

PD 8010-1:2015+A1:2016



BSI Standards Publication

PUBLISHED DOCUMENT

Pipeline systems –

Part 1: Steel pipelines on land –
Code of practice

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Summary of pages

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Foreword

Publishing information

This part of PD 8010 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 March 2015. It was prepared by Subcommittee PSE/17/2, *Pipeline transportation systems*, under the authority of Technical Committee PSE/17, *Materials and equipment for petroleum*. A list of organizations represented on these committees can be obtained on request to their secretary.

Supersession

This part of PD 8010 supersedes PD 8010-1:2015, which is withdrawn.

Relationship with other publications

The PD 8010 series comprises:

- Part 1: *Steel pipelines on land – Code of practice*;
- Part 2: *Subsea pipelines – Code of practice*;
- Part 3: *Steel pipelines on land – Guide to the application of pipeline risk assessment to proposed developments in the vicinity of major accident hazard pipelines containing flammables – Supplement to PD 8010-1:2004*;
- Part 4: *Steel pipelines on land and subsea pipelines – Code of practice for integrity management*;
- Part 5: *Subsea pipelines – Guide to operational practice*.

This part of PD 8010 has been prepared to take into account the publication of BS EN 14161, which is based on ISO 13623. It provides a more comprehensive approach and covers a number of issues that are outside the scope of BS EN 14161.

This part of PD 8010 takes into account the publication of BS EN 1594 and IGEM/TD/1 Edition 5:2012.

BS EN 1594 and BS EN 12007 contain requirements for gas supply systems operating above and below 1.6 N/mm² (16 bar) respectively.

BS EN 13480-3 and BS ISO 15649, which incorporates ASME B31.3 by normative reference, give design stresses and guidelines for pipe materials required to operate outside the temperature range –25 °C to +120 °C, and for pipelines routed above ground on supports, racks and bridges. BS ISO 15649 also contains requirements for buried piping.

Information about this document

The start and finish of text introduced or altered by Amendment No. 1 is indicated in the text by tags **A1** and **A1**. Minor editorial changes are not tagged. Previous amendments are not indicated.

PD 8010-1:2015 was a full revision of the standard, and introduced the following principal changes:

- general updating of the text to take into account new standards and legislation introduced since the 2004 edition;
- update of the guidance for pipelines carrying carbon dioxide;
- update of the guidance on HIPPS, strain based design, fracture and fatigue.

This part of PD 8010 is intended for use by designers, manufacturers, operators and owners of pipelines. Clause 4 deals with health, safety and assurance and is relevant to all users of this document. Clause 5 to Clause 9 are mainly of relevance to designers. Clause 10 and Clause 11 are mainly of relevance to constructors. Clause 12 might be of relevance to both constructors and operators. Clause 13 and Clause 14 are mainly of relevance to operators.

The guidance given in this part of PD 8010 on the design of pipelines for the transmission of dry natural gas is based on the philosophy and guidance contained in the Institution of Gas Engineers and Managers' recommendations for transmission and distribution practice (IGEM/TD series). The IGEM's guidance is applicable to first, second and third family gases as defined in BS EN 437 provided the impact on design, material, operations and maintenance is taken into account. The 2012 revision of IGEM/TD/1 gives requirements for the transmission of dry natural gas (predominantly methane), at a maximum allowable operating pressure (MAOP) not exceeding 10 N/mm² (100 bar) at temperatures between a range of -25 °C and +120 °C inclusive. The scope of IGEM/TD/1 may be extended beyond 10 N/mm² (100 bar), but specific areas will require further justification and documentation that embraces a safety evaluation.

For pipelines laid on land which cross inland waterways experiencing extreme hydraulic conditions, PD 8010-2 might provide better guidance.

The International System of Units (SI) (see BS EN ISO 80000-1) is followed in this part of PD 8010, except for units of pressure where the bar equivalent is provided for information.

NOTE 1 bar = 10⁵ N/m² = 10⁵ Pa. All references to pressure are gauge pressure, unless otherwise stated.

Hazard warnings

WARNING. This part of PD 8010 calls for the use of substances and/or procedures that can be injurious to health if adequate precautions are not taken. It refers only to technical suitability and does not absolve the user from legal obligations relating to health and safety at any stage.

Use of this document

As a code of practice, this part of PD 8010 takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Any user claiming compliance with this part of PD 8010 is expected to be able to justify any course of action that deviates from its recommendations.

It has been assumed in the drafting of this Published Document that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

Presentational conventions

The provisions of this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is "should".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Where words have alternative spellings, the preferred spelling of the Shorter Oxford English Dictionary is used (e.g. "organization" rather than "organisation").

Contractual and legal considerations

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

Compliance with a Published Document cannot confer immunity from legal obligations.

Particular attention is drawn to the following specific regulations:

- Construction (Design and Management) Regulations 2007 [1];
- Deregulation (Pipe-lines) Order 1999 [2];
- Electricity and Pipe-lines Works (Assessment of Environmental Effects) Regulations 1990 and subsequent amendments [3];
- Environmental Protection Act 1990 [4];
- Factories Act 1961 [5];
- Factories Act (Northern Ireland) 1965 [6];
- Gas Act 1995 [7];
- Gas Safety (Management) Regulations 1996 [8];
- Health and Safety at Work, etc. Act 1974 [9];
- Health and Safety at Work (Northern Ireland) Order 1978 [10];
- Oil and Pipelines Act 1985 [11];
- Petroleum Act 1998 [12];
- Pipe-line Works (Environmental Impact Assessment) Regulations 2000 [13];
- Pipe-lines Act 1962 [14];
- Pipelines Safety Regulations 1996 [15];
- Pipelines Safety Regulations (Northern Ireland) 1997 [16];
- Pipelines Safety (Amendment) Regulations 2007 [17];
- Planning Act 2008 [18];
- Pressure Equipment Regulations 1999 [19];
- Pressure Systems Safety Regulations 2000 [20];
- Town and Country Planning Act 1990 [21] in respect of planning permission for local pipelines.

Attention is also drawn to guidance notes published by appropriate authorities. For planning applications, consent and environmental regulations, it might be necessary to refer to local/regional authorities, e.g. Northern Ireland, Scotland, Wales, etc.

1 Scope

This part of PD 8010 gives recommendations for and guidance on the design, selection, specification and use of materials, routeing, land acquisition, construction, installation, testing, operation, maintenance and abandonment of land pipeline systems constructed from steel. The principles of this part of PD 8010 apply to new pipelines and major modifications to existing pipelines. It is not intended to replace or duplicate hydraulic, mechanical or structural design manuals.

This part of PD 8010 is applicable to pipelines intended for the conveyance of oil, gas, carbon dioxide and other substances that are hazardous by nature of being explosive, flammable, toxic, reactive, or liable to cause harm to persons or to the environment. It covers pipelines operating at temperatures between a range of $-25\text{ }^{\circ}\text{C}$ and $+120\text{ }^{\circ}\text{C}$ inclusive.

The extent of pipeline systems covered by this part of PD 8010 is shown in Figure 1.

NOTE Annex A shows the full range of onshore oil and gas pipeline systems covered by this part of PD 8010.

This part of PD 8010 does not give recommendations for subsea pipelines, which are covered in PD 8010-2.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Standards publications

ASME B16.5, *Pipe flanges and flanged fittings*¹⁾

ASME B16.9, *Factory-made wrought steel butt welding fittings*

ASME B16.11, *Forged fittings, socket-welding and threaded*

ASME B16.20, *Metallic gaskets for pipe flanges – Ring joint spiral wound and jacketed*

ASME B16.21, *Nonmetallic flat gaskets for pipes flanges*

ASME B16.47, *Large diameter steel flanges*

ASME B31.3, *Chemical plant and petroleum refinery piping – Process piping*

ASME B31.8, *Chemical plant and petroleum refinery piping – Gas transmission and distribution piping systems*

ASME BPVC-VIII-1, *Boiler and pressure vessels code – Section VIII, Division 1: Rules for construction of pressure vessels – Design and fabrication of pressure vessels*

ASTM A193/A193M 12b, *Standard specification for alloy-steel and stainless steel bolting for high temperature or high pressure service and other special purpose applications*

ASTM A194/A194M 13, *Specification for carbon and alloy steel nuts for bolts for high-pressure or high-temperature service, or both*

¹⁾ American Society of Mechanical Engineers (ASME) standards are available from BSI Customer Services, Tel: +44 (845 0860) 9001.

Figure 1 Extent of pipeline systems that are covered by this part of PD 8010 (1 of 2)

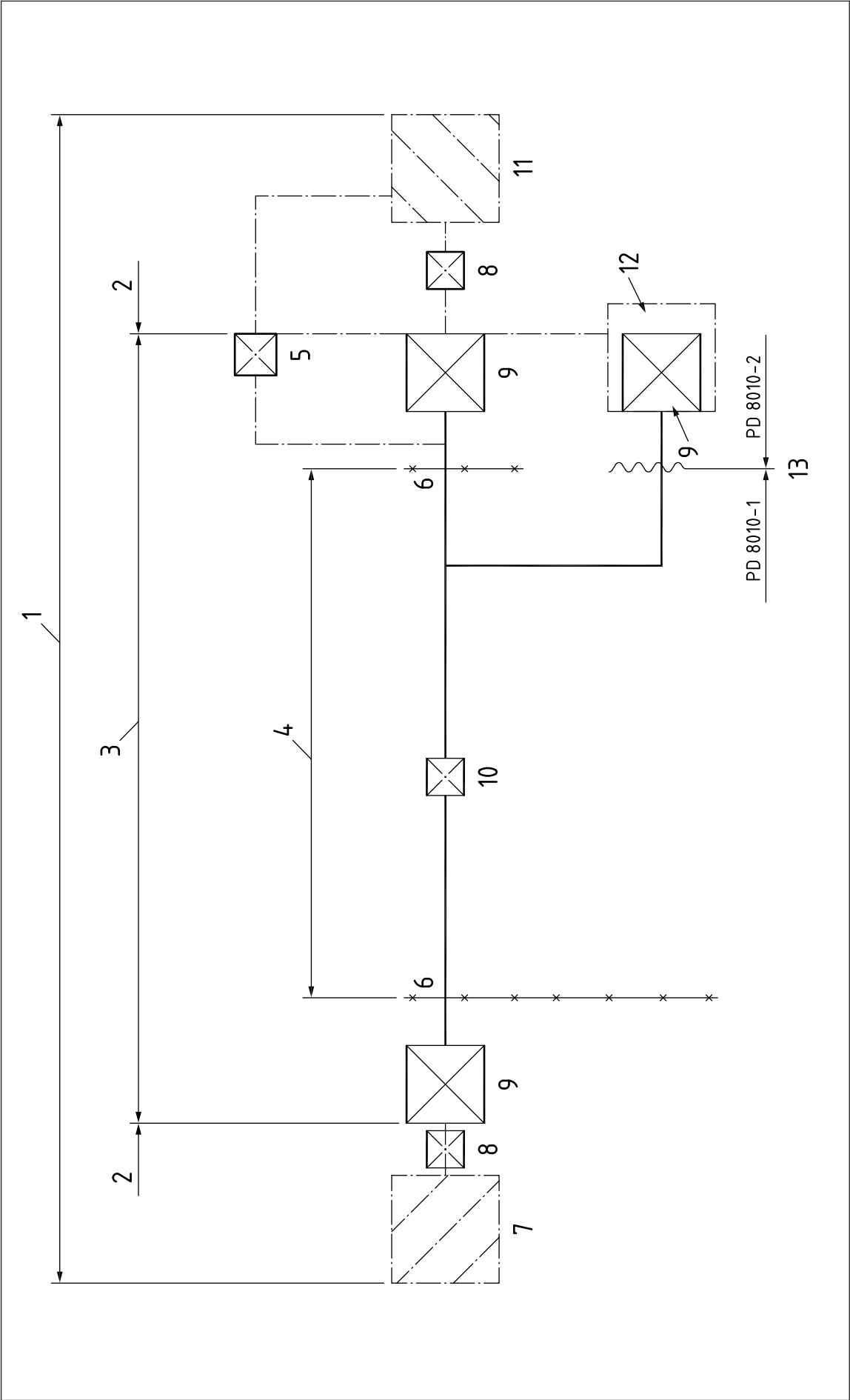


Figure 1 Extent of pipeline systems that are covered by this part of PD 8010 (2 of 2)

Key	
1 Pipeline system	8 Metering/integrity monitoring facility ^{E)}
2 Plant pressure system ^{A)}	9 Emergency shutdown device ^{F)}
3 Pipeline limit ^{B)}	10 In-line station ^{G)}
4 Third party land or business undertaking	11 Pressure letdown or storage facility ^{H)}
5 Relief device ^{C)}	12 Offshore platform (PD 8010-2)
6 Boundary fence	13 High water tide level ^{I)}
7 Pressure source ^{D)}	
NOTE The pipeline system covers all operational equipment needed to control and operate the pipeline.	
^{A)} Pressure system of wellhead or terminal. Such equipment is outside the scope of this part of PD 8010.	
^{B)} The mechanical limit of the pipeline, including emergency shutdown devices.	
^{C)} This can be for thermal relief or overpressure protection.	
^{D)} For example, a pump, compressor, wellhead or pressure reservoir.	
^{E)} This can be positioned either inside or outside the pipeline limit. It can comprise commercial metering devices and/or other facilities for monitoring the safe operation and integrity of the pipeline. For low-hazard fluids or pipelines in safe areas it can comprise a single meter at one end of the pipeline.	
^{F)} See 7.8 for position of emergency shutdown device.	
^{G)} Major isolation between plant and pipeline. For example a single block and bleed, and a pig launcher or receiver.	
^{H)} For example, a tank, vessel, letdown valve to low pressure distribution pipeline system or reservoir.	
^{I)} This indicates the cut-off point between PD 8010-1 (onshore pipelines) and PD 8010-2 (subsea pipelines).	

- ASTM A312, *Standard specification for seamless and welded austenitic stainless steel pipes*²⁾
- ASTM A320/A320M 11a, *Specification for alloy/steel bolting materials for low-temperature service*
- ASTM A790, *Standard specification for seamless and welded ferritic/austenitic stainless steel pipe*
- ASTM B423, *Standard specification for nickel-iron-chromium-molybdenum-copper alloy (UNS N08825 AND N08221)* seamless pipe and tube*
- ASTM B444, *Standard specification for nickel-chromium-molybdenum-columbium alloys (UNS N06625) and nickel-chromium-molybdenum-silicon alloy (UNS N06219) pipe and tube*
- BS 3293, *Specification for carbon steel pipe flanges (over 24 inches nominal size) for the petroleum industry*
- BS 3518-1, *Methods of fatigue testing – Part 1: Guide to general principles*
- BS 3518-3, *Methods of fatigue testing – Part 3: Direct stress fatigue tests*
- BS 3799, *Specification for steel pipe fittings, screwed and socket-welding for the petroleum industry*
- BS 4515-1, *Specification for welding of steel pipelines on land and offshore – Part 1: Carbon and carbon manganese steel pipelines*
- BS 4515-2, *Specification for welding of steel pipelines on land and offshore – Part 2: Duplex stainless steel pipelines*
- BS 4882, *Specification for bolting for flanges and pressure containing purposes.*
- BS 7448 (all parts), *Fracture mechanics toughness tests*
- BS 7608, *Guide to fatigue design and assessment of steel products*
- BS 7910, *Guide to methods for assessing the acceptability of flaws in metallic structures*
- BS EN 10204, *Metallic products – Types of inspection documents*
- BS EN 10224, *Non-alloy steel tubes and fittings for the conveyance of water and other aqueous liquids – Technical delivery conditions*
- BS EN 13480-3, *Metallic industrial piping – Part 3: Design and calculation*³⁾
- BS EN 60079-10-1, *Explosive atmospheres – Part 10-1: Classification of areas – Explosive gas atmospheres*
- BS EN 60079-14, *Explosive atmospheres – Part 14: Electrical installations design, selection and erection*
- BS EN 62305 (all parts), *Protection against lightning*
- BS EN ISO 148-1, *Metallic materials – Charpy pendulum impact test – Part 1: Test method*
- BS EN ISO 3183:2012, *Petroleum and natural gas industries – Steel pipe for pipeline transportation systems*⁴⁾
- BS EN ISO 9606-1, *Qualification testing of welders – Fusion welding*

²⁾ ASTM International (formerly American Society for Testing and Materials) standards are available from BSI Customer Services, Tel: +44 (845 086) 9001.

³⁾ This part of PD 8010 also gives an informative reference to BS EN 13480-3:2012.

⁴⁾ API 5L:2012 is the same as BS EN ISO 3183:2012, except that the API standard does not include Annex M.

- BS EN ISO 15156 (all parts), *Petroleum and natural gas industries – Materials for use in H₂S-containing environments in oil and gas production*
- BS EN ISO 15607, *Specification and qualification of welding procedures for metallic materials – General rules*
- BS EN ISO 15609 (all parts), *Specification and qualification of welding procedures for metallic materials – Welding procedure specification*
- BS EN ISO 15610, *Specification and qualification of welding procedures for metallic materials – Qualification based on tested welding consumables*
- BS EN ISO 15614 (all parts), *Specification and qualification of welding procedures for metallic materials – Welding procedure test*
- BS EN ISO 15653, *Metallic materials – Method of test for the determination of quasistatic fracture toughness of welds*
- BS EN ISO 21809-1, *Petroleum and natural gas industries – External coatings for buried or submerged pipelines used in pipeline transportation systems – Part 1: Polyolefin coatings (3-layer PE and 3-layer PP)*
- BS EN ISO 21809-2, *Petroleum and natural gas industries – External coatings for buried or submerged pipelines used in pipeline transportation systems – Part 2: Fusion-bonded epoxy coatings*
- BS ISO 1143, *Metallic materials – Rotating bar bending fatigue testing*
- BS ISO 7005-1, *Pipe flanges – Part 1: Steel flanges for industrial and general service piping systems*
- BS ISO 10474, *Steel and steel products – Inspection documents*
- BS ISO 12107, *Metallic materials – Fatigue testing – Statistical planning and analysis of data*
- BS ISO 15589-1, *Petroleum and natural gas industries – Cathodic protection of pipeline transportation systems – Part 1: On-land pipelines*
- BS ISO 21809-4, *Petroleum and natural gas industries – External coatings for buried or submerged pipelines used in pipeline transportation systems – Part 4: Polyethylene coatings (2-layer PE)*
- ISO 14313, *Petroleum and natural gas industries – Pipeline transportation systems – Pipeline valves*
- ISO 15590-1, *Petroleum and natural gas industries – Induction bends, fittings and flanges for pipeline transportation systems – Part 1: Induction bends*
- ISO 15590-2, *Petroleum and natural gas industries – Induction bends, fittings and flanges for pipeline transportation systems – Part 2: Fittings*
- ISO 15590-3, *Petroleum and natural gas industries – Induction bends, fittings and flanges for pipeline transportation systems – Part 3: Flanges*
- ISO 21809-3, *Petroleum and natural gas industries – External coatings for buried or submerged pipelines used in pipeline transportation systems – Part 3: Field joint coatings*
- PD 5500, *Specification for unfired fusion welded pressure vessels*⁵⁾
- PD 8010-3:2009+A1:2013, *Pipeline systems – Part 3: Steel pipelines on land – Guide to the application of pipeline risk assessment to proposed developments in the vicinity of major accident hazard pipelines containing flammables – Supplement to PD 8010-1:2004*

⁵⁾ This part of PD 8010 also gives an informative reference to PD 5500:2012+A3:2014.

Industry standards publications

API 5L:2012 (45th edition), *Specification for line pipe* ⁶⁾

API 5LC, *Specification for CRA line pipe*

API 5LD, *Specification for CRA clad or lined steel pipe*

API 6A, *Wellhead and Christmas tree equipment*

API RP 5L2, *Internal coating of line pipe for non-corrosive gas transmission service*

IGEM/TD/1 Edition 5:2012, *Steel pipelines for high pressure gas transmission* ⁷⁾

MSS SP 44, *Specification for steel pipelines flanges* ⁸⁾

NACE MR0175, *Metals for sulfide stress cracking and stress corrosion cracking resistance in sour oilfield environments* ⁹⁾

NFPA 30, *Flammable and combustible liquids code* ¹⁰⁾

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

For the purposes of this part of PD 8010, the following terms and definitions apply.

NOTE Additional definitions are given in BS EN 14161 and ISO 13623.

3.1.1 cathodic protection

system that reduces the rate of external corrosion of a steel pipeline, and the ferrous compounds of pipeline components, by regulating the electrical potential between a pipeline and its environment

3.1.2 commissioning

introduction of product into a pipeline to put the system into operation

3.1.3 component

any item that is part of a pipeline other than a straight pipe or field bend

NOTE A component can also be referred to as a fitting.

3.1.4 control zone

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

3.1.5 decommissioning

activities required to take out of service any pipework, station, equipment or assemblies and to isolate them from the pipeline system

NOTE This does not necessarily include abandonment.

⁶⁾ American Petroleum Institute (API) standards are available from BSI Customer Services, Tel: +44 (845 086) 9001.

⁷⁾ Institute of Gas Engineers and Managers (formerly Institution of Gas Engineers) (IGE) standards are available from the Institution of Gas Engineers and Managers, Charnwood Wing, Holywell Park, Ashby Road, Loughborough, Leicestershire LE11 3GR.

⁸⁾ Manufacturers Standardization Society (MSS) standards are available from BSI Customer Services, Tel: +44 (846 086) 9001.

⁹⁾ National Association of Corrosion Engineers (NACE) Standards are available from BSI Customer Services. Tel: +44 (846 086) 9001.

¹⁰⁾ National Fire Prevention Association (NFPA) Standards are available from BSI Customer Services. Tel: +44 (846 086) 9001.

- 3.1.6 design factor**
factor applied to hoop stress when calculating the wall thickness or pressure
- 3.1.7 design life**
time period for which a pipeline is to be used for its intended purpose with planned integrity management
- 3.1.8 design pressure**
pressure on which design criteria are based
- 3.1.9 design temperature**
maximum or minimum temperature which determines the selection of material for the duty proposed
NOTE This represents the most arduous condition expected.
- 3.1.10 easement**
legally binding agreement granted by a landowner to the promoter of a pipeline, either in perpetuity or for a defined period, which sets out the rights and obligations of both parties (and their respective successors in title) in relation to the matter, but under which ownership of the land remains with the landowner
- 3.1.11 emergency**
situation which could affect the safe operation of the pipeline system and/or the health, safety and environment of the surrounding area, requiring urgent action
- 3.1.12 gas**
fluid that has a gaseous state at a temperature of 15 °C under normal atmospheric pressure
- 3.1.13 header drain**
length of land drainage pipe, usually installed parallel to a pipeline, used to convey sub-surface water from existing land drainage systems that are severed by a pipeline
- 3.1.14 holiday**
flaw in the coating or lining of a pipe
- 3.1.15 holiday detector**
device for detecting flaws in the coating or lining of a pipe
- 3.1.16 incident**
unexpected occurrence that could lead to an emergency situation
- 3.1.17 incidental pressure**
level of pressure that occurs incidentally within a system, at which a safety device becomes operative
- 3.1.18 installation**
equipment and facilities for the extraction, production, chemical treatment, measurement, control, storage or offtake of the transported fluid
- 3.1.19 installation temperature**
temperature arising from ambient or installation conditions during laying or during construction
- 3.1.20 isolation joint**
fitting having high electrical resistance, which can be inserted in a pipeline to electrically insulate one section of pipeline from another

- 3.1.21 intermediate station**
pump, compressor, valve, pressure control, heating or metering station, etc.
located along a pipeline route between the pipeline terminals
- 3.1.22 internal design pressure**
maximum sustained pressure exerted by the pipeline contents which a pipeline is designed to withhold
- 3.1.23 lease**
period of time during which ownership of land is temporarily transferred to the promoter
- 3.1.24 line pipe**
standard length of pipe (3.1.33) as supplied for the construction of pipelines
- 3.1.25 lining**
durable material applied to the internal surface of steel pipes and fittings to protect the metal from corrosion, erosion or chemical attack
- 3.1.26 maximum allowable operating pressure (MAOP)**
maximum pressure at which a system can be operated continuously under normal conditions at any point along the pipeline and which is the sum of the static head pressure, the pressure required to overcome friction losses and any required backpressure
- 3.1.27 night cap**
temporary closure at the end of a section of pipeline
- 3.1.28 operating pressure**
pressure that occurs within a pipeline system under normal operating conditions
- 3.1.29 operating temperature**
temperature that occurs within a pipeline system under normal operating conditions
- 3.1.30 operator**
person or organization having control over the conveyance of fluid through a pipeline system at any time during all stages of its life cycle
NOTE Further information on the definition of "operator" is given in the Pipelines Safety Regulations 1996 [15], Regulation 2.
- 3.1.31 pig**
device propelled through a pipeline by fluid pressure, for cleaning, swabbing, gauging, inspection or batch separation
- 3.1.32 pig trap**
device allowing entry to a pipeline for the launching and receiving of pigs, inspection tools and other equipment to be run through a pipeline
- 3.1.33 pipe**
hollow cylinder through which fluid can flow, as produced by the manufacturer prior to assembly into a pipeline

3.1.34 pipeline

continuous line of pipes of any length, without frequent branches, used for transporting fluids

NOTE 1 Pipelines do not include piping systems such as process plant piping within refineries, factories or treatment plants. However, the pipeline system covers the pipeline plus all operational equipment needed to control and operate the pipeline. Refer to Figure 1 for physical clarification of a pipeline system and a pipeline limit.

NOTE 2 A pipeline on land is a pipeline laid on or in land, including those sections laid under rivers, lakes and inland watercourses. A subsea pipeline is a pipeline laid under maritime waters and estuaries and the shore below the high water mark. Recommendations for subsea pipelines are given in PD 8010-2.

NOTE 3 Information on establishing the interface between a pipeline and other connecting pipework systems is given in HSE publication L82 [22]. Various examples of the interfaces of pipelines with other piping systems are given in Clause 5 of this part of PD 8010 and while these are indicative, they give an illustration of the limits where the application of PD 8010 can be applied.

3.1.35 pipeline spread

continuous length of sequential pipeline installation on which a contractor is currently working

3.1.36 pipeline system

full pressure envelope from the pressure source to the receiving vessel or pressure letdown station

NOTE Attention is also drawn to the definition given in the Pipelines Safety Regulations 1996 [15]. The extent of pipeline systems covered in this part of PD 8010 is illustrated in Figure 1.

3.1.37 pipework

assembly of pipes and fittings

3.1.38 pre-commissioning

activities, including cleaning, pigging, testing, de-watering, purging and drying as appropriate, carried out prior to commissioning

3.1.39 pressure

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

3.1.40 pressure safety system

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

NOTE This can be a pressure relief valve or a system of pressure letdown by any means.

3.1.41 promoter

organization that seeks to install, operate and maintain a pipeline under statutory powers

3.1.42 pup

short make-up piece of pipe

3.1.43 re-commissioning

activities required to put a decommissioned pipeline, associated stations and equipment back into service

- 3.1.44 redundancy**
incorporation of components in parallel in a control system, in which the system fails to operate only if all its components fail to operate
- 3.1.45 reliability**
probability of a device or system performing in the manner desired for a specified period of time
- 3.1.46 right of way**
corridor of land within which a pipeline operator has the right to conduct activities in accordance with an agreement with the landowner
- 3.1.47 spacer**
non-stress distribution element provided to locate and support pipelines within the configuration of strapped or encased bundles
- 3.1.48 station**
plant or facility for the operation of a pipeline system and/or the processing of fluid
- 3.1.49 statutory notice**
notice issued under an Act of Parliament by a promoter to a landowner, occupier or relevant authority stating the statutory powers which the promoter will exercise in surveying, installing, operating and maintaining a pipeline
NOTE Such notice is sometimes required to be displayed for public comment.
- 3.1.50 strength test**
specific procedure used to ascertain whether the pipeline, pipework and/or station meets the recommendations for mechanical strength
- 3.1.51 surge pressure**
maximum pressure caused by:
a) rapid closure of valves during pipeline operation;
b) pump trips and re-start operations;
c) vacuum cavities in the pipeline;
d) reverse flow operations;
e) a combination of the above usually caused by mal-operation
NOTE Surge pressure is applied to liquid lines and multi-phased lines. Uninhibited surge pressure is the maximum of the combination of liquid surge pressure at maximum operation conditions and the pump shut-in head pressure.
- 3.1.52 test pressure**
pressure to which a system is subjected to ascertain whether it can operate safely
- 3.1.53 tie-in weld**
weld carried out between two sections of pipeline to join the sections together before or after a pressure test
NOTE A tie-in weld after pressure test is also known as a non-pressure-tested closure weld (golden weld).
- 3.1.54 voting system**
system incorporating parallel components which operate only if a predetermined proportion of the components indicate that the system should operate

3.1.55 way leave

agreement granted by a landowner to a promoter, permitting the promoter to execute works on the terms specified

NOTE This is similar in nature to but less specific than an easement.

3.1.56 working width

strip of land used by a contractor for the purpose of installing a pipeline

NOTE The working width is usually wider than that covered by an easement, lease or way leave.

3.2 Symbols

For the purposes of this part of PD 8010, the following symbols apply.

A	cross-sectional area of pipe wall, in square millimetres (mm ²)
a	design factor
C_f	flattening coefficient
C_p	ovalization magnification factor accounting for pressure effects
D	outside diameter of a pipe, as used in testing and buckling calculations, in metres (m)
D_i	inside diameter of a pipe, in millimetres (mm)
$D_{\max}$	maximum (oval) outside diameter, in metres (m)
$D_{\min}$	minimum (oval) outside diameter, in metres (m)
D_o	outside diameter of a pipe, in millimetres (mm)
E	Young's modulus of elasticity, in newtons per square millimetre (N/mm ²)
E_b	Young's modulus of elasticity, as used in buckling calculations, in newtons per square metre (N/m ²)
e	weld joint factor
F	axial force, in newtons (N)
F_s	shear force applied to a pipeline, in newtons (N)
F_x	compressive axial force, in newtons (N)
F_{xc}	mean axial compression load or force, in newtons (N)
F_y	yield load or force, in newtons (N)
f	total ovalization of a pipe
f_o	initial ovalization of a pipe cross-section
<i>NOTE 1 The term "initial" refers to the deflection due to influences, including fabrication and bending loads, other than hydrostatic pressure.</i>	
H_c	characteristic upheaval buckle imperfection height, in metres (m)
I	moment of inertia, in metres to the power 4 (m ⁴)
i	stress intensification factor (see BS EN 13480 or ASME B31.3)
k	ratio D_o/D_i
L_c	characteristic length associated with upheaval buckle imperfection, in metres (m)
M	bending moment, in newton metres (N·m)
M_b	bending moment applied to a pipeline, in newton metres (N·m)

M_c	characteristic bending moment, in newton metres (N·m)
M_p	full plastic moment capacity of pipeline cross-section, in newton metres (N·m)
n	inner bend radius divided by pipe diameter for wall thinning formulae
P	external overpressure (buckling), in newtons per square metre (N/m ²)
P_c	characteristic external pressure (collapse), in newtons per square metre (N/m ²)
P_{cm}	cracking carbon equivalent
P_e	critical pressure for an elastic circular tube, in newtons per square metre (N/m ²)
P_{eff}	effective axial force, in newtons (N)
P_i	internal pressure, in newtons per square metre (N/m ²)
P_o	external pressure, in newtons per square metre (N/m ²)
P_p	buckle propagation pressure, in newtons per square metre (N/m ²)
P_y	yield pressure, in newtons per square metre (N/m ²)
p	internal design pressure (N/mm ²)
Q	substance factor
S_L	total longitudinal stress (combination of direct and bending stresses), in newtons per square millimetre (N/mm ²)
S_{L1}	total restrained longitudinal tensile stress for a restrained section of a pipeline, in newtons per square millimetre (N/mm ²)
S_{L2}	total unrestrained longitudinal tensile stress for unrestrained sections of a pipeline, in newtons per square millimetre (N/mm ²)
S_{ae}	allowable equivalent stress, in newtons per square millimetre (N/mm ²)
S_{ah}	allowable hoop stress, in newtons per square millimetre (N/mm ²)
S_e	equivalent stress, in newtons per square millimetre (N/mm ²)
S_h	actual hoop stress, in newtons per square millimetre (N/mm ²)
S_{hl}	hoop stress using nominal pipe wall thickness, in newtons per square millimetre (N/mm ²)
S_y	SMYS of pipe, in newtons per square millimetre (N/mm ²) <i>NOTE 2 See BS EN ISO 3183:2012 and API 5L:2012 (SI equivalent).</i>
T	torque applied to the pipeline, in newton metres (N·m)
T_f	temperature factor change during a test <i>NOTE 3 This is obtained from Figure 5.</i>
T_1	installation temperature, in degrees Celsius (°C)
T_2	maximum or minimum metal temperature, in degrees Celsius (°C)
t	actual pipeline wall thickness, in metres (m) <i>NOTE 4 The nominal wall in metres may be substituted if the actual thickness is not known.</i>

$t_{\min}$	minimum design thickness, in millimetres (mm) <i>NOTE 5 This excludes corrosion allowance and mill tolerance.</i>
t_{nom}	nominal pipe wall thickness, in millimetres (mm)
t_{thin}	wall thinning, as a percentage (%)
V	volume of a test section, in cubic metres (m ³)
Y	minimum distance between a pipeline and an occupied building, in metres (m)
Z	pipe section modulus, in cubic millimetres (mm ³)
α	linear coefficient of thermal expansion, per degree Celsius (°C ⁻¹)
α_{fab}	fabrication factor
α_{τ}	torsion coefficient
γ	factor used in the calculation of load combinations
Δ_V	incremental volume of water added during a test, in cubic metres (m ³)
Δ_P	incremental pressure change during a test, in newtons per square millimetre per degree Celsius (N/mm ² /°C)
ε_b	maximum bending strain
ε_{bc}	characteristic bending strain
ε_p	equivalent uniaxial plastic strain
ε_{pH}	hoop plastic strain
ε_{pL}	longitudinal plastic strain
ε_{pr}	radial plastic strain
Φ_L	imperfection coefficient
Φ_W	download coefficient
ν	Poisson's ratio
σ_{hb}	hoop stress used in buckling analysis, in newtons per square metre (N/m ²)
σ_{hcr}	critical compressive hoop stress when pressure is acting alone, in newtons per square metre (N/m ²)
σ_{hE}	critical compressive hoop stress for completely elastic buckling, in newtons per square metre (N/m ²)
σ_y	SMYS of pipe, as used in buckling calculations, in newtons per square metre (N/m ²)
τ	shear stress, in newtons per square millimetre (N/mm ²)
τ_C	characteristic torsional shear stress, in newtons per square metre (N/m ²)
τ_y	yield shear stress, in newtons per square metre (N/m ²)
ω	submerged weight of pipe plus over-burden, in newtons (N)

3.3 Abbreviations

For the purposes of this part of PD 8010, the following abbreviations apply.

AGI	above-ground installation
ALARP	as low as reasonably practicable
AUT	automated ultrasonic testing
CE	carbon equivalent
CIPS	close interval potential survey
cpm	chance per million per annum of an individual receiving a dangerous dose (equivalent to 1% lethality) or worse from a flammable, toxic or asphyxiate gas release from a pipeline leak, rupture or pipeline component failure
CRA	corrosion-resistant alloy
CTOD	crack tip opening displacement
DP	dye penetrant
DWT	deadweight tester
DWTT	drop weight tear testing
ECA	engineering critical assessment
EIA	environmental impact assessment
ES	environmental statement
GIS	geographical information system
HAZ	heat-affected zone
HFW	high frequency welding
LPG	liquefied petroleum gas
MAHP	major accident hazard pipeline
MAOP	maximum allowable operating pressure
MPI	magnetic particle inspection
NDT	non-destructive testing
NGL	natural gas liquid
SAW	submerged arc welding
SMYS	specified minimum yield strength
SRA	structural reliability analysis
SSSI	site of special scientific interest
TPO	tree preservation order
UT	ultrasonic testing
UTS	ultimate tensile strength

4 Health, safety and assurance

4.1 Health, safety and the environment

The recommendations included in this part of PD 8010 are based upon considerations of safety extending throughout the lifetime of a pipeline system.

Experienced and competent engineering judgement should be employed to assess the individual requirements of each pipeline project undertaken.

The design, chosen materials, route, environmental impact and hazard/risk analysis should all be fully assessed and the most appropriate measures selected to ensure as far as possible that the pipeline system will be fit for service throughout its lifetime.

To increase the overall safety of the installation, as many of the following additional measures as are deemed appropriate should be taken against third-party interference:

- modification of the design factor by increasing the wall thickness or using high-strength pipe steels (including selection of appropriate toughness properties for fracture-arrest capability);
- route of the pipeline at an appropriate distance from buildings. The distance should be fixed by the particular hazards (see 5.5.3);
- increase in depth for the pipeline greater than that of normal agricultural/horticultural activities expected in the area;
- route of the pipeline clearly identified by a locating system such as additional route markers;
- increase in frequency of surveillance, inspection and control;
- regular communication with landowners, occupiers, local authorities and the emergency services along the pipeline route;
- additional forms of mechanical protection. Designers should carefully select the forms of additional protection to minimize any adverse effects on the efficiency of the cathodic protection.

NOTE 1 The probability of third-party interference to the pipeline decreases if a depth greater than the minimum recommended in this part of PD 8010 is adopted.

NOTE 2 Ensuring an adequate frequency of surveillance can further increase pipeline safety.

NOTE 3 Attention is drawn to the Pipe-lines Act 1962 [14] in respect of application for a Pipeline Construction Authorization for pipelines greater than 10 miles (16.093 km) long. Attention is drawn to the Town and Country Planning Act 1990 [21] in respect of planning permission for local pipelines.

NOTE 4 Attention is drawn to the Pipelines Safety Regulations 1996 [15] and the Pressure Systems Safety Regulations 2000 [20] in respect of inspection and operation safety regimes.

4.2 Competence assurance

The design, construction, testing, operation, maintenance and abandonment of the pipeline system should be carried out by suitably qualified and competent persons, under the supervision of an experienced chartered engineer or equivalent.

NOTE The best manufacturing and construction methods cannot compensate for inadequate design.

Procedures should be established and maintained to control and verify the design, construction and testing of the pipeline, to ensure that the pipeline specification is met, and to minimize error during this process.

4.3 Quality assurance

4.3.1 General

Quality assurance procedures should be applied throughout the feasibility, investigation, design, procurement, construction, testing, operation, maintenance and modification of a pipeline system to ensure compliance with all the relevant standards.

An efficient document control system is essential. A quality plan should be developed appropriate to the duty and nature of the substance to be carried. For pipelines conveying category A, category B or category C substances, some of the quality recommendations given in Annex B may be omitted as appropriate for the nature of the hazard and the pressure of the system, provided that it can be demonstrated that the integrity of the pipeline and quality system can be maintained. For pipelines conveying category D or category E substances, all of the recommendations given in Annex B should be followed.

Assessed capability. *Users of this Published Document are advised to consider the desirability of quality system assessment and registration against the appropriate standard in the BS EN ISO 9000 and BS EN ISO 14001 series by an accredited third-party certification body.*

4.3.2 Inspection

The level of inspection should be such as to meet the requirements of the quality plan (see Annex B and C.6). Inspection activities should be certified by appropriately qualified personnel.

4.3.3 Records and document control

All documents, specifications, drawings, certificates and change orders relating in any way to project quality should be retained, cross-referenced and filed in accordance with the quality plan

Annex C gives details of the documents that should normally be included in the quality system. For pipelines conveying category A, category B or category C substances, some of these documents may be omitted due to the low risk nature of the hazard and the low pressure of the system, provided that it can be demonstrated that the integrity of the pipeline and its essential documentation can be maintained.

NOTE *The control of pipeline records and operations can be improved by the use of electronic systems, such as pipeline databases and geographical information system (GIS).*

All design, procurement, construction, testing, inspection and survey documentation should be retained for the life of the pipeline.

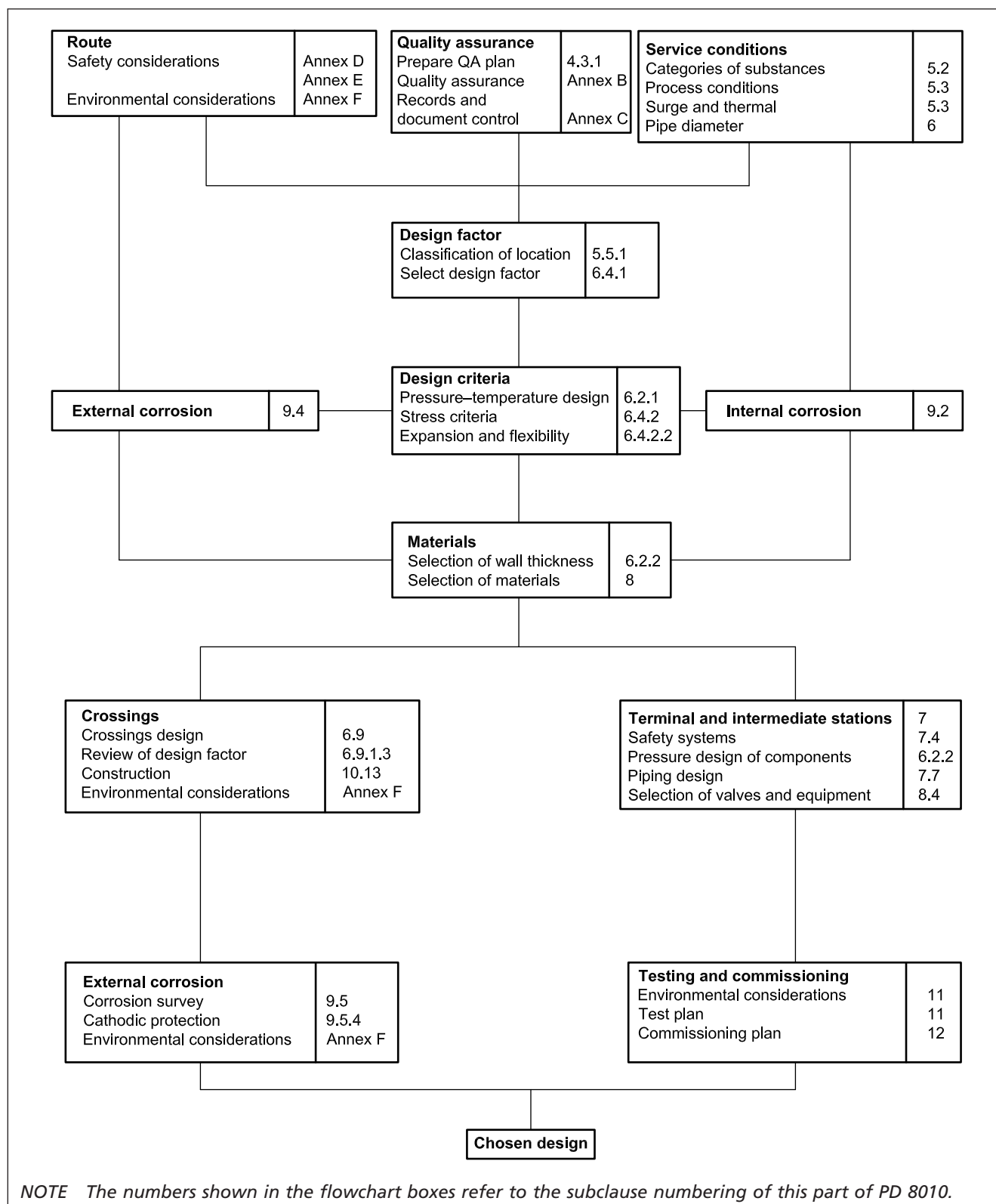
4.4 Design, construction and commissioning assurance

A design assurance system should be established, such as the one shown in Figure 2, which should include all aspects of the design process. As a minimum it should include all of the issues addressed in Clause 5 to Clause 9. It should also address practicalities and limitations associated with construction (Clause 10 and Clause 11), and requirements for pre-commissioning and commissioning (Clause 12), operation (Clause 13), and abandonment (Clause 14).

The construction through to commissioning process should reflect the design and should take into account, validate and record any changes or deviations from the original design (see also 4.6.6).

NOTE The pipeline design flowchart shown in Figure 2 has been developed to give general guidance on the design process. This flowchart may be used as a guide through the design process. It does not attempt to show all the various pathways required to arrive at the chosen design.

Figure 2 Example of a pipeline design flowchart



4.5 Operation and abandonment assurance

The operation and abandonment process should take into account the design, any changes made during or subsequent to construction, and the condition of the system (see Clause 13 and Clause 14 for more detailed recommendations).

4.6 Plans and drawings

4.6.1 Preliminary routing plans

For preliminary routing plans, maps of either 1:25 000 or 1:50 000 scale should be used, according to the complexity of the terrain.

4.6.2 Field reconnaissance plans

For field reconnaissance plans, Ordnance Survey maps of either 1:10 000 or 1:25 000 scale should be used.

NOTE 1 The use of 1:10 000 maps can obviate duplication, since this is the smallest scale acceptable for applications under the Pipe-lines Act 1962 [14].

NOTE 2 For local and cross-country pipelines, aerial photographs with a resolution of 250 mm or better, overlaid with Ordnance Survey coordinates at scales of 1:10 000 and less, are acceptable provided they are located by a known Ordnance Survey coordinate.

NOTE 3 Ordnance Survey Maps and Sheets may not be reproduced or copied without the permission of the Director-General of Ordnance Survey¹¹⁾.

4.6.3 Final field survey plans

For final field survey plans, Ordnance Survey sheets of 1:2 500 scale with field numbers should be used.

4.6.4 Strip plans

Strip plans (also commonly referred to as alignment sheets) should be prepared from Ordnance Survey sheets or aerial imagery of 1:2 500 scale. In built-up areas, plans of 1:1 250 scale should be used if necessary. Any alteration to land drainage works should be detailed on these plans. Any vertical section or profile along the pipeline route should be shown to a scale appropriate to the variations in ground elevation. Crossings should be detailed on separate drawings that should be cross-referenced to the appropriate strip plan; the scale should be between 1:250 and 1:25 depending on the complexity of the work.

4.6.5 Plans for landowner agreements

Plans for landowner agreements should normally be based on the Ordnance Survey sheets, preferably the 1:2 500 scale. Exceptions to this are when the area of land is very small or complex, when a larger scale should be used, and when the area of land is very large and uniform, when a smaller scale should be used.

4.6.6 As-built plans

If during construction of the pipeline there are any changes or deviations from any issued plans following discussions with third parties or changes in design, as-built plans (to the same scale as the original plans) should be issued to all the original recipients on completion of the work.

NOTE If found more convenient, the strip plans detailed in 4.6.4 may be used for this purpose.

¹¹⁾ Ordnance Survey, Romsey Road, Southampton, S016 4GU. Tel: +44 (0) 8456 050505. Fax: +44 (0)23 8079 2615.

5 Design – System and safety

COMMENTARY ON CLAUSE 5

This clause addresses the safety of the entire pipeline system, including pipeline process engineering.

The extent of a pipeline system covered by this part of PD 8010 is shown in Figure 1.

An example of a design flowchart is given in Figure 2.

5.1 System definition

The extent of the pipeline system, its functional requirements and applicable legislation, including proposals for future abandonment, should be defined and documented.

The extent of the system should be defined by describing the system and its boundaries, including the facilities with their general locations and the demarcations and interfaces with other facilities.

The definition of functional requirements should include the intended design life and design conditions. The design conditions should include foreseeable normal operating conditions, upset and operational extremes, including shut-in operating conditions. It should also include possible ranges in flow rates, pressures, temperatures, fluid compositions and fluid qualities.

5.2 Categorization of substances

5.2.1 General

The substances to be transported should be categorized, with respect to hazard potential in respect of public safety, into one of the five categories given in Table 1.

NOTE 1 Attention is drawn to the Pipelines Safety Regulations 1996 [15] for the definition and classification of dangerous fluids (hazardous substances).

Gases or liquids not specifically included by name should be classified in the category containing substances most closely similar in hazard potential to those quoted. If the category is not clear, the more hazardous category should be assumed.

NOTE 2 Guidance is given in a number of publications including HSE publication L82 [22] and ICE publication Nomenclature for hazard and risk assessment [23].

NOTE 3 Additional guidance on CO₂ pipelines is given in DNV-RP-J202.

5.2.2 Hazard potential

COMMENTARY ON 5.2.2

In the event of a rupture of a pipeline conveying a gas, the blast effect owing to stored energy is an important factor in the hazard potential of the substance. The rupture of a pipeline conveying a liquid has a much lower blast effect owing to the relatively incompressible nature of liquids. Gases conveyed as liquids have an intermediate effect. The characteristics of some hazardous substances commonly conveyed in pipelines are described in Annex D, to assist the designer in determining the category into which hazardous substances are to be placed.

See also Annex E, which gives recommendations for safety evaluation.

The designer should determine the category into which hazardous substances are to be placed.

Table 1 Categorization of substances according to hazard potential

Category	Description	Typical examples
A	Typically non-flammable water-based fluids	Water, brine, dilute effluents
B	Flammable and/or toxic fluids that are liquids at ambient temperature and at atmospheric pressure conditions	Oil and petroleum products Methanol
C	Non-flammable fluids that are non-toxic gases at ambient temperature and atmospheric pressure conditions	Nitrogen, oxygen, argon and air
D	Non-toxic, single-phase natural gas	—
E	Flammable and/or toxic fluids that are gases at ambient temperature and atmospheric pressure conditions and are conveyed as gases and/or liquids Mixtures of petroleum or chemical substances, having a Reid vapour pressure greater than 31 kPa absolute	Hydrogen, carbon dioxide, natural gas (not otherwise covered in category D), ethane, ethylene, liquefied petroleum gas (e.g. propane and butane), natural gas liquids, ammonia and chlorine Spiked or live crude oil

5.3 Pipeline process design

5.3.1 General

All pipelines should have a pipelines process data sheet or document including:

- means of pressure;
- fluid characteristics;
- process;
- pipeline size;
- fluid volume;
- fluid transfer rates;
- modes of pipeline operation;
- process operating conditions;
- hydraulic route analysis;
- maximum operating and surge pressure;
- direction of flow;
- maximum shut-in head;
- surge pressure and surge control;
- proposed relief systems;
- thermal relief control;
- fracture control.

5.3.2 Hydraulic analysis

The hydraulics of the pipeline system should be analysed to demonstrate that the system can operate safely at the design conditions identified in 5.3.1, and to identify and determine the constraints and requirements for its operation. The analysis should cover steady state and transient operating conditions.

NOTE Examples of constraints and operational requirements are:

- allowances for pressure surges;

- *prevention of blockages, e.g. caused by the formation of hydrates and wax deposition;*
- *measures to prevent unacceptable pressure losses from higher viscosities at lower operating temperatures;*
- *measures for the control of liquid slug volumes in multi-phase fluid transport;*
- *flow regime for internal corrosion control;*
- *erosional velocities and avoidance of slack line operations.*

5.3.3 Pressure control and overpressure protection

If the operating pressure could exceed the MAOP anywhere in the pipeline system, provisions such as pressure safety systems, control valves or automatic shutdown of pressurizing equipment should be installed. Such provisions or procedures should prevent the operating pressure exceeding MAOP under normal steady-state conditions.

Overpressure protection, such as relief or source isolation valves, should be provided if necessary to prevent incidental pressures exceeding the limits recommended in 6.2.1.5 anywhere in the pipeline system.

5.3.4 Operation and maintenance

The requirements for operation and maintenance of the pipeline system should be established and documented. For operation and maintenance plans, the specific recommendations given in Clause 13 should be followed.

5.3.5 Heated pipeline systems

Temperature indication and controls should be provided where heating or cooling of the fluids is required for operation of the pipeline system.

NOTE For heating stations, trace heating can be required on pipework, pump bodies, drains and instrument lines to ensure satisfactory flow conditions following shutdown.

Account should be taken of the safety, technical reliability, electrical efficiency, repair difficulty and system track record of the proposed system. The impact on the surrounding ground water, coatings and cathodic protection systems should be assessed.

5.4 Public safety and protection of the environment

COMMENTARY ON 5.4

The recommendations given in this subclause are expected to be adequate for public safety and environmental protection under conditions usually encountered in pipelines, including those in offshore and nearshore areas. However, these recommendations do not replace the need for appropriate experience and competent engineering judgement.

Materials and practices not specifically recommended in this part of PD 8010 may be used providing they can be shown to achieve comparable safety standards.

5.4.1 General

The design and location of a pipeline should take account of the hazard potential of the substance to be conveyed (see 5.2.1), the proximity of the pipeline to normally occupied buildings, the density of population in areas through which the pipeline passes, whether the pipeline is located within a corridor of hazardous pipelines and the likely causes of failure.

Potential causes of pipeline damage which can lead to subsequent failure include the activities of third parties carrying out agricultural or construction works along the route of the pipeline, such as those associated with deep working of the land, drainage, installation and maintenance of underground services and general road works.

The provision of suitable and safe access for in-service inspection should be included at the design stage.

NOTE The safety and reliability of a pipeline system can be improved by the application of quality assurance procedures in design (see Clause 4).

5.4.2 Safety evaluation

Where a safety evaluation is required, it should be carried out in accordance with Annex E.

NOTE Attention is drawn to the Pipelines Safety Regulations 1996 [15] in respect of the requirement to carry out a safety evaluation for major accident hazard pipelines (MAHPs).

5.5 Location of pipeline systems

5.5.1 Classification

The location of pipelines conveying category C, category D or category E substances should be classified in relation to population density along the route of the pipeline, to determine the operating stress levels and proximity distances from normally occupied buildings. Location should be classified in accordance with Table 2.

NOTE The location of pipelines conveying category A or category B substances need not be classified in relation to population density, but pipelines conveying category B substances can require extra protection or be subjected to a safety evaluation (see 5.4.2 and Annex E).

Table 2 Classification of location in relation to population density

Location class	Description
1	Areas with a population density less than 2.5 persons per hectare
2	Areas with a population density greater than or equal to 2.5 persons per hectare and which might be extensively developed with residential properties, schools and shops, etc.
3	Central areas of towns and cities with a high population and building density, multi-storey buildings, dense traffic and numerous underground services

NOTE The measurement of population density is described in 5.5.2.

Any relevant additional factors should be taken into account when classifying pipeline location, such as possible future developments, topographical features in the area through which the pipeline passes, and watercourses crossed or adjacent to the pipeline leading to areas of higher population density. In these and other comparable cases, a more stringent classification of location should be used when necessary, especially where the effects of a pipeline failure could be experienced by population centres outside the immediate vicinity of the pipeline.

5.5.2 Population density

The population density should be expressed in terms of number of persons per hectare. Measurement of population density should be based on a survey of normally occupied buildings, including houses, schools, hospitals, public halls, and industrial units. The population should be estimated following consultation with local authorities to assess the population level in the area concerned.

For pipelines conveying category C, category D or category E substances, the population density should be calculated as the total of the average number of persons normally occupying buildings lying within the 0.3 cpm individual risk contours for the pipeline.

Individual risk contours used for the purposes of calculating the population density and the minimum distance between a pipeline and occupied buildings should be calculated using a casualty criterion corresponding to a dangerous dose or worse (equivalent to 1% lethality), in order to be consistent with land use planning zones, as detailed in PD 8010-3:2009+A1, Annex A.

NOTE A casualty criterion corresponding to a significant likelihood of death (50% lethality) is commonly used in risk assessments; see Annex E and PD 8010-3:2009+A1.

Where individual risk levels are not available, the population density for pipelines conveying category C substances should be calculated as the total of the average number of persons normally occupying buildings within a strip centred on the pipeline of width three times the minimum distance given in 5.5.3.2 for any 1.6 km length of pipeline. For pipelines conveying category D or category E substances, the population density should be calculated as the total of the average number of persons normally occupying buildings within a strip centred on the pipeline of width eight times the minimum distance given in 5.5.3.2 for any 1.6 km length of pipeline.

It is recommended that the boundary between location class 1 and class 2 in relation to population density is determined in a manner equivalent to that used in IGEM/TD/1 Edition 5:2012 to determine the boundary between Type R and Type S areas. On this basis, the point at which the required degree of protection changes adjacent to the boundary between location class 1 and class 2 areas should be determined as the point at which the population density exceeds the class 1 limit. In order to determine the boundary position, the population should be calculated within circles of diameter equivalent to twice the 0.3 cpm risk contour distance from the pipeline or eight times the distance calculated in accordance with 5.5.3.2. By using such circles in sequence outwards from the high density area, the circle within which the population density first falls below/above 2.5 persons per hectare should be determined. The centre of this circle should then be taken as the class 1/class 2 boundary.

Occasionally the method of population density assessment can lead to an anomaly in location class such as might occur, for example, in a ribbon development area. In such cases, a more stringent classification than would be indicated by population density alone should be used where necessary. Societal risk should be taken into account in these instances.

When routeing pipelines conveying toxic substances, a more stringent classification should be given where populated areas with the characteristics of location classes 2 or 3 are outside, but close to the edge of, the strip used to define the population density. Societal risk should be taken into account in these instances.

A strip centred on the pipeline of width sixteen times the minimum distance given in 5.5.3.2 should be used when identifying populated areas that might be of concern.

5.5.3 Proximity to occupied buildings

5.5.3.1 Pipelines conveying category A or category B substances

The minimum distance between a pipeline conveying category A or category B substances and occupied buildings should be determined by the designer, who should take into account both access requirements during construction, and access requirements for maintenance and emergency services during operation.

5.5.3.2 Pipelines conveying category C, category D or category E substances

For pipelines conveying category C, category D or category E substances, the initial route and population density assessment should be established by the designer at the feasibility study stage.

- a) Where individual risk contours have been calculated for the pipelines, these should be used. The distance for routeing purposes between a pipeline and occupied buildings should be no less than the distance to the 10 cpm risk contour.

NOTE 1 Land use planning controls exercised by local planning authorities can require this distance to increase, with the consequent reappraisal of pipe wall thickness or mitigating measures. See also E.10.

- b) Where individual risk contours are not available, the initial route and population density assessment should take account of the proximity to occupied buildings.
- c) For pipelines having a design factor not exceeding 0.72, the minimum distance for routeing purposes between the pipeline and occupied buildings, Y , should be determined using equation (1).

$$Y = Q \left(\frac{D_o^2}{32000} + \frac{D_o}{160} + 11 \right) \left(\frac{p}{3.2} + 1.4 \right) \quad (1)$$

The substance factor Q should be determined in accordance with Table 3.

NOTE 2 The substance factors give cautious estimates of the minimum distance for routeing purposes. A more rigorous analysis using a risk-based approach gives smaller distances.

Table 3 **Substance factors**

Substance	Substance factor, Q
Ammonia	2.5
Carbon dioxide	2.0 for dense phase and 1.0 for gas phase ^{A)}
Ethylene	0.8
Hydrogen	0.45
Liquid petroleum gas	1.0
Natural gas liquids	1.25
Category C	0.3

^{A)} The substance factor for carbon dioxide is informative. The selected value should be supported by reference to joint industry or project specific research and guidance on the routeing of pipelines conveying carbon dioxide.

The proximity distances for pipelines conveying category C substances at pressures less than 3.5 N/mm² (35 bar) should be the same as those for the substance calculated at 3.5 N/mm² (35 bar).

Substances not specifically listed by name in Table 3 should be given the substance factor most closely similar in hazard potential to those quoted.

For pipelines conveying category C substances and having a design factor not exceeding 0.3, the initial route may be established by allowing a minimum distance of 3 m between the pipeline and occupied buildings. For pipelines conveying category D substances and having a design factor not exceeding 0.3 and a wall thickness greater than or equal to 11.91 mm, the initial route may be established by allowing a minimum distance of 3 m between the pipeline and occupied buildings.

For pipelines conveying category E substances and having a design factor not exceeding 0.3 and a wall thickness greater than or equal to 11.91 mm, the initial route may be established by allowing a minimum distance of 5.5Q m between the pipeline and occupied buildings.

A more rigorous analysis using a risk-based approach should be used for the final design limits. For pipelines conveying category D or category E substances, societal risk should be taken into account.

NOTE 3 Guidance is given in PD 8010-3:2009+A1.

NOTE 4 A societal risk calculation is not normally required for pipelines conveying category D substances if the area types and proximity distances in IGENITD/1 Edition 5:2012 are followed.

Societal risk calculations should be carried out for pipelines conveying toxic category E substances (e.g. ammonia or carbon dioxide).

5.6 Route selection

Safety, environmental, technical and economic considerations should be the primary factors governing the choice of pipeline routes. The shortest route might not be the most suitable, and physical obstacles, environmental and other factors should be taken into account.

Route selection should further take into account the design, construction, operation, maintenance and abandonment of the pipeline. To minimize the possibility of future corrective work and limitations, anticipated urban and industrial developments should be taken into account.

For pipeline route selection, the specific recommendations given in Annex F should be followed.

6 Design – Mechanical integrity

COMMENTARY ON CLAUSE 6

This clause deals with the mechanical integrity of a pipeline. Recommendations for pipeline system and safety design are given in Clause 5.

6.1 General

The methods used in designing pipelines should be selected in accordance with good engineering practice. Methods of analysis may be based on analytical, numerical or empirical models, or a combination of these methods.

6.2 Design criteria

COMMENTARY ON 6.2

The design criteria or design basis of a pipeline are determined by how hazardous the fluid to be conveyed is and how difficult the route is. The more hazardous the fluid, the higher the design quality and the more detailed the design.

6.2.1 Process conditions (pressure–temperature ratings)

6.2.1.1 Pipe and components having specific pressure–temperature ratings

The pressure–temperature ratings for pipe and components should be consistent with the appropriate component standard(s) selected for the project.

6.2.1.2 Components not having specific pressure–temperature ratings

If components not having specific pressure–temperature ratings are to be used, the pressure design should be based on sound engineering analysis supported by proof tests, experimental stress analysis and/or engineering calculations as appropriate.

6.2.1.3 Normal operating conditions

For normal operation the MAOP should not exceed the internal design pressure and pressure ratings for the components used. It should exclude surge pressure, thermal relief pressure and other variations that can occasionally occur above the design pressure.

NOTE The MAOP may be reviewed and revised during the lifetime of the pipeline according to the pressure source, overall pipeline system integrity and condition of the pressure envelope.

6.2.1.4 Allowance for variations from normal operation

NOTE Surge pressures that occur in liquid pipelines can be produced by sudden changes in flow, for example, following valve closure, pump shutdown, pump start-up or blockage of the moving stream.

Surge pressure calculations should be carried out to assess the maximum positive and negative surge pressures in the system. Account should be taken of surge pressures produced within the pipeline affecting systems that are outside the scope of this part of PD 8010, such as upstream of pumping stations or downstream of pipeline terminals.

6.2.1.5 Overpressure protection

Controls and protective equipment should be provided to ensure that the incidental pressure which is the sum of the operational pressure, the surge pressure, thermal relief pressure or other variations from normal operations does not exceed the internal design pressure at any point in the pipeline system by more than 10%.

NOTE The safe operating limit defined in the Pipelines Safety Regulations 1996 [15] is equal to or greater than the incidental pressure.

6.2.1.6 Different pressure conditions

When two pipeline systems operating at different pressure conditions are connected, the valves or components separating the two pipeline systems should be designed for the more severe design conditions.

6.2.2 Pressure design of pipeline and pipeline components

6.2.2.1 Straight pipe under internal pressure

The nominal thickness of steel pipe, minus the specified manufacturing tolerance on wall thickness and the designated corrosion allowance where applicable, should be not less than the design thickness used in the calculation of hoop stress (see 6.4.2.1). A nominal pipe wall thickness should be selected to ensure structural integrity in construction handling and welding.

NOTE For treatment of corrosion allowance, see 6.8.1.

6.2.2.2 Straight pipe under external loading

Pipe wall thickness should be sufficient to prevent collapse under conditions during construction or operation when the external pressure exceeds the internal pressure, taking into account pipe mechanical properties, bending stresses, dimensional tolerance and external loads (see BS EN 13480-3 or ASME B31.3).

For pipelines assuming a natural curvature that incurs a permanent elastic bending stress, the minimum bending radius should be determined at the design stage through stress analysis.

6.2.2.3 Bends

Changes in direction may be made by bending pipe or installing factory-made bends or elbows. All bends should be free from buckling, cracks or other evidence of mechanical damage. The nominal internal diameter of a bend should not be reduced in ovality by more than 2.5% at any point around the bend. Sufficient tangent lengths should be left at each end of a bend to ensure good alignment and to facilitate welding. Pipes bent cold should not contain a girth weld within the bent section.

The wall thickness of finished bends should take into account wall thinning at the outer radius and the torus effect, and therefore should be greater than the design thickness shown in 6.2.2.1. An indication of wall thinning as a percentage can be calculated using equation (2).

$$t_{\text{thin}} = \frac{50}{n + 1} \quad (2)$$

This formula does not take into account other factors that depend on the bending process, and the bend manufacturer should be consulted where wall thinning is critical.

NOTE 1 See 8.3.5 for materials aspects of bending and 10.12.5 for field bending during construction.

Mitred, wrinkled or gusseted bends should not be used in pipelines, with the exception of pipelines conveying category A substances at low pressure (see Note 2). Account should be taken of the use of cleaning, scraper and internal inspection devices (pigs) when specifying the radius of bends intended for installation in pipelines.

NOTE 2 For existing pipelines with mitred, wrinkled or gusseted bends, a fitness-for-purpose assessment is needed for revalidation to ensure structural integrity.

Factory-made bends and factory-made wrought steel elbows may be used provided that they are in accordance with 8.3.5 and the present subclause.

NOTE 3 Additional forces might need to be taken into account.

6.3 Loads

6.3.1 General

The design should account for loads that can cause or contribute to pipeline failure or loss of serviceability. The design should be for the most severe coincident conditions of pressure, temperature and loading which could occur during normal operation or testing.

The loads described in Annex G should be taken into account, and the recommendations in Annex G should be followed for each type of load.

6.3.2 Internal design pressure

The internal design pressure used in design calculations should be not less than the MAOP at that point.

NOTE 1 The MAOP is the sum of the operating pressure, static head pressure, the pressure required to overcome friction losses and any necessary backpressure. The net internal design pressure used in design calculations may be modified by taking into account the difference in pressure between the inside and outside of any pipeline component.

NOTE 2 The pressure definitions are illustrated in Figure 3.

6.4 Strength

6.4.1 Design factors

6.4.1.1 General

NOTE 1 See 5.2 for fluid categorization and 5.5.1 for location classifications.

NOTE 2 BS EN 14161 allows a design factor of up to 0.77 to be used (up to 0.83 for environments such as desert and tundra).

The design factors in 6.4.1.2, 6.4.1.3 and 6.4.1.4 should be used.

6.4.1.2 Category B substances

For pipelines designed to convey category B substances, the design factor, a , should under normal circumstances not exceed 0.72 in any location (see 6.4.1.3). In areas of high population density extensively developed with residential properties, schools, shops, public buildings and industrial areas, extra protection to the pipeline should be provided where necessary, as described in E.9.

6.4.1.3 Category C, category D and category E substances

For pipelines designed to convey category C, category D or category E substances, the design factor, a , should under normal circumstances not exceed 0.72 in class 1 locations. In class 2 locations, the design factor should normally not exceed 0.30, but this may be raised to a maximum of 0.72 provided that it can be justified to a statutory authority by a risk analysis carried out as part of a safety evaluation for the pipeline.

For pipelines designed to convey category C substances that are to be pneumatically tested, the design factor should not exceed 0.30, unless this can be justified through a fracture mechanics analysis.

Pipelines designed to convey category D or category E substances in class 2 locations should either have a nominal wall thickness of at least 9.52 mm or be provided with impact protection in accordance with 6.9.7 (see also E.9) to reduce the likelihood of penetration from mechanical interference.

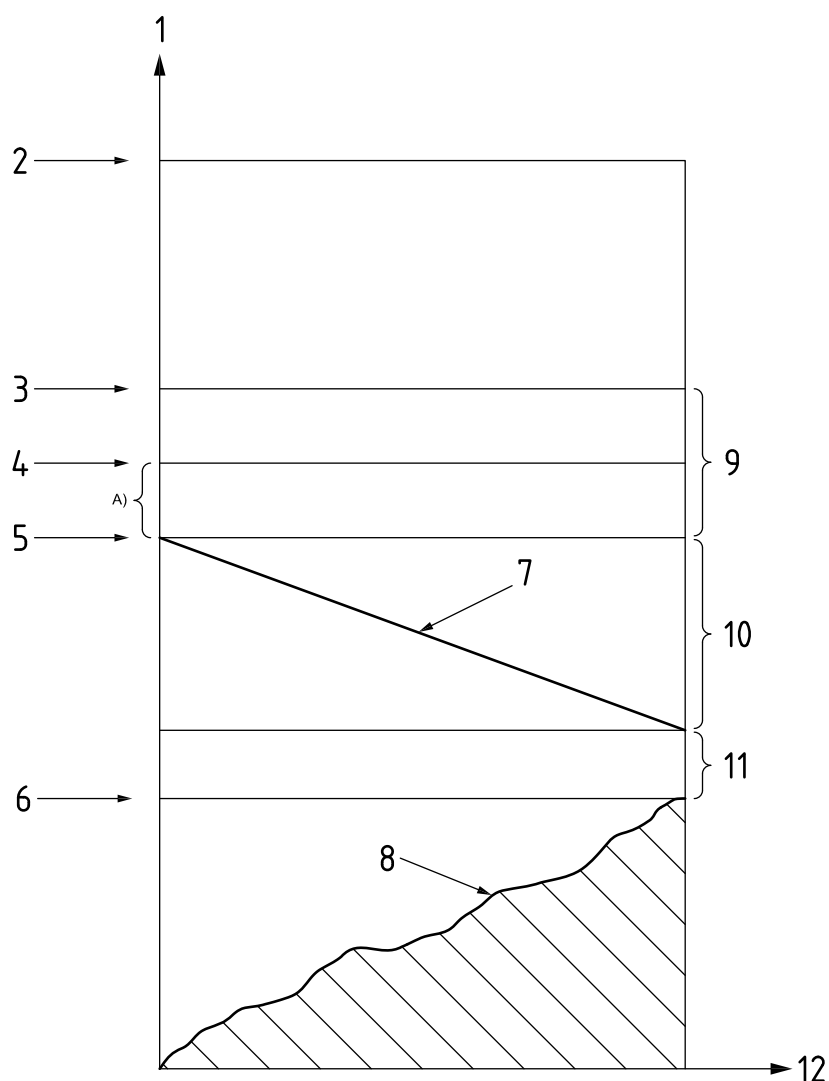
Routeing of pipelines conveying category C (hazardous), category D or category E substances through class 3 locations should be avoided.

6.4.1.4 Design factors above 0.72

NOTE 1 The UK regulatory authorities recommend that design factors be no higher than 0.72. A full risk assessment (see Annex E) is recommended if design factors above 0.72 are used, and might be subject to regulatory review.

Any increase in design factor above 0.72 should be applied to pipelines in class 1 areas or minor incursions into class 2 areas only.

Figure 3 Design and test pressure

**Key**

- | | |
|--|---|
| 1 Pressure | 8 Ground profile |
| 2 Test pressure | 9 Surge pressure, thermal and other variations |
| 3 $1.10 \times$ internal design pressure | 10 Pressure recommended to overcome friction losses |
| 4 Net internal design pressure ^{A)} | 11 Recommended backpressure |
| 5 Maximum allowable operating pressure ^{A)} | 12 Distance along pipe |
| 6 Static head pressure | |
| 7 Hydraulic gradient | |

^{A)} The MAOP may vary between these limits dependent upon the test pressure.

If design factors above 0.72 are to be adopted, it should be demonstrated to the regulatory authorities that the increase in failure probability and risk due to the ultimate limit states is not significant when compared to operation at the design factors recommended in 6.4.1.2 and 6.4.1.3. Such demonstration should be provided through the use of risk-based techniques and structural reliability analysis or other relevant advanced analysis methods.

All relevant ultimate limit states should be taken into account and the limit state principles and requirements should be applied consistently and comprehensively throughout the design.

The design should also take account of the relevant serviceability limit states.

NOTE 2 Further information on these methods and their application to category D substances and the justification and use of higher design factors is given in IGM/ITD/1 Edition 5:2012. Information is also given in BS EN ISO 16708.

All relevant sources of uncertainty in loads (including fatigue) and load resistance should be taken into account, and statistical data should be obtained for characterization of these uncertainties.

NOTE 3 BS EN 1594 provides some general guidance on the application of structural reliability-based limit state design principles.

NOTE 4 Ultimate limit states are normally associated with loss of structural integrity (product containment), e.g. rupture, fracture, or collapse, whereas exceeding serviceability limit states prevents the pipeline from operating as intended.

6.4.2 Calculation of stresses

6.4.2.1 Hoop stress

The hoop stress, S_h , developed in the pipe wall at the internal design pressure should not exceed the allowable hoop stress, S_{ah} , given in 6.4.3.1. The hoop stress should be calculated using equation (3) for thin pipe walls and equation (4) for thick pipe walls (the thick wall equation should be used when the D_o/t_{min} ratio is less than or equal to 20). This gives the maximum hoop stress encountered at the outside face of the pipe wall.

Thin wall:

$$S_h = \frac{pD_o}{2t_{min}} \quad (3)$$

Thick wall:

$$S_h = \frac{p(D_o^2 + D_i^2)}{(D_o^2 - D_i^2)} \quad (4)$$

where D_i is given by $(D_o - 2t_{min})$.

NOTE Equation (4) gives a more accurate calculation of hoop stress and always gives the lowest value of maximum stress. When the D_o/t_{min} ratio is greater than 20, the difference between the stresses calculated from the two formulae is less than 5%.

6.4.2.2 Expansion and flexibility

Pipelines and piping should be designed with sufficient flexibility to prevent expansion or contraction causing excessive forces or stresses in pipe material, joints, equipment, anchors or supports.

Expansion calculations should be carried out for buried and above-ground pipelines where flexibility is in doubt, and where significant temperature changes are expected such as those which occur in heated oil or refrigerated

pipelines. Thermal and pressure expansion or contraction of buried pipelines can cause movement at termination points, changes in direction or changes in size. The necessary flexibility should be provided if such movements are unrestrained. Account should be taken of buckling forces that can be imposed on pipelines laid where ground movement might occur (see 6.4.4).

The effect of restraints, such as support friction, branch connections and lateral interferences, should be taken into account.

Calculations should take into account stress intensification factors found to be present in components such as bends and field joints (other than plain straight pipe). Account should be taken of any extra flexibility of such components.

NOTE In the absence of more directly applicable data, the flexibility factors and stress intensification factors given in BS EN 13480-3 or ASME B31.3 may be used.

Above-ground pipelines and piping can be restrained by anchors so that the longitudinal movement owing to thermal and pressure changes is absorbed by direct axial compression or tension of the pipe. In such cases expansion calculations should be carried out taking into account all the forces acting on the pipeline. Account should be taken of elastic instability due to longitudinal compressive forces.

Where movement is restrained, flexibility should be provided by means of loops, offsets or special fittings. The total operating temperature range should be taken as the difference between the maximum and minimum metal temperatures for the operating cycle under consideration and should be used in calculating stresses in loops, bends and offsets.

The temperature range used in the calculation of reactions on anchors and equipment should be taken as the difference between the maximum or minimum metal temperatures and the installation temperature, whichever gives the greater reaction.

Where there is a likelihood of repeated stress changes (including thermal stress) giving rise to fatigue conditions, the stress range and allowable number of cycles should be calculated in accordance with 6.4.6.

Nominal pipe wall thickness (including any corrosion allowance) and nominal outside diameter should be used for expansion and flexibility calculations.

6.4.2.3 Longitudinal stress

The total longitudinal stress should be the sum of the longitudinal stress arising from pressure, bending, temperature, mass, other sustained loadings and occasional loadings (see Annex G).

NOTE A pipeline is deemed to be totally restrained when axial movement and bending resulting from temperature or pressure change is totally prevented.

For totally restrained sections of a pipeline, the longitudinal tensile stress, S_{L1} , resulting from the combined effects of temperature and pressure change alone should be calculated using equation (5) for thin wall or equation (6) for thick wall.

Thin wall:

$$S_{L1} = \nu S_{hl} - E\alpha(T_2 - T_1) \quad (5)$$

Thick wall:

$$S_{L1} = \nu(S_{hl} - p) - E\alpha(T_2 - T_1) \quad (6)$$

where S_{hl} is calculated using equation (3) or (4) as appropriate, but using the nominal pipe wall thickness, t_{nom} , instead of t_{min} .

For unrestrained sections of a pipeline, the longitudinal tensile stress, S_{L2} , resulting from the combined effects of temperature and pressure change alone should be calculated using equation (7) for thin wall or equation (8) for thick wall.

Thin wall:

$$S_{L2} = \frac{S_{hl}}{k^2 + 1} + \frac{1000M_b i}{Z} \quad (7)$$

where $k = 1$.

Thick wall:

$$S_{L2} = \frac{S_{hl}}{k^2 + 1} + \frac{1000M_b i}{Z} \quad (8)$$

where $k = D_o/D_i$.

6.4.2.4 Shear stress

The shear stress, τ , should be calculated from the torque and shear force applied to the pipeline using equation (9).

$$\tau = \frac{1000T}{2Z} + \frac{2F_s}{A} \quad (9)$$

6.4.2.5 Equivalent stress

The equivalent stress, S_e , should not exceed the allowable equivalent stress, S_{ae} , given in 6.4.3.2. The equivalent stress should be calculated using equation (10).

$$S_e = (S_{hl}^2 + S_L^2 - S_{hl}S_L + 3\tau^2)^{0.5} \quad (10)$$

where S_{hl} is calculated using equation (3) or (4) as appropriate, but using the nominal pipe wall thickness, t_{nom} , instead of t_{min} .

NOTE Equation (10) gives the von Mises equivalent stress criterion. This has been derived from the full equation by assuming that the third principal stress is negligible.

6.4.3 Limits of calculated stress

6.4.3.1 Allowable hoop stress

The allowable hoop stress, S_{ah} , should be calculated using equation (11).

$$S_{ah} = aeS_y \quad (11)$$

The weld joint factor, e , should be 1.0 for pipe conforming to BS EN ISO 3183:2012 and/or API 5L:2012 when supplied as seamless, longitudinally welded or spirally welded pipe. If the pipe history is unknown, the weld joint factor e should not exceed 0.60 for pipe of 0.114 m outside diameter or smaller, or 0.80 for pipe larger than 0.114 m outside diameter.

NOTE The effect of temperature de-rating on the SMYS of carbon steel is included in the design factors for temperatures up to 120 °C.

6.4.3.2 Allowable equivalent stress

The allowable equivalent stress, S_{ae} , should be calculated using equation (12).

$$S_{ae} = 0.9S_y \quad (12)$$

NOTE Further guidance is given in BS EN 13480, ASME B31.3 and ASME B31.8.

6.4.4 Strain-based design

The limit on equivalent stress recommended in 6.4.2.5 may be replaced by a limit on allowable strain, provided that all the following conditions are met.

- a) The allowable hoop stress criterion (see 6.4.2.1 and 6.4.2.2) is met.
- b) Under the maximum operating temperature and pressure, the plastic component of the equivalent strain does not exceed 0.005 (0.5%).
- c) The reference state for zero strain is the as-built state (after pressure test). The plastic component of the equivalent uniaxial tensile strain should be calculated using equation (13).

$$\varepsilon_p = \left\{ \frac{2}{3} (\varepsilon_{pL}^2 + \varepsilon_{pH}^2 + \varepsilon_{pr}^2) \right\}^{0.5} \quad (13)$$

This analysis can be performed conservatively by assuming a linearly elastic – perfectly plastic stress/strain curve. Other, more realistic stress/strain curves may be used. However, it is essential that the assumed curve is validated as being conservative by material stress/strain curves from the manufactured pipe.

- d) Any plastic deformation occurs only when the pipeline is first raised to its maximum operating pressure and temperature, but not during subsequent cycles of depressurization, reduction in temperature to the minimum operating temperature, or return to the maximum operating pressure and temperature.

This should be determined via analytical methods or an appropriate finite element analysis. The analysis should include an estimate of the operational cycles that the pipeline is likely to experience during the operational lifetime.

- e) The D_o/t_{nom} ratio does not exceed 60.
- f) Axial or angular misalignment at welds is maintained within defined tolerances.
- g) A fracture analysis is carried out in accordance with 6.4.6.
- h) A fatigue analysis is carried in accordance with 6.4.7.
- i) The weld metal yield stress matches or overmatches the longitudinal yield stress of the pipe.
- j) For welds where allowable defect sizes are based on an ECA, UT supplements radiographic testing, unless automated ultrasonic testing (AUT) is performed.
- k) Additional limit states are analysed as follows:
 - 1) bending failure resulting from application of a moment in excess of the moment capacity of the pipe;
 - 2) ovalization – distortion of the pipe wall associated with bending to high strain levels (see 6.4.5.2 and Annex H);
 - 3) local buckling (see 6.4.5.1 and Annex H);
 - 4) global buckling – lateral or upheaval buckling due to overall axial compression (see 6.4.5.1 and Annex H).

Plastic deformation reduces pipeline flexural rigidity; this effect can reduce resistance to upheaval buckling and should be checked if upheaval buckling might occur. The effects of strain localization should be taken into account in the strain-based design.

NOTE Strain localization is associated with discontinuities in stiffness of the pipeline (bending or axial) and can therefore develop in the following locations:

- *changes in wall thickness;*
- *locally thinned regions, e.g. due to corrosion;*
- *field joints and coatings;*
- *welds, due to under matching of the strength of the weld.*

6.4.5 Buckling

6.4.5.1 General

NOTE 1 Buckling on above-ground pipelines is usually covered by a local stress analysis.

For onshore buried pipelines, the need for buckling analysis should be assessed.

Buckling due to overburden and/or external loads should be taken into account at areas of impact protection or increased overburden, areas where landscaping will cause increased overburden or where ground movement could occur, road, rail, river, and water crossings/parallel encroachments, and areas where the external loads are or could in the future be substantial.

The following buckling modes should be taken into account:

- a) local buckling of the pipe due to external pressure, axial tension or compression, bending and torsion, or a combination of these loads (see H.1). For fabrication processes which introduce cold deformations giving different strength in tension and compression, a fabrication factor, α_{fab} , should be determined;

NOTE 2 Guidance on the selection of a suitable fabrication factor is given in DNV-OS-F101:2013, Section 5.

- b) propagation buckling due to external pressure following the formation of local buckles or localized damage (see H.2);
- c) restrained pipe buckling due to axial compressive forces induced by high operating temperatures and pressures. This can take the form of horizontal snaking for exposed pipelines or vertical upheaval of trenched or buried pipelines (see H.3).

NOTE 3 The formulae given in Annex H define one approach to analysis. Alternative approaches are available and may be used where justified.

NOTE 4 To supplement the above methodology, the approaches defined within DNV-OS-F101 and DNV-RP-F110 may be adopted.

In all buckling analyses, the nominal wall thickness should be used.

6.4.5.2 Ovality

Ovality, or out-of-roundness, of pipes or a section of pipeline that could cause buckling or interference with pigging operations should be avoided.

NOTE 1 In some situations, where loading is dominated by bending, buckling might not occur but unacceptable levels of ovalization can result.

NOTE 2 Ovalization may be calculated in accordance with H.4 in the absence of a more rigorous evaluation.

6.4.5.3 Coatings

Any beneficial effect of weight coating or insulation coating on buckling should not be taken into account in an analysis, unless analytical and experimental evidence is provided that indicates its effectiveness in providing additional stiffness.

6.4.5.4 Controlled deformation

Internal pressure and temperature can lead to transverse movements if the pipeline is not restrained, e.g. by burial. For exposed pipes in contact with the land and not on a formalized pipe rack structure, lateral movement is more likely and analysis for snaking and buckling should be performed. For buried pipelines, upheaval buckling analysis should be performed (see 6.4.5.5).

NOTE Annex H, H.1 gives information on the critical strain limits. H.1.7 provides a conservative estimate of the bending strain.

6.4.5.5 Upheaval buckling

For exposed pipelines in contact with the land surface, lateral buckling can develop at relatively low levels of effective compression and checks should be carried out to demonstrate the pipeline's fitness for purpose.

An upheaval buckling design should demonstrate integrity of the buried pipeline with an overall agreed safety margin, taking into account the variability of all design parameters. The design should establish cover levels along the route taking into account the as-laid vertical, out-of-straight pipeline profile and the long-term and short-term characteristics of the cover material. Additionally, the stress/strain levels along the pipeline should be shown to be within allowable limits.

The effect of soil liquefaction should be taken into account.

6.4.6 Fracture

6.4.6.1 Fracture control

A pipeline should be designed to prevent brittle and ductile fracture.

NOTE 1 The principal means of fracture control is by the selection of materials with adequate toughness through notched bar impact testing (see 8.2.5).

The material properties should be in accordance with 8.2.5 such that brittle fracture initiation or propagation does not occur, and that ductile fracture propagation is limited in length.

NOTE 2 Pipelines conveying a gas or a volatile liquid are susceptible to long running fractures (also known as propagating fractures). Toughness requirements for preventing long running fractures are given in BS EN ISO 3183:2012, Annex G.

6.4.6.2 Engineering critical assessments (ECA)

Weld flaw acceptance criteria may be based on workmanship acceptance levels or fitness-for-service limits, determined by either an engineering critical assessment (ECA), or segment or full-scale testing. Fitness-for-service limits should take into account all static and cyclic (dynamic) loading that occurs during installation and operation. It should be demonstrated that fabrication flaws in the weld metal and heat-affected zone (HAZ) will not cause failure during installation or operation.

ECA should be conducted in accordance with BS 7910. The equations of BS 7910 are potentially non-conservative for strain-based design (>0.4% strain). In this case assessment should be confirmed by numerical simulation [finite element analysis (FEA) crack modelling]. If necessary, account should be taken of relevant results of full scale pipe tests, with pre-cracked girth welds, subjected to internal longitudinal strain and internal pressure.

NOTE 1 Guidance on conducting an ECA of pipeline girth welds is given in DNV-OS-F101:2013, Appendix A and DNV-RP-F108.

NOTE 2 An ECA is not normally required if the maximum total strain is less than or equal to 0.4%.

NOTE 3 Full scale testing is time consuming and complex to produce a statistically significant amount of data. ECA based on small scale (segment) tests is the main method.

ECA requires fracture toughness testing of representative welds to determine the fracture toughness of the weld and HAZ. The fracture toughness should be determined under representative environmental and service conditions. Fracture toughness testing should be conducted in accordance with BS EN ISO 15653 and BS 7448 as appropriate.

NOTE 4 BS 7910 gives guidance on the fracture toughness testing required for an ECA. DNV-OS-F101 and DNV-RP-F108 give guidance on testing pipeline girth welds.

6.4.7 Fatigue

6.4.7.1 General

All cyclic stresses due to pressure, thermal, or external loading, occurring during the entire life of the pipeline, should be taken into account when establishing the predicted significance or effect of fatigue.

In the assessment of stress ranges, the effect of construction activities that can cause stress concentrations should be taken into account.

All cyclic stresses between the threshold limit and the maximum allowable design stress should be addressed (see ASTM E1049).

NOTE Typical sources of cyclic stresses include:

- *transportation, installation and testing activities;*
- *dynamic stresses (wind, waves, currents, rivers, vortex shedding, road/rail and other traffic-induced stresses);*
- *pulsation-induced vibration (at or near stations, reciprocating pumps and compressors);*
- *vibrations caused by surge and product flow;*
- *full stress cycles (start-up to shutdown cycles);*
- *fluctuations in operational (pressure and thermal) cycles;*
- *external thermal stress cycles (above-ground pipelines);*
- *earthquakes and ground movements.*

6.4.7.2 Fatigue life

The fatigue life of a pipeline is determined from the total number of full stress cycles together with the number of equivalent stress cycles (i.e. range of stress cycles that are expected or experienced by the pipeline) which could cause fatigue failure. Pipelines should be designed to provide a fatigue life that exceeds the proposed design life of the pipeline.

The need for a fatigue analysis depends upon the number and value of stress cycles predicted to occur over the operational life of the pipeline and should be assessed in accordance with 6.4.7.3. In the case of revalidation it should be based on the actual number and known stresses experienced by the pipeline, plus the predicted life. Where required, the fatigue analysis should be carried out in accordance with 6.4.7.4.

6.4.7.3 Assessment of need for fatigue analysis

Any engineering assessment undertaken to revalidate a pipeline for a change of operating conditions, including an extension of the design life, should include an assessment of the fatigue life.

A simplified assessment should be carried out to establish whether a pipeline fatigue analysis is required. A fatigue analysis is not required if either:

- a) the maximum hoop stress cycle experienced by the pipeline is less than 35 N/mm²; or
- b) the system designed can be shown to replicate closely a previously analysed acceptable design.

The 35 N/mm² criterion should not be used for girth welds or circumferential flaws.

NOTE 1 Fatigue of girth welds depends mainly on the longitudinal stress range rather than hoop stress range.

NOTE 2 Additional guidance on the requirement for a fatigue analysis can be obtained from:

- *IGEM/ITD/1 Edition 5:2012, which provides guidance on determining the fatigue life of pipelines constructed and tested to IGE standards, made from materials conforming to API 5L:2012 and subjected to a high-level hydrostatic test (Clause 11);*
- *BS EN 13480-3:2012, Clause 10 for above-ground pipelines;*
- *ASME B31.3 and ASME BPVC-VIII-1 for pipelines designed in accordance with ASME standards;*
- *PD 5500:2012+A3, Annex C, which includes criteria for establishing whether a detailed fatigue analysis is required, and gives guidance on how to conduct a fatigue analysis.*

BS EN 13480-3 and PD 5500 may be used in combination with BS 7608 for the appropriate equivalent material S-N curves.

6.4.7.4 Fatigue analysis

A fatigue analysis should be carried out to determine the fatigue life of the pipeline unless shown otherwise in 6.4.7.3.

NOTE 1 The fatigue life is dependent upon the number and range of stress cycles that are expected to occur, and the maximum size of defect that can exist.

The fatigue analysis should be carried out using one of the standards listed in the Note to 6.4.7.3 together with an appropriate S-N curve (i.e. one that is specific to the material type, environment, frequency, workmanship and quality achieved during construction).

Account should be taken of stress concentrations owing to pipe ovality, misalignments, material type change and local shape deviations.

The fatigue analysis method, material properties and other input data used in the assessments should be documented and fully justified.

The actual cycles accumulated during operation should be recorded and maintained for future evaluation of the pipeline.

Where an appropriate S-N curve is not available then an S-N curve should be produced through fatigue testing or a fracture mechanics based fatigue analysis should be conducted.

NOTE 2 The S-N curves in BS 7608 might not be applicable to low cycle, high strain fatigue loading that might be encountered in a strain-based design.

The S-N curves recommended in BS 7608 have been developed for application to normal structural joints which are in general accessible to inspection and have a level of redundancy. Pipelines are non-redundant structures and accessibility for inspection is limited, so an appropriate factor of safety should be included on the fatigue life predicted using the S-N technique.

The safety factor should be selected and justified as part of the design fatigue analysis, taking into account accessibility for and reliability of inspection, uncertainty in the number and value of stress cycles and the severity of consequences of failure.

NOTE 3 Safety factors typically applied to pipeline fatigue design analysis range from 1 for non-hazardous, non-critical pipelines to between 3 and 10 for hazardous pipelines.

NOTE 4 These safety factors may be relaxed for pipelines that are located above ground provided the area of the defect can be fully mapped and assessed.

6.4.7.5 Re-qualification of pipeline design

A fatigue analysis should be carried out to re-qualify the pipeline if an extension to the current design life or a change in the duty of the pipeline (i.e. change in product or service causing a modification which raises the internal pressure, or introduces more pressure cycles) is proposed.

The analysis should demonstrate that the largest defect in the system will not grow through fatigue to failure during the re-qualified design life of the pipeline. The largest defect size should be determined through non-destructive testing (NDT) methods such as the use of an in-line inspection tool or, if necessary, a repeat hydrotest (conducted at a level determined by the largest defect that may be accepted). Any NDT approach should be capable of detecting and reliably sizing crack-like defects, particularly in the longitudinal direction.

Mid-wall (lamellar) defects should be taken into account in the fatigue analysis, and a specific fitness-for-purpose assessment of these defects undertaken.

NOTE API RP 579 contains guidance on the assessment of dents, gouges and laminations.

6.5 Stability

Pipelines should be designed to prevent horizontal and vertical movement, or should be designed with sufficient flexibility to allow predicted movements within the strength criteria as recommended in 6.4 and stress limits as stated in 6.4.3.

Factors that should be taken into account in the stability design include:

- a) hydrodynamic and wind loads;
- b) axial compressive forces at pipeline bends and lateral forces at branch connections;
- c) lateral deflection due to axial compression loads in the pipelines;
- d) exposure due to general erosion or local scour;
- e) geotechnical conditions including soil instability, e.g. due to seismic activity, slope failures, frost heave, thaw settlement and groundwater level;
- f) construction method;
- g) trenching and/or backfilling techniques.

NOTE Stability for pipelines can be enhanced by such means as pipe mass selection, anchoring, control of backfill material, soil cover, soil replacement, drainage, and insulation to avoid frost heave.

6.6 Spanning pipelines

Spans in pipelines should be controlled to ensure compliance with the strength criteria as recommended in 6.4 and stress limits as stated in 6.4.3. Factors that should be taken into account in spanning design include:

- a) support conditions;

- b) interaction with adjacent spans;
- c) possible vibrations induced by wind;
- d) axial force in the pipeline;
- e) soil accretion and erosion;
- f) possible effects from third-party activities;
- g) soil properties;
- h) excessive yielding.

6.7 Seismic analysis

Pipelines should be designed against the seismic loads listed in Annex G.

NOTE 1 The risk from seismic loadings in the UK is low.

NOTE 2 Further guidance on seismic design criteria is given in IGEN/ITD/1 Edition 5:2012.

6.8 Other activities

6.8.1 Corrosion allowance

A corrosion allowance on design thickness need not be included provided the substance to be conveyed is non-corrosive or measures are taken to prevent corrosion. Where internal corrosion, external corrosion or erosion is expected, a corrosion allowance should be made following a study or test that takes into account the type of corrosion expected and the intended life of the pipeline. No external corrosion allowance is needed if both an anti-corrosion coating system and cathodic protection are installed. Where a corrosion allowance is applied it should be added to the value of the design thickness (see 6.2.2).

6.8.2 Thermal insulation

Where pipelines are designed to convey substances that are either heated or refrigerated, thermal insulation can be necessary in addition to an anti-corrosion coating. Account should be taken of the differences between installation and operating temperatures in relation to axial stresses and movement. Thermal insulation systems should be designed to retain the operating temperature of the substance being conveyed within its process design limits at the lowest design flow rates.

NOTE Further information on the design of thermally insulated pipelines is given in BS 4508.

Thermal insulation may be built up from layers of different materials selected according to the temperature gradient through the system. Differences in coefficient of thermal expansion of the various materials and the pipe should be taken into account. Vapour barriers should be installed to prevent the migration of moisture within the insulation and subsequent damage to the pipeline material.

The design of insulation and anti-corrosion coatings should take account of the maximum operating temperature. Since the likelihood of external corrosion at elevated temperatures is higher than at ambient temperatures, and since above-ground coating damage inspection techniques are ineffective, the pipeline should be designed to accommodate internal inspection devices.

The depth of cover of heated or refrigerated pipelines in agricultural land should be sufficient to prevent adverse thermal effects on crop growth.

For refrigerated pipelines the possibility of frost heave should be taken into account.

6.8.3 Pipeline cover

Buried pipelines should be installed with a depth of cover not less than that shown in Table 4, unless a similar level of protection is provided by alternative methods.

Table 4 Pipeline cover

Location	Minimum depth of cover ^{A)}
Areas of limited or no human activity	0.9
Agricultural or horticultural activity ^{B)}	1.1
Watercourses, canals, rivers ^{C)}	1.2 ^{D)}
Roads ^{E)}	1.2 ^{D)}
Railways	1.4 to 1.8 ^{D)}
Residential, industrial, and commercial areas	1.2 ^{D)}
Rocky ground ^{F)}	0.5

^{A)} Depth of cover should be measured from the lowest possible ground surface level to the top of the pipe, including coatings and attachments.

^{B)} Cover should be not less than the depth of normal cultivation.

^{C)} To be measured from the lowest anticipated true clean bed level.

^{D)} Refer to the appropriate authorities.

^{E)} To be measured from the true clean bottom of the drainage ditches.

^{F)} The top of the pipe should be not less than 0.15 m below the surface of the rock with a total cover not less than 0.5 m. Impact protection should be used in vulnerable locations

NOTE An increased depth of cover can apply under the following cases:

- situations where frost heave could occur;
- areas where agriculture or horticultural practices require a greater depth;
- areas which could be subject to erosion;
- main rivers and other waterways;
- pipeline route sections where future construction is planned or likely to occur.

If a waterway is navigable, the pipeline should be protected against damage from ships' anchors or other hazards, e.g. existing or known future dredging activities.

6.8.4 Location of cathodic protection stations

The selection of sites for cathodic protection stations should take account of:

- distance from the pipeline route;
- ground resistivity;
- ease of access for maintenance;
- proximity to other buried metallic services and railways;
- proximity to power supplies;
- existing ground beds for other pipelines;
- minimum interference with agricultural operations.

Cathodic protection should be designed in accordance with BS ISO 15589-1.

6.9 Crossings and encroachments

6.9.1 Road crossings

6.9.1.1 General

NOTE Major roads would normally include motorways and trunk roads. Minor roads would normally include all other public roads.

The design of pipeline road crossings and parallel encroachments to roads should take account of daily and seasonal traffic density and risk of external interference in the area.

Private roads or tracks should be classified as minor roads only if there is reason to believe that they might be used regularly by heavy traffic. Assessments of traffic densities should be carried out by consultation with the national and local highway authorities concerned.

The design should take into account the intended method of installation of the road crossing, e.g. open-cut, boring or tunnelling, which is determined following consultation with the relevant highway authorities. The crossing design should take account of the ground conditions and include temporary works design.

6.9.1.2 Category A, category B and category C substances

For pipelines designed to convey category A, category B or category C substances, no revision to design factor or wall thickness is needed at road crossings.

For pipelines designed to convey category A or category B substances, impact protection should be provided at open-cut crossings of major roads, where necessary.

For pipelines designed to convey category C substances, impact protection should be provided at open-cut crossings of major roads.

6.9.1.3 Category D and category E substances

For pipelines designed to convey category D or category E substances, roads should be classified as major roads or minor roads for allocation of design factor and wall thickness.

For pipelines designed to convey category D or category E substances the design factor, a , should be 0.30 for both major and minor road crossings. However, the design factor may be raised to a maximum of 0.72 if this can be justified to a statutory authority by a risk analysis carried out as part of a safety evaluation for the pipeline (see Annex E).

Pipeline crossings of major roads should be carried out using either:

- a) pipe with a nominal wall thickness of 11.91 mm or greater without impact protection; or
- b) pipe with a wall thickness appropriate to the design factor and with impact protection in accordance with 6.9.7 (see also E.9).

For major roads the design factor, wall thickness or impact protection should extend for a distance equal to the minimum building proximity distance shown in IGEM/TD/1 Edition 5:2012 for methane, or the final minimum distance (see 5.5.3.2) for other category D and category E substances, measured at a right angle from the edge of the carriageway.

Pipeline crossings of minor roads should be carried out using either:

- 1) pipe with a nominal wall thickness of 9.52 mm or greater without impact protection; or

- 2) pipe with a wall thickness appropriate to the design factor and impact protection in accordance with **6.9.7** (see also **E.9**).

For minor roads the design factor, wall thickness or impact protection should extend between highway boundaries on each side of the crossing.

NOTE API 1102 gives detailed methods for analysis of road and rail crossings.

6.9.2 Rail crossings

Pipeline rail crossings should be designed and classified in the same manner as described in **6.9.1** for road crossings.

NOTE 1 Major rail routes would normally include intercity and high-density commuter routes. Minor rail routes would normally include all others.

The minimum distance between the top of the pipe or sleeve and the top of the rail should be 1.4 m for open cut crossings and 1.8 m for bored or tunnelled crossings. Assessment of traffic densities and crossing requirements should be carried out by consultation with the appropriate railway authority.

NOTE 2 Issues of settlement and settlement monitoring can arise on some routes.

6.9.3 Water crossings

Pipeline water crossings, e.g. river and canal crossings, should be designed in consultation with the water and waterways authorities to determine the minimum depth of cover and additional protection needed. The design of additional protection should take account of potential pipeline damage by ship's anchors, scour and tidal effects, flood defences and any known future works such as dredging, deepening and widening of the river or canal (see **10.13.4**).

NOTE Pipelines crossing rivers and estuaries which cannot be designed and constructed using normal land pipeline methods are classified as subsea pipelines and are outside the scope of this part of PD 8010. Recommendations for the design and construction of such pipelines are given in PD 8010-2.

6.9.4 Pipe bridge crossings

The preferred design for pipeline crossings is for the buried installation of pipe. Where it is necessary to utilize pipe bridges, these should be designed in accordance with good structural engineering practice. Pipe bridge design should take into account thermal and structural stresses, pipe carrier stresses and foundation loadings. Sufficient headroom should be provided to avoid possible damage from the movement of traffic or shipping beneath the pipe bridge. Account should be taken of accessibility requirements for maintenance and security, and of restrictions on access to the general public. The design should take account of potential cathodic protection interference between the pipeline and bridge supporting structure.

6.9.5 Sleeved crossings

The preferred design for pipeline crossings is for the installation of pipe without the use of sleeves to reduce the likelihood of corrosion and for ease of maintenance. Where particular circumstances indicate the need for a sleeved crossing, the guidance in **10.13.5** and IGEM/TD/1 Edition 5:2012, **7.21** should be followed, as necessary.

6.9.6 Parallel encroachments

Pipelines running parallel to major roads or major rail routes should have design factors appropriate to major road crossings if they encroach within the minimum building proximity distance shown in IGEM/TD/1 Edition 5:2012 for category D substances, or the final minimum distance (see **5.5.3.2**) for category C and category E substances.