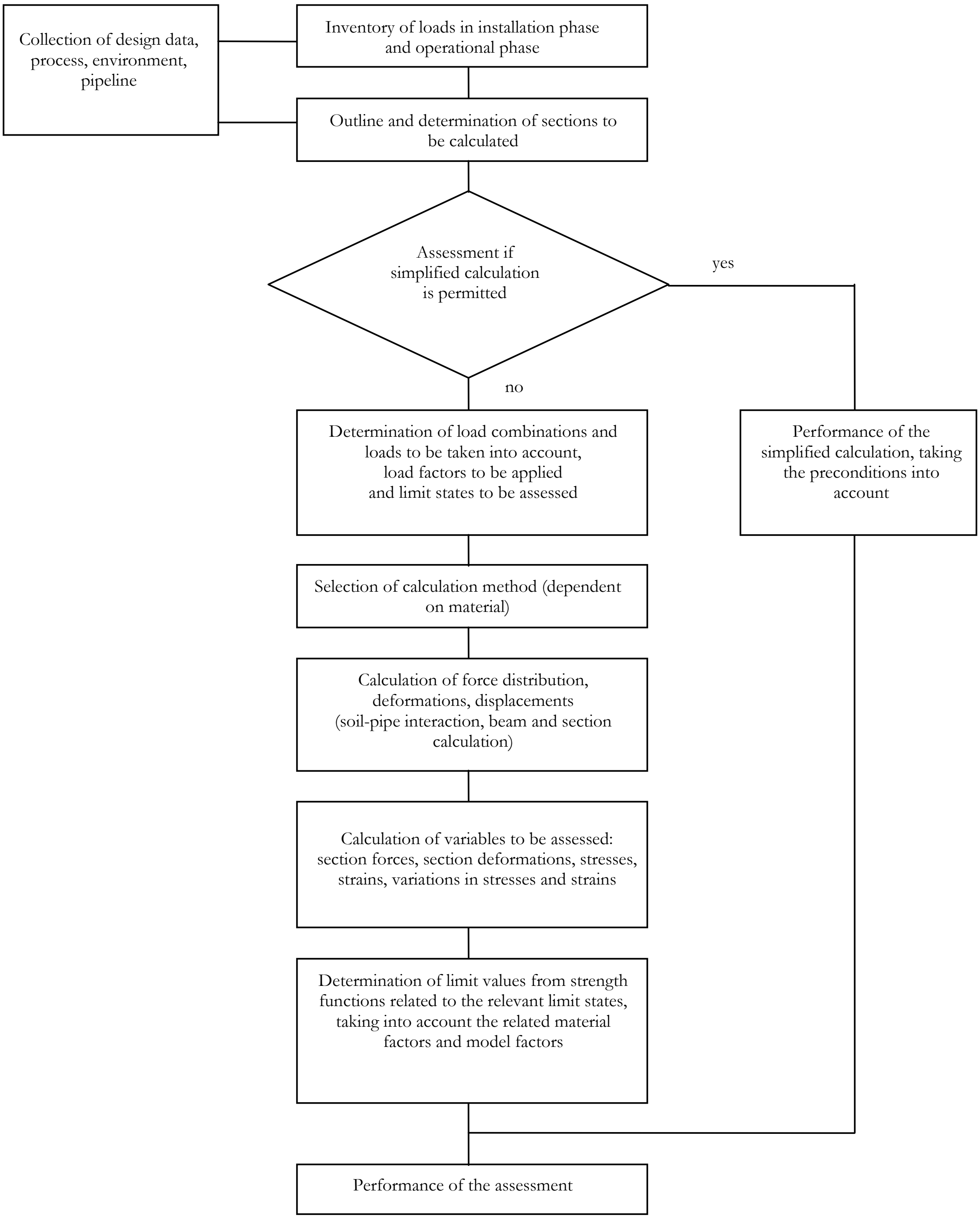


Figure 8 – Strength Calculation Flow Chart

8.2.6 Simplified Calculation

The examination can be limited or be dropped for certain sections when:

- a simplified calculation is permitted (specified in Figure 8 to the right). This calculation, however, is material-dependent and applies under specific preconditions. See the relevant material section in this standard;

- there are results available from a previously performed examination of an identical or comparable pipeline system and the loads that apply to these results are also comparable and/or higher;
- there is no doubt about the subordinated and/or non-relevant or contrary (favorably working) character thereof in relation to certain loads.

8.2.7 Loads

8.2.7.1 General

Load means any physical processes that lead to deformations and/or stresses in the pipeline material and/or displacements of the pipeline.

An inventory of permanent and incidental loads that may act on the pipeline system is required for the pipeline system design.

The analyses should include both the installation phase and the operational phase.

NOTE Loads arising from the installation phase can be of a permanent nature and can, therefore, persist into the operational phase; for example, the application of pretension.

The size of every load should be checked for both phases. The loads thus obtained or the combinations thereof form the basis for the design of the pipeline with regard to strength, deformations and stability.

The following load types and/or load causes, respectively, shall be taken into account in the design if applicable:

- pressure (internal and external);
- temperature;
- soil;
- traffic;
- pipe weight;
- abutting structures;
- vibrations;
- other installation loads;
- incidental external loads;
- meteorological loads;
- water and ice.

A short explanation is given in 8.2.7.2 regarding the load types. Refer to 11.4.2.3 for specific load types or load causes for offshore pipelines.

Annex C offers methods that can be utilized to determine the size of the loads.

NOTE The characteristic value of a specific load can be utilized as the representative value whereby a distinction can be made based on:

- variable loads; the highest value which is expected to be reached no more than once during the design life is generally taken as characteristic value;

- permanent loads; for which usually the average value is utilized as the characteristic load unless the load concerned shows a relatively high variation coefficient. The utilized load, in the latter cases is the load of which the probability of the value being exceeded is less than 5%.

8.2.7.2 Load Type Specific Information

Pressure

The pressures to be included in the analyses are:

- the maximum and minimum negative pressure and excess pressure (maximum operational pressure, design pressure), respectively. The negative pressure has to be increased with any (hydrostatic) existing external excess pressure;

- pressure surges in the fluid due to opening or closing the valves and/or starting or stopping the pumps, compressors and such (incidental pressure increase), cavitations after pipe burst;
- internal pressure during testing;
- pressure variations during the operating phase (in relation to limit state of fatigue).

The determination method for the size of these loads is specified in C.2.

Temperature

All thermal loads (loads arising from hampered and/or hindered thermal expansion of the pipeline) shall be included in the analyses.

NOTE Thermal deformation can occur due to temperature variations of both the fluid and the environment. Thermal load can occur as a result of nn-uniform heating or cooling of the pipeline (for example, because of the sun or wind) or as a result of a statified flow of hot and cold media. In exceptional cases cases: loads due to significant temperature gradients across the wall. Heating as a result of sun radiation can lead to a significant pressure increase (for example, between two closed valves) in a liquid filled aboveground closed pipesection..

The procedure for quantifying thermal loads is described in C.3.

Soil Load

The design of the pipeline system shall take account of:

- load due to directly and indirectly transfered soil loads (neutral earth pressure up to a maximum of the passive earth pressure);
- horizontal earth pressure;
- load due to non-uniform vertical and/or horizontal displacement of the pipeline and/or non-uniform vertical and/or horizontal displacement of the subsoil;
- reaction forces from the soil due to loads on and deformation and displacement of the pipeline in relation to the surrounding soil (lateral vertical downward and and upward, lateral horizontal, axial frictional reaction and tangential friction reaction), respectively;
- load due to soil deformations as a result of the vibratory extraction of sheet pile walls.

soil study for swelling clays to include special requirements regarding protection against moisture and/or closely controlling it in order to avoid significant local swelling.

The design of the pipeline shall also take into account of soil loads which may occur during installation, for example earth fill on the pipe or unilateral soil loading during excavation.

The designer shall also take any load on the pipeline into account associated with nearby foundations of public works, structures or buildings.

The procedure for quantifying the soil loads is described in C.4.

Traffic Load

The traffic loads that occurs during the installation phase or operational phase shall be included in the design.

The procedure for quantfying the traffic load is described in C.5.

Load due to pipeline weight

The weight of the pipeline, coating and everything attached to the pipeline as well as the weight of the media to be transported or the test media shall be included in the analyses (the appendages and other equipment forming part of to the pipeline shall be included in the pipeline's own weight).

In the case of aboveground pipelines inparticular the weight of snow or ice on the pipelines shall be included in the analyses.

Underground pipelines below groundwater level may be forced up by buoyancy when in soft soil types (for example, peat or mild clay) or by liquefaction of the trench backfill. Vertical soil anchors or weight reinforcements of the pipeline can be used to prevent the above.

The procedure for quantifying these loads is described in C.6.

Loads due to connected structures

Both the reaction forces that are exerted on the pipeline by the supports (elastic and fixed) and by connected equipment andstructures (tanks, vessels, pumps, bridges, safety valves, platforms) shall be included in the analyses.

Special attention shall be given to displacement or rotation of supports or connected structures.

Load due to vibrations

Vibrations caused by the fluid (compressor or pump) or as a result of the environment (machines, but also wind, waves or currents) can impose pipeline loads. This shall be investigated during the design phase. The procedure for quantifying the loads due to vibrations is described in F.2.2.4. Refer also to Appendix J of EN 1594:2000.

Load due to transport and storage

Bearing loads of pipes during transport and storage demand necessary attention; especially in relation to thin-walled pipes and their stacking height, free span and bearing saddles or blocking.

Other Installation Loads

Various load situations can occur during the installation of the pipeline which shall be investigated, such as:

- imposed load during storage, transport and lowering-in of the pipeline;
- loads due to the elastic curvatureof the pipeline when installing;
- load due to the pretensioning of the pipeline;
- loads in relation to jacking, drag sag pipes and horizontal directional drilling.

Incidental External Loads

External incidental loads are generally of the nature of impact loads. Impact loads are, for example, created by:

- loads due to excavation, pile driving, soil sampling drilling and cone penetration works, drilling operations, deep ploughing, mechanical drainage work, geoseismic surveys, etc. (see also Appendix K of EN 1594:2000);
- falling objects;
- anchor forces at waterway crossings;
- failure of nearby pipelines;

- mining activities and earthquakes (see also Appendix C and Appendix F, respectively, of EN 1594:2000);
- landslides or movements of soil deposits, etc., as a result of processing due to heavy rainfall.

Use can be made of data from available literature for determining incidental external loads. Generally, these loads are not involved in the normal strength calculation of the pipeline but the resistance of the pipeline against these types of loads is assessed separately in a risk assessment and the pipeline is provided with additional risk limiting provisions if required.

8.2.8 Load Combinations and Load Factors

8.2.8.1 Load Combinations and Load Factors for Ultimate Limit States

Pipelines and related components, such as, fittings and supports or attachments, shall be able to withstand unfavorable combinations of loads that may occur simultaneously with sufficient reliability, provided that:

- the extreme value of a changing load does not have to be combined with the extreme values of other changing loads or with special loads;
- a special load does not have to be combined with extreme values of changing loads or with other special loads.

The Q load combination to be considered can, in general, be formulated as follows:

$$Q = \gamma_{\mathrm{g}} \times G_{\mathrm{rep}} + \gamma_{\mathrm{q1}} \times Q_{1;\mathrm{rep}} + \sum_{i \geq 2}^{n} \gamma_{\mathrm{qi}} \times \psi_{\mathrm{t}} \times Q_{\mathrm{i;rep}}$$

where:

γ_{g} is the load factor for the permanent load;

G_{rep} is the representative value for the permanent load such as the own weight of the pipeline and the weight of the soil cover;

γ_{q1} is the load factor of the contemplated extreme changing load;

ψ_{t} is the reduction factor dependent on the anticipated duration of use (often it is taken to be 1);

$Q_{1;\mathrm{rep}}$ is the representative value for the contemplated extreme changing load;

$\gamma_{\mathrm{q}i}$ is the load factor for the *i* load;

$Q_{i;\mathrm{rep}}$ is the representative value for the *i* load.

By constantly taking a different load extreme, all load combinations can be determined that can occur with a certain degree of certainty.

The effects of every load combination shall be determined on the pipeline (forces, deformations, stresses, strains, etc.) and it shall be shown that no extreme limit state is being exceeded.

Load combinations and related load factors to be taken into account are partly material-dependent. This is due to the fact that some of the contemplated limit states and calculation models to be applied are material-dependent. Refer to the material-dependent section in connection to this to obtain further elaboration of the load combinations and load factors to be taken into account.

A number of geotechnical properties play a role in relation to soil loads. The calculation values of these geotechnical parameters shall be determined before determining the soil load calculation value. Next, the load should be determined via a calculation model to which a model factor (as load factor) is applied. Refer to B.4.2 for more information.

It is not always clear from the start whether a certain geotechnical variable will contribute positively or negatively towards the contemplated limit state. Both options shall be considered in that case.

8.2.8.2 Load Combinations and Load Factors for Serviceability Limit States

The same formulation can be utilized for the verification of the serviceability limit states for the load combinations to be taken into account as utilized with the extreme limit states with the provision that lower load factors are taken into account (usually $\gamma_q = \gamma_{qi} = 1.0$) and the number of load combinations is fewer. Material influence is also active here and we again refer to the material-dependent sections.

8.2.9 Verification Procedure and Material Factors

For every load combination, the effect of the load combination on the structure has to be assessed for all relevant mechanisms in relation to the calculation value of a corresponding strength size. The calculation value for the strength has to be larger than or at least equal to the load effect in all those cases:

$$R_d \geq S_d$$

where

S_d is the calculation value for the load effect for the effective load combination;

R_d is the calculation value for the strength of the effective mechanism.

The following general formula applies for determining the calculation value for the strength:

$$R_d = \frac{1}{\gamma_M} R \left\{ \frac{X_{k1}}{\gamma_{m1}}, \frac{X_{k2}}{\gamma_{m2}}, ... \right\}$$

where

$R\{..\}$ is the strength function;

X_{ki} is the characteristic value of a material property;

γ_M is the partial factor for the whole calculation model;

γ_{mi} is the partial material factor related to an individual X_i strength property;

Examples of material properties are yield stress or failure strain.

Refer to B.4 for the size of the factors concerning soil and refer to the material dependent sections in this standard for material specific factors.

NOTE 1 Often a value is taken, which may be below the limit by 5%, as typical value for strength functions or material properties. An average value or a safe average value may be involved with soil. The above is related to the nature of the mechanism and the quantity of data (see B.4).

NOTE 2 Geometric variables (diameter, wall thickness) can also occur in the strength function. Usually the nominal value is used. Exceptions are geometric variables with an important influence of the safety such us out-of-roundness.

NOTE 3 The uncertainties in the calculation model (of load based on load effect) are sometimes taken into account on the strength side and sometimes on the load side. It is absolutely crucial that these uncertainties are not forgotten.

Figure 9 specifies the variables that are important when assessing structural safety.

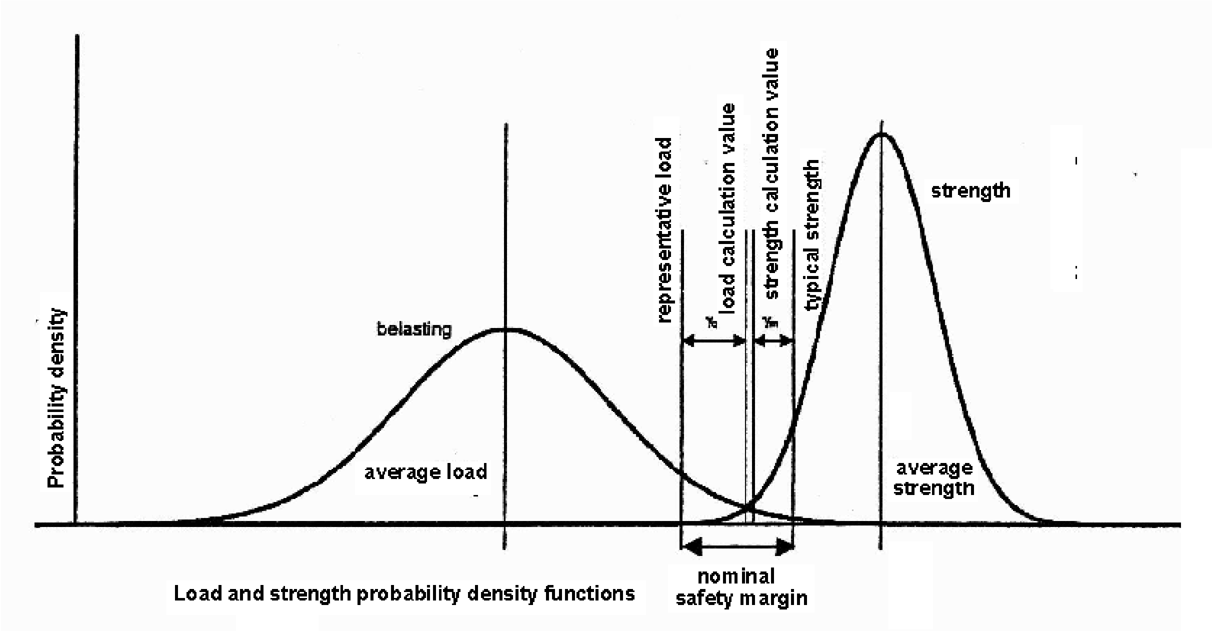


Figure 9 – Frequency distribution for load and strength

8.2.10 Pipeline Outline and Classification in Sections to be Calculated

8.2.10.1 Outline

The pipeline is outlined to obtain a system of beam elements for the pipeline and spring elements for the supports. The surrounding soil is also outlined to obtain a spring system in the case of underground pipelines.

Loads, displacements and restraints for the whole pipeline system shall be considered as cohesive for both static and dynamic aspects. This means that in case the analyses considers the pipeline in sections, the connection and equilibrium conditions throuhout the pipeline system shall be sufficiently met.

It also means that for the pipeline section under consideration shall be (de)limited by points, in respect of which are known:

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

8.2.10.2 Sections to be Calculated

The sections to be calculated are, among others, the following:

1) field section with special attention to:
   - bends (especially at elevated operational pressures and temperatures) and mitres;
   - Tees;
   - areas , subject to settlement and subsidence;
   - pipeline sections,supported by piles;

2) interfaces with plant areas with special attention to:

- underground bends at the end of long straight pipeline sections (thermal and pressure expansion);

- points of transition from an excavated trench to a rigid support structure aboveground or not (for example, footings or pipeline bridges). It is advisable to include both the underground and aboveground sections into a single calculation model;

- at interfaces with installationconnections, paying special: attentionto the often occurring changes in wall thickness;

3) civil engineering infrastructure crossings:

- roads;

- railways;

- watercourses;

- high-level-drainage-canal water and impounding dikes;

- primary, secondary and other flood defences;

4) changes in construction method:

- which gives rise to a settlement and/or subsidence difference (for example, a trench layed pipe section connecting to a jacked or drilled section).
  Also when applying casing pipes, special attention should be given to subsidence differences;

5) abrupt transitions in soil conditions;

6) casing pipe:

- transition of the pipeline within the casing pipe to the section installed in the trench. Also the casing pipe should be checked for strength.

8.2.11 Interaction of pipelines and abutting structures

The analyses of the effects of the loads shall include both the fluid carrying pipeline.as well as the structures that play a substantial role in relation to safeguarding the structural integrity of the pipeline system.

Anchor blocks, casing pipes, supports and connected structures (for example, pipeline connections to stations; see also 8.3.4) and such are involved.

Supports

The locations and design of the supports shall be such that forces are equally distributed and transmitted between the supports and pipeline avoiding high local stresses in the pipe wall.
Sttlement and subsidence differencesmay give rise to large bearing reactions at support(s). The bearing angle shall be at least 60º to avoid peak stresses due to point loads.
Supports shall be designed with at least the same safety level as the pipeline itself.

NOTE In special cases, it may be advisable to limit the support's ultimate bearing capacity to avoid excessive bearing pipe reaction local loads

Local stresses in the pipeline due to the support reaction, such as bending and shear stresses in the pipe wall, shall be analysed.

The influence of the rigidity and/or deformation capacity of the support including its foundation on the static and dynamic behavior of the pipeline system shall be investigated by taking the force/ displacement relationship of the foundation into consideration.

Connecting equipment and structures

Forces, moments, forced deformations from displacements and distortions arising from the presence of connected equipment shall be included in the pipeline stress analysis.

Non-Supported Sections

Should non-supported sections (for example, free spans) occur during the installation, burying or during the operational phase, the stresses that arise shall be determined.
The maximum admissible free span shall be specified in the calculations. Dynamic aspects of the free span shall be included In the analyses.
The free span, actually created shall be checked in the field,.

NOTE Unchecked free spans virtually do not occur in land pipelines; the phenomenon occurs more often in offshore pipelines due to sand transport over the sea bottom.

8.2.12 Specific Design Aspects

8.2.12.1 Specific Design Aspects for Underground Sections

Required geotechnical data:

- for field section often occurring geotechnical values can be assumed (see table C.3) in combination with or without a limited site investigation;

- the geotechnical parameters have to be determined based on local soil (field) investigation including advise from an expert geo-mechanical consultant (see also 1.3) in case of special structures and/or widely varying soil properties or where substantial settlements are expected.

Load types:

- pipelines under groundwater level shall be checked on upward buoyancy forces, during both the construction and operational phase.

Construction subsidence:

- In addition to settlement differences due to consolidation allowance shall be made for subsidence from construction activities as a consequence of soil disturbance , the use of different construction methods or from vibratory extraction of a sheet pile wall

- a construction subsidence difference of f_v due to soil disturbance, gradually (for example, sinusoidal) going from 0 to f_v over a length *L* and back again shall be used for pipelines installed in open excavations and with a careful trench backfill. The distance over which the subsidence difference extends, is therefore equal to 2*L*. See C.4.7.2 for the determination of *L*.
  Should no further survey take place on site in relation to the construction subsidence, use shall be made of the values of f_v as specified in the tables in Appendix C;

- should certain minimum requirements be demanded from the construction method to limit subsidence and subsidence differences, they shall be mentioned in the geotechnical report and shall be respected during construction.

8.2.12.2 Specific Design Aspects for Aboveground Sections

Load types:

- own weight including fluid respectively, liquid load for hydrostatic testing;
- any condensate and/or liquid slugs in gas pipelines;
- wind load (only where necessery due to diameter and elevation of the pipeline);
- snow and glaze in relation to cold media (< 0 ºC) and/or thermally insulated pipelines.

8.3 Station Design

8.3.1 General

Rules are given in this paragraph that shall be observed when designing and operating stations.

Gas pressure regulating stations shall comply with EN 12186:2000 and NEN 1059:1994 and Draft NEN 1059-2000. Compressor stations shall comply with EN 12583:2000. The strength-technical design of the stations falls under this standard.

NOTE Stations may include components (pressure equipment and pipework) with a pressure > 0.05 MPa) which are under the scope of the Pressure Equipment Directive (PED); [34]. The PED has been implemented in the Netherlands in the Pressure Equipment Decrees; see Appendix K. Transportation Pipelines do not fall under the scope of application of the Decrees.

8.3.2 Requirements

General Requirements

The requirements that shall be met by the station layout depend on the surrounding area, climate conditions, the station type and the fluid conveyed.

Each station shall be designed such that:

- nuisance and hazard to the surrounding area are limited to a minimum;
- the station (or parts thereof) can be simply taken out of service by operating a few valves;
- all components are easy accessable for operation, inspection and maintenance purposes;
- Effective long-tem operation is quaranteed under all weather conditions
- it suffers no detrimental consequences from settlement and subsidence differences between pipeline and station, corrosion or any other cause;
- unauthorized operation, vandalism and sabotage are prevented or hampered considerably.

Measures shall be taken for arrangements in an unheated space as well as in the open air – sheltered or not sheltered by a side shelter or a few walls – that will prevent disturbance of the correct operation due to weather influences.

NOTE These measures can be, among other measures, the following:

- providing a heat tracing to ensure certain parts are not frozen (for example, controllers);
- special measures against corrosion, among others, sealing the space between flanges;
- measures against seepage, for example, via a ventilation opening towards a membrane chamber of a regulator, safety, electronic and instrumental equipment, etc.

Distances

Stations shall be positioned in such a way that hindrance and danger to the environment is avoided as much as possible. The distances used between stations, on the one hand, and buildings, roads, railways, high-voltage lines, etc., on the other hand, have to meet certain requirements.

When choosing the distances between stations and the underlying distances of equipment and devices in the station, safety, maintenance and operational management shall be taken into account.

NOTE 2 NEN-1059:1994 and Draft NEN 1059:2002 include safety distances for gas pressure regulating and measuring stations. The distances contained in these standards apply as minimum safety distances for objects where people can be found; the distances in relation to roads, railways, watercourses, other ignition sources and boundary partitions are also relevant. The size is determined by the station being continued.

Fencing

All stations should be surrounded by fencing, if circumstances require this, to prevent access by unauthorized persons if possible and which should be provided with a clearly visible warning and prohibition sign; see SI 3864-1.

To facilitate the evacuation of personnel from the station in case of an emergency, there shall be sufficient access points (one or more, depending on the requirements of the local authorities) in the fencing. This also applies in the case when a station has been housed in a building.

The access points shall open towards the outside and you should be able to open these from the inside without a key. Other provisions can also be made that offer the same escape possibilities. If the size of the station justifies it, accesses shall have been measured and constructed in such a way that accessibility for fire-fighting equipment and ambulances is safeguarded.

Electric Installation

The electric installation in stations shall comply with the requirements set down in the Israeli Electric Law – Code of Laws 164, 1.9.1954, EN 50110-1:1996 and SI 60079 for as far as these are applicable. The electric lighting shall be constructed in such a way that exits and critical places around and in the station are clearly visible during the night and when there is fog.

Lightning

Provisions shall be made against lightning strikes where this is required based on EN 50110-1:1996 (for example, when explosion hazards are present at the installations). The provisions shall comply with the requirements contained in SI 1173.

Electrostatic Loads

Liquids can generate electrostatic loads, when flowing along the wall of a pipeline that can ignite an explosive mixture. Pipelines, casing pipes and devices that can have an electrostatic load shall be grounded or shall be conductively connected.

The resistance between the pipeline and soil shall amount to not more than 6 ohms to offer protection against electrostatic loads.

8.3.3 Components

General

Each individual component of a station shall comply with their functional requirements.

These include mechanical devices (such as compressors and pumps), electrical components, s (generators, batteries), components connected to pipe work (pipes, ancillary equipment, flanges, bolts, gaskets, valves) are examples of the above.

The installation as a whole shall, moreover, comply with the requirements with regard to reliability in operation, safety and dependability. Safety in relation to the environment and hindrance of third parties shall also be at an acceptably high or low, respectively, level.

Protections

Aspects, such as the ones given below, shall be given attention in relation to the above:

- explosion hazard (corrosion and leak detection, ventilation, hot surfaces, pressure safety);
- fire hazard (heat insulation, fire-extinguishing equipment);
- noise insulation (sound-dampening provisions).

Auxiliary Lines, Etc.

Devices within stations are often linked to each other using in house pipelines. Pipelines for oil, gas, steam, compressed air, water, chemicals (for example, inhibitors) as well as measurement, control, auxiliary gas and sampling pipelines are examples. This pipelines and related valves, flanges, adaptors, bends, etc., shall be manufactured from adequate material and shall be suitable for the operational pressure and temperature of the connected devices. Pipelines in stations shall be designed based on this standard as far as it is applicable. Requirements that should be met by flanges, gaskets, bolts, nuts, valves and other fittings are given in the material sections concerned in this standard.

8.3.4 Connection between Pipeline and Station

Mutual influencing shall be taken into account when designing the connections between the sections and the stations (see also 8.2.7).

Special attention shall be given to the following regarding connections of the aboveground components with the underground pipelines:

- displacement differences due to thermal expansion of the pipelines;
- subsidence of the subsoil as a consequence of pipeline installation and settling or swelling as a consequence of grade changes;
- vibrations in components and aboveground sections due to machines (for example, compressor throbbing or flow induced throbbing);
- expansion and shrinking of the pipeline as a consequence of temperature fluctuations and pressure changes. If required, the pipeline shall be anchored or shall be constructed flexibly to ensure that temperature or pressure fluctuations do not lead to unacceptable stresses in components, supports or foundations.

NOTE The (welded or flanged) valve that forms the separation between the station and the pipeline can be positioned on a transition in foundation method (uneven subsidence). It is advisable to investigate whether the valve (and any flanges) can withstand this.

9. Installation (on Land)

9.1. General

The installation of the pipeline system shall be performed as described and specified in the approved specifications and approved drawings from the design phase. The methods, the organization chart and the work procedures for the installation and delivery shall also be specified in the descriptions. The documents shall be available before the construction phase is started.

The requirements and provisions for the protection of health and safety of the public, involved personnel and the environment shall be specified in a safety, health and environmental plan. The requirements stipulated in the relevant legislation and regulations, standards and licenses and the identification of potential risks and hazards including the corresponding measures and emergency procedures shall be described in the plan.

Competent supervisory personnel shall supervise the construction of the work. The persons carrying out the work shall have all required qualifications for constructing the work.

Hindrance of the owners and/or users of the involved lots and damage to goods or crops shall be limited as much as possible.

NOTE It is advisable to identify beforehand the objects that could be influenced by the construction of the pipeline system, such as, for example, existing roads, railways, watercourses, footpaths, cables, pipelines and buildings.
It is recommanded to identify the temporary provisions and safety provisions required to protect these objects during construction and to harmonize these with the involved owners, managers and authorities.
In case large (construction) subsidences are expected, it is recommended that adjacent properties which are influenced by the installation are subjected to a 'zero value investigation' (determination of the situation on the contract date).

9.2 Subdivision, based on installation method

9.2.1 General

Regarding the installation of onshore pipelines, a distinction can be made between aboveground and underground pipelines . An underground pipeline can be further subdivided into field sections and crossings.

Refer to 11.5 for information regarding the installation of offshore pipelines. In this standard the landfalls of offshore pipelines are considered as land pipelines.

9.2.2 Aboveground Pipelines

Installation of aboveground pipelines includes the assembly and installation of pipelines that are not continuously supported (in relation to the ground) but locally.

9.2.3 Open Excavations

The pipeline is directly buried in a dry, excavated trench or the pipeline is floated into and immersed in a trench filled with water.

9.2.4 Field section

The installation of an underground pipeline in the field section includes assembly and installation of a pipeline in an excavated and backfilled trench. Trenchless technology can be used for field sections, when this is attractive financially or for other reasons.

9.2.5 Crossings

Crossings are installed depending on the circumstances:

a) in an open excavation;

b) using trenchless technology (drill and thrust boring techniques and HDD);

c) by jetting;

d) by sinking;

e) using jumpers and pipeline bridges.

9.2.6 Trenchless technology

Drill and thrust boring techniques are subdivided into four main groups based on accepted terminology:

- Open Front Technique (OFT);
- Closed Front Technique (GFT,CFT);
- Pneumatic Boring Technique (PBT);
- Horizontal Directional Drilling (HDD).

NOTE Due to required uniformity in the method used for referring to trenchless technology, the abbreviations given above have become standard abbreviations in this sector.

Each drilling technique has its own specific application criteria and the choice of the most suitable method depends on:

- diameter, material and joint type of the pipeline;
- type of object to be crossed;
- length of the crossing;
- soil conditions;
- groundwater level or groundwater potential.

The main groups are further specified in Appendix G.

9.2.7 Landfall

The installation of a landfall may include the crossing of a primary water-retaining structure (see also NEN 3651:2003). Special (temporary or permanent) structures are required to secure the stability of the coastline during installation or operation time.

In addition to the onshore pipeline aspects, the wave, current, storm surge, morphology and sand transport phenomena play a role for the landfall.

9.2.8 Sinking

The pipeline is installed in a watercourse to be crossed by sinking. First a trench is dredged in the bottom.

Installing a prefabricated pipeline or sag pipe can be achieved by dragging with a winch or hoisting with cranes or hoisting floating sheers or driving, filling and immersing or using combinations of the aforementioned methods.

The dredged trench shall be backfilled with care after the sag pipe has been installed.

9.3 Installation Preparations

The approved calculations, the drawings, the specifications, the geotechnical report, the construction descriptions, the safety, health and environmental plan and the identification of objects and facilities that are influenced by the construction shall be available before the start and permits/licences shall be available or it shall be made sure that they will be obtained.

If a pipeline has to pass cultivated land (arable land and meadows), a land-use survey (see I.1) shall be performed during the design phase. The land-use requirements and recommendations shall be adhered to when the pipeline is installed.

If groundwater extraction is required during the installation, a geohydrologic survey (see I.2) shall be performed during the design phase. This shall be done in relation to the extraction of groundwater and drainage thereof. The geohydrologic report shall contain data related to the water quantity, water quality, environmental aspects related to this, the drainage type to be applied, period, discharge of drainage water and artificial recharge. Possible displacement of bottom contamination elsewhere should be taken into account. During the installation and thereafter, the discharge (of groundwater) shall be registered.

Before starting with the installation, permits/licenses shall be obtained and private agreements with land owners and users shall be concluded.

Arrangements shall be made with third parties involved in relation to the site, the access to the site for personnel and material and/or the use of storage areas for material, machinery and equipment.

All interested parties (private persons, authorities and other managers) in relation to the installation shall be warned and informed regarding the nature, the size and the duration of the installation activities before the activities start.

Owners of existing cables and pipelines in the route shall be informed regarding the planned activities. A sentence has been deleted.

NOTE Depending on the nature and size of the activities, the decision may be taken to hold a kick-off meeting at which the involved pipeline managers and/or their representatives, license and/or permission holders and licensing authorities are present. The contractor presents, during this meeting, a plan of approach (working plan, planning, protective provisions, approved drawings and such). The customer (entrepeneur of the new pipeline work will also provide in writing the name, address, and telephone and fax number of the contact that he has appointed for the duration of the works.

9.4 Transport and Storage

Loading and unloading, transport and storage of pipes, fittings and other material shall be performed carefully to avoid damaging pipes, pipe ends, coatings and other material.

Materials shall be inspected to check for damage, deformations and deterioration. Materials with unacceptable damage, deformations or deterioration shall not be installed.

NOTE Aspects that are important: pipe shall be supported well to ensure that the coating is not damaged, do not roll or drag pipe, a stable storage, sufficiently wide hoisting belts made of a soft material, hooks shall have a plastic layer, the bottom of the pipes should not touch the ground when stored, adequate (temporary) protection against material degradation such as corrosion or UV and O_3 effect, completeness of inspection certificates and other cover documents. In relation to transport and storage activities, the prevailing safety regulations (as supplied by the ARBO-wet, (Working Conditions Act), and the Wet Gevaarlijke Werktuigen, Hazardous Plant and Equipment Act) shall be observed.

9.5 Installation Field sections and Aboveground Pipelines

9.5.1 Tracing and Marking

The center of the pipeline route is measured and staked out in the field. The pipeline route and the working strip as well as the special objects within the influence zone thereof are marked whereby the location, type, depth and properties of the structure concerned are specified. The markings shall be adhered to and/or ensured during installation.

9.5.2 Route Study

Prior to the site preparation and the start of the construction works a detailed route survey shall be performed. Survey reports shall be drafted in consultation with the parties involved.

9.5.3 Site Layout

A working strip with sufficient width shall be established for good and safe realization of the activities and supply of material, machines and equipment.

Aspects that shall be observed during construction and, later, restoring the working strip are:

- tracing, marking and placing warning signs near aboveground high-voltage lines under which the working strip can be found (in compliance with Chapter 6 of SI 5664-2);
- bearing capacity of the subsoil;
- accessibility in relation to, for example, cattle;
- original land use (for example, arable land, grassland, protected natural area, industrial area) and restoration of this function after pipeline installation (see the agriculture-technical report);
- felling trees with a permit or removing obstacles;
- any need to remove and separately store the topsoil (restoration of the original state, see the land-use report);
- sand lane (quality and processing);
- well-point drainage and discharge point;
- land-use drainage;
- land-use drainage header or reservoir (temporary);
- demolition of above ground structures.

9.5.4 Activities near High-Voltage Connections and /or Overhead Wires of Railways and Tramways

Prior consultation shall take place with the company under whose management the wires (or installation) fall in relation to the safety provisions to be made when work is performed near aboveground high-voltage cabling (also overhead wires of railways and tramways) and transmitter towers.

The safety provisions for high-voltage connections to be observed are included in chapter 6 of SI 5664-2.

9.5.5 Underground Pipeline Excavation work

9.5.5.1 General

Excavation work shall be performed in such a way that damage to the cables and pipelines present in the ground is avoided. In case excavation work is performed within a distance of 1 m in parallel to existing cables and pipes, excavation shall, by preference, be done using hand tools unless measures have been taken to avoid damage. This also applies for crossings with existing cables and pipelines. Damage to existing (deep) land-use drainage systems or irrigation systems shall be avoided or adequately be repaired after installation. In case of non-horizontal trenches, it shall be prevented that the trench can act as a water discharge ..

9.5.5.2. Trenches

The pipeline shall be installed, according to the working drawings, with sufficient soil cover. It is important that excavation is not deeper than the level that is specified for the bottom of the pipeline in order to minimize consolidation/subsidence of disturbed soil. The slope of the trench walls shall be adjusted to the trench depth, the drainage and the soil type to ensure the trench walls cannot collapse and/or subside. If required, the trench wall shall be shored up using trench partitions.

NOTE The relevant safety regulations for slopes shall be observed.

It is important to construct the trench bottom in such a way that the pipeline is installed as anticipated in the calculation. It may be necessary to lay a sand layer under the pipeline. To excavate deeper than required shall be avoided in connection with occurring consolidation of the disturbed soil. Additional settling may occur as a consequence in soft subsoil's.

The trench wall border shall match the excavation depth, drainage and soil type.

The trench shall be kept free of objects that may damage the pipe or coating of the pipe. Gravel, stones and/or other hard/sharp material near the final position of the pipeline shall be removed. If this is not possible, the pipe shall be provided with a protective coating or the pipeline shall be embedded in clean (sandy) soil.

9.5.5.3 Storage of Excavated Soil

Excavated soil shall be stored in such a way that the original constitution of the soil profile is re-obtained as much as possible when the trench is later backfilled (at least the top 300 mm of the backfill).

Topsoil present shall be stored separately from the underlying layers as specified in the land-use report or in consultation with the land owner/user. In certain cases, it may also be necessary to excavate and store the subsoil separately. The storage shall be harmonized in relation to the local soil composition.

In principle, soil deposits are not planned above an existing underground pipeline. If this is necessary, however, it shall be checked, in consultation with the pipeline owner, whether this is possible and whether special provisions shall be made to protect this pipeline.

9.5.5.4 Use of Explosives

If explosives are to be used, it shall be provided for in the design of the pipeline. Special regulations apply and an explosion plan shall be drafted.

The note has been deleted.

9.5.6 Pipeline Installation in Open Trenches

9.5.6.1 General

A subdivision can be made between installation of an axially rigid and an articulated pipeline in a dry trench or in a wet trench.

9.5.6.2 Dry Trench Installation

Axially Rigid Pipeline

The pipeline is lowered in the trench after mounting the string and finishing the connections between the pipe elements. The trench shall be dry at this moment and shall remain dry until the trench is backfilled. The pipeline shall be installed in a dry bed.

NOTE 1 The installed pipeline can be set afloat should there be water in the trench.

The string shall be lowered using hoisting equipment. The hoisting resources to be used such as hoisting belts and slings shall be covered to ensure that the pipe and coating are not damaged.

It is important that as little as possible stress is allowed to build up in the pipeline both during assembly and lowering of the pipeline. The admissible curvature of the pipeline and the slight bending rigidity of the bends should be taken into account. The lowering shall also be done without shocks to avoid buckling and wrinkling of the pipeline or other permanent deformations. After lowering the pipeline, the position should be corrected if required. The position of the pipeline shall be surveyed thereafter. The use of resources not anticipated in the design to keep the pipeline in its place is not permitted.

Articulated Pipeline

Pipeline elements that are connected with a bell-and-spigot joint form an articulated pipeline which is not axially rigid. Articulated pipelines are, in general, built up in the trench. The trench shall be dry during installation up to backfilling.

A rubber ring provides the sealing of the pipe connection for the internal pressure. The correct assembly of the rubber ring can be checked during assembly of the pipe elements. This often leads to the decision to backfill the trench immediately after installation of the pipe elements. Buoyancy forces on the empty pipe in the returning groundwater shall be taken into account. The trench backfill also prevents the articulated pipeline from becoming deformed through initial thrust force at the location of the couplings during the hydrostatic test.

The available slide-out length with non- tension couplings shall be divided among the construction phase and the operational phase. Any direction corrections and the method for backfilling shall be geared towards the available length by which it can be extended. During installation, the joint displacement that is available for the installation, whether internal or external, shall be monitored.

NOTE 2 It is advisable to record the jointing openings of every coupling in case of accessable articulated pipelines.. Thejoint opening is measured round the pipe circumference at 3:00, 6:00, 9:00 and 12:00 o'clock position . The angle of rotation of the joint and the axial width of the joint can be determined from the measurements as well as the three-dimensional position of the pipeline. Requirements can be included in the design regarding the admissible rotation and width.

NOTE 3 It has been observed based on joint measurements that some pipe elements undergo a slight axial movement when pipelines are immediately backfilled after installation in soft Holocene soil. The impression exists that the elements only lay still after the groundwater level is stable again.

9.5.6.3 Submerged Installation

Submerged installation is appropriate when the area has relatively many watercourses or when the soil conditions are such that many provisions are required (or it is impossible).to achieve a dry trench

The trench is oversized in order to make a channel through which a section can be floated or towed in and, subsequently, sunk.

This installation method can be applied for both rigid and articulated pipelines. The couplings in the articulated pipeline shall, in that case, be tension resistant..

9.5.6.4 As-Built Survey Pipelines

In general, it applies that the position and(X,Y AND Z) of the pipeline shall be surveyed in the open trench during installing. Preferably in coordinates ("Rijksdriehoekscoördinatensysteem; national triangulation coordinate system). The survey work shall be recorded accurately in digital or analog form. The recorded data are the basis for the as-built drawing of the pipeline.

9.5.7 Trench Backfill

9.5.7.1 General

The backfill work and site finishing shall take place based on the land-use report and the safety regulations to be observed. The backfill of the soil in layers shall take place after lowering the pipeline.

If installed submerged, backfill shall take place, by preference, in the water when the flow is directed downwards to ensure good compaction. The water has to also be driven forwards when backfilling, to avoid water closing off in the trench.

In peaty areas, lightweight material is applied under the groundwater level (peat and wood fiber pellets) and 'Flugsand' (i.e. volcanic tuff sand) or another lightweight granular material on top to limit soil settling.

The excavated material shall be backfilled with care in the correct sequence and should be free of stones and such to restore as much as possible the original profile. The trench shall be filled with soil free of coarse and hard components up to a height of 0.3 m above the top of the pipeline to protect the pipeline and coating. This first backfill layer shall have such a quality and compaction that the pipeline is given an even and sturdy support on all sides and over the whole length. Backfilling shall occur in such a way that the assumptions for the soil mechanical parameters, as used in the design, are fulfilled

A slight surplus soil cover on top of the trench shall be applied , if necessary, to compensate for subsidence of the backfill material. At road crossings this shall be done in such a way that the traffic will not be greatly disrupted or is otherwise warned using temporary traffic measures in consultation with the road manager.

9.5.7.2 Pipeline Design Requirements and Soil Property Changes

Softening the soil

If the modulus of subgrade reaction is too high to ensure safe soil bedding conditions for the pipeline , increasing the freedom of movement of the pipeline may be considered by applying lightweight compressible plastics. Its application may only occur where no additional risk can occur for public works.

The plastics shall be made for the type of structure being considered for application.

The elasticity modulus of the plastics to be applied shall be low ($E \leq 1$ N/mm^2).

The compressive and tensile strengths may not be exceeded in the course of time.

The material shall be able to withstand hydrolysis and mold.

NOTE For now only cell rubber (foam rubber made of butyl rubber with 100% closed cells) is deemed suitable for this aim.

Hardening the soil

Adequate chemical soil injection methods may be applied ,to ensure that the top load on the pipeline is diverted sideways and/or the reaction force at the pipe bottom is more evenly spread.

An adverse side effect is that the modulus of sub grade reaction also increases.

Sand and gravel-containing sand can be considered for application: clay and peat soils are not suitable for injection.

Soil of sufficient bearing capacity (sand) shall be present under the soil to be treated. Soft layers (clay and peat) will lead to subsidence.

Before switching to chemical injection, a soil investigation shall be performed to obtain insight into the grain size distribution of the soil and the composition of the layers to be injected.

In order not to increase the volumetric mass of the soil too much, the volumetric mass of the chemical injection liquid shall not be much heavier than the volumetric mass of water (approx. 1050 kg/m^3).

The best result with regard to a regular distribution of the injection agents is obtained in undisturbed soil whereby the top injection level shall lay at least 0.75 m below grade.

NOTE With less soil cover, the injected chemicals may not arrive at the required location due to the formation of leakage paths. Injecting in a backfill may give less adequate results due to irregular packing density (leakage paths) and contamination.

The effect of the injection on the soil properties shall be checked using cone penetration tests and sample borings. The petrified sand mass can also be excavated for inspection.

Compaction

In case more horizontal soil support on the pipe is required the trench backfill next to the pipeline has to be compacted The following applies in order to be able to deem the backfill as compacted (for strength calculation purposes, see also D.3.5 for the other requirements)

The backfill soil is sand that is placed carefully in the dry trench and is compacted mechanically in layers at a maximum of 30 cm. This is continued up to a minimum of 0.15 m above the top of pipe before the trench is backfilled with other soil and compacted if required. The percentage of the maximum proctor density shall be larger than or equal to 94%. This shall be proven with manual cone penetration tests. The backfill will be deemed not compacted within the framework of this standard if the percentage is lower.

9.5.7.3 Requirements Related to Grade Use

The use of the grade (for example, paved surface or surface with plants and shrubs) puts requirements in relation to the finish of the (top) of the trench.

Below Paving

The compaction below the paving can be checked measuring cone resistance (cone surface of 100 mm^2 and vertex angle of 60 degrees).

The resistance shall increase by a minimum of 0.2 MPa per 10 mm penetration depth and/or it shall amount to at least 4 MPa.

The cone resistance shall amount between 4 MPa and 6 MPa at a depth of 0.6 m.

The compaction from 1.0 m below the grade is not relevant.

Paving

Paving that has been taken up shall be relayed in its original state.

Quality ,color and dimensions of building materials to be supplied shall agree as far as possible with the building materials present.

Paving brick and concrete pavior roadway paving shall be strewn with sand or crusher sand and compacted (using a vibrating machine). Pavior paving shall be washed in.

The longitudinal and cross-sectional profile of the paving shall agree with the original altitude with sufficient surplus height to compensate for the remaining consolidation/subsidence after the compaction of the trench backfill

Non-stabilized foundation

Non-stabilized foundations that have been taken up shall be reinstalled and shall be supplemented with equivalent building materials up to the original layer thickness unless otherwise agreed.

Under Plants and Shrubs

Soil, except topsoil, that is used in backfills in plant and shrub sections or below grass at a depth of less than 0.8 m shall have a cone value of no more than 1.5 MPa after compaction. This does not apply to water-retaining structures or verges.

Excessive compaction of subsoil or structure decay shall be prevented when compacting soil in plant and shrub sections or below grass.

Topsoil shall not be compacted.

Provisions Related to Activities in or near Green Areas

In consultation, it will be determined which plants and shrubs (trees, shrubs, plants and turfs) may be removed for the activities and which and how they shall be put back once the activities have finished. Plants and shrubs that has been removed shall be stored professionally on a temporary basis to prevent them from dying.

Removed plants and shrub material that does not strike once it has been returned shall be replaced with new similar material in a favorable season after consultation.

Damage to the plants and shrubs that are to be kept shall be compensated for.

NOTE Root growth (for example, in asphalt coating or bell-and-spigot joints) can occur with certain plants and shrubs. Root growth can be discouraged by applying a root sheet or by installing the top of the pipeline 0.50 m below groundwater level.

9.5.7.4 Soil Deficits and Soil Surpluses

Soil deficits can occur with certain soil types after backfilling the trench. These deficits shall be supplemented with soil that meets requirements that agree with the land use (prior soil analysis).

Any soil surpluses (after the surplus height has been installed) or soil that cannot be used for backfilling shall be removed after approval from the ground owner. This shall never be the top layer or the topsoil, respectively.

NOTE Soil deficits occur especially in peaty areas as a consequence of oxidation and irreversible contraction. Surpluses can occur (aside from the surplus created by the pipeline volume) in ice cap preloaded areas as a consequence of over-consolidation.

9.5.7.5 Warning Tape

If warning tape may clearly prevent damages to the pipeline, such tape shall be installed. The correct location is on top of the pipeline half-way between the top of the pipeline and the grade. This tape shall be in a bright and eye-catching color (for example, yellow).

9.5.7.6 Site Finish

As soon as possible after backfilling completion, the site shall be cleaned. All material, extra plants and equipment and leftover material shall be taken away. The working strip shall be restored to its original state. When cultivated land is involved, due attention shall be paid to the final cultivation of the work strip used based on the land-use report.

Drainage of cultivated land shall be restored if applicable.

A final inspection of the site shall be performed with all involved parties, including the land users, land owners and licensing authorities.

9.5.8 Proximity and Crossing of Underground Structures (Including Existing Cables and Pipelines)

The method used for crossing and excavating shall be determined in consultation and agreement with the user or owner of the underground structure. Special measures may be necessary to avoid structural damage. If necessary, hand tools shall be used for excavating.

Special provisions apply to pipelines near aboveground high-voltage lines (see also 9.5.4).

9.6 Installation of Crossings

9.6.1 General

The way in which pipelines cross roads, railways, watercourse, dikes and embankments depends on the local circumstances and shall be determined in consultation with and with the permission of the relevant licensing authorities. If casing pipes are to be used or sheet pile wall structures will be applied, it will be specified in the design.

The design shall specify provisions such as sheet pile walls, casing pipes and construction methods. These shall also be depicted in drawings and descriptions for construction.

The crossing shall comply with clause 6.5 in relation to major public works. Crossings including eventually related safety zones can be constructed separately from field sections. special attention shall be given, in this case, to the connection, especially the “tie-in” (outside the safety zone), the bedding of the pipe and the backfilling of the trench on site.

9.6.2 Casing pipe

The following requirements shall be met when installing casing pipes (also see 8.1.7):

- the fluid carrying pipe shall be provided with sufficiently suitable spacers (“thinsulators”) at adequate distances. This shall especially be taken into account (concentration of spacers) at the ends of the casing pipes where there is a transition in installation method (construction settling difference). It is advisable to jack up and retain thefluid carrying pipe prior to backfilling the trench or the pit to ensure the spacers in the top of the casing pipe make contact and the differential construction subsidence can (partially)occur without the fluid carrying pipe resting on the casing pipe;

- there shall not be any internal projections in the casing pipe. The casing pipe ends shall not have any sharp edges.

Refer to 9.7 of SI 5664-2 in relation to pipelines that shall be provided with cathodic protection and are in a casing pipe.

9.6.3 Trenchless

In certain cases (for example, a road that cannot be closed) and in other cases (most economic or safest solution) a crossing may be constructed without a trench.

Meticulous construction shall take place at the transition of a thrust bored or drilled crossing to the field section to limit the subsidence difference of the pipeline. A good compaction of the backfill of the jacking pit and collection(receiving?) pit is required; especially for a crossing with a thrust bored or drilled casing pipe. This requirement is less stringent for two cases:

- if the crossed road embankment is heavily susceptible to subsidence (for example, a ramp to a bridge or viaduct);

- if the pits are provided with a groundwater retaining floor (made of underwater concrete) and the sheet pile wall boards are not removed (burnt down above the floor).

The various trenchless methods are described in Appendix G.

9.6.4 From the Building Pit without Groundwater Extraction

If no groundwater extraction should take place, the bottom of the building pit can be closed off with (underwater) concrete. The building pit and concrete slab shall be dimensioned in such a way that forcing up is prevented.

The closing off shall be done in such a manner that there is no communication between phreatic water and artesian water.

The foundations of the concrete floor that stays behind in the works can be pile driven on a sand layer with bearing capacity to limit the additional (construction) subsidence or the pit can be filled above the floor with lightweight material (for example, peat or wood fiber pellets under the groundwater level and expanded clay pellets, polyurethane foam, foam concrete or Flugsand above the groundwater level) to limit the particle tension under the concrete floor to the original level. It may be necessary to bed in the pipeline using ‘soft material’ to prevent hard line support; for example, peat bales whereby the spaces are filled with bentonite powder.

NOTE The peat bales with bentonite powder fulfill three functions to prevent oxidation (if under the phreatic surface): 1) light, 2) closed (after swelling) and 3) soft material.

The vibratory extraction of sheet pile walls leads, in all cases, to greater subsidence of the soil and a larger subsidence difference, respectively, for the pipeline (see C.4.7.4). Burning of the walls above the concrete floor will prevent this.

Also, there should be no communication between the phreatic water and the artesian water once the sheetpile walls have been extracted. There should be a sealing soil layer underneath (not disturbed) or above (disturbed) the concrete floor.

9.7 Station Construction

The installation of the station units shall be carried out with care and skill and in compliance with the design. Attention should be given to the following among others:

- the various devises and pipelines shall be effectively supported;
- the installation instructions from the manufacturers shall be taken care of;
- incoming and outgoing pipelines shall be installed and supported in such a way that no inadmissible tension can occur in the equipment. Attention shall especially be given to possible subsidence differences between the pipeline foundation and the station especially when piles are supporting the station.

9.8 Cleaning and Out-of-roundness Check

9.8.1 General

After completion of the pipeline construction or a part thereof, it shall be cleaned and tested, and, if necessary, calibrated and dried.

9.8.2 Cleaning

Before starting the hydrostatic test (see 9.9), the pipeline shall be cleaned using a suitable brush (pig) until all the dirt has been removed.

The pig speed shall be checked and registered.

The pipeline shall be provided with a seal before and after the test to prevent dirt, animals and such from entering the pipeline.
Once the pipeline hydrostatic test has been approved, the pipeline shall be cleaned and emptied using pigs. The discharge of the water that is used for the hydrostatic test shall not be a nuisance.

Drinking water pipelines shall be delivered bacterially reliable.

9.8.3 Out-of-roundness Check

The calibration, checking for any out-of-roundness, root welding penetration and dents shall take place by sending a pig provided with a thin metal disc, ("for example," has been deleted) made of aluminum, with a thickness of 3 mm to 5 mm through the pipeline.
The diameter of the metal (aluminum) disk shall be 95% of the internal pipeline diameter, with 25 mm clearance.

Calibration is not necessary in relation to pipeline sections that can be adequately inspected visually (for example, because of the large diameter) or through another method.

9.8.4 Drying

Once the pipeline has been cleaned and emptied, it can be dried, if necessary, using, for example air up to a dew point as specified in the pipeline design requirements.

If the pipeline will not be put to use immediately after delivery, it is advisable to protect the pipeline.

9.9 Tests

9.9.1 General

Transport pipelines shall be tested for strength and tightness before handover. The test shall be performed with water. In exceptional cases other media may be used. This shall be specified in the design. The water shall be suitable (not too dirty, not too aggressive) for the application.

A strength test is sufficient for tests of casing pipes that have to withstand the design pressure of the media transportation pipeline (see also 8.1.7). A tightness test is not necessary.

The pipeline shall be filled in such a way that inclusion of air that influence test results is avoided. The filling of the pipeline is usually performed with rubber balls or foam pigs.

The trench is usually backfilled to prevent large temperature differences during the test. If the soil temperature at the pipeline is below 2 ºC, in general, antifreeze has to be added to the water.

NOTE 1 Additions such as antifreeze can be a problem in relation to obtaining permission for discharging.

NOTE 2 Time should be taken for leveling the temperature and stabilizing for the resolution of small inclusions of air pockets.

9.9.2 Plan for Testing

Regardless of the material type, a test plan shall be drafted before the test takes place. As a minimum the following should be described in the plan:

- the pipeline (section) to be tested;
- the duration of the leveling and stabilization before the test;
- the pressure level and the duration of the tests;
- the realization of the strength and tightness tests;
- the calibrated measuring equipment including inaccuracies of, among other elements, pressure gages, thermometers, recording manometers and discharge meters;
- the location of the measuring equipment;
- the registration method of the measurements;
- the test values and/or calculation of the acceptability of the test.

9.9.3 Completion

A report is drafted for the test in which at least the following data is included:

- interested parties or applicant;
- pipeline builder;

- identification of the tested section;
- the value for the design pressure;
- the value for the pressure during the strength test and the duration thereof;
- the value for the pressure during the tightness test and the duration thereof;
- the test medium;
- the results;
- reference to the test procedure.

9.9.4 Safety during Testing

The safety of personnel carrying out the tests, the environment and the installation shall be safeguarded during testing. Although explosions do not occur when testing using liquid, the propulsion of a section or spraying away of the test liquid during failure may constitute a hazard to people.

A test procedure including the safety measures (ARBO-technical) to be taken shall be drafted.

If it is unavoidable that the test is to be performed during a period in which the pipeline and the pumped in water are liable to temperature fluctuations, the necessary measures shall be taken against an inadmissible pressure increase or decrease.

9.10 Handover

9.10.1 Documents

Quality records that contain all documents ("as built" construction drawings, geomechanical reports, design calculations, welding and pipe book, NCR's, etc.) with the location and description of the pipeline shall be put together by the end of the works. These files are transferred to the owner of the pipeline system and is a part of the management system (refer to Chapter 10). For offshore pipeline, pipeline's owner shall take the necessary steps required in order to mark the pipeline route in the relevant Admiralty maps.

9.10.2 Precommissioning and Commissioning

Preparation for commissioning ("precommissioning") shall occur before bringing up to pressure for the commissioning of the pipeline system. During precommissioning, the correct operation of all parts and of the system as a whole shall be demonstrated. The provisions and control sections required for a safe transportation of hazardous substances shall be configured and adjusted during that phase. The system shall undergo a test with a (harmless) medium to demonstrate correct operation. It is advisable to draft a plan with all sequential activities that shall be performed including "hold and witness" points before precommissioning.

The pipeline system shall be transferred to the manager after precommissioning along with inspection certificates, quality administration, as-built drawings and maintenance and control manuals.

The system may only be commissioned if completely installed, tested and cleaned and connected to upstream and downstream installations if applicable. The management control system shall be in place and shall be operational at that moment.

9.11 Verification and Inspection

Effective inspection (by or in the name of the pipeline owner) is essential to check and verify that the specified materials have been applied and that the structural works are performed according to this standard, the specifications and the drawings during the installation of a pipeline system or parts thereof.

Verification shall be performed in relation to:

- land survey for route marking, partitioning and fencing the working strip;
- land-use activities;
- excavation work; especially the separation of different layers, setting out trench dimensions;
- groundwater extraction;
- quality and dimensions of pipes and other material included related inspection documents;
- material transport, storage and management; especially in relation to pipe and coating damage;
- removal of rejected material at the site;
- connections including pretreating and adjusting;
- installation of the pipeline including admission into the trench and setting out dimensions for the installation and survey for revised drawing as well as sufficient clearance in relation to other structures (sheetpile walls, pipelines from third parties, etc.);
- trench backfilling including compaction, surplus height; install subsidence and/or settlement markers if necessary;
- testing;
- trench and site final finishing;
- additional supervision for crossings.

With inspection is meant the verification of the deliveries of materials and structures. The pipeline elements shall be inspected and it should be checked whether the requirements of the standards and specifications through tests and inspection documents have been met. These inspections involve both the (parent) material and the assembly and the proper operation of accessories and structures.

Certain parts of the pipeline system fall under the Machine Directive (for example, valve or actuator combinations). Refer to Appendix J for information in relation to verification points based on this directive.

Third party approved

Prior to handover, the pipeline system, or part of, as applicable, shall be approved by a third party organization (Type A institution according to ISO/IEC 17020:1998).

The approval shall be based on an inspection plan, agreed upon by the contractor, the pipeline owner and the third party. Refer to Annex L for guidelines for such a plan.

9.12 Safety

9.12.1 General

All activities related to the construction of the pipeline systems shall be installed in compliance with the prevailing legislation and regulations regarding the safety and working conditions. The regulations that are applicable to this area shall be available at the works.

9.12.2 Compliance with Safety Regulations

Personnel involved in the construction of pipelines shall be trained regarding the legislation and regulations for safety and working conditions applicable to the site. Executive personnel and supervisors shall ensure that the prevailing regulations are complied with.

9.12.3 Construction, Environmental and Safety Plan

The construction, environmental and safety plan shall have been drafted before the activities begin. As a minimum, the following should be included in the construction, environmental and safety plan:

- the prevailing safety regulations;
- environmental regulations;
- the manner in which the instruction and personnel information is arranged;
- the manner in which supervision is arranged;
- the manner in which contamination of the environment is avoided and managed, respectively;
- a risk inventory and evaluation in relation to the activities to be performed;
- the manner in which mishaps are concluded and accidents are dealt with.

Personnel involved in the performance of the activities shall be informed regarding the content of the safety plan and shall act accordingly.

9.12.4 Accessibility of Adjoining Buildings

The accessibility of houses, public buildings and such should be safeguarded for (disabled) pedestrians. The degree of accessibility can be further determined in consultation with the involved parties.

Local motorized traffic to houses, shops, companies, buildings, farms, etc., shall be maintained as much as possible in consultation with the involved parties.

If due to limited accessibility, emergency services cannot arrive sufficiently near objects or the supply of shops and companies shall be arranged in a different way than normally, it is necessary that interested parties and the municipality are consulted beforehand.

9.12.5 Third Party Requirements

For activities on or near the properties and installations of third parties, prior consultation shall occur regarding any specific precautionary safety measures. These measures shall also be included in the safety plan.

9.13 Environmental Contamination

Environmental contamination shall be avoided.

If contamination, however, occurs, the size and duration shall be limited to the minimum. Contamination shall be cleaned up in consultation with the appropriate authorities.

10 Operational Management and Termination of Operations

10.1 General

The Operator/Owner of the pipeline system is responsible for the durable and economic operational management of the pipeline system whereby human life and the environment (physical surroundings and property) are protected.

Prevention policy shall be implemented for the execution of the above through what will be referred to in this document as a management system.

Four lines have been deleted.

Pipeline Management System

The management system shall apply for the whole of the operational management period up to the decommissioning of the pipeline system. The premises are:

- to have the pipeline system operational durably, economically and safely and complying as a minimum with prevailing requirements;
- monitor its condition
- carry out maintenance safely and effectively;
- limit harmful consequences for human life, the environment and property to a minimum in case of incidents and emergencies;
- monitor the immediate surroundings of the pipeline.

Management System Setup and Scope

The environmental management system of the ISO 14000 series for environmental systems is the basis for the tasks of care within a management system. Requirements have been included in relation to the organizational aspects and working methods of a management system in the SI-ISO 14001:2005 and SI-ISO 14004:2005 standards. A system that is designed based on the requirements of these standards can be audited. External safety requirements (see 6) shall also be described and shall be implemented in a pipeline management system, as well as environmental requirements.

NOTE Where the SI-ISO 14001:2005 and SI-ISO 14004:2005 standards refer to environment as the only field of application, this term can be replaced with human life, the environment, physical surroundings and property in relation to a pipeline management system.

Technical aspects that are content-specific in relation to management systems can be found (for steel pipeline systems) in Chapter 10 of EN 1594:2000 for natural gas and in Chapter 13 of ISO 12623:2000 for oil and natural gas as well as elsewhere.

A management system will give center stage to the integrity of the pipeline system. Just like the environmental system (see ISO 14000 series), the management system for pipelines shall be in a process of constant improvement. This takes place in the shape of a quality cycle in which the risk is assessed, plans for risk limitation are drawn up and implemented and, subsequently, a check is done to verify whether expectations are being met and/or whether implementations shall be adjusted.

10.2 Operational Management

10.2.1 General

The pipeline system is constructed according to the design and drawings that have been developed in the stages that preceded the commissioning of the system. The possible risks of the system will have been identified during those stages, they will have been allowed for in the design and, where necessary, will have been described in the operation manual. The operational management itself will be carried out within the Pipeline Integrity Management cycle of the pipeline system. Figure 10 provides a diagram of this cycle.

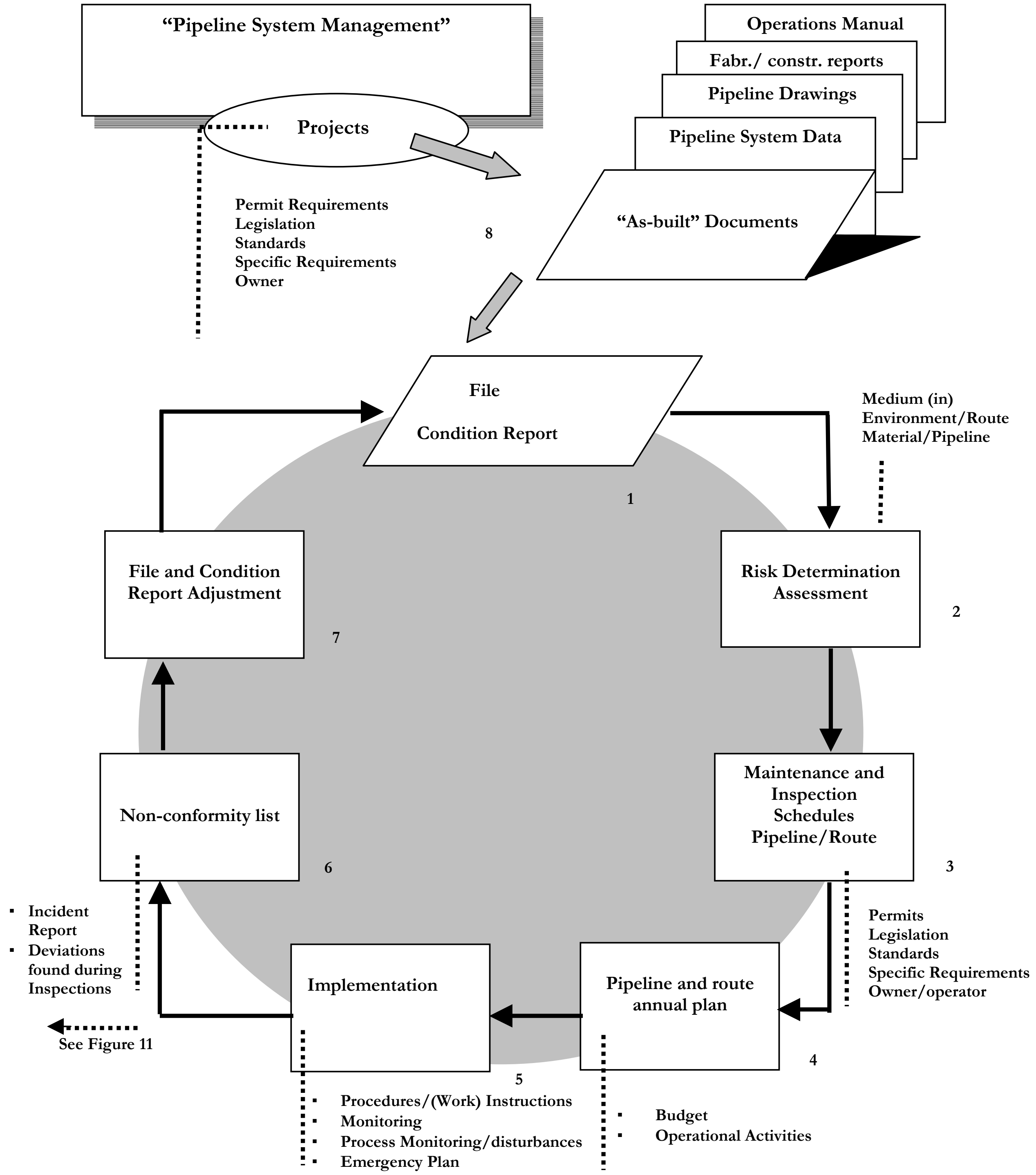


Figure 10 – Pipeline Integrity Management Cycle

10.2.2 Quality Cycle Activity Description

The “Integrity Management cycle” cycle has been subdivided in seven steps in Figure 10. A description is given below regarding the activities that shall be performed for each subsequent step.

Condition Report (1)

The file will contain all information and documents regarding the pipeline system ,created during the design, installation and commissioning of the pipeline system. in addition to the necessary procedures for the operational management, they may include:

- information concerning the physical position of the pipelines;
- pipeline data, material, lining, inspection documents;
- inspection reports and test certificates;
- safety systems;
- permits.

The file will also include the (annual) report regarding the integrity of the pipeline system (the result of the completed circle).

Risk Determination (2)

It is important to know the existing internal (own company) and external incident frequencies (for example, the CONCAWE, EGIG, DOT-OPS and VELIN databases, or equivalent, approved by the Natural Gas Authority) for determining the risk.

It is important that factual knowledge is available regarding risk of failure mechanisms and risk-reducing measures.

Knowledge of the consequences of ‘’ of pipeline failure on its surroundings is also important when determinating the risk (probability x effect).

Risks arise from:

- the route environment (around); for example, threats due to activities of ‘third parties’;
- the transported fluid (in); for example, corrosiveness or exceeding the maximum allowable operational pressure (MAOP)
- the used pipeline materials and/or construction methods ; for example, installation faults, failure of the cathodic protection system, soil overburden, etc.

The sequential working method when determining the seriousness of a risk takes place as follows:

1) select an activity (for example, gasoline transportation) in one of the three risk areas given above;
2) iIdenify the potential aspects (scenarios) of the activity based on knowledge of the possible failure mechanism (for example; leakage caused by third parties interference);
3) determine the effect (potential harmful consequences) of the scenario (for example, duration, scale and seriousness of the harmful effect in relation to the environment, safety, health, reputation, finances and product quality service);
4) identify the probability (with and without own activity) of the scenario becoming a reality. Knowledge of risk-limiting measures is important. If these measures are not being met, the probability shall be assessed as being higher than when all known risk-limiting measures are implemented.
5) calculate the estimated risk from 1) up to 4) for each scenario. The calculation will supply two figures: with and without limiting measures (low and high, respectively);
6) determine the limit in relation to the significance of the scenario (estimated risks). This figure (estimated risk) results from an annual policy decision;
7) check whether legislation and regulations have been complied with (including permits/licenses) for each scenario. The scenario concerned is significant if this is not the case. Risk-limiting measures shall be implemented to (again) comply;
8) list the scenarios based on importance;

9) determine and activate measures based on significance and/or importance;

10) necessary measures can be:

- adjustment of activities (management system or maintenance schedule);
- implement projects or annual plan (once-only actions)

Maintenance and Inspection Plans (3)

The objective of maintenance and inspection is geared toward maintaining the pipeline system in good working order to ensure an optimal operational management ('fitness for purpose') during the planned operational life cycle while complying the company policy. An optimal operational management is achieved when the failure mechanisms have been identified, legislation is complied with and the license requirements and relevant standards as well as specific requirements of the owner are being met.

The performance standards for the activities shall be determined as well as the acceptance criteria for what will still be deemed as being acceptable when unusual incidents and uncommon operational circumstances occur. The manager shall give shape (or allow someone else to give shape) to this in connection with the effective company policy.

1) Periodic Surveillance of Pipelines

As a means of maintaining the integrity of its pipeline system, each operating company shall establish and implement procedures for periodic surveillance of its facilities. Studies shall be initiated and appropriate action shall be taken where unusual operating and maintenance conditions occur, such as failures, leakage history, drop in flow efficiency due to internal corrosion, or substantial changes in cathodic protection requirements.

When such studies indicate the facility is in unsatisfactory condition, a planned program shall be initiated to abandon, replace, or recondition and proof test. If such a facility cannot be reconditioned or phased out, the maximum allowable operating pressure shall be reduced

2) Pipeline patrolling

Each operating company shall maintain a periodic pipeline patrol program to observe surface conditions on and adjacent to each right-of-way pipeline, indications of leaks, construction activity other than that performed by the company, natural hazards, and any other factors affecting the safety and operation of the pipeline. Patrols shall be performed at least once each year in Locations Classes 1 and 2, at least once every 6 months in Location Class 3, and at least once every 3 months in Location Class 4. Weather, terrain, size of line, operating pressures, and other conditions will be factors in determining the need for more frequent patrols. Main highways and railroad crossing, as well as swelling clay areas, shall be inspected with greater frequency and more closely than other pipelines.

3) Maintenance of Cover at Road Crossings and Drainage Ditches

The operating company shall determine by periodic surveys if the cover over the pipeline at road crossings and drainage ditches has been reduced below the requirements of the original design. If the operating company determines that the normal cover provided at the time of pipeline construction has become unacceptably reduced due to earth removal, erosion or line movement, the operating company shall provide additional protection by providing barriers, culverts, concrete pads, casing, lowering of the line, or other suitable means.

4) Maintenance of Cover in Cross-Country Terrain.

If the operating company learns, as a result of patrolling, that the cover over the pipeline in cross-country terrain does not meet the original design, it shall determine whether the cover has been reduced. If the level is unacceptable, the operating company shall provide additional protection by replacing the cover, lowering the line, or other suitable means.

5) Leakage Surveys

Each operating company of a transmission line shall provide for periodic leakage surveys of the line in its operating and maintenance plan. The types of surveys selected shall be effective for determining if potentially hazardous leakage exists. The extent and frequency of the leakage surveys shall be determined by the operating pressure, piping age, class location, and whether the transmission line transports gas without an odorant.

Annual Plan (4)

The annual plan determines the actions that should be undertaken including the required budgets and other resources, including:

- the maintenance plan for the pipeline system for that year;
- the once-only activities that are required;
- the co-ordination with with and the planning of operational activities and operation stops
- the inspection of equipment required for performing operational activities;
- the inspection of the fluid to ensure the correct composition and conditions.

Implementation (5)

The next step is the implementation of the plans and schedules in the cycle. Procedures and (work) instructions for the execution of the annual plans shall have been determined as well as the way these activities will be monitored

The ‘normal’ process monitoring and processing of breakdowns and defects must continue to function.

An emergency plan

1) Basic requirements

Each operating company having gas transmission facilities within the scope of this Code shall:

(a) have a written plan covering operating and maintenance procedures in accordance with the scope and intent of the Code;

(b) have a written emergency plan covering facility failure or other emergencies;

(c) operate and maintain its facilities in conformance with these plans;

(d) modify the plans periodically as experience dictates and as exposure of the public to the facilities and changes in operating conditions require;

(e) provide training for employees in procedures established for their operating and maintenance functions. The training shall be comprehensive and shall be designed to prepare employees for service in their area of responsibility;

(f) keep records to administer the plans and training, properly.

2) Written Emergency Procedures

Each operating company shall establish written procedures that will provide the basis for instructions to appropriate operating and maintenance personnel that minimize the hazard resulting from a gas pipeline emergency. As a minimum, the procedures shall provide for the following:

(a) a system for receiving, identifying, and classifying emergencies that require immediate response by the operating company;

(b) indicating clearly the responsibility for instructing employees in the procedures listed in the emergency plans and for training employees in the execution of those procedures;

(c) indicating clearly those responsible for updating the plan;

(d) establishing a plan for prompt and adequate handling of all calls regarding emergencies whether they are from customers, the public, company employees, or other sources;

(e) establishing a plan for the prompt and effective response to a notification of each type of emergency;

(f) controlling emergency situations, including the action to be taken by the first employee arriving at the scene;

(g) the dissemination of information to the public;

(h) the safe restoration of service to all facilities affected by the emergency after proper corrective measures have been taken;

(i) reporting and documenting the emergency.

3) Training Program

Each operating company shall have a program for informing, instructing, and training employees responsible for executing emergency procedures. The program shall acquaint the employee with the emergency procedures and how to promptly and effectively handle emergency situations. The program may be implemented by oral instruction, written instruction, and, in some instances, group instruction, followed by practice sessions. The program shall be established and maintained on a continuing basis with provision for updating as necessitated by revision of the written emergency procedures. Program records shall be maintained to establish the training each employee has received and the date of such training.

An emergency organization that has been well trained and exercised and which has been provided with material and equipment to deal with emergency situations shall be ready.

Identified risks (and the possible effects when incidents occur) can be managed, reported and assessed by the execution of the appended management system (see Figure 10).

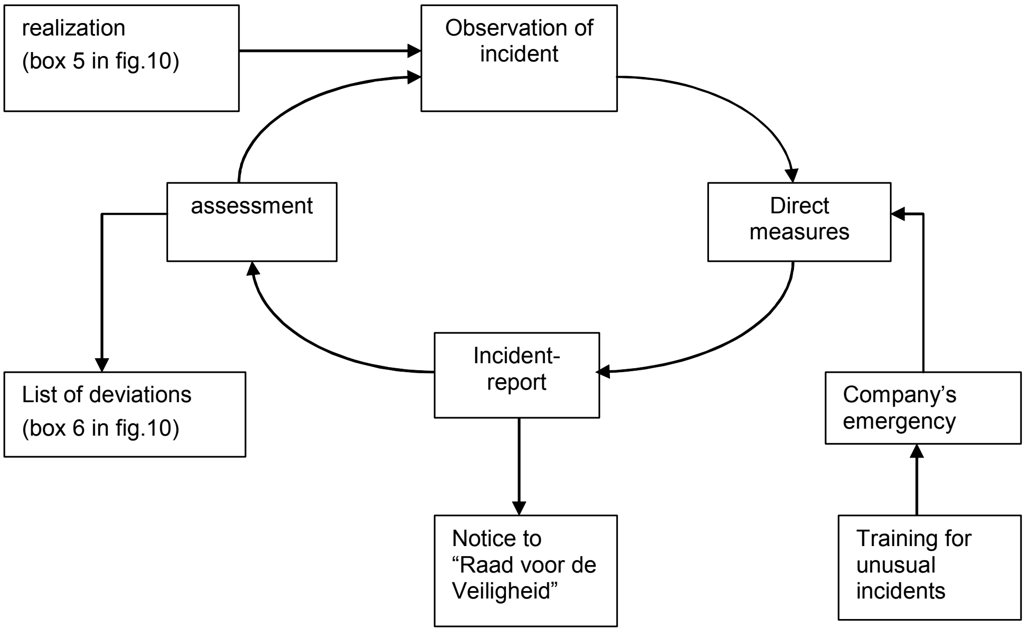


Figure 11 – Incident Management Quality Cycle

Non-conformity list (6)

The observed deviations during maintenance and inspection activities shall be registered.

Incidents, like damages, near accidents and unsafe situations. shall be reported and analysed (to avoid recurrence of such incidents)

Note: Category 1 'accidents' and category 2 'serious incidents' shall be reported to the 'Chief Safety Officer' of the Gas Authority (see also Figure 11). Notification of the incident analyses is part of the duty.

File Adjustment (7)

The data and observations from the previous steps are placed in the file for the pipeline system. The pipeline manager shall compare the actual data with data from earlier inspections and must evaluate the whole from a historic perspective with the benefit of hindsight toward the quality control operations that should be included in the coming years' plans.

The actual condition of the pipeline system shall also be updated in the file.

10.2.3 Miscellaneous Facilities maintenance

10.2.3.1 Maintenance of Pressure Limiting and Pressure Regulating Stations

10.2.3.1.1 All pressure limiting stations, relief devices, and other pressure regulating stations and equipment shall be subject to systematic, periodic inspections and suitable tests, or be reviewed to determine that they are:

(a) in good mechanical condition. Visual inspections shall be made to determine that equipment is properly installed and protected from dirt, liquids, or other conditions that might prevent proper operation. The following shall be included in the inspection where appropriate:

(1) station piping supports, pits, and vaults for their general condition and indications of ground settlement;
(2) station doors and gates and pit vault covers to determine that they are functioning properly and that access is adequate and free from obstructions;

(3) ventilating equipment installed in station buildings or vaults for proper operation and for evidence of accumulation of water, ice, snow, or other obstructions;

(4) control, sensing, and supply lines for conditions that could result in a failure;

(5) all locking devices for proper operation;

(6) station schematics for correctness.

(b) adequate from the standpoint of capacity and reliability of operation for the service in which they are employed and set to function at the correct pressure.

(1) If acceptable operation is not obtained during the operational check, the cause of the malfunction shall be determined, and the appropriate components shall be adjusted, repaired, or replaced as required. After repair, the component shall again be checked for proper operation;

(2) At least once each calendar year, a review shall be made to ensure that the combined capacity of the relief devices in a piping system or facility is adequate to limit the pressure at all times to values prescribed by the Code. This review should be based on the operating conditions that create the maximum probable requirement for relief capacity in each case, even though such operating conditions actually occur infrequently and / or for only short periods of time. If it is determined that the relief equipment is of insufficient capacity, steps shall be taken to install new or additional equipment to provide adequate capacity.

10.2.3.1.2 Whenever abnormal conditions are imposed on pressure or flow control devices, the incident shall be investigated and a determination shall be made as to the need for inspection and / or repairs. Abnormal conditions may include regulator bodies that are subjected to erosive service conditions or contaminants form upstream construction and hydrostatic testing.

10.2.3.1.3 (a) An inspection and / or a test of stop valves shall be made to determine that the valves operate and are correctly positioned. (Caution shall be used to avoid any undesirable effect on the pressure during operational checks.) The following shall be included in the inspection and / or test:

(1) station inlet, outlet, and bypass valves;

(2) relief device isolating valves;

(3) control, sensing, and supply line valves.

(b) The final inspection procedure shall include the following:

(1) a check for proper position of all valves. Special attention shall be given to regulator station bypass valves, relief device isolating valves, and valves in control, sensing, and supply lines;

(2) restoration of all locking and security devices to their proper position.

10.2.3.2 Valve Maintenance

Pipeline valves that are required to operate during an emergency shall be inspected periodically and operated at least once a year to provide safe and proper operating conditions.

(a) Routine valve maintenance procedures shall include, but not be limited to, the following:

(1) servicing in accordance with written procedures by adequately trained personnel;

(2) accurate system maps for use during routine or emergency conditions;

(3) valve security to prevent service interruptions, tampering, etc., as required;

(4) employee training programs to familiarize personnel with the correct valve maintenance procedures.

(b) Emergency valve maintenance procedures include:

(1) written contingency plans to be followed during any type of emergency;

(2) training personnel to anticipate all potential hazards;

(3) furnishing tools and equipment as required, including auxiliary breathing equipment, to meet anticipated emergency valve servicing and / or maintenance requirements.

10.3 Termination of Operations

When operations must be terminated whereby (parts of) the pipeline system is (are) being decommissioned, the related measures shall be observed. In a similar way as with the risk assessment for the operational management within the quality cycle (see 10.2), the risks shall also be assessed and the required risk-limiting measures or activities shall be taken or performed when operations are terminated.

The relevant and applicable legislation and regulations and the information provided in relation to this supplied by issued licenses in relation to abandoning and/or removing the pipeline, including fittings, shall be respected.

Sections that are being decommissioned for longer periods shall be uncoupled, made medium-free, sealed and conditioned. The management system remains applicable for the monitoring of the pipeline and the recording of position and pipeline data.

Slurry, scrapings, waste and left behind fluid shall be removed from pipelines that are being permanently abandoned. These elements shall be disposed of in a suitable manner.

Reuse of released materials is permissible for pipelines that have been built under the SI 5664-2 series that was published during the 1992 to 1998 period. These materiasl can be used in a pipeline system with the same load conditions when the original data is known and it has been demonstrated, through inspection and applicable testing, that there are no defects or faults and/or that the residual strength has not lost its value. A reduced residual strength due to, for example, ageing effects, shall, in that case, be taken into account.

11. Offshore Pipelines

11.1 General

This chapter contains provisions that are specific to offshore pipelines.

The following are classed as offshore pipelines: all pipelines in or on the sea bottom of the continental shelf (whether in territorial waters or not) and in areas with similar environmental conditions such as inland seas and estuaries.

Landfalls are classified as onshore pipelines (see also 8.2.1). Drilling platforms are not included in the present standard.

11.2 Safety

11.2.1 General

Offshore pipelines shall not hamper or present a dangerous obstacle to fishing, shipping, dredging works and recreational users. The pipeline shall be designed, installed and used in such a way that the additional risk to the environment (contamination of the marine environment) is acceptable.

The possibility of secondary consequential harm shall be taken into account; for example, blocking of shipping routes. The other (underground) pipelines that are situated in the immediate area of the subject pipeline shall also be taken into account as well as the domino effect that occurs when one of the pipelines fails.

11.2.2 Safety Assessment

It shall be demonstrated through safety assessment that the risk is acceptable. A distinction shall be made between ‘sensitive’ and ‘other’ areas. Sensitive areas include, among others: anchorage areas, roadstead areas, approach routes to harbors and seaports, dumping areas, areas for sand excavation and areas with a considerable natural sand transportation, areas with sandbanks, sand waves and/or large sand ridges and the coastal zone.

Possible threats to offshore pipelines can be the following:

- design and construction errors, material faults;
- errors in relation to operational management and maintenance;
- corrosion or other forms of material degradation;
- external damages caused by third parties (fishing, anchored, stranded, sinking vessels, military activities, geotechnical and geo-seismic surveys);
- weather conditions;
- scouring, liquefaction, shifts in steep bottom slopes;
- biodegradation of coating or abrasion due to sand.

The probability of failure as a consequence of each of the aforementioned reasons shall be investigated and quantified All failure frequencies together shall be combined to a failure frequency per kilometer x year.

When determining the effect of the medium being released, the characteristics of the medium shall be taken into account, especially in relation to contamination of the (marine) environment.

11.2.3 Acceptable Risk

The risk, including any risk-limiting measure, shall be acceptable. For the ‘other’ areas, the risk (failure frequency multiplied by the effect) of transported hydrocarbons shall meet the following criteria:

a) the probability of failure shall be smaller than 10^{-6} per kilometer x year;

b) the effect of failure; the volume of liquid hydrocarbons released shall be smaller than:
   - 100 m^3 (within 22 km from the coast);
   - 400 m^3 (between 22 km and 46 km from the coast);
   - 700 m^3 (more than 46 km from the coast);

c) only one of the two aforementioned criteria is complied with but the combination (probability times effect) is acceptable within the contemplated limitation of the risk.

11.2.4 Risk-limiting Measures

Soil cover

When criteria 11.2.3 have been met, an offshore pipeline with a diameter that is smaller than 400 mm shall be buried at least 0.20 m in the ‘other’ areas. For offshore pipelines with a larger diameter, soil cover is, in this case, not required. In all other cases (sensitive areas), the pipelines shall be provided with a soil cover. The dimension of the soil cover is determined in the safety assessment.

Note 1 Regardless the diameter, when the water depth is less than 60 m, the pipe shall be buried at least 1 m below the seabed.

NOTE 2 The safeguard of the stable position of the pipeline (for example, upheaval buckling) and/or protection against stranded ships (coastal zone) may be a reason to have deeper soil cover.

The burial depth or soil cover is partly determined by the prediction in connection with beach and coastal erosion (lowest envelope risk function) at the location of the landfall.

Rock dump

Especially against damage from outside, the offshore pipeline near platforms can be provided with rock dump or an alternative solution (for example, concrete protection pads).

NOTE Rock dump may disturb the saturation of the water with sand locally and may lead to changes in the bottom.

Pressure Protection

An offshore pipeline shall be protected against internal pressure that is too high through an adequate pressure safety system (see 7.2).

Riser Valve

A valve shall be affixed to the riser above the sea level. It should be controlled from the pressure safety system and its objective is to separate the offshore pipeline and the platform to prevent, thus, the possible escalation of an incident due to the supply of medium from the offshore pipeline to the platform. The valve does not have to be affixed when this has been so determined in the results of the platform safety study.

Installation and Pipeline System Limitation

At least one valve shall be affixed between the production installations on the platform and the pipeline system.

Pipeline Check

Regular checks and inspections shall be performed in relation to, among other issues, the position of the pipeline, soil cover depth and scouring, any clear spans, rock dumps and other protective structures, cathodic protection and any deterioration of the riser. Actions shall be performed for the repair of observed faults where necessary.

Riser Construction

The riser shall be installed in such a way that it is sufficiently protected against forces from outside and/or is sufficiently strong to resist the loads brought about by these forces.

Riser Valves under Sea Level

Riser valves under the sea level are applied when a risk analysis has shown that this is necessary. Using these valves is, in principle, avoided in relation to the required inspections and maintenance.

11.2.5 Environmental Impact Report (EIR)

It shall be determined whether there is an EIR requirement or an EIR assessment requirement (see also 6.4.4) for offshore pipelines that are to be newly installed, adjusted or extended.

NOTE It is advisable to determine as soon as possible together with the appropriate authorities whether the pipeline has an EIR requirement. An EIR procedure can take a lot of time. An EIR procedure is not necessary when a section of a pipeline will be replaced if the section to be replaced can be viewed as being identical.

11.3 Functional Design

Offshore pipelines virtually do not distinguish themselves functionally from onshore pipelines. Both are meant to be used for the safe transportation of substances.

The distinction between offshore pipelines and onshore pipelines is mainly related to environmental conditions. The marine environment applies specific loads to the offshore pipeline. Pipeline design and the installation and the management of an offshore pipeline involve different aspects than those encountered in relation to onshore pipelines.

The material choice for offshore pipelines is also based on the depth of the water, the method used for installation the pipeline, the marine environment and the application, or not, of soil cover. The pipeline material that is used the most is steel; thermo-harder, thermoplastics or flexible (steel) pipelines are also applied. The pipelines are provided with a weight coating if necessary.

11.4 Structural Design
11.4.1 Route Determination
11.4.1.1 In Principle: Straight line
A straight line between the starting and end points of the pipeline is the point of departure for the route survey. Deviation from the straight line can be due to:

- obstacles on the sea bottom (other pipelines, platforms, cables, bored wells, cable reinforcements, wrecked ships, ammunition dumps, mine fields, etc.);
- the use of the sea and sea bottom (fishing with dragnets, military operations, shipping routes, sand excavation, environmental sensitivity, installations, pipeline corridors, cables and pipelines);
- installation method;
- natural appearance of the sea bottom (profile and stability, for example, sand waves);
- connection possibilities for the riser and/or the pipeline corridor, if any, near the platform;
- anchorage areas, location of the spuds and drilling platform;
- future developments.

See F.1 for further descriptions concerning the route determination and approval.

11.4.1.2 Licensing Requirements
The appropriate authorities give permission and will retract the permission, if there are reasons for doing so, before putting an offshore pipeline into operation for the transportation of minerals on the Dutch continental shelf.

NOTE The point of departure for the decision-making by the appropriate authorities is the risk of the (new) pipeline system. Risk analysis and assessment are essential parts of this process and will help to determine the choice of the route.

F.1.1 includes the applicable legislation and regulations and the work method for the approval of the route and the pipeline.

11.4.1.3 Route Survey
A survey into the condition of the sea bottom shall be carried out. Data on both sides of the design route shall be gathered (see also F.1.2 and F.1.3). The route and bottom profile shall be provided through drawings in a coordination system that is suitable for the determination of the location and depth. The design route is submitted to the appropriate authorities, and will obtain approval from the government agencies and departments involved, who will give their approval in turn and/or specify a route change or further requirements.

11.4.1.4 Soil Investigation
The route survey also includes a soil investigation for the pipeline strength, stability and any (automatic) burying considerations.

11.4.2 Pipeline Design
11.4.2.1 General
The stable position of the offshore pipeline, the static condition of the riser(s) and any landfalls shall be safeguarded during the life span of the pipeline system. The loads that the system will be subjected to shall be determined according to size. Calculations shall demonstrate that the system meets the strength, rigidity and stability requirements both during installation and when operational.

Many loads and their treatment are similar to the ones involved with onshore pipelines. Only the additional requirements for the design of onshore pipelines are included in this paragraph. See 8.2 for further information about the other loads and their treatment.

11.4.2.2 Calculation Philosophy
See 8.2.2.

11.4.2.3 Loads
The following load types and causes, respectively, that may occur during the construction, testing, commissioning and operational phases, shall be included in the design if applicable:

a) pressure;

b) temperature;

c) soil

d) traffic

e) own weight;

f) connected structures;

g) vibrations;

h) other installation loads;

i) incidental external loads;

j) meteorological loads;

k) water and ice.

The load types f) up to and including k) demand another approach for offshore pipelines than the one used for onshore pipelines. The applicability in relation to offshore pipelines is briefly explained for each type.

F.2 provides methods for determining the size of the load.

Loads Due to Connected Structures

Both the reactions that act upon the pipeline through the supports (springy or rigid) and due to connected structures (tanks, barrels, pumps, bridges, safety valves and platforms) shall be taken into account in the investigation. Special attention is required for displacements which occur, the rotation of the support or connected structures.

Loads due to platform movements and any related (for gravity structures) sea bottom deformation under the influence of wind, waves and currents shall be determined based on the points of departure of the platform design paying attention to liquefaction.

Load Due to Vibrations

Vibrations due to the medium (liquid slugging in wet gas) or the environment (water flow, waves) can bring about loads on the pipeline. This shall be investigated at the design phase. The determination of the size of the load due to vibrations as a result of water flow and wind is described in F.2.2.4.

Installation Loads

Various load situations which can occur during pipeline installation shall be investigated, such as:

- bearing load during storage, transportation and lowering of the pipeline;
- loads due to elastic installation of the pipeline;
- external forces that occur during installation, especially, offshore pipelines (unreeling or towing and burying of pipeline);
- load due to pretensioning the pipeline.

Incidental External Loads

Incidental loads from outside are usually similar to an impulse load. Impulse loads are, for example, brought about by:

- loads due to driving, foundation, cone penetration and drilling activities, geoseismic surveys, etc.;
- falling objects;
- anchor forces;
- passing fishing gear;
- collisions (riser).

Information provided by the literature can be utilized for determining incidental external loads such as, for example, due to passing fishing gear. Usually these loads are not included in the normal strength calculation of the pipeline when the pipeline has been provided with a concrete weight coating but the safety of the pipeline against this type of loads is tested separately and, if required, it is safeguarded by making special provisions.

Meteorological Loads

Loads as a consequence of meteorological conditions, wind loads and hydrodynamic loads are stochastic in nature and location-specific and shall be determined through probability methods using the available data. The simultaneous occurrence of different environmental influences is allowed for by superposition's of the individual effects whereby the coincidence probability is taken into account.

When determining the hydrodynamic loads, attention shall especially be given to the effects of marine growth, among others, the increase of the diameter, the external wall roughness and, in particular, the influence on the determination of hydrodynamic coefficients.

It shall be specified which marine growths have been assumed and (if applicable) which special measures have been taken to limit and monitor these growths when determining the size of the hydrodynamic loads

NOTE 1 A layer thickness of 50 mm over a length of LAT +2 up to the sea bottom can be considered for marine growth on risers (LAT is the acronym for Lowest Astronomical Tide).

Load Due to Water and Ice

Hydrostatic water pressure and hydrostatic buoyancy shall be taken into account. Hydrodynamic loads can, furthermore, occur as a consequence of flow, waves and ice formation. The determination of the size of the load due to water is described in F.2.

NOTE 2 The water depth on-site is utilized when determining the hydrostatic load. Ice, floating ice and drifting ice are only, generally, considered in shallow coastal waters.

11.4.2.4 Calculation Procedure and Scope

11.4.2.4.1 Pipeline Outline and Classification in Sections to be Calculated

The pipeline is subdivided into sections in which the loads in relation to nature differ little. The behavior of the pipeline shall be investigated for each section. The following shall be given special attention in connection to offshore pipelines:

- areas with an uneven sea bottom in view of possible clear spans including the consequences for the horizontal stability, stresses and deformations;
- areas with significantly different meteorological, geotechnical and/or marine circumstances, characteristics and loads;
- areas with different safety conditions and risks;
- areas with an uneven sea bottom where it is possible that upheaval may cause buckling to occur;
- offshore pipeline connections at locations or other pipelines;
- crossings with other offshore pipelines and cables.

11.4.2.4.2 Specific Design Aspects for Offshore Pipelines

General

It shall be demonstrated that the pipeline has a sufficiently stable position both during the installation phase and during the operational phase.

Offshore pipelines shall be checked for radial stability as a consequence of external hydrostatic pressure (implosion).

It shall be demonstrated that the pipeline has sufficient resistance against local creasing in relation to the most adverse combination of external excess pressure, axial forces and bending moments.

The possibility of vibrations occurring as a consequence of vortex shedding and other hydraulic instability phenomena shall be investigated for risers and for pipeline sections not supported (by soil) that are exposed to waves and flow.

Interaction Between Offshore Pipelines and Connected Structures

The possible deformation of the platform under the influence of the wind and hydrodynamic loads shall be taken into account in relation to the riser. It may be necessary to also consider a section of the horizontal pipeline to assess the effect of this.

Loads Due to Soil

The displacement of the pipeline in an axial direction shall be checked. Sufficient flexibility and space shall be reserved especially near platforms, connections to other pipelines and/or locations where the pipeline changes direction. The calculation of the expansion shall be based on conservative values for the axial friction between pipeline and soil.

Repeated load as a consequence of waves may lead, in shallow waters, to a decrease in shearing force of the soil. The choice of backfill shall be based on the prevention of the complete washing out by cyclic wave loads (this may, especially, be the case with a trench backfill that has been artificially applied).

Buoyancy

Buoyancy as a result of the hydrostatic water pressures and hydrodynamic lifting power acting on the pipeline, shall be taken into account in both the installation phase and the operational phase.

NOTE 1 When calculating buoyancy, a possible liquefaction of the surrounding mixture of soil and water in which the pipeline is being installed (buoyancy in a slurry with a higher weight per unit volume than water) shall be taken into account especially during the installation phase.

Wind

The influence of wind pressure shall be considered at the riser.

The possibility of occurring vibrations shall also be investigated.

NOTE 2 The same wind data shall be used as for the platform design for determining the wind effect on the risers. If the position of the riser is such that the wind field is disturbed by the bordering structure, this disruption shall be included in the consideration.

Water Flows and Waves

Loads caused by water flows shall be considered at the same time as wave effect (orbital movement) and shall be combined with hydrodynamic loads.

The water flow shall include the tidal flow, flows caused by wind and storm and possibly due to other effects as a result of water movement (river flows, return flows due to shipping activity, orbital movement of waves).

NOTE 3 Sand banks (shoaling) and refraction shall be taken into account in coastal zones; that is to say, changes that waves are subjected to when, for example, they arrive in shallow waters in coastal zones. Flows that run in parallel to the coast caused by breaking waves, if applicable, shall also be taken into account.

The flow speed near the bottom shall be determined in areas where bottom erosion can occur and when the pipeline is not being buried to demonstrate a sufficiently stable position of the pipeline.

A vertical speed profile of the flow shall be determined for risers and for pipelines during installation.

NOTE 4 The wave and flow data used will, generally, be the same as has been used for the platform design in relation to the riser. For the calculation and testing of the riser, however, the same rules apply as for the rest of the pipeline.

The following phenomena require special attention in relation to free spanning offshore pipelines:

- hanging/tensile forces (second order effect: ‘Seilwirkung’; ‘rope effect’) with large deflection;
- change of an initially straight section in a bent configuration with large deflection which makes the longitudinal stress increase as a consequence of the internal pressure.

Loads During Installation Phase

The effect of vessel movements on the pipeline as a consequence of the waves shall be considered during installation.

A similar effect can also occur when the riser is installed from a vessel.

NOTE 5 The load that occurs shall be determined based on the response characteristic of the vessel in relation to the waves.

Special attention shall be given to bending stresses that are initiated during any burying or deepening and/or covering of the offshore pipeline after the installation phase.

In relation to burying and deepening the pipeline, an investigation shall be done to establish how far an axial tensile force occurs due to this and what the influence would be on the occurring bending moments (“Seilwirkung”).

Upheaval Buckling

The pipeline wants to expand in an axial direction when a high-pressure pipeline is used with a temperature which is significantly higher than the environmental temperature. If the expansion is not allowed to occur freely (by, for example, soil friction), an axial pressure force will occur in the pipeline.

Lateral soil reactions will develop in the soil or rock filling will take place around the pipelines depending on the geometry and rigidity of the pipeline.

If the maximum possible soil reactions are reached, the pipeline will deform unstably (buckle). Locally, this may lead to the accumulation of the expansion of the pipeline (upheaval) and, due to this, to bending moments that are too large and produce excessive local buckling and stretching of the pipeline which may make the pipeline unusable.

11.4.2.4.3 Load Combinations

The load combinations that have to be calculated are the same as used for onshore pipelines (8.2.4).

It shall also be investigated whether a stable position is being safeguarded with hydrodynamic loads and vibrations for offshore pipelines that have not been buried.

The most suitable combination of simultaneously occurring vertical and horizontal loads shall be considered. The following shall be taken into account in relation to the above:

- that the loads will vary in size along the route of the pipeline;
- that the wave and flow directions are, generally, not the same;
- that phase differences occur between the vertical and horizontal hydrodynamic loads.

Wave characteristics as specified in F 2.2.1 can be counted with F 2.2.2 provides a calculation method for lateral stability.

See DnV [5], RP E305, relevant literature, recent studies and model tests for external load due to dragging of nets on pipelines that have not been buried.

11.4.3 Structural Aspects

Mechanical Damage to Offshore Pipelines in the vicinity of the platform

An increased probability of mechanical damage to the offshore pipeline shall be taken into account for an area of 500 m around the platform. The same load factors apply for offshore pipelines as for the riser in this area.

A safety analysis taking all the activities and aspects around the platform into account can result in a distance of less than 500 m. Aspects such as loading and unloading activities, location and access routes for the drilling platform, position of the crane with respect to the pipeline, falling objects and anchor cables shall be taken into consideration.

Riser

The riser shall be installed in such a manner that it is sufficiently protected against external forces and/or that it is sufficiently strong to resist the load of such forces.

NOTE 1 When a riser is installed outside the platform substructure (jacket), a shock-absorbing load should be taken into account in relation to the possible operational collision by a maneuvering supply ship (for example, water displacement 2,500 ton, speed 0.5 m/s). A protection caisson (casing) or floating fender can be placed around the riser if necessary.

The riser shall be secured with riser clamps to the platform substructure. Platform movement, wind, hydrodynamic loads and its own weight shall be appropriately absorbed.

NOTE 2 It is advisable to mount the (fixed or guided) riser clamps in such a manner that the pretensioned bolted connection does not loosen due to creep or relaxation (apply bolts with extra length for gripping).

Any expansion provisions and flanged joints therein or additional reinforcement of the riser shall be investigated in relation to technical calculations.

NOTE 3 The following expansion solutions are applicable:

- vertical riser on the pipeline on the sea bottom (structure is sensitive to platform subsidence);
- vertical riser on a buried pipeline (structure is sensitive to platform subsidence);
- vertical riser on a buried pipeline and a pipeline including rock dump (structure is sensitive to subsidence of the platform and the surrounding environment);

- horizontal expansion element on a section of the sea bottom that has been rock dumped to provide room for the expansion (structure is sensitive to subsidence of the dump rock, unplanned dump rock and falling objects);
- horizontal expansion element connected to the pipeline with rock dump to limit the expansion (structure is sensitive to subsidence of the soil due to the rock dump);
- pipelines that are on the sea bottom are mainly sensitive to clear spans due to erosion, unplanned rock dumping and falling objects.

Valves under Sea Level

If valves are mounted under sea level, appropriate provisions shall be made to ensure accessibility, inspection and maintenance and to protect it against mechanical damage and falling objects. The valves shall be flanged or of the top entry type to make maintenance possible. The valves should have an opening which is sufficiently large for allowing pigs or inspection equipment to go through.

Protective Structures

Pipeline elements shall be protected underwater against mechanical damage wherever necessary (for example, side taps or valves). Steel frame structures can be used for the above. The structure may not cause fishing gear or nets to become hooked to it or be the cause of any damage thereof. The minimally required remaining depth above the structure shall be guaranteed. A structure may not lie at more than 6.0 m above the surrounding sea bed. The structure shall be resistant to an impact load of at least 350 kN by fishing gear. Appropriate provisions shall be taken to prevent scouring of the sea bottom at the location. Any space created under the frame due to scouring may not be larger than 50 cm measured vertically. The stability and strength of the frame shall be determined by applying the conditions of the one hundred year storm. The structure shall be anchored to the sea bottom or be so heavy that there is no danger of any lateral displacement. The frame shall be a closed or partially closed structure with inspection covers to provide access to divers.

11.5 Pipeline Installation

11.5.1 Differentiation Based on Pipeline Installation Methods

General

The installation of offshore pipelines can be divided into the installation of risers, the pipe section in or on the sea bottom and (when applicable) the landfall pipe. Landfalls are considered to be part of onshore pipelines.

Riser

The riser is the connection between the section of the offshore pipeline on the sea bottom and the platform station. Risers are secured during or after construction of the platform using special supporting structures, clamps, to the platform structure for the purpose of the required stability.

Offshore Pipeline Sea Bottom Section

The installation of a sub-sea pipeline consists of assembling and installing the pipeline on or in the sea bottom. A choice can be made from assembling the pipeline from pipe elements at sea or onshore in relation to the pipeline installation method. The pipeline is installed directly at sea (lay barge). If the pipeline or section is constructed onshore, the reeling method can be chosen to lay the pipeline (the pipes are reeled from a reel) or the towing method can be chosen to lay the pipeline (the pipes are towed from the shore to sea). See also 11.5.3 for further information.

Landfalls

Landfalls are required when the pipeline system includes a station onshore. The landfall section is the section connecting the offshore pipeline to the onshore pipeline.

The installation of the landfall can also include the crossing of a main water-retaining structure. Special (temporary or permanent) structures may be necessary to guarantee the stability of the coastal strip.

11.5.2 Installation Aspects

Soil Cover

If soil cover or partial soil cover is required for the pipeline for stability or damage prevention reasons, the pipeline can be totally or partially buried. The burying can be carried out by a natural or a mechanical burial process or by covering it with a rock dump. The natural burial process is acceptable if it can be demonstrated that within a year of installation of the pipeline the process will lead to the required burial depth or soil cover. If the required depth of installation of the pipeline or soil cover required is not obtained, the pipeline shall still be buried mechanically or it shall be provided with sufficient soil cover. Depending on the circumstances and the soil conditions, this can be carried out by jetting, digging, dredging, cutting or plowing to dig in or bury the pipeline and/or by liquefying the soil package under the pipeline which will ensure the pipeline subsides into the soil package.

Local rock dumping on top of a pipeline is mainly used where stable position of the pipeline shall be guaranteed.

NOTE A soil cover of approximately 1.5 m to 2.0 m can, generally, only be carried out through dredging as the probability that excavating equipment may damage the pipeline cannot be ruled out.

Connection to or Crossing Other Pipelines or Cables

Provisions have to be made to prevent damage to either pipelines when making a connection onto an existing offshore pipeline or when the offshore pipeline crosses another offshore pipeline or cable.

Provisions can be made in relation to:

- preventing mutual loading;
- preventing damage to or influencing the corrosion protection;
- securing stable positioning of the pipeline or cable at and near the crossing and preventing external damage from occurring;
- limiting nuisance for fishing and shipping.

Parallel Position in Relation to Other Pipelines or Cables

Between two pipelines a horizontal distance of at least 20 m shall be observed or a larger distance shall be observed as required by pipeline installation, by the licensing authority or by the owner of existing nearby cables or pipelines.

11.5.3 Installation of offshore pipelines

The decision in relation to the method to be applied for installation of pipelines using a lay barge, according to the reel lay method or the towing method, can already be taken during the design phase. The choice is determined by technical and financial considerations and the requirements made by the licensing authority.

The lay barge method is, generally, the method that is mostly used.

NOTE 1 The available material and the specific know-how of the contractor and/or any new developments can be included at the earliest possible stage of the design phase.

Lay Barge Method

The lay barge method consists of two varieties, S-lay and J-lay. The S-lay technique is used for water depths of more than 6 m through a maximum of 1300 m. The J-lay technique is used for water depths of 500 m or more.

Reel Lay Method

The reel lay method is used for rigid and flexible pipelines. The reel lay method has the following advantages when compared to the lay barge method: the installation of the pipeline takes less time and the assembly of the pipeline can take place onshore. The disadvantages of the method are: the diameter of the pipeline is limited to approximately 400 mm (16 inches), the risk of damaging the covering is higher and the pipeline length for larger diameters (> 250 mm, 10 inches) is limited. Concrete weight coating cannot be applied.

NOTE 2 Only a limited number of contractors have the equipment to use this method. The reel lay method is specialized work and specific to the contractor and his equipment, capacity and experience. The design shall, generally, have to be adjusted to the available equipment. Pipelines and cables can be combined and installed simultaneously.

Towing Method

The pipeline strings are, generally, assembled onshore and are, subsequently, pulled out to sea in a previously installed trench or not. The pipeline string can be towed over the sea bottom or only a few meters under the water surface.

NOTE 3 A friction coefficient of 1.0 can be used for pipelines that are towed over the sea bottom.

11.5.4 Testing, Commissioning and Delivery

The same processes apply to the testing, commissioning (determining whether the pipeline meets all requirements) and delivery of offshore pipelines as for onshore pipelines. For pressure testing or similar purposes, only potable water, or sea water treated with environmental friendly inhibitors, shall be used.

NOTE A license is required to discharge chemically-treated water.

11.6 Operational Management and Termination of Operations

11.6.1 General

Management System

A management system as described in chapter 10 shall be set up for offshore pipeline systems. Additional set-up aspects which are specific to offshore pipelines in comparison to onshore pipelines are described below.

NOTE Sections 10 and 11 of the "DnV Rules for Submarine Pipeline Systems" [5] can be used as a guide or as reference material when setting up the management system.

Offshore Pipeline Specific Aspects

- Route inspection: an acoustic inspection of the offshore pipelines has to be carried out regularly to determine the position of the pipeline, the soil cover and the position and presence of the protective structures and/or the sea bottom profile shall be determined (see 11.6.3 for further information).
- Leak-tightness of the transport pipeline (loss of wall thickness): the necessity of and frequency with which pipelines are inspected using intelligent equipment (intelligent pigs) is determined based on the composition of the medium, the operational performance compliance and the RBI principles (Risk Based Inspection). The determined necessity and frequency is recorded in the management system.
- Proof of monitoring resources: the results of the offshore pipeline inspections and corresponding descriptions of the results shall also be submitted to a number of authorities (see 11.6.4).

11.6.2 Operating Instructions

The required information for the safe operation, control and management of offshore pipelines shall have been installed down in a management plan. The information includes the following information as well as other data:

- objective of the pipeline system;
- design data, system description;
- operational limits and permissible deviations;
- proof of supervision;
- overview of the applicable licenses and any limitations regarding their period of validity;
- operating conditions and instructions;
- procedure for start up and decommissioning;
- pigging;
- scope and frequency of inspections;
- maintenance.

The plan shall regularly be checked for completeness.

11.6.3 Route Inspection

Route inspections of offshore pipelines shall be performed periodically. The objective of the inspection is to check the horizontal and vertical position of the pipelines, umbilical and cables and any protective structures with reference to the surrounding sea bottom. The check shall at least determine any exposures, undermining and the presence of any objects on or in the proximity of the pipelines (for example, left behind by fishing or shipping activities) which are or could become a threat to the integrity of the pipeline, cable or umbilical in question. The method of inspection depends on the diameter and burial requirements of the pipeline.

11.6.4 Proof of Monitoring Resources

The owner of the pipeline is required to submit the results of the route inspections to the appropriate authorities.

NOTE The inspection reports should be submitted to the following appropriate authorities:

- State Supervision of Mines (Staatstoezicht op de Mijnen);
- Directorate-General for Public Works and Water Management (Rijkswaterstaat), Directorate North Sea (Directie Noordzee);
- Ministry of Defense (Ministerie van Defentie), Hydrology Department (afdeling Hydrografie);
- Ministry of Agriculture, Nature Management and Fisheries (Ministerie van Landbouw, Natuurbeheer en Visserij);

- Netherlands Institute for Fisheries Research (Rijksinstituut voor visserijonderzoek);
- Directorate-General for Public Works and Water Management (Rijkswaterstaat), Directorate North Friesland (Directie Noord Friesland) with regard to pipelines in the territorial waters north of the Wadden Sea area.

11.6.5 Termination of Operations

Any required measures shall be taken to prevent hindrance or danger to fishing, shipping and the marine environment when a pipeline is to be taken out of operation permanently. The measures shall be approved by the appropriate authorities.

Offshore pipelines do not have to be removed unless the pipeline endangers fishing, shipping, the environment or safety. If the pipeline does represent a danger, it shall be removed, buried or covered to ensure that the danger is removed. The appropriate authorities shall be consulted before abandoning pipelines that have been taken out of operation. Additional requirements based on the license requirements and the dredging regulations could be in force for pipelines that are within territorial waters.

A proposal to take the pipeline out of operation shall be submitted to the appropriate authorities when a mining installation is taken out of operation and removed (the appropriate authorities are the State Supervision of Mines (Staatstoezicht op de Mijnen) and the Directorate-General for Public Works and Water Management (Rijkswaterstaat), Directorate North Sea (Directie Noordzee). The plan will contain the method and procedures for taking the pipeline out of operation, for the removal of hydrocarbons and any other contaminants from the pipeline and for partial pipeline removal, burial or covering.

The riser and the section of offshore pipeline directly connected to the riser are, in general, removed when the platform substructure (jacket) is removed. The riser is cut free of the pipeline at some distance from the jacket. The appropriate authorities shall be consulted to agree on whether inspections are required after abandoning the pipeline and, if so, their scope and frequency.

Appendix A
(normative)

This appendix has been deleted.

Appendix B
(normative)

Design Aspects – Design Data

B.1. General

Design data, which depend on the type and size of the pipeline, are required for the design, the strength analysis and the assessment of the pipeline system. B.2 through B.4 contain the minimum requirements for the design data.

B.2 General and Management Data

The general and management data are the following:

a) general project data; description of the access system, limits for the pipeline, protective measures.

b) data regarding the medium and design conditions, such as:
   - the design pressure and design temperatures;
   - the values that are considered to be critical design conditions which are:
     - Mass flow of the medium per phase;
     - Density;
     - Viscosity (dynamic);

c) the data for the operational management:
   - the design life span;
   - operational pressures and temperatures;
   - quantity of (complete) operational temperature changes and pressure changes and the duration of these during the life span of the pipelines (the expected operational pattern for the pipelines during the life span of the pipelines).

NOTE The pressure data should include the indication whether the data refers to excess pressure or to absolute pressure.

B.3 Pipeline Data

B.3.1 Data Related to Pipeline Location and Special Provisions

a) Data for the route, the length profile, the pipeline configuration and special and engineering structures. All information required for the safety and reliability of the design shall be provided on the drawings. The information could include the following:
   - overview of the design route on an appropriate scale with the beginning and the end of the route and the location of the stations for the pipeline system;
   - length profile with the altitude of the pipeline, the grade or the canal bottom with respect to NAP (Normaal Amsterdams Peil, Amsterdam Ordnance Datum) or any other relevant reference level. The minimally required soil cover for the length profile or the minimally required altitude shall also be specified;
   - location of the pipeline with respect to other objects, among others, crossing or parallel pipelines or cables, buildings, obstacles and temporary foundations;
   - location of the diameter transitions, wall thickness, structure type or partial factor, materials or covering;
   - location of horizontal bends (nod point), other shaped elements, pipe facilities, casings, fixed points, guiding supports, etc.;
   - location and type of screw anchors or weight coatings, or any other structural details to prevent pipeline buoyancy or subsidence;

- detailed data on the engineering structures, crossings with water-retaining structures, roads, watercourses, railways and crossings with other pipelines and cables;
- detailed data on special structures such as supports, protective structures, etc.;
- references to drawing numbers of standard structures and as-built drawings.

The above data may be presented in the following formats:

- geographical overview drawings with, if applicable, route map disposition;
- route maps or comparable drawings;
- detailed maps and maps of standard structures specifying the corresponding route maps on which all the required information for the design and installation of the pipelines is given.

The following drawings are often required:

- pipeline element drawings, fixed points, guiding supports and such;
- isometric (calculation) drawings for special structures;
- the effect distance (testing distance) and area classification on a separate list or route map;
- drawings of the sheetpile wall structures (piling plan).

b) Installation data; the following data may be required:

- allowable elastic bending radiuses for the pipeline, both permanent and temporary ones;
- any pretension to be applied, at which points and how;
- test pressure, type and weight of the testing medium;
- installation temperature;
- specific installation methods for the pipeline or the pipeline sections (open trench (dry or wet)), pipe jacking, horizontal directional drilling method, etc.) specifying the related data, the structures to be used and the installation specifications (for example, the backfilling and trench compacting methods);
- land-use and geohydraulic data in relation to soil treatment, well-point drainage, grade finish, etc. A description of the possible size and content of the land-use, geohydraulic and geotechnical investigation is specified in Appendix I.

B.3.2 Pipeline Size and Material Data

a) Data regarding the dimensions of the pipeline:

- exterior diameter(s);
- nominal wall thicknesses;
- wall thickness tolerances;
- relevant data on the applied pipe fittings, such as bend radiuses or any other data dependant on the element (reduction parts, Tees, etc.);
- used abrasion and/or corrosion allowance;
- data related to the connected structures and supports which influence the distribution of the forces on the pipe that transport the medium.

b) Data related to the calculation method used:

This means the calculation method(s) used and/or the computer program used.

c) Data related to the material:

The pipeline material for which this standard is applicable is further described in separate sections of the standard.

B.4 Geotechnical Data for Ultimate and Serviceability Limit States

B.4.1 Geotechnical Parameters

The following geotechnical parameters are important for the pipeline calculation:

- neutral soil load (vertical);
- passive soil load (vertical);
- vertical bearing capacity;
- horizontal bearing capacity (passive horizontal soil load) and horizontal soil resistance (active, neutral or passive);
- soil stiffness values (modules of sub grade reaction, vertical upwards and downwards as well as horizontal);
- friction between pipeline and soil;
- displacement of friction;
- settlement and subsidence differences.

These parameters are only required for the most extensive calculation method. Only the neutral soil load, the passive soil load and the settlement and subsidence differences are required for the more simple calculation methods.

The geotechnical parameters are determined based on soil properties that are determined through field research and laboratory tests. Table B.1, taken from NEN 6740:1991, provides indicative values for soil properties. The description of the type of soils is made concrete in table B.1 by specifying the cone index value (cone surface 10 cm^2).

Table B.1 – Soil properties (order of size)

Soil properties			Sand			Clay			Peat
Description		unit	firm	mode-rate	loose	firm	mode-rate	soft	soft
Indicative cone value [a]	q_c [b]	MPa	25	15	5	2	1	0.5	0.1
Elasticity modulus	E_{100} [b]	MPa	125	75	25	4	2	1	0.2
Elasticity modulus for trench material	E_1 [c]	MPa	20	10	5	4	2	1	0.2
weight per unit volume, dry	γ_d	kN/m^3	19	18	17	19	17	14	10
Weight per unit volume, wet	γ_{wet}	kN/m^3	21	20	19	19	17	14	10
Effective angle of internal friction	φ'	-	35	32.5	30	17.5	17.5	17.5	15
Effective cohesion	c'	kN/m^2	-	-	-	25	10	0	2
Undrained ultimate shearing strength	c_u	kN/m^2	-	-	-	100	50	25	10
Primary compression index	C'_p	-	1000	600	200	25	15	7	5
Secondary compression index	C'_s	-	-	-	-	320	160	80	20
Permeability factor	$K_{v,h}$	m/s	[d]						

[a] The q_c values are the entry for Table B.1 and shall not be used for calculations.
[b] q_c E_{100} are standardized on an effective vertical tension of 100 kPa.
[c] E_1 elastic modulus for the trench backfill above the pipeline with a cover of 1 meter.
[d] The hydraulic conductivity of sand is strongly dependant on the packing and the range of the granules. The hydraulic conductivity of clay and peat are influenced by the structure and the compression of the soil. The following classification of soil types and corresponding values is used.

Description of soil type	Permeability factor m/s
Very coarse sand and gravel	10^{-3} - 10^{-2}
Average coarse sand through very coarse sand	10^{-4} - 10^{-3}
Very fine sand through average fine sand	10^{-5} - 10^{-4}
Silty sand through very fine sand	10^{-6} - 10^{-5}
Slightly sandy clay through very sandy clay	10^{-7} - 10^{-6}
Very silty clay	10^{-8} - 10^{-7}
Average silty through very silty clay	10^{-9} - 10^{-8}
Slightly silty clay	10^{-10} - 10^{-9}
Peat, vertical (K_v)	10^{-6} - 10^{-5}
Peat, horizontal (K_h)	2 × K_v through to 5 × K_v

B.4.2 Spatial Distribution of Soil Properties

Soil properties are determined based on geotechnical research. Various uncertainties should be taken into consideration during soil investigation. The main sources of uncertainty are the following:

- a limited number of spots along the route of the pipeline are investigated for the soil investigation. The soil properties between these spots may be different;

- geotechnical properties required for the pipeline calculations are determined during the soil investigation by means of sounding, soil-drilling tests and testing soil samples. The occurring uncertainties should be taken into account with respect to the measurements and the testing methods.

The soil properties as determined based on the geotechnical investigation (cohesion, angle of internal friction, etc.) should be considered as average values. The soil properties could actually have a higher or lower value than the values determined by the soil investigation. The average values for the soil properties should, therefore, be multiplied or divided by partial factors γ to determine the lower or higher values for the soil properties. If measurement values are available for a specific soil property, the partial factor would be:

$$\gamma = e^{-t_n V_m \sqrt{(1+1/n)}}$$

whereby:

V_m is the measured coefficient of variation (= standard deviation divided by the average value);

n is the number of measurement values;

t is the t-distribution value according to the table below.

number of measurements *n*		3	6	10	20	30
t value	Serviceability limit state	3.24	2.48	2.25	2.11	2.06
	Ultimate limit state	9.22	4.90	3.96	3.42	3.27

An alternative method is:

a) to use the coefficient of variation according to NEN 6740:1991 and use the values t = 2 and t = 3 for the serviceability limit state and the maximum limit state, respectively;

b) to use the partial factors for spatial distribution according to table B.2.

NOTE The values in Table B.2 are based n the results of the investigation according to [38].

Table B.2 – Partial factors for soil properties in relation to spatial distribution

Soil property			Factor
Weight per unit volume of dry soil	γ_d	(kN/m^3)	1.1
Weight per unit volume of saturated soil	γ_n	(kN/m^3)	1.1
Effective angle of internal friction	φ	(°)	1.1
Effective cohesion	c'	(kN/m^2)	1.4
Undrained ultimate shearing strength	c_u	(kN/m^2)	1.4
Modulus of elasticity	E	(MPa)	1.25
Compression coefficient (primary C'_p or secondary C'_s)			2.2
Permeability factor	$K_{v,h}$	(m/s)	10
NOTE The values for the partial factors for soil properties are applicable to the ultimate and serviceability limit states at crossings and/or field reaches.			

The geotechnical report should clearly specify whether spatial distribution factors have been used for the calculations and, if so, which. The partial factors in Table B.2 are only applicable when a geotechnical investigation has been performed for the calculation of the pipeline.

The geotechnical report shall be drafted independently of the strength analysis report for the pipeline.

NOTE It is recommended to have various areas of expertise involved in the reports.

B.4.3 Model Uncertainty When Determining Geotechnical Parameters

The values for soil properties obtained through the methods described in B.4.2 can be used to determine the geotechnical parameters for the strength analysis of the pipeline. Geotechnical calculation models are used for this and the model uncertainties shall be taken into consideration. The model uncertainties can be determined by correlating the calculated values to the results of the practical tests [38].

The corresponding model factors should be multiplied or divided by the geotechnical parameters when these are used for the strength analysis.

Table B.3 contains the partial factors for geotechnical parameters for sand and clay and peat, respectively.

The left-hand column gives the partial factor for the spatial distribution (V) for the corresponding parameter whereby the spatial variation of the soil properties used for the calculations is taken into account.

When the geotechnical parameters are determined according to paragraph C.4, the model factor (M) in the center column of Table B.3 should be used. This includes the possible variation between the results of the formulas and the results from the practical tests.

The right-hand column of Table B.3 gives total partial factors (V x M) for the geotechnical parameters. The spatial distribution of the soil properties and the model uncertainties have been taken into account in these values. The parameters shall hereby also be determined according to C.4.

Table B.3 – Partial factors based on geotechnical parameters for the strength analysis

Geotechnical parameter	Partial factors					
	Sand			Clay/Peat		
	spatial distribution V	calculation model M	total factor V x M	spatial distribution V	calculation model M	total factor V x M
Neutral soil load	1.1	1.0	1.1	1.1	1.0	1.1
Passive soil load	1.1	1.35	1.5	1.1	1.35	1.5
Horizontal bearing capacity	1.4	1.16	1.6	1.4	1.46	2.0
Vertical bearing capacity	1.5	1.35	2.0	1.5	1.16	1.7
Horizontal modulus of sub grade reaction	1.4	1.25	1.7	1.4	1.25	1.8
Vertical modulus of sub grade reaction, downwards	1.8[a]	1.83[a]	2.0[a]	1.9[a]	1.57[a]	2.0[a]
Vertical modulus of sub grade reaction, upwards	1.2	1.16	1.4	1.5	1.25	1.9
Friction	1.1	1.25	Refer to [b]	1.4	1.57	Refer to [b]
Axial displacement	1.3	1.25	1.6	1.2	1.25	1.5
Subsidence	2.0	1.0	2.0	2.0	1.0	2.0
Construction subsidence (tables C.3 – C.5)			1.5			1.5

a The E modulus has been introduced in the formulas on a theoretical basis, but it has a large distribution range and, therefore, the total factor value would become unrealistically high. The total factor of the vertical modulus of sub grade reaction is, therefore, related to that of the bearing capacity in accordance with the earlier approach.

b The representative friction depends on the circumstances:

- the representative load circumstances in the combination whereby k_w and k_l are multiplied by the model uncertainty factor (k_w and k_l *high*), generally, apply to pipelines with a low operational temperature. This is mainly at crossings with public works, larger diameters and when constructed as a vertical bow. In that case, the calculation is based on the product of the factors for the spatial distribution and the model factor. The remaining soil properties are also taken as being high. The situation k_w low and k_l high or k_w high and k_l low do not have to be researched.
- often a low friction value is design determining for the calculation of the displacement where the bends are located in relation to warm pipelines in field sections. The assessment of the total soil properties determine the measure of this. In a 'good' soil with a good amount of compaction, the value of, for example, the volume weight, the *E* modulus and the angle of internal friction remain relatively high; that is to say, the average values for all the geotechnical parameters are multiplied by the spatial distribution factor. Subsequently, the bedding indices are also taken as being high in relation to the model uncertainty (multiplied by the model factor). The representative friction, however, would be determined by dividing by the model factor. But in a 'bad' soil the friction would be determined by dividing the average value by the product of the spatial distribution factors and the model factor. In that case, the other geotechnical parameters, such as modulus of sub grade reactions and bearing capacity are also taken to be low.

Appendix C
(normative)

Design aspects - Loads

C.1 General

The corresponding terms and formulas for the determination of the size of a load, mentioned in Paragraph 8.2.7.2, are described in this appendix.

Other formulas may be applied, if it can be substantiated by experiments or references to corresponding literature that the formulas are physically correct.

C.2 Internal pressure

C.2.1 Design pressure (p_d)

The design pressure shall be applied in calculating the strength of any point of the pipeline. The design pressure is determined by the maximum operating pressure, in combination with the applied pressure control system.

A determination of the maximum operating pressure shall include:

- the maximum pressure differential, required for pumping the design volume of medium between the locations;
- the required pumping head at the delivery location;
- the available pre-pressure at the pumping location;
- possible level differences between the starting and the terminal point.

If the fluid carrying pipe is encased in a jacket pipe and a vacuum is maintained in the annular space between jacket pipe and carrier pipe, , then the design pressure shall be increased by 0.1 MPa.

C.2.2 Pressure surges

Pressure surges can occur as a consequence of closing or opening shutoff valves, the start or shutdown of pumps, and a sudden rupture of the pipeline.

Pressure surges can be calculated according to the following three principles, in ascending order of applicability and predictive value/accuracy:

- with the simple formula for pressure surges, due to instantaneous valve closure (Joukowski, 1898);
- with the “characteristics” water hammer calculation method (Bergeron, 1935);
- with the dynamic calculation of liquid-pipeline interaction.

a) Pressure surge due to instantaneous valve closure

Maximum instantaneous pressure surge according to Joukowski:

$$\Delta H = \frac{c}{g} \times \Delta v$$

where:

ΔH is the increase in pressure head of the fluid (in case of friction-free flow), in metres liquid column;

Δv is the change in flow velocity, in m/s;

g is the acceleration due to gravity, in m/s^2;

c is $\sqrt{\dfrac{1}{\rho_v \times \left(\dfrac{D_i}{d_n \times E} + \dfrac{1}{K}\right)}}$

where:

c is the rate of propagation of the pressure surge, in m/s;

p_v is the density, in kg/m^3;

D_i is the internal diameter of the pipeline, in m;

d_n is nominal wall thickness of the pipeline, in m;

K is the compression modulus of the fluid, in N/m^2;

E is the elasticity modulus of the pipe material, in N/m^2.

The calculated pressure surge can be added to the maximum operating pressure (measured at the location of the pump) as a static pressure increase.

The formula of Joukowski should only be used for getting a quick indication of the pressure increase, generated by fa relatively rapid (instantaneous) closure of a shutoff valve at the end of a (long) pipeline.

The method is not suitable for calculation of the consequences of pump shutdown (negative pressure wave, cavitations), and of 'slowly' closing shutoff valves.

The Joukowski formula also gives an incorrect picture if pressure waves are likely to be reflected, for instance due to the changes in the diameter, or in branched systems.

In comparison to the water hammer calculation using characteristics, the Joukowski ‘s method can give both to too high and too low pressures.

b) The water hammer calculation, with the use of characteristics

Calculation methods (for instance the characteristics method), which take into account the effective closing time of the shutoff valve(s) and the propagation rate of the pressure wave, give a better picture than the Joukowski formula.

Furthermore, computer simulations may be used to calculate, the effects of "line packing", branched or interlinked systems, reduction of pipe diameter, changes in wall thicknesses, pump failure, the behavior of non-return and safety valves, as well as cavitations..
They also provide an efficient manner,to analyze facilities to prevent/reduce the effect of water hammer

With this traditional water hammer calculation method, the fluid dynamics in rigidly anchored pipeline systems (to which most underground pipeline systems can be counted) can be calculated reasonably well. The results of such calculations, namely the dynamic pressure profile in the fluid at a large number of calculated points, are frequently used for calculating stresses and deformations of the pipeline structure as well as anchoring forces.

If the pipeline has some freedom of movement, this method can lead to substantial deviations in the forecast of pressures, stresses, strains and deformations, when compared with a full simulation using the fluid-pipeline interaction method. This is true in particular in case of aboveground pipelines.

c) Dynamic calculation with fluid-pipeline interaction

In this method, pressure and stress waves ,due to pump or valve operations are calculated in combination. The effect of high-frequency phenomena, such as an advance stress wave ("precursor"), namely the stress wave in the pipeline material with a much higher propagation velocity than that of the pressure surge in the fluid, can lead to substantial deviations in stresses and strains, when compared with the forecast of the classical water hammer calculation methods.

These deviations show that the traditional, non-combined method of calculation can lead to both over and underestimation of the dynamic phenomena depending on the pipeline system that is under consideration, in particular with aboveground (locally supported) pipelines.

NOTE Detailed information, with regard to the pressure surge analyses in accordance with c, is provided in references [1] and [2].

C.2.3 Test pressure

For determining the magnitude of the test pressure (p_t), refer to the relevant material sections of the standard. The size is usually related to the design pressure of the pipeline system, or to the wish for having a certain hoop stress occurring in the pipeline during testing.

C.3 Temperature variations

By temperature is understood the pipe wall material temperature of the fluid carrying pipeline. The highest and the lowest operating temperature, as well as the relevant temperature fluctuations, shall be determined through an analysis of the expected operating procedures and the ambient conditions, during the design life of the pipeline.

Temperature fluctuations shall be discounted in the strength calculation as follows:

- in determinating the stress range in a pipeline or pipe element, in which temperature flutuations occur, the full temperature range (that is the difference between the highest and the lowest operating temperature) shall be used in the calculation;

- in determinating the displacements, forces and moments, on connected equipment and/or structures, the analyses can be based on the difference between the installation temperature and the critical operating temperature.

In view of the interrelated forces and the interaction between the pipe and soil, it is recommended to take thermal expansion in account, right from the start, in combination with the expansion due to internal pressure (this also applies for aboveground pipelines).

C.4 Soil

C.4.1 Interaction between pipelines and soil: model description

C.4.1.1 General

A pipeline has different stiffness characteristics ,compared with the surrounding soil. Relative displacement between the pipeline and the soil, for instance caused by soil settlements, pipe subsidence, thermal expansion or expansion by internal pressure, is counteracted by the soil. This gives rise to bending moments and forces in the pipe. For assessment, whether the pipeline has sufficient strength and stiffness for resisting these forces, an analyses is made in a calculation model. The calculated values of bending and torque moments, axial and shear forces, relative displacements and soil reactions for underground pipelines, strongly depend on:

- a correct modeling of the interaction between the pipe and the surrounding soil;

- the reliability of the utilized geotechnical parameters.

For the calculation of the pipeline in the soil (system or 'beam' analyses), the pipe can be represented as a rod ('beam'), which is supported by springs in three directions (k_x, k_y and k_z), which represent the soil reactions ($u \times k_x$, $v \times k_y$ and $w \times k_z$) in an axial, horizontal and vertical direction (see figure C.1).

NOTE As an alternative for the ' discrete spring model' (beam model), theories for beams on elastic foundation or finite element models are also applied.

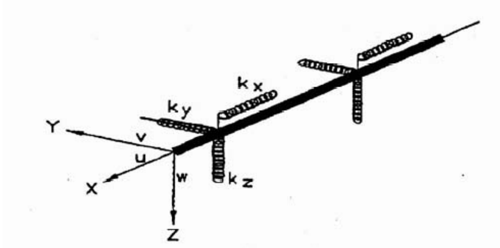
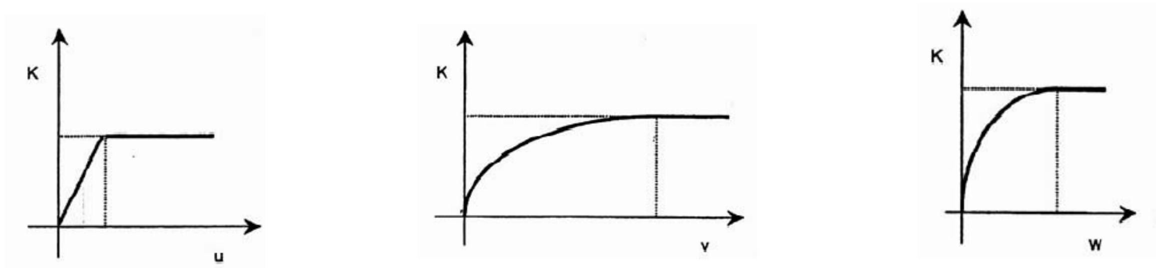


Figure C.1: Soil-pipeline interaction

The magnitude of the soil reactions is represented by a non-linear function of the relative displacement (*v, w, u*) between the pipe and the surrounding soil, and it can be schematically represented as a combination of bilinear springs in three principal directions (see figure C.2).:

- axial and torsion (along the pipeline axis, in the X direction);
- horizontal (perpendicular to the pipeline axis, in the Y direction);
- vertical (perpendicular to the pipeline axis, in the Z direction).

Each of these springs is characterized by a deformation related component and, once the limit value is reached, a constant component, namely the 'ultimate bearing capacity' in the corresponding direction. The relationship between the relative displacement and the magnitude of the soil reactions in the deformation related component is represented by the 'modulus of sub grade reaction'.



X: Friction

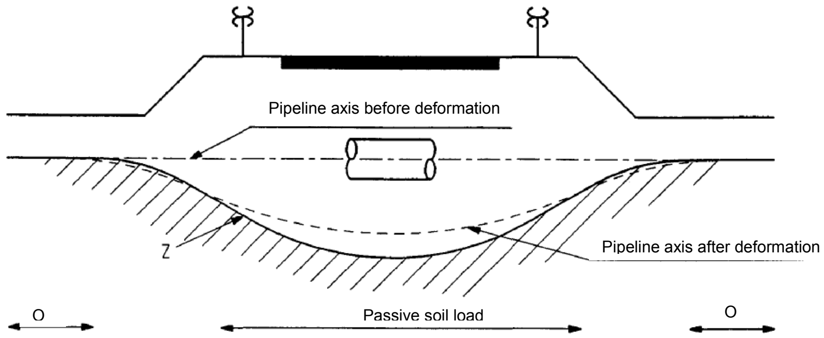
Y: Horizontal ultimate bearing capacity

Z: Vertical ultimate bearing capacity / passive soil load

Figure C.2 - Load-displacement diagram for soil reactions

C.4.1.2 Pipeline considered as a beam during settlement and subsidence differences

The pipeline behaves as a beam when the soil is subject to differential settlement or the pipeline is subject to subsidence differences from construction activities (Figure C.3); the soil above the pipeline will force it to follow soil movements entirely or partially (so-called forced deformation), depending on the beam stiffness of the pipe.



O = support zone (maximum reaction = ultimate bearing capacity)
Z = settlement

Figure C.3 - Beam- behavior

The load, required to achieve this is the settlement load (Q_z); it is not directly transmitted (by tangential moments and forces in the wall) to the subsoil. Instead it is transmitted to the bedding zones, to the left and right of the settlement area. Through this, axial bending moments and shear forces are created in the pipeline.It may also give rise to tensile forces in the axial direction (catenary effect).

Higher soil reactions occur in the bedding zone, which shall balance with the settlement load. The magnitude of the settlement load and the soil reactions is limited by the amount of settlement, the pipe stiffness and the stiffness of the soil. The behavior of an underground pipeline can be schematically represented by an infinitely long beam that is supported by springs, as is shown in the figures C.1, C.2 and C.4*(this text to be deleted?)*.

The upper limit of the settlement load Q_z is equal to the sum of the upper limits of the earth pressure on the pipeline (passive earth pressure) and the weight of the pipeline and the fluid ($Q_p + Q_{eg} + Q_{vul}$). As long as Q_z is smaller than $Q_p + Q_{eg} + Q_{vul}$, then, in addition to the indirect load transfer of Q_z (as in figure C.4) to the bedding zones (Q_r in figure C.4), the remainder of the load ($Q_n + Q_{eg} + Q_{vul} - Q_z$) will be directly transmitted to the soil under the pipeline.

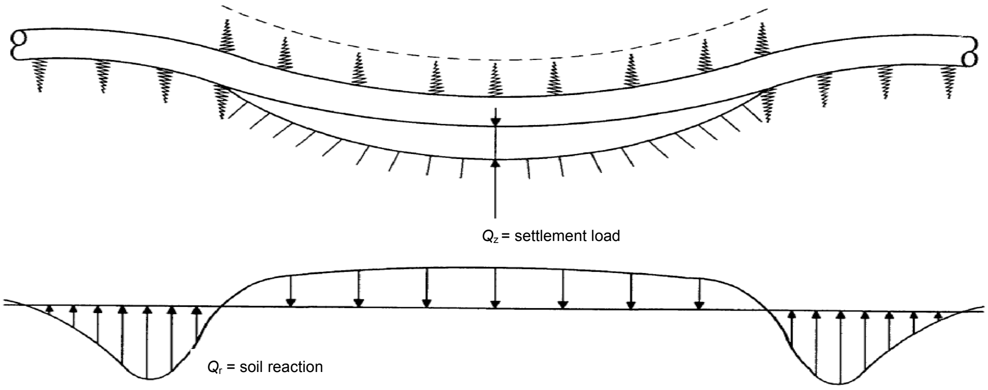


Figure C.4 - Settlement load and soil reaction

NOTE In highly compressible soils phenomena such as 'swelling' and compression ("squeezing") (by relief of the subsoil), may give rise to substantial lateral displacements. With swelling is meant the elastic relaxation of the soil, which occurs when the upper load is removed. "Squeezing" can for instance occur in a thin and weak clay layer at trench bottom level. The clay can be pushed sideways into the trench by the greater overhead load on the clay layer next to the trench. The possible occurrence of these phenomena shall be separately recognized/analysed and can be taken into account in combination with the settlement differences and/or construction subsidence differences.

C.4.1.3 Circumferential ("Ring") interaction, load angle and support angle

In addition to considerint the pipeline "as a beam', considering the pipeline 'as a ring' is also important in every pipe cross-section, The overhead load is transmitted, perpendicular to the longitudinal axis, by the pipe cross-section to the subsoil, frequently under ovalization of the pipe cross-section. In the case of tangentially flexible pipes in a 'rigid' subsoil, the ovalization (also called deflection) can give rise to additional horizontal earth pressure.

In translating the spring load into a load on the pipeline, the concepts 'load angle', 'support angle' and 'contact angle for horizontal soil resistance' are used .

a) *Load angle*

By 'load angle' α is understood the angle, over which the soil load acts on the top of the pipe. In the calculations, a load angle of α = 180° can be assumed, i.e. the pipeline is considered to be subject to a uniform load over the full width of the pipe.

b) *Support angle*

By 'support angle' β is understood the angle, over which the soil reacts against the pipeline bottom.

The support angle is dependent on the manner of installation and size of the soil reaction. A safe calculation value for the support angle is at least 70° for tangentially flexible pipelines, and 30° for tangentially rigid pipes.

120° is used for, pressed, or jacked (trenchless installation) pipelines..

A larger support angle can be applied, depending on the relationship between the load and the ultimate bearing capacity:

From the vertical equilibrium it follows that:

$$Q_n + Q_d = P_{we} \,.\, D_o \times \sin {}^1/_2\beta$$

where:

$Q_n + Q_d$ is the neutral earth load on the pipeline (Q_n), and the indirect load (Q_d) from the pipeline acting as a beam, that has to be transmitted permanently in kN/m^2;

P_{we} is the ultimate bearing capacity, in kN/m^2;

D_o x sin ½ β is the support width, in m (also see the Figure D.2).

The angle β can be derived from the following formula:

$$\sin ½\,\beta = (Q_n + Q_d) / D_o \times P_{we}$$

NOTE Field tests have shown ,that the support angle in the range of 60° < β < 90° can be equated with β + 10°. For β > 110° the support angle is equal to β, and for 110° > β > 90° the angle can be increased proportionally between 0° and 10°. For pipes with a ring stiffness $E \times I_w / D^3_g \leq 60\ kN/m^2$ (plastic, thin-walled steel and nodular cast iron), β = 120° is applied for the load case without internal pressure.

c) *Contact angle for horizontal soil resistance*

By contact angle χ for horizontal soil resistance, is understood the angle at which the pipeline is subject to horizontal soil resistance from the sides. The level of side resistance is dependent on the type of soil and manner of installation. In the case of sand, it is also dependent on the deflection (also see figure D.2). 120° can be used as the angle for γ.

C.4.1.4 Shell effect (effective load carrying width)

Shell effects near local bedding reactions or zones with high earth pressures, can be included in the calculations. In this regard, the generally recognized literature (for instance Mang, [7]) or finite element models can be used.

NOTE A calculation for the determination of the fictitious effective load carrying width of the pipe, due to shell effect in tangentially flexible pipelines, is included in Section 5.6 of NPR 3659:1996. Shell effect is an equalization of the deflection (ovalization) differences. In the case of tangentially rigid pipes, deflection hardly occurs, leading to minimal shell effect and negligible additional effective width...

C.4.2 Soil load

C.4.2.1 General

The soil on, next to and under the pipeline subjects the pipeline to load. Differentiated are:

- neutral soil load, which is the vertical load on a pipeline, which does not displace with regard to the surrounding soil;
- effective soil load, which is the vertical load that is due to consolidation of the trench filling and, which can occur in the first few years after the installation of pipelines in trenches;
- passive soil load, which is the upper limit value of the vertical load that occurs when the soil settles in comparison to the pipeline, or the pipeline moves upwards in comparison to the surrounding soil;
- horizontal soil resistance (also called horizontal soil load, if the axis of the pipeline is not displaced), which can be active, neutral or passive, and is dependent on the relative movement between the soil and the pipeline.

C.4.2.2 Neutral vertical earth pressure

The neutral vertical earth pressure (Q_n) is the weight of the vertical column of soil above the pipe (vertical intergranular pressure at the level of the top of the pipe). Neutral earth pressure occurs, if there is no relative displacement between the pipeline and the soil. The neutral soil load is directly transmitted via the pipe wall to the subsoil.

$$Q_n = q_n \times D_o - \gamma \times H \times D_o$$

where:

Q_n is the neutral vertical earth pressure in kN/m^1;

q_n is the neutral vertical earth pressure in kN/m^2;

γ is the weight per unit volume of the soil in kN/m^3;

H is the soil cover on the top of the pipeline, in m;

D_o is the outside diameter, increased by the thickness of the outside coating, in m.

If the pipeline is located below the ground water level (phreatic surface) then the following applies (see figure C.5):

$$q_n = \gamma_d \times H_d + \gamma_n \times H_n - \gamma_w \times H_w$$

where:

γ_d is the weight per unit volume of the dry soil, above the phreatic surface;

γ_n is the weight per unit volume of the saturated soil, under the phreatic surface;

γ_w is the weight per unit volume of the water;

H_d is the soil cover above the ground water table(freatic level);

H_w is the soil cover under the ground water tablel.

For large diameter pipes the neutral earth pressure can be expanded to:

$$Q_{n;large\phi} = Q_n + (0.5 - \pi/8) \times \gamma' \times D_o^2$$

where:

γ' is the effective weight per unit volume of the soil.
($\gamma' = \gamma_d$ above the ground water table and $\gamma' = \gamma_n - \gamma_w$ below the ground water table.)

NOTE 1: This formula takes all soil above the pipeline axis into account.

NOTE 2: In the case of clay, capillary action can cause the soil above the phreatic level to become saturated with water, giving rise to an increase of intergranular pressure σ_k, due to the present capillary water (water pressures according to the dotted line in figure C.5). In case of strongly layered soils, each layer with a different weight per unit volume, this phenomenon should be correctly taken into account.

NOTE 3: If narrow trenches are used (width at pipe axis level < 1.5 D_o) then the load will be temporarily (for 1 or 2 years after installation) lower than Q_n, due to positive adhesion between the compacting trench fill and the trench walls (active soil load).

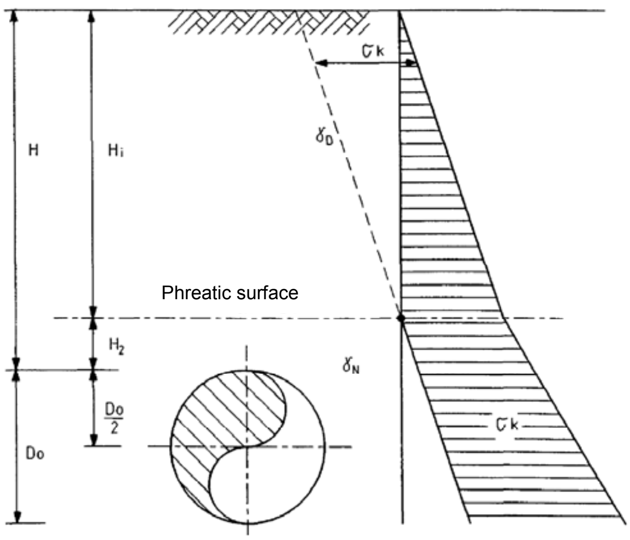


Figure C.5: Neutral soil load

C.4.2.3 Effective earth pressure

During the process of compaction, which takes approximately 1 to 2 years after installation, the effective earth pressure q_k ,wil be greater than q_n in the case of wider trenches (1.5 D_o < b ≤ 3 D_o), (see [11]). As the negative adhesion relaxes during that process, q_k reduces to q_n . q_k shall be combined with the installation subsidence difference; q_n also with the possible consolidation settlement difference. The critical load combination shall be determined, which requires, in principle, two calculations (also see D.3.4).

For the determination of q_k the following formula can be used:

$$q_k = \frac{q_n + \frac{\mu \times D_o}{z_{max}}\left(q_p - q_n\right)}{1 + \frac{q_p - q_n}{z_{max} \times k_{v,bottom}}}$$

which, when applying the formula for $k_{v,top}$ from C.4.3.2, can also be written:

$$q_k = \frac{q_n + \mu \times D_o \times k_{v,top}}{1 + \frac{k_{v,top}}{k_{v,bottom}}}$$

where:

q_k is equal to the effective vertical earth pressure, in N/mm^2

q_n is equal to the neutral vertical earth pressure, in N/mm^2

q_p is maximum passive vertical earth pressure, with f_m = 0.1 (see C.4.2.4.2), in N/mm^2

D_o is the external diameter, in mm;

$k_{v,top}$ is equal to the vertical modulus of sub grade reaction, for upward pipe movement, in N/mm^3, calculated according to C.4.3.2;

$k_{v,bottom}$ is the minimum of vertical modulus of sub grade reaction,for downward pipe movement, calculated according to C.4.3.3., or selected from the table C.6-C.8, in N/mm^3;

μ is the compaction 'percentage' (depending on the compaction of the trench filling);

Z_{max} is the displacement difference between the pipe and the soil, at maximum vertical passive earth pressure , as calculated according to C.4.3.2, in mm.

NOTE: In a calculation of q_k, the following values for μ can be maintained:

Trench fill		**Soil type**			
		Peat/soft clay	Stiff clay	Normal sand	Hard sand
not compacted	μ	0.20	0.15	0.075	0.075
Compacted	μ	0.10	0.075	0.02	0.02

C.4.2.4 Passive earth pressure

C.4.2.4.1 Action

Passive earth pressure (q_P) acts on the top of the pipeline and occurs, when the pipeline is unable to partially or fully follow the movements of the surrounding soil mass. In vertical direction,this can arise for instance in the case of settlements. The soil to the left and right of the pipeline settles, but the pipeline resists this movement because of its own stiffness and lags behind the settlement. This situation is shown at the left in Figure C.6.

In the contact surfaces, of the vertical column of soil above the pipeline, shear forces are exerted by the surrounding soil mass, which increase the total vertical load on the pipeline. The upper limit of that load is known as the ‘passive earth pressure’, and is reached when these shear forces have reached a maximum. (soil rupture).

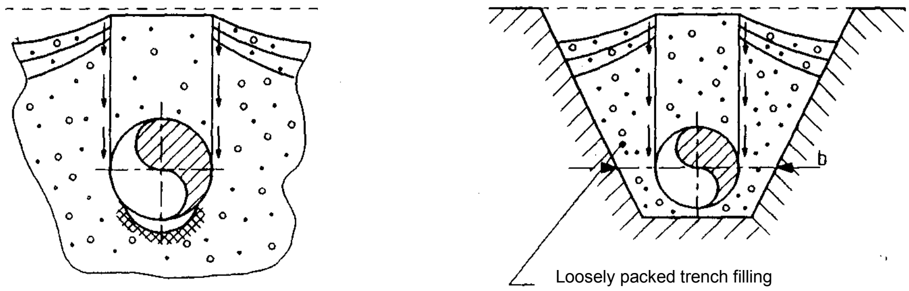


Figure C.6: Passive soil load

Passive earth pressures can also be exerted on a pipeline, if a wide trench (b > 3 D_o at the level of the pipeline axis) is backfilled. After some time this soil will consolidate and $q_p \Rightarrow q_n$. The pipeline is a relatively rigid element in this, so that more consolidation can occur on either side of the pipe, than vertically above it. This is the so-called "Marston" effect, shown at the right in figure C.6. In this case, the pipeline is supported on the subsoil and the load is transmitted directly, in contrast to the situation in the left of the figure.

C.4.2.4.2 Maximum vertical passive earth pressure

The following formula can be used for calculating the maximum vertical passive earth pressure (q_p) on pipelines (actually the resistance that occurs when the pipeline is 'pulled out of the soil'), as a function of the trench width and trench depth, the stiffness of the subsoil and the method of trench backfilling:

$$q_p = q_n \times \left(1 + f_m \frac{H}{D_o}\right)$$

In principle, the value f_m = 0.3 applies for cohesive soils. For sand, f_m is strongly influenced by the degree of compaction of the trench backfill. If a very high degree of compaction is achieved, then the factor f_m may be as high as f_m = 0.8. In view of the compaction levels ,normally achieved in pipeline technology, there is no justification for departing from the value, applied by Marston (f_m = 0.3) (soil rupture).

If the trench width is smaller or equal to 3D_o at the level of the pipe axis ($b \leq 3D_o$), it can be assumed that, while the trench backfill is consolidating, the passive earth pressure on the pipeline is reduced by negative adhesion against the trench walls. The value of f_m can be taken f_m = 0.1 in that case. q_p is here a reference value for the determination of q_k (this does not apply in the case of soil rupture, also see page 112 of NPR 3659:1996). If the trench width is less than 1.5 D_o, a value of f_m = 0 may be used.

C.4.2.4.3 Passive soil load for deeply positioned pipelines (arching)

The Marston method proceeds from a shallow rupture mechanism of the soil. The shear planes, along which the soil theoretically fails extend up to grade level. For deeply positioned pipelines, the maximum soil load is determined by a rupture mechanism, whose shear pattern is comparable to that of a deeply positioned strip foundation. At greater soil cover (H > 5 to 10 x the pipeline diameter), the Marston method no longer gives a good approximation of the passive earth resistance (see [11]).

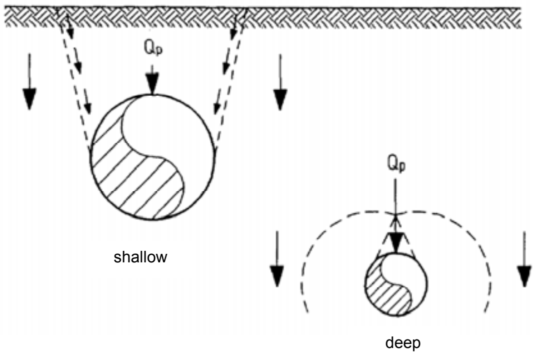


Figure C.7: Shallow and deep rupture mechanism

The maximum (reduced passive) earth pressure on the deeply positioned pipelines can be calculated with the help of the spatial expansion-theory. A derivation can be found in [26]. The radius of the plastic zone extends up to grade level in this case. The formula for the maximum soil load is:

$$P'_{\max} = \left(P'_{\mathrm{f}} + c \times \cot\varphi\right) \cdot \left\{ \left(\frac{0{,}5 \times D_{\mathrm{o}}}{0{,}5 \times D_{\mathrm{o}} + H} \right)^2 + Q \right\}^{\frac{-\sin\varphi}{1+\sin\varphi}} - c \times \cot\varphi$$

where:

P'_{f} is $\sigma'_{\mathrm{o}}(1 + \sin\varphi) + c. \times \cos\varphi$;

Q is $(\sigma'_{\mathrm{o}} \times \sin\varphi + c. \cos\varphi)/G$;

- σ'_{o} is the effective isotropic stress = $(\sigma_{\mathrm{kv}} + \sigma_{\mathrm{kh}})/2$;
- $\sigma_{\mathrm{kv,h}}$ is the vertical or horizontal intergranular stress;
- G is the shear modulus of the soil

c is the cohesion;

φ is the angle of the internal friction;

D_{o} is the outside diameter of the pipeline;

H Depth of soil cover above the pipe.

C.4.2.5 Horizontal earth pressure

C.4.2.5.1 Tangentially rigid pipes

In the case of tangentially rigid pipes, the neutral horizontal earth pressure (contact angle γ = 120°) is taken into account for all soil types, both for load cases with or without internal pressure.

C.4.2.5.2 Tangentially flexible pipes

When taking horizontal earth pressure into account with tangentially flexible pipes, the following applies (also see figure D.2):

Sandy soil, non-pressurized pipeline

In the case of sandy soil and an un-pressurized pipeline, the neutral horizontal earth pressure can be included in the calculation, increased by the (passive)horizontal earth resistance resulting from the application of the IOWA formula (see D.4), but limiting the contribution of the soil resistance according to this formula to a maximum of:

$$D_o \times \frac{2k_h}{3} \times \frac{\delta_y}{2} \times \sin\frac{\gamma}{2}$$

where:

δ_y is the vertical deflection of the pipeline (to be calculated according to D.4);

NOTE: For pipelines crossing major public works (see 6.5) , the value of $\delta_y/2$, in the formula,.shall not exceed the value of δ_E

δ_E is the elastic, horizontal displacement of the soil, calculated according to C.4.4.3, at reaching 50% of the ultimate horizontal bearing capacity. See table C.1 for indicative values.

γ is the contact angle, which = 120°

k_h is the modulus of horizontal sub grade reaction.

Table C.1 - Indicative values for δ_E

Diameter mm	**Elastic horizontal displacement δ_E in mm with *H* m soil cover in sand**	
	H = 0.8	*H* = 2.5
100	2	11
300	6	13
600	9	16
1200	16	22

For low-pressure pipelines and the load case with internal pressure, it is permitted to take:

- in sand: horizontal earth resistance, resulting from the neutral horizontal earth pressure and from passive resistance conform the IOWA formula;

- in clay and peat: the neutral horizontal earth pressure

into account, without "re-rounding", under the condition that the design pressure would lead to a value for f_{rr} that complies with the formula:

$$f_{rr} \geq \delta_{y2}/\delta_{y1}$$

where:

f_{rr} is the "re-rounding" factor;

δ_{y1} is the deflection without horizontal earth resistance;

δ_{y2} is the deflection with horizontal earth resistance.

Sandy soil, pipeline with internal pressure and $f_{rr} < \delta_{y2}/\delta_{y1}$

In sandy soil, for a pressurized pipeline with "re-rounding" effect, underneath the phreatic level, up to a maximum of active horizontal earth pressure may be taken into account.

If in the un-pressurized condition $\delta_y/2 < \delta_E$, then, in the pressurized condition a neutral horizontal earth pressure may be taken into account, both above and under the phreatic level.

Clay and peaty soil

With a pipeline in an un-pressurized condition in clay and peaty soils, a neutral horizontal soil pressure may, at the most, be brought into the calculation.

No passive horizontal earth resistance shall be taken into account for a pipeline under internal pressure, except forthe case when $f_{rr} \geq \delta_{y2} / \delta_{y1}$

Superposition

If horizontal soil pressure (active, neutral or (50%) passive, also see C.4.4.3) can be included in the calculation, then, for the points of the cross-section to be taken into consideration (for instance top (t), side (s) or bottom (b)), the circumferential bending moments resulting from Q_{tot} and from Q_n shall be correctly superimposed, taking into account the manner in which the pipe ovalizes.

Horizontal lateral soil rupture

If, in the case of horizontal soil deformation, the pipeline cannot follow the deformation of the soil (horizontal lateral soil rupture), then no horizontal earth resistance shall be taken into account.

C.4.2.6 Compaction of trench backfill (sand)

in case a certain level of compaction is required for the sand in the trench backfill, this may be indicated as a percentage of the so-called 'maximum Proctor density' (MPD). In everyday practice, a (hand) cone penetration apparatus (1 cm^2 cone) will normally be used for determining the density. The relationship between a percentage of MPD and the slope of the cone resistance is documented in table C.2 [25].

Table C.2 - Relation percentage MPD and slope of cone resistance

Relation of sand density to slope of cone resistance		
Density in % of MPD	Increase of cone resistance with depth in MPa/m [a])	
	Cone 10 cm^2	Cone 1 cm^2
94	3	10
95	4	15
96	6	20
97	8	26
98	10	33

[a])20 MPa/m = 20 N/cm^3, means: a cone resistance of 400 N will be recorded at a depth of 20 cm, using a cone cross section of 1 cm^2.

NOTE The relationship, documented in the table is only valid up to the 'limit depth', which amounts to approximately 15 to 25 times the cone diameter.

C.4.3 Soil reaction, modules of sub grade reaction

C.4.3.1 General

The stiffness of the soil, which is the reaction of the soil to a displacement of the pipe, is called the modulus of sub grade reaction. This is to be viewed as the tangent modulus of the load displacement diagram (see figure C.8; the modulus of sub grade reaction is determined by dividing the soil reaction by the corresponding displacement). The modulus of sub grade reaction is primarily dependent on the type of soil and its consistency (i.e. the elasticity modulus of the soil), but also on the pipe diameter.

Both undisturbed soil and disturbed trench backfill influence the spring characteristics. In the horizontal and in the downwards direction, the ultimate bearing capacity is primarily determined by the undisturbed soil. The deformation-dependent component is, however, in part defined by the properties of the loose trench backfill.

In an upward direction, and in an axial and sideways direction, the properties of the trench backfill are decisive for the spring characteristics that shall be put into the calculation. This is also true for the torsion springs.

Besides the filling material, with its specific characteristics,, the parameters that shall be applied in the (pipe-soil interaction) analyses are influenced by installation method, as well as the care that is taken in excavation, backfilling and compacting the trench.

Since the determination of moduli of sub grade reaction, by means of a geotechnical investigation, requires a deeper understanding of soil mechanics, values for the modulus of sub grade reaction are only presented in terms of indicative values, (see table B.6-B.8)). For the purpose of extended strength analyses, moduli of sub grade reaction shall be determined by a geotechnical adviser.

C.4.3.2 Vertical modulus of sub grade reaction,(upward pipe movement)

The modulus of sub grade reaction can be derived by determination of the displacement z_{max} of the pipeline, needed to increase the soil pressure from neutral earth pressure q_n up to the maximum (q_p).

This displacement (z_{max}) is dependent on the diameter of the pipeline (D), the soil cover, and the E modulus of the trench backfill on top of the pipe. The following formulas can be used for z_{max}:

Clay/peat $$z_{max} = 0.25\frac{D_o}{E^{1.5}\sqrt{H/D_o}}$$

Sand $$z_{max} = 0.2\frac{D_o}{E^{0.5}\sqrt{H/D_o}}$$

where:

D_o is the outside diameter, in m;

E is the elasticity modulus of the trench backfill material in MPa;

H is the soil cover on the top of the pipe, in m.

The spring behavior, up to and including a maximum displacement, can be described with a bilinear modulus of sub grade reaction:

$$k_{v,top} = \frac{q_p - q_n}{z_{max}}$$

NOTE: If, as a standard procedure, the calculation program used for the beam analyses, only decribes vertical springs which, in case of a displacement from zero to z_{max}, let the top load increase from zero to the passive vertical earth pressure($k_v = q_p/z_{max}$), then a correction should be applied on the value of $k_{v,top}$, calculated with the above formula.

C.4.3.3 Vertical modulus of sub grade reaction, (downward pipe movement)

a) Clay and peat

For clay (and for the time being also for peat), the vertical modulus of sub grade reaction k_v can be derived as follows:

The ultimate bearing capacity P_{we} is determined in accordance with C.4.4.2.b. The vertical modulus of sub grade reaction is determined from the calculated ultimate bearing capacity as follows:

$k_{v;1} = 0.25 \times c_u \times \frac{P_{we}}{D_o}$ from 0 to $^2/_3$ times the vertical ultimate bearing capacity

$k_{v;2} = 0.04 \times c_u \times \frac{P_{we}}{D_o}$ from $^2/_3$ to 1.0 times the vertical ultimate bearing capacity

The formula as derived describes the plastic penetration process of the pipe in the trench bottom, and can be used both for instantaneous applied loads (undrained situation) and for slowly applied loads (drained situation). The corresponding load- displacement curve is approximated here with a trilinear spring characteristic.

b) Sand

The same penetration process occurs in sand. P_{we} is determined here in accordance with C.4.4.2.a. in case a trilinear spring characteristic is used, the following formulae apply:

$k_{v,1} = 0.5 \times E \times P_{we} / D_o$ from 0 to $^2/_3$ times the vertical ultimate bearing capacity

$k_{v,2} = 0.1 \times E \times P_{we} / D_o$ from $^2/_3$ to 1.0 times the vertical ultimate bearing capacity

The value of the elasticity modulus E shall be determined for the undisturbed subsoil, in accordance with table 1 of NEN 6740:1991, or through compression or triaxial tests.

NOTE: The above-mentioned formulas for clay, peat and sand, describe a trilinear spring characteristic. It is also permitted to utilize a bilinear spring characteristic, on the basis of $k_{v,1}$.

c) Trenchless

For pipelines installed by boring or jacking, a support angle of *ß* 120° shall be maintained. In this case the value of *ß* will not increase in time. k_v can be determined according to the formula of Schleicher.

$$k_v = E_{grond} / m\left(1 - \nu^2\right)\sqrt{A}$$

where:

k_v is the vertical modulus of sub grade reaction, in N/mm³;

E_{soil} is the elasticity modulus of the soil, in MPa;

A is $l \times b$ = area of support, in mm²;

- b is the support width = D_o;
- l is the minimum support length, $l = \pi / \lambda$ in mm;
- λ is the pipe-soil stiffness characteristic in mm^{-1};

ν is the contraction coefficient (ν = 0.35 is maintained);

m is the form coefficient and is determined by *l/b*.

l/b	1,5	2	3	5	10	100
m	0,94	0,92	0,88	0,82	0,71	0,37

C.4.3.3 Horizontal modulus of sub grade reaction (lateral)

Use is made of the following general relationship for sideways displacement (see Audibert and Nyman [8]), see Figure C.8:

$$\frac{q_h}{q_{he}} = \frac{y/y_{max}}{A + B \times y/y_{max}}$$

where:

q_{he} is the maximum horizontal soil resistance (the horizontal ultimate bearing capacity) at a displacement y_{max}, in N/mm^2;

q_h is the soil resistance ($q_h < q_{he}$), at a horizontal displacement y_1 ($y < y_{max}$), in N/mm^2;

y_{max} is the horizontal displacement at reaching the ultimate horizontal bearing capacity, in mm.

The following values are applied to the constants A and B:

	Sand and clay/peat (slowly loaded, drained situation)	**Clay/peat (fast loading,undrained situation)**
A	0.145	0.1
B = 1 - A	0.855	0.9

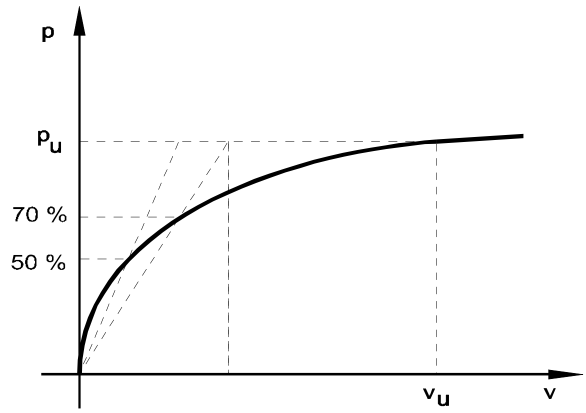


Figure C.8: Load displacement diagram for horizontal displacements according to Audibert and Nyman

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The load displacement diagram shows elastic soil behavior at smaller displacements (approached by the modulus of sub grade reaction), and plastic soil behavior following large displacements, when the horizontal ultimate bearing capacity is reached.

The following relationship can be used for the maximum displacement y_{max}:

$$y_{max} = D_o \times [0.05 + 0.03 \times (Z/D_o + 0.05)]$$

where:

D_o is the outside pipe diameter of the;

Z is the depth from grade level to the axis of the pipeline = $H + D_o/2$;

H is the soil cover on top of the pipeline.

A bilinear load -displacement diagram can be used for the calculation model, whereby the modulus of sub grade reaction is selected as a percentage of the horizontal ultimate bearing capacity, divided by the corresponding displacement, see Figure C.8. The horizontal modulus of sub grade reaction (the secant modulus as obtained from the load displacement diagram), is determined here at 30% of the horizontal ultimate bearing capacity:

$$k_{h,30} = \frac{q_{h,30}}{y_{30}} = \frac{q_{he}}{y_{max}} \times \frac{1 - 0.3 \times B}{A}$$

NOTE: Test loads (in Kesteren and at the Bergambacht pipeline, in the Netherlands) have shown that a trilinear spring characteristic also gives a good estimation of the real load-deformation behavior (derived from tests with *Z/D* ratios up to approx. 3). The following has been derived from these measurements:

$k_{h1} = 33 \times q_{he}$ N/mm^3 from 0 to $^2/_3$ times q_{he} (sand and clay)
$k_{h2} = 4.8 \times q_{he}$ N/mm^3 from $^2/_3$ to 1 times q_{he} (sand)
$k_{h2} = 2.2 \times q_{he}$ N/mm^3 from $^2/_3$ to 1 times q_{he} (clay)

A bilinear characteristic may also be used, by only utilizing k_{h1}.

C.4.4 Ultimate bearing capacity (lateral)

C.4.4.1 General

The horizontal part of the bilinear spring characteristic, which indicates the connection between load and a displacement, corresponds to the ultimate bearing capacity of the soil. Actually, soil rupture occurs in this situation.

C.4.4.2 Vertical ultimate bearing capacity

The limit value for the vertical load is given by the vertical ultimate bearing capacity. This is the load needed to cause the soil under the pipeline to fail over the full width of the pipe. The failure mechanism is shown in Figure C.9. The load/displacement diagram (or the spring characteristic for downward movement) is shown in Figure C.10.

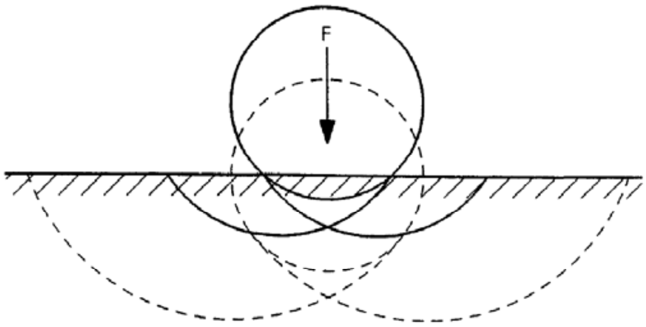

Figure C.9 - Failure mechanism for vertical ultimate bearing capacity

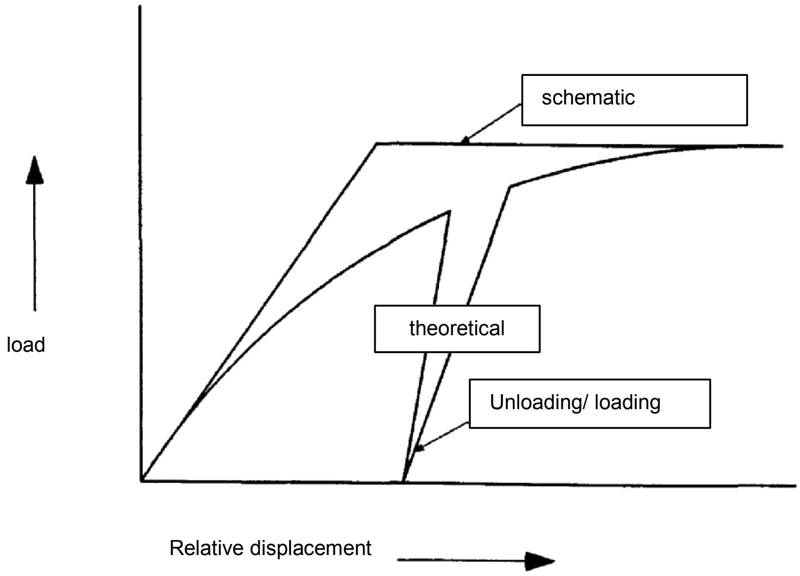

Figure C.10 - Load displacement diagram

As failure of the soil under the pipe progresses, this creates a steadily wider bedding area. At cyclical loading, the bedding of the pipe will develop a good fit.. The soil will then show greater stiffness at loading after previous unloading

Experiments have shown that the vertical ultimate bearing capacity can be predicted with the Brinch Hansen method, both for sand, clay and peat.

a) Sand

For sand, the ultimate bearing capacity, determined at pipe axis level, can be described with the Brinch Hansen formula for the drained situation:

$$P_{we} = 0.95\left\{\ 0.5\ \gamma'_{gem}\ B\ N_y S_y\ d_y + S_q N_q\ d_q\left(q_n + c'\cot\varphi\right) - c'\cot\varphi\ \right\}$$

where:

P_{we} is the ultimate verticalbearing capacity;

.γ_{gem} is the average effective weight per unit volume from the grade level, up to the pipe axis level;

B is the installation width (chord), (at pipe axis level B = D_o applies)

D_o is the outside diameter of the pipeline;

$N_y = 1.5\,(N_q - 1)\tan\varphi$;

$S_y = 1 - 0.4\,B/L$;

L is the minimum support length, (here applies: $B/L = D_o/L = 0.1$);

d_y = 1;

$_q$ is the plate factor for pipelines; $S_y = 1 + \sin\varphi \times B/L$

N_q $= e^{\pi\tan\varphi}\tan^2(45 + \varphi/2)$

d_q $= 1 + 2\tan\varphi(1 - \sin\varphi)^2\arctan(Z/B)\,d_q$

Z is the depth from grade level to the pipeline axis = $H + D_o / 2$;

H is the cover on top of the pipeline;

c' is the effective cohesion, (for sand: $c' = 0$ applies).

The correction factor 0.95 is related to a systematic deviation, demonstrated when comparing the results of the formula with the average of field tests results.

b) Clay and peat, drained situation (slow deformation)

For the ultimate bearing capacity at slow deformation, for instance settlements,or pipeline expansion from temperature, the same formulas are applicable as under a).

c) Clay and peat, undrained situation (quick deformation)

The ultimate bearing capacity for clay and peat, for an undrained ('rapid') deformation is obtained by the formula:

$$P_{we} = 0.85 \times c_u\,(\pi + 2) \times (1 + S_c + d_c)$$

where:

c_u is the undrained shear strength (from the trench bottom down to 1D there under);

S_c is the form factor, $S_c = 0.2\,B/L$ (for pipelines $S_c = 0.02$);

d_c is the depth factor, $d_c = 0.4\arctan(Z/B)$, in radials.

The factor 0.85 stands in relationship to a systematic deviation, which occurs when the result of the formula is compared with the average of the results from practical tests.

C.4.4.3 Horizontal ultimate bearing capacity

At rest, an underground pipe is subject to lateral earthepressure, which normally is the neutral horizontal earth pressure. The earth pressure changes, as soon as the pipe is moving at right angles to its axis in a horizontal direction. As the pipe moves against the earth pressure, this will rise to a maximum passive horizontal earth resistance, and as the pipe is moving away from the soil, a minimal and active earth pressure will develop.

This is illustrated in Figure C.11, while Figure C.12. presents the spring characteristic for a single horizontal spring.

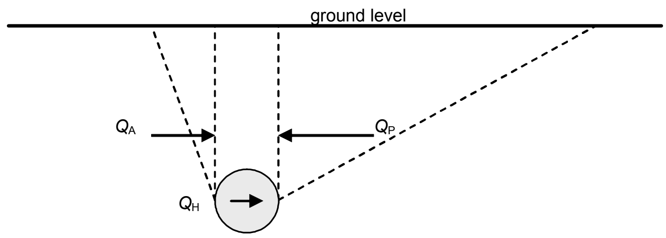

Figure C.11 - Horizontal earth pressure

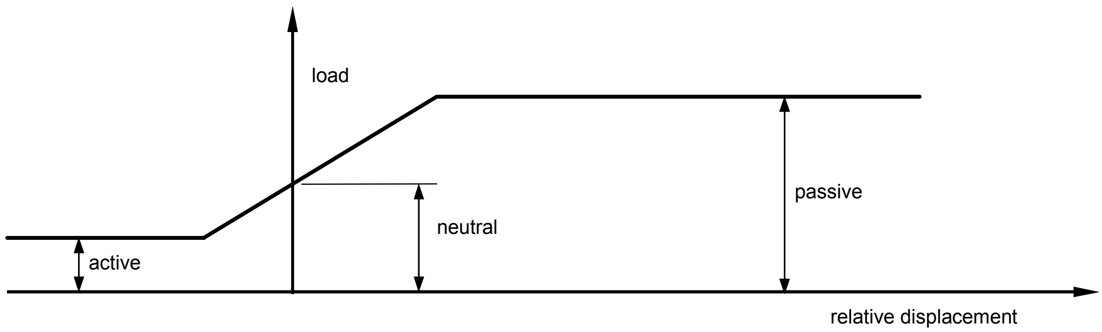

Figure C.12: Spring characteristic for one single spring

In the calculation model two horizontal springs have been included. The resulting pipe-soil interaction can then be represented with a combined spring characteristic, as in Figure C.13.

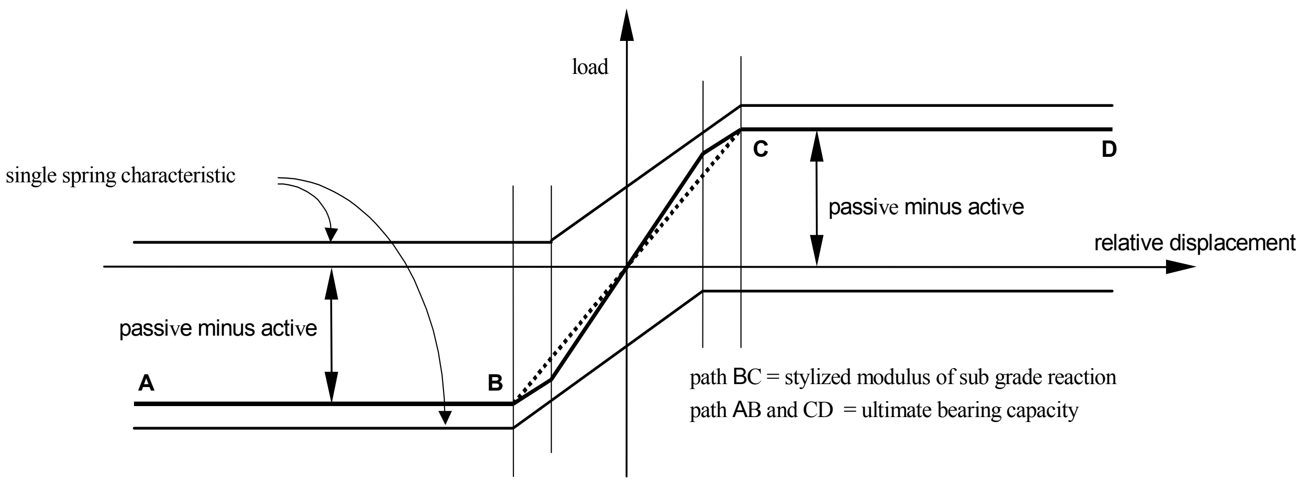

Figure C.13: Combined spring characteristic

NOTE Horizontal displacements of a pipeline for instance occurs at bends, as a consequence of operating conditions, (such as)temperature and/or pressure.

The upper limit value for the horizontal soil load is determined by the ultimate bearing capacity.

a) Sand, clay and peat (slow deformation, drained)

Using the Brinch Hansen theory [4],the horizontal ultimate bearing capacity can be determined(for sandy soi)l:

$$q_{he} = K_q \times \sigma'_k + 0.7\alpha \times K_c \times c'$$

where:

q_{he} is the horizontal ultimate bearing capacity;

K_q is the load coefficient according to Brinch Hansen, depending on φ and Z/D, see Figure C.14;

K_C is the load coefficient according to Brinch Hansen, depending on φ and Z/D, see Figure C.14;

c' is the effective cohesion of the soil

σ'_k is the vertical intergranular soil stress at the level of the pipe axis.

The correction factor 0.7 is related to a systematic deviation, demonstrated when the result of the formula is compared with the average of the results from practical tests.

NOTE For sand, only the first term of the formula ($c^1 = 0$) is applicable. For clay and peat, the approximation , valid for slowly changing circumstances (for instance the thermal expansion of the pipeline) is used

In case of trench in cohesive soil, backfilled with sand,.it is recommended to apply an augmentation factor of 1.4, compared to the original soil composition

b) Clay and peat (rapid deformation, undrained)

For cohesive soil (clay and peat), it appears the theory of Brinch Hansen can be used as well. The upper limit for horizontal earth pressure is for $H > 2D_o$:

$$q_{he} = 0.7\alpha \times K_{cu} \times c_u$$

where:

c_u is the undrained cohesion of the trench backfill, also referred to as undrained shear strength;

α is equal to 0.6, in case of open excavation;
α is equal to 1,0, in case of boring or jacking methods

K_{cu} is the load coefficiens according to Brinch Hansen, dependent on Z/D, see Figure C.14.

NOTE The assumption in the derivation of the above-mentioned formulas is that the soil level lies horizontally. The correction factor (model factor) for the determination of K_c amounts to 0.85 and for K_q to 1.0.

C.4.5 Soil friction

C.4.5.1 General

Whenever a pipeline is subject to a relative displacement, relative to the surrounding soil, a frictional force develops in the contact surface between the pipeline and the soil, acting in a direction, opposite to the displacement vector. The magnitude of this force is dependent on the relative displacement between the pipeline and the soil. Whenever the relative displacement reaches a certain size, this frictional force no longer increases. The magnitude of the friction per unit of contact area(shear stress) is determined by:

- the intergranular pressure around the pipe;
- the angle of the internal friction;
- the adhesion of the soil to the pipe wall;
- the roughness of the pipe wall.

The friction can be represented by the characteristics of a torsion or longitudinal frictional spring (see Figure C.15)

The displacement (u_{max}) of the pipe relative to the surrounding soil, required to achieve the upper limit value (W_{max}) of the friction, is referred to as the frictional displacement, see Figure C.15. The frictional modulus of sub grade reaction (k_w) is the quotient of friction and displacement.

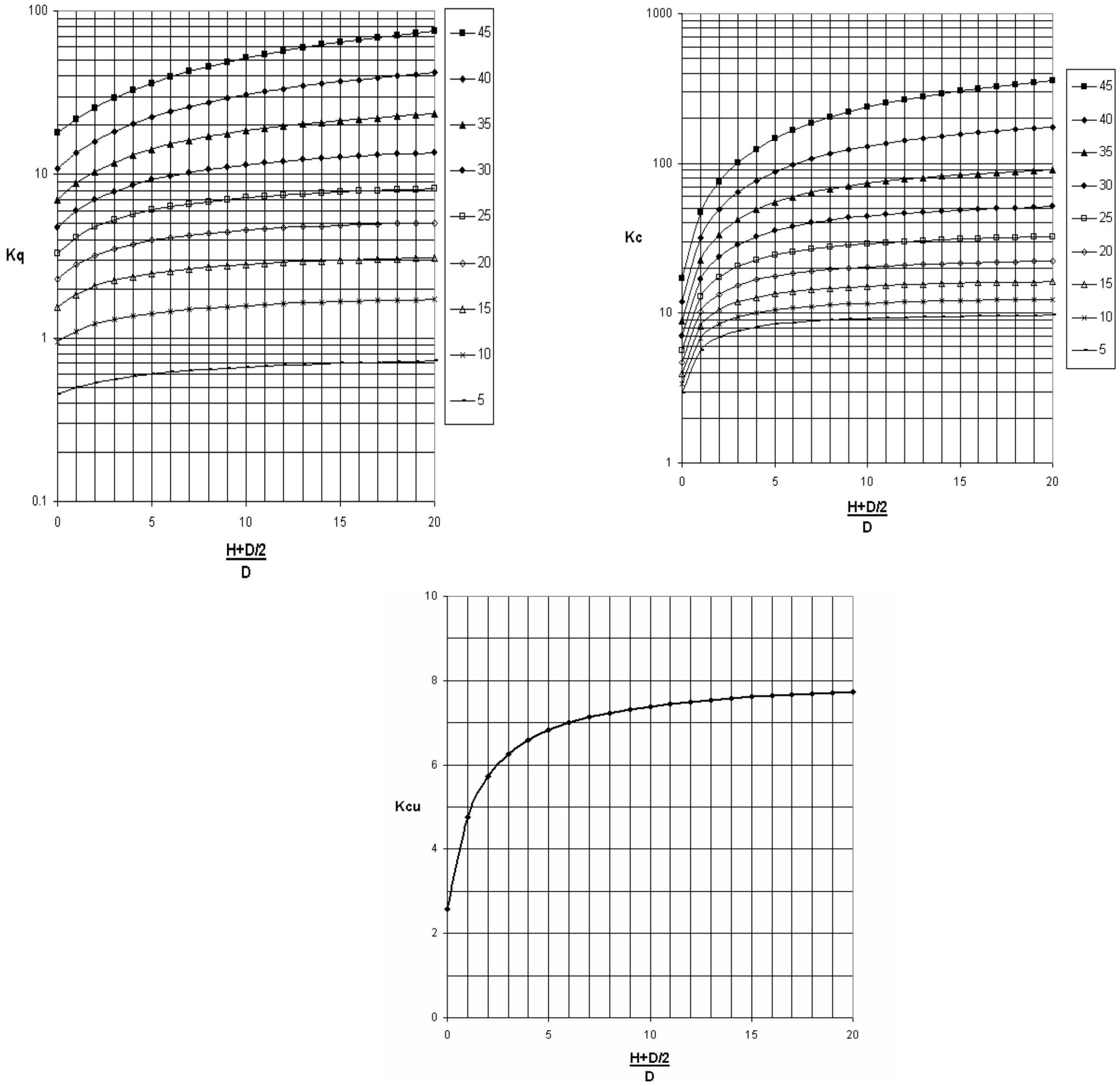

Figure C.14 - Load coefficients K_q, K_c and K_{cu}

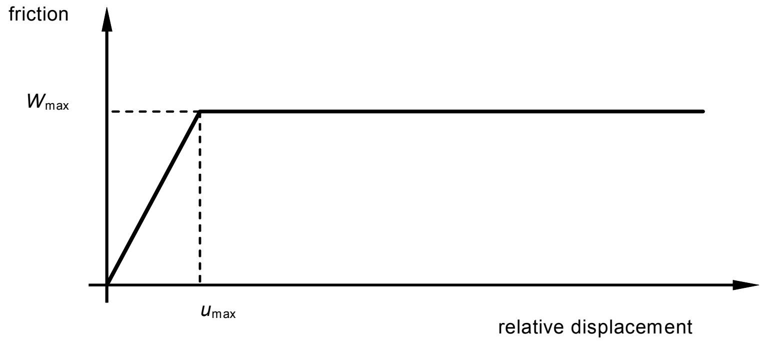

Figure C.15 - Diagram of frictional displacement

NOTE Measurements in the field have provided the following values for the frictional displacement, at maximum frictional resistance (u_{max}):

Type of soil	u_{max} in mm
tightly packed sand	1-3
moderately packed sand	3-5
loosely packed sand	5-8
stiff clay	2-4
moderately stiff clay	4-6
soft clay	6-10
moderately solid peat	6-10
soft peat	10-15

The values included in the table are based on limited information. Up to the maximum frictional resistance, an almost linear relationship between displacement and friction can be used. Compaction of sand reduces the displacement under maximum friction

C.4.5.2 Friction between pipe wall and soil

The maximum friction resistance per length-unit of pipeline length can be determined both for axial and torsion friction with the formula:

$$W = \pi\ D_o \left(\frac{1+K}{2} \times \sigma_k \times \tan\delta + 0.6 \times a \right)$$

where:

πD_o is the outside pipe circumference;

K is a relationship between the horizontal/vertical intergranular pressure; in the case of neutral horizontal earth pressure, K is equal to $K_o = 1 - \sin \varphi'$;

φ' is the angle of the internal friction of the soil;

σ_k is the vertical intergranular pressure at the pipe axis level;

δ Is the angle of the friction between the soil and the pipe wall, dependent upon the soil type and the surface roughness of the pipeline or its coating, $\delta \approx 2\varphi / 3$;

a is the adhesion (only with clay or peat), which is dependent on the soil type and the time elapsed since trench backfilling..

The correction factor 0.6 for the adhesion stands in relation to the systematic deviation, demonstrated when the results of the formula are compared with the average of the results from field tests.

With large diameter pipelines, the dead weight of the the pipeline ad its content may have a significant effect on the friction acting on the pipeline.. This can be conveniently incorporated into the friction equation as follows:

$$W = \pi\ D_{\mathrm{o}} \left(\frac{1+K}{2} \times \sigma_{\mathrm{k}} \times \tan\delta + 0.6 \times a \right) + \left(Q_{\mathrm{eg}} + Q_{\mathrm{vul}} - Q_{\mathrm{op}} \right) \times \tan\delta$$

NOTE In the determination of the average intergranular soil stress around the circumference of the pipe, the following aspects shall be taken into account:

- horizontal neutral earth pressure will occur in sand, with elastic soil behavior and a pipeline being subject to internal pressure. With flexible pipelines and large fluctuations in the internal pressure, the horizontal earth pressure can theoretically reduce, to the level of active horizontal earth pressure, as a result from an alternating increase and decrease of the horizontal pipe diameter;
- In cohesive soils, the neutral horizontal earth pressure in theory reduces to zero in pipelines under internal pressure , when pipelines has been depressurized for several weeks. Lateral consolidation has not occurred then. In pipelines ,subject to temperature fluctuations, associated with small diameter changes, this process may lead to a reduction of the horizontal intergranular pressures, reducing axial friction friction and allowing larger displacements.

C.4.5.3 Adhesion

Sand is a non-cohesive material, and adhesion therefore not occurs. With clay soil types, adhesion is still low immediately after trench backfill and it only develops in the course of time. In that case, the time elapsing between the installation of a pipeline and its being taken into operation becomes important.

The adhesion of clay to the outside of a pipe wall appears to be approximately equal to the drained cohesion c'.

C.4.5.4 Angle of internal friction and pipe wall surface roughness

Clay

In clay soils, adhesion appears to determine primarily the shear stress.

In water saturated clays the frictional angle φ appears to amount to less than 5° (rapid loading).

Consequently, at normal pipeline depths, the effect of friction angle is negligibly small, compared with the effect of adhesion, If, however, the water content is reduced, then the frictional angle will increase strongly, while the adhesion remains the same.

In case of pipelines in clay soils, which are subject to variations in diameter and degree of ovalization under the effect of temperature and internal pressure, the plastic behavior of clay soil may result in a certain relaxation of soil friction with time, This phenomenon is still a subject for further study.

Sand

Sand has an internal friction angle φ of approx. 30°. With strongly compacted sands, a higher φ value are encountered. This higher value is due to dilatantion phenomena. If a smooth pipe moves in such a strongly compacted sand package, no dilatantion phenomena can occur along the smooth surface, but it can however occur with a rough surface.

By decoupling these two effects, the relationship $f(\delta)$ between the pipe wall to soil friction angle (δ) on one hand, and the angle of internal soil friction φ on the other hand can also be decoupled. After the application of this correction, the ratio δ/φ can be set to 2/3 for all sand types and materials. This results in a friction angle of 20°, irrespective of the density and the roughness of the pipe wall ($\delta = f(\varphi) \times \varphi$ = 20°).

C.4.6 Soil settlements

Normally, settlements are determined in accordance with the combined settlement formula of Terzaghi-Buisman.

$$S_t = 0.9 \times \sum_{i=1}^{n} \frac{H_i}{C_i} \times \ln\left(1 + \frac{\Delta p_i}{p_{oi}}\right)$$

where:

H_i is the thickness in m of the layer *i*:

C_i is the compressibty modulus of the layer *i*:

$$\frac{1}{C'} = \frac{1}{C_p'} + \frac{1}{C_s'} \times \log t \quad \text{(see Tables B.1 and B.2);}$$

where:

t is the time that is passed in days;

p_{oi} is the average intergranular pressure in the layer *i,* before the application of a load;

S_t is the final settlement, in m, at the completion of the consolidation period, for instance 30 years: $t = 10^4$ days (log $t = 4$);

n is the number of layers;

Δp_i is the increase in intergranular pressure.

The compression modulus is determined on the basis of soil tests.

NOTE 1: The correction factor 0.9 is related to the systematic deviation, demonstrated when the results of the formula are compared with the average of the results from practical tests.

NOTE 2: By preloading, a part of the settlement will already have occurred when the pipeline is installed. In addition the consolidation process can be accelerated., by a surcharge (additional load) and/or vertical drainage, The difference, between the final settlement and the settlement that has already taken place when the pipeline is installed, is the residual settlement that will impose a load on the pipeline.
With good coordination of the preloading, surcharge embankment, vertical drainage and preloading period, a substantially less progressive settlement process can be created, causing far less problems to the pipeline.

For initial analyses, the values of the compression moduli can be taken from Table B.1 or, if the values from cone penetration tests (values for cone resistance and adhesion) are known, from Table 1 in NEN 6740:1991. In general, the settlement prediction, preloading with surcharge embankment, or the application of vertical drainage, shall be determined by a geotechnical consultant on the basis of a local soil examination.

C.4.7 Subsidence's during installation works

C.4.7.1 General

Subsidence differences from installation provide an indication of the unevenness over the length of the pipeline bedding. These differences result from disturbance of the soil strata underneath the pipe bottom, during installation of the pipeline. These differences can vary with the soil type, installation method, trench width, soil cover and pipe diameter. The values that shall be applied (continuous subsidence profile) are included in the Tables C.3 and C.4.

A jump in installation subsidence (abrupt subsidence difference) occurs in the case of pipelines, parts of which are installed by boring or jacking, with adjacent pipeline sections installed in an open excavated trench, or otherwise has partially been installed on dry land and under water (for instance submerged pipelines). The values that shall be applied (discontinuous subsidence profile) have been included in Table C.5.

Pulling out of sheet pile walls gives rise to soil deformations. If this concerns sheet pile walls for press or receiving pits, or temporary stability provisions for the trench, to be removed after pipeline installation, then a subsequently subsidence of the pipeline will occur.

C.4.7.2 Length of installation subsidence difference

The profile representing the difference in installation subsidence for an pipeline with inflexible couplings, installed in an open trench, and which is assumed to have a sinus curved shape, stretches over the length *L* and on both sides of the detected point of maximum subsidence of the pipeline (also see 8.2.12.1).

$$L = 10 \times \sqrt[4]{4 \times E \times I_b \ / D_o \times k_v}$$

where:

E is the elasticity modulus, in N/mm^2;

I_b is the moment of inertia of the pipe, in mm^4;

D_o is the outside diameter, in mm;

k_v is the vertical modulus of sub grade reaction, in N/mm^3.

If the calculated length of *L* is smaller than 20 m, then 20 m will be taken up in the calculation.
If this value is a larger than 50 m, then 50 m will be taken into account.

Table C.3 - Installation subsidence difference f_v for insufficiently compacted soil backfill, under or adjacent to the pipeline in a dry trench, and with a continuous subsidence profile (f_v in mm)

Soil type	**Soft clay/peat**						**Stiff clay**						**Normal sand**						**Hard sand**					
soil cover (m)	2,5			1,25			2,5			1,25			2,5			1,25			2,5			1,25		
Trench type / *D* nom. (mm)	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
100	20	30	30	20	25	30	15	25	30	15	20	20	10	10	15	10	10	10	10	10	10	10	10	10
200	20	35	40	20	30	35	15	25	35	15	20	25	10	10	15	10	10	10	10	10	15	10	10	10
300	25	40	50	25	30	40	15	25	35	15	20	25	10	15	20	10	10	10	10	10	15	10	10	10
400	25	40	55	25	30	40	20	30	40	20	25	30	10	15	20	10	10	15	10	10	15	10	10	10
450	25	40	60	25	30	45	20	30	40	20	25	30	10	15	20	10	10	15	10	10	15	10	10	10
600	25	45	65	25	35	50	20	30	45	20	25	30	10	15	20	10	10	15	10	10	15	10	10	10
750	30	45	70	30	35	50	20	30	50	20	25	35	10	15	25	10	10	15	10	10	15	10	10	10
900	30	50	75	30	40	50	20	35	50	20	30	35	10	15	25	10	10	15	10	15	15	10	10	15
1200	30	50	75	30	40	55	25	35	55	25	35	40	10	15	25	10	15	15	10	15	20	10	15	15

Table C.4 - Installation subsidence difference f_v for well compacted soil backfill, under or adjacent to the pipeline in a dry trench, and with a continuous subsidence profile (f_v in mm)

Type of soil	**Soft clay/peat**						**Stiff clay**						**Normal sand**						**Hard sand**					
soil cover (m)	2,5			1,25			2,5			1,25			2,5			1,25			2,5			1,25		
Trench type / *D* nom. (mm)	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
100	10	15	20	10	15	20	10	10	15	10	10	10	0	5	5	0	5	5	0	5	5	0	0	5
200	10	15	25	10	15	20	10	15	5	10	10	15	0	5	5	0	5	5	0	5	5	0	0	5
300	10	20	25	10	15	20	10	15	20	10	10	15	0	5	5	0	5	5	0	5	5	0	0	5
400	10	20	30	10	15	25	10	15	20	10	10	15	0	5	5	0	5	5	0	5	5	0	0	5
450	10	20	30	10	15	25	10	15	20	10	10	15	0	5	5	0	5	5	0	5	5	0	0	5
600	15	20	35	15	20	25	10	15	25	10	10	15	5	5	5	5	5	5	5	5	5	5	5	5
750	15	25	35	15	20	25	10	15	25	10	15	20	5	5	10	5	5	5	5	5	5	5	5	5
900	15	25	40	15	20	25	10	15	25	10	15	20	5	10	10	5	5	5	5	5	5	5	5	5
1200	15	25	40	15	20	30	10	20	30	10	15	20	5	10	10	5	5	5	5	5	5	5	5	5

In the tables C.3 and C.4, a, b and c indicate trench types, determined on the basis of the trench width *b* at pipeline axis level, expressed as the outside diameter D_o of the pipeline. The following values are applicable:

- for trench type a: $b \leq 1.5\ D_o$
- for trench type b: $1.5\ D_o < b \leq 3\ D_o$
- for trench type c: $b > 3\ D_o$

Table C.5 - Installation subsidence difference f_v for a prefabricated crossing, installed in a submerged trench and a for well or insufficiently compacted jacking or receiving pit with a discontinuous subsidence profile (H ≤2.5 m, f_v in mm)

Location	Submerged trench				Insufficient compacted pit				Well compacted pit			
Soil type / *D* nom. (mm)	Soft clay/peat	Stiff clay	Normal sand	Hard sand	Soft clay/peat	Stiff clay	Normal sand	Hard sand	Soft clay/peat	Stiff clay	Normal sand	Hard sand
100	110	85	40	40	110	85	40	40	65	50	20	15
200	120	95	45	40	120	95	45	40	70	55	25	15
300	130	100	45	40	130	100	45	40	75	55	25	15
400	135	105	50	45	135	105	50	45	80	60	25	15
450	140	105	50	45	140	105	50	45	80	60	25	15
600	150	110	50	45	150	110	50	45	85	65	25	20
750	155	110	55	45	155	110	55	45	90	65	30	20
900	160	115	55	50	160	115	55	50	95	70	30	20
1200	160	120	60	50	160	120	60	50	95	70	30	20

For an interpretation of the installation subsidence profile, along the axis of a pipeline with inflexible,couplings, reference is made to the figures that accompany the 'simplified analyses procedure'. These figures have been included in Appendix D of SI 5664-2.

In Table C.6, those values have been included that shall be taken into account for:

- the vertical modulus of sub grade reaction k_v in an open trench; the average value can be used in the beam calculation, the minimum value in the calculation of the circumferential stress from the effective soil load (see C.4.2.3);

- the horizontal modulus of sub grade reaction k_h in an open trench; the average value is used for the benefit of the beam calculation (k_h = 0.7 x k_v; see C.4.3.3), the minimum value is used for the calculation of the circumferential stress, in case of pipelines in sand and under application of the IOWA formula.

NOTE The values for the modules of sub grade reaction in tables C.6, C.7 and C.8 are informative and can be applied, when no geotechnical site investigation has been carried out..

Table C.6:
***k*-values for well compacted soil backfill, under or aside the pipeline in the trench, and with a continuous subsidence profile**

Type of soil	**Soft clay/peat**		**Stiff clay**		**Normal sand**				**Hard sand**	
Modulus of sub grade soil reaction (N/mm^3)	k_v (min)	k_v (gem)	k_v (min)	k_v (gem)	k_v (gem)		$k_{h,}$ (IOWA) [a]		k_v (min)	k_v (gem)
					Cover of soil					
D nom. (mm)					1,0 m	3,0 m	1,0m	3,0m		
100	0,007	0,011	0,016	0,024	0,045	0,11	0,028	0,0345	0,1	0,158
200	0,004	0,006	0,0085	0,013	0,025	0,058	0,020	0,0281	0,055	0,087
300	0,0025	0,004	0,006	0,009	0,018	0,040	0,016	0,0242	0,04	0,063
400	0,002	0,003	0,0045	0,007	0,015	0,032	0,014	0,0214	0,03	0,0475
450	0,002	0,003	0,004	0,006	0,013	0,029	0,013	0,0203	0,025	0,0395
600	0,001	0,002	0,003	0,005	0,011	0,022	0,011	0,0172	0,02	0,0315
750	0,001	0,002	0,0025	0,004	0,009	0,018	0,010	0,0148	0,015	0,0235
900	0,001	0,001	0,002	0,003	0,008	0,015	0,009	0,0134	0,015	0,0235
1200	0,0005	0,001	0,0015	0,002	0,007	0,012	0,007	0,0112	0,01	0,016

[a] The k_h (IOWA) value is for normal sand can also be used for hard sand, since the soil next to the pipeline will always been disturbed.

C.4.7.3 Abrupt subsidence difference

An abrupt subsidence difference occurs in axial rigid pipeline sections, with sections, installed by boring or jacking, and abutting straight sections installed in open excavation in the jacking or receiving pit.

In particular the subsidence difference between these two section causes axial stresses within the pipeline, due to longitudinal bending as well as tangential stress, due to direct or indirect transmitted loads.

The procedure for a manual calculation of these stresses has been included in Chapter 1 of the Change Sheet NPR 3659/A1:2003. A distinction is made between situations in which no soil failure (k-step method) occurs, and situations in which soil failure does occur (z-step method). The relevant method is determined by the size of the subsidence difference f_v and the modules of sub grade reaction at opposite sides of the front wall of the pit, respectively k_1 (for the jacked section)and k_2 (for the excavated section). It is a condition that possible vertical bends for a connection to the (higher located) field section shall be located at the back of the jacking or receiving pit.

The subsidence difference f_v, between the jacked and the backfilled sections that shall be taken into account, is given in Table C.5 (jacking or receiving pit).

NOTE It is emphasized that no settlements or subsidence, caused by vibration pulling of sheet pile walls, are discounted for in the values of f_v in Table C5.

The tables C.7 and C.8 include values that shall be taken into account for:

- the vertical modulus of sub grade reaction k_v in the jacked or boored sections (k_1), and for the sections installed in the jacking and receiving pit (k_2) and backfilled;

- the horizontal modulus of sub grade reaction k_h, for pipelines in sand and with the application of the IOWA formula (see D.4).

Table C.7 - *k* values for insufficiently compacted backfilling under or aside the pipeline in a jacking or receiving pit, and with a discontinuous subsidence profile (soil coverage *H* ≤ 2.5 m)

Type of soil	Soft clay/peat		Stiff clay		Normal sand				Hard sand			
installation method	jacked section	back-fiiled section	jacked section	back-filled section	jacked section		backfilled section		jacked section		backfilled section	
Modulus of sub grade soil reaction (N/mm^3) / *D* nom. (mm)	k_v=k_1 (max)	k_v=k_2 (min)	k_v=k_1 (max)	k_v=k_2 (min)	k_v=k_1 (max)	k_h (IOWA) (max)	k_v=k_2 (min)	k_h (IOWA) (min) [a]	k_v=k_1 (max)	k_h (IOWA)	k_v=k_2 (min)	k_h (IOWA) (min) [a]
100	0,007	0,0035	0,016	0,008	0,1	0,07	0,02	0,02	0,25	0,175	0,05	0,02
200	0,004	0,002	0,0085	0,004	0,055	0,0385	0,011	0,0165	0,13	0,091	0,025	0,0165
300	0,0025	0,001	0,006	0,003	0,04	0,028	0,008	0,014	0,095	0,0665	0,02	0,014
400	0,002	0,001	0,0045	0,002	0,03	0,021	0,006	0,016	0,07	0,049	0,015	0,016
450	0,002	0,001	0,004	0,002	0,025	0,0175	0,005	0,012	0,063	0,044	0,015	0,012
600	0,001	0,0005	0,003	0,0015	0,02	0,014	0,004	0,010	0,05	0,035	0,01	0,010
750	0,001	0,0005	0,0025	0,001	0,015	0,0105	0,003	0,009	0,04	0,028	0,01	0,009
900	0,001	0,0005	0,002	0,001	0,015	0,0105	0,003	0,008	0,035	0,0245	0,005	0,008
1200	0,0005	0,0005	0,0015	0,0005	0,01	0,007	0,002	0,007	0,025	0,0175	0,005	0,007

[a] The k_h values in the column 'backfiilled' are equal to k_h-values according table C.6 at 3,0 m cover divided by the total factor or 1,7 in conformity with table B.3.

Table C.8 - *k* values for well-compacted backfill under or aside the pipeline in a jacking or receiving pit, and with a discontinuous subsidence profile (soil coverage *H* ≤ 2.5 m)

Type of soil	Soft clay/peat		Stiff clay		Normal sand				Hard sand			
installation method	jacked	back-filled	jacked	back-filled	jacked		backfilled		jacked		backfilled	
Modulus of sub grade soil reaction (N/mm^3) / *D* nom. (mm)	k_v=k_1 (max)	k_v=k_2 (min)	k_v=k_1 (max)	k_v=k_2 (min)	k_v=k_1 (max)	k_h (IOWA) (max)	k_v=k_2 (min)	k_h (IOWA) (min) [a]	k_v=k_1 (max)	k_h (IOWA) (max)	k_v=k_2 (min)	k_h (IOWA) (min) [a]
100	0,007	0,007	0,016	0,016	0,1	0,07	0,04	0,035	0,25	0,175	0,1	0,035
200	0,004	0,004	0,0085	0,0085	0,055	0,0385	0,022	0,028	0,13	0,091	0,055	0,028
300	0,0025	0,0025	0,006	0,006	0,04	0,028	0,016	0,024	0,095	0,0665	0,04	0,024
400	0,002	0,002	0,0045	0,0045	0,03	0,021	0,012	0,021	0,07	0,049	0,03	0,021
450	0,001	0,001	0,004	0,004	0,025	0,0175	0,01	0,020	0,063	0,044	0,025	0,020
600	0,001	0,001	0,003	0,003	0,02	0,014	0,008	0,017	0,05	0,035	0,02	0,017
750	0,001	0,001	0,0025	0,0025	0,015	0,0105	0,006	0,015	0,04	0,028	0,015	0,015
900	0,001	0,001	0,002	0,002	0,015	0,0105	0,006	0,013	0,035	0,0245	0,015	0,013
1200	0,0005	0,0005	0,0015	0,0015	0,01	0,007	0,004	0,011	0,025	0,0175	0,01	0,011

[a] The k_h values in the column 'laid' are equal to k_h-values according table C.6 at 3,0 m cover

C.4.7.4 Soil deformations through pulling of sheet piling

Deformations in the soil can occur when sheet pile walls are pulled out by vibration.

Compaction of sand under the influence of vibrations and the filling of annular space, after a sheet pile wall is pulled out, are the two critical mechanisms that can occur during the pulling of sheet pile walls with vibrating equipment.

Both mechanisms can be cosidered in isolation, and their effects on subsidence can be summarized:

- subsidence (at grade level), caused by the filling of annular space, are approximately a function of the distance to the sheet pile wall. The relevant parameters are the equivalent thickness of the sheet piles, their length, and the angle of distribution, which lies between 45° and 45° - ½ φ in comparison to the perpendicular;
- subsidence (at grade level), due to compaction, can be calculated with a compaction model. In this model, the initial relative density is determined from the cone resistance and the intergranular pressure, using the correlation of van Lunne. The density increase depends on the accelleration level and the shear strength of the soil. The influence of the shear strength is counted for by a factor, which varies from 3 (for soil with a high intergranular pressure, that is a large shear strength) to 5 (for soil with a low intergranular pressure, that is little shear resistance).

The determination of the magnitude of the subsidence and its effects on the pipeline could be a incorporated in the geotechnical report. For more detailed technical information with regard to this phenomenon is referred to [15].

C.4.8 Soil load during horizontal directional drilling (HDD)

For a strength calculation covering the operational phase, it can be assumed that the bore hole will disappear and that a neutral earth pressure will come to rest on the pipeline. The neutral earth pressure can be assumed to be the maximum vertical soil load, on a pipeline that has been constructed with HDD technology. it may also be assumed that, in combination a neutral horizontal earth pressure is acting. The neutral vertical earth pressure may be substantially reduced through arching action, especially in sand. If a reduced neutral vertical earth pressure is used in the calculation, then, in combination, active horizontal earth pressure may be assumed as a maximum.

C.4.8.1 Arching

The bentonite soil shell around the pipeline will stiffen up after installation of the pipeline. This shell acts as a highly compressible layer, which will allow arching to develop with subsequent reduction of the vertical earth pressure on th e pipe. If it is assumed that vertical shear planes, with associated friction, develop in the soil mass above the pipeline, then the calculation method according C.4.8.2 can be used for the vertical soil load.

This calculation method is based on the theories of K. Terzaghi (also see [16]), which is described in [17] and [18], and applies to a homogenous soil mass.

C.4.8.2 Calculation method for vertical soil load (homogeneous soil mass)

If the thickness of the soil mass under consideration extending above the pipe is larger than four times the width of the soil column in shear, exteding above the pipeline (= $8B_1$), then:

$$Q_{n,r1} = \frac{B_1 \times \left(\gamma' - c/B_1\right)}{K \times \tan\varphi} \times \left(1 - e^{\frac{-K \cdot h \cdot \tan\varphi}{B_1}}\right) \times D_o$$

where:

$Q_{n,r1}$ is the reduced neutral earth pressure on the pipe, in N/mm;

B_1 is the half-width of the soil column in shear, in mm, $B_1 = ½ D_o + D_o \times \tan(45° - ½ \varphi) \geq R$;

R is the radius of the bore hole, in mm;

K is the coefficient for the horizontal neutral earth pressure, $K = 1 - \sin \varphi'$;

h is the depth of soil cover above the bore hole, in mm;

c is the cohesion, in N/mm^2 $c \leq B_1 \times \gamma'$;

γ' is the effective weight per unit volume of the soil, in N/mm^3;

φ is the angle of the internal friction, in degrees;

D_o is the outside diameter of the pipe, in mm.

For sand, the above formula provides the value of the vertical earth pressure to be taken into account.

In compressible soil types, such as clay and peat, the soil load thus calculated only applies to the situation directly after the installation of the pipeline. The original shear stress (positive adhesion) which reduces the vertical load on the pipeline, diminishes due to consolidation in the adjacent soil columns, caused by the same shear stress (negative adhesion).

The following formula is applicable for clay and peat:

$$Q_{n,r2} = (h \times \gamma - F_r / 2B_1) \times D_o$$

where:

F_r is the permanent friction (adhesion) due to arching, in N/mm;

$$F_r = \frac{0.9 \times F_{max}}{1 + \dfrac{B_1 \times (3H - 2h) \times \alpha}{2C \times H(\delta_d + F_{max}/2B_1 \times k_v)}}$$

F_{max} is the maximum friction(adhesion) that can be developed, in N/mm, $F_{max} = (h \times \gamma' - Q_{n,r1} / D_o)\, 2B_1$;

H is the thickness of the compressible soil mass, in mm;

α is a dimensionless factor, $\alpha = \ln (h/h_{ref})$ met $h_{ref} = 1$ (m);

C is the compression modulus;

k_v is the modulus of sub grade reaction for the bentonite-soil mixture, after stiffening, inN/mm^3;

δ_o is the relative displacement between the soil columns with fully developed friction, in mm;

0.9 is a modelling factor

For background information on F_r is referred to [17].

C.4.8.3 Calculation method for vertical earth pressure (layered soil mass)

As in a homogenous soil mass,the vertical earth pressure acting on a pipe in a layered soil mass, is reduced through the effect of arching. Determining the amount of this reduction is, however, substantially more complex, due to the variation in the soil properties over the entire height of the soil mass.

A soil profile exists in the west of the Netherlands which can the schematized as a two-layer system. The upper layer consists of a compressible package of clay or peat (Holocene deposits with a thickness of 10 to 20 meters), and the lower layer consists of sand (Pleistocene deposits down to a considerable depth).

On the assumption that:

- the layers have sufficiently homogeneous mechanical properties;
- the arching effect in the Holocene layer is negligible in comparison to the Pleistocene layer;
- the pipeline lies dat a depth greater than $8B_1$ in the sand;
- the sand is cohesionless ($c = 0$),

then the reduced vertical earth pressure on the pipe can be calculated with the following formula:

$$Q_{n,r} = \frac{B_1 \times \gamma'}{K \times \tan\varphi}(1 - e^{-K.h.\tan\varphi/B_1}) \times D_o + \sigma_c D_o e^{-K \cdot h \cdot \tan\varphi/B_1}$$

where:

γ' is the effective weight per unit volume of the sand, in N/mm^3;

h is the depth of soil cover on the bore hole in the sand, in mm;

φ is the angle of the internal friction of the sand, in degrees;

σ_c is the vertical intergranular pressure(effective stress) in the interface between the two layers, in N/mm^2, ($\sigma_c = \gamma'_h x\ h_h$);

γ'_h is the average effective weight per unit volume of the Holocene layer, in N/mm^3

h_h is the thickness of the Holocene layer, in mm;

See C.4.8.2 for the other parameters.

NOTE 1 The above formula is actually equivalent to that for a homogeneous soil package (see C.4.8.2), under addition of a top load (the Holocene package), which decreases as the depth of the pipe in the sand increases.

Where the pipe lies in the Holocene package, $Q_{n,r}$ can be calculated conform the calculation method of C.4.8.2.

Where the pipe lies underneath the Holocene/Pleistocene, interface but at a depth of less than $8B_1$ in sand, the calculation methods for $Q_{n,r}$ are not valid.

The following can be adopted as a practical approach for the determination of $Q_{n,r}$ in this transition area:

1) $0 < h < 2B_1$: $Q_{n,r}$ is constant and is equal to $Q_{n,r}$ interface

2) $2B_1 \leq h < 4B_1$: interpolation between $Q_{n,r}$ interface and $Q_{n,r}$ Pleistocene for $h = 4B_1$

3) $h \geq 4B_1$: $Q_{n,r}$ Pleistocene as a function of h.

If it appears that $Q_{n,r}$ Pleistocene ($h = 4B_1$) is larger than $Q_{n,r}$ interface, then 1) is deleted and 2) is applicable for $0 < h < 4B_1$.

NOTE 2 The critical vertical earth pressure will generally be found at the Holocene /Pleistocene interface, and not at the deepest point of the pipeline.

C.4.8.4 Calculation method for vertical earth pressure (layered soil mass with embankment)

If soil embankments (dike, road substructure) has been added to the original grade level and where the subsoil consists of a layered soil mass, as described in C.4.8.3, then the following method may be employed for the calculation of the vertical soil load:

a) The pipeline is lying in situ in the Pleistocene layer:

- calculation in accordance with C.4.8.3, whereby in σ_c the intergranular(effective) stress at the interface and caused by the embankment, is also included, ;

b) The pipeline is lying in situ in the Holocene layer:

- calculation in accordance with C.4.8.2, whereby the embankment is considered as forming part of the (homogeneous) Holocene soil package and an adapted, average effective weight per unit volume is applied (sand is heavier than clay or peat).

C.4.8.5 Calculation method for horizontal soil resistance

The horizontal earth pressure($Q_{h,r}$), which may be taken into account if the pipe is in unpressurized condition, shall be determined with the following formula:

$$Q_{h,r} = \left\{ \tan^2\left(45^0 - \varphi/2\right) \times Q_{n,r} - 2 \times c \times D_0 \times \tan\left(45^0 - \varphi/2\right) \right\} \times \sin 60^0 \text{ (contact angle } 120^0\text{)}$$

For $Q_{n,r}$ the value of $Q_{n,r}$ as calculated in accordance with C.4.8.2, C.4.8.3 or C.4.8.4. shall be used.

C.5 Traffic load

C.5.1 General

A realistic system of axle loads, such as will actually occur in the operating life of the pipeline, shall be the basis for a calculation.

At road crossings the axle load system shall be taken in account, which was applied in the design of civil engineering structures for the concerning road, such as bridges and viaducts.

For primary and secondary roads (national highway and provincial roads), a "Fatigue Load Model 3" (in conformity with EN 1991-2:2003 and concerning special transports) is assumed. For other roads, a "Fatigue Load Model 2, Lorry 4" is assumed, in conformity with EN 1991-2:2003.(The latter load system covers the "set of frequent lorries", in accordance with EN 1991-2:2003, as may occur on European roads, with the exception of special transports.)

NOTE: In the load systems of the "Fatigue Load Models", in accordance with EN 1991-2:2003, dynamic effects have been included. The applied(dynamic) factor is applicable to "pavements of good quality" (see (7) in section 4.6.1 of EN 1991-2:2003). No impact coefficients need to be taken into account for underground pipelines. The loads have been reduced with a factor of 1.2, in conformity with Attachment B of EN 1991-2:2003, this being a factor for "surfaces with good roughness". No dynamic factor has been included in the load system for special transports.

The distribution of axle loads in the subsoil can be calculated according to the method of Boussinesq or Braunstorfinger. Graph I in figure C.17 shows the traffic load at pipe top level, caused by "Fatigue Load Model 3", while Graph II shows the (reduced) traffic load caused by "Fatigue Load Model 2, Lorry 4" as calculated for several outside pipe diameters and according to the method of Braunstorfinger [6].

Graph I is applicable to primary and secondary roads. Graph II applies to roads of a lower category. Graph II is also applied for the shoulders of the road. Outside of roads, on flat terrain or soft slopes, an axle load system that conforms to "Fatigue Load Model 2, Lorry 4" (Graph II) is generally taken in account,, whereby the axle loads are halved. Figure C.16 gives an overview of the road cross-section.

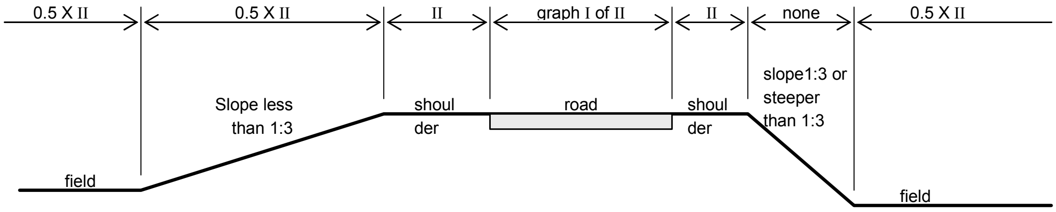

Figure C.16 – Overview of distribution of axle load systems

The traffic load per length unit:

$$Q_v = P_v \times D_o$$

where:

Q_v is the traffic load, in kN/m;

D_o is the outside diameter, including coating, in m;

P_v is the traffic load at pipe top level, caused by the axle load system, in kN/m^2;

NOTE Due attention should be paid to traffic loads, caused by (temporary) heavy construction traffic.during the installation phase of a pipeline, or due to activities of third parties above existing pipelines,

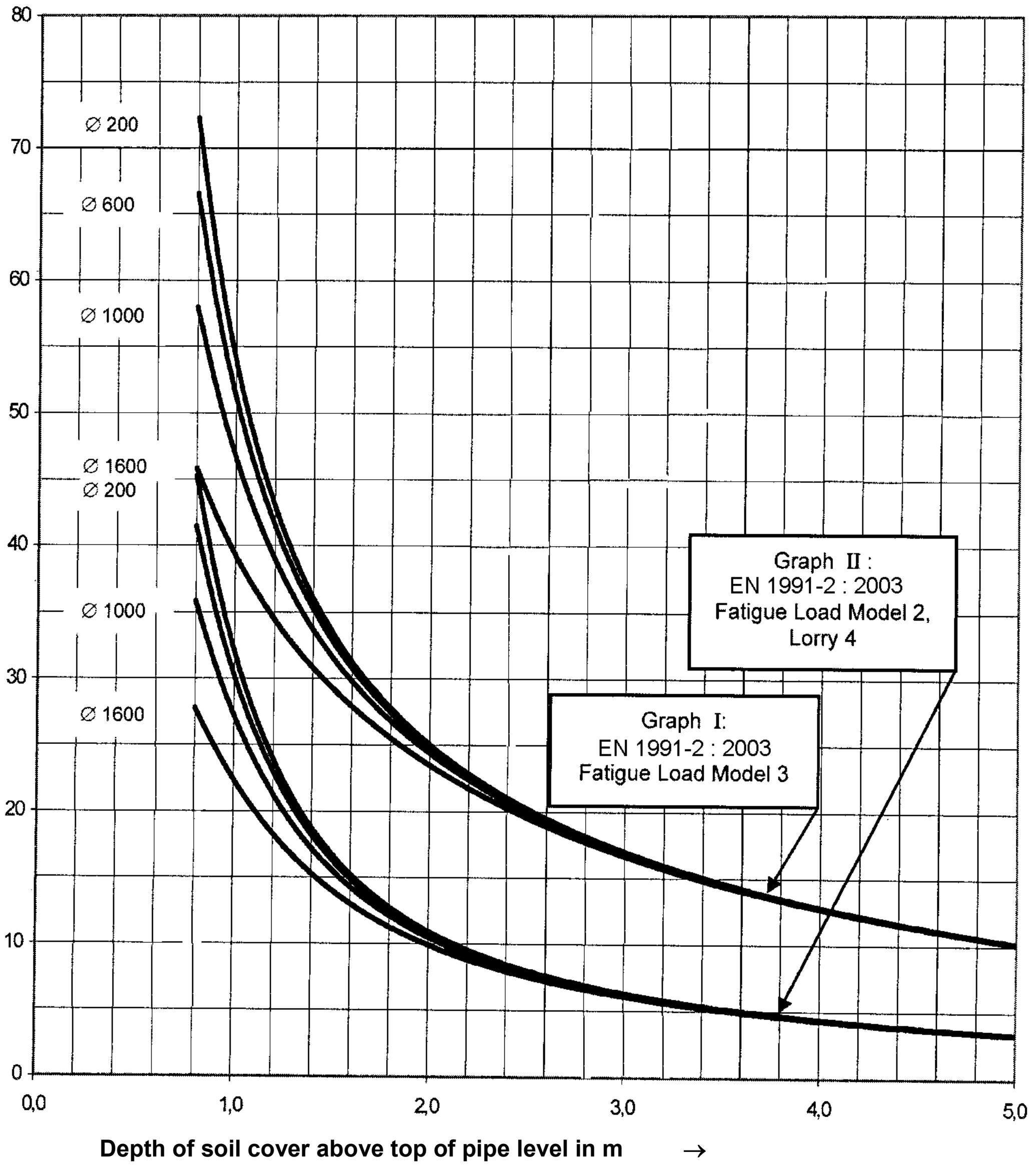

Figure C.17 - Traffic load of pipes on continuous soil foundation, caused by representative axle load systems, in accordance with EN 1991-2, without impact coefficient, differentiated according to Braunstorfinger by outside diameter (mm)

NOTE: On the vertical axis, the soil pressure at pipe top level as caused by the relevant axle load systems, is plotted in KN/m^2 ,

C.5.2 Effect of road constructions in reducing traffic loads

The load-relieving influence of road constructions, which is due to a wider distribution of the axle loads, may be discounted in the calculation of the traffic load, under certain preconditions (according to Braunstorfinger [6]).

It is permitted in the following cases:

- road constructions consisting of a multiple-layer system, i.e. one or more foundation layers have been laid on the subsoil and finished with a top layer;

- road constructions, whereby the subsoil is or has been paved with asphalt or concrete.

The calculation method comes down to a conversion of the effect of the foundation layer and top layer into an equivalent depth of soil cover on the pipe. Subsequently the traffic load on the pipeline can be found, by using the thus calculated 'fictional depth of cover ' as input in figure C.18.

The formula that shall be used for calculating the equivalent depth of cover is:

$$H_{n,eq} = 0.9 \times H_n \times \sqrt[3]{E_n / E_g}$$

where:

H_n is the thickness of the layer to be converted;

E_n is the elasticity modulus of the layer to be converted;

E_g is the elasticity modulus of the subsoil

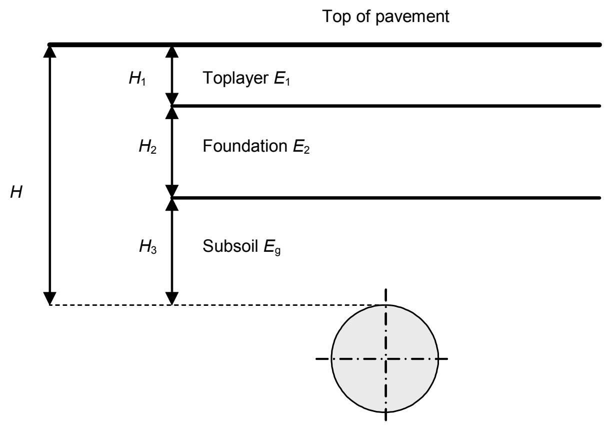

Figure C.18 - Calculation of equivalent coverage

In case of a three-layer system (subsoil, foundation layer and top layer) for example, the foundation layer is first converted to an equivalent soil cover, and the same procedure is followed for the top layer. The equivalent depth of cover (H_{eq}) is then obtained by: $H_3 + H_{1eq} + H_{2eq} = H_{eq}$.

Table C.9 includes typical values,,which can be used in calculations. These values have been chosen such that the calculated traffic load is approximately equal to a 'characteristic value' (5% probability of the load being exceeded).

If values other than those indicated, are used, or where the material in question is not one of those listed, then it shall be satisfactorily demonstrated by new or existing research that these different values are correct.

The formula for the equivalent depth of cover can also be written as: $H_{eq} = H + \alpha H_1 + ßH_2$, whereby α is dependent on covering layer and $ß$ is dependent on the foundation layer. In case of a certain thickness of the top layer (H_1), thickness of the foundation layer (H_2) and a depth of cover H, the equivalent depth of cover (H_{eq}) can be calculated with this formula. Values for α and $ß$ have been included in Table C.9.

Table C.9: Typical values for different top layers and foundation layers

Material	*E* modulus N/mm^2	Factor *a* or *ß*	γ_{dr} kg/m^3
Polystyrene foam	4 or 14 [a]	0	15 or 40
Subsoil	100 [b]	-	-
Fly ash	150	0.03	
Lava, macadam, crushed stone, chalk stabilizer, foundation of soft rubble	200	0.134	-
Cellular concrete	300	0.298	400
Asphalt layers, clinkers, concrete rubble foundation	500	0.539	-
Cellular concrete	650	0.680	500
Sand cement, sand asphalt	1000	0.939	-
Cellular concrete	1200	1.060	600
Blast furnace slag	1500	1.220	-
Cellular concrete	3700	1.999	1000
Cellular concrete	11500	3.377	1600

[a] $E = 4+2\ (\pi_{dr} - 15)\ /\ 5$ N/mm^2 is applicable for in-between values.
[b] Well compacted sand.

C.5.3 Pipelines on piles

Tangentially inflexible pipelines, founded on pile supports, will be imposed to a greater soil load in comparison with the neutral soil load acting on pipes which are continuously supported by soil. In extreme cases, a pipe supported by piles shall be able to withstand the maximum passive earth resistance (see C.4.2.4).

Underneath roads, the pipe will also be affected by a greater traffic load , in comparison with soil supported pipes. It is recommended to increase the traffic load as used for soil supported pipelines with the impact factor by 1.2 ,in case of pipelines on pile supports.

NOTE Other aspects, that may arise as a consequence of the supporting structure (such as a free span, resonance, fatigue) should be examined for pipelines on pile foundations. It is recommended to avoid pile foundations with pipelines and, if possible, to opt for a pipeline foundation on soil.

C.6 Dead weight

a) The dead weight of the pipeline (Q_{eg}):

$$Q_{eg} = \pi\ (D_e^2 - D_i^2) \times \rho_l \times g\ /4$$

b) The weight of the coating of the pipeline; for example the weight of concrete weight coatings , thermal insulation, etc. The weight of a corrosion-protection layer of only a few mm thickness need not be calculated.

c) The weight of the fluid (Q_{fill});

$$Q_{fill} = \pi\ D_i^2 \times \rho_v \times g\ /4$$

d) Buoyancy force of the pipeline (Q_{opw}) in case of a submersion in a liquid with a weight per unit volume p_v;

$$Q_{opw} = \pi\ D_e^2 \times \rho_v \times g\ /4$$

Appendix D
(normative)

Design aspects — Stress and deformation through load

NOTE Please see chapter 4 for an explanation of the symbols.

D.1 Stress due to internal pressure

D.1.1 Circumferential stress

The circumferential stress (hoop stress) in thin-walled pipes made of homogenous material due to internal pressure is calculated from the (boiler) formula:

$$\sigma_{\mathrm{p}} = \frac{p \times D_{\mathrm{g}}}{2d}$$

$$D_{\mathrm{g}} = D_{\mathrm{e}} - d$$

D.1.2 Additional stress in bends

For bends with a radius R < 10 D_{e}, tangential stress due to internal pressure shall be corrected as follows (torus formula):

$$\sigma_{\mathrm{p}}(\mathrm{bi}) = \frac{2R - 0{,}5D_{\mathrm{e}}}{2R - D_{\mathrm{e}}} \times \sigma_{\mathrm{p}}$$

$$\sigma_{\mathrm{p}}(\mathrm{bu}) = \frac{2R + 0{,}5D_{\mathrm{e}}}{2R + D_{\mathrm{e}}} \times \sigma_{\mathrm{p}}$$

This assumes that the minimum wall thickness at the bend is not less than the minimum required wall thickness of the end of the abutting pipe ends, for the same grade of material.

D.1.3 Axial stresses and deformations

D.1.3.1 Pipelines, resistant to axial tension

The axial stress due to internal pressure varies as a function of the pipeline's freedom of movement.

The following formula is applicable for a pipeline component that cannot undergo any change of length in axial direction:

$$\sigma_{\mathrm{pi}} = \nu \times \sigma_{\mathrm{p}}$$

Poisson's constant (ν) is material-dependent.

If a pipeline component is free to expand in axial direction, then, with internal pressure against a closed end (end cap or bend) :

$$\sigma_{\mathrm{pl}} = \frac{p_{\mathrm{d}} \times (D_{\mathrm{e}} - 2d)^2}{D_{\mathrm{e}}^2 - (D_{\mathrm{e}} - 2d)^2} \qquad (p_{\mathrm{d}} \text{ in N/mm}^2)$$

For a thin wall pipe it can be assumed that:

$$\sigma_{pl} = (0.2 + \nu) \times \sigma_p$$

D.1.3.2 Pipelines not resistant to axial tension

In pipelines of which the pipe elements are not resistant to axial tension, no axial stress occurs due to internal pressure. Lateral thrust from internal pressure in bends or branches shall therefore be absorbed by strutting the bend or branch in case the resistance provided by the soil thereto is insufficient.

D.1.4 Combinations of internal and external pressure

In the calculation according to D.1.1, internal overpressure may be reduced with any permanent external hydrostatic pressure. (This is especially important with offshore pipelines).

If there is any possibility of a vacuum surrounding the pipeline, the design pressure shall be increased by 0.1 MPa (an example of this are pipe-in-pipe systems where the annular space between the fluid carrying pipe and the jacket pipe is frequently evacuated.

D.2 Stresses and deformations due to changes in temperature

D.2.1 General

The formulas presented in this paragraph are based on the calculation model illustrated in figure D.1.

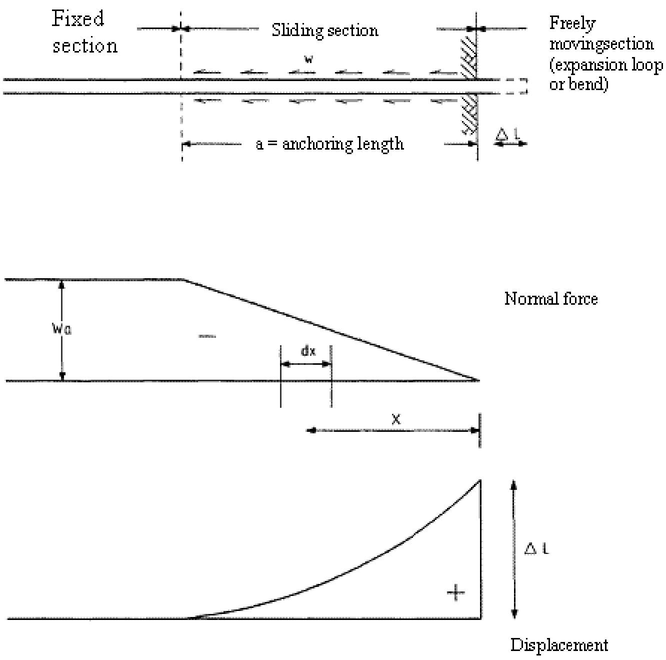

Figure D.1 — Calculation model

Three components are differentiated here:

— the freely moving section of a pipeline;

— the ‘sliding’ section, characterized by relative movement between pipe wall and soil;

— the fixed or restrained section, with no relative movement between pipe wall and soil.

D.2.2 Stress in the fixed or restrained section

$$\sigma_{ax} = \alpha_g \times E(t_2) \times \Delta t$$

where:

Δt is the temperature difference, in K, $\Delta t = t_1 - t_2$;

σ_{ax} is the axial membrane stress due to restraint, in N/mm^2;

α_g is the coefficient of linear expansion averaged between t_1 and t_2, in mm/mm·K;

t_1 is the temperature, in °C (at time 1);

t_2 is the temperature, in °C (at time 2);

$E(t_2)$ is the modulus of elasticity at the temperature t_2, in N/mm^2.

The force $N(t_2)$, generated by a change in temperature of t_1 towards t_2,expansion of the pipeline being estrained equals:

$$N(t_2) = \sigma_{ax} \times A$$

where:

A is the cross sectional area of the pipe material, in mm^2.

D.2.3 Displacements of the sliding section

Whenever a pipeline over a length a displays a relative movement in relation to the surrounding soil, the total axial force exerted by the soil on the pipeline and impeding expansion of the pipe equals:

$$N_g = W \times a$$

When $N_g = N(t_2)$, the pipeline is no longer in movement and the following is valid

$$a = \alpha_g \div \Delta t \frac{E(t_2) \times A}{W}$$

where:

a is the anchoring length, in m;

W is the friction between soil and pipe wall, in N/m; (divided by contingency factor)

The expansion of the sliding section can be calculated from:

$$\Delta L = 0.5 \times \alpha_g \times \Delta t \times a$$

Deformation calculated in this manner may be used as a boundary condition with the calculation of strength of the connected bend or expansion feature.

Whenever the length L of the sliding section is shorter than a (for example, because there is a fixed point present within the anchored length), the following applies:

$$\Delta L = 0.5 \times \alpha_g \times \Delta t \times (2L - L^2/a)$$

where:

ΔL is expansion of sliding section, in mm;

L is length of sliding section, in mm.

D.2.4 The effect of internal pressure on displacement of the sliding section

With high pressure pipelines, when calculating the deformation of long straight pipeline sections at locations of changes in direction (bends, T-sections) and at the locations of connecting installations, the effect of internal pressure shall always be taken into account.

The length of the transition area between the freely moving section and the restrained section (the anchoring length) can be determined overall from (when D_o = the and p_d is in N/mm^2):

$$a = \frac{\pi D_e \times d_n \times E \times \alpha_g \times \Delta t}{W}\left\{1 + \frac{p_d \times D_e}{4d_n \times E \times \alpha_g \times \Delta t}(1-2\nu)\right\}$$

The contribution made by a pipe element of length (dx), located at a distance (x) from the freely moving section (see figure D.1), to the total change in length equals:

$$\frac{\Delta L(\mathrm{d}x)}{\mathrm{d}x} = \alpha_g \times \Delta t + \frac{p_d \times D_e}{2E \times d_n}\left(0{,}5 - \nu - \frac{2W \times x}{\pi p_d D_e^{\,2}}\right)$$

The maximum change in length of the sliding section therefore equals:

$$\Delta a = \frac{\pi D_e \times d_n \times (\alpha_g \Delta t)^2 \times E}{2W}\left\{1 + \frac{p_d D_e (1-2\nu)}{4d_n \times E \times \alpha_g \times \Delta t}\right\}^2$$

NOTE It should be noted that in the described formulas, soil friction is assumed to be constant, i.e. the formulas apply to a constant depth of soil cover and consistant soil type. Likewise the formulas assume that maximum friction is attained at low relative displacement between the pipe and soil, is. This is generally acceptable for sand and clay soil types. In very soft clay and peat strata, the so-called 'tail effect' should be examined (see D.2.5).

D.2.5 Axial movement and friction without reaching ultimate soil friction ('tail effect')

In very soft clay and peat strata the influence of the 'tail effect', in which the maximum value of pipe to soil friction is only reached after a certain relative movement, shall be examined in more detail .

Soil friction along the pipeline during axial movement of the pipeline developes as illustrateded in figure C.15. For the elastic range($w < w_{max}$), there is a linear relationship between the friction and the relative movement:

$W = -u \times \delta$

where:

W is the friction force = $\pi D_e \times w$, in kN/m^1;

δ is the relative movement between pipe and soil, in m;

u is the ratio W/δ, in kN/m^2;

w is the friction, in kN/m^2.

At the point (point 0) where the friction attains a constant value (ultimate frictional soil resistance) the following formula applies:

$\delta_o = \delta_{max}$, $W_o = W_{max} \Rightarrow u = W_{max} \times \pi D_e/\delta_{max}$

and the normal force equals $N_o = \sqrt{\delta_{max} \times w_{max} \times \pi D_e \times AE}$

NOTE In computer calculations the asymptotic 'tail' point is usually cut off at initiation of ultimate frictional soil resistance (point 0) and replaced by an axial end spring with a spring constant of: N_o/δ_o with $\delta_o = \delta_{max}$.

D.3 Circumferential stresses due to vertical load

In C.4.1 it was deduced that the interaction between pipe and soil in circumferential direction can be represented by a system of soil springs (pipeline considered as a ring). This gives the load diagram as shown in figure D.2.

D.3.1 Directly transmitted vertical load

For straight pipe sections, not subject to internal pressure, the circumferential stress is given by:

$$\sigma_q = \frac{M_{tot}}{W_w} = \frac{K \times Q_{tot} \times r_g}{W_w}$$

where:

M_{tot} is the tangential moment in the pipe wall due to Q_{tot};

K is the moment coefficient, as a function of load angle (α), support angle (β) and position on the ring circumference, see table D.1;

Q_{tot} is the total vertical load;

Q_{tot} is Q_n (or Q_x) + Q_v + Q_{eg} + Q_{vul} – Q_{op};

Q_{op} is the upward force by buoyancy,

Only in the case of tangentially flexible pipes under internal pressure, the so-called "re-rounding" effect may be taken into account when calculating the stress around the circumference:

$$\sigma_q = f_{rr} \frac{M_{tot}}{W_w} = f_{rr} \times \frac{K \times Q_{tot} \times r_g}{W_w}$$

where:

$$f_{rr} = 1 \Bigg/ \left(1 + \frac{2p_d \times r_g^3 \times k_y}{E \times I_w}\right)$$

where:

f_{rr} is the "rerounding"-factor

p_d is the design pressure, in N/mm^2;

k_y is the deflection factor (see table D.1).

NOTE Theoretically , when calculating bending moments due to $Q_{e.g}$ and Q_{vul},, moment coefficients other than for Q_n should be used; the effect on the end result is, however, negligible. In many cases, the effect of $Q_{e.g}$ and Q_{vul} on M_{tot} can be neglected.

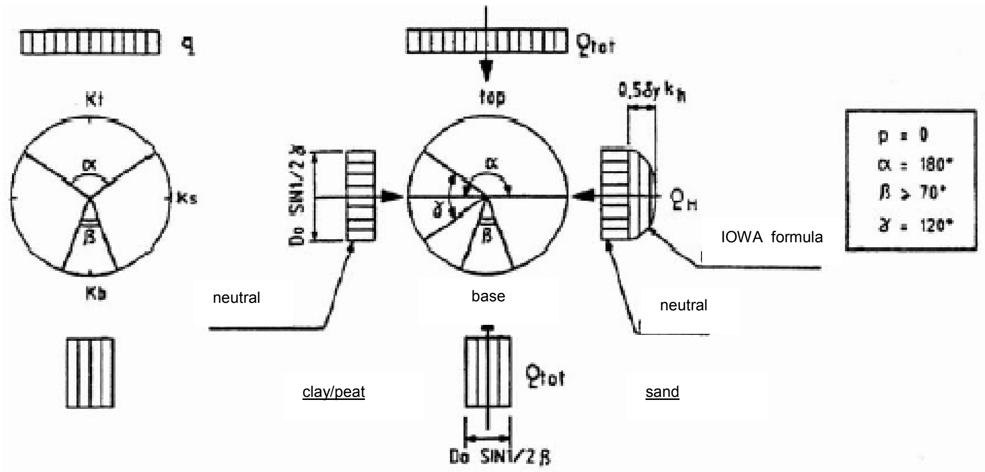

Figure D.2 - Load diagram for directly transmitted vertical load

Table D.1 — Moment coefficients and deflection factors for directly transmitted vertical load

α degrees	β degrees	K_b base	K_t top	K_z sides	k_y vertical	α degrees	β degrees	K_b base	K_t top	K_z sides	k_y vertical
0	0	0.318	0.318	–0.182	0.149	90	0	0.306	0.182	–0.168	0.129
	30	0.259	0.317	–0.180	0.146		30	0.246	0.180	–0.166	0.127
	60	0.213	0.312	–0.175	0.138		60	0.201	0.175	–0.161	0.118
	90	0.182	0.305	–0.168	0.129		90	0.169	0.169	–0.154	0.110
	120	0.162	0.299	–0.161	0.122		120	0.150	0.163	–0.147	0.103
	150	0.153	0.295	–0.156	0.117		150	0.140	0.158	–0.142	0.098
	180	0.150	0.294	–0.153	0.119		180	0.137	0.157	–0.140	0.096
30	0	0.317	0.259	–0.180	0.146	120	0	0.299	0.162	–0.161	0.122
	30	0.257	0.257	–0.178	0.143		30	0.240	0.160	–0.159	0.119
	60	0.211	0.252	–0.173	0.135		60	0.194	0.156	–0.154	0.111
	90	0.180	0.246	–0.166	0.127		90	0.163	0.150	–0.147	0.103
	120	0.160	0.240	–0.159	0.119		120	0.143	0.143	–0.143	0.096
	150	0.151	0.236	–0.154	0.115		150	0.139	0.139	–0.135	0.091
	180	0.148	0.235	–0.152	0.113		180	0.138	0.138	–0.133	0.089
60	0	0.312	0.213	–0.175	0.138	150	0	0.295	0.153	–0.156	0.117
	30	0.252	0.211	–0.173	0.135		30	0.236	0.151	–0.154	0.115
	60	0.207	0.207	–0.168	0.122		60	0.190	0.146	–0.149	0.107
	90	0.175	0.201	–0.161	0.118		90	0.158	0.140	–0.142	0.098
	120	0.156	0.194	–0.154	0.111		120	0.139	0.134	–0.135	0.091
	150	0.146	0.190	–0.149	0.107		150	0.129	0.129	–0.129	0.086
	180	0.143	0.189	–0.147	0.105		180	0.126	0.128	–0.128	0.085
						180	0	0.294	0.150	–0.153	0.116
							30	0.235	0.148	–0.152	0.113
							60	0.189	0.143	–0.147	0.105
							70	0.178	0.141	–0.145	0.102
							90	0.157	0.137	–0.140	0.096
							120	0.138	0.131	–0.133	0.089
							150	0.128	0.126	–0.127	0.085
							180	0.125	0.125	–0.126	0.083

D.3.2 Indirectly transmitted vertical loads

The preceding formulas are also used in the analyses of stresses due to indirectly transmitted loads. In this case, the moment coefficients and the deflection factors shall be utilized according to table D.2. (see also figure D.3).

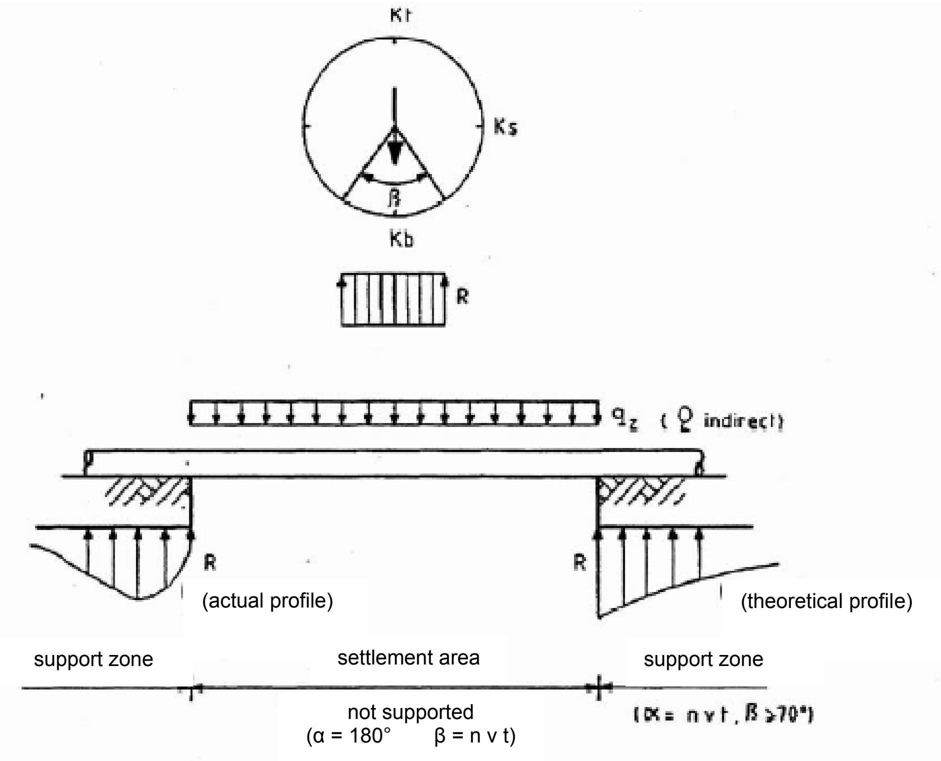

Figure D.3 — Load diagram for indirectly transmitted vertical loads

Table D.2 — Moment coefficients and deflection factors for indirectly transmitted vertical loads

		support zone				settlement area			
α	*β*	K_t	K_s	K_b	K_y	K_t	K_s	K_b	K_y
–	0	+0.080	–0.091	+0.239	+0.074	–	–	–	–
–	30	+0.078	–0.089	+0.179	+0.071	–	–	–	–
–	60	+0.073	–0.084	+0.134	+0.064	–	–	–	–
–	70	+0.071	–0.082	+0.122	+0.061	–	–	–	–
–	90	+0.067	–0.077	+0.102	+0.055	–	–	–	–
–	120	+0.061	–0.070	+0.083	+0.048	–	–	–	–
–	150	+0.056	–0.065	+0.073	+0.043	–	–	–	–
–	180	+0.055	–0.062	+0.070	+0.042	–	–	–	–
180	–	–	–	–	–	+0.070	–0.062	+0.055	+0.042

D.3.3 Stresses resulting from vertical load with horizontal directional drilling

For an operational phase of tension resistant as well as articulated pipelines,installed using the horizontal directional drilling method, the tangential moments at the critical cross section of the curved pipeline are calculated by:

— directly transmitted load:

$$M = K \times Q_{tot} \times r_g$$

where:

Q_{tot} is $Q_{n,r} + Q_v + Q_{eg} + Q_{vul} - Q_{op}$;

$Q_{n,r}$ is the reduced neutral vertical earth load (see also C.4.8);

K is the moment coefficient from table B.5.1 for α = 180° and β = 120°.

— indirectly transmitted load as a result of the curvature of the pipeline:

$M = K \times Q_r \times r_g$ (only applicable for tension resistant pipes)

$Q_r = y \times k_v \times D_o$

$$Y = \frac{0.322 \times \lambda^2 \times EI_b}{k_v \times D_o \times R}$$

where:

R is the radius of curvature of the pipeline axis.

Since, $\lambda = \sqrt[4]{(k_v \times D_o)/4EI_b}$ than $M = 0.322 \times \frac{EI_b}{R} \lambda^2 \times r_g$.
The values from table D.2 for β = 120° are applicable for the moment coefficient (K) (supported pipeline zone).

NOTE Pipeline sections installed in an excavated trench are connected onto both sides of an HDD. A subsidence difference may arise between the two methods of pipeline installation. The pipeline that is pulled in will push up against the top side of the drilled bore hole The abutting pipe sections, laid in an open trench will subside after trench backfilling and will push the pipeline in the drilled bore hole downward into the soft bentonite or soil slurry. An abrupt difference in subsidence such as is the case with jacked or bored pipe sections (C.4.7.3) need not be assumed here. It is recommended that, at the location of the connection, an axial bending moment be taken into account which is in accordance with the requirement for a straight field section (C.4.7.2).

D.3.4 Stresses due to external load with pipelines installed in a trench

For pipelines installed in a trench, two situations can be differentiated: The situation immediately after installation and the situation which has developed after one to two years. In the first situation, the effective earth pressure shall be taken into account (C.4.2.3), in the second situation, neutral vertical earth pressure shall be taken into account (C.4.2.2)

In the strength calculation of the pipeline, no stresses due to settlement differences need to be taken into account in the situation with effective earth pressure; but in the situation with neutral earth pressure it has to be done

In the strength calculations of both situations the other loads (such as subsidence differences from instalation, traffic load, difference in temperature, internal pressure) shall also be observed.

D.3.5 Reduction of circumferential stresses resulting from soil compaction (Leonhardt)

With tangentially flexible or rigid (low pressure and unpressurized) pipelines installed in a trench, it may be necessary to increase the horizontal earth pressure, thus reducing circumferential bending stresses. In this case, the trench backfill is mechanically compacted (see also under ‘compaction’ in 9.5.7.2).

The method of analyse , utilized in the determination of the circumferential stresses is known as the Leonhardt method, see appendix A of [27] and see [28] for a practical interpretation.

For pipelines crossing major public works (see 6.5), the Leonhardt method may be utilized when:

— the pipelines are articulated or;

— continuous pipelines in a area which is free of settlement are involved (no load indirectly transmitted by the pipeline);

— the pipelines are not made of steel;

— the support angle is determined according to C.4.1.3.;

— the pipelines do not lie in a peat or clay area (the horizontal earth pressure in the sand backfill recedes due to horizontal consolidation);

— the pipelines do not lie in a body of sand of major public works through which expected granular shifting can decrease of the built up soil support;

— an geotechnical investigation has been conducted including advice on trench backfilling and -compaction;

— the compaction is measured with a manual cone penetration device (on both sides of the pipeline, at 5.0 m intervals between center lines) and the results are checked against the values, used in the calculation. See section C.4.2.6 for the relationship between Proctor density and increase in cone resistance;

— the achieved degree of compaction shall equal at least 94 % or more of the Maximum Proctor Density. In all other cases the trench backfill shall be considered as uncompacted; the Leonhardt method is not acceptable within the scope of application of this standard and the method of calculation according to D.3.1 can be employed.

NOTE The reliability of the calculation method is dependant, to a great degree, on the actual execution of the trench backfill compaction works as well as its continuity over time.

D.4 Deflection

D.4.1 General

Deflection of the ring diameter in a unpressurized condition can be calculated with the formula:

$$\delta_{\mathrm{y}} = \frac{k_{\mathrm{y}} \times Q_{\mathrm{tot}} \times r_{\mathrm{g}}^{3}}{EI_{\mathrm{w}}}$$

where:

k_{y} is the deflection factor (see tables D.1 and D.2);

δ_{y} is the vertical deflection.

In sand, horizontal passive earth pressure (see figure D.2) can be taken into account and the deflection can be calculated with the adjusted IOWA formula (see also 5.2.1.7.3 of NPR 3659:1996):

$$\delta_{\mathrm{Y}} = \frac{D \times Q_{\mathrm{tot}} \times r_{\mathrm{g}}^{3}\left(k_{y} - 0.083\lambda_{n}\right)}{EI_{\mathrm{w}} + 0.061 \times k_{\mathrm{h}} \times r_{\mathrm{g}}^{4}}$$

where:

D is the ‘deflection lag’ (creep) factor related to lateral consolidation. D = 1.5 for uncompacted sand and D = 1.0 for well-compacted sand (95 % or more of the Maximum Proctor Density);

k_{h} is the modulus of horizontal subgrade reaction (see table C.6: $k_{\mathrm{h,min}}$);

λ_{n} is the coefficient of neutral horizontal earth pressure (λ_{n} = 1 — sin φ).

NOTE 1 If D = 1.5 is applied with lower values of k_{h}, the second formula may give a higher deflection than the first formula, which does not take into account horizontal earth resistance. In this case, the lowest value, arrived at by one of the two formulas given above, can be used.

NOTE 2 In areas which are susceptible to settling (embankments, causeways, dikes, etc.), a “deflection lag” factor of *D* = 1.0 can be utilized in situations with effective vertical earth pressure (see D.3.4) and a well-compacted trench. In the situation which develops after this, it can be assumed that *D* = 1.0 is too small and the factor should increase to *D* = 1.5.

D.4.2 Specific cases

In order to ensure the correct use of the formula in D.4.1, the following cases are described:

Case 1: unpressurized pipelines with lateral earth pressure; (load angle α = 180°, support angle β = 120° and contact angle γ = 120°).

$$\delta_Y = \frac{(0.089 \times Q - 0.083 \times Q_{n;h} + 0.048 \times Q_{indir})r_g^3}{E' I_w}$$

Case 2: as with case 1 in sandy soil, taking into account the (elastic) reaction of the soil due to horizontal ovalization of the pipeline (IOWA formula).

$$\delta_Y = D\frac{(0.089 \times Q - 0.083 \times Q_{n;h} + 0.048 \times Q_{indir})r_g^3}{E' I_w + 0.061 \times k_h\ r_g^4}$$

Case 3: sagging sag pipes according to D.5.2.2. If the sag pipe cannot follow the settlements and hangs free, the deflection is determined by the reduced (passive) earth load Q_r on the pipes. If the reduced soil load Q_r is equal to or greater than the neutral soil load Q_n, then the load Q is no longer relevant. The neutral horizontal earth pressure $Q_{n:h}$ is still relevant (the column of soil next to the pipe remains intact). With the application of the deflection coefficient (0.042) for an unsupported pipeline section (settlement zone in table D.2) and where $Q_r \geq Q_n$, the following formula applies:

$$\delta_Y = \frac{(-0.083 \times Q_{n;h} + 0.042 \times Q_r)r_g^3}{E' I_w}$$

Case 4: as with case 3, however, in case Q_r is smaller than Q_n. The load Q is obtained through the term ($Q_n - Q_r$). For a sagging sag pipe where $Q_r < Q_n$ and β = 70° (for example, nodular cast iron), the following applies:

$$\delta_Y = \frac{(0.102 \times (Q_n - Q_r) - 0.083 \times Q_{n;h} + 0.042 \times Q_r)r_g^3}{E' I_w}$$

For a sagging sag pipe where $Q_r < Q_n$ and β = 120° (for example, PVC), applies:

$$\delta_Y = \frac{(0.089 \times (Q_n - Q_r) - 0.083 \times Q_{n;h} + 0.042 \times Q_r)r_g^3}{E' I_w}$$

Case 5: HDD; The (elastic) reaction of soil resulting from ovalization of pipelines which are attached with the HDD technique does not need to be taken into account (no IOWA), irrespective of the surrounding soil. After the bentonite-sand mixture around the pipeline has hardened, it will behave as a compressible layer. With a support angle of β = 120°, the deflection is:

$$\delta_Y = \frac{(0.089 \times Q_{n;r} - 0.083 \times Q_{h;r} + 0.048 \times Q_{indir})\ r_g^3}{E' I_w}$$

Symbols and variables utilized in the formulas:

D is the dimension-less creep age factor due to lateral consolidation ("deflection lag" factor). D = 1 for compact sand with an averaged cone penetration value equal to or greater than 8 MPa; D = 1.5 for other sandy soil areas and for a sag pipe:

E' is the modulus of elasticity, as well as the fictitious modulus of elasticity with materials that are susceptible to creep age (plastics), in N/mm^2:

k_n is the modulus of horizontal subgrade reaction, in N/mm^3;

Q is dependent on the load condition equal to $Q_n + Q_v$ or $Q_x + Q_v$ in N/mm;

$Q_{h:r}$ is the reduced horizontal earth resistance with arching (see C.4.8.5), in N/mm;

Q_{indir} is the indirectly transmitted earth load, in N/mm;

Q_k is the vertical effective earth load, in N/mm;

Q_n is the vertical neutral earth load, in N/mm;

$Q_{n:h}$ is the neutral horizontal earth resistance, in N/mm; $Q_{n:h} = (1 – \sin \varphi) x (Q_n + Q_v)$;

$Q_{n:r}$ is the reduce (passive) earth load with arching (see C.4 8), in N/mm;

Q_r is the reduced (passive) earth load, in N/mm;

Q_v is the traffic load, in N/mm:

δ_y is the deflection, in mm:

φ is the internal friction angle of the soil backfill, in degrees.

D.5 Calculations for articulated pipelines

D.5.1 Calculation of the elongation of couplings that are not tension-resistant

Relative displacements in non tension-resistant couplings can have five causes:

— increase of length along the pipeline axis, caused by settlement differences (u_1);

— angular rotation in the flexible rubber ring coupling (u_2);

— horizontal deformation of soft subsoil due to maintenance embankments (u_3);

— (axial) contraction due to internal pressure and cooling down (u_4);

—(lateral)expansion due to internal pressure (lateral thrust) in bends (u_3).

Formulas to calculate the displacements are provided below. For the derivations of these formulas reference is made to a supplement to NPR 3659:1995.

a) *elongation required in case of differences in settlement* (u_1)

a1) if the settlement profile is assumed to be parabolic, the characteristic value of the required elongation (u_1) which a specific coupling shall be able to withstand is calculated from:

$$u_1 = \frac{2l}{3n}\left(\frac{j_z \times \Delta z + f_v}{0.5l}\right)^2$$

where:

j_z is the contingency factor for the settlement, being a function of the partial uncertainty factors for spatial spreading and model uncertainty, see tables B.2 and B.3;

Δz is the difference in settlement, in mm;

f_v is the installation subsidence difference, in mm;

l is the length (horizontal projection) of the settlement profile, in mm;

n is the number of couplings in the settlement profile.

NOTE 1 For pipelines that satisfy the conditions for application of the simplified strength calculation (see App. A of SI 5664-2) 0.5 l can be equated to L according to C.4.7.2.

a2) if the settlement profile is determined from geotechnical investigation, u_1 can be determined as follows:

— multiply the value of the settlement (z) by factor j_z, proportionally add f_v (proportionally means adding the whole value of f_v with the largest value of z, and proportionally with smaller values of z), approximate the settlement profile thus obtained with arcs. Determine the difference in length of the arc with the smallest radius compared with the length of the corresponding pipeline section during installation. This difference has to be provided by the *(n)* couplings which are projected for that section of pipeline.

NOTE 2 The angular rotation in the couplings can also be determined with the help of the settlement profile by projecting the lengths of pipes along the settlement profile. Based on an allowable angular rotation, the (varying) lengths of pipe elements (with tension resitant couplings) needed to follow the settlement profile, may also be determined. It is recommended to monitor the actual subsidence of the pipes with sag beacons (for at least a year in time) and to compare it with the predicted settlement.

b) *Elongation caused by angular rotation* (u_2)

The maximum allowable free angular rotation (*a*) of a coupling, not causing failure of the bell socket, can be calculated with the detailed dimensions of the coupling. Based on this physical upper limit, the elongation in the coupling caused by angular rotation (u_2) can be calculated with:

$$u_2 = D_e \times \tan \alpha$$

where:

D_e is the outside diameter of the spigot-end of the pipeline, in mm;

α is the maximum possible angular rotation, in rad.

NOTE 3 This elongation will only occur if the spigot is pushed into the socket so that it rests firmly against the inside collar of the socket. This will generally not be the case (this only occurs when $\Sigma u - u_2 = 0$, i.e. immediately after installation). There is usually a joint opening along the circumference. With angular rotation, the neutral line of the outside of the bend will become 0.5 $D_e \tan\alpha$ longer and the insides will slide 0.5 $D_e \tan\alpha$ into one another. The pipeline as a whole will not change in length. In the calculation of the required sliding length of a single coupling, 0.5 $D_e \tan\alpha$ will suffice for Σu.

c) *Elongation caused by a horizontal deformation of a soft subsoil*(u_3)

As a result of, for example, embankments for maintenance of a road, brought up after installation of the pipeline and in the presence of soft soil strata underneath the road body, the pipe elements under the road body will be pulled away from each other, whereas the pipe elements, lying just beside the body will be pushed together

The displlacement directly below the body of the road (sand) and directly above the Pleistocene sand is zero. The displacement is at its maximum halfway through the soft soil layer (starting point). The following formula can be used for the characteristic elongation per coupling in this case:

$$u_3 = 0.13 \ \frac{h \times j_q \times q}{E / j_E} \times \frac{L}{5}$$

where:

h is the thickness of the soft soil layer, in mm;

q is the weight per surface unit of the cumulative maintenance embankments of the road following installation of the pipeline, over its technical service life (for example, 50 years), in N/mm^2;

E is the modulus of elasticity of the soft soil layer, in N/mm^2; an average value shall be calculated in case of a layered soil structure ;

j_q is the partial uncertainty factor for the weight of the cumulative embankments (equal to 1.1, see table B.2);

j_E is the partial uncertainty factor for the modulus of elasticity of the soft soil layer (equal to 1.25, see table B.2);

L is the length of the pipe element, in m.

d) *Contraction resulting from internal pressure and difference in temperature* (u_4)

Contraction of each pipe component occurs as a function of the internal pressure and difference in temperature (cool down):

$$u_4 = \Delta L = \varepsilon \cdot L = \left(\frac{\nu \times \sigma_p}{E} + \alpha \times \Delta T \right) L$$

where:

ΔL is the contraction of the pipe element, in mm;

L is the length of the pipe element, in mm;

ν is the dimensionless contraction coefficient (Poisson's ratio);

σ_p is the hoop stress due to of p, in N/mm^2;

p is the internal pressure, in N/mm^2;

E is the modulus of elasticity of the pipe material, in N/mm^2;

α is the linear expansion coefficient of the pipe material, in (mm/mm) K^{-1};

ΔT is the difference in temperature, in K.

The strength test pressure shall be utilized as the calculation value for internal pressure. In that situation, no temperature difference need be taken into account unless the temperature of the test water is lower than the temperature at installation.

The difference between the temperature at installation and the lowest design temperature (absolute value) shall be utilized as the calculation value for the temperature difference (ΔT). If the lowest design(operation?) temperature is higher that the temperature at installation, 0 K shall be applied as the value. This temperature difference is to be combined with the design pressure in the calculation.

The highest value of the calculated contraction is to be used.

e) *Expansion due to internal pressure, lateral thrust* (u_5)

At locations of changes in direction (bends, branches) of pipelines under internal pressure, an unbalanced force, lateral thrust, prevails, which can be absorbed with 1) an anchor block, 2) the soil behind the bend or branch, supplemented, if necessary, by 3) soil friction along the (tension-resistant) connecting pipe sections asides of the bend or branch.

In the event that the elongation of the (non-tension resistant) bend shall be absorbed by the soil behind the bend, the size of the elongation is completely determined by moduli of subgrade reaction. The (average) values of these moduli of subgrade reaction shall therefore be determined via geotechnical investigation. For pipelines satisfying the conditions for a simplified strength calculation (see App. A of SI 5664-2) these values may be taken from table C.6.

The characteristic value of the elongation u_5 for vertical bends can be calculated with the formula:

$$u_5 = \frac{1.5\,\pi \times j_k \times p \times D_e \times \sin(0.5\,\alpha)}{4\,k_\perp \times R} = \frac{0.38\,\pi \times j_k \times p \times D_e \times \sin(0.5\,\alpha)}{R\left\{k_v - \frac{\alpha}{180^0}\left(k_v - k_h\right)\right\}}$$

Furthermore, for vertical bends applies: $u_5/\sin\alpha \le 0.07 D_e$ (quasi-elastic soil deformation)

For horizontal bends applies:

in sand: $u_5/\sin\alpha \le 0.5 \times Q_p/D_e \times k_n$ (elastic soil deformation in sand)

in clay or peat: $u_5/\sin\alpha \le Q_p/D_e \times k_n$ (no horizontal consolidation in clay and peat)

where:

p is the test pressure, in MPa;

D_e is the outside diameter of the pipeline, in mm;

α is the bend angle ,in degrees;

R is the bend, radius in mm;

k_v is the vertical modulus of subgrade reaction, in N/mm^3;

k_h is the horizontal modulus of subgrade reaction, in N/mm^3;

$k_\perp$ is the modulus of subgrade reaction acting perpendicularly to the direction of movement of the elongation, in N/mm^3;

j_k is the contingency factor for the lateral subgrade reaction modulus, being a function of the partial uncertainty factor for spatial variation and model uncertainty, see tables B.1 and B,2;

Q_p is the passive horizontal earth pressure, in N/mm;

Q_n is the neutral horizontal earth pressure, in N/mm.

The formula for u_5 applies for vertical bends; with horizontal bends and in the formula for u_5, the modulus of vertical subgrade reaction k_v shall be switched with the modulus of horizontal subgrade reaction k_h and the factor 1.5 ceases to be valid. The factor 0.38 changes to 0.25 as a result.

For articulated bends, the calculated value of u_5 shall be divided by 0.5 × *n,* where *n* is the number of couplings in the bend.

f) *Required socket depth*

The axial displacement tolerance of the rubber ring in the socket-spigot construction, at which the coupling is still leak-proof shall be at least equal to the required extension length Σ*u:*

$$\Sigma u = (u_1 + u_2 + u_3 + u_4 + u_5 + u_{\mathrm{uitv}}) \times \gamma_{\mathrm{u}}$$

where:

Σu is the necessary extension length:

u_{uitv} is the maximum elongation allowed to occur during the installation, i.e. up until the moment of time immediately following the backfilling of the trench;

γ_{u} is the safety factor for the extension length (usual value: γ_{u} = 1.5).

Thus, a division shall be made during the design between the available capacity for elongation during the installation and the available capacity for elongation for the purpose of the absorption of the subsidence. u_{uitv} shall encompass elongations occurring during the installation, during alignment corrections and during backfilling. During the installation, u_{uitv} shall be monitored.

NOTE 4 With large diameter articulated pipelines projects it has been demonstrated that in case of settlement differences of some magnitude, this requirement dictates the choice of material and sometimes even determines feasibility itself.

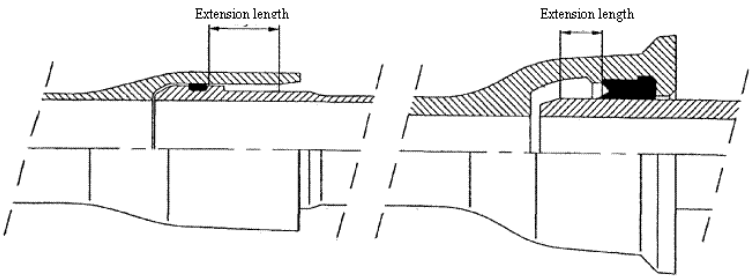

Figure D.4 — Examples of couplings that are not tension-resistant

NOTE 5 The extension length is the socket depth minus the width of the (compressed) rubber ring minus the distance between the rubber ring and the end of the spigot minus the width of the section, possibly with sloping inside diameter, at the end of the socket (see figure D.4).

D.5.2 Tensile stresses in non-rigid, tension-resistant pipelines

D.5.2.1 Straight pipeline section

With an articulated pipeline with tension resistant couplings installed in open excavation, secondary bending occurs as a result of a deviation of the system centerline from the centerline of force. In case of a straight pipe alignment,, this deviation between system line and line of force is considered to be negligible. Secondary bending then equals zero. However, an additional tensile force shall be taken into account, which equals:

$$H = \sqrt{n\, u_1\, \pi\, D_{\mathrm{e}}\, W\, E\, F}$$

where:

n is the number of tension-resistant couplings in the subsidence and settlement profile;

u_1 is the elongation per coupling, in mm, necessary for the creation of additional developed length (along the pipeline axis) according to D.5.a;

D_e is the outside diameter, in mm;

W is the friction generated by the soil, in N/mm^2;

E is the modulus of elasticity of the pipe material, in N/mm^2;

F is the cross section od the pipe material, in mm^2.

The additional stress in articulated pipelines with tension-resistant couplings (straight alignment) then equals:

$$\sigma_1 = H/F$$

D.5.2.2 Sagging sag pipe

With sag pipes composed of articulated pipelines with tension-resistant couplings, tensile stress occurs with differences in settlement and subsidence (system centerline deviates from the centerline of force), and as a result of which secondary bending occurs in the pipe elements. This bending is at its maximum in the pipe element which is installed at the deepest point. The secondary bending in the pipe components installed at the highest point is negligible, but tensile force is at its maximum: $T = H/\cos\alpha$. Generally, the pipe installed at the deepest point will be critical for the design; the calculation of the additional tensile force and moment at that location is done by putting the maximum of the eccentricity equal to y_o at the halfway point of the pipe elements and equal to zero at the couplings (see also chapter 3 in NPR 3659/A1:2003).

$$y_0 = 0.5\, l \times \cot\alpha \left\{ 0.5 \left(e^{\frac{L}{l}\tan\alpha} + e^{-\frac{L}{l}\tan\alpha} \right) - 1 \right\}$$

where:

l is the horizontal projected length of the sag pipe, in mm;

L is the length of a pipe element, in mm;

α is the angle of entrance and egress of the sag pipe, in degrees.

The maximum angular rotation β in the tension-resistant flexible couplings of an articulated sag pipe is to be determined with (see chapter 3 in NPR 3659/A1:2003):

$$\tan\beta = \frac{0.5\, l \times \cot\alpha \left\{ 0.5 \left(e^{\frac{3L}{l}\tan\alpha} + e^{-\frac{3L}{l}\tan\alpha} \right) - 0.5 \left(e^{\frac{L}{l}\tan\alpha} + e^{-\frac{L}{l}\tan\alpha} \right) \right\}}{L}$$

where:

β is the maximum angular rotation in a flexible tension-resistant coupling.

The tensile force H can be reduced through the interaction between the soil and the pipeline with the help of figure D.5. Reduction of y_o through secondary effects is negligible.

NOTE By calculating this reduction is departed from the principle that soil failure is ignored in the simplified calculation. The reduction can be important in case the tension-resistant couplings are weaker than the pipes they are connecting.

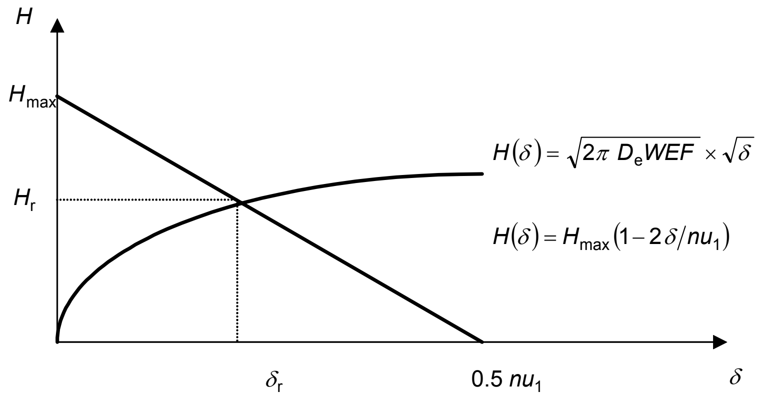

Figure D.5 — Interaction of tensile force *H* and relative displacement *δ* between sag pipe and soil.

Maximum tensile force H_{max} arises at relative displacement δ is zero. The force is of magnitude:

$$H_{max} = a \times Q_p$$

where:

a is a length dependent on the angle of entrance and angle of egress of the sag pipe (α/sin α, where α is in radials), where the horizontal projected length of the sag pipe is processed according to the catenary theory, see table 25 of Fluid-structure interaction in flexible liquid-filled piping [2]. The developed length shall correspond with the number of pipe lengths to be set in the sag pipe, in mm;

Q_p is the passive earth pressure on the sag pipe, in N/mm.

The reduced tensile force H_r and movement δ_r can be determined as follows (see also chapter 3 NPR 3659/A1:2003):

$$\delta_r = 2\,c\left(b^2c + H_{max} - b\sqrt{b^2c^2 + 2\,c\,H_{max}}\right)$$

$$H_r = -b^2c + b\sqrt{b^2c^2 + 2\,c\,H_{max}}$$

with $b = \sqrt{2\ \pi\ D_e\ W E F}$ and $c = n\,u_1/4\,H_{max}$

The additional stress resulting from tensile stress and secondary bending for sag pipes, comprised of articulated pipes with tension-resistant couplings, then becomes:

$$\sigma_x = \frac{H_r}{F} + \frac{H_r\ y_o}{W_b}\ \alpha_{axiaal}$$

For crossings under the scope of NEN 3651:2003,and under application of a safety factor of 1,5 (not including the damage factor *S,* tension-resistant couplings shall be able to resist a tensile force, equal to:

$$T_r = \frac{H_r}{\cos\alpha} + 0.5\,S_p\,F$$

where:

σ_p is the circumferential stress as a result of the test pressure, in N/mm^2.

In sag pipes composed of articulated pipes with tension-resistant couplings, the stress shall be calculated in a tangential direction, and is dependent on the size of the reduced soil load.

The reduced soil load equals:

$$Q_r = \frac{H_r}{H_{max}} Q_p$$

When the reduced soil load Q_r is equal to or greater than the neutral soil load Q_n, additional stress resulting from tangential bending shall be taken into account:

$$\sigma_y = \alpha_{tan} \times f_{rr} \times 0.07 \times Q_r \frac{r_g}{W_w}$$

where:

σ_{tan} is the ratio between (axial) tensile strength and (circumferential)bending tensile strength;

f_{rr} is the reduction factor resulting from “re-rounding” (straight pipe sections);

0.07 is the value of the moment coefficient (top side) for an unsupported pipeline section (settlement area), see table D.2;

Q_r is the reduced soil load, in N/mm;

r_g is the average radius of the pipe, in mm;

W_w is the resistance moment of the pipe wall, in mm^3/mm.

If the reduced soil load Q_r is less than the neutral soil load Q_n, this additional stress shall be taking into account as follows:

$$\sigma_y = \alpha_{tan} \times f_{rr} \{ 0.07 Q_r + K_b (Q_n - Q_r) \} \frac{r_g}{W_w}$$

where:

K_b is the moment coefficient of the pipe bottom (6 hours) for a supported pipeline section (support zone), see table D.1,

— for a support angle β = 70° (steel, nodular cast iron), K_b = 0.178 applies;

— for a support angle β = 120° (synthetics) K_b = 0.138 applies.

D.6 Stress intensification and flexibility at bends

D.6.1 General

At the location of bends in the pipeline, excess stress in the hoop stress (torus formula, see D.1.2) shall be additionally taken into account as well as intensification of stresses from bending moments

The stress intensification factors *(i_x* and i_y) are critical, when analyzing the magnitude of the (axial and/or circumferential) stresses, caused by axial bending moments. The flexibility factor (*k*) is used to calculate the reduction on axial stiffness (*EI*) of the bend, when compared to a straight pipe section.
Internal pressurereduces the size of these factors ("re-rounding" effect).

For use in stress analyses applies: $i_x \geq 1$, respectively $i_{x:p} \geq 1$, $i_y \geq 0$, respectively $i_{y:p} \geq 0$ and $k \geq 1$, respectively $k_p \geq 1$.

The calculation of these factors can be performed according to sections D.6.2 to D.6.5, inclusive, as well as according to "ANSI/ASME Boiler and Pressure Vessel Code, section III, subsection NB 3600, table NB-3685.1-2".

Symbols utilized in D.6 ***(waarom niet het symbool d_n voor nominale wanddikte ?)***

R is the (fictitious) bend radius;

r is the (average) pipe radius ;

α is one half of the miter angle (maximum 7.5 degrees);

s is the center-to-center distance between two consecutive miters;

t is the (nominal) wall thickness of the pipeline:

i_x is the stress intensification factor in the axial direction;

i_y is the stress intensification factor in circumferential direction;

k is the flexibility factor ≥ 1 (partial factor factor to reduce bending stiffness at bend);

h is the flexibility characteristic.

D.6.2 Material dependent

The relation between the factors i_x and i_y is dependent on the type of (pipe)material:

— for tangentially flexible isotropic material applies: $i_y = 2\, i_x$ respectively $i_{y:p} = 2\, i_{x:p}$;

— for tangentially flexible anisotropic material (for example, *G*VK), the stress intensification factors shall be delivered by the manufacturer;

— for tangentially rigid materials applies: $i_x = 1$, $i_y = 0$ and $k = 1$.

D.6.3 Smooth bends

For smooth tangentially flexible isotropic bends, the factors are calculated with the formulas:

$$h = \frac{t \cdot R}{r^2}, \qquad k = \frac{1.65}{h}, \qquad i_x = \frac{0.9}{h^{2/3}}$$

D.6.4 Miter bends

The clause has been deleted.

D.6.5 "Re-rounding" effect

The factors *k* and i_x are reduced for tangentially flexible isotropic material as a result of internal pressure ("re-rounding" effect) to k_p and i_{xp}:

$k_p = k / c_1$ and $i_{xp} = i_x / c_2$

with $\quad c_1 = 1 + 6\,\dfrac{p_\mathrm{d}}{E}\left(\dfrac{r}{t}\right)^{7/3} \cdot \left(\dfrac{R}{r}\right)^{1/3}$ and $c_2 = 1 + 3.25\,\dfrac{p_\mathrm{d}}{E}\left(\dfrac{r}{t}\right)^{5/2} \cdot \left(\dfrac{R}{r}\right)^{2/3}$

Appendix E
(normative)

Installation with HDD
Calculation

E.1 Determination of installation loads

E.1.1 Introduction

During the installation of pipelines according to the HDD technique, a pilot hole is first drilled under the object to be crossed, after which the pipeline to be installed is pulled through the bore hole from a system of rollers. The bore hole is permanent filled with a mixture of bentonite, water and drilled soil.

When the pipeline is being pulled in, tensile forces and bending moments arise in the pipeline:

– tensile forces resulting from pulling the pipeline over the rollers respectively through the bore hole;

– bending moments in a longitudinal direction due to the curvature of the pipeline:

– moments around the circumference resulting from lateral reaction forces, which bend the pipeline while following the curves of the bore hole.

After the pipeline has been installed, a stable situation develops over time. Arching may be taken into account in the determination of the magnitude of the vertical earth pressure on the pipeline (see C.4.8).

E.1.2 Determination of the pulling forces

E.1.2.1 Design and contingency factors

Stochastic variation in the values of the different frictional components shall be taken into account when determining the pulling forces . Utilization of an contingency factor of 1.4 for all components (f_1, f_2 and f_3) will suffice (see also table B.2).

E.1.2.2 Roller system

As the pipeline is being pulled over the roller system, it experiences frictional resistance from the rollers. The tensile force (7) which shall be taken into account equals:

$$T_1 = f \times L \times g \times f_1$$

where:

T_1 is the pulling force (calculation load) required to overcome the friction of the pipeline on the roller system, in N;

f is the partial load factor (f = 1,1 see also table 2 of SI 5664-2);

L is the length of the pipeline on the roller system, in mm;

g is the weight of the pipeline per unit length, in N/mm;

f_1 is the friction coefficient of the roller system (f_1 = 0.1) or, in the absence of a roller system, of the soil surface (f_1 = 0.3).

E.1.2.3 Straight section of bore hole

As the pipe is being pulled through a straight section of the bore hole, it experiences frictional resistance made up of two components:

a) the friction between the pipeline and the drilling fluid (f_2):

b) the friction between the pipeline and the wall of the bore hole (f_3).

The pulling force (T_2) required to overcome this friction equals:

$$T_2 = f \times L_2 \, (\pi D_u \times f_2 \times g_{ef} \times f_3)$$

where:

T_2 is the pulling force (calculation load) in a straight section of the bore hole, in N;

L_2 is the pipeline length in a straight section of the bore hole, in mm;

D_u is the outside diameter of the pipe, in mm;

f_2 is the friction between the pipe and the drilling fluid, in N/mm^2 (f_2 = 0,00005 N/mm^2 = 50N/m^2);

f_3 is the friction coefficient between the pipe and the wall of the bore hole (f_3 = 0,2);

g_{eff} = $\left| g - g_{buoy} \right|$ in N/mm;

g_{opw} is the buoyancy force of the pipeline per unit length in the drilling fluid, in N/mm.

NOTE 1 In the determination of the upper limit value of the necessary pulling force for the purpose of settling material, it is advisable to set the contingency factor of f_1, f_2, f_3 at 2.0 instead of 1.4. This namely applies for areas where local, hard to detect gravel pockets are present in the subsoil.
In the event an uncoupled bundle of pipelines will be pulled in, a circumference for the bundle that is smaller than the sum of the individual pipes can be taken into account. For *n* pipes, a reduction factor of 1/*n* x 0.3 can be taken into account. Furthermore, increasing the contingency factor of f_1, f_2, f_3 by 30 % to 1.8 is recommended for a pipeline bundle.

NOTE 2 The presence of bentonite slurry around the pipe greatly reduces , the friction between the wall of the bore hole and the pipe. In order to get an impression of this reduction, direct shear tests have been performed in the past where both sand as well as a sand-bentonite mixture were sheared off over a piece of epoxy coated pipe . The results were as follows:

sand	:	δ = angle of friction = 22°
sand with 10% bentonite	:	δ = 12°
		$f_3 = \tan \delta = \tan 12° = 0.2$

For hard sand, application of the same value of f_3 is advised. The reason for this is twofold. First, as a result of the drilling, a reduction in intergranular (effective)stresses takes places all around the bore hole; secondly, the angle of friction δ (Pipe/soil interface) in sand hardly increases when the value of the angle of internal friction increases.
In clay, the value of f_3 is less than or equal to the value of sand. Application of f_3 = 0.2 with clay is therefore on the safe side.

E.1.2.4 Curved sections of the bore hole

The pipeline is bent elastically in the curved sections of the bore hole when it is pulled in.

In addition to the pulling forces due to friction, referred to under E.1.2.2 , additional friction forces arise in the curved sections of the bore hole.

Friction resulting from a reaction from the soil in bends

When the pipeline is being pulled in, an elastic bending of the pipeline occurs as a result of torque at the end of the bend.

This torque has to be provided by the soil. With the help of Hetényi's theory, the profile of the soil reaction can be determined (see figure E.1). The reaction of the soil at the ends of the bend creates an additional friction force

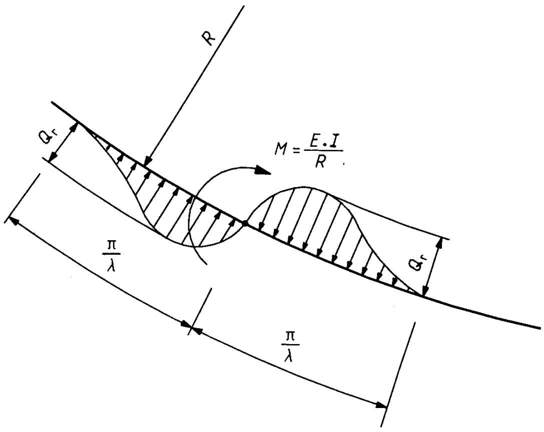

Figure E.1 — Reaction of the soil at the end of an elastic bend

Taking an average value for the forces on the pipeline, the additional pulling force due to a single bend can be calculated as follows:

$$T_{3a} = f \times 4 \times \frac{q_r}{2} \times D_o \times \frac{\pi}{\lambda} f_3$$

where:

T_{3a} is the pulling force (calculation load) for a single bend in the bore hole, in N;

q_r is the maximum soil reaction near the end of the bend, in N/mm^2;

$$q_r = k_v \times y = \frac{0.322 \times \gamma^2 \times \cdot EI}{D_o \times R} \qquad \text{(see also D.3.3);}$$

k_v is the vertical modulus of subgrade reaction, in N/mm^3;

y is the maximum displacement, in mm;

EI is the bending stiffness of the pipe, in N/mm^2;

R is the radius of the bend, in mm;

f_3 is 0.2;

λ $\lambda = \sqrt[4]{k_v \times \frac{D_o}{4EI}}$

Friction due to bending force

When the pipeline is being pulled in, a force will arise in a bend directed towards the midpoint of the arc (see figure D.2). This causes a reaction force on the pipeline from the soil. The size of this force acting on the pipe (g_t) is dependent on the pulling force in the pipeline and the radius of curvature.

$T_{3b} = f \times L_B \times g_t \times f_3$

where:

T_{3b} is the pulling force (calculation load) resulting from the bending force, in N;

L_B is the chord of the bend, in mm, where ($L_B = 2 \times R \times 2\pi \times \alpha/360$);

α is half of the bend angle, in degrees;

g_t is the bending force, in N/mm, $g_t = (2T\sin\alpha)/L_B$;

T is the total pulling force in the pipe, in N.

NOTE The size of T_{3b} depends on the pulling force in the pipeline at the location of the bend and shall be determined iteratively. Since α is generally small, T_{3b} is also small in relation to T.
T_{3b} can be considered to be a fixed value: $T_{3b} = f \times 2T \times \sin\alpha \times f_3$
for $\alpha = 6°$, then: $T_{3b} = 1.1 \times 2T \times \sin 6° \times 0.2 = 0.044T$.

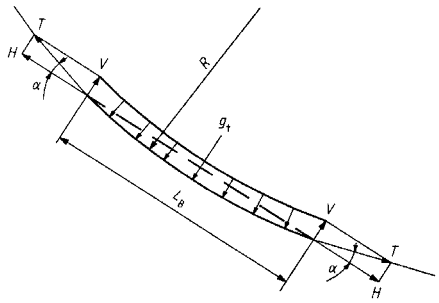

Figure E.2. — Forces in a bend

E.1.2.5 Total pulling force

The pulling force in the pipeline at the positions A through F inclusive, shown in figure E.3 can be calculated with the forementioned calculation methods.

Obviously, account shall be taken for the fact that the length of the pipeline on the roller system decreases as the pulling operation progresses.

The calculation of the pulling force is based on a stable bore hole.

The profile of the pulling force in the pipeline can be graphically represented as a function of the length that has been pulled.

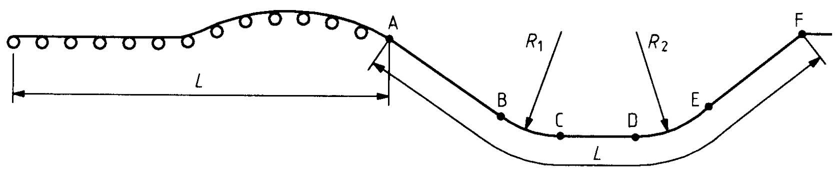

Figure E.3 — Pulling forces in the pipeline

E.1.3 Determination of the longitudinal bending moment

The following formula applies:

$$M = f \times E \times I/R$$

where:

M is the moment as a result of curvature, in Nmm;

E is the modulus of elasticity of the pipe material, in N/mm^2;

I is the moment of inertia of the pipe, in mm^4;

R is the radius of curvature in a downward curve between roller system and bore hole or in bends of the bore hole, in mm;

f is the load factor.

E.1.4 Determination of the circumferential bending moment

Consult D.3.3 for the determination of the bending moment along the circumference. Consult C.4.8.2 (homogenous soil mass) and C.4.8.3 (layered soil mass) for the determination of the vertical load bearing on the pipe.

E.1.5 Determination of stress

For each situation affecting the pipeline during the pulling operation and final operating condition, the representative load combination shall be determined. A sentence has been deleted.

Assessment for implosion by drilling fluid pressure is only necessary for plastic pipelines during the pulling operation. In case of a gas pipeline, also an assessment for implosion due to external water pressure following completion of the drilling, shall be conducted, employing the long term (fictitious) modulus of elasticity(of the plastic pipe material).

E.2 Determination of maximum allowable pressure in the bore hole as a function of the plastic zone

E.2.1 General

The functions of the drilling fluid (bentonite-water slurry) include supporting the bore hole and removing the loose drilled soil. In order to perform these functions a certain pressure must be maintained in the head of the bore hole. The pressure in the drilling fluid is, however subject to limitations. If the pressure in the bore hole (p) exceeds the prevailing earth pressure, then the bore hole will expand. Such expansion is initially elastic.

With continuing increase of the pressure ($p > p_t$), the deformation around the bore hole will become plastic., the deformation around the bore hole begins to increase progressively once that point is reached. Continuous deformation occurs at the limit pressure (p_u). At a certain pressure $p_f < p < p_u$, the bore hole has been expanded over a certain length, whereas the plastic zone has extended to a certain area.

In order to avoid soil failure during drilling, the zone of plastic deformation must be kept below the soil surface or below the bottom of the water course.

Thus the extent of the plastic zone is to be limited. The pressure corresponding to this limit is the maximum pressure, allowed in the bore hole (without safety margin).

E.2.2 Methods of Calculation

A possible method of calculation for allowable pressure (mud pressure) in the bore hole is given below (derivations can be found in “Directional Drilling in Soft Soil; Influence of Mud pressure [28]).

Under the condition that:

– the system is in equilibrium;

– the a material behavior is elastic, described by Hooke’s law for increments of stress and strain;

– the failure condition can be describeb by Mohr-Coulomb’s equation;

– no isotropic deformation occurs in the plastic zone,

the following formula applies:

$$p_{max} = (p'_f + c \times \cot\ \varphi)\left((R_o / R_{p,max})^2 + Q\right)^{\frac{-\sin\varphi}{1+\sin\varphi}} - c \times \cot\varphi + u$$

where:

p_{max} is the maximum allowable mud pressure, in N/mm^2;

p_f is the effective drilling fluid pressure where the first plastic deformation takes place, in N/mm^2
$p_1 = \sigma_o' \times (1 + \sin\varphi) + c \times \cos\varphi$,

σ_o' is the initial effective stress (soil stress), in N/mm^2;

φ is the angle of internal friction, in degrees;

c is the cohesion, in N/mm^2;

R_0 is the initial radius of the bore hole, in mm;

Q is $(\sigma_o' \times \sin\varphi + c \times \cos\varphi) / G$;

G is the shear modulus, in N/mm^2:

$R_{p,max}$ is the maximum allowable radius of the plastic zone, in mm ($R_{p,max} = 0.5H$ is applicable for clay or peat, where H is the depth of soil cover; for sand see E.2.3);

u is the (ground) water pressure in the layer where drilling is taking place, in N/mm^2.

In addition to these values for the maximum allowable drilling fluid pressure, the limit pressure p_{lim} shall also be observed. That limit pressure is derived from the previous formula by letting the value of $R_{p,max}$ approach infinity:

$$p_{max} = (p'_f + c \times \cot\ \varphi)\left((R_o / R_{p,max})^2 + Q\right)^{\frac{-\sin\varphi}{1+\sin\varphi}} - c \times \cot\varphi + u$$

In some cases the maximum allowable drilling fluid pressure p_{max} calculated with the first equation can be very close to the limit pressure p_{lim}. It is therefore recommended to use not more than 90 % of the limit pressure as maximum allowable pressure.

NOTE 1 The abovementioned formulas are valid as the quotient of soil cover and the diameter of the bore hole is greater than 5.

NOTE 2 The minimum required drilling fluid pressure (diluted bentonite) at the drilling head is the pressure,required to cause the mixture of water, bentonite and loose drilled soil (bore slurry) to flow through the finished bore hole along the drill pipe towards the ground surface. This pressure includes:

— static pressure of the slurry column up to the ground surface;

— frictional resistance over the length of the finished bore hole.

The maximum allowable drilling fluid pressure at the drilling head (loss of equilibrium in surrounding soil) is comprised of:

— local maximum allowable intergranular pressure(effective stress);

— local effective water pressure.

A sufficient margin shall be present between the calculated required drilling fluid pressure and the maximum allowable drilling fluid pressure. If this is not satisfied when designing the pipeline junction, then the pipeline has to be installed deeper.

In principle, two options are available for control (monitoring) of the drilling fluid pressure at the drilling head:

— measurement at the location of the drilling rig: the pressure is measured on the delivery side of the drill fluid pump. The measured pressure shall be reduced with the loss of friction in the drill pipe and the exit loss at the boring head in order to determine the pressure in front of the drilling head. This option only makes sense when the losses are known. The loss of friction in the drill pipe can be determined by means of the outcomes of fin tests on samples of the applied drilling fluid; the exit loss is dependent on the type and design of the drilling head;

— measurement at the drilling head: the total pressure in the mixture is measured at the drilling head; it is assumed equal to the drilling fluid pressure which is present following the withdrawal and checked directly with the maximum allowable drilling fluid pressure. This method is more accurate than the first option and it is preferable, if the necessary measurement armamentarium is developed to a level enabling practical application of this method.

E.2.3 Determination of R_{pmax} on the basis of maximum strain of the wall of the bore hole (sand)

With reference to “Directional Drilling in Soft Oil; Influence of Mud Pressure” [26].

The strain of the bore hole wall ε_g is:

$$\varepsilon_g = R_g/R_0 - 1 \Rightarrow R_g = R_0(\varepsilon_g + 1)$$

substitution in formula 4 of [26] with $Q = (\sigma_o \sin \varphi + c \cos \varphi)/G$ gives:

$$R_0^2 \left(\varepsilon_g + 1\right)^2 = R_0^2 + R_p^2 \times Q \qquad \text{or} \qquad R_p^2 \times Q = R_0^2 \left(\varepsilon_g^2 + 2\varepsilon_g\right)$$

$$R_p^2 \approx \frac{R_0^2}{Q} \times 2\varepsilon_g$$

The following formula can be used for $R_{p,max}$:

$$R_{p,max} = \sqrt{\frac{R_0^2}{Q} \times 2\varepsilon_{g,max}}$$

where:

R_0 is the initial radius of the bore hole;

R_g is the radius of the bore hole with mud pressure p:

ε_g is the strain of the bore hole wall as a result of the mud pressure p;

$R_{p,max}$ is the maximum allowable radius of the plastic zone;

$\varepsilon_{g,max}$ = 0.05 can be adopted for sand.

Appendix F
(normative)

Aspects of offshore pipelines

F.1 Route determination

F.1.1 Permitted routes

F.1.1.1 Legislation and regulation

The transport of `natural gas` via offshore pipelines shall comply with legislation and regulations laid down by the appropriate authority.

NOTE 1 The governmental requirements for route selection, design, installation, testing and operation (including inspection and maintenance) of offshore pipelines for the transport of minerals are presented in:

-- Mining Directive [39];

-- Mining Regulations [41].

Both serve for the implementation of the Mining Law [40], which went into effect as of January 1, 2003.

NOTE 2 For offshore pipelines that are used for the direct winning of minerals, the Ministry of Economic Affairs is the appropriate authority. Certain aspects are delegated to the Staatstoezicht op de Mijnen (SodM; Supervising Agency for Mining). There is close consultation with the Ministry of Transport and Public Works (North Sea Directorate). For offshore pipelines that are not used for the direct winning of minerals (for example, transit pipelines), the Ministry of Transport and Public Works (North Sea Directorate) is the appropriate authority. The Wet Beheer Waterstaatswerken (Administration of Public Works Law) is then in force.

F.1.1.2 Permits and agreements

The appropriate authority

In order to receive a permit to put an offshore pipeline into service, a preliminary consultation procedure shall be initiated by the pipeline owner with the appropriate authority.

The proposed pipeline route is to be presented to the appropriate authority. The appropriate authority coordinates consultation with the competent bodies concerning feasibility and possible restrictions to the chosen pipeline route.

The appropriate authority or its authorized representative assesses, inspects or verifies the design, installation and testing. In case of a positive judgement on all phases, the permit (Proof of Inspection) is issued for operating the pipeline.

Public Works and Water Management

Public Works and Water Management, Directorate North Sea, is the administrator for the sea bottom of the Netherlands continental shelf. For offshore pipelines that are to be installed within territorial waters, a permit (Public Works and Water Management and Domains) is also required in the context of the Law Administration of Public Works.

Cable and pipeline owners

For the installation of pipelines nearby or crossing cables and pipelines of third parties, agreements shall be reached with the owners of the cables and pipelines whereby conditions are established for installation, maintenance and eventual removal. The owners can make specific demands with respect to design, construction details and reciprocal liability.

F.1.2 Route study

Field study

A route study shall be performed in a 600 m wide corridor whose axis coincides with the chosen route. The study shall provide the following information over the width of the corridor.

— the seabed profile;

— obstacles present;

— position of existing cables and pipelines;

— geotechnical properties;

— stratigraphy of the sea bottom;

— bottom samples and probes (cone penetration tests).

NOTE 1 In practice, seven longitudinal strips are evaluated along the corridor with a center-to-center separation of 100 m, wherein depth measurements, sub-bottom stratification, seabed profile and presence of obstacles are registrated. In the vicinity of platforms and areas where eventual branching of the pipeline and crossing with pipelines and cables are anticipated, evaluations are made in a 500 m x 500 m area along rows separated by 50 m and in a 100 m x 100 m area at its center along survey lines separated by 20 m (dependent upon the offshore pipeline, riser and junctions).

Geotechnical investigation

The geotechnical investigation shall provide parameters for determining the stability of pipeline positioning. If the pipeline is to be buried, the investigastion shall extend to at least 0.5 m below the planned trench depth. In the case where the pipeline is to be provided with a cover, the expected settlements shall be investigated and calculated. The seabed profile as well as an advisory on the stability of the layout (ridges, dunes) are part of the investigation The general practice is that probes and soil samples are taken at regular intervals. Soil samples are taken using "dropcores" as well as "vibracores"; the interval of the "dropcores" and "vibracores" being dependent upon, among other things, the length of the route, the anticipated variations in sub-bottom stratification, the need for pipeline burial as well as further information that may become available while the investigation is being carried out. In case of geotechnical investigation for self-burying pipelines, special attention shall be paid to the top layer with regard to its silt content.

At platform locations and locations of projected junctions with other pipelines,soil samples shall be taken down to 3 m below the solid seabottom or that much deeper as is required for a possible foundation. The (sampling)locations are also determined on the basis of the SBP ("Sub Bottom Profile") study on bottom stratification.

NOTE 2 In the North Sea, a great deal of geotechnical investigation has already been carried out. The data is bound and available to the public (TNO-NITG).

Laboratory testing of the soil samples is to be carried out to determine properties such as soil classification, sieve curves, silt, sludge and organic-material content, cohesion, undrained shear resistance, internal friction angle, volume, wet and dry mass, porosity, permeability (vertical and horizontal), compressibility (consolidation coefficient) and if necessary,with subsequently determination of properties such as flood sensitivity and erosion resistance.

Reporting

The route study shall be set down in a report comprising, at a minimum, the following items:

— a description of the work;

— an account of the measurements taken and the apparatus used;

— results of the measurements, conclusions and recommendations;

- route maps at a scale of 1:10,000 (with kilometer scale);
- maps of the (500 m x 500 m and 100 m x 100 m) detailed studies;
- probe graphs, boring results and photos;
- results of laboratory investigations and tests;
- geotechnical parameters.

F.1.3 Route aspects

Factors in the choice of routes

- A constant separation of at least 1500 m between the route to be chosen and existing or projected platforms, wells and cable amplifiers.
- Nearby (future) platforms, pipeline routes should be bundled as much as possible in order to leave room for supply ships to maneuver, for anchoring of drilling installations, for installation vessels(lay barges?) and for future platform extensions.
- Whenever possible and economically feasible, the pipelines should be layed parallel to one another in a 'pipeline corridor'.

Coordinate systems

The clause has been deleted.

Cable and pipeline crossings

When an existing offshore pipeline or cable is crossed, the following shall be taken into consideration:

- make the crossing as perpendicular as possible (45° minimum);
- there shall be no adverse interference with the cathodic protection system of the pipeline;
- stable bedding of the crossing (stabilize with rock dump):
- vertical separation of 0.3 m or more (e.g., by installing mattresses);
- selection of a suitable crossing location. When another pipeline is crossed, the support fill shall be such that sufficient resistance is obtained against buckling of the pipeline being bent from bottom upheaval ("upheaval buckling") or removal of supporting soil by erosion (giving rise to pipeline"ratcheting");
- agreements with the owner of the crossed pipeline in a written accord;
- a crossing shall be so stabilized with stone that it can withstand a 100-year storm;
- in connection with limiting risks from fishing activities outside the 500 meter zone, the top layer of the rock dump shall have a sufficiently small grading (D90 ≤ 80 mm) and a minimal layer thickness of 0.2 m;
- in the case where separation mattresses are not feasible, artificial rise or sleepers may be considered for the crossings.

Determining riser location

Among other things, the following are pertinent aspects in determining the location of risers:

- pipeline routes;
- location of living quarters;
- minimum separation between risers, because of installation requirements for already installed risers;
- probability of damaging the risers;
- available space with respect to existing and future risers and platform facilities;
- the horizontal angle of the pipeline relative to the platform shall be such that future pipelines and platform extensions are not blocked;
- additional load on the platform foundation ("jacket");
- obstacles such as jacket anodes, deck overhangs;
- sufficient space and separation distances for supporting/clamping the riser pipe ;
- installation methods;
- anchoring zones;
- accessibility requirements for drilling installations with respect to drilling and workover(well treatment?);
- position and reach of the crane.

NOTE 1 Pipeline risers are generally placed within the platform foundation ("jacket") as a protection against (ship)collisions. An alternative solution can be to provide the pipeline risers(s) with a protective shell.

Location for landfall

The location of the landfall shall be determined in consultation with the owner of the seawater retaining barriers and of property (ies) further inland. The following considerations shall thereby be taken into account:

- routes of the pipeline on land and offshore;
- positions of other offshore pipelines and cables near the coast and their landfalls;
- available space for installation on land and at sea;
- near shore shipping and fishing;
- crossing dunes and/or sea dykes (see also NEN 3651:2003);
- environmental impact and disturbance;
- coast morphology (accretion, abrasion, erosion, stability, sand suppletion).

NOTE 2 New locations for landfalls should generally be planned near existing ones,(the words in parentheses have been deleted)

F.2 Concepts and formulas for loads specific to offshore pipelines

F.2.1 General

Only loads that are specific to offshore pipelines or loads that need another approach than on-land pipelines are considered in these paragraphs.

F.2.2 Marine environment

Loads specific to offshore pipelines arise from the marine environment of the pipeline. These can be subdivided as:

a) Physical, chemical and biological parameters of the seawater:

--- temperature variations related to tides and depths;

--- water circulation and refreshment;

--- electrical resistance;

--- salt content;

--- pH value;

--- oxygen content;

--- biological activity (sulfate-reducing bacteria, rate of marine growth, etc.).

b) Tides.

c) Wind.

d) Waves:

--- wave height;

--- wave frequency;

--- wave direction;

--- water depth;

--- bottom topography.

e) Currents:

--- current velocity;

--- currents caused by tides;

--- currents caused by wind;

--- currents caused by rise and fall of waves;

--- currents,due to differences in density;

--- other current phenomena.

f) Ice, ice flow and drift ice .

F.2.2.1 Wave and current characteristics

The determination of wave and current loads for strength analyses in the operational phase shall be based on the maximum wave and current characteristics that can be exceeded, on average, once every 100 years. The testing of horizontal stability for unburied offshore pipelines shall be based on significant wave and current characteristics that can be exceeded, on average, once every 100 years (see also "Recommended Practice RP E305" from DnV [20]).

The determination of wave and current loads for transitional phases, e.g. during installation, for strength analyses shall be based on the wave and current characteristics that can be exceeded, on average, once every 3 years during the season in question.

Whenever the duration of such a transitional phase is equal to or less than 5 days and whenever such a phase can be interrupted in a responsible manner based on a 48-hour warning, the loads utilized for such a phase can be based on wave and current characteristics resulting from reliable weather predictions.

The wave characteristic to be used related to the type of analyses is presented in Table F.1.

Table F.1 --- Basic points for hydrodynamic loads in the design

Design aspect	Section	Load case	Wave height m	Wave period s	Repeat interval yr
stress analysis	pipeline	buried within a year after installation	maximum	maximum	1
		self-burying after N year	maximum	maximum	3 N
		not buried	maximum	maximum	100
	riser	attached to platform	maximum	maximum	100
pipeline stability	pipeline	buried within a year after installation	significant	significant	1
		self-burying after N yr	significant	significant	3 N
		not buried	significant	significant	100
	riser	attached to platform	maximum	maximum	100

Wind, wave and current loads based on known data as well as relevant hydrodynamic coefficients can be determined in agreement with generally accepted guidelines, publications and/or model tests.

With respect to place of occurrence and frequency of presence, these data shall generally be the same as those used for platform design.

NOTE The significant wave height shall be determined over a period of time (in years). The length of the period is dependent on the installation method (see Table F.1).

F.2.2.2 Hydrodynamic loads

Hydrodynamic loads are loads initiated by current and waves and caused by the relative movement between the pipeline and surrounding water.

The following forces shall be taken into account:

- the inertia force F_m;
- the drag force F_d;
- the lift force F_l.

The inertia force is calculated as follows:

$$F_{\mathrm{m}} = 0.25 \times \pi \times D_o^2 \times \rho_{\mathrm{w}} \times C_{\mathrm{m}} \times a$$

The drag force is calculated as follows:

$$F_{\mathrm{d}} = 0.5 \times \rho_{\mathrm{w}} \times |v| \times v \times C_{\mathrm{d}} \times D_{\mathrm{o}}$$

The lift force is calculated as follows:

$$F_{\mathrm{l}} = 0.5 \times \rho_{\mathrm{w}} \times |v| \times v \times C_{\mathrm{l}} \times D_{\mathrm{o}}$$

where:

D_0 is the outside diameter of the pipeline, in m;

ρ_{W} is the mass per unit volume of the water, in kg/m^3

a is the acceleration of the water particles perpendicular to the pipeline axis, in m/s^2;

v is the velocity of the water particles perpendicular to the pipeline axis, in m/s;

C_{m} is the mass coefficient;

C_{d} is the drag coefficient;

C_{l} is the lift coefficient.

To arrive at the combined effect of the inertia, drag and lift forces under the action of waves and currents, the vectors of these forces are added, making due allowance for differences in phase angle.

The orbital velocities and accelerations are determined from the theory of waves (e.g., Airy, third-order Stokes, fifth-order Stokes) applicable to the situation, wherein the design wave characteristics, water depth, and depth of the section of the transport pipeline being considered are taken into account.

To arrive at the total water particle velocity (v) for the drag force and the lift force to be taken into account, the orbital velocities are combined with the current velocities for the relevant location along the pipeline, whereby these variables are to be added vectorially. This takes into account the effect of any differences in direction of the variables.
In determining C_{m}, C_{d} and C_{l}, data can be used from “On-bottom stability design of submarine pipelines” ERP 305, DnV [20], accepted recent research or model tests. Possible scatter of these factors shall be taken appropriately into account.

Lateral stability

The required submerged weight for offshore pipelines can be determined using:

$$f_{\mathrm{w}}(W_{\mathrm{s}} - F_{\mathrm{l}}) \geq f(F_{\mathrm{m}} + F_{\mathrm{d}})$$

where:

W_{s} is the required submerged weight;

f is the load factor (see table 2 of SI 5664-2);

f_{W} is the lateral coefficient of soil friction;

F_m, F_d, F_l are the inertia, drag and lift forces.

Forces shall be added vectorially and account shall be taken of mutual phase differences and direction (phase?) angles.

NOTE The calculation presented here is based on the assumptions that no displacement occurs ("no-movement" criterion). Recent research has indicated that under certain circumstances the possibility of lateral movement of the pipeline is imperative.
With respect to the stability calculation, a limited amount of initial burying ("embedment") of the pipe in the seabed can be taken into account, if justified by the soil composition and properties.
With respect to the choice of the friction coefficient of soil, one can make use of accepted literature as well as research and results of model tests..

F.2.2.3 Hydrostatic loads

$$Q_{op} = 0.25 \times \pi \times D_o^2 \times \rho_w \times g$$

The buoyancy of the pipeline under operating conditions shall be less than its own weight increased by the weight of the submerged weight coating and, where applicable, increased by the neutral earth pressure, which is divided by the appropriate contingency factors, see Table B.2 and B.3.

NOTE It is advised to take into account the possibility of an increased density in the surrounding medium due to the occurrence of a liquefied sand-water mixture.

F.2.2.4 Vibrations

General

Vibrations due to the medium flowing in the pipe as well as vibrations from wind and/or hydrodynamic loads shall be such that the allowable stress level is not exceeded nor that there is a risk of damage from fatigue.

All stress fluctuations of such magnitude and/or number that might give rise to a significant fatigue effect on the pipeline system shall be investigated.

Fatigue analysis shall be based either on fracture mechanics or fatigue tests.

Since the majority of fatigue-inducing loads are random in nature, a probabilistic approach shall generally be required.

NOTE The calculation method in F.2.2.4 is the same as that used in DnV of 1981. Advanced methods have meanwhile been developed within the DnV packet (such as in OSF 101). The advantage of the described method is its familiarity and relative transparency. This does not detract from the fact that one can also do the calculations using the more advanced methods.

Vibrations from water currents along free spans of offshore pipelines

The velocity of water particles perpendicular to the pipe axis (v) caused by currents and waves can result in a non-stationary flow pattern around the pipe from vortex shedding (Von Karman effect). Where pipeline sections are not continuously supported this can, dependent of the length of the unsupported pipeline section (the "span") and the pipeline‘s bending stiffness,cause the pipeline to 'oscillate'.

A distinction is made between:

– oscillations parallel to the current ("in-line"); these occur from oblique flows parallel to the current direction, horizontal;

– oscillations perpendicular to the current ("cross-flow"); these occur perpendicular to the current direction, vertical.

In order to avoid oscillations, the length of the span shall be chosen such that the reduced velocity, which is a function of the natural frequency(of the pipe span) and the pipeline’s diameter, falls outside the resonance range.

The calculation to check this aspect contains the following two important variables:

– the stability parameter, K_s;

– the ‘reduced velocity', V_r (an imaginary variable, which is a function of the natural frequency of the pipeline and its diameter).

First the stability parameter, Ks, has to be checked for the susceptibility of the construction.

$$K_s = \frac{2m \times \delta}{\rho_w \times D_o^{\ 2}}$$

where:

K_s is the stability parameter

m is the mass including the added mass per unit length, in kg/m;

δ is the logarithmic reduction (damping factor) = factor x 2 π;

δ_{water} is 0.02 x 2 π;

δ_{air} is 0.005 x 2 π;

ρ_W is the mass per unit volume of the surrounding medium, in kg/m^3;

D_0 is the outside diameter including coating, in m.

Resonance will occur for "in-line" vibrations if $K_s \leq 1.8$ and for "cross-flow" vibrations if $K_s \leq 16$. If K_s satisfies these conditions, the resonant range shall be avoided by adjusting the length of the span. For this, the 'reduced velocity' shall be checked. First, the natural frequency of the affected pipeline section is calculated.

The first natural frequency of a beam is:

$$f_1 = \frac{a}{2\pi}\sqrt{\frac{E \times I}{m \times L^4}}$$

where:

a is the frequency factor, a = 22.0 when bilaterally clamped and a = 9.87 when bilaterally hinged;

f_1 is the first natural frequency, in s^{-1}, Hertz;

E is the elasticity modulus, in N/m^2;

I is the moment of inertia, in m^4;

m is the mass including the added mass per unit length, in kg/m, Ns^2/m^2;

L is the distance between two supports, in m.

The actual natural frequency will generally lie between the limiting values (bilaterally clamped for bilaterally hinged).

The reduced velocity is now given by:

$$V_r = \frac{v}{f_1 \times D_o}$$

The resonant range for "in-line" oscillations (parallel to the direction of flow, horizontal) is limited by:

$1.0 \le V_r \le 3.5$

The resonant range for "cross-flow" oscillations (perpendicular to the flow, vertical) is a function of the Reynolds number (Re), see also Figure F.1.

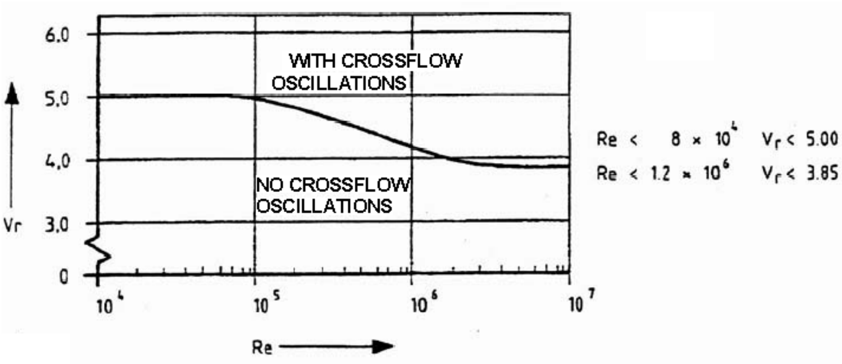

Figure F.1 - Reduced philosophy, V_r, for "cross-flow" oscillations

NOTE Use may also be made of other accepted methods as well as results from accepted research and tests.

Wind

The above method can equally well be applied for wind.

For the reduced velocity then applies:

"In-line": $1.7 < V_r < 3.2$

"Cross-flow": $4.7 < V_r < 8.0$

The 'static' wind pressure per unit length of pipe is calculated with:

$$F_w = 0.613 \times C \times V_n^2 \times D_0$$

where:

F_W is the wind pressure per unit length, perpendicular to the pipe, in N/m

C is the shape coefficient

V_n is the component of the wind velocity perpendicular to the pipe, in N/m;

D_0 is the total outside diameter, in m.

F.3 Acoustic survey

F.3.1 Location of offshore pipelines

After the installation phase, a survey shall be carried out to establish the horizontal and vertical positioning of the pipeline and the protective structures.

During the operational phase, regular inspections shall be carried out to determine, verify or confirm position, burial depth, exposure and wash away. The scope of the study can vary depending on the burial requirements of the pipeline.

The goal of the survey is to determine whether the required installation dept and/or depth of soil cover has been met and to demonstrate that any length of free span or the level in height does not indeed exceed the maximum allowable values.

F.3.2 Other acoustic survey

Combined study

When a pipeline, "umbilical" or cable lies parallel with an (other) pipeline, the survey can be combined provided there is sufficient overlap. If necessary, an extra survey line shall be performed.

"As-Built"

Immediately after installation of the pipeline, umbilical and/or cables, an "as-built" survey study shall be performed. An "as-built" survey study shall comprise, as a minimum, the following information:

- the horizontal and vertical positioning with regard to the surrounding seabed;
- number and positioning of mattresses and/or quantity and location of rock dump;
- location and type of connection flanges;
- size and location of spools, expansion pieces, etc.;
- location, number and configuration of temporarily or permanently installed pipeline supports (sand, gravel or cement sacks);
- location and configuration of pipeline, "umbilical" or cable crossings;
- position and stabilization of protective structures.

Platforms

A detailed acoustic survey study shall be performed for each pipeline end (at the platforms) to check for exposure and wash away. This study starts as close as possible to the platform extending out to the place where the pipeline is buried (after the rock dump or mattresses) up to a maximum of 300 m from the platform.

Pipeline and cable crossings

A detailed acoustic survey study shall be performed periodically on pipelines/cable crossings. The crossings, specifically the border areas of the pipeline or rock dump (or mattresses), shall be checked for wash away and/or exposure.

Branches and T-joints

A detailed acoustic survey check shall be periodically performed at the location of branches and T-joints. The survey shall indicate the positioning of the in and outgoing pipelines and whether the protective measures (rock dump or mattresses) still satisfy their requirements.

Protective steel cages

A detailed acoustic and also, whenever necessary, visual check shall be performed periodically on the protective steel cages. The check shall provide the following information:

- that all access hatches are intact;
- configuration of the rock dump (check for possible loss due to wash away);
- positioning of the in and outgoing pipelines, check for wash away.

Reporting

Results and findings as well as possible corrective actions shall be reported to the appropriate authority.

Appendix G
(normative)

Installation -- Trenchless techniques

G.1 General

The trenchless installation of pipelines comprises various techniques. Each technique has its own specific acceptance criteria and the choice of the most appropriate method is dependent on:

- diameter, material and connections of the pipeline;
- nature of the object to be crossed;
- length of the crossing;
- soil composition;
- existing (ground)water table or water pressure.

In Figure G.1, a schematic overview is given of the techniques for installation of new pipelines.

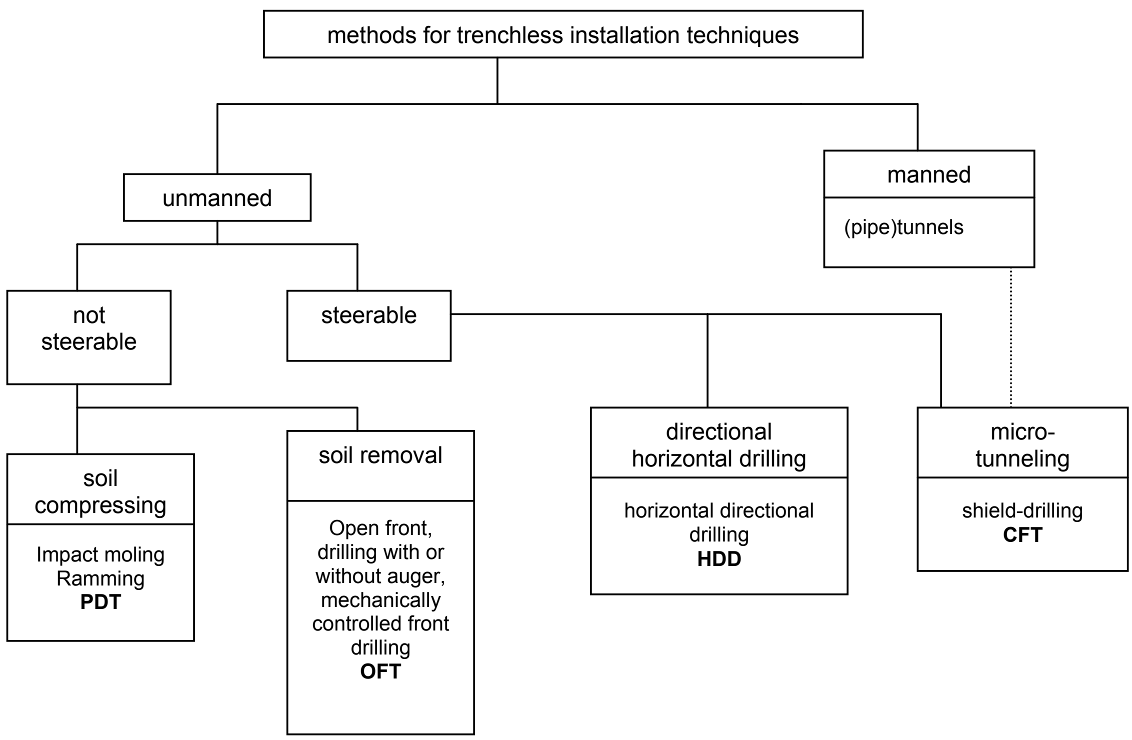

Figure G.1 - Trenchless techniques

Pneumatic boring technique (PBT)

The pneumatic jacking technique (also sometimes designated as 'rocketing' or hammering) is further subdivided into:

- *Impact Moling*, method whereby a pneumatic piercing tool (in the shape of a rocket) is driven into the soil from a starting pit thereby creating a hole into which it draws a pipe after itself or a pipe is afterwards shoved in the soil, if suitable.

– *Impact Ramming*, method whereby a pneumatic tool acting as a hammer drives the steel pipe into the soil from a starting pit. The soil is forced into the pipe and is removed by manual removal, high-pressure water jet or compressed air or with an auger either continuously or after the completion of the crossing.

NOTE 1 PBT cannot be applied under the groundwater level and is not steerable.

Open-front technique (OFT)

A pipe is driven into the soil formation from out of a starting pit by hydraulic jackscrews. The soil is forced into the open front of the pipe. The soil is regularly removed from the pipe during or after completion of the process by manual removal, jetting or blowing.

When an auger is appropriate, the soil is continuously removed from the pipe while it is being forced into the soil by a rotating transport screw (auger).

NOTE 2 OFT is inappropriate for use below the groundwater table. In order to make OFT appropriate for drilling below the groundwater level, the excavation front can be kept under high air pressure.

In the mechanically-supported front method, the pipeline is jacked into the soil formation with jackscrews just like in the open front method. The excavation front is supported, over its full diameter, by a rotating cutting shield. Adequate control of the size of the openings in the cutting shield is required in order to prevent uncontrolled soil removal..

Closed-front technique (CFT)

A mechanical tool, the 'shield', placed on the front of the pipe to be jacked, grinds its way through the soil with a rotating cutting wheel while simultaneously hydraulic jackscrews in the jacking pit press the pipe and shield into the soil formation. The shield is characterized by a retaining wall perpendicular to the longitudinal axis of the pipe and prevents soil and groundwater from being able to penetrate into the jacked pipe.

With the bulkhead, the loose soil at the drilling front is carried off to grade level via the pipe by:

– circulation of an hydraulic transport fluid whether water or a bentonite-water mixture (applied in the slurry shield);

– a screw transporter,transporting soil in in dry (plastified) form (applied in the earth pressure balanced solid shield with constant soil removal).

The prevailing intergranular(effective) soil stress and groundwater pressure in front of the retaining wall is held back (equalized) by hydrostatic pressure on the hydraulic transport fluid or by controlling the rotation rate of the screw transporter. in case of an earth pressure shield with liquid removal, a combination of both methods is employed.

NOTE 3 CFT can be employed below and above the groundwater table and is fully steerable.

Horizontal Directional Drilling technique (HDD)

Here, a small-diameter drilling rod is first forced into the soil formation; the "pilot drilling".

The drilling rod is equipped on its front end with a jet bit as well as a rotating cutter driven by a displacement motor (mud motor).

While it is being jacked in, the drilling rod can be controlled, guided by a location determining system, along a previously determined drilling line.

A drilling fluid, mostly a bentonite-water mixture (mud), is pumped into the drilling rod under pressure and serves as "jet-medium" or driving medium of the mud-motor and thereby cuts the soil loose.

The drilling fluid fulfills, at the same time, the functions of transport fluid for the loosened soil, supporting, cementing and lubricating the walls of the drill hole.

After the pilot drilling, the pilot hole is reamed or enlarged to the desired diameter of the drilling hole with a drilling bundle or, when appropriate, with a flush pipe (wash-over pipe) equipped with reaming tools. After the reaming, the carrier pipeline to be installed is then inserted. Consideration should be taken for the removal or recycling of the drilling flush.

NOTE 4 HDD is quite appropriate for use below groundwater table and is fully steerable.

Other trenchless techniques

Pressure-jetting

The pipeline is introduced into a waterway to be crossed by high pressure hydraulic jetting This is done with a special jetlance, jet plow or jet module. This lance, plow or module is generally attached to or hangs on a hoisting machine on board a boat and is operated from that boat.

The lance, plow or jet module flushes away the soil under the pipe while it is advanced by a winch or the like. Simultaneously, the flexible pipeline is pulled from the boat by the lance, plow or module to the resulting trench.

Bow burial

A jet lance in the form of a semi-circle is driven through the soil under a water course. On the opposite bank of the waterway, a flexible pipeline (or cable) is attached to the lance and pulled through the borehole

Chain grinding

A semi-trenchless technique for field pipelines is the insertion of small-diameter plastic pipes with a chain-excavator. The pipe can be pulled from a reel as the machine advances or can be laid out beforehand at grade level. An impediment to this method is the presence of subsoil infrastructure that cause a proportional number of interruptions in the execution of the method. The method is exclusively applicable to continuous and flexible (non-articulated) pipelines.

For an overview of the trenchless techniques, please refer to EN 12889: 2000.

NOTE 5 A more complete and extensive overview is to be found in a publication from the NSTT: 'Sleufloze technieken voor de leiding-infrastructuur' [19].

G.2 Requirements for application of trenchless techniques

G.2.1 Open-front technique (OFT)

G.2.1.1 OFT basics

For jacking through sand embankments, the following options exist (see also Figure G.2):

a) The pipeline is jacked through the sand, whereby the height above the impermeable layer and the permeability of the sand are such that well-point drainage would be able to satisfy the requirement of lowering the water-table level to 0.5 m below the bottom side of the pipe. If the permeability is too low (very fine, silty sand) to satisfy the above requirement, jacking is not allowed.

b) The pipeline is jacked through the sand at a short distance above the non-permeable layer. This and the upswelling of the freatic line between the drainage well points have as a consequence that, even with sufficient permeability of the sand, the requirement given in a) cannot be satisfied at all points. In this case, one can consider for those sections where the groundwater table is too high, to rely on the soil- and water-retaining effect of the particular configuration of funnel, central tube and auger used (see Figure G.3). This is however conditional upon such sections being short. Evn so there is a risk of erosion ,occurring where the jacked pipe passes through the front wall of the jacking and receiving pits.

c) The pipeline is jacked deep below the sand embankment through cohesive layers (for example, clay) provided a more or less impenetrable protective layer of adequate thickness (at least one m) seperates the top of the jacked pipe from the bottom side of the sand formation. The latter protection is necessary to prevent the flow of groundwater and, with it, the transport of soil from the sand formation towards the front of the jacked pipeline. Care shall be taken when performing the geotechnical investigation, to establish wether the sand embankment overlies old ditches filled with sand (bathtub effect), whereby the sealing effect of the separating layer would be lost locally. In this case, the pipe shall be jacked through at a greater depth under the sand formation. If the separating layer is more than 2 m thick, the drainage of the sand embankment to lower the water flow (potential) may be dispensed. Well drainage will cause settling of the road or dike embankments.

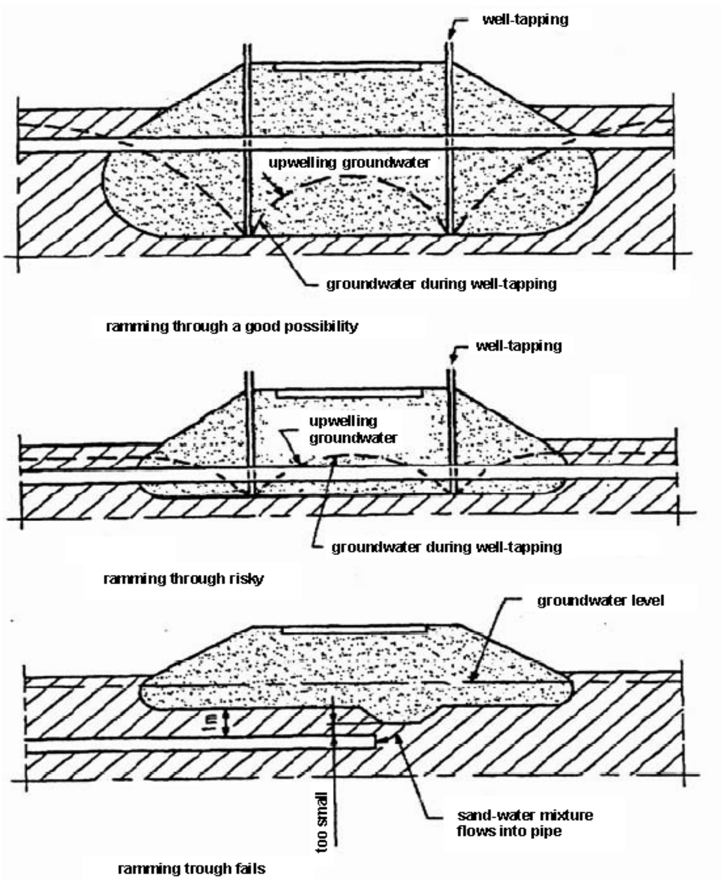

Figure G.2 - Possibilities for jacking through sand embankments

However, to be able to directly intervene in case of emergencies, it is recommended to have a well point drainage system installed. When jacking deep under sandy embankments, it is preferable to work with a large auger without funnel. Peat layers at greater depths are often so firmly structured and sometimes reinforced by tree trunks that even the maximum available jackscrew pressure cannot achieve progress due to the great resiliency of the peat.

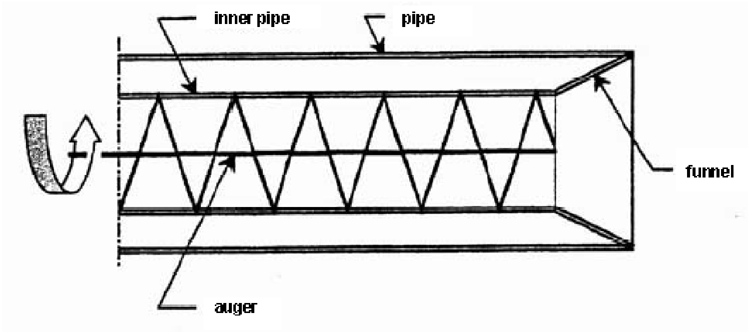

Figure G.3 --- Central tube with funnel and auger

NOTE 1 A large auger without funnel would be employed on the one hand in soil with natural cohesion (clay and peat) and on the other hand in soil with pseudo-cohesion (fine sand held together by capillary stress). It is then preferable not to operate with a plug of material at the pipe front, which can result in jamming from a silo effect, leading to the risk of ground heave. This is prevented by having the auger arranged at the pipe front.

NOTE 2 If groundwater lowering causes undesired settllement installation in an open trench is to be considered.

NOTE 3 When jacking through sand embankements, the danger exists of creating quicksand (especially with fine sand present below the groundwater table).

G.2.1.2 OFT prognosis for jacking

A prediction shall be drawn up, giving the anticipated, maximum jacking pressures required at each stage during the jacking operation.The prediction shall be based on the geotechnical report for the particular crossing

NOTE 1 In determining the profile of maximum required jacking force, it is assumed that the force builds up gradually during the jacking due to the constant average specific soil friction. In practice, this is generally not the case while, after every interruption (of the jacking operation) for making a weld and (possible) coating of the pipe to be jacked, the force required to get everything moving again is greater than what was recorded immediately before the interruption. The actual pressure curve will therefore be more capriciously than the predicted curve (jacking pressure vs. length of jacked pipe).

The goal of the prognosis is to establish maximum limits for the jacking pressure needed in various stages during the operation. The following considerations may apply here:

- the rate of progress of the pipe to be jacked is almost constant and directly proportional to the capacity of the (hydraulic) jacking pump;
- the jacking pressure will automatically match the encountered resistance.

If the rate of progress of the pipe to be jacked is greater than the capacity of the auger to remove the excavated material, front-end pressure can build up, rising to a maximum whenever the auger is not working (plugging).

The occurring front-end pressure cannot exceed the difference between the applied jacking pressure (thrust) and the thrust needed exclusively for overcoming frictional resistance. In view of the risk of soil heave, the front-end pressure shall be limited. For this reason, a prediction is needed for the jacking pressure needed to overcome the frictional resistance only.

NOTE 2 In drawing up the prediction, one should refer to experience already gained in previous jacking operations. Experience has shown that the total applied forces, uniformly distributed over the entire external pipe surface, are independent of the installation depth of the pipe.. The forces seem to vary little with the type of soil.

G.2.1.3 OFT- procedure

Groundwater table

During the jacking operation, the groundwater table shall be lowered by a well point drainage, down to at least 0.5 m below the bottom of the pipe to be jacked.

Jacking pressure

Throughout the jacking operation, the actual jacking pressure shall be continuously measured and recorded. The actual jacking pressure shall not exceed the allowable pressure, which is equal to the prediction pressure.

To facilitate the check, the actual jackig pressure and the permitted pressure are to be plotted on a single graph.

If the allowable pressure is seriously exceeded (more than 10%), than the jacking shall be stopped. The cause of the obstruction of the jacking shall be investigated if possible. Work may be resumed if it is demonstrated that no hazardous situation can arise.

NOTE 1 If pipes are jacked in sands above which traffic passes, the pipe to be jacked can become stuck during a break in the operation due to compaction of the sand from traffic vibrations.

Soil removal

Throughout the jacking operation, the mechanical soil removal shall be performed by a clearance fitting standard auger which is secured against 'drilling ahead of the pipe'.

In large-diameter pipelines, the soil can be removed by hand. In such cases, hazardous situations shall be taken into account, such as:

- break through of a soil-water mixture;
- presence of marsh gas (CH_4 and/or H_2S) when jacking through peat pockets and the danger of gas ignition.

Front-end pressure getting too high can be monitored from by comparing the volume of the soil being removed (allowing for expansion factors) with the volume of the jacked pipe section.

Throughout the jacking operation, the rate of progress of the pipe and the soil removal capacity of the auger shall be matched with each other by properly regulating the rotation rate of the auger.

NOTE 2 If the rotation rate of the auger is too high, there is a risk for subsidence at grade level while too low a rotation rate can cause ground heave. For jacking operations under high-level-drainage-canals, these movements of the water bottom are only observable with settlement beacon.

Cutting edge

During the jacking operation, the jacked pipe shall be provided, on its front side, with a cutting edge that shall not, in general, project outside the pipe circumference.

For roads, this edge may project up to a maximum of 12.5 mm beyond the pipe circumference, since a lubricating tube shall be dragged along; the lubricating tube nipples may not stick out beyond the cutting edge.

Coating

If no casing pipe is used, the (fluid carrying)pipeline shall be provided with a coating that will not be damaged by the jacking process even if rubble or stones are encountered in the soil.

G.2.2 Closed-front technique (CFT)

G.2.2.1 CFT with slurry shield

The closed-front technique with fluid (slurry) shield shall fulfil at least the following requirements:

a) Front-end or slurry pressure

The pressure exerted at the excavation front can be actively controlled by the rate of advance of the jacking operation and the supply rate of the fluid.

The slurry pressure in the drilling chamber shall be able to be kept within predetermined limits in order to prevent cave-in or collapse or conversely soil heave from occurring. (As a minimum pressure could, for example, be established the active intergranular(effective) stress plus pore water pressure plus 0.02 MPa as; a maximuml pressure the neutral effective stress plus pore water pressure) Adequate provisions shall be taken to prevent pressures from getting too high or too low (continuous monitoring, pressure-limiting equipment and alarm set points).

b) Drilling Fluid supply

The supply of drilling fluid shall be adjustable for pressure and flow so as to be able to respond immediately to changing conditions such as changes in the depth of cover, soil type, water pressure, rate of advancement and slurry removal.

c) Stability of the drilling front

It is important, particularly for non-cohesive soil, to ensure that the drilling fluid pressure cannot cause the intergranular (effective)stress to drop. Adding bentonite is necessary for fine-sand formations with uniform grain size in general and for fine-sand formations that are sensitive to settlement fluidization in particular.

d) Soil balance

The soil removal (soil, groundwater and drilling fluid) shall always be in balance with the rate of delivery of drilling fluid and the progress of the jacking operation. Continuous monitoring is demanded.

e) Torque on drilling or cutting head

Changes in the torque on the drilling head reflect changes at the excavation front. A sudden drop in the torque, for example,can indicate that the excavation front has turned to quicksand. Continuous monitoring is necessary.

f) Registration

Continuous registration (over the time and length of pipe jacked) of:

- jacking pressure;
- pressure in the supply line, drilling chamber and discharge line;
- fluid delivery;
- slurry removal;
- drilling or cutting head torque;
- rate of advance.

G.2.2.2 CFT with solid shield and solid soil removal

The closed-front technique with solid shield and solid soil removal shall fulfil at least the following requirements

a) Front-end or slurry pressure

The pressure applied to the excavation front can be actively controlled by the rate of advance of the jacked pipe and the rate of soil-removal via the auger.

The soil pressure in the drilling chamber shall also be able to be kept within determined limits in order to prevent cave-in or collapse or conversely soil heave from occurring. (For minimal pressure and maximal pressure, see G.2.2.1.a)). Adequate provisions shall be taken to prevent pressures from getting too high or too low.

b) Stability of the drilling front

In permeable soils where groundwater is present, additives shall be used with both 'plasticizing' as well as,water sealing properties.

c) Soil balance

See G.2.2.1 d).

d) Torque on drilling or cutting head

See G.2.2.1 e).

e) Torque on auger

Changes in the torque on the auger can indicate changes in the wet soil mixture and therefore possible changes in the sealing effect of the auger. Continuous monitoring is necessary.

f) Registration

Continuous registration (over the time and length of the jacked pipe) of:

- jacking pressure;
- soil pressure;
- rate of additives delivery;
- drilling or cutting head torque;
- auger torque;
- rate of soil removal (auger rotation rate);
- rate of advance.

G.2.2.3 CFT with balanced solid shield and liquid soil removal

The closed-front technique with solid shield and fluid soil removal shall satisfy at least the following requirements:

a) Front-end or soil pressure

The pressure exerted at the excavation front can be actively controlled by the rate of advances of the jacked pipe and the rate of soil removal through the controllable openings into the mixing chamber.

During the jacking operation, equilibrium shall be maintained in the drilling chamber by balancing the advancement rate and the delivery of the dug-out soil particles to the mixing chamber (for minimum and maximum pressures, see G.2.2.1.a)).

b) Fluid delivery

The supply of drilling fluid shall be adjustable for pressure and flow so as to be able to respond immediately to changing conditions such as changes in the soil type, rate of advance, slurry removal, etc.

c) Stability of the drilling front

The drilling front is maintained in equilibrium by maintaining the appropriate rate of advance in combination with the drilling-front support of the bulkhead with its controllable openings behind the drilling chamber.

d) Soil balance

The soil removal rate (soil and groundwater) shall match the rate of advance of the jacked pipe at all times. Continuous monitoring is desired.

e) Torque on drilling or grinding head

Changes in the torque on the drilling or grinding head reflect changes in the soil type at the excavation front. Continuous monitoring is necessary.

f) Registration

Continuous registration (over the time and length of the pipe jacked) of:

- jacking pressure;
- pressure in the supply line, drilling chamber and discharge line;
- rate of slurry removal;
- drilling or grinding head torque;
- rate of advance.

G.2.3 HDD requirements for realization

a) Drilling fluid

It shall be demonstrated that the drilling fluid (bentonite) is sufficiently stable taking the acidity level of the soil and the salinity of the groundwater into consideration.

The drilling fluid shall consist of a mixture of water and bentonite with possible additives.

Directional horizontal drillings using only water as a drilling fluid are not allowed when crossing major public works.

b) Drilling-fluid pressure

The maximum pressure in the drilling fluid during insertion of the pilot string or likewise wash-over pipe or carrier pipeline, may not exceed the predetermined limit , derived in advance on the basis of (soil)investigation (see E.2).

c) Depth of soil cover

Whenever vertical drainage systems (for example, sand columns or plastic drainage pipes) are present, the pipeline shall pass about 2 m below the bottom of the drainage system.

d) Coating

The outside coating of the pipeline shall be resistant to abrasion, especially at welds if these can be seen as a ridge in the surface the coating.

Appendix H
(informative)

Design aspects – Pipeline land routes

H.1 General

All procedures and consultations necessary for the selection and acquisition of the final routes for pipelines can be classified as "Right-of-Way" (RoW) activities.

The RoW activities result in instructions and/or data relative to the design of the pipeline system, such as information regarding crossings of which strength calculations are needed, location classification, permit requirements or stipulations, location determination and situate of pig- launching and receiving stations, valve stations, junction locations, etc.

The RoW activities also produce data regarding required permits and exemptions.

NOTE For pipelines, a concession is generally requested from the Minister of Economic Affairs, which, together with a Declaration of Public Interest provided by the Ministry of Transport and Public Works, is the first step in the right of way proceeding according to the Impediment Laws for Private Rights and Regulations.

H.2 Provisional route determination

The provisional route is to be determined through field studies, study of regional planning, municipal planning, soil maps and historical maps and through consultation with the appropriate Provinces, Municipalities, Regional Water Boards and other authorities and organizations.

The following considerations and aspects can be of importance in determining the provisional route:

- as short a route as possible;
- the appropriate municipal, regional and governemental planning and the Structure Scheme Pipelines;
- distances from houses, buildings and special objects;
- route with minimum risk of affecting the environment as well as the maximum possibility of avoiding sensitive areas (groundwater protection areas, nature reserves, environmental and cultural demands);
- in parcels of meadow and agricultural land, try to follow parcel boundaries as much as possible, to cross waterways as seldom as possible, to disturb drainage systems as little as possible and to cause as little crop damage as possible;
- suitable soil type;
- avoid major crossings (roads, waterways, railroads, dykes, enclosing dykes and the like) and obstacles as much as possible;
- avoid running parallel with high-voltage lines wherever possible and provide sufficient clearance for possible maintenance;
- geotechnical unstable areas, mining areas, mineral winning;
- flooding areas;
- locations for possible blow-off provisions, taking into acount noise restrictions.

NOTE The Provincial Council can point out a provincial pipeline corridor in a regional planning instruction. Such instructions are advisory (regional plans are not automatically binding). These instructions should be taken into account as much as possible when selecting a pipeline route.

H.3 Final route (further elaboration of the route)

As far as not yet completed during the provisional route selection process, final determination is made, in consultation with the appropriate authorities, landowners and land users, for:

- locations for crossings of roads, waterways, groundwater protection areas, etc. and special measures to be taken;
- location of valve stations, launching and receiving stations, etc.;
- distances from other pipelines and their property right corridors, high-voltage cables.

H.4 Permits, exemptions and approvals

For the purpose of installation, owning, operating and maintaining pipeline(s), all necessary permits and exemptions shall be acquired from the appropriate authorities and governemental organizations In the private sector, agreements and approvals have to be attained.

Public permits

Permits and approvals in the public sector can be:

- installation permit from a municipality (mostly in sensitive areas);
- permit for the withdrawal of large quantities of groundwater from well point drainage;
- notice in case of withdrawal of a small quantity of groundwater;
- permit for disposal of water from well-point drainage to surface water;
- disposal permit (quantity and quality of well point drainage water);
- permit for crossing roads, waterways, dykes, railroads, etc.;
- agreement with the land-use authority in case of re-parceling;
- building permit for building structures (such as valve stations, fencing, etc.);
- timber felling permit for felling trees;
- exemption for using secondary roads and/or exit permits when necessary for the work.

Private agreements and approvals

In general, the real estate property right is arranged with the landowner with regard to the installation, use and maintenance of pipelines. In the agreement, the right to a restricted corridor of a determined width (property right corridor) is acceded. The centerline of this corridor is, in principle, the same as the centerline of the pipeline.

With land users and leasers, arrangements should be made with respect to the use of the soil strip for the working corridor necessary for the installation of the pipeline(s).

The note has been deleted.

H.5 Areas with dense underground infrastructure

In (harbour) areas with intense (chemical) industrial activities, restrictive regulations are generally in force in relation to the selection of the route. This is due to the highly dense underground infrastructure and the limited space yet available. In these areas, the pipelines are bundled in pipe corridors and the owner of the corridor will play an important role in the route selection for the new pipelines in order to receive his permission for installing the pipeline.

The procedure can occur as follows:

1) the pipeline to be installed is noticed in writing to the owner declaring, among other things, the purpose of the pipeline, start and end points, the fluid to be transported, design pressure, design temperature, diameter, material and available data;

2) after reception of the request, a provisional route is provided by the owner on the owner's charts;

3) the provisional route is discussed with regard to bottlenecks, program of requirements for crossings, etc.;

4) subsequent negotiations are carried out for setting tighter details and possible arrangements for trial pits, (in order to verify and measure the exact position of nearby or crossing cables and pipelines)

5) under the supervision of the owner or his representative, trial pits are excavated and measured;

6) the route is definitively established on the basis of the results of the trial pits.

H.6 Information to be supplied regarding installation and management

With regard to construction documentation necessary for tendering the project, all relevant data and information concerning RoW matters shall be collected. This includes data concerning the width of the working strip or deviations from the general procedures and stipulations, such as work-corridor limitations, environmental regulations, special fencing, marking procedure, the required clearance from third-party pipelines, etc.

With regard to installation and operation, important regulations, data and information shall be collected. This includes, among other things:

- special permit requirements;
- contact persons, certified inspection institutions;
- RoW data with regard to land users;
- water disposal regulations, etc.

Appendix I
(informative)

Design aspects – Field data

I.1 Land-use study

The land-use study comprises the collection of data (research, documentation and fieldwork) and reporting with regard to soil-science, water-management and agricultural aspects along the pipeline route.

These data are to be used to limit damage as much as possible to agricultural and land-use aspects resulting from the installation of the pipeline.

The report contains a description of the soil composition along the entire pipeline route and specifies preconditions and recommendations for prescribed working methods and/or precautions specific to the project or area. The risk of buoyancy of the pipeline and measures to prevent this are also considered in the land-use report.

The land-use report constitutes, in general, an integral part of the pipeline plan.

I.2 Geohydrologic study

The geohydrologic study consists of collecting data on geologic, geohydrologic and water-management aspects along the pipeline route.

The study comprises:

- study of available documentation (geohydrologic, geologic and geotechnical charts, groundwater and contour-line maps, etc.);
- fieldwork along the route;
- laboratory research;
- calculating the effects of permeable trench backfilling and drainage, including well-point drainage;
- reporting.

The geohydrologic report specifies the deeper soil composition and groundwater-management aspects along the entire route and can serve as an appendix when applying for various permits for groundwater withdrawal and groundwater disposal.

Whoever is to realize the work bases a drainage plan for the entire route on this study with specifics for each crossing, each facility and each pipeline section.

NOTE The fieldwork and reporting for the land-use and geohydrologic studies are often combined.

I.3 Environmental study

An assessment of the environmental consequences of installing the pipeline (see also 6.4) should cover at minimum:

- working methods for installation, repair and modifications of the pipeline;
- the long-term presence of the pipeline;
- evaluation of all the consequences of a possible product spill and the measures to be taken, both preventative and repressive.

I.4 Historical study

It is recommended that one should be concerned about possible sub grade obstacles while developing the route. This means objects and foundations (such as bridgeheads, sluice walls, sheet piling walls, foundation piles, rubble, foundations of retaining walls or city walls, etc.) that are left behind after the obstacle above grade level has been removed.

An important aspect of the historical study is a search for areas with polluted soil in the (provisional) route. The cost of removal of the soil can be a reason for considering changing the route.

Likewise, it shall be stated that no valuable archeological and historical-cultural area should be passed without permission from the owner and the appropriate authorities.

NOTE Community archives, old topographical maps, (infrared) photos, radar images, SLAR (sideways looking airborne radar) and other "remote sensing" methods and interviewing local (older) residents can be of great help in the historical study.

I.5 Geo-technical investigation

I.5.1 General

The primary purpose of carrying out the geotechnical investigation is to determine the structure, composition and important characteristics of the (sub)soil lstrata present in the planned route.

The choice of the type of study and its scope depends on many factors. Familiarity with local soil conditions plays an important role here. This will also have a major influence on the way the pipeline is installed.

The optimal approach to the geotechnical study is to first perform a preliminary study and thereafter organize a definitive study based on this preliminary study.

I.5.2 Preliminary study

Research the existing geotechnical information based on:

- geological charts;
- results of previously performed geotechnical studies (archives of the geotechnical consultant);
- ground water levels and maximum levels of groundwater in permeable layers (`The words within the parentheses have been deleted`).

Establish a general picture of the subsoil and outline the definitive geotechnical study, based on the results of the preliminary study.

I.5.3 Definitive geotechnical investigation

The soil study comprises:

- site investigations;
- laboratory testing and advise.

In the Netherlands, cone penetration testing is frequently applied. Dependent of the soil composition found with the cone penetration tests, soil borings are carried out in addition. Also in addition, the groundwater table can be determined with, for example, sounding tubes.

For CFT and HDD drilling projects,it is necessary to locate investigation points away from the drilling route in order to prevent eruptions of drilling fluid in a later stage. A minimum distance of 5 m from the CFT or HDD drilling route shall be maintained.

The soil samples taken with the borings are to undergo closer investigation in a laboratory. Various characteristics of the soil layer under consideration can be determined from tests on these soil samples.

The site investigation with cone penetration tests and borings provide soil data for a limited number of points along the pipeline route.. If more knowledge is needed on the profile of subsoil layers between the investigation points, use can be made of geophysical soil-survey methods (e.g., geo-electric or electromagnetic survey or survey with ground radar). Using these methods in combination with cone penetration tests and borings can provide a continuous profile of the subsoil.

The geotechnical investigation to be carried out for HDD and for pipeline jacking comprises:

HDD

Field study

The study consists of cone penetration tests and borings with samples being taken.

The interval between investigation points needs to be determined for each project. In each case, a cone penetration test shall be carried out on each side of the object to be crossed. Also, at the entry and exit points of the drilling or boring a cone penetration test should be made.

The depth of the cone penetration tests and borings should be such that, over the length of the drilling, the profile and composition of the soil layers are known down to a depth of 5 m below the borehole. Soil samples should be taken from layers relevant to the drilling for closer laboratory investigation.

In case HDD drilling is to be done through permeable sand layers it is of great importance to know groundwater table levels and groundwater potential in aquifers, in detail if. Whenever insufficient account is taken of the prevailing groundwater pressure in these layers, it can lead to cave-in of the bore hole and cause the pipeline to jam when inserted. It is necessary to locate a water level gauge tube in the relevant permeable layer. The water level in the tube shall be monitored at regular intervals.

Laboratory testing

At a minimum, the following tests should be performed on the soil samples:

- determine weight per unit volume;
- grain size distribution of the sand and gravel layers crossing the drilling profile;
- determine the undrained shear strength of the clay layers crossing the drilling profile.

The grain size distribution in particular is extremely important. The probability of success of this drilling method is partly dependent on the presence of gravel.

Pipe jacking

Site investigation

A cone penetration test should be made and a boring with soil sampling for laboratory testing is required, up to some distance beyond the confines of the jacking and receiving pits. The geotechnical investigation for the pits shall extend to sufficient depth; in case sheet piling is applied, up to at least 2.5 times the excavation depth of the pit.

Cone penetration tests and borings are needed to understand the profile and properties of the subsoil layers between the jacking and receiving pits. The investigation shall reach to a depth of about 3 m below the pipe bottom . The interval between the investigation points depends on the already available information and the anticipated variation in the subsoil. The investigation locations should be situated at least 5 m away from the drilling route.

Information on groundwater table levels and groundwater potential in deeper acquifers is of great importance. This information can be obtained from water level gauge tubes and regular readings.

Laboratory testing

Information on the grain size distribution of the sandy layers is necessary both for the design of possible drainage as well as for realization of the pipeline jacking. A representative grain size distribution per layer shall be established.

In order to determine the required soil-mechanical parameters for sheet piling and pipeline calculations, data for the weight per unit volume of the various soil layers and for the stiffness and shear strength of the soil is needed. It is recommended that a sufficient number of mass per unit volume tests and triaxial tests be performed.

I.5.4 Geotechnical report

The geotechnical report to be issued, must cover specific to each drilling method:

HDD

a) Description of the soil type encountered.

- One shall be able to infer from this description to what extent the soil structure encountered poses a risk for the drilling process (e.g., presence of gravel, extremely soft soil layers, etc.).

b) Information on groundwater tables and groundwater potential in sand aquifers.

c) Soil-mechanical parameters for a possible strength calculation of the pipeline.

d) Calculation of maximum allowable drilling-fluid pressure.

- This pressure is dependent on the diameter of the bore hole, the depth of the bore hole and the strength characteristics of the soil. For a bore hole at large depth, an analytical calculating method can be used (see I.2) based on the space(volumetric?) -expansion theory. A limit is set on the extent of the plastic zone around the bore hole and thereby the resulting deformation of the bore hole so that no appreciable cracks can form. For cohesive soil layers, an extra assessment is needed on the limit pressure (the pressure at which a theoretical, infinitely large plastic zone appears). The permissible pressure then follows as a factor (0.9) times the limit pressure.

- For a bore hole at a depth less than five times the bore hole diameter, other failure mechanisms may become critical and another calculation method shall be employed. More precision can be achieved by using FEM (finit element method).

e) Calculating minimum required drilling-fluid pressures.

--- In order to perform the horizontal directional drilling, a minimum drilling-fluid pressure needs to be achieved in the bore hole. This pressure is required to carry off the drilled-out soil and to maintain the bore hole. The design of the drilling (its depth) needs to be such that the minimum required pressure is less then the maximum allowable pressure. The minimum required drilling pressure is, among other things, dependent on the bore hole length, the bore hole diameter and the characteristics of the drilling fluid.

--- The pilot drilling, in most cases, represents the critical situation for the design. For reaming and pulling in of the pipeline, the required pressure is lower due to a larger bore hole diameter and because the drilling fluid can flow in two directions.

--- The minimum required pressure in the bore hole is determined by the static water pressure (depth) and the pressure required to get the return flow going.

f) Study of possible seepage along the drilled pipeline.

--- If the drilling is made through a non-permeable, non-permeable layer with over-pressurized groundwater below it, a seepage -path can result. The existent groundwater flow pattern is not to be disturbed by the installation and presence of the pipeline. Natural seepage shall not be augmented by seepage along the pipeline. This should be counted for during the drilling procedure by selecting the appropriate density of the drilling fluid.

--- The water level in the trench generally is lowered while making the connections to the abutting field sections. The pressure difference over the length of the bore hole therefore increases. This can cause seepage to occur. In some cases, a temporary well point drainage to lower the ground water potential at the crossing is required. Also the possible extent of long term seepage along the pipeline shall be investigated . It shall be checked whether at either the entry or the exit point a potential seepage route along the pipeline is longer than the natural seepage route and that no "piping" can occur.

g) Impact of the drilling process on the environment.

--- The pressure in the drilling fluid shows large variations during the drilling process. The minimum pressure here is equal to the static pressure of the current drilling-fluid column. The maximum occurring pressure is strongly dependent on the drilling process.

--- Earth pressures around the bore hole will change due to the drilling process. Changes in the earth pressures will give rise to deformations of the soil around the bore hole.

--- Near the entry and exit points of the drilling, the bore hole can become unstable from an insufficient arching effect. This manifests itself in subsidence at grade level. The length over which this subsidence occurs depends on the entry or exit angle of the drilling and the diameter of the bore hole in relation to its depth.

--- Grade-level subsidence can also occur if, at greater depths, for example in case of drilling problems, an oversized bore hole is made related to the pipeline.

--- In addition to grade-level subsidence, heave of the grade level can also occur, for example if the bore hole pressure is too great. In this case, expansion of the bore hole or escape of drilling fluid can occur. This may especially cause problems at shallow pipe depths. It is known that peat layers near the entry and exit points are sensitive to heave.

--- If deformations of the grade level are anticipated, this also means that buildings with foundations on soil close to the drilling route can be adversely influenced. Deformations around the bore hole may affect structures at the same depth, such as foundation piles.

--- Foundation piles in the vicinity of the pipeline shall not experience any negative effect from the occurring ground deformations and the pile bearing capacity shall not be affected. Drilling fluid shall be prevented from reaching the lower end of the pile or along the shaft and no relaxation of the soil stress is to occur around the pile.

--- The influence zone of the pile extends to four times the pile diameter below and next to the pile. The zone of plastic soil deformation around the bore hole shall therefore remain outside this area so as to prevent damage to the pile foundation. When setting a limit to the plastic zone in these locations, the calculated maximum allowable drilling-fluid pressure shall also be correspondingly adjusted.

Pipeline jacking operation

a) Description of the prevailing soil type.

b) Information on groundwater tables and groundwater potentials in aquifers.

c) Soil-mechanical parameters (including settlements prediction) for a possible strength calculation of the pipeline.

d) Soil-mechanical parameters for possible sheet piling calculations.

e) Influence of the drilling on the environment.

--- This influence is strongly dependent on the jacking process. With respect to deformations in the subsoil, it is primarily the amount of over-cutting by the drilling front and the magnitude of the earth support pressure that are important.

Appendix J
(informative)

Pipeline Systems and European Machine Directive 98/37/EG

J.1 General

Attention shall be paid to the European Machine Directive [33] and other safety legislation when building pipeline systems, including their stations, in connection with rotating components (shutoff/actuator combinations, safety valves, pumps, compressor units and the like).

J.2 Points of consideration for certain situations

J.2.1 New construction

For a new construction, attention needs be paid to the following aspects:

1) design and construction carried out in conformity with the fundamental requirements of Appendix I from the Machine Directive, the appropriate recognized standards and proper building and construction applications;

2) performing a HAZOP or risk analysis (e.g., according to NEN-EN 1050:1997 [45]);

3) verification of essential points of safety with regard to the basic design, detailed design and all construction. For verification items, see J.3;

4) components of the station or installations that can be operated as independent machines and have been built in, are given a CE label and come with an 'EG conformity certificate for machines' (sometimes also called a II A certificate), API label or equal;

5) components of the station or installations that cannot work as independent machines and are built in, come with a II B certificate along with a copy of the construction file;

6) safety components sold separately on the market have a II C certificate and a copy of the file;

7) the operating manuals and maintenance instructions are provided in Hebrew or English;

8) verification of worker safety is performed in a common inspection (designer, builder, user and inspection agency) before handover (stairways, landings, control apparatuses, meter readouts, escape routes, etc.);

9) adequate training of personnel and users (a requirement of the Safety Order);

10) granting of a 'agreement for operation' by an inspection service (internal and/or external) before the start of operations;

11) project handover by the designer and builder to the user during startup;

12) warranty period in which defects observed during use are solved by the designer and builder.

NOTE The installation or station, considered as a combination of components, is not provided with a CE label as a whole (no CE sign on the fence).

J.2.2 Expanding existing station or installation

For an extension of an existing station or installation, the following aspects apply:

1) the extension conforms to the aspects given under J.2.1;

2) the existing parts are not checked if a certifiable inspection regime has been previously maintained, is present at site and the alterations exert no influence on the existing parts;

3) the HAZOP or risk analysis is performed for the entirety (existing + expansion);

4) if the operating parameters are changed, the design of an existing part is also checked (to the extent that it is influenced by the operating parameters).

J.2.3 Machine alteration and/or modification

An alteration is referred to as fundamental if the alterations on the machine fall outside factory specifications and/or new hazards arise:

1) the alterations are handled in conformity with the aspects given under J.2.1 and conform to NEN-EN 1050:1997 [45];

2) after the points under J.3 have been dealt with, the CE certificate should be modified. The original CE label remains unchanged.

NOTE In the case of new machines (or ones that are considered as such after modifications and/or alteration), the employer bears the responsibility for obtaining a CE label for the machine. Machines already in use (from before the Machine Guidelines were passed) should satisfy the Work Implements Guideline, including amendments (95/63/EG) [36].

J.2.4 Self-developed or modified machines

Self-developed and/or modified machines fall under the Machine Guideline. In that case, the owner of the machine is also the manufacturer.

J.2.5 Replacement with new components

The following aspects apply for replacing with new components:

1) components that can work as independent machines have a CE label and come with a II A certificate;

2) components that cannot work as independent machines come with an 'EG certificate from the manufacturer or authorized deputy' (sometimes also called a II B certificate) with a copy of the construction file;

3) safety components have a II C certificate and a copy of the file;

4) the use of components, whether OEM or not, for repair or maintenance, of itself, not relevant for the CE labeling of the affected machines, is a matter of whether new hazards are introduced;

5) old, identical reserve components (from before the Machine Guidelines were passed) may be used if the entirety remains within factory specifications;

6) if components are changed because the operating parameters have been altered, a new HAZOP or risk analysis is performed and the project is checked along with the installation of the component in question.

J.2.6 Second-hand machines

Used machines from before the Machine Directive were passed that are again placed on the market require no CE label (but do have to satisfy all other relevant legislation and regulations).

J.2.7 Valid CE markings

The owner, operator or employer is responsible for maintaining a valid CE label on the machine.

J.3 Verification

J.3.1 Verification with respect to Machine Directive

Verification of the essential items regarding safety relative to basic design, detailed design and construction involves:

- choice of process and substances;
- operational management during expansion, renovation and new construction;
- external safety;
- mutual influences from high-tension connections;
- zoning;
- gas-detection systems;
- acoustic and optical signals;
- fire-detection and extinguishing systems, extinguishing equipment, shielding equipment, EHBO, escape routes;
- storage of substances and chemicals;
- hoisting and lifting equipment (list in appendix A of NEN-EN 1050:1997[45]);
- emergency-stop measures;
- grounding, lightning protection and inductive influences;
- safe placement of tapping and filling points;
- exposure to hazardous materials;
- HAZOP and risk analyses;
- assessing layout with respect to safety distances;
- removal of chemical spills;
- ergonomics;
- closed spaces;
- installation-safety and environmental plan;
- worker safety (including noise and electrical and high-temperature touch hazards);
- safety from explosions;
- integrity of basic design;
- integrity of detailed design;
- electrical safety;
- radiation shielding;

- connections, including welds;
- pressure controls and setting of pressure safety system;
- materials;
- non-destructive tests;
- tests;
- maintenance manuals;
- operating instructions.

J.3.2 Construction file

The construction file should contain at least the following:

a) general diagram and operating circuits;

b) drawings and possible calculations;

c) list with materiel, standards and specifications;

d) certificates and test reports;

e) operating manual, instructions and audits;

f) maintenance manual, instructions and audits.

Such a file should be able to be drawn up and made available within a reasonable period of time. With respect to the content of the construction file, the following clarifications can be given:

- the manufacturer or deliverer should keep the entire technical construction file available for 10 years. After which the technical construction file should be handed over to the user;
- for a): Use of the design and process diagrams should be appropriate for obtaining necessary safety information;
- for b), c) and d): It might be wise, as user, to have certain parts readily available partly dependent on the complexity of the machines or installation. When purchasing, it is recommended that the order specify that delivery is to be made in conformity with the Machine Directive [33] relative to adherence to documentation requirements. This is particularly important outside of the EU. It is likewise recommended that ordering data (datasheet and performance requirements) be kept.
- for e) and f): In addition to having the operating and maintenance manuals, it is important that personnel receive instructions and that an account is kept of performed audits.

NOTE The verification file can also serve as construction file. The list with verification points serves as 'product control chart'. After a verification points has been performed, this is noted on the list and it is indicated where information is available.

Appendix K
(informative)

Scope of Pressure Equipment Directive

The Pressure Equipment Directive comprise:

- (the national implementation of pressure-equipment guidelines) Pressure Equipment Directive (PED) [34];
- Alteration Pressure Equipment Directive concerning manufacture and first use (Alteration Directive 1);
- Alteration Pressure Equipment Directive concerning the operation phase (Alteration Directive 2).

Pressure Equipment Directives are applicable to pressure equipment and pipelines (“piping”)with pressure > 0.05 MPa at stations. Transportation pipelines do not fall under the scope of the Directives.

The Directives essentially comprise safety requirements that shall be satisfied and set inspection requirements.

Based on a grouping by substance (Group I and II) and pressure x volume or else pressure x diameter, a category is assigned. One distinguishes five categories (0, I, II, III and IV). The category assignment gives a possible inspection module. There are, in total, 13 distinct modules, namely A, A1, B, B1, C1, D, D1, E, E1, F, G, H and H1. From module A1 on, there is an obligation to make use of an inspection agency. This inspection agency can be an Accredited inspection institution ("Notified Body") or an Accredited Users Self-Inspection Service.

Pressure equipment (such as pressure vessels, valves, metering boxes) are required under the Decrees for Pressure Apparatus to be delivered with a CE label and an ‘EG certificate of conformity' or 'EG certificate of type/design inspection'.

If the inspection is performed by an Certified Users Self-Inspection Service, no CE label is given.

NOTE With regard to the pressure specifications for pressure equipment, including safety devices and piping, note should be taken of the definition differences between the Pressure Equipment Directive and this standard for, among others: design pressure, operating pressure and incidental pressure.

For pressure equipment and piping under Alterations Directive 1, the inspection agency, in addition to the above named certificates, is to also provide a 'Certificate of suitability for use' before the pressure equipment and piping is put into service.

For pressure equipment and pipeline under Alteration Directive2, periodic inspection is indicated according to the Rules for Pressure Vessels [37], specifically according to clause T 0102 (Periodic Reassessment).

Appendix L

(informative)

Inspection Plan

Table L.1 includes proposed inspection points for the construction phase of the pipeline project. The parties involved may use this table as a basis for the inspection plan

Table L.1 – Guidelines for Inspection Plan (Informative)

Activity	Inspection performed by		
	Contractor	Pipeline owner	Third party
Typical pipeline			
Procurement phase			
Procure materials to defined specifications		x	x
Quality management - QA/QC			
Prepare and approve inspection and test plan	x	x	x
Meetings, Audits and Inspections	x	x	x
Material QA /QC	x	x	x
Pipeline Construction phase			
Open Cut trenching / Reinstatement			
Mobilise site	x		
Prepare material lay down areas	x		
Receive and stockpile pipe and materials	x	x	x
Set out pipeline route and right of way (ROW)	x	x	
Set out special crossings	x	x	
Fence off ROW, access and working areas	x	x	
Trial hole to locate services	x		
Top soil strip access and working areas	x		
String out pipe along ROW	x	x	
Welding	x	x	x
Radiography and NDT	x	x	x
Coat and wrap	x	x	x
Holiday inspection	x	x	x
Trenching operations	x	x	
Ditching operations	x	x	
Fine fill surround	x	x	
Backfill / land drainage	x	x	
Reinstate and pull out	x	x	
Special Crossings			
Fabrication of special crossings	x	x	x
Radiography and NDT	x	x	x
Coat and wrap	x	x	x
Holiday inspection	x	x	x
Trenching operations	x	x	
Ditching operations	x	x	
Fine fill surround	x	x	
Backfill / land drainage	x	x	
Reinstate and pull out	x	x	

Activity	Inspection performed by		
	Contractor	Pipeline owner	Third party
Trenchless Crossings (HDD) per site			
Mobilise launch and receive sites	x	x	
Install mud return line	x	x	
Pilot drill operations	x	x	x
Back reaming operations	x	x	x
Barrel reaming operations	x	x	x
Welding Radiography and NDT	x	x	x
Coat and wrap	x	x	x
Holiday inspection	x	x	x
Pre installation Hydrostatic test	x	x	x
Weld / NDT pull head and swivel	x	x	x
Pull back (installation) operations	x	x	
Remove mud return line	x	x	
Demobilise launch and receive sites	x	x	
Hydrotesting Period			
Pre test review and audit	x	x	x
Fill test sections	x	x	x
Hydro test	x	x	x
Dewater	x	x	x
Dry	x	x	x
Pre commission and handover	x	x	x
Cathodic Protection			
TR / Groundbed installation	x	x	
Marker posts	x		
Commission CP system	x	x	x
CIPPS / Pearson Survey	x	x	
As build / Records stage			
Prepare As built and handover documentation package	x	x	x
Typical PRMS Program			
Procure Materials	x	x	x
Materials On Site	x	x	x
Pre-Qualify Designers And Contractors		x	x
Prepare Tender Documentation		x	x
Submission Review Period		x	
Contamination Survey	x	x	
Award Consultancy Contract	x	x	
Review Risk Ass. & Method State.	x	x	x
Ground Contamination Survey	x	x	
Lab Results	x		
Contamination Report	x	x	
Land Survey	x		
Ground Investigation Survey	x		
Background Noise Survey	x		
Award Consultancy Contract	x	x	
Background Noise Survey Report	x	x	
Third Party Consultations		x	x
Equipment Details From Suppliers	x	x	
Select Equipment For Use	x	x	
Procurement Period			
Prepare and approve Inspection and Test Plan	x	x	x
Procure Materials	x	x	

Activity	Inspection performed by		
	Contractor	Pipeline owner	Third party
Construction Period			
Mobilise And Set Up Site Office Establishment	x	x	
Prepare Laydown Area	x	x	
Receive Material Deliveries	x	x	x
Civil Works	x	x	
Set Out Site	x		
Top Soil Strip	x	x	
Construct Fencing and Access / Emergency Gates	x		
Install Site Drainage System and Silt Traps	x		
Set Out Locations For Concrete Pours	x		
Prepare Falsework / Formwork For Pours	x		
Pour Concrete	x	x	x
Curing Period / Cube Tests	x	x	
Excavation For Pipe and Ducts	x	x	
Install Ductwork	x		
Mechanical Works	x		
Shop Mechanical Works	x	x	x
Pipe Spool Fabrication and Welding	x	x	x
Radiography and NDT	x	x	x
Fill and Hydrotest	x	x	x
Dewater and Dry	x	x	x
Coating / Painting	x	x	
Holiday Inspection	x	x	x
Transport to Site	x		
Site Mechanical Works	x	x	
Install Skid Mounted Equipment	x	x	x
Site Fabrication And Welding	x	x	x
Radiography and NDT	x	x	x
Coating / Painting	x	x	x
Holiday Inspection	x	x	x
Install Pipe Supports	x	x	x
Fit Instrumentation	x	x	x
Instrumentation Piping	x	x	x
C, E & I Works	x	x	
Electrical Power Supplies	x	x	
Cable Tray / Duct Work	x	x	
Install / Connect Instrumentation	x	x	
Install Flow Computer / Peripherals	x	x	
Scada / Communications Installations	x	x	
Install Site Lighting	x		
Loop Checks / Site Acceptance Tests	x	x	x
Testing And Drying	x	x	x
Pre-Test Review and Audit	x	x	x
Establish Test Limits	x	x	x
Fill Test Sections	x	x	x
Hydro Test	x	x	x
Dewater	x	x	
Vacuum / Desiccant Dry	x	x	x
Instrumentation Pipework Pneumatic Leak Tests	x	x	x
Pre Commission	x	x	x

Activity	Inspection performed by		
	Contractor	Pipeline owner	Third party
Site Finishes	x	x	
Backfill Excavations	x		
Lay Access Roads	x	x	
Lay Pathways	x	x	
Touch Up Painting	x		
Planting / Screening / Bunding	x	x	

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