
**Petroleum and natural gas industries —
Design and operation of subsea
production systems —**

**Part 11:
Flexible pipe systems for subsea and
marine applications**

*Industries du pétrole et du gaz naturel — Conception et exploitation des
systèmes de production immergés —*

*Partie 11: Systèmes de canalisations flexibles pour applications sous-
marines et en milieu marin*



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 13628-11 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 4, *Drilling and production equipment*.

This first edition of ISO 13628-11 cancels and replaces ISO 10420:1994, which has been technically revised.

ISO 13628 consists of the following parts, under the general title *Petroleum and natural gas industries — Design and operation of subsea production systems*:

- *Part 1: General requirements and recommendations*
- *Part 2: Unbonded flexible pipe systems for subsea and marine applications*
- *Part 3: Through flowline (TFL) systems*
- *Part 4: Subsea wellhead and tree equipment*
- *Part 5: Subsea umbilicals*
- *Part 6: Subsea production control systems*
- *Part 7: Completion/workover riser systems*
- *Part 8: Remotely Operated Vehicle (ROV) interfaces on subsea production systems*
- *Part 9: Remotely Operated Tool (ROT) intervention systems*
- *Part 10: Specification for bonded flexible pipe*
- *Part 11: Flexible pipe systems for subsea and marine applications*

A part 12 dealing with dynamic production risers, a part 13 dealing with remotely operated tools and interfaces on subsea production systems and a part 15 dealing with subsea structures and manifolds are under preparation.

Introduction

This part of ISO 13628 is based on API RP 17B and on matching ISO procedures and API procedures. This ISO standard has been technically updated and revised to cater for the needs of the international oil and natural gas industries. This part of ISO 13628 provides information complementary to ISO 13628-2 and ISO 13628-10.

Users of this International Standard should be aware that further or differing requirements can be needed for individual applications. This International Standard is not intended to inhibit a vendor from offering, or the purchaser from accepting, alternative equipment or engineering solutions for the individual application. This can be particularly applicable where there is innovative or developing technology. Where an alternative is offered, the vendor should identify any variations from this International Standard and provide details.

Petroleum and natural gas industries — Design and operation of subsea production systems —

Part 11: Flexible pipe systems for subsea and marine applications

1 Scope

This part of ISO 13628 provides guidelines for the design, analysis, manufacture, testing, installation and operation of flexible pipes and flexible pipe systems for onshore, subsea and marine applications. This part of ISO 13628 supplements ISO 13628-2 and ISO 13628-10, which specify minimum requirements for the design, material selection, manufacture, testing, marking and packaging of unbonded and bonded flexible pipe, respectively.

This part of ISO 13628 applies to flexible pipe assemblies, consisting of segments of flexible pipe body with end fittings attached to both ends. Both bonded and unbonded pipe types are covered. In addition, this part of ISO 13628 applies to flexible pipe systems, including ancillary components.

The applications covered by this part of ISO 13628 are sweet- and sour-service production, including export and injection applications. This part of ISO 13628 applies to both static and dynamic flexible pipe systems used as flowlines, risers and jumpers. This part of ISO 13628 does cover, in general terms, the use of flexible pipes for offshore loading systems.

NOTE Refer also to Reference [30] for offshore loading systems.

This part of ISO 13628 does not cover flexible pipes for use in choke and kill lines or umbilical and control lines.

2 Normative references

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

ISO 13628-2:2006, *Petroleum and natural gas industries — Design and operation of subsea production systems — Part 2: Unbonded flexible pipe systems for subsea and marine applications*

ISO 13628-3:2000, *Petroleum and natural gas industries — Design and operation of subsea production systems — Part 3: Through flowline (TFL) systems*

ISO 13628-10:2005, *Petroleum and natural gas industries — Design and operation of subsea production systems — Part 10: Specification for bonded flexible pipe*

NACE TM0177, *Laboratory testing of metals for resistance to sulfide stress cracking and stress corrosion cracking in H₂S environments*

3 Terms, abbreviated terms, definitions and symbols

For the purposes of this document, the following terms, definitions, symbols and abbreviated terms apply.

3.1 Terms and definitions

3.1.1

annulus

space between two concentric plastic sheaths of an unbonded flexible pipe cross-section

3.1.2

Arrhenius plot

log-linear scale used to plot service life against the inverse of temperature for some polymer materials

3.1.3

basket

device used for storage and transport of flexible pipe

NOTE All pipes are laid freely into the basket.

3.1.4

bird-caging

buckling of the tensile-armour wires, usually caused by extreme axial compression, which results in significant radial deformation

3.1.5

buoyancy module

buoys used in significant numbers at discrete points over a section of riser to achieve wave-shape riser configurations

NOTE See 4.4.6.

3.1.6

carousel

device used for storage and transport of very long lengths of flexible pipe and which rotates about a vertical axis

NOTE Pipe is wound under tension around the centre hub.

3.1.7

Chinese fingers

woven steel wire or fabric sleeve that can be installed over a flexible pipe and drawn tight to grip it for support or applying tension to the pipe

3.1.8

end fitting

termination in a flexible pipe

3.1.9

flexible pipe system

fluid conveyance system for which the flexible pipe(s) is/are the primary component and which includes ancillary components attached directly or indirectly to the pipe

3.1.10

free-hanging catenary

riser configuration that spans the water column in a catenary shape modified by the bending stiffness of the riser

NOTE See Figure 4.

3.1.11**integrated service umbilical****ISU™¹⁾**

structure in which the inner core is a standard flexible pipe construction

NOTE 1 Umbilical components are wound around the core pipe and covered with a protective outer sheath (see 4.3.6).

NOTE 2 ISU is a trademark of Coflexip Stena Offshore.

3.1.12**lazy wave**

free-hanging catenary modified by a section with distributed buoyancy modules

NOTE See Figure 4.

3.1.13**lazy-S**

free-hanging catenary modified by a section with concentrated buoyancy modules

NOTE See Figure 4.

3.1.14**multibore**

multiple flexible pipes or umbilicals contained in a single construction with an outer sheath extruded over the bundle

NOTE See 4.3.7.

3.1.15**multiple configuration**

riser system with more than one riser connected at a mid-depth location

3.1.16**ovalization**

out-of-roundness of the pipe, calculated as follows:

$$\frac{D_{\max} - D_{\min}}{D_{\max} + D_{\min}}$$

where $D_{\max}$ and $D_{\min}$ are maximum and minimum pipe outside diameter, respectively.**3.1.17****piggy back**

attachment of two parallel and adjacent independent pipes, rigid or flexible, over a significant length

3.1.18**prototype test**

test to establish or verify a principal performance characteristic for a particular pipe design, which may be a new or established design

3.1.19**rapid decompression**

sudden depressurization of a system during which gas in the pipe expands rapidly and can cause blistering or collapse of the internal pressure sheath or other gas-saturated layers

1) ISU™ is an example of a suitable product available commercially. This information is given for the convenience of users of this part of ISO 13628 and does not constitute an endorsement by ISO of this product.

3.1.20

reel

large-diameter structure used for storage of long lengths of flexible pipe, which rotates about a horizontal axis

3.1.21

riser base

structure positioned on the seabed, used to provide a structural and pressure-tight connection between a flexible riser and a flowline

NOTE 1 See 4.4.8.

NOTE 2 It may be a PLET or a PLEM.

3.1.22

riser hang-off

structure for supporting a riser at the connection to a platform

EXAMPLE Jacket, semi-sub, tanker, etc.

3.1.23

steep wave

lazy wave with a touchdown point fixed to the seabed

NOTE See Figure 4.

3.1.24

steep-S

lazy-S with a touchdown point fixed to the seabed

NOTE See Figure 4.

3.1.25

subsea buoy

concentrated buoyancy system

NOTE This system generally consists of steel or syntactic foam tanks, as used in S-type riser configurations (4.4.5). See also buoyancy module (3.1.4).

3.1.26

tensioner

mechanical device used to support or apply tension to a pipe during installation

3.1.27

umbilical

bundle of helically or sinusoidally wound small-diameter chemical, hydraulic, and electrical conductors for power and control systems

3.2 Symbols and abbreviated terms

The following symbols and abbreviated terms are used in this document.

CPE chlorinated polyethylene

CR polychloroprene

DA dynamic application

DBS dibutyl sebacate

DOF degrees of freedom

EPDM	ethylene propylenediene monomer rubber
FAT	factory acceptance test
FPS	floating production system
FPSO	floating production storage and offloading
HDPE	high density polyethylene
HIC	hydrogen-induced cracking
HNBR	hydrogenated nitrile rubber
ID	inside diameter
ISU	integrated service umbilical
MBR	minimum bend radius
MDPE	medium density polyethylene
MWL	mean water level
NBR	nitrile butadiene rubber
NR	natural rubber
OD	outer diameter
PA	polyamide
PE	polyethylene
PP	polypropylene
PLEM	pipeline end manifold
PU	polyurethane
PVC	polyvinyl chloride
PVDF	polyvinylidene fluoride
REF	riser end fitting
ROV	remotely operated vehicle
SA	static application
SBR	storage bend radius
SSC	sulfide stress cracking
TFL	through flowline
UV	ultraviolet

VIV	vortex-induced vibration
XLPE	cross-linked polyethylene
C_d	hydrodynamic drag coefficient
C_m	hydrodynamic inertia coefficient
$D_{\max}$	maximum pipe outside diameter
$D_{\min}$	minimum pipe outside diameter
σ_u	material ultimate stress
σ_y	material yield stress

4 System, pipe, and component description

4.1 Introduction

4.1.1 General

Clause 4 provides a general overview of flexible pipe systems, pipe cross-section designs and ancillary components. In addition, Clause 4 gives an overview of all aspects of flexible pipe technology and identifies the clauses and subclauses of this part of ISO 13628 and of ISO 13628-2:2006 and ISO 13628-10:2005 to be consulted for relevant issues.

In general, flexible pipe is a custom-built product that can be designed and manufactured in a variety of methods. It is not the intent of this part of ISO 13628 to discourage novel or new developments in flexible pipe. On the contrary, it is recognized that a variety of designs and methods of analysis are possible. For this reason, some topics are presented in general terms to provide guidance to the user while still leaving open the possibility of using alternative approaches.

The reader should be aware that flexible-pipe technology (concepts, design and analysis methodologies and criteria, components manufacturing and testing, operational roles and demands, maintenance and inspection, etc.) is in a state of rapid and continuing evolution. Potential users shall, therefore, apply care in their application of the recommendations within this part of ISO 13628.

4.1.2 Recommended practice and specification overview

4.1.2.1 This part of ISO 13628 provides the current best practice for design and procurement of flexible pipe systems and gives guidance on the implementation of the specification for standard flexible-pipe products. In addition, the recommended practice shows guidelines on the qualification of prototype products.

4.1.2.2 All aspects of flexible-pipe technology, from functional definition to installation, are addressed in either this part of ISO 13628 or in ISO 13628-2 and ISO 13628-10. Some issues are addressed in all three documents. The various stages in the procurement and use of flexible pipes are defined in Figure 1.

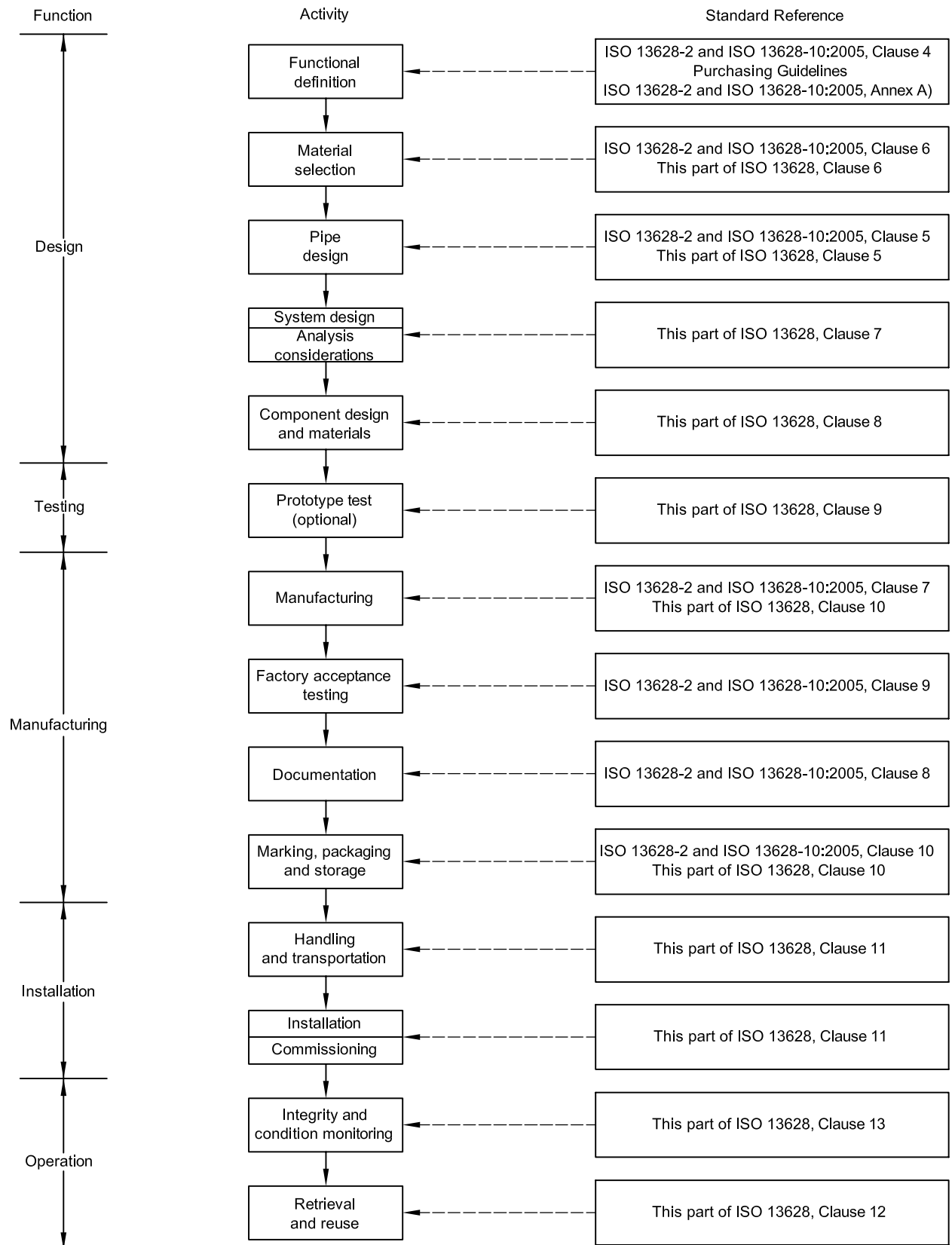


Figure 1 — Flexible pipe overview

4.2 Flexible pipe systems

4.2.1 Definition of system

4.2.1.1 The flexible pipe system is an important part of the overall field development and can influence or be influenced by the design and specification of other components in the development. The definition of the flexible pipe system should therefore commence at the initiation of the overall project as development strategies evolve. Aspects of the development strategy that can influence the flexible pipe system include field layout (template versus satellite wells) and production-vessel type (platform, tanker including turret location, semi-sub, etc.). Current limitations in flexible-pipe technology, such as application range and manufacturing capability, can also fundamentally influence potential overall field development options.

4.2.1.2 It is necessary to address the flexible pipe system and the flexible pipe or pipes within that system. It is necessary to consider the relevant parameters, as well as the interactions between the pipe design and the system design. Critical parameters that can affect the pipe design should be identified early in the process and can include the following:

- a) severe internal conditions, such as high H₂S content (sour service);
- b) extreme external environmental conditions;
- c) difficult installation conditions (such as extreme environment);
- d) frequent, cyclic, large-amplitude pressure and temperature fluctuations;
- e) large vessel offsets.

4.2.1.3 To define accurately all relevant parameters, interaction between the purchaser and manufacturer is required at an early stage in the project. An important aspect of this is the identification of critical system issues, such as interfaces. See 7.6 for potentially critical interfaces that should be considered at project commencement.

4.2.1.4 ISO 13628-2 and ISO 13628-10:2005, Annex A, provide purchasing guidelines, which may be used in the definition of the flexible pipe system and which address all aspects from general design parameters to detailed flowline- and riser-specific requirements.

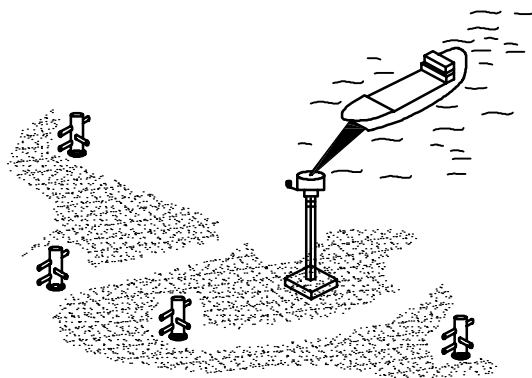
4.2.2 Applications

4.2.2.1 General

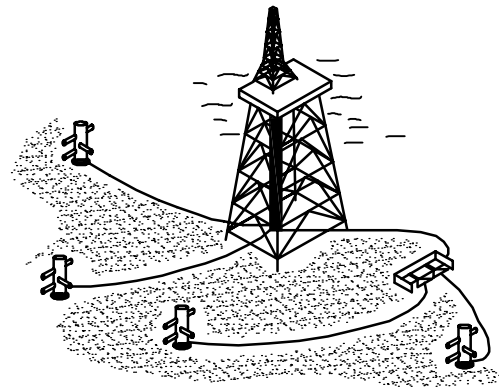
4.2.2.1.1 Flexible pipe for offshore and onshore applications is grouped into either a static or dynamic category (Figures 2 and 3). It is used for a multitude of functions, including the following:

- a) production: oil, gas, condensate, water;
- b) injection: water, gas, downhole chemicals;
- c) export: semi-processed oil and gas;
- d) services: wellhead chemicals, control fluids.

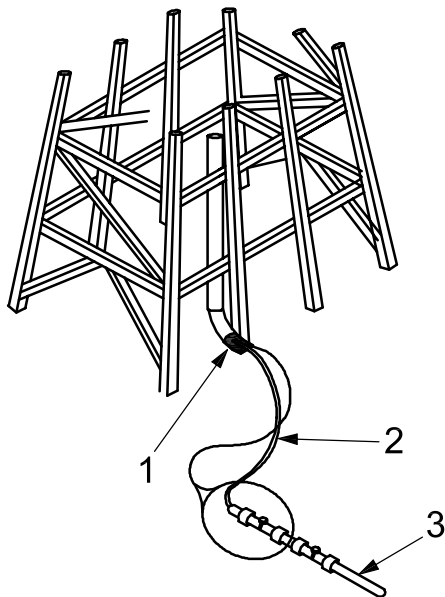
4.2.2.1.2 The static and dynamic categories place different physical demands on the pipe. While both require long life, mechanical strength, internal and external damage resistance and minimal maintenance, dynamic service pipes also require pliancy and high fatigue resistance.



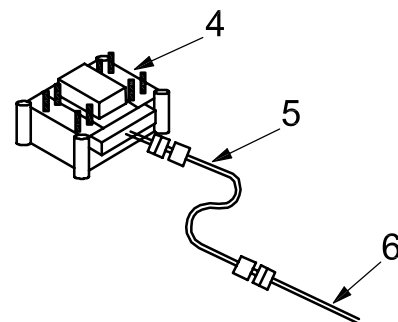
a) Early field production scheme



b) Flowlines repositioned for mature field production scheme



c) Flexible pipe connected to a J-tube

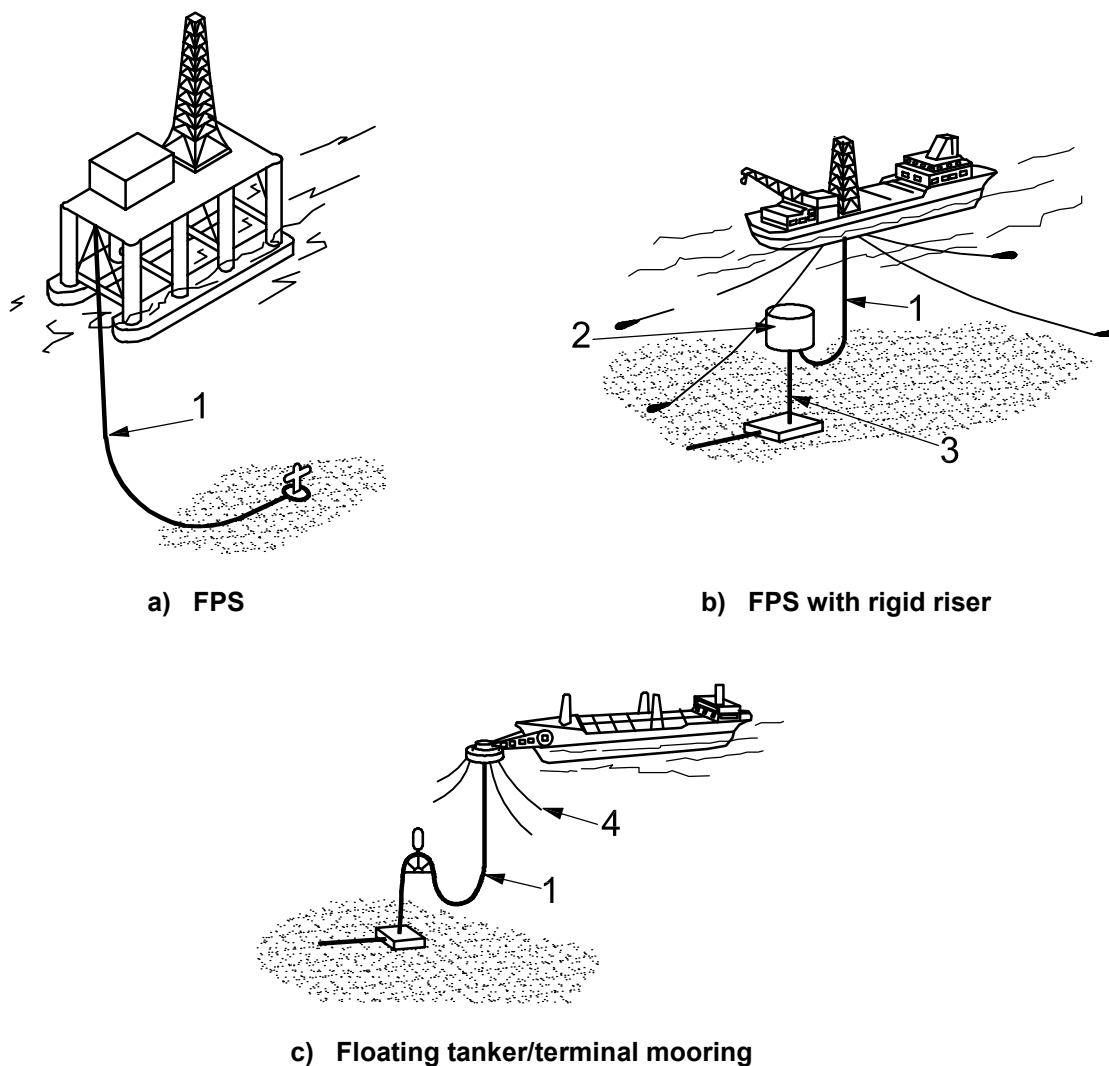


d) Flexible pipe connected to the manifold

Key

- 1 J-tube
- 2 flexible pipe
- 3 rigid pipe
- 4 manifold
- 5 flexible pipe spool piece
- 6 rigid steel flowline

Figure 2 — Examples of static applications for flexible pipe



Key

- 1 flexible riser
- 2 subsea buoy
- 3 rigid riser
- 4 anchor chain

Figure 3 — Examples of dynamic applications for flexible pipe

4.2.2.2 Static applications

4.2.2.2.1 The use of flexible pipe for static applications is primarily for flowline and fixed jacket-riser service. Flexible pipe is used in these applications to simplify design or installation procedures, or for its inherent insulation or corrosion-resistant properties. In addition, reduction of installation and end-connection loads and moments may be achieved using flexible pipe. Examples of where the use of flexible pipe results in simplified flowline design or installation include the following (see Figure 2):

- a) subsea flowline end connections where expensive or difficult operations, such as exact orientation measurements for spool pieces or the use of large alignment equipment to reposition the flowline, can be eliminated;
- b) situations involving gross movements and damage to flowlines because of mudslides can be reduced through the use of slack sections of flexible pipe;
- c) applications in which field hardware and flowline location change with the field's production characteristics, which can necessitate the recovery and reuse of the flowlines;
- d) applications with uneven seabed to avoid seabed preparation;
- e) in deepwater or severe environment applications, where flexible pipe installation is economically attractive relative to rigid pipe installation.

NOTE Instead of mobilizing an expensive pipe-laying spread, it is often preferable to use flexible pipe installed from a dynamically positioned vessel.

4.2.2.2.2 Flexible pipe flowlines generally range in internal diameter from 0,05 m to 0,5 m (2 in to 20 in) although some low-pressure, bonded flexible pipes, such as oil suction and discharge hoses, have internal diameters up to 0,91 m (36 in). Section lengths are limited by transport capabilities and diameter is limited only by current manufacturing capability.

4.2.2.2.3 The functional requirements of a flexible-pipe flowline are generally the same as for a steel-pipe flowline. Significant dynamic loading or motions are generally not experienced, so the flexibility properties of flexible pipe simplify the project transport and installation phases.

4.2.2.3 Dynamic applications

4.2.2.3.1 Dynamic applications use flexible pipe between supply and delivery points if there is relative movement between these two points while in service. These types of applications usually involve an offshore floating production facility or terminal connected to another floating facility, fixed structure or fixed base (Figure 3). Examples of dynamic applications include the following:

- a) flexible-pipe risers for offshore loading systems;
- b) flexible-pipe riser connections between floating production facilities and subsea equipment.

4.2.2.3.2 Figure 4 illustrates schematics of the riser configurations typically used. In general, the critical sections in the riser configurations are at the top (or bottom), where there are high tensile forces (and large curvatures); at the sag bend, where there is large curvature (at low tension); and at the hog of a wave buoyancy section, where there is large curvature (at low tension).

4.2.2.3.3 The present dynamic applications of flexible pipes have only been for the production phase. However, with the advent of downhole motors, flexibles may also be used as drilling risers, as described by FPS 2000 [23].

4.2.2.3.4 In addition to riser systems that use flexible pipe throughout, systems that combine flexible pipe and rigid pipe in the flow path have been used. Described as hybrid riser systems, they typically use a lower rigid-riser section (such as a free-standing riser) and an upper flexible-pipe section (jumper line).

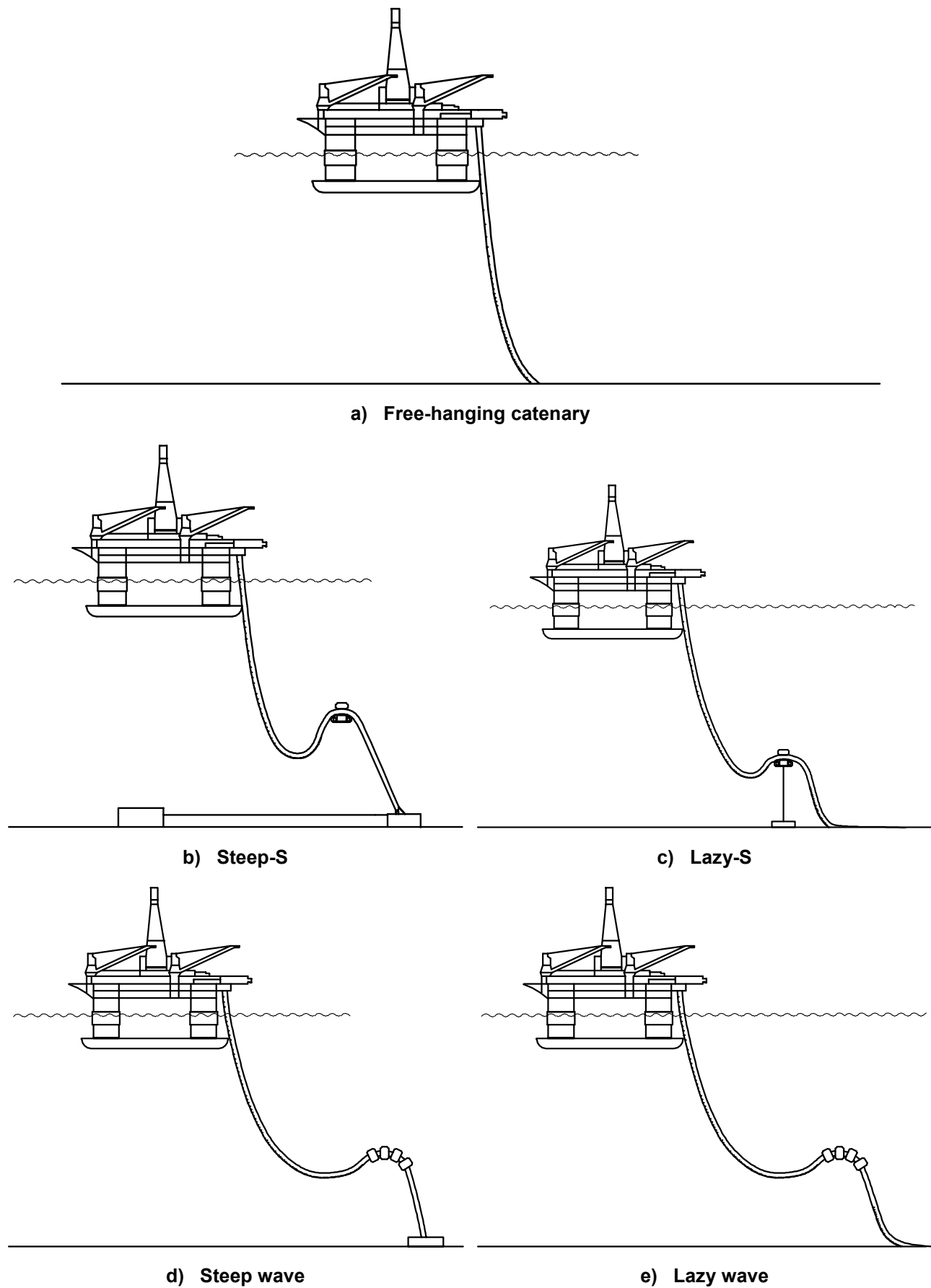


Figure 4 — Examples of flexible riser configurations

4.2.2.4 Jumper lines

4.2.2.4.1 In addition to flowlines and risers, jumper lines, a further category, may be used for either static or dynamic applications. Examples of flexible pipes used in jumper-line applications include the following (Figure 5):

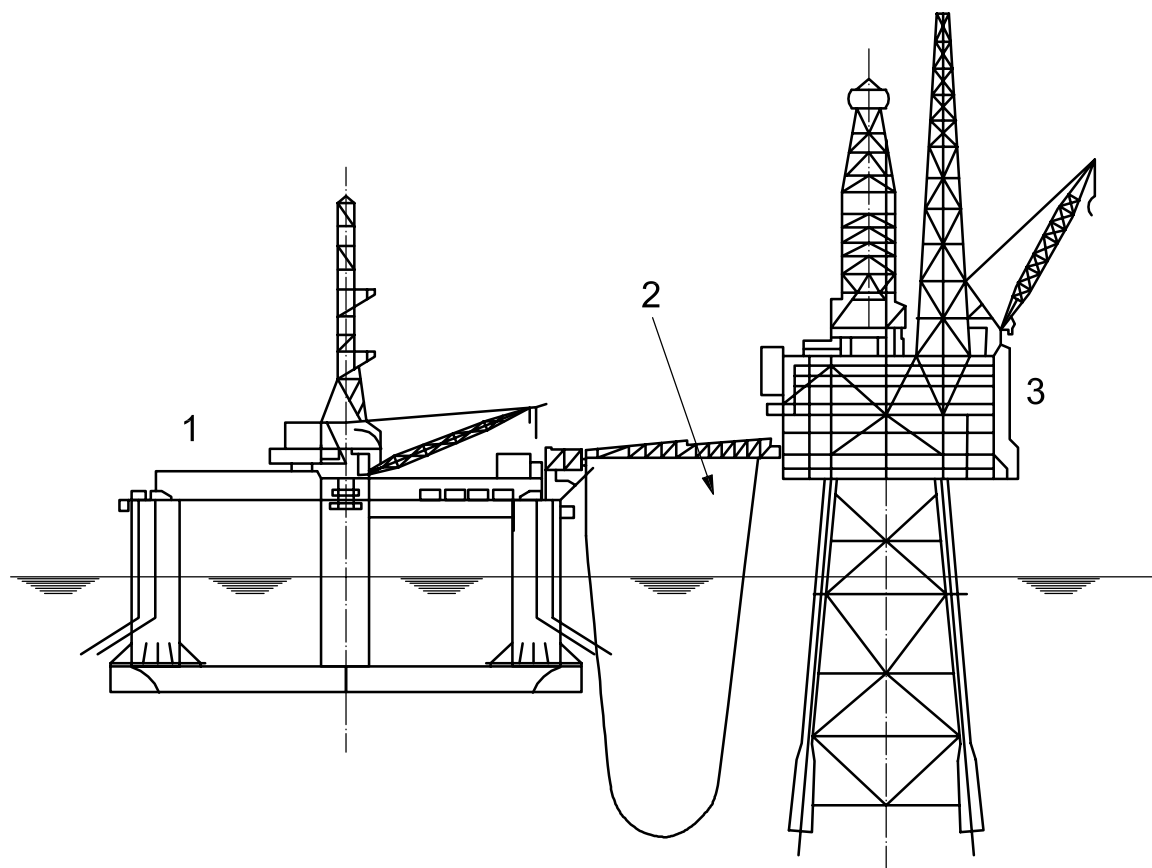
a) static applications:

- 1) intra-field connection of wellheads and manifolds (typically in lengths less than 100 m),
- 2) connection of topside wellheads and platform piping on tension leg platforms (TLPs);

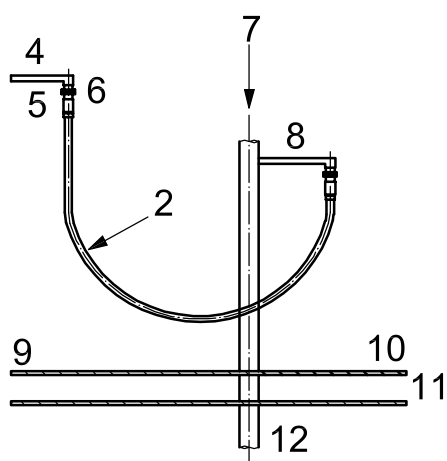
b) dynamic applications:

- 1) connection of wellhead platforms and floating support vessels,
- 2) lines in FPSO turret motion transfer systems.

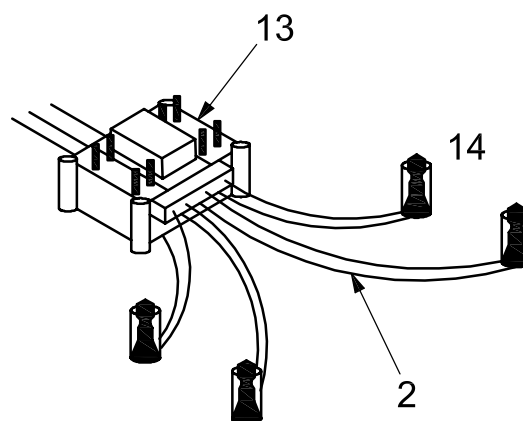
4.2.2.4.2 The functions of the dynamic jumper lines (excluding internal turret lines) are similar to riser systems. Their operation, however, is somewhat different. The lines are generally more exposed to wave loading, and the configuration varies between the connected condition and the stand-off condition, which imposes extra requirements on the end connectors and bend stiffeners. The performance of these components should be evaluated carefully for dynamic jumper-line applications.



a) Flexible pipe as a fluid transfer line



b) Flexible pipe connected to Xmas tree



c) Flexible pipe connected to manifold

Key

- | | |
|---------------------|----------------|
| 1 support vessel | 8 moving end |
| 2 flexible jumper | 9 wellbay |
| 3 wellhead platform | 10 grated deck |
| 4 fixed end | 11 tree deck |
| 5 topsides piping | 12 rigid riser |
| 6 end fitting | 13 manifold |
| 7 Xmas tree | 14 wellheads |

Figure 5 — Examples of flexible-pipe jumper-line applications

4.3 Flexible pipe description

4.3.1 General

4.3.1.1 This part of ISO 13628 does not apply to flexible pipes for use in choke and kill line or umbilical applications.

4.3.1.2 A flexible pipe generally combines low bending stiffness with high axial tensile stiffness, which is achieved by a composite pipe wall construction. This is more applicable to unbonded flexible pipes than to bonded flexible pipes. The two basic components are helical armouring layers and polymer sealing layers, which allow a much smaller radius of curvature than for a steel pipe with the same pressure capacity. Generally, a flexible pipe is designed specifically for each application and is not an off-the-shelf product, although flexible pipes may be grouped according to specific designs and, hence, applications. This allows the pipe to be optimized for each application.

4.3.2 Unbonded flexible pipe construction

4.3.2.1 Figure 6 shows a typical cross-section of a flexible pipe. The main layers in this cross-section are identified in 4.3.2.2 to 4.3.2.6

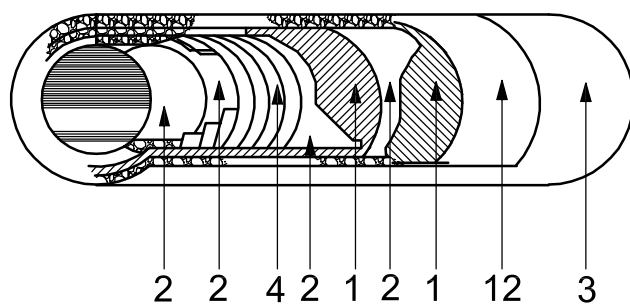
4.3.2.2 The carcass is an interlocked metallic layer which provides collapse resistance. Figure 7 illustrates an example of a carcass profile.

4.3.2.3 The internal pressure sheath is an extruded polymer layer which provides internal fluid integrity.

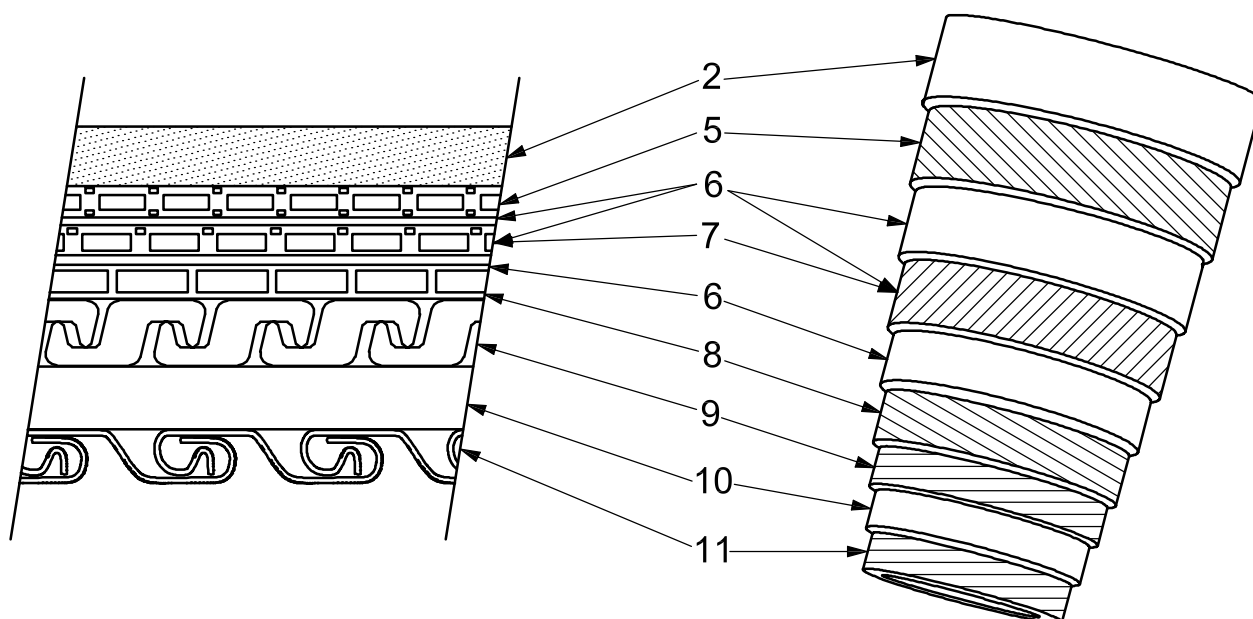
4.3.2.4 The pressure armour is an interlocked metallic layer which supports the internal pressure sheath and system internal-pressure loads in the radial direction. Figure 7 includes some example profiles for the pressure-armour wires. A back-up pressure-armour layer (generally not interlocked) also can be used for higher-pressure applications.

4.3.2.5 The tensile-armour layers typically use flat, round, or shaped metallic wires, in two or four layers crosswound at an angle between 20° and 60°. The lower angles are used for pipe constructions which include a pressure-armour layer. Where no pressure-armour layer is used, the tensile-armour layers are crosswound at an angle close to 55° to obtain a torsionally balanced pipe and to balance hoop and axial loads.

4.3.2.6 The outer sheath is an extruded polymer sheath that provides external fluid integrity.



a) Bonded flexible pipe

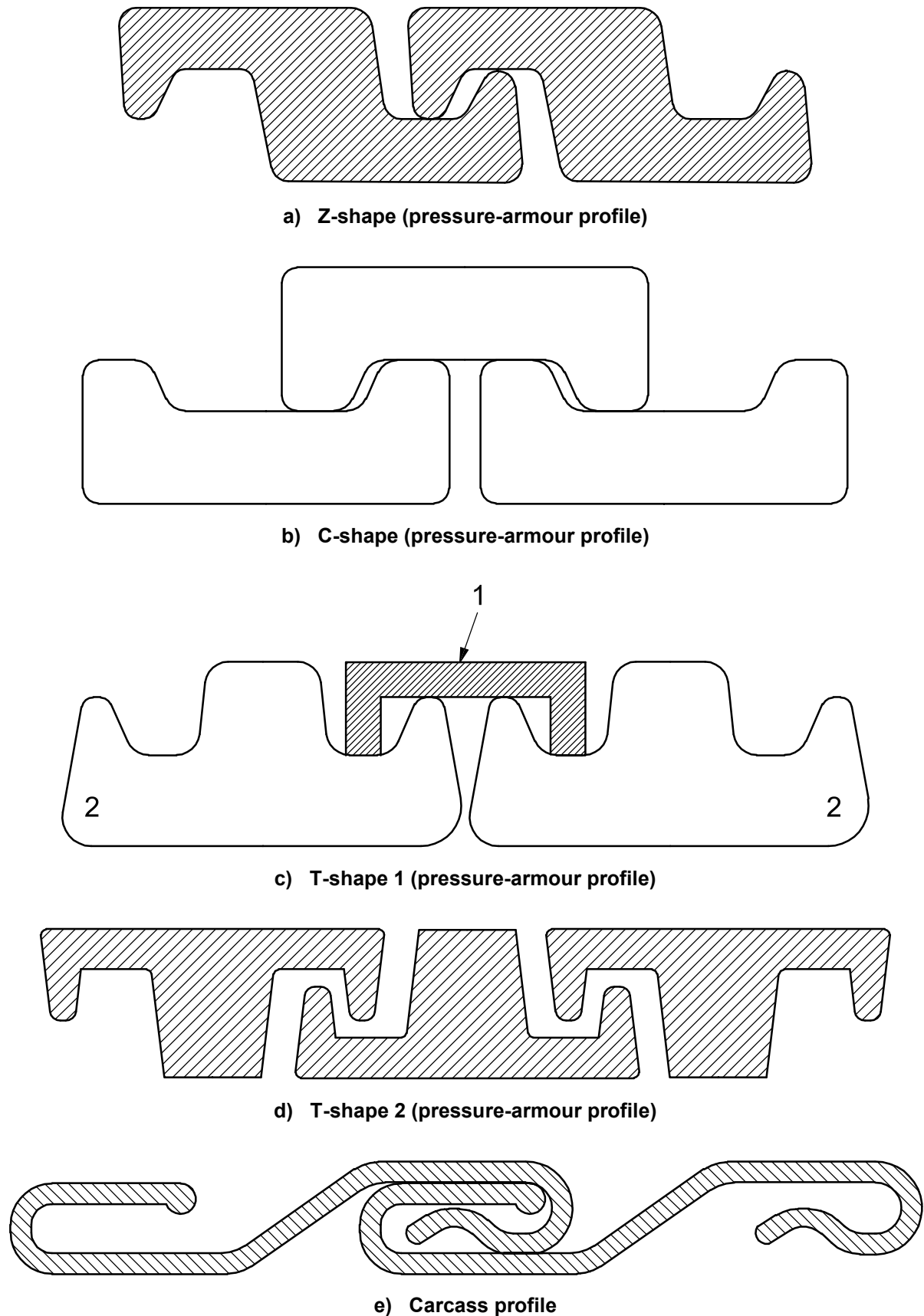


b) Unbonded flexible pipe

Key

- 1 tensile layer
- 2 anti-friction layer
- 3 outer sheath
- 4 hoop stress layer
- 5 outer layer of tensile armour
- 6 anti-wear layer
- 7 inner layer of tensile armour
- 8 back-up pressure armour
- 9 interlocked pressure armour
- 10 internal pressure sheath
- 11 carcass
- 12 anti-bird-cage layer

Figure 6 — Schematic of typical flexible riser cross-sections



Key

1 clip

2 T-wire

Figure 7 — Pressure-armour and carcass interlock profiles

4.3.3 Bonded flexible pipe construction

4.3.3.1 A typical bonded flexible pipe consists of several layers of elastomer either wrapped or extruded individually and then bonded together through the use of adhesives or by applying heat and/or pressure to fuse the layers into a single construction. Figure 6 shows an example of a bonded pipe construction. The main layers are identified in 4.3.3.2 to 4.3.3.5.

4.3.3.2 The carcass is an interlocked, metallic layer, which provides collapse resistance. Figure 7 shows an example of a carcass profile.

4.3.3.3 The liner is a wrapped or extruded elastomer layer, which provides internal fluid integrity.

4.3.3.4 The reinforcement layer is comprised typically of helically wound, steel cables in an embedding elastomer compound used to sustain tensile and internal pressure load on the pipe. The steel cables are typically laid at an angle of 55° to obtain a torsionally balanced pipe, in addition to equivalent hoop and longitudinal forces in the layer due to pressure. However, this angle may increase or decrease depending on the required strength characteristics of the pipe. For example, a higher angle may be used if increased strength in the hoop direction is required at the expense of tensile capacity and axial stiffness of the pipe.

4.3.3.5 The outer layer is a wrapped or extruded elastomer layer that provides external fluid integrity and protection against external environments, corrosion, abrasion and mechanical damage.

NOTE The concept of separate layers in a bonded pipe construction is notional because the final pipe cross-section is a bonded composite construction.

4.3.4 Classification of flexible pipe

4.3.4.1 Currently, unbonded flexible pipes can generally be classified into three distinct families. These classifications are identified in Table 1. Distinctions exist between pipes for static and dynamic applications within these families, with the main distinction being the use of anti-wear layers for dynamic applications if they are required to achieve service-life criteria.

Table 1 — Description of standard flexible-pipe families — Unbonded pipe

Layer No.	Layer primary function	Product family I Smooth-bore pipe	Product family II Rough-bore pipe	Product family III Rough-bore, reinforced pipe
1	Prevent collapse	Pressure-armour layer(s)	Carcass	Carcass
2	Internal fluid integrity	Internal pressure sheath	Internal pressure sheath	Internal pressure sheath
3	Hoop stress resistance	Pressure-armour layer(s)	—	Pressure-armour layer(s)
4	External fluid integrity	Intermediate sheath	—	—
5	Tensile-stress resistance	Crosswound tensile armours	Crosswound tensile armours	Crosswound tensile armours
6	External fluid integrity	Outer sheath	Outer sheath	Outer sheath
NOTE 1 All pipe constructions can include various non-structural layers, such as anti-wear layers, tapes, manufacturing aid layers, etc.				
NOTE 2 An external carcass can be added for protection purposes.				
NOTE 3 The pressure layer can be subdivided into interlocked layer(s) and back-up layer(s).				
NOTE 4 The number of crosswound armour layers can vary, though is generally either two or four.				
NOTE 5 Thermal insulation can be added to the pipe.				
NOTE 6 The internal pressure and outer sheaths can consist of a number of sublayers.				
NOTE 7 Product family III is generally used for higher-pressure applications than II.				
NOTE 8 The intermediate sheath for smooth-bore pipes is optional if there is no external pressure or the external pressure is less than the collapse pressure of the internal pressure sheath for the given application.				

4.3.4.2 The classifications for bonded flexible pipe are identified in Table 2. Smooth-bore flexible pipes (product family I, unbonded and product family IV, bonded) often are used for water injection or dead crude applications.

Table 2 — Description of standard flexible pipe families — Bonded pipe

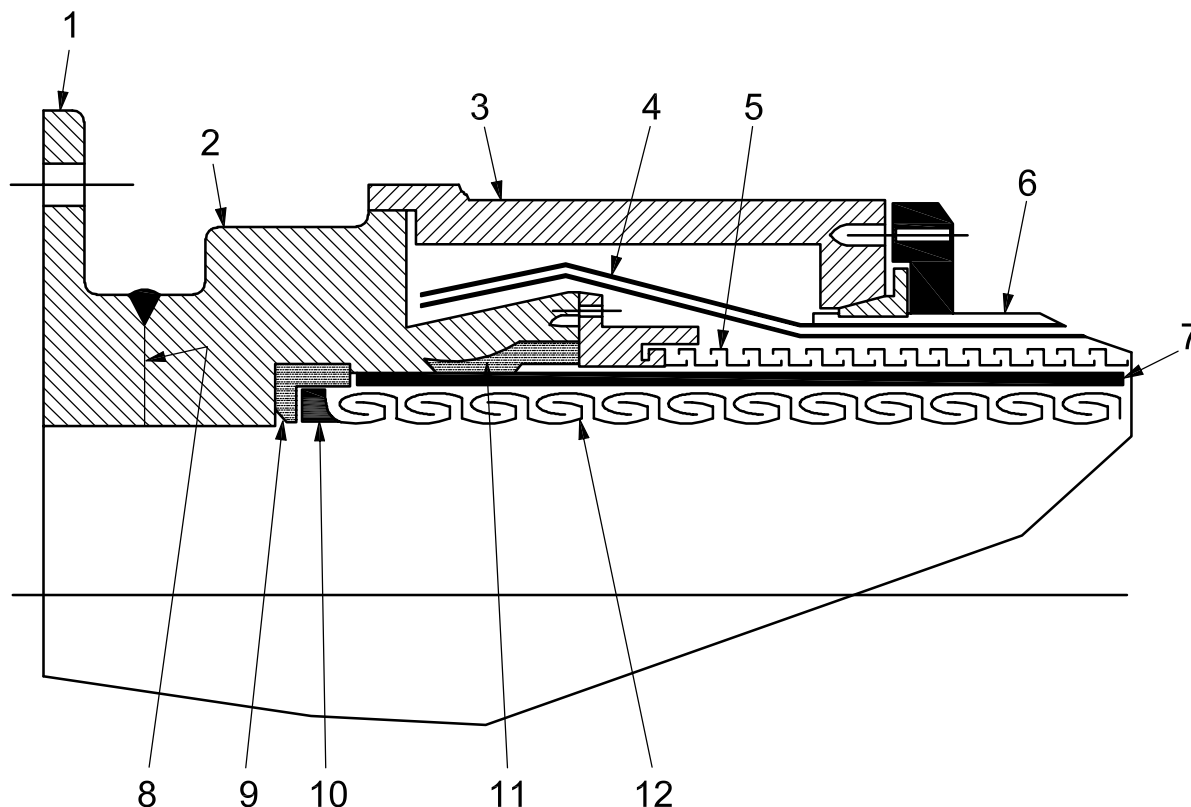
Layer No.	Layer primary function	Product family IV Smooth-bore pipe	Product family V Rough-bore pipe
1	Prevent collapse	—	Carcass
2	Internal fluid integrity	Liner	Liner
3	Hoop and tensile-load resistance	Reinforcement layer(s)	Reinforcement layer(s)
4	External fluid integrity and protection	Cover	Cover
NOTE 1 All pipe constructions can include various non-structural layers, such as filler layers and breaker fabrics.			
NOTE 2 An external carcass can be added for protection purposes.			
NOTE 3 The number of crosswound reinforcement plies can vary, though is, generally, either two, four, or six.			

4.3.5 End fittings

4.3.5.1 Figure 8 illustrates a typical unbonded-pipe end fitting. End fittings may be built in during pipe manufacture or installed in the field. The two purposes of a flexible-pipe end fitting are to

- terminate all the strength members in the pipe's construction, so that axial loads and bending moments can be transmitted into the end connector without adversely affecting the fluid-containing layers, and
- provide a pressure-tight transition between the pipe body and the connector.

4.3.5.2 End connectors can be an integral part of, or attached to, the end fitting. A variety of end connectors exist, such as bolted flanges, clamp hubs, proprietary connectors and welded joints (two end fittings welded together to join pipe segments into a longer segment). The selection of end connectors depends on operational and service requirements.



Key

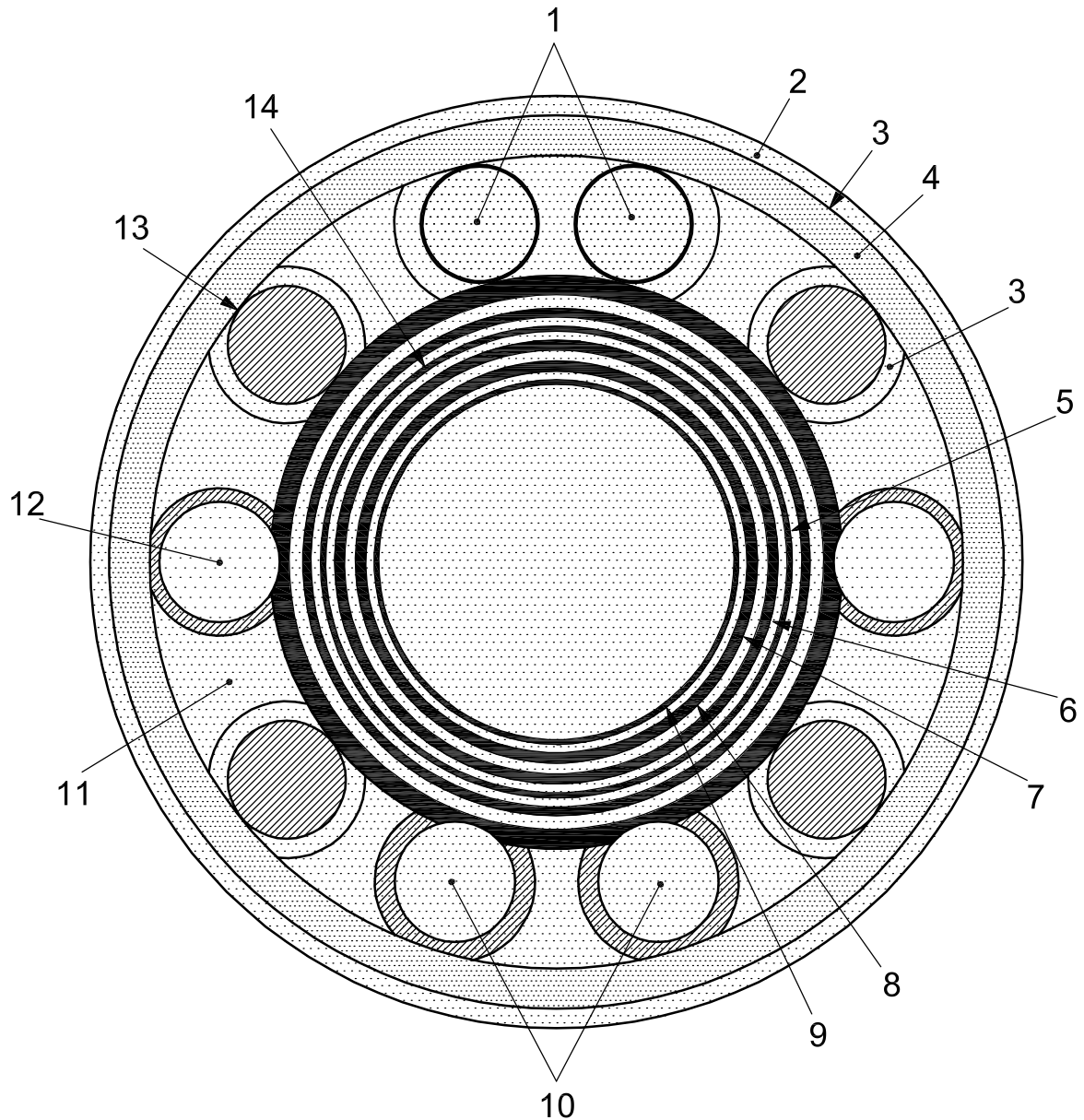
- 1 mounting flange
- 2 end-fitting housing (inner casing)
- 3 end-fitting housing (outer casing)
- 4 tensile armours (embedded in epoxy)
- 5 pressure-armour layer
- 6 outer sheath
- 7 internal pressure sheath (and sacrificial layers)
- 8 end-fitting neck
- 9 insulator
- 10 carcass end ring
- 11 seal ring
- 12 carcass

Figure 8 — Example of an unbonded-flexible-pipe end fitting

4.3.6 Integrated service umbilicals

4.3.6.1 The functionality of flexible pipes can be combined with umbilicals to form an integrated service umbilical (ISUTM)²⁾. Figure 9 is a schematic of a typical ISU. The inner core is a standard flexible-pipe construction and provides the axial load-bearing capacity of the structure. The umbilical components (electrical, hydraulic and control lines) are helically (or sinusoidally) wound around the core pipe.

2) ISU is an example of a suitable product available commercially. This information is given for the convenience of users of this part of ISO 13628 and does not constitute an endorsement by ISO of this product.



Key

- 1 electric power cable
- 2 outer sheath
- 3 tape
- 4 pipe outer sheath
- 5 tensile-armour layer
- 6 internal tensile-armour layer
- 7 pressure-armour layer
- 8 internal pressure sheath
- 9 carcass
- 10 electrical signal cable
- 11 filler material
- 12 fibre optical cable
- 13 hydraulic hose
- 14 anti-friction tape

Figure 9 — Schematic drawing of an example ISU

4.3.6.2 Spacers (fillers) are included between the umbilical lines to increase the crushing load resistance of the ISU. The assembly is covered by a protective outer sheath. In some cases, a layer of helical or sinusoidal armouring is applied between the control lines and the outer sheath. This layer increases the mass-to-diameter ratio of the ISU, which reduces the dynamic motions, thereby minimizing the potential for interference with adjacent risers. This layer also protects the control lines against external damage.

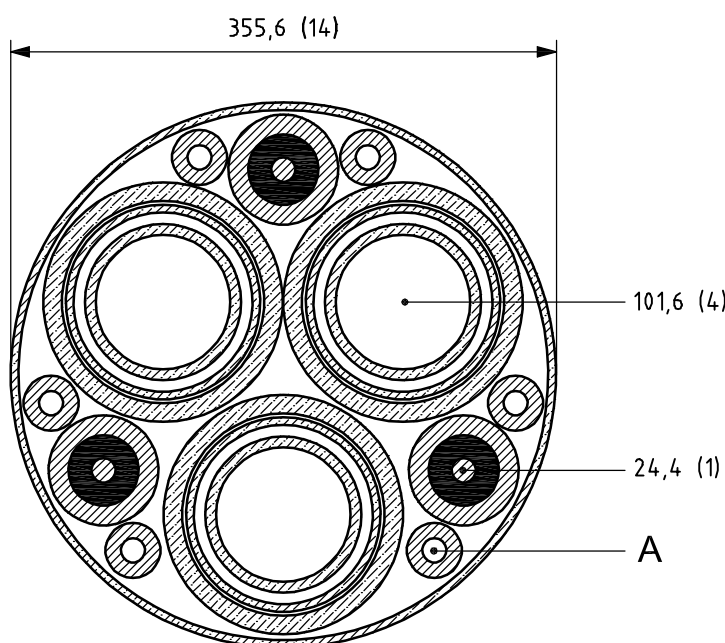
4.3.6.3 The end terminations of an ISU are complex constructions. The core of the termination is the end fitting of the central flexible pipe around which the terminations of the control lines are grouped. This assembly is integrated in a steel housing or frame, which may also carry the bend stiffener and transfer bending loads. The detailed design of the termination is governed by the installation and tie-in strategy.

4.3.6.4 Stainless steel conduits may also be used in the ISU. These overcome the problem of fluid diffusion through the polymer hoses (in particular methanol) and reduce response time in control systems. However, stainless steel conduits can be sensitive to fatigue in dynamic applications and installation loads.

4.3.7 Multibores

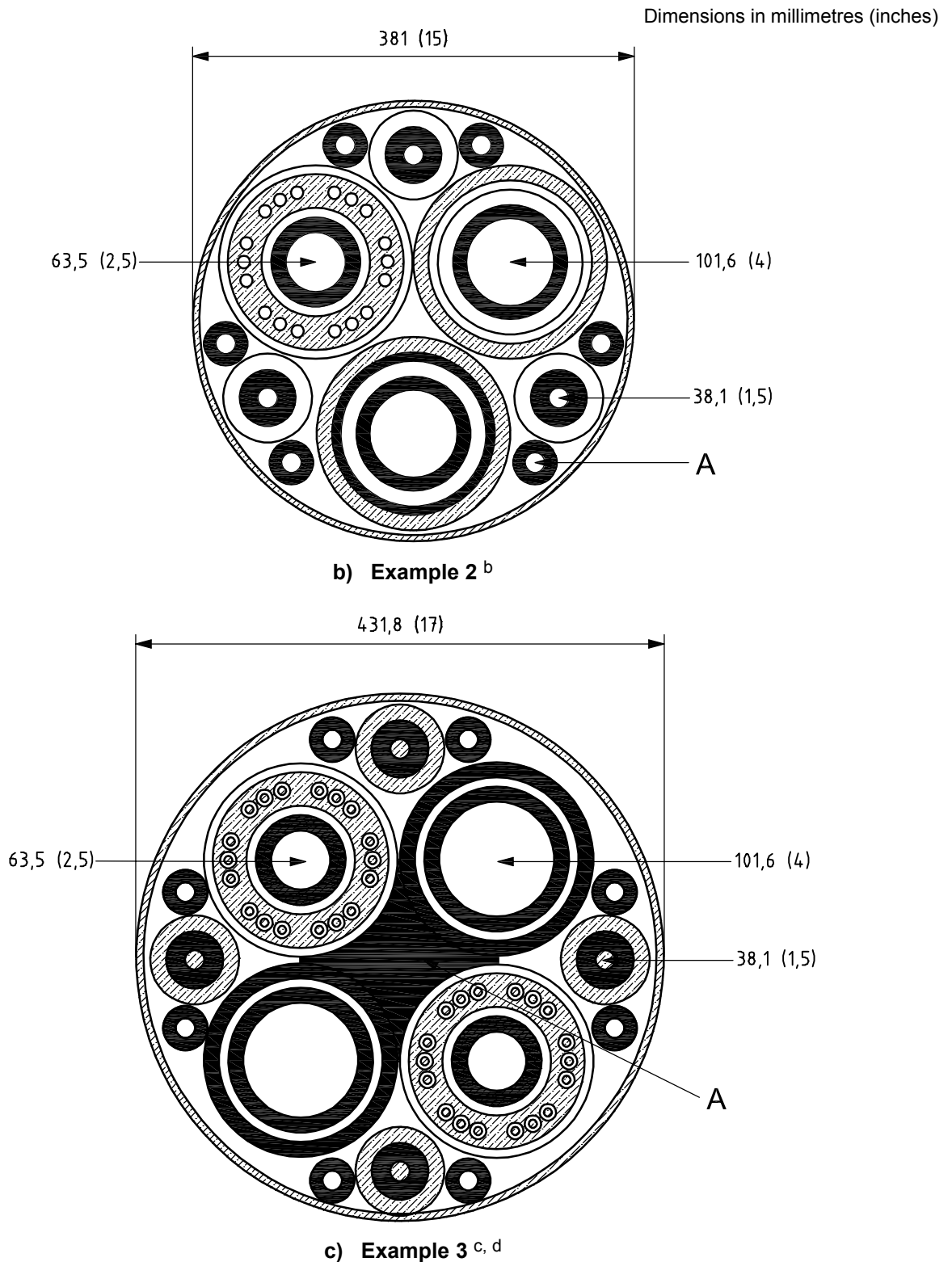
4.3.7.1 The multibore concept involves combining multiple flexible pipes and/or umbilical components into a single construction, thus reducing the number of lines in a field development and thereby simplifying the field layout and installation requirements. It can also reduce the number of I-tubes or J-tubes required for some development options. Figure 10 illustrates some examples of multibore constructions. The individual pipes are helically or sinusoidally wound and filler/spacer materials are used to obtain a circular cross-section. External armouring may be applied outside the bundle. A polymer sheath is extruded over the bundle and provides structural integrity and protection.

Dimensions in millimetres (inches)



a) Example 1^a

Figure 10 (continued)

**Key**

A filler

NOTE Properties given for the three examples are typical.

- ^a Linear mass in air, empty, is 181 kg/m (121,63 lb/ft); minimum bending radius is 2,4 m (7,87 ft).
- ^b Linear mass in air, empty, is 201 kg/m (135,07 lb/ft); minimum bending radius is 2,5 m (8,2 ft).
- ^c Linear mass in air, empty, is 249 kg/m (167,32 lb/ft); minimum bending radius is 2,9 m (9,51 ft).
- ^d Umbilical.

Figure 10 — Examples of multibore constructions

4.3.7.2 The design of a multibore construction is much more complex than a single bore. Important considerations are described in 4.3.7.2.1 to 4.3.7.2.7.

4.3.7.2.1 The most desirable shape in a multibore structure is a circular cross-section, since this results in optimal hydrodynamic performance, efficient space utilization and easy handling during installation and retrieval.

4.3.7.2.2 Standard components (flexible pipes and umbilicals) are recommended for use as much as possible.

4.3.7.2.3 The internal components can possibly provide the axial-load capacity of the structure, depending on the manufacturing process. The axial-load capacity or additional capacity can be provided by armour layers. The structural stability (differing elongations in the components) and torsional balance of the multibore under various loading conditions (unequal pressure levels and bending) should be evaluated.

4.3.7.2.4 The crushing resistance of the multibore shall be large enough to allow for flexibility in installation methods.

4.3.7.2.5 The maximum outer diameter is limited by the extrusion capability of the manufacturer for the outer sheath.

4.3.7.2.6 Care should be taken during winding to minimize torsion loads induced in the individual components.

4.3.7.2.7 A symmetrical construction is recommended to ensure uniform mechanical properties and to prevent structural rearrangement under dynamic loading.

4.3.7.3 The end termination for the multibore construction typically uses standard end fittings contained within a box-type structure.

4.4 Ancillary components

4.4.1 General

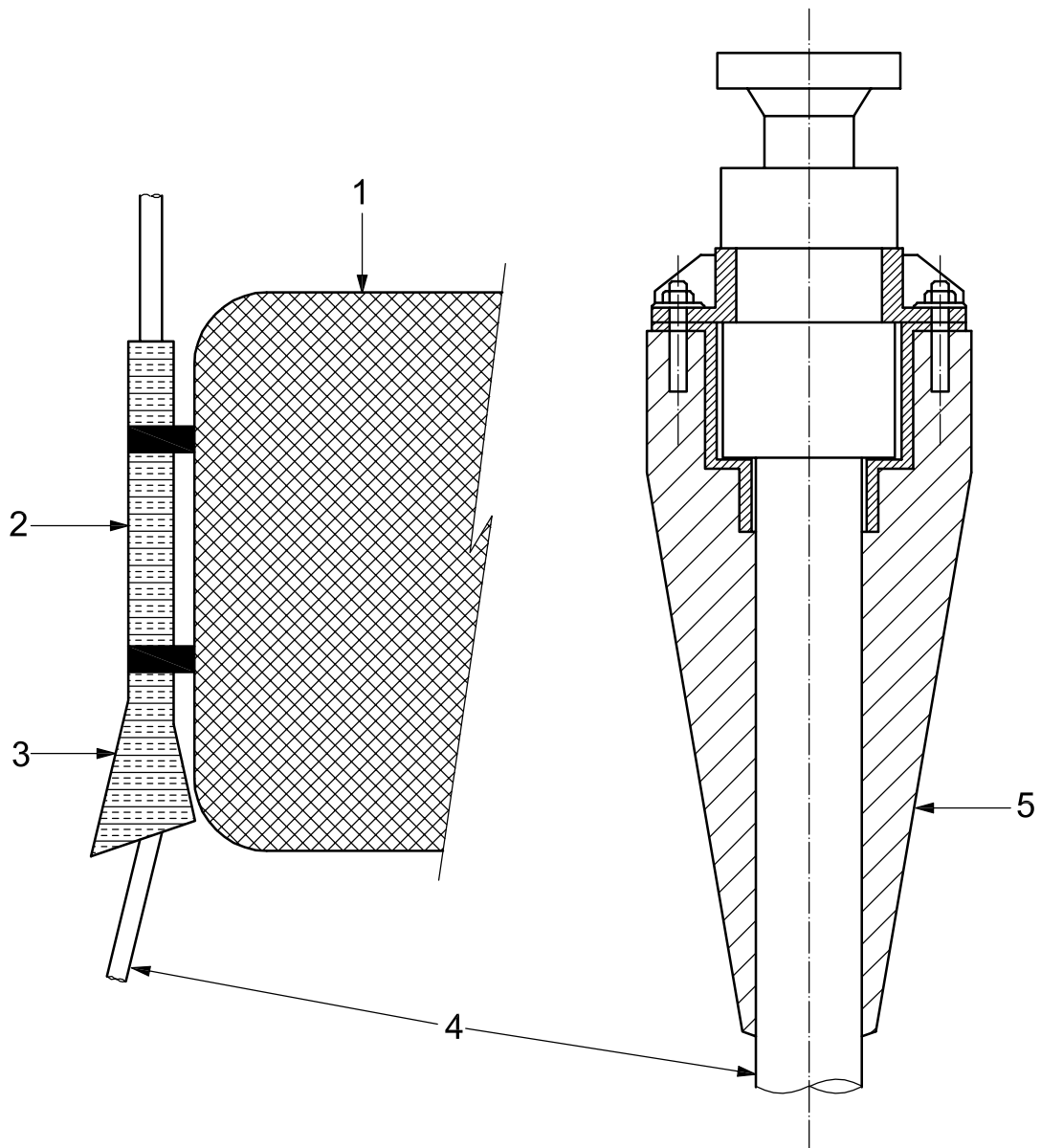
Ancillary components commonly used in flexible pipe systems are described in 4.4.2 to 4.4.9.

4.4.2 Bend limiters

4.4.2.1 Figure 11 illustrates two types of bend limiter in common use: bend stiffeners and bellmouths. A third type is a bend restrictor as described in 4.4.3. Bend stiffeners and bellmouths are generally used for dynamic applications. However, they can also be used in static applications. An example of the latter is the use of bend stiffeners on flowlines to prevent overbending at the end fitting during installation.

Bend limiters should be designed to give no bending in the pipe for a length of approximately one OD from the end fitting. Below this, the bending is allowed to increase gradually, with a smooth variation of bending moment within MBR criteria limitations.

4.4.2.2 Bend limiters may be built into the pipe construction in some bonded pipes. This is achieved by extruding or wrapping additional layers of elastomer and then curing the structure to form an integral bend limiter and pipe.

**Key**

- 1 pontoon
- 2 I-tube
- 3 bellmouth
- 4 flexible riser
- 5 bend stiffener

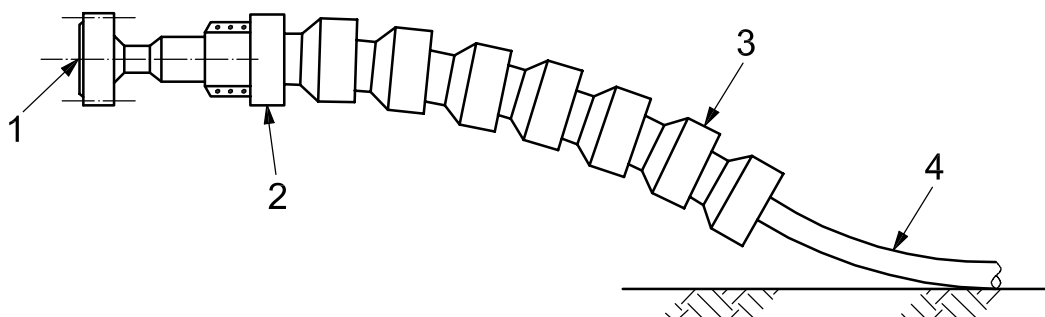
Figure 11 — Bend limiters

4.4.3 Bend restrictors

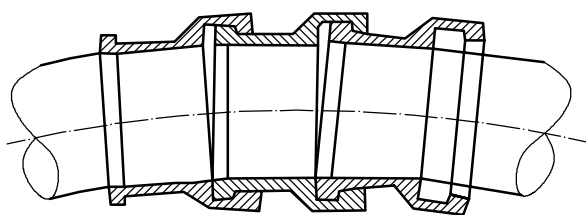
4.4.3.1 Bend restrictors are designed to mechanically restrict the flexible pipe from bending beyond its allowable MBR and are currently only used in static applications. An example of a bend restrictor is shown in Figure 12. Bend restrictors are used to support a flexible pipe over free spans where there is the possibility of damaging the pipe structure because of overbending. Typical applications are at wellhead connections, J-tube exits and rigid-pipe crossovers. Restrictors may also be used to prevent overbending during installation.

4.4.3.2 The restrictor consists of interlocking half rings that fasten together around the pipe so that they do not affect the pipe until a specified bend radius is reached, at which stage they lock. Full rings are permitted if the restrictor is mounted ahead of the end fitting. The locking of the restrictor prevents further bending of the pipe and additional loads are carried by the bend restrictor. Care should be taken that the locking of the rings does not damage the outer sheath of the pipe, i.e. there is smooth support with no sharp edges in the restrictor design.

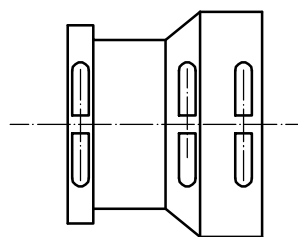
4.4.3.3 The bend restrictor elements may be manufactured from metallic materials, creep-resistant elastomers or glass-fibre-reinforced plastic. All materials should be selected for the specified environment and have sufficient corrosion resistance.



a) Bend restrictors covering flexible pipe



b) Bend restrictor in locked position



c) Side elevation

Key

- 1 end fitting
- 2 reaction collar
- 3 bend restrictor
- 4 subsea line

Figure 12 — Schematic of a bend restrictor

4.4.4 Connectors

4.4.4.1 The design of flexible-pipe end fittings allows for the use of a variety of end connectors, such as bolted flanges, clamped hubs and proprietary connectors. The connectors are typically welded to the end fitting prior to connecting to the flexible pipe or they may be integrally machined from the end-fitting body.

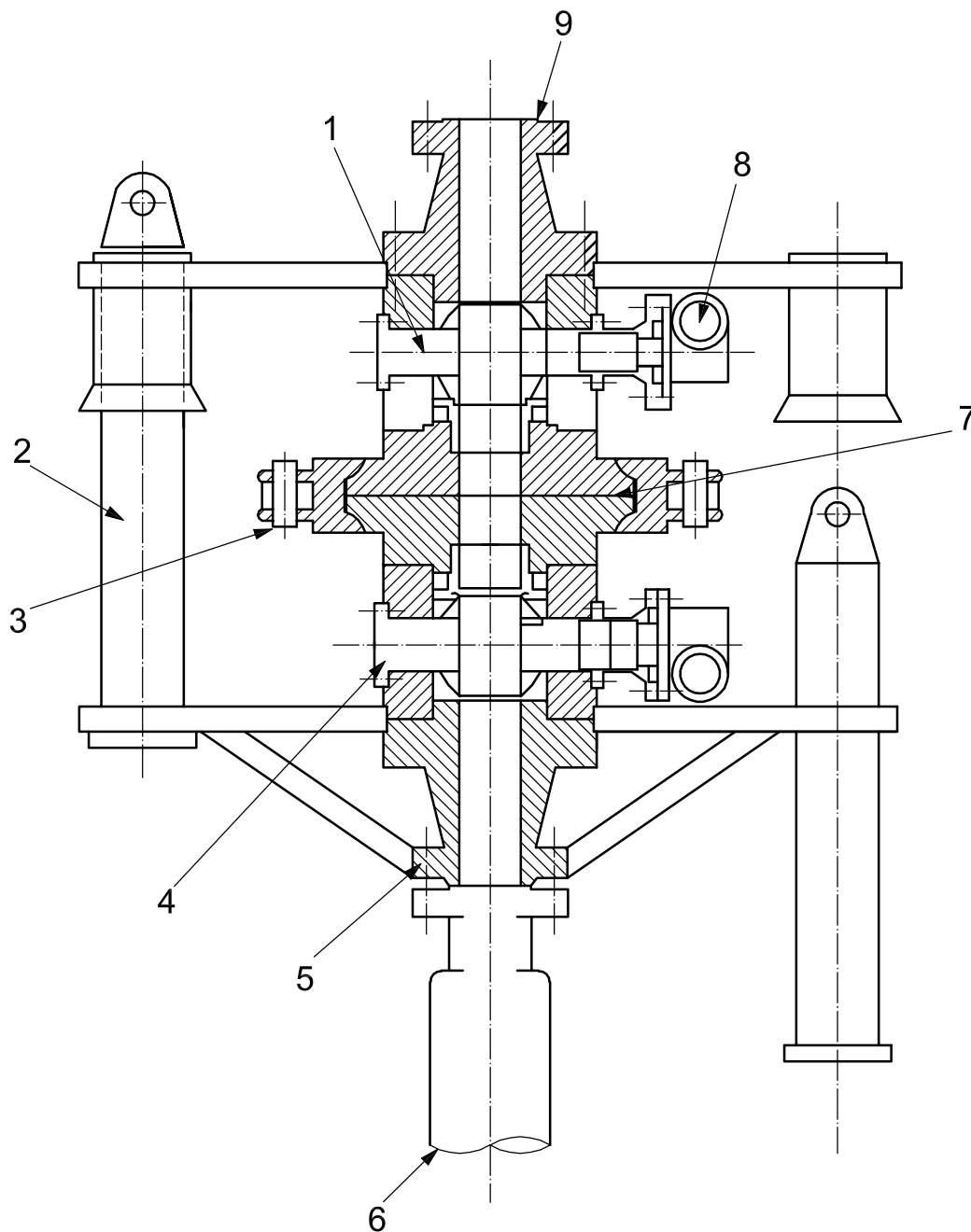
4.4.4.2 The flexible pipe and end fitting can also be connected directly to a steel pipe, e.g. by welding. However, welding close to the end fitting [approximately 0,5 m to 0,8 m (1,64 ft to 2,62 ft)] should not be performed when the end fitting is already connected to the flexible pipe because overheating of the end fitting can adversely affect the layer terminations or seals.

4.4.4.3 Quick-disconnect and quick-connect/disconnect systems may be used as connectors where emergency release is an operational requirement for dynamic-riser applications. Figure 13 illustrates an example of a quick-disconnect system. The main features of emergency release systems are typically as follows:

- a) isolation ball valve in upper and lower halves of the structure;
- b) ability to disconnect under full design loads and internal pressure;
- c) minimal size and mass for structure;
- d) full-bore throughout to allow for pigging;
- e) pressure-tight connection with face-to-face type primary seals to avoid damage to seals during disconnect/reconnect and dynamic loading;
- f) ball valves are interlocked with release mechanism to ensure closure on disconnection (might not be required for all applications);
- g) simplified support structure (guide-post funnels) to allow easy and safe reconnection;
- h) capability to periodically test release mechanism without releasing the riser or breaking primary seals (or, if this is not feasible, an alternative test procedure is required that includes retesting of primary seals after reconnection).

4.4.4.4 Disconnect systems can have emergency shutdown valves on one or both sides of the interface. There can be cases where no valve is required. Important considerations in this decision include

- a) risk of disconnection,
- b) transported fluid,
- c) environmental concerns, and
- d) topsides valving.



Key

- 1 upper ball valve
- 2 support structure
- 3 emergency release coupler
- 4 lower ball valve
- 5 riser interface flange
- 6 internal pressure sheath
- 7 primary seals
- 8 ball valve actuators
- 9 hard piping interface flange

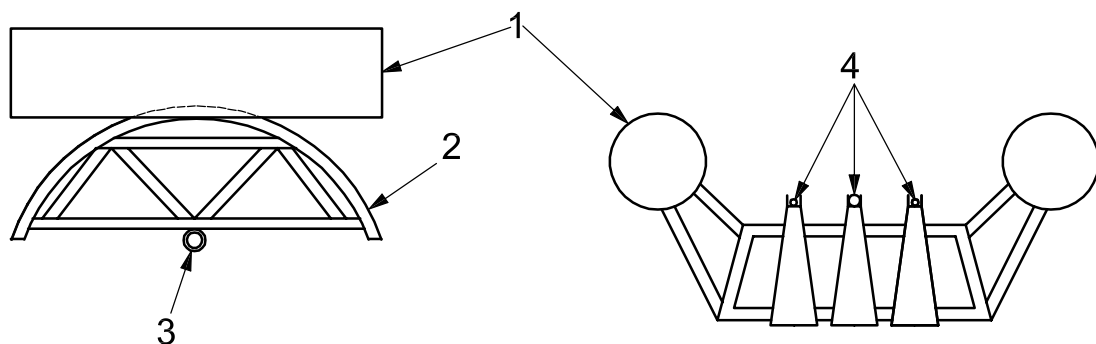
Figure 13 — Example of a quick-disconnect system

4.4.5 Subsea buoys

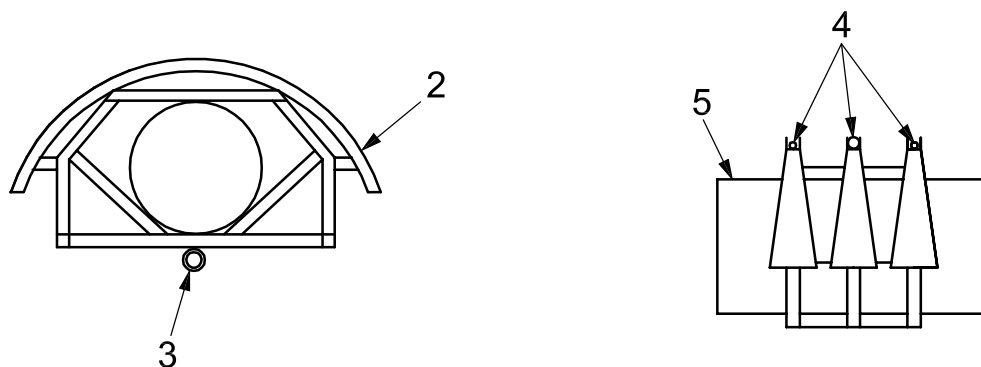
4.4.5.1 Subsea buoy/arch systems are used to achieve S-shaped riser configurations, including lazy, steep, and reverse configurations. (Note that in the reverse configuration, the lower catenary of the riser passes back underneath the buoy.) The systems typically consist of one or more buoyancy tanks supported by a steel structure over which lie individual gutters (arches) for each riser. Figure 14 shows two typical systems. The buoyancy tanks may be constructed from either steel tanks or syntactic foam modules. The tanks can be positioned as shown in Figure 14.

4.4.5.2 The S-shaped riser configuration can alternatively be achieved by using a fixed support instead of a floating buoy (Figure 14). The main disadvantage of this system is the reduction in compliancy of the riser system.

4.4.5.3 The subsea buoy/arch system is held in place by a riser base to which it is connected by tethers (lazy-S) or by flexible risers (steep-S). The subsea buoy/arch systems are typically designed to support two to six risers, though there is no theoretical limit on the number. The risers are held in place on the arch.

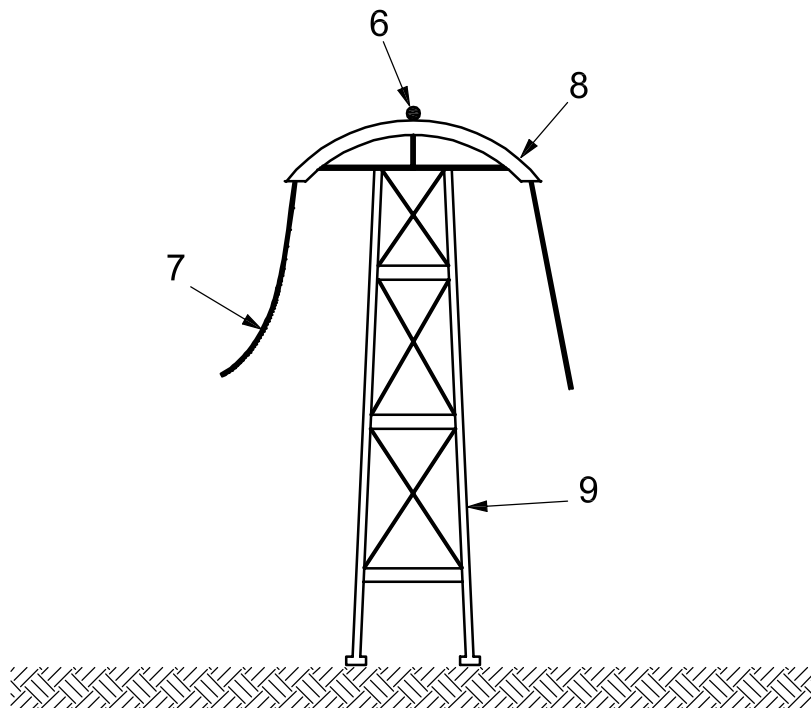


a) Option 1 — Twin buoys



b) Option 2 — Single buoy

Figure 14 (continued)



c) Option 3 — Fixed arch

Key

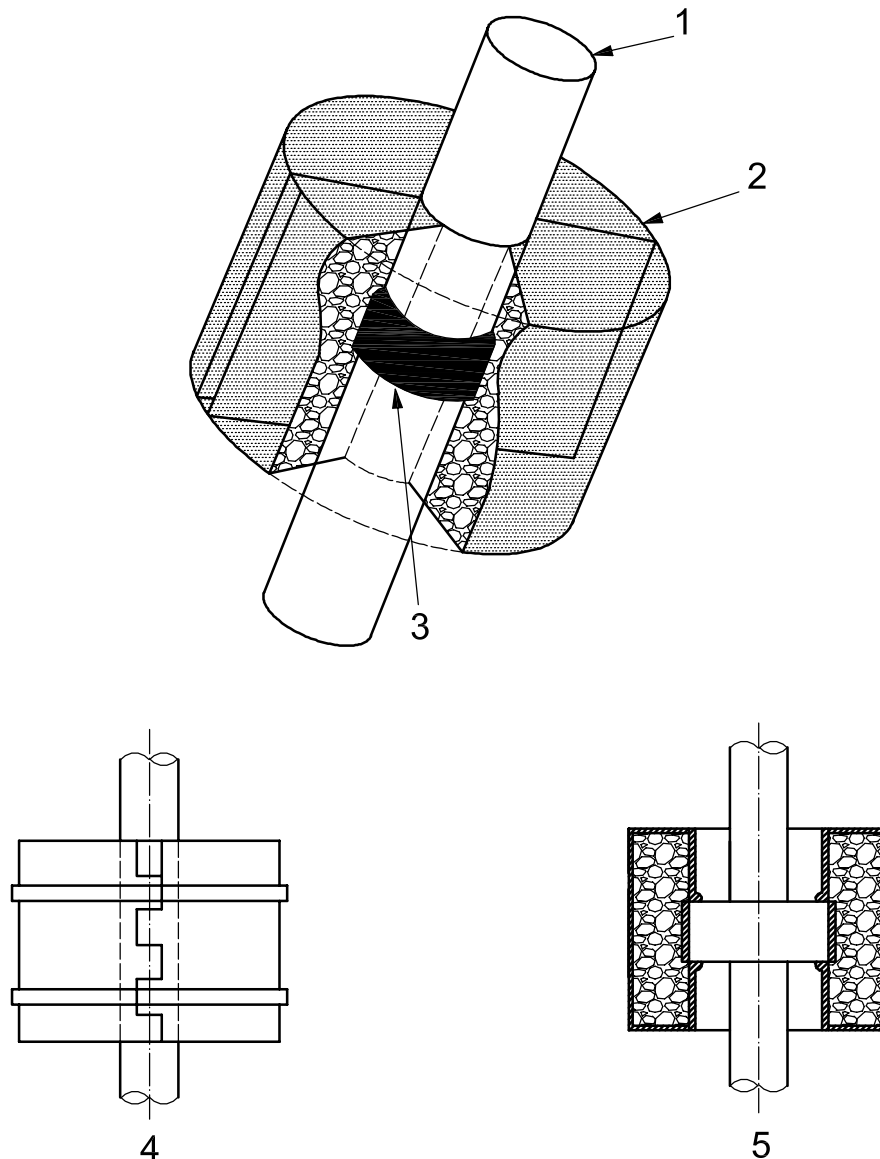
- 1 buoys
- 2 gutters
- 3 tethering point
- 4 risers
- 5 buoy
- 6 riser clamp
- 7 flexible riser
- 8 arch/gutters
- 9 support structure

NOTE The buoys can be steel tanks or syntactic foam structures.

Figure 14 — Subsea buoy/arch systems**4.4.6 Buoyancy modules**

4.4.6.1 Buoyancy modules are used to achieve the wave-shape riser configurations (lazy, steep, and pliant). Figure 15 is a schematic of a typical module. A specific number of modules (such as 30) is required to achieve the wave configuration and are generally sized (both length and diameter) to be about two to three times the pipe OD, though this depends on buoyancy and installation requirements. The number of modules is based largely on riser mass, water depth, offset requirements, and manufacturing/commercial issues. The modules are individually clamped to the riser, so the design should ensure that they do not slide along the pipe or damage it. Some bonded flexible pipes have integral elastomer collars at intervals along the pipe to facilitate the attachment of ancillary devices. These collars are generally built and cured with the pipe.

4.4.6.2 The buoyancy module is comprised, typically, of an internal clamp and a syntactic foam buoyancy element. A polymer casing (polyurethane, for example) provides impact and abrasion resistance. The internal clamp bolts directly onto the flexible pipe, and the buoyancy element fits around the clamp. The buoyancy element is generally in two halves that are securely fastened together. The density of the syntactic foam is selected based on the specified water depth and service life. A typical density is 350 kg/m^3 ($21,8 \text{ lb/ft}^3$).



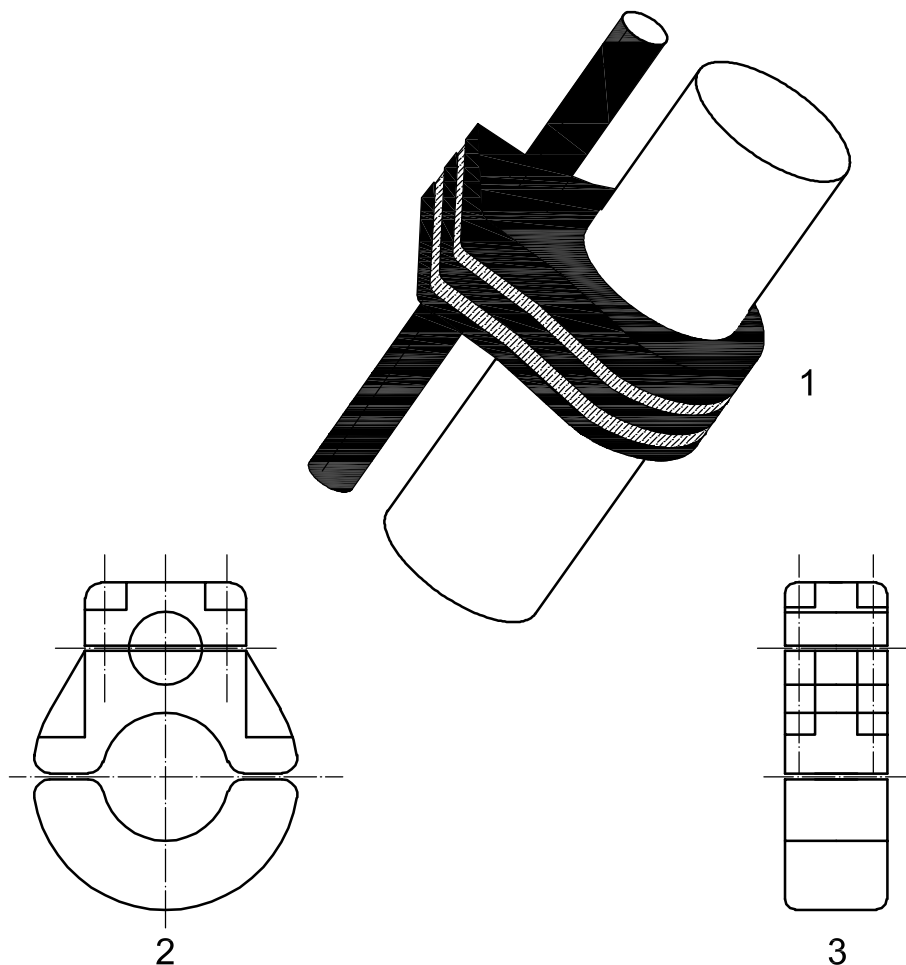
Key

- 1 flexible pipe
- 2 buoyancy module
- 3 clamp
- 4 side elevation
- 5 cross-section

Figure 15 — Example of a buoyancy module for wave configurations

4.4.7 Clamping devices

4.4.7.1 Clamping devices can be used in flexible-pipe applications to connect ancillary components, such as buoyancy modules, subsea arches, tethers and bend restrictors, to the pipe. In addition, bundle clamps can be used to join several pipes together at discrete intervals, such as with piggy-back lines (Figure 16). The main component of bundle and piggy-back clamps is a spacer device or body, which can be in two half sections. The body is provided with cylindrical recesses into which individual lines are fitted. The assembly is joined together with bolts or a set of circumferential straps. Alternatively, band straps may be used for static piggy-back assemblies where they are needed only for installation.



Key

- 1 riser clamp
- 2 front elevation
- 3 side elevation

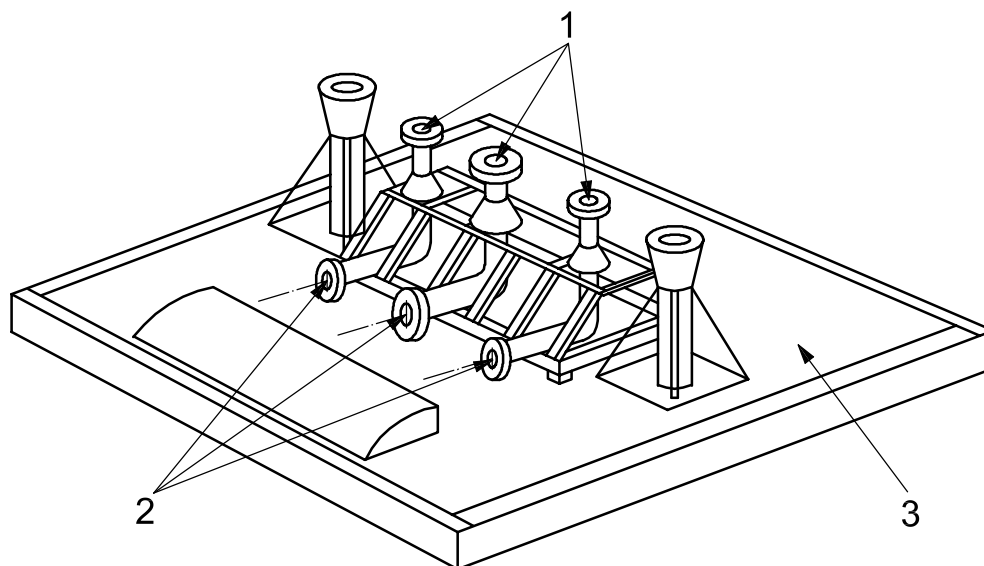
Figure 16 — Example of a clamp for piggy-backed flexible risers

4.4.7.2 Avoid excessive contact pressure. If high contact pressure is required, fit some type of protection shell to distribute the applied load. The clamp design should also ensure that there are no sharp edges that can cause local overbending of the pipe.

4.4.8 Riser and tether bases

4.4.8.1 Riser bases are used to connect flexible risers to flowlines and can also be required to support subsea buoy/arch systems (steep-S configuration). Tether bases are used only to anchor subsea buoy/arch systems (lazy-S configuration).

4.4.8.2 The riser base may be a gravity structure, a piled structure or a suction/anchor pad. Selection of a gravity-based or piled structure depends on applied loads and soil conditions. Figure 17 illustrates a typical riser-base structure. As an alternative, the flexible pipe can be connected directly to a manifold or a PLEM, in which case the manifold or PLEM acts as the riser base.



Key

- 1 flexible riser connections
- 2 spool pieces to the flowlines
- 3 concrete slab

Figure 17 — Example of a typical riser base

4.4.9 Riser hang-off structures

4.4.9.1 The top connection of a flexible riser can be hung off from the support structure (such as a platform, tanker or semi-sub) either externally or internally.

EXAMPLE 1 The riser is connected to topsides piping at pontoon level or hung off at upper-deck level in an external connection.

EXAMPLE 2 The riser is typically pulled through an I-tube and hung off at the top of the I-tube in an internal connection (Figure 18).

The loading on the two hang-off structures is very different, with the internal connection subject only to axial loads while the external connection experiences axial, bending and shear loads.

4.4.9.2 Important considerations in the design of riser hang-off structures are described in 4.4.9.3 to 4.4.9.8.

4.4.9.3 The main constraints in the design of the hang-off structure are load limitations, space limitations, and spool-piece requirements.

4.4.9.4 The design of the hang-off structure for internal connections should account for the weight of the riser within the I-tube.

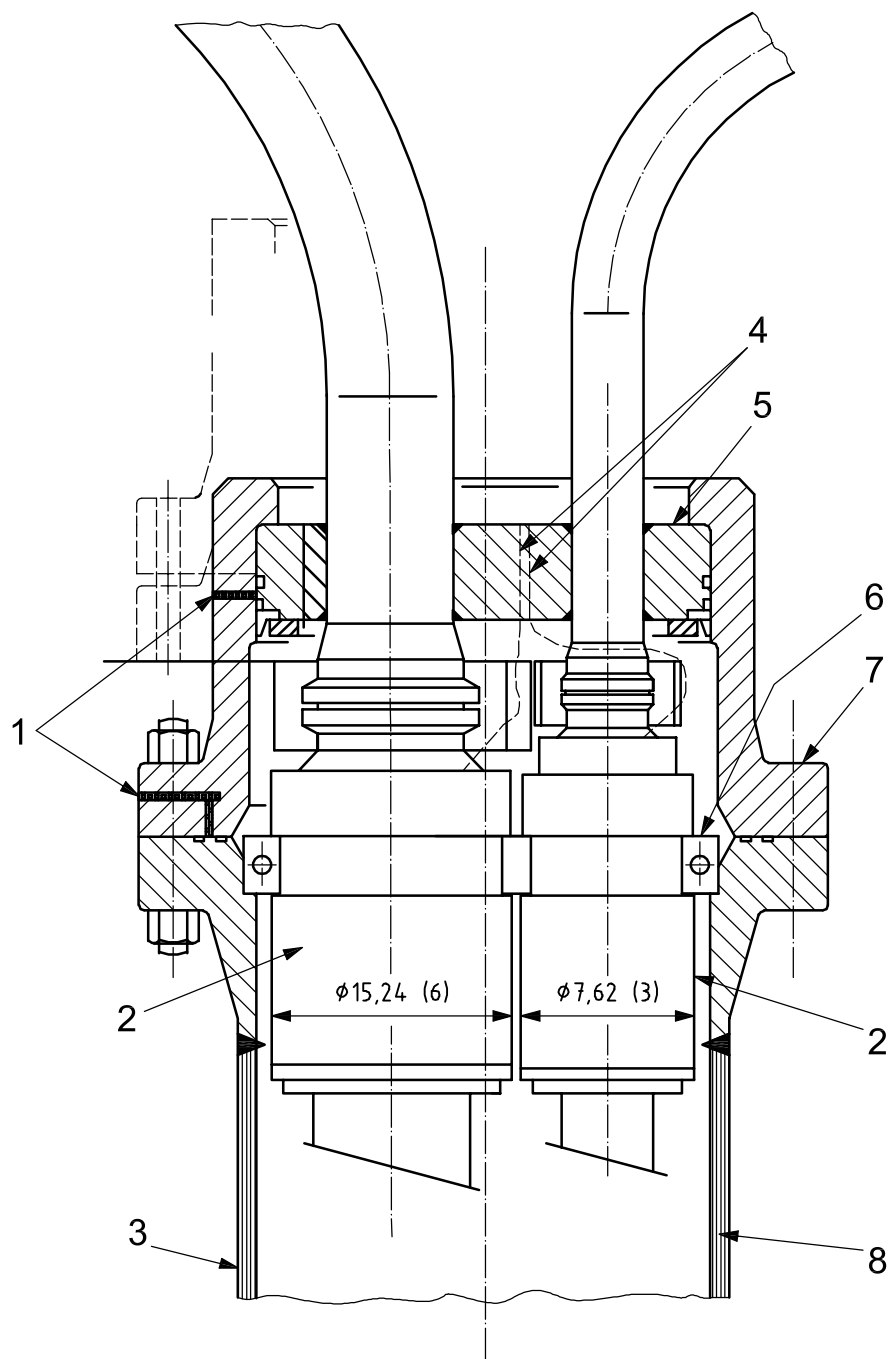
4.4.9.5 The critical loading for some hang-off structures occurs during installation, when there can be a significant pull-in load (including friction effects).

4.4.9.6 Overbending of the riser at a base of an I-tube is prevented by use of a bend limiter (bend stiffener or bellmouth).

4.4.9.7 The limiter is structurally supported by the I-tube, and can induce substantial loads on the I-tube, which should be designed for all relevant loads. These loads can be significantly increased by the use of short spool pieces (such as between a bend stiffener and the base of an I-tube), and this should be considered during design of the I-tubes.

4.4.9.8 Corrosion inhibitors are added, in some cases, to the seawater inside the I-tubes, which requires the bottom of the I-tube to be sealed to prevent loss of inhibitor. If relevant, the design of the riser installation and connection system should account for the requirement for sealing of the I-tube. Compatibility of corrosion inhibitors in the I-tube with materials of the flexible pipe riser shall be verified.

Dimensions in millimetres (inches)



Key

- | | |
|-----------------------|---------------|
| 1 test port | 5 bonnet |
| 2 flex riser | 6 split plate |
| 3 top of deck | 7 skirt |
| 4 anunulus bleed line | 8 J-tube |

Figure 18 — Example of a typical riser hang-off structure

5 Pipe design considerations

5.1 General

Clause 5 elaborates and provides guidance on flexible-pipe design consistent with the requirements of ISO 13628-2 and ISO 13628-10. Clause 5 addresses the following specific issues:

- a) design process;
- b) pipe structural-failure modes;
- c) design criteria;
- d) design load cases.

5.2 Design overview

5.2.1 General

In 5.2.2 and 5.2.3 a general overview is outlined on the typical design process for flexible-pipe applications. The design process, however, is a function of the pipe application, and a distinction is made between the processes for the design of the following two generic flexible-pipe applications:

- a) static (applies to static riser, flowline and jumper applications);
- b) dynamic or loading line (applies to dynamic riser, loading-line and jumper applications).

Design of the end fitting is also discussed in 5.2.4. The end fitting is considered an integral part of the pipe.

5.2.2 Static-application design

5.2.2.1 The main design stages for static applications are represented in flowchart form in Figure 19 and are as follows:

- a) Stage 1: Materials selection;
- b) Stage 2: Cross-section configuration design;
- c) Stage 3: System configuration design;
- d) Stage 4: Detail and service-life design;
- e) Stage 5: Installation design.

5.2.2.2 In Stage 1, the pipe-material selection is made based on internal environment (transported product), functional requirements and material options. Materials compatible with the transported product are selected. Clause 6 contains guidelines for material selection.

5.2.2.3 In Stage 2, the cross-section configuration and dimensions are selected based on the pipe's functional requirements and experience in the selection of the layer structure. Cross-section design calculations and checks are typically carried out by the manufacturer using proprietary software that has been validated with test data.

5.2.2.4 Stage 3 involves selection of the system configuration. This is generally a straightforward task in the case of a flowline, with the only complications typically being the design of the end sections and any requirements to accommodate the relative movement envelope. However, thermal analysis, upheaval buckling and stability analysis can dictate design requirements in certain situations.

5.2.2.5 Stage 4 includes the detailed design of ancillary components, as described in 4.4, and corrosion protection. Service life analysis is also performed at this stage as it applies to the pipe and components.

5.2.2.6 Stage 5 completes the design process and involves the selection and design of the installation system, including vessel, equipment, methodology and environment conditions. Stage 5 requires detailed global and local analyses to confirm the feasibility of the selected installation system. This stage, in the case of flowlines, is in many cases critical for the pipe design, and it is therefore recommended that preliminary installation analyses be performed at an early stage in the design process.

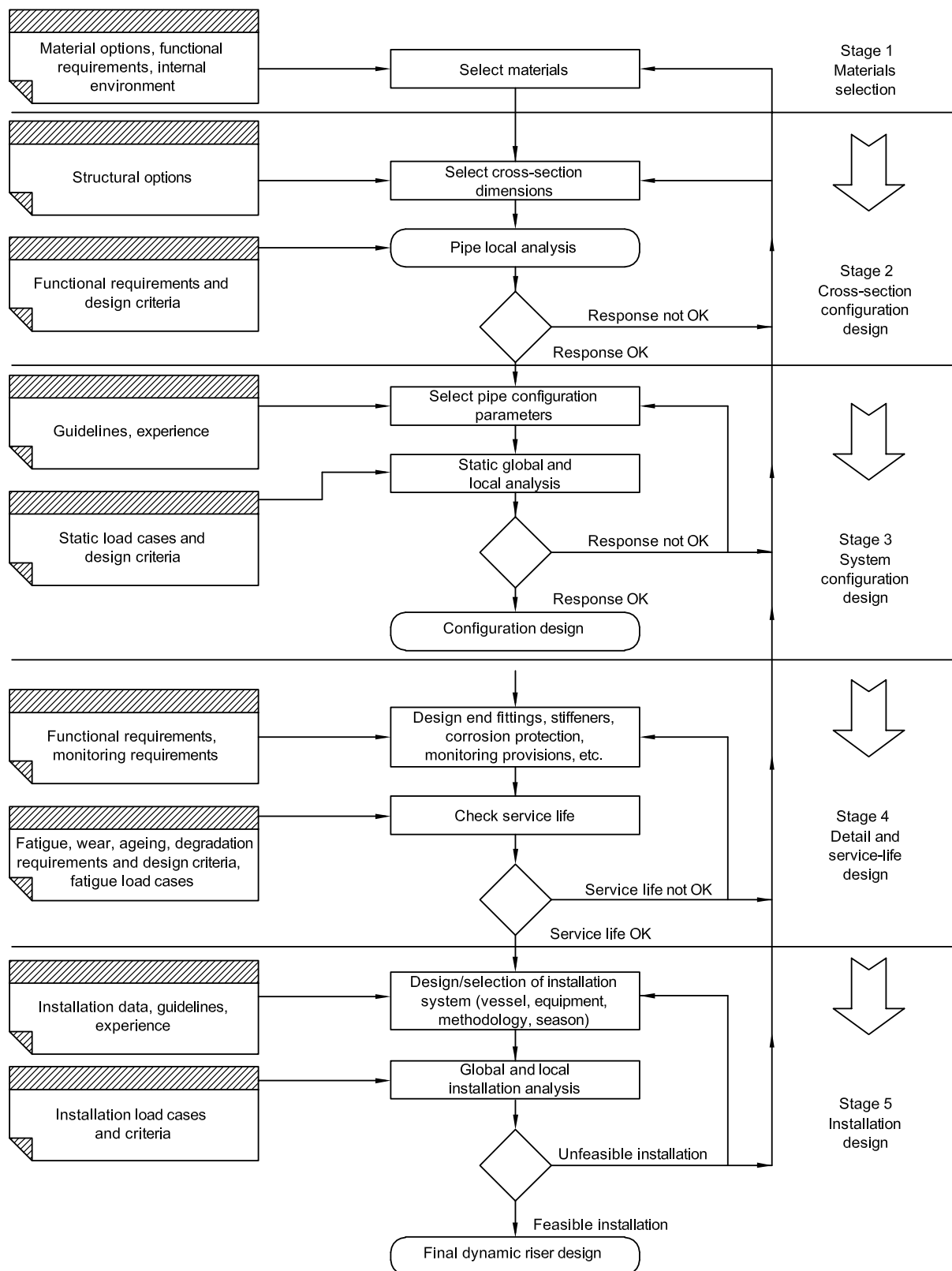


Figure 19 — Static-application design flowchart

5.2.3 Dynamic-application design

5.2.3.1 The main design stages for dynamic applications are represented in flowchart form in Figure 20, and are as follows:

- a) Stage 1: Material selection;
- b) Stage 2: Cross-section configuration design;
- c) Stage 3: System configuration design;
- d) Stage 4: Dynamic analysis and design;
- e) Stage 5: Detail and service-life design;
- f) Stage 6: Installation design.

5.2.3.2 In Stage 1, the pipe-material selection is made, as for a static flowline, based on internal environment (transported product), functional requirements, and material options. In this case, materials compatible with both the transported product and the dynamic service of the flexible pipe are selected (Clause 6).

5.2.3.3 In Stage 2, the cross-section configuration and dimensions are selected and design calculations and checks are carried out as those for a static flowline.

5.2.3.4 Stage 3 involves selection of the system configuration. This task, for a dynamic riser, involves selecting a pipe configuration from available options, some of which are shown in Figure 4. Some guidelines on the selection of riser configurations are provided in 7.4.1. System configuration design also requires that the effect of ancillary components, such as concentrated or distributed buoyancy, be quantified at this stage.

5.2.3.5 Stage 4 involves the dynamic design of the riser or riser system. Typically, this considers the dynamic response of the riser subject to a series of imposed loading conditions derived from the functional, environmental and accidental loads on the system. Other important issues to be addressed here include possible interference with other system components, top tensions, departure angles and curvatures. Such analysis is typically performed using finite-element dynamic analysis software (8.2.3.3).

5.2.3.6 Stage 5 includes the detailed design of ancillary components, as described in 4.4, and corrosion protection. Service-life analysis is also performed at this stage, as it applies to the pipe and components. Clause 7 gives guidelines on the design of the pipe system and ancillary components.

5.2.3.7 Stage 6, installation design, completes the design process and is largely similar to the equivalent stage in static-flowline design. The complexity of the system installed for risers is generally significantly greater than for a flowline.

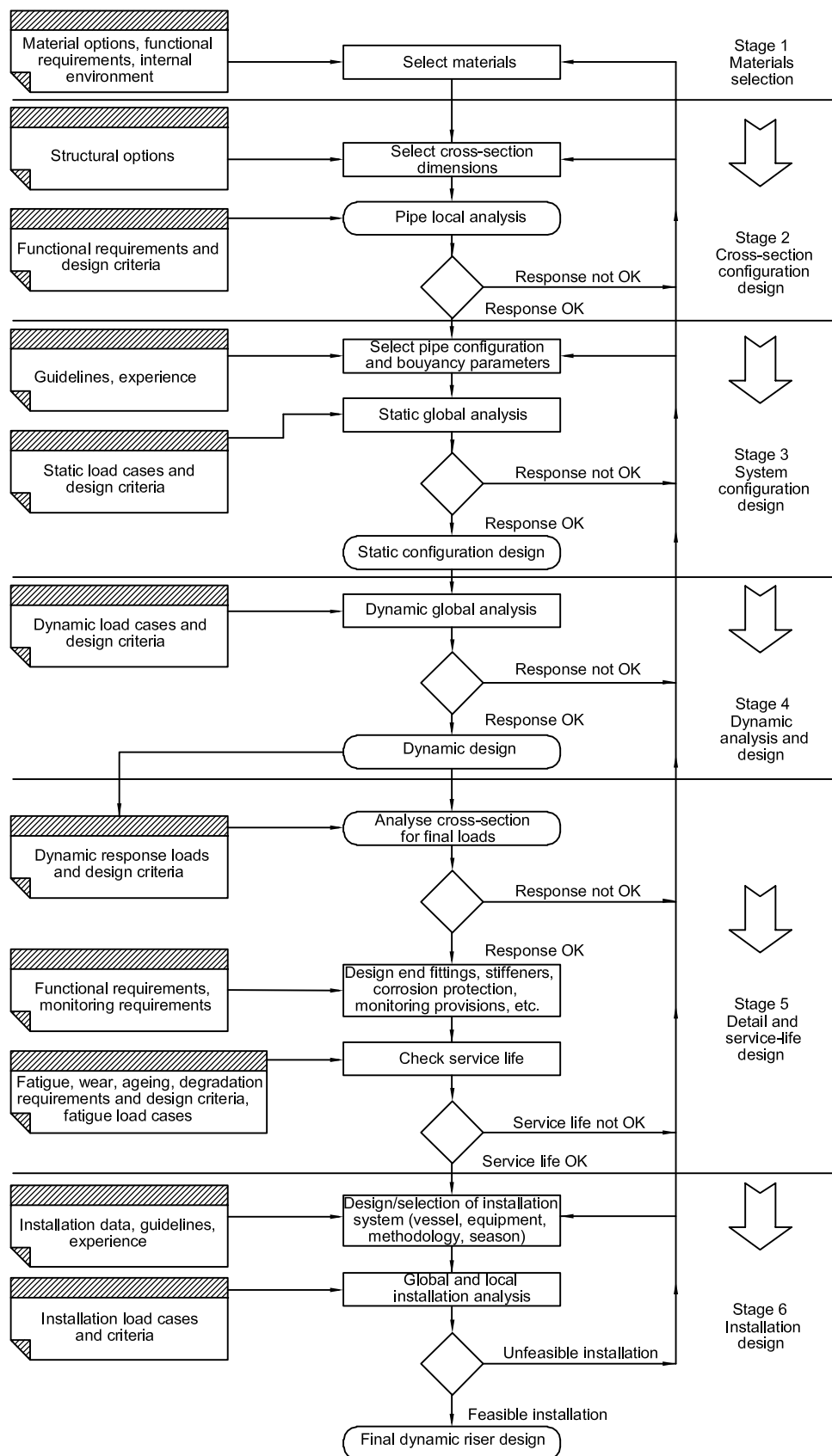


Figure 20 — Dynamic-application design flowchart

5.2.4 End-fitting design

5.2.4.1 General

The design of the end fitting for flexible pipes is critical. In 4.3.5 the end fittings used for flexible pipes are described, while Figure 8 shows a schematic of a typical unbonded-pipe end fitting. As a minimum, the end fitting design should meet the requirements of ISO 13628-2 and ISO 13628-10.

5.2.4.2 Unbonded pipe

5.2.4.2.1 The end fitting design for unbonded flexible pipes should consider the potential pipe defects identified in 13.3. Of particular relevance are high pressure, deep water and the potential for pull-out of the internal pressure sheath from the inner seal. Critical issues include the following:

- a) loss of plasticizer from internal pressure sheath;
- b) dimensional changes in sheath because of plasticizer loss and other phenomena;
- c) friction coefficient between seal and adjacent layers;
- d) creep and stress relaxation in the sheath material;
- e) thermal coefficient of expansion for the sheath material;
- f) variation of sheath-material properties over service life;
- g) requirement for multiple layers in the internal pressure sheath;
- h) for vertical risers, potential support of the internal carcass by the internal pressure sheath during periods when pipe is depressurized;

NOTE Decompression results in no support from the pressure armour, as depressurization results in insignificant frictional force between the sheath and the supported pressure armour.

- i) number and range of temperature cycles;
- j) cool-down rates during temperature cycles of the end fitting and the main pipe body;
- k) variations in polymer-material properties with temperature;
- l) armour-wire pull-out;
- m) epoxy degradation;
- n) corrosion;
- o) pressure- and tension-retaining capability;
- p) resistance to seawater ingress;
- q) resistance to external-sheath pull-out during installation.

5.2.4.2.2 The design of the end-fitting internal crimping/sealing mechanism, for PVDF-based pipes in particular, is critical for riser applications. The effectiveness of the seal can be reduced by large temperature cycles, a high thermal-expansion coefficient, plasticizer loss or the use of a multiple-layer construction for a PVDF internal pressure sheath. The end-fitting design should be verified with high-temperature cycling tests (Annex A). These tests should be representative of service conditions, including thermal and dynamic loading, and the effect of plasticizer loss as applicable. For new designs, the prototype tests of Clause 9 should also be considered.

5.2.4.3 Bonded pipe

The end-fitting design for bonded flexible pipes should consider the potential pipe defects identified in 13.3. Issues of particular relevance include high pressure, deep water, the potential for pull-out of reinforcing cables and loss of fluid-seal integrity. Critical issues include the following:

- a) change of pipe body, particularly liner-material properties over service life;
- b) dimensional changes in pipe body due to the highly elastic nature of pipe-body elastomer material;
- c) bonding of liner-material layers and bonding of liner to remainder of flexible-pipe body;
- d) reinforcing-armour pull-out;
- e) epoxy degradation;
- f) corrosion;
- g) pressure- and tension-retaining capability;
- h) resistance to seawater ingress;
- i) integrated gasket integrity;
- j) crimping over-pressure applied;
- k) number and range of temperature and pressure cycles;
- l) incorporation of integrated bend stiffeners.

5.3 Failure modes

It is important to design a flexible pipe with the knowledge of the potential degradation and failure modes for the intended application. It is important to note that other modes of pipe degradation and failure possibly can be implicitly provided for in design (such as through materials selection, see Clause 6) or are considered, for example, as part of manufacture (Clause 10) or handling, transportation and installation (Clause 11).

Tables 3 and 4 provide lists of pipe-failure modes that are explicitly provided for in typical unbonded- and bonded-pipe design, respectively, and identify relevant failure mechanisms and appropriate design strategies/solutions. The design solutions shall, in all cases, meet the design criteria specified in ISO 13628-2 and ISO 13628-10. A more complete, though not exhaustive, list of potential pipe defects for flowline and riser applications is presented in Tables 30 to 32. Furthermore, some of the modes identified in Table 3, Table 4, Table 30, Table 31 and Table 32 are being addressed by continuing design improvements and are therefore not necessarily relevant to future pipe designs.

Table 3 — Checklist of failure modes for primary structural design of unbonded flexible pipe

Pipe global failure mode to design against	Potential failure mechanisms	SA or DA	Design solution or variables (ISO 13628-2)
Collapse	1) Collapse of carcass and/or pressure armour due to excessive tension. 2) Collapse of carcass and/or pressure armours due to excess external pressure. 3) Collapse of carcass and/or pressure armour due to installation loads or ovalization due to installation loads. 4) Collapse of internal pressure sheath in smooth-bore pipe.	SA, DA SA, DA SA, DA SA, DA	1) Increase thickness of carcass strip, pressure armour or internal pressure sheath (smooth-bore collapse). 2) Modify configuration or installation design to reduce loads. 3) Add intermediate leak-proof sheath (smooth-bore pipes). 4) Increase the area moment of inertia of carcass or pressure armour.
Burst ^a	1) Rupture of pressure armours because of excess internal pressure. 2) Rupture of tensile armours due to excess internal pressure.	SA, DA SA, DA	1) Modify design, e.g. change lay angle, wire shape, etc. 2) Increase wire thickness or select higher-strength material if feasible. 3) Add additional pressure- or tensile-armour layers.
Tensile failure ^a	1) Rupture of tensile armours due to excess tension. 2) Collapse of carcass and/or pressure armours and/or internal pressure sheath due to excess tension. 3) Snagging by fishing trawl board or anchor, causing overbending or tensile failure.	SA, DA SA, DA SA, DA	1) Increase wire thickness or select higher-strength material if feasible. 2) Modify configuration designs to reduce loads. 3) Add two more armour layers. 4) Bury pipe.
Compressive failure	1) Bird-caging of tensile-armour wires. 2) Compression leading to upheaval buckling and excess bending (see also upheaval buckling failure mode, 7.3.4).	SA, DA SA, DA	1) Avoid riser configurations that cause excessive pipe compression. 2) Provide additional support/restraint for tensile armours, such as tape and/or additional or thicker outer sheath.
Overbending ^a	1) Collapse of carcass and/or pressure armour or internal pressure sheath. 2) Rupture of internal pressure sheath. 3) Unlocking of interlocked pressure or tensile-armour layer. 4) Crack in outer sheath.	SA, DA SA, DA SA, DA SA, DA	Modify configuration designs to reduce loads.
Torsional failure ^a	1) Failure of tensile-armour wires. 2) Collapse of carcass and/or internal pressure sheath. 3) Bird-caging of tensile-armour wires.	SA, DA SA, DA SA, DA	1) Modify system design to reduce torsional loads. 2) Modify cross-section design (e.g. change lay angle of wires, add extra layer outside armour wires, etc.) to increase torsional capacity.
Fatigue failure	1) Tensile-armour-wire fatigue. 2) Pressure-armour-wire fatigue.	DA DA	1) Increase wire thickness or select alternative material, so that fatigue stresses are compatible with service-life requirements. 2) Modify design to reduce fatigue loads.
Erosion	Of internal carcass.	SA, DA	1) Modify material selection. 2) Increase thickness of carcass. 3) Reduce sand content. 4) Increase MBR.
Corrosion	1) Of internal carcass. 2) Of pressure- or tensile-armour exposed to seawater, if applicable. 3) Of pressure- or tensile-armour exposed to diffused product.	SA, DA SA, DA SA, DA	1) Modify material selection. 2) Cathodic protection system design. 3) Increase layer thickness. 4) Add coatings or lubricants.
^a Burst, tensile, overbending and torsional failure are not considered in isolation for final design of the flexible pipe. NOTE See Tables 30 to 32 for defects important in end-fitting designs.			

Table 4 — Checklist of failure modes for primary structural design of bonded flexible pipe

Pipe global failure mode to design against	Potential failure mechanisms	SA or DA	Design solution or variables (ISO 13628-10)
Collapse	1) Collapse of carcass due to excessive tension. 2) Collapse of carcass due to excess external pressure. 3) Collapse of carcass and due to installation loads or ovalization due to installation loads. 4) Collapse of pipe in smooth-bore pipe.	SA, DA SA, DA SA, DA	1) Increase thickness of carcass strip or pipe body (smooth-bore collapse). 2) Modify configuration or installation design to reduce loads. 3) Increase the area moment of inertia of carcass.
Burst ^a	1) Rupture of reinforcing armours due to excess internal pressure.	SA, DA	1) Modify design, e.g. change lay angle, cable type, etc. 2) Increase cable thickness or select higher strength material if feasible. 3) Add additional reinforcing-armour layers.
Tensile failure ^a	1) Rupture of reinforcing armours due to excess tension. 2) Collapse of carcass and/or pipe-body sheath due to excess tension. 3) Snagging by fishing trawl board or anchor, causing overbending or tensile failure.	SA, DA SA, DA SA, DA	1) Increase cable thickness or select higher-strength material if feasible. 2) Modify configuration designs to reduce loads. 3) Add two more armour layers. 4) Bury pipe.
Compressive failure	1) Compression leading to upheaval buckling and excess bending (see also upheaval buckling failure mode, 7.3.4).	SA, DA	Avoid riser configurations that cause excessive pipe compression.
Overbending ^a	1) Collapse of carcass or pipe body. 2) Rupture of liner. 3) Crack/tear in outer sheath.	SA, DA SA, DA SA, DA	Modify configuration designs to reduce loads.
Torsional failure ^a	1) Failure of tensile-armour wires. 2) Collapse of carcass and/or liner. 3) Birdcaging of tensile-armour wires.	SA, DA SA, DA SA, DA	1) Modify system design to reduce torsional loads. 2) Modify cross-section design (e.g. change lay angle of wires, add extra layer outside armour wires, etc.) to increase torsional capacity.
Fatigue failure	1) Tensile-armour-wire fatigue. 2) Pressure-armour-wire fatigue.	DA DA	1) Increase wire thickness or select alternative material, so that fatigue stresses are compatible with service-life requirements. 2) Modify design to reduce fatigue loads.
Erosion	1) Of internal carcass or liner.	SA, DA	1) Modify material selection. 2) Increase thickness of carcass. 3) Reduce sand content. 4) Increase MBR.
Corrosion	1) Of internal carcass. 2) Of pressure- or tensile-armour exposed to seawater, if applicable. 3) Of pressure- or tensile-armour exposed to diffused product.	SA, DA SA, DA SA, DA	1) Modify material selection. 2) Modify cathodic protection system design. 3) Increase layer thickness. 4) Add coatings or lubricants.

^a Burst, tensile, overbending and torsional failure are not considered in isolation for final design of the flexible pipe.

NOTE See Tables 30 to 32 for defects important in end-fitting design.

5.4 Design criteria

5.4.1 Unbonded flexible pipe

5.4.1.1 Introduction

5.4.1.1.1 The design criteria for unbonded flexible pipes are given in ISO 13628-2 in terms of the following:

- a) strain (polymer sheath);
- b) creep (internal pressure sheath);
- c) stress (metallic layers and end fitting);
- d) hydrostatic collapse (buckling load);
- e) mechanical collapse (stress induced from armour layers);
- f) torsion;
- g) crushing collapse and ovalization (during installation);
- h) compression (axial and effective);
- i) service-life factors.

5.4.1.1.2 These criteria are discussed further in 5.4.1.2 to 5.4.1.10, in which some guidance on their derivation is given. Criteria are also introduced that provide for design against failure in addition to the criteria specified in ISO 13628-2.

5.4.1.1.3 The criteria specified by ISO 13628-2 apply to the materials currently used in flexible-pipe applications. Where new materials are proposed or used, the design criteria for the new materials should give at least the safety level specified in this part of ISO 13628 and in ISO 13628-2. The design criteria should consider all material characteristics, such as susceptibility to such conditions as creep, fatigue, excessive strain and cracking.

5.4.1.1.4 Simplified approaches exist for the approximation of pipe characteristics (axial, bending and torsional stiffness, etc.) and for calculating loads in the individual layers. These simplified methodologies may be used for preliminary comparison of design loads with design criteria. For final design calculations, however, it is necessary to use a verified (with prototype tests) methodology, as defined in ISO 13628-2.

5.4.1.2 Strain

5.4.1.2.1 A critical parameter in the design of the internal pressure and outer sheaths is the allowable strain. ISO 13628-2 specifies allowable-strain values for the most commonly used materials. The allowable strain for materials not explicitly provided for in ISO 13628-2 is specified by the manufacturer.

5.4.1.2.2 Allowable strains have been verified by material tests performed under relevant service and ageing conditions. A safety factor is typically applied to results of such tests to derive the allowable strain of the material over its service life, accounting for material ageing and degradation in the appropriate environment.

5.4.1.2.3 ISO 13628-2 also provides for the calculation of MBR to prevent locking of the interlocked pressure-armour wires.

5.4.1.3 Creep

5.4.1.3.1 Under normal service conditions, the internal pressure sheath creeps into gaps in the pressure- or tensile-armour layer as a result of pressure and temperature effects. If the sheath is too thin or the gap too large, the internal pressure sheath will creep until a failure (leakage) occurs. Creep of the sheath at the end-fitting seal is also an important issue (see Table 5).

Table 5 — Recommended allowable degradation for unbonded pipes

Component	Degradation mode	Recommendation
Carcass	1) Corrosion	1) Limited corrosion acceptable provided structural capacity and functional requirements are maintained.
	2) Erosion	2) Same as for corrosion.
Internal pressure sheath	1) Creep	1) Limited creep acceptable provided — structural capacity to bridge gaps maintained, — no cracks, — no locking of carcass or pressure-armour layers, — no leakage, — sealing maintained at end fittings.
	2) Thermal/chemical degradation	2) Capacity at design life remains within specified usage factors with maximum gaps between layers. No leakage allowed. Increased permeation allowed if system has been designed for the increased level of permeation. Important considerations are increased damage rates (corrosion, HIC, SSC) for armours and limits on gas-venting-system capacity. Strain capacity sufficient to meet the design requirements of ISO 13628-2.
	3) Cracking	3) No cracking because of dynamic service.
Pressure and tensile armours	1) Corrosion	1) Only general corrosion accepted; no crack initiation acceptable.
	2) Disorganization or locking of armouring wires	2) No disorganization of armouring wires when bending to minimum bend radius.
	3) Fatigue and wear	3) See 8.2.4.
Anti-wear layer	1) Wear	1) No wear through the thickness of the layer over its service life.
Intermediate sheath	1) Thermal degradation	1) Functional requirements are maintained.
Thermal insulation	1) Thermal degradation	1) Insulation capacity is maintained equal to or above minimum specified value.
Outer sheath	1) General degradation	1) Strain capacity is sufficient to meet the design requirements of ISO 13628-2.
	2) Radial deformation (loosening)	2) No loosening that causes the disorganization of armour wires or strain failure of outer sheath material.
	3) Breaching	3) No breaching allowed unless pipe design under flooded annulus conditions can be shown to meet the design requirements and remaining service-life requirements.
End fitting and carcass/sheath interface	1) Corrosion	1) No corrosion that results in reduction of capacity, possibility for leakage, or damage to any sealing or locking mechanism is acceptable.