# DIN EN ISO 14692-3

DIN

ICS 23.040.01; 75.200

Ersatz für
DIN EN ISO 14692-3:2005-07 und
DIN EN ISO 14692-3
Berichtigung 1:2007-02

## Erdöl- und Erdgasindustrie – Glasfaserverstärkte Kunststoffrohrleitungen (GFK) – Teil 3: Systemauslegung (ISO 14692-3:2017); Englische Fassung EN ISO 14692-3:2017

Petroleum and natural gas industries –
Glass-reinforced plastics (GRP) piping –
Part 3: System design (ISO 14692-3:2017);
English version EN ISO 14692-3:2017

Industries du pétrole et du gaz naturel –
Canalisations en plastique renforcé de verre (PRV) –
Partie 3: Conception des systèmes (ISO 14692-3:2017);
Version anglaise EN ISO 14692-3:2017

Gesamtumfang 46 Seiten

DIN-Normenausschuss Erdöl- und Erdgasgewinnung (NÖG)



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# Nationales Vorwort

Der Text von ISO 14692-3:2017 wurde vom Technischen Komitee ISO/TC 67 „Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries“ der Internationalen Organisation für Normung (ISO) erarbeitet und als EN ISO 14692-3:2017 durch das Technische Komitee CEN/TC 12 „Materialien, Ausrüstungen und Offshore-Bauwerke für die Erdöl-, petrochemische und Erdgasindustrie“ übernommen, dessen Sekretariat von NEN (Niederlande) gehalten wird.

Für Deutschland hat hieran der Arbeitskreis NA 109-00-01-06 AK „Verfahrenstechnische Anlagen und Ausrüstungen“ im DIN-Normenausschuss Erdöl- und Erdgasgewinnung (NÖG) mitgearbeitet.

Diese Europäische Norm enthält unter Berücksichtigung des DIN-Präsidialbeschlusses 1/2004 nur die englische Originalfassung der ISO Norm.

Für die in diesem Dokument zitierten Internationalen Normen wird im Folgenden auf die entsprechenden Deutschen Normen hingewiesen:

ISO 14692-1 siehe DIN EN ISO 14692-1

ISO 14692-2 siehe DIN EN ISO 14692-2

**Änderungen**

Gegenüber DIN EN ISO 14692-3:2005-07 und DIN EN ISO 14692-3 Berichtigung 1:2007-02 wurden folgende Änderungen vorgenommen:

a) neuer Abschnitt 6 „Generation of design envelopes“;

b) Reduzierung der Anhänge auf Anhang A (normativ) „Cyclic de-rating — factor $A_3$“ und Anhang B (normativ) „General“;

c) redaktionelle Überarbeitung des gesamten Dokuments.

**Frühere Ausgaben**

DIN EN ISO 14692-3: 2005-07
DIN EN ISO 14692-3 Berichtigung 1: 2007-02

# Nationaler Anhang NA
(informativ)

# Begriffe, Symbole und Abkürzungen

Die Benummerung der folgenden Begriffe und Abkürzungen sind identisch mit der Benummerung in der englischen Fassung.

## 3 Begriffe, Symbole und Abkürzungen

Für die Anwendung dieses Dokuments gelten die Begriffe, Symbole und Abkürzungen nach ISO 14692-1.

ISO und IEC führen Terminologiedatenbanken für Normen unter den folgenden Adressen:

— IEC Electropedia: verfügbar unter: http://www.electropedia.org/;

— ISO Online Browsing Platform: verfügbar unter http://www.iso.org/obp.

# Nationaler Anhang NB
(informativ)

## Literaturhinweise

DIN EN ISO 14692-1, *Erdöl- und Erdgasindustrie — Glasfaserverstärkte Kunststoffrohrleitungen (GFK) — Teil 1: Begriffe, Symbole, Anwendungen und Werkstoffe*

DIN EN ISO 14692-2, *Erdöl- und Erdgasindustrie — Glasfaserverstärkte Kunststoffrohrleitungen (GFK) — Teil 2: Zulassung und Herstellung*

EUROPEAN STANDARD

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**EN ISO 14692-3**

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ICS 75.200; 83.140.30

Supersedes EN ISO 14692-3:2002

English Version

# Petroleum and natural gas industries - Glass-reinforced plastics (GRP) piping - Part 3: System design (ISO 14692-3:2017)

Industries du pétrole et du gaz naturel - Canalisations en plastique renforcé de verre (PRV) - Partie 3: Conception des systèmes (ISO 14692-3:2017)

Erdöl- und Erdgasindustrie - Glasfaserverstärkte Kunststoffrohrleitungen (GFK) - Teil 3: Systemauslegung (ISO 14692-3:2017)

This European Standard was approved by CEN on 22 June 2017.

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**CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels**



Ref. No. EN ISO 14692-3:2017 E

# European foreword

This document (EN ISO 14692-3:2017) has been prepared by Technical Committee ISO/TC 67 "Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries" in collaboration with Technical Committee CEN/TC 12 “Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries” the secretariat of which is held by NEN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2018 and conflicting national standards shall be withdrawn at the latest by March 2018.

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

This document supersedes EN ISO 14692-3:2002.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

**Endorsement notice**

The text of ISO 14692-3:2017 has been approved by CEN as EN ISO 14692-3:2017 without any modification.

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This second edition cancels and replaces the first edition (ISO 14692-3:2002), which has been technically revised. It also incorporates the Technical Corrigendum ISO 14692-3:2002/Cor 1:2005.

This document was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 6, *Processing equipment and systems*.

A list of all the parts of ISO 14692 can be found on the ISO website.

# Introduction

The objective of this document is to ensure that piping systems, when designed using the components qualified in ISO 14692-2, will meet the specified performance requirements. These piping systems are designed for use in oil and natural gas industry processing and utility service applications. The main users of the document will be the principal, design contractors, suppliers contracted to do the design, certifying authorities and government agencies.

# Petroleum and natural gas industries — Glass-reinforced plastics (GRP) piping —

## Part 3:
## System design

## 1 Scope

This document gives guidelines for the design of GRP piping systems. The requirements and recommendations apply to layout dimensions, hydraulic design, structural design, detailing, fire endurance, spread of fire and emissions and control of electrostatic discharge.

This document is intended to be read in conjunction with ISO 14692-1.

Guidance on the use of this document can be found in Figure 1, which is a more detailed flowchart of steps 5 and 6 in ISO 14692-1:2017, Figure 1.

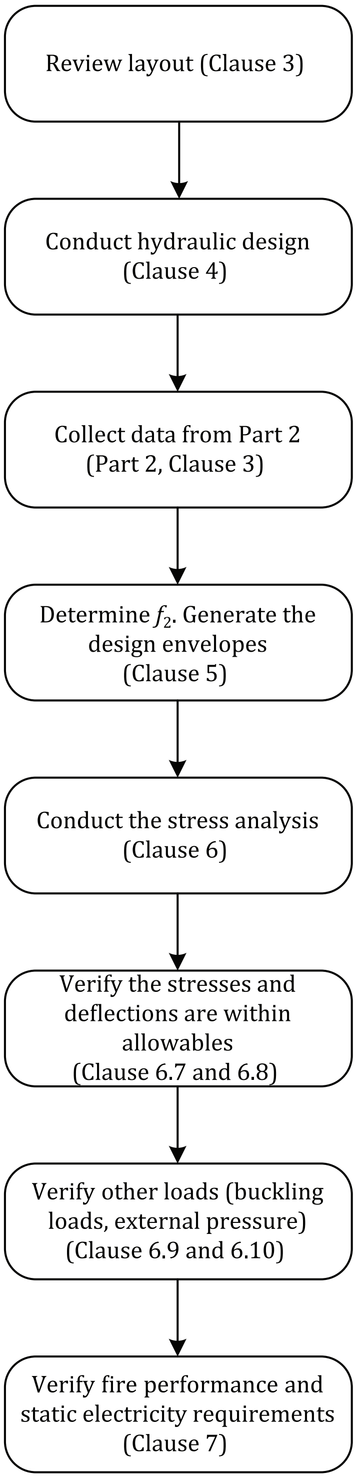



**Figure 1 — Guidance on the use of this document**

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 14692-1:2017, *Petroleum and natural gas industries — Glass-reinforced plastics (GRP) piping — Part 1: Vocabulary, symbols, applications and materials*

ISO 14692-2:2017, *Petroleum and natural gas industries — Glass-reinforced plastics (GRP) piping — Part 2: Qualification and manufacture*

ASTM D2992, *Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for Fiberglass (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings*

ASTM D2412, *Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading*

AWWA Manual M45, *Fiberglass pipe design*

## 3 Terms and definitions

For the purposes of this document, the terms, definitions, symbols and abbreviated terms given in ISO 14692-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

## 4 Layout requirements

### 4.1 General

GRP products are proprietary and the choice of component sizes, fittings and material types can be limited depending on the supplier. Potential vendors should be identified early in design to determine possible limitations of component availability. The level of engineering support that can be provided by the supplier should also be a key consideration during vendor selection.

Where possible, piping systems should maximize the use of prefabricated spoolpieces to minimize the amount of site work. Overall spool dimensions should be sized taking into account the following considerations:

— limitations of site transport and handling equipment;

— installation and erection limitations;

— limitations caused by the necessity to allow a fitting tolerance for installation (“cut to fit” requirements).

The designer shall evaluate system layout requirements in relation to the properties of proprietary piping systems available from manufacturers, including but not limited to the following:

a) axial thermal expansion requirements;

b) ultraviolet radiation and weathering resistance requirements;

c) component dimensions;

d) jointing system requirements;

e) support requirements;

f) provision for isolation for maintenance purposes;

g) connections between modules and decks;

h) flexing during lifting of modules;

i) ease of possible future repair and tie-ins;

j) vulnerability to risk of damage during installation and service;

k) fire performance;

l) control of electrostatic charge.

The hydrotest provides the most reliable means of assessing system integrity. Whenever possible, the system should be designed to enable pressure testing to be performed on limited parts of the system as soon as installation of those parts is complete. This is to avoid a final pressure test late in the construction work of a large GRP piping system, when problems discovered at a late stage would have a negative effect on the overall project schedule.

## 4.2 Space requirements

The designer shall take account of the larger space envelope of some GRP components compared to steel. Some GRP fittings have longer lay lengths and are proportionally more bulky than the equivalent metal component and may be difficult to accommodate within confined spaces. If appropriate, the problem can be reduced by fabricating the pipework or piping as an integral spoolpiece in the factory rather than assembling it from the individual pipe fittings.

If space is limited, consideration should be given to designing the system to optimize the attributes of both GRP and metal components.

## 4.3 System supports

### 4.3.1 General

GRP piping systems can be supported using the same principles as those for metallic piping systems. However, due to the proprietary nature of piping systems, standard-size supports will not necessarily match the pipe outside diameters.

The following requirements and recommendations apply to the use of system supports.

a) Supports shall be spaced to avoid sag (excessive displacement over time) and/or excessive vibration for the design life of the piping system.

b) In all cases, support design shall be in accordance with the manufacturer’s guidelines.

c) Where there are long runs, it is possible to use the low modulus of the material to accommodate axial expansion and eliminate the need for expansion joints, provided the system is well anchored and guided. In this case, the designer shall recognize that the axial expansion due to internal pressure is now restrained and the corresponding thrust loads are partly transferred to the anchors.

d) Valves or other heavy attached equipment shall be adequately and, if necessary, independently supported. When evaluating valve weight, valve actuation torque shall also be considered.

   NOTE Some valves are equipped with heavy control mechanisms located far from the pipe centreline and can cause large bending and torsional loads.

e) GRP piping shall not be used to support other piping, unless agreed with the principal.

f) GRP piping shall be adequately supported to ensure that the attachment of hoses at locations such as utility or loading stations does not result in the pipework being pulled in a manner that can overstress the material.

Pipe supports can be categorized into those that permit movement and those that anchor the pipe.

### 4.3.2 Pipe-support contact surface

The following requirements and recommendations apply to GRP piping support.

a) In all cases supports shall have sufficient length to support the piping without causing damage and shall be lined with an elastomer or other suitable soft material.

b) Point loads shall be avoided. This can be accomplished by using supports with at least 60° of contact.

c) Clamping forces, where applied, shall be such that crushing of the pipe does not occur. Local crushing can result from a poor fit and all-round crushing can result from over-tightening.

d) Supports should be preferably located on plain-pipe sections rather than at fittings or joints. One exception to this is the use of a "dummy leg" support directly on an elbow or tee (or piece of pipe).

Consideration shall be given to the support conditions of fire-protected GRP piping. Supports placed on the outside of fire protection can result in loads irregularly transmitted through the coating, which can result in shear/crushing damage and consequent loss of support integrity. Supports in direct contact with intumescent coatings can also alter the performance of the coating (i.e. prevent expansion of the coating under fire). This may require application of intumescent coatings to the pipe support itself in order to protect the pipe at the hanger or pipe support.

Pipe resting in fixed supports that permit pipe movement shall have abrasion protection in the form of saddles, elastomeric materials or sheet metal.

Anchor supports shall be capable of transferring the required axial loads to the pipe without causing overstress of the GRP pipe material. Anchor clamps are recommended to be placed between either a thrust collar laminated to the outer surface of the pipe or two double 180° saddles, adhesive-bonded to the outer surface of the pipe. The manufacturer’s standard saddles are recommended and shall be bonded using standard procedures.

## 4.4 Isolation and access for cleaning

The designer should make provision for isolation and easy access for maintenance purposes, for example, for removal of scale and blockages in drains. The joint to be used for isolation or access should be shown at the design stage and should be located in a position where the flanges can in practice be jacked apart, e.g. it should not be in a short run of pipe between two anchors.

## 4.5 Vulnerability

### 4.5.1 Point loads

Point loads shall be minimized and the GRP piping locally reinforced where necessary.

### 4.5.2 Abuse

The designer shall give consideration to the risk of abuse to GRP piping during installation and service and the need for permanent impact shielding.

Sources of possible abuse include the following:

a) any area where the piping can be stepped on or used for personnel support;

b) impact from dropped objects;

c) any area where piping can be damaged by adjacent crane activity, e.g. booms, loads, cables, ropes or chains;

d) weld splatter from nearby or overhead welding activities.

Small pipe branches (e.g. instrument and venting lines), which are susceptible to shear damage, should be designed with reinforcing gussets to reduce vulnerability. Impact shielding, if required, should be designed to protect the piping together with any fire-protective coating.

#### 4.5.3 Dynamic excitation and interaction with adjacent equipment and piping

The designer shall give consideration to the relative movement of fittings, which can cause the GRP piping to become overstressed. Where required, consideration shall be given to the use of flexible fittings.

The designer should ensure that vibration due to the different dynamic response of GRP (as compared with carbon steel piping systems) does not cause wear at supports or overstress in branch lines. The designer should ensure that the GRP piping is adequately supported to resist shock loads that can be caused by transient pressure pulses, e.g. operation of pressure safety valves, valve closure etc. Reference [8] provides further guidance.

#### 4.5.4 Exposure to light and ultraviolet radiation

Where GRP piping is exposed to the sun, the designer shall consider whether additional ultra violet radiation (UV) protection is required to prevent surface degradation of the resin. If the GRP is a translucent material, the designer should consider the need to paint the outside to prevent possible algae growth in slow-moving water within the pipe.

#### 4.5.5 Low temperatures and requirements for insulation

The designer shall consider the effects of low temperatures on the properties of the pipe material, for example, the effect of freeze/thaw. For liquid service, the designer should particular pay attention to the freezing point of the internal liquid. For completely filled lines, solidification of the internal fluid can cause an expansion of the liquid volume, which can cause the GRP piping to crack or fail. For water service, the volumetric expansion during solidification or freezing is more than sufficient to cause the GRP piping to fail.

The pipe may need to be insulated and/or fitted with electrical surface heating to prevent freezing in cold weather or to maintain the flow of viscous fluids. The designer shall give consideration to:

a) additional loading due to mass and increased cross-sectional area of the insulation;

b) ensuring that electrical surface heating does not raise the pipe temperature above its rated temperature.

Heat tracing should be spirally wound onto GRP piping in order to distribute the heat evenly round the pipe wall. Heat distribution can be improved if aluminium foil is first wrapped around the pipe.

### 4.6 Fire and blast

The effect of a fire event (including blast) on the layout requirements shall be considered. The possible events to be considered in the layout design of a GRP piping system intended to function in a fire include the following:

a) blast overpressure, drag forces and projectile impacts;

b) fire protection of joints and supports;

c) interface with metal fixtures;

d) formation of steam traps in piping containing stagnant water, which would reduce the conduction of heat away by water;

e) jet fire;

f) heat release and spread of fire for piping in manned spaces, escape routes or areas where personnel are at risk;

g) smoke emission, visibility and toxicity for piping in manned spaces, escape routes or areas where personnel are at risk.

Penetrations (wall, bulkhead, deck) shall not weaken the division that they penetrate. The main requirements are to prevent passage of smoke and flames, to maintain structural integrity and to limit the temperature rise on the unexposed side. Penetrations shall therefore comply with the same requirements that apply to the relevant hazardous divisions. This requires the penetration to have been fire-tested and approved for use with the specific type of GRP piping under consideration.

# 5 Hydraulic design

## 5.1 General

The aim of hydraulic design is to ensure that GRP piping systems are capable of transporting the specified fluid at the specified rate, pressure and temperature throughout their intended service life. The selection of nominal pipe diameter depends on the internal diameter required to attain the necessary fluid flow consistent with the fluid and hydraulic characteristics of the system.

## 5.2 Flow characteristics

Fluid velocity, density of fluid, interior surface roughness of pipes and fittings, length of pipes, inside diameter of pipes, as well as resistance from valves and fittings shall be taken into account when estimating pressure losses. The smooth surface of the GRP can result in lower pressure losses compared to metal pipe. Conversely, the presence of excessive protruding adhesive beads will increase pressure losses.

## 5.3 General velocity limitations

When selecting the flow velocity for the GRP piping system, the designer shall take into account the following concerns that can limit velocities in piping systems:

a) unacceptable pressure losses;

b) prevention of cavitation at pumps and valves;

c) prevention of transient overloads (water hammer);

d) reduction of erosion;

e) reduction of noise;

f) reduction of wear in components such as valves;

g) pipe diameter and geometry (inertia loading).

For typical GRP installations, the mean linear velocity for continuous service of liquids is between 1 m/s and 5 m/s with intermittent excursions up to 10 m/s. For gas, the mean linear velocity for continuous service is between 1 m/s and 10 m/s with intermittent excursions up to 20 m/s. Higher velocities are acceptable if factors that limit velocities are eliminated or controlled, e.g. vent systems that discharge into the atmosphere.

## 5.4 Erosion

### 5.4.1 General

The following factors influence the susceptibility of GRP piping to erosion damage:

a) fluid velocity;

b) piping configuration;

c) particle size, density and shape;

d) particulate/fluid ratio;

e) onset of cavitation.

The designer shall refer to the manufacturer and consider reducing the velocity if doubts exist on erosion performance.

### 5.4.2 Particulate content

The erosion properties of GRP are sensitive to the particulate content. The designer shall take into account the likely particulate content in the fluid and reduce the maximum mean velocity accordingly. For GRP, the maximum erosion damage typically occurs at a hard-particle impingement angle of between 45° and 90°, i.e. at bends and tees. At low impingement angles (<15°), i.e. at relatively straight sections, erosion damage is minimal. Further information on erosion can be found in DNV RP 0501.

### 5.4.3 Piping configuration

The presence of turbulence generators can have a significant influence on the erosion rate of GRP piping, depending on fluid velocity and particulate content. The designer shall consider the degree of turbulence and risk of possible erosion when deciding the piping configuration. To minimize potential erosion damage in GRP piping systems, the following shall be avoided:

a) sudden changes in flow direction;

b) local flow restrictions or initiators of flow turbulence, e.g. excessive adhesive (adhesive beads) on the inside of adhesive-bonded connections.

### 5.4.4 Cavitation

GRP piping is susceptible to rapid damage by cavitation. Cavitation conditions are created in piping systems more easily than is generally realized, and the general tendency for systems to be designed for high velocities exacerbates the situation further. Potential locations of cavitation include angles at segmented elbows, tees and reducers, flanges where the gasket has been installed eccentrically and joints where excessive adhesive has been applied.

The designer shall use standard methods to predict the onset of cavitation at likely sites, such as control valves, and apply the necessary techniques to ensure that cavitation cannot occur under normal operating conditions.

## 5.5 Water hammer

The susceptibility of GRP piping to pressure transients and out-of-balance forces caused by water hammer depends on the magnitude of pressure and frequency of occurrence. A full hydraulic transient analysis shall be carried out, if pressure transients are expected to occur, to establish whether the GRP piping is susceptible to water hammer. The analysis shall cover all anticipated operating conditions including priming, actuated valves, pump testing, wash-down hoses, etc.

If there is a significant risk of water hammer, the designer shall employ standard techniques to ensure that pressure transients do not exceed the hydrotest pressure.

A typical cause of water hammer is the fast closing of valves. The longer the pipeline or piping section and the higher the liquid velocity, the greater the shock load will be. Shock loading generally induces oscillation in the piping system. Since GRP pipe has a lower axial modulus of elasticity than the equivalent steel pipe, longitudinal oscillations are generally more significant.

A hydraulic transient analysis can identify the potential requirement for vacuum breakers to prevent vacuum conditions and vapour cavity formation. The proper selection and sizing of vacuum breakers (also known as air-vacuum valves) can prevent water-column separation and reduce water hammer effects. The sizing and the location of the vacuum breakers are critical. The air shall be admitted quickly to be effective and shall be sized to account for the substantial pressure that can occur due to the compression of the air during resurge. Air removal is often accomplished with a combined air-release/air-vacuum valve.

# 6 Generation of design envelopes

## 6.1 Partial factors

### 6.1.1 Design life

$A_0$ shall be used to scale the long term envelopes to the design envelopes at design lives other than 20 years. $A_0$ shall be defined by Formula (1):

$$A_0 = \frac{1}{10^{(\log(t) - \log(175\ 200)) \times G_{xx}}} \tag{1}$$

where

$t$ is the time expressed in h;

$G_{xx}$ is the gradient of regression line at xx °C;

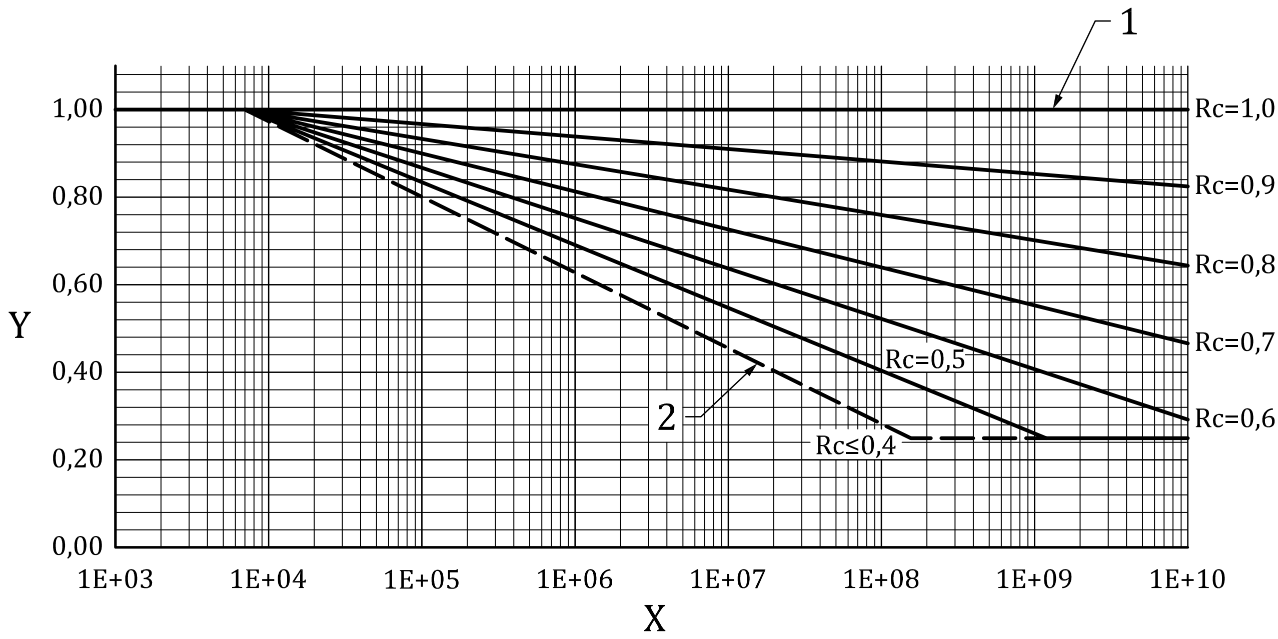
$A_0$ shall not be greater than 1,0.

### 6.1.2 Chemical degradation

$A_2$ shall be used to scale the long term envelopes to the design envelopes to account for the effect of chemical degradation. See ISO 14692-2:2017, 4.5.2.

### 6.1.3 Fatigue and cyclic loading

$A_3$ shall be used to scale the long term envelopes to the design envelopes and shall be calculated taking into account Figure 2 and Annex A.




**Key**

1 fully static loading

2 fully cyclic loading

$R_c$ cyclic loading ratio, $=\sigma_{min}/\sigma_{max}$

$f_c$ cyclic long term strength factor (default value of 4,0), $=\sigma_{100\ 000\ (static)}/\sigma_{150\ 000\ 000\ (cyclic)}$

**Figure 2 — $A_3$ as a function of the number of cycles and the loading ratio**

## 6.2 Part factor, $f_2$

The part factor for sustained loading, $f_2$, to be used in the assessment of sustained loads, shall be determined taking into account operating conditions and risk associated with the piping system. The value to be applied for specific piping systems shall be specified by the user. Recommended typical values for $f_2$ are

a) 0,67 for sustained loading conditions,

b) 0,83 for sustained loading plus self-limiting displacement conditions, and

c) 0,89 for occasional loading conditions.

Table 1 provides examples of loads experienced by a GRP piping system. The designer shall have discretion in defining the load cases.

**Table 1 — Examples of loads experienced by a GRP piping system**

| **Sustained,** $f_2$ = 0,67 | **Sustained + self-limiting displacements,** $f_2$ = 0,83 | **Occasional,** $f_2$ = 0,89 |
|---|---|---|
| Operating and sustained internal, external or vacuum pressures, MOP (maximum operating pressure), $P_{des}$ | Thermal induced loads, electric surface heating or other heat tracing methods | Hydrotest and other occasional pressures<br>Water hammer or other pressure transients<br>Pressure safety valve releases |
| Piping self-mass, piping insulation mass, fire protection mass, transported medium mass, buoyancy, other system loads | Installed curve radius (roping) | Impact<br>Occasional vehicular traffic loads on buried pipes |
| Sustained inertia loads (e.g. daily wave action, ship movement, inundation through high tides, other motions during operation)<br>Displacement of supports due to operational conditions (such as flexing of the hull during operations) | Ring bending due to long term vertical pipe deflection in a buried system | Occasional inertia loads (e.g. motion during transportation, storms, etc.)<br>Earthquake-induced horizontal and vertical forces<br>Displacement of supports due to occasional conditions (such as flexing during lifting) |
| Environmental loads, ice | Soil loads (burial depth) | Adiabatic cooling loads |
| Soil subsidence | Vehicular traffic loads on buried pipes | Wind (from occasional conditions such as a storm) |
| | Encapsulation in concrete | Blast over-pressures |
| | | Thermal induced loads due to upset conditions |

NOTE 1 Some cases, such as ice and snow, may be considered either sustained or occasional, depending on the local environment.

NOTE 2 The sustained + self-limiting displacements column is meant to cover those load cases where both sustained loads and self-limiting displacements occur simultaneously.

NOTE 4 Soil subsidence may be considered a sustained + self-limiting displacements load.

NOTE 4 In buried systems, the hydrotest load case may need to be evaluated in the open trench (i.e. not buried) condition.

NOTE 5 In buried systems, stable soils are required for loads to be self-limiting.

## 6.3 Combinations of part factor and partial factors

The designer shall determine the applicable combination(s) of loading cases.

For the field hydrotest loading case, $A_0$, $A_2$ and $A_3$ shall be 1,0 and $f_2$ shall be 0,89.

## 6.4 Design envelope

Construct each design envelope based on the following formulae. The design envelope shall be based on Formulae (2) through (7) and as graphically presented in Figure 3:

$$\sigma_{\text{h,des,2:1}} = f_2 \times A_0 \times A_2 \times A_3 \times \sigma_{\text{h,LT,2:1,xx}} \tag{2}$$

$$\sigma_{\text{a,des,2:1}} = f_2 \times A_0 \times A_2 \times A_3 \times \sigma_{\text{a,LT,2:1,xx}} \tag{3}$$

$$\sigma_{\text{h,des},R\text{test}} = f_2 \times A_0 \times A_2 \times A_3 \times \sigma_{\text{h,LT},R\text{test,xx}} \tag{4}$$

$$\sigma_{\text{a,des},R\text{test}} = f_2 \times A_0 \times A_2 \times A_3 \times \sigma_{\text{a,LT},R\text{test,xx}} \tag{5}$$

$$\sigma_{a,des,0:1} = f_2 \times A_0 \times A_2 \times A_3 \times \sigma_{a,LT,0:1,xx} \tag{6}$$

$$\sigma_{a,des,0:-1} = 1,25 \times f_2 \times A_0 \times A_2 \times A_3 \times \sigma_{a,des,0:1} \tag{7}$$

where

$f_2$ is the part factor for loading;

$A_0$ is the partial factor for design life;

$A_2$ is the partial factor for chemical resistance;

$A_3$ is the partial factor for cyclic service;

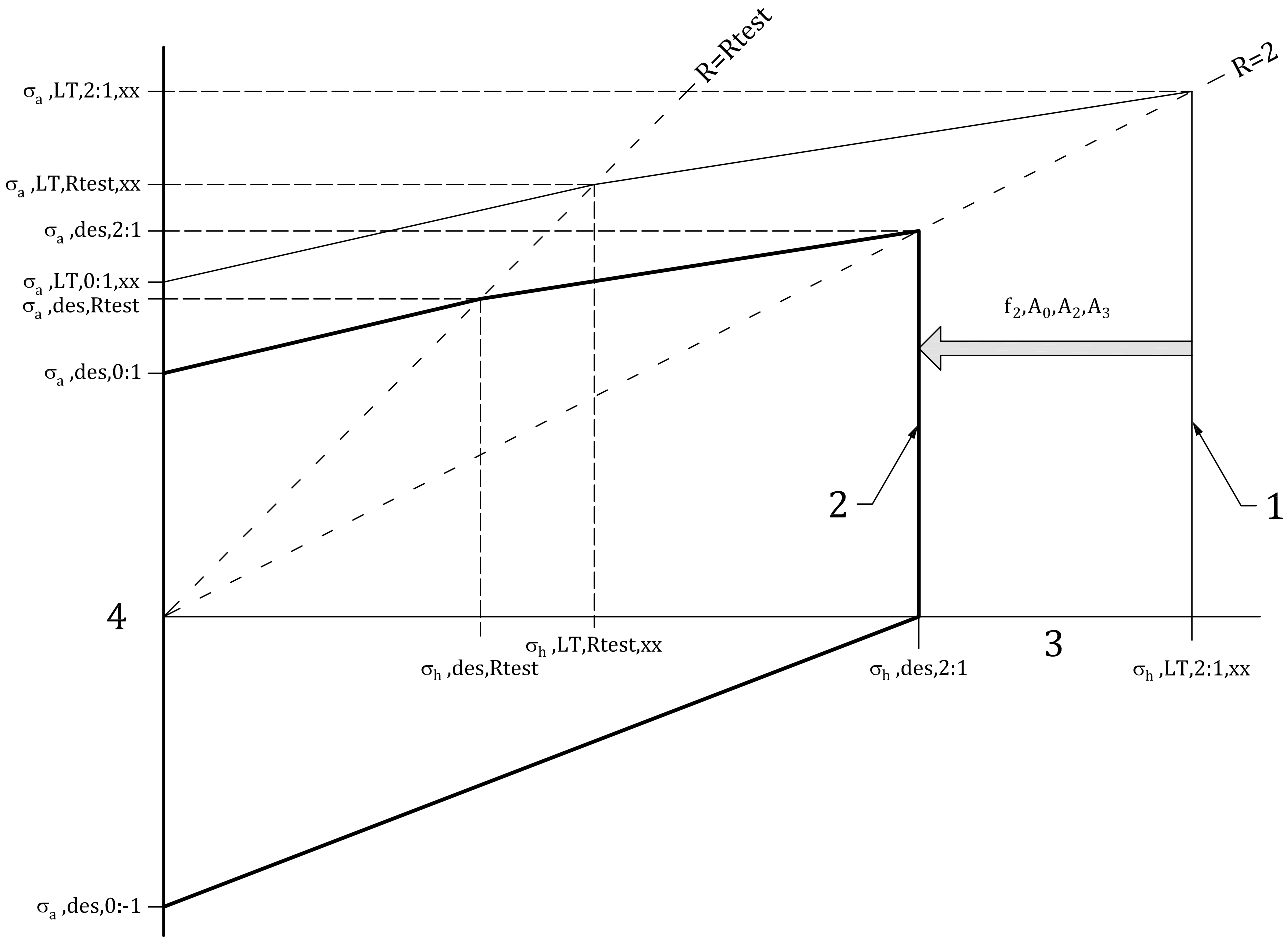
$\sigma_{a,LT,2:1,xx}$ is the long term envelope axial stress for an unrestrained, hydraulic (2:1) condition at xx °C, expressed in MPa;

$\sigma_{h,LT,2:1,xx}$ is the long term envelope hoop stress for an unrestrained, hydraulic (2:1) condition at xx °C, expressed in MPa;

$\sigma_{a,LT,0:1,xx}$ is the long term envelope axial stress for a pure axial loading condition at xx °C, expressed in MPa.

NOTE The design procedure in this document is based on the premise that the fittings and joints are at least as strong as the plain pipe under any loading condition. The angle of reinforcement in the construction method of some fittings and joints, however, can vary greatly from the typical 55° winding angle of filament wound pipe. Thus, the theoretical shape of a long term envelope of a fitting or joint with equal amounts of reinforcement in the axial and hoop directions can be closer to a rectangular shape or can even approach that of a square. The use of these construction methods which differ from the pipe can have an effect on the long term envelope(s), design envelope(s) and $f_3$ factor. In some cases, the fitting or joint can be significantly stronger than the filament wound plain pipe in the axial direction, but weaker in the hoop direction. In others, the opposite can be true. To satisfy the premise that the fittings and joints are at least as strong as plain pipe may require additional reinforcement, additional wall thickness or other means of improving the strength.




**Key**

1 long term envelope

2 design envelope

**Figure 3 — Relationship between the long term envelope(s) and design envelope(s)**

# 7 Stress analysis

## 7.1 Analysis methods

Either manual or computer methods shall be used for the structural analysis of piping systems. However, the degree of analysis depends on the following factors:

a) pipework flexibility;

b) layout complexity;

c) pipe supports;

d) pipework diameter;

e) magnitude of temperature changes;

f) system criticality and failure risk assessment.

## 7.2 Pipe stress analysis software

All current pipe stress analysis software for pipelines and piping starts with an isometric "stick drawing". The hoop stress and axial stress from pressure are calculated separately, outside the analysis. The analysis utilizes a "beam element" in order to calculate axial bending stresses from externally applied moments and axial stress from externally applied axial forces. Global forces and moments are translated to local axial forces and bending moments. Out of plane shear that is perpendicular to the pipe wall is ignored since the stress values are low.

In an analysis of the piping system, the calculated stresses are all based on the pipe wall properties using a beam element that models the properties of the pipe wall throughout the isometric "stick diagram". Calculated pipe response (stress and deflection) is then modified by the use of default axial SIFs and axial flexibility factors for each component in order to mimic or predict the performance of the component (fitting or joint) versus the calculated values in the analysis based on the pipe wall response. The default axial SIFs account for unknown performance of the components for applied loads between $R = 0$ and $R = 2{,}0$. True or measured axial SIFs can be determined in 1 000 h qualification testing at $R_{\text{test}}$ for each component at the discretion of the supplier. Hoop pressure modifiers are not needed for components, since all components have been qualified at $R = 2$.

This document compares calculated stresses in the hoop and axial directions to a "trapezoidal design envelope". This envelope defines the allowable combinations of axial and hoop stress. Other standards might report Von Mises stress or maximum shear stress such as those determined by Mohr's circle. These reported or calculated stresses have no correlation for an anisotropic material like a composite and only apply to an isotropic material like steel. As such design standards that report these stresses (e.g. BS 7159) should not be selected as the design code.

## 7.3 Analysis requirements

The designer shall evaluate the total piping system, including system criticality and risk of failure due to operating/material factors, in order to assess the need for flexibility/stress analysis. Anchor (support) loading shall be checked for acceptability.

NOTE 1 At large diameters, the design of the piping system can be determined more by the support conditions than the internal pressure conditions.

NOTE 2 The dimensions of GRP piping are usually referenced in terms of the inner diameter and wall thickness because of the nature of the manufacturing process.

## 7.4 Flexibility factors

Flexibility factors for GRP bends and tees shall be determined in accordance with Annex B.

## 7.5 Stress intensification factors

Axial stress intensification factors (both in-plane and out-of-plane) for GRP bends and tees shall be

— 1,5, or

— qualified in accordance with B.5.

Since all components are subject to the qualification programme in ISO 14692-2, which includes the generation of hoop stresses from an $R = 2$ test, hoop SIFs are not required for any components.

There are no SIFs for flanges nor reducers nor pipe joints.

Since all components are subject to the qualification programme in ISO 14692-2, pressure stress multipliers are not required.

Additional information on stress intensification factors is given in Annex B.

### 7.6 Modelling fittings

For fittings that have an MPR equal to the plain pipe, the fitting shall be modelled in the stress analysis with the dimensional properties (*ID*, $t_{r,min}$) of the pipe, not the fitting.

For fittings that have an MPR different than the plain pipe, the fitting shall be modelled in the stress analysis with the dimensional properties (*ID*, $t_{r,min}$) of the equivalent-rated pipe, not the fitting.

EXAMPLE A 200NB piping system is constructed with 10 bar rated plain pipe and 20 bar rated fittings. The minimum reinforced wall thickness of the 10 bar components is 3,0 mm for the plain pipe and 5,0 mm for the bends. The minimum reinforced wall thickness of the 20 bar components is 6,0 mm for the plain pipe and 10,0 mm for the bends. The fitting should be modelled in the stress analysis with a 6,00 mm wall thickness, which is the wall thickness for the equivalent-rated (20 bar) pipe.

Some software programs for stress analysis model tees and other branches as a single node (the intersection). This does not allow for modelling the tee different than the plain pipe. If the tee has an MPR different than the plain pipe and the designer wishes to properly model the tee, it will require the designer to model 3 nodes for the tee. For simplicity, it may be acceptable to use a default laying length of 1,0 × *D* for each leg of the tee, where *D* is the nominal pipe size. The same practice would be required for saddles (also called olets), except that only one additional node would be required.

### 7.7 Allowable deflections

#### 7.7.1 Vertical deflection in aboveground piping systems

For aboveground piping systems, vertical deflections shall not exceed 12,5 mm or 0,5 % of span length or support spacing, whichever is smaller. If the manufacturer's minimum spacings for support are not exceeded, then deflections shall be within these allowable limits. It shall be agreed between the principal and the manufacturer that the quoted minimum spacings for support do not result in deflections greater than prescribed.

#### 7.7.2 Vertical deflection in buried piping systems

The predicted vertical pipe deflection, $\Delta y$, as a fraction of $D_{r,min}$, shall be less than 5 %:

$$\frac{\Delta y}{D_{r,min}} \leq 5\ \% \tag{8}$$

The predicted vertical pipe deflection, as a fraction of $D_{r,min}$, shall be calculated according to Formula (9):

$$\frac{\Delta y}{D_{r,min}} = \frac{(D_L \times W_c + W_L) \times K_x}{149 \times PS + 61\ 000 \times M_s} \tag{9}$$

where

$D_L$ is the deflection lag factor, see AWWA Manual M45 (second edition), 5.7.3.3; $D_L$ shall be 1,0 for the hydrotest loading case;

$W_c$ is the vertical soil load on the pipe, expressed in N/m$^2$, AWWA Manual M45 (second edition), 5.7.3.5;

$W_L$ is the live load on the pipe, expressed in N/m$^2$, see AWWA Manual M45 (second edition), 5.7.3.6; the designer shall have the option of setting $W_L$ = 0 for the hydrotest loading case if live loads are not present;

$K_x$ is the dedding coefficient, see AWWA Manual M45 (second edition), 5.7.3.4;

$PS$ is the pipe stiffness, expressed in kPa, determined by conducting parallel-plate loading tests in accordance with ASTM D2412 with a vertical diameter reduction of 5 %;

$M_s$ is the composite soil constrained modulus, expressed in MPa, see AWWA Manual M45 (second edition), 5.7.3.8.

NOTE 1 Formula (9) is similar to AWWA Manual M45 (second edition), Formula (5) to Formula (8) with $D_{r,min}$ substituted for $D$.

NOTE 2 There is no check of predicted vertical pipe deflection against any allowable vertical pipe deflection other than the 5 % limit. This is because a combined stress will be checked using Formula (10) to Formula (12).

NOTE 3 The deflection lag factor is intended to convert the short-term deflection of the pipe to the long-term deflection after several years. This increase in deflection is due to an increase in the overburden load due to the loss of soil arching [see AWWA Manual M45 (second Edition), 5.7.3.3]. While a majority of this increase in deflection is theorized to occur in a matter months (and even weeks), it is most likely not appropriate to include a deflection lag factor for the hydrotest case. The designer has the option to set $D_L$ to 1,0 for the hydrotest loading case if the pipework have not been backfilled.

## 7.8 Allowable stresses

The sum of the hoop stresses shall be defined by the following formulae:

$$\sigma_{h,sum} = \sigma_{hp} + \sigma_{hu} \tag{10}$$

$$\sigma_{hp} = \frac{P \times D_{r,min}}{2 \times t_{r,min}} \tag{11}$$

$$\sigma_{hu} = r_c \times D_f \times E_{hb} \times \frac{\Delta y}{D_{r,min}} \times \frac{t_{r,min}}{D_{r,min}} \tag{12}$$

where

$P$ is the internal pressure, expressed in MPa;

$t_{r,min}$ is the minimum reinforced pipe wall thickness, expressed in mm;

$D_{r,min}$ is the mean diameter of the minimum reinforced pipe wall, expressed in mm;

$t_l$ is the internal liner thickness of the pipe wall, expressed in mm;

$r_c$ is the rerounding coefficient, for $P \leq 3$ then $r_c = 1 - P / 3$, for $P > 3$ then $r_c = 0$;

$D_f$ is the shape factor, see AWWA Manual M45 (second edition), Table 1;

$\Delta y / D_{r,min}$ is the predicted vertical pipe deflection [see Formula (9)];

$E_{hb}$ is the hoop bending modulus, expressed in MPa.

NOTE 1 Because of the combined effects of internal pressure and burial conditions, it is possible that the sum of the hoop stresses can be outside the design envelope even though the designer is using the product within the design limits of the product. In this case, the designer may need to select a product with a higher MPR, de-rate the product, lower the design conditions, reduce the stresses due to earth load, and/or go back to the manufacturer for more data points on the design envelope.

NOTE 2 The $\sigma_{hu}$ term is calculated by deflection and $E_{hb}$. It is not based on long term testing according to ASTM D5365 or ASTM D3681. Those particular tests are loaded in the hoop direction only and the mode of failure can be glass rupture. However, piping that is only loaded in the hoop direction is outside the scope of this document (e.g. joining method has to be a restrained joint). The strain or stress obtained from ASTM D5365 and ASTM D3681 will be much higher than that predicted by ASTM D2992 simply because the samples are only loaded in the hoop direction. Data from ASTM D5365 and ASTM D3681 are not needed and are excluded from consideration.

NOTE 3 The $\sigma_{hu}$ term can be positive or negative (tensile or compressive), but it is only necessary to consider the tensile component in the stress calculations.

NOTE 4 The rerounding coefficient, which is theorized to be primarily a function of internal pressure, accounts for the reduction in ring bending stress as internal pressure increases. When the piping is initially installed, it deflects due to the weight of the soil. This is the initial bending strain. When they are pressurized, the piping "re-rounds" and some of that strain is removed. The formula in the AWWA Manual M45 is meant to approximate the ratio of the bending strain at a given pressure to the initial bending strain. $R_c$ may be an important concept for the hydrotest loading case for large diameter, lower pressure rated piping, but may not be needed for high pressure, thick-wall piping.

NOTE 5 Deflection is a very important parameter for buried piping design that needs controlling. The soil loads, live loads, soil properties (most importantly stiffness) and the pipe stiffness all have a direct effect on the calculated (or predicted) vertical pipe deflection. The AWWA Manual M45 makes the conclusion that the theories used to predict the vertical pipe deflection can provide results that vary from the actual deflections in the field. It also states in AWWA Manual M45 Second Edition, 5.7.3.2 "Experience has shown that deflection levels... can be higher or lower than predicted by calculation if the design assumptions are not achieved." Therefore, the AWWA Manual M45 recommends that the permitted vertical pipe deflection (which is typically set at 5 %, as a fraction of the mean pipe diameter) is to be used in the calculations. This document specifies that $\Delta y$ be used in lieu of $\delta_d$ when calculating the hoop (ring) bending stress due to earth loads.

NOTE 6 $D_f$ is a factor to account for the deviation of the shape of the pipe compared to the idealized ellipse in a deflected condition. This factor was determined experimentally by measuring the local shape changes in buried pipe of various pipe stiffnesses in various soil conditions. $D_f$ is not a derived number.

The sum of the axial stresses shall be defined by the following formulae:

$$\sigma_{a,sum} = \sigma_{ap} \pm \sigma_{ab} + \sigma_{af} \pm \sigma_{ac} + \sigma_{at} \tag{13}$$

$$\sigma_{ap} = \frac{P \times D_{r,min}}{4 \times t_{r,min}} \tag{14}$$

for a closed, unrestrained pipe

$$\sigma_{ap} = \upsilon_{ah} \times \frac{P \times D_{r,min}}{2 \times t_{r,min}} \tag{15}$$

for an axially restrained pipe

$$\sigma_{ab} = 1\,000 \times \frac{\sqrt{(SIF_{ai} \times M_i)^2 + (SIF_{ao} \times M_o)^2}}{Z_r} \tag{16}$$

$$Z_r = \frac{\pi}{32} \times \frac{(OD_{r,min}^4 - ID_r^4)}{OD_{r,min}} \tag{17}$$

$$\sigma_{af} = \frac{F_a}{A_r} = \frac{F_a}{\frac{\pi}{4} \times (OD_{r,min}^2 - ID_r^2)} \tag{18}$$

$$\sigma_{ac} = \frac{OD_{r,min}}{2 \times C \times 1\ 000} \times E_a \tag{19}$$

$$\sigma_{at} = \alpha_a \times (T_{install} - T_{design}) \times E_a \tag{20}$$

where

| | |
|---|---|
| $P$ | is the internal pressure, expressed in MPa; |
| $ID_r$ | is the inside diameter of the reinforced pipe wall, expressed in mm; |
| $OD_{r,min}$ | is the minimum outside diameter of the reinforced pipe wall, expressed in mm; |
| $\sigma_{ap}$ | is the axial stress from internal pressure, calculated using either Formula (14) or Formula (15), expressed in MPa; |
| $\nu_{ah}$ | is the minor Poisson's ratio, hoop strain resulting from a stress in the axial direction; |
| $SIF_{ai}$ | is the axial in-plane stress intensification factor; |
| $SIF_{ao}$ | is the axial out-of-plane stress intensification factor; |
| $M_i$ | is the in-plane bending moment, expressed in Nm; |
| $M_o$ | is the out-of-plane bending moment, expressed in Nm; |
| $Z_r$ | is the minimum reinforced pipe wall section modulus, expressed in mm$^3$; |
| $F_a$ | is the localised axial force, expressed in N; |
| $A_r$ | is the minimum reinforced pipe wall cross section, expressed in mm$^2$; |
| $C$ | is the curve radius, expressed in m; |
| $E_a$ | is the axial tensile modulus, expressed in MPa; |
| $\alpha_a$ | is the coefficient of thermal expansion in the axial direction, expressed in mm/mm/°C; |
| $T_{install}$ | is the installation temperature, expressed in °C; |
| $T_{design}$ | is the design temperature, expressed in °C. |

NOTE 7 $\sigma_{at}$ only occurs in piping systems where axial growth is restrained. In other configurations (such as in an expansion loop or direction change), thermal growth can create reaction forces and moments which need to be properly analysed.

NOTE 8 Temperature changes are assumed to produce no hoop stress component.

NOTE 9 Piping subject to internal pressure will be treated as unrestrained pipes, which will grow axially with increasing pressure, plus an axial end load, which, for a fully restrained system, will return the pipe to its original length (i.e. no length change for a fully restrained system). This method will provide a consistent approach for the analysis of unrestrained, anchored and buried piping systems. In a similar manner, piping subject to temperature changes will be treated as unrestrained pipes, which will grow axially with increasing temperature, plus an axial end load, which, for a fully restrained system, will return the pipe to its original length. Temperature changes are assumed to produce no hoop stress component.

NOTE 10 Restrained piping is assumed to be restrained in the axial direction only, there is no restraint in the hoop direction. In long buried piping, the axial friction forces accumulate to prevent axial movement. But, in the hoop direction, the typical soil elastic modulus is much lower than the pipe hoop modulus and is ineffective in restraining the pipe. Consequently, the calculated hoop stress from internal pressure for both unrestrained and restrained pipes is the same. The calculated axial stress from internal pressure, however, includes the Poisson's effect for restrained pipes only. One exception to this rule may be piping encased in concrete where the internal pressure is unable to generate a hoop stress. In this exception, the assumption regarding directional restraint would produce a conservative design and should remain safe.

NOTE 11 $\sigma_{at}$ can be considered a form of $\sigma_{af}$, taking care that these stresses are twice not applied. $\sigma_{at}$ is intended to be applied to fully-restrained piping systems (either aboveground or buried).

The $\sigma_{ab}$ term will typically include both tensile and compressive stresses on opposite sides of the pipe. These sides may be the top/bottom or the left/right sides. Consequently, it shall be necessary to properly sum the stresses (taking note of whether each stress is positive or negative) in each plane and determine a vector sum of the two totals according to Formula (21):

$$\sigma_{a,sum} = \sigma_{ap} + \sqrt{\left(\sum \sigma_{ab,top/bottom}\right)^2 + \left(\sum \sigma_{ab,left/right}\right)^2} + \sigma_{af} \pm \sigma_{ac} + \sigma_{at} \qquad (21)$$

NOTE 12 For aboveground cross country pipelines, both $\sigma_{ac}$ (roping curvature) and $\sigma_{ab}$ (free span bending) can be present in both planes at some locations and thus require the resulting stresses to be determined by proper vector-summation.

NOTE 13 The reference to restrained and unrestrained in the guidance above is not referring to the type of joint (e.g. a laminated or adhesively bonded joint is a restrained joint). Rather, it is referring to the type of installation for the system.

The sum of the hoop stresses and the sum of the axial stresses shall be within the design envelope for each loading case.

## 7.9 External pressure

Plain pipe and fittings shall have sufficient stiffness to resist vacuum and/or external pressure loads. The minimum stiffness shall be sufficient to resist a short-term vacuum (e.g. by the operation of an upstream valve) with a safety factor $F_e$ of 1,5.

Piping susceptible to long-term vacuum and/or external pressure loads shall have a stiffness sufficient to resist the induced load with a safety factor $F_e$ of 3,0.

The external collapse pressure, $P_e$, in MPa, of GRP pipes shall be calculated by Formula (22) which assumes that the length of the pipe is significantly greater than the diameter:

$$P_e = 2 \times \frac{1}{F_e} \times E_{hb} \times \left(\frac{t_{r,min}}{D_{r,min}}\right)^3 \qquad (22)$$

where

$F_e$ is the safety factor, equal to 3,0;

$E_{hb}$ is the hoop bending modulus, expressed in MPa;

$t_{r,min}$ is the minimum reinforced pipe wall thickness, expressed in mm;

$D_{r,min}$ is the mean diameter of the minimum reinforced pipe wall, expressed in mm.

## 7.10 Axial compressive loading (buckling)

### 7.10.1 Shell buckling

The axial elastic buckling stress, $\sigma_{u,s}$, in MPa, for a cylinder in pure bending shall be taken as:

$$\sigma_{u,s} = 0,90 \times \beta \times \frac{E_a \times t_{r,min}}{D_{r,min}} \tag{23}$$

where

$E_a$ is the axial tensile modulus, expressed in MPa;

$t_{r,min}$ is the minimum reinforced pipe wall thickness, expressed in mm;

$D_{r,min}$ is the mean diameter of the minimum reinforced pipe wall, expressed in mm.

The value $\beta$ is obtained from Formula (24):

$$\beta = 0,188\ 7 + 0,811\ 3 \times \beta_0 \tag{24}$$

The value $\beta_0$ is obtained from Formula (25):

$$\beta_0 = \frac{0,83}{\sqrt{0,1 + 0,005 \times (\frac{ID_r}{t_{r,min}})}} \tag{25}$$

The ratio of the axial elastic buckling stress to $\sigma_{ab}$ shall be greater than or equal to 3:

$$\frac{\sigma_{u,s}}{\sigma_{ab}} \geq 3,0 \tag{26}$$

NOTE Shell buckling is primarily an issue for thin-walled large-diameter pipe.

### 7.10.2 Euler buckling

For axial compressive system loads, e.g. constrained thermal expansion or vertical pipe runs with end compressive loads, and a given length of unsupported pipe, $L$, the axial compressive load shall not exceed $F_{a,max}$, in N, defined using Formula (27):

$$F_{a,max} = \frac{\pi^2 \times I_r}{L^2} \times E_a \times 10^6 \tag{27}$$

where

$I_r$ is the minimum reinforced pipe wall moment of inertia, expressed in mm$^4$;

$L$ is the length of unsupported pipe, expressed in m;

$E_a$ is the axial tensile modulus, expressed in MPa.

NOTE 1 Both ends of the pipe are assumed to be pinned or free to rotate. If the ends of the pipe are fixed or anchored, the value of $F_{a,max}$ increases by a factor of 4.

The equivalent Euler buckling stress, in MPa, is given by Formula (28):

$$\sigma_{u,e} = \frac{F_{a,max}}{A_r} \tag{28}$$

where

$F_{a,max}$ is the maximum axial compressive load, expressed in N;

$A_r$ is the minimum reinforced pipe wall cross section, expressed in mm$^2$.

The ratio of the equivalent Euler buckling stress to the maximum compressive stress shall be greater than or equal to 3:

$$\frac{\sigma_{u,e}}{\sigma_{a,comp}} \geq 3,0 \tag{29}$$

where

$\sigma_{u,e}$ is the equivalent Euler buckling stress, expressed in MPa;

$\sigma_{a,comp}$ is the maximum compressive stress on the unsupported length of piping, expressed in MPa.

NOTE 2 $\sigma_{ap}$, $\sigma_{af}$ and $\sigma_{at}$ can have axial compressive stress components that are due to axial compressive system loads. Only compressive loads are considered when evaluating Euler buckling.

NOTE 3 The designer may also need to consider Euler buckling from internal pressure (i.e. the water column is what is causing the buckling). Theoretically, this buckling pressure is equal to the pressure that provides a “virtual” axial pressure thrust load equal to the Euler column buckling load. This phenomenon can occur in small bore aboveground piping systems.

### 7.10.3 Buckling pressure — Buried piping

The external radial stress, $\sigma_{u,b}$, in MPa, for buried pipe shall be calculated using either Formula (30) or Formula (31):

$$\sigma_{u,b} = \frac{\gamma_w \times h_w + R_w \times W_c}{10^6} + P_v \tag{30}$$

$$\sigma_{u,b} = \frac{\gamma_w \times h_w + R_w \times W_c + W_L}{10^6} \tag{31}$$

where

$\gamma_w$ is the specific weight of water, 9 800 N/m$^3$;

$h_w$ is the height of water surface above the top of the buried pipe, expressed in m;

$R_w$ is the water buoyancy factor;

$W_c$ is the vertical soil load on the pipe, expressed in N/m², see AWWA Manual M45 (second edition), 5.7.3.5;

$W_L$ is the live load on the pipe, expressed in N/m², see AWWA Manual M45 Second Edition, 5.7.3.6; the designer shall have the option of setting $W_L = 0$ for the hydrotest loading case if live loads are not present;

$P_v$ is the internal vacuum pressure, expressed in MPa, calculated as the atmospheric pressure less the absolute pressure inside the pipe.

Live loads and internal vacuum are typically not considered simultaneously in any single loading case.

The allowable buckling stress, in MPa, is given by Formula (32):

$$\sigma_{q,a} = \frac{1,2 \times C_n \times (E_{hb} \times 10^3 \times \frac{t_{r,min}^3}{12})^{0,33} \times (\phi_s \times 10^6 \times M_s \times k_v)^{0,67}}{0,5 \times D_{r,min}} \quad (32)$$

where

$C_n$ is the scalar calibration factor to account for some nonlinear effects,=0,55;

$E_{hb}$ is the hoop bending modulus, expressed in MPa;

$t_{r,min}$ is the minimum reinforced pipe wall thickness, expressed in mm;

$\Phi_s$ is the factor to account for variability in stiffness of compacted soil,=0,9 if no other data is available;

$M_s$ is the constrained soil modulus, expressed in MPa, see WWA Manual M45 (second edition), 5.7.3.8;

$k_v$ is the modulus correction factor for Poisson's ratio of the soil.

The ratio of $\sigma_{q,a}$ to $\sigma_{u,b}$, the external radial pressure shall be greater than or equal to 2,5:

$$\frac{\sigma_{q,a}}{\sigma_{u,b}} \geq 2,5 \quad (33)$$

where

$\sigma_{q,a}$ is the allowable buckling stress, expressed in MPa;

$\sigma_{u,b}$ is the external radial pressure, expressed in MPa.

### 7.10.4 Upheaval buckling pressure

Upheaval buckling is a common design issue for buried pipelines operating at high temperatures and/or high pressures. When the high axial compressive forces are imposed on the pipeline due to the operating conditions, the pipeline tends to buckle upwards. In order to prevent upheaval buckling, the pipeline shall be buried deep enough so that the soil cover provides sufficient resistance to the upheaval forces.

The designer shall consider acceptable practices to design for upheaval buckling in buried pipelines.

### 7.11 Longitudinal pressure expansion

The strain from longitudinal pressure expansion in an unrestrained piping system, $\varepsilon_{p,avg}$, commonly referred to as "Poisson's effect", can be determined with Formula (34):

$$\varepsilon_{ap,avg} = \frac{\sigma_{ap,avg}}{E_a} - \upsilon_{ha} \times \frac{\sigma_{hp,avg}}{E_h} \tag{34}$$

where $\sigma_{hp,avg}$ is calculated differently from Formula (35):

$$\sigma_{hp,avg} = \frac{P \times ID_r}{2 \times t_{r,min}} \tag{35}$$

and $\sigma_{ap,avg}$ is calculated differently from Formula (36):

$$\sigma_{ap,avg} = \frac{P \times ID_r^2}{OD_{r,min}^2 - ID_r^2} \tag{36}$$

NOTE Elastic response is associated with the average stress in the pipe wall.

## 8 Other design aspects

### 8.1 Fire

#### 8.1.1 General

The designer shall determine the fire performance requirements of the piping system. Fire performance is characterized in terms of the following properties:

a) fire endurance;

b) fire reaction.

Fire endurance is the ability of an element of the structure or component to continue to perform its function as a barrier or structural component during the course of a fire for a specified period of time.

Fire reaction properties are material-related and concerned with time to ignition; the surface flame spread characteristics including smouldering and post-fire-exposure flaming; and the rate of heat, smoke and toxic gas release.

If piping cannot satisfy the required fire endurance or fire reaction properties, the designer shall consider alternative options which include

— re-routing of piping to reduce or eliminate the fire threat,

— use of alternative materials, and

— application of a suitable fire-protective coating.

If a fire-protective coating is used, the designer shall take into consideration the reliability by which the coating can be applied and its ability to maintain its properties over service lifetime.

The designer shall assign the required fire performance of the piping system according to the fire classification code given in ISO 14692-2:2017, 5.5.4. It is not necessary for the entire piping system to have the same fire classification.

### 8.1.2 Fire endurance

The fire protection requirements for piping shall be evaluated from the total endurance time established in the safety case for the facility and/or requirements for asset protection. The designer shall consider the alternative use of protective shielding, particularly if the severest fire threat, for example a jet fire, concerns just a small proportion of the piping.

The fire endurance of GRP piping components shall be determined using the appropriate method in ISO 14692-2:2017, Annex H as agreed between the principal and the authority having jurisdiction.

The designer shall also take into consideration the following factors:

a) orientation of the piping and fittings;

b) fluid conditions inside the piping, i.e. dry, stagnant or flowing;

c) possibility of the formation of steam traps within the piping, i.e. local removal of the cooling effect provided by water;

d) fire performance of penetrations;

e) interface with metal fittings (e.g. valves, support clamps) that may provide a path for heat conduction into the GRP component. Consideration shall be given to applying fire-protective coatings;

f) risk of premature failure of the supports in a fire, which can subject the piping to additional stresses;

g) length of support span compared to the length used to qualify the fire performance in ISO 14692-2:2017, Annex H. If necessary, the designer shall reduce the span or provide additional wall thickness to ensure the piping can maintain its integrity while subject to self-weight in a fire.

NOTE GRP is able to provide substantial fire resistance over a prolonged period of time because of the insulating and mechanical properties of the glass reinforcement and because pyrolysis of the resin, which is an endothermic reaction, absorbs heat from the fire and delays temperature rise. Both also enable an insulating and protective char to form, which protects the underlying material.

For non-fire-protected water service piping, the slow weepage of water through the pipe wall is an important factor that contributes to the fire performance of GRP piping since it reduces the surface temperature of the piping. The designer shall be satisfied that the fluid loss by weepage will not adversely affect the function of the system. The fire endurance properties of GRP piping may be different for piping containing fluids other than water, for example produced water, glycol, diesel fuel lines and closed drains. The designer shall be satisfied that the GRP piping can provide the required fire resistance under these conditions. This may require a risk analysis and/or additional testing to be carried out.

### 8.1.3 Fire reaction

Fire reaction is concerned with the following properties:

a) ease of ignition;

b) surface spread of flame characteristics;

c) rate of heat release;

d) smoke emissions;

e) toxic gas emissions.

### 8.1.4 Fire-protective coatings

The designer shall consider the following when determining the performance of the fire-protective coating:

a) fire risk (fire zone) and fire type for the area in which the piping is installed;

b) type, grade and diameter(s) of pipe;

c) jointing system(s) used;

d) whether the piping is “dry” or contains stagnant or flowing water;

e) type and thickness of passive fire-protective coating;

f) effect of long-term weathering, exposure to salt water, temperature and exposure to UV radiation;

g) effect of flexing, vibration, mechanical abuse, impact and thermal expansion;

h) liquid-absorption properties of the coating and piping. The fire-protective properties of the coating shall not be diminished when exposed to salt water, oil or bilge slops;

i) ease of attachment of the coating under site conditions and the effect of interfacial liquid entrapment. The adhesion qualities of the coating shall be such that the coating does not flake, chip, or powder when subjected to an adhesion test;

j) ease of repair.

The fire-protective coating should preferably be applied by the manufacturer in the factory. The application of fire-protective materials to achieve the flame spread, smoke or toxicity requirements shall be permanent to the piping construction. On-site application of such material shall be limited to that required for installation purposes, e.g. field joints and pipe supports.

## 8.2 Static electricity

Possible static electricity build-up in GRP piping systems and subsequent discharging shall be considered during design. Factors that affect the build-up of static electricity include the following:

a) conductivity of pipe laminate;

b) conductivity of transported fluid;

c) flow rates;

d) turbulence of flow;

e) environmental humidity;

f) external impingement of non-conducting media (e.g. wind, steam, etc.);

g) interface area between pipe and fluid.

Electrostatic charges can be generated on the inside and outside of GRP piping or on any insulated metallic components in the line. Sparks from subsequent discharging can puncture pipe walls, ignite surrounding explosive atmospheres, or ignite flammable pipe contents if sufficient air is present. Consideration during design shall therefore be given to these hazards when GRP piping systems are used to carry fluids capable of generating electrostatic discharges (static accumulators) or when using GRP piping systems in hazardous areas (i.e. areas that can in fault conditions, contain an explosive atmosphere).

In practice, fluids with a conductivity of less than 1 000 pS/m are considered to be non-conductive and therefore capable of generating electrostatic charges. Refined products and distillates fall into this category and piping used to convey these liquids shall therefore be electrically conductive. Fluids with a conductivity of greater than 1 000 pS/m are considered to be static non-accumulators, and can therefore be conveyed through pipes not having special conductive properties when located in non-hazardous areas. Where conductive piping is required due to the fluid being non-conductive, volume resistivity of the GRP piping shall not exceed $10^3$ Ωm.

Regardless of the fluid being conveyed, the need for GRP piping to be electrically conductive shall be considered if the piping passes through a hazardous area. Where conductive piping is required in a hazardous area, surface resistivity shall not exceed $10^5$ Ω/mr.

NOTE 1 A definition of a hazardous area is provided in ISO 14692-1. This definition can differ from the definitions in the International Electrotechnical Commission (IEC) nor the National Electric Code (NEC).

NOTE 2 More recent studies (see References [9] and [10]) have shown that non-conductive GRP is not capable of producing an incendive discharge in methanol, which has a minimum ignition energy that is approximately half that of typical hydrocarbons. Therefore, the risk of incendive discharge in a hazardous area will be primarily due to metal objects of significant size that are electrically isolated on the piping, rather than the GRP piping itself.

The resistance to earth from any point in the piping system shall not exceed $10^6$ Ω. In addition, metallic fittings and mechanical joints shall be individually grounded if there is not a sufficient electrical path through the GRP piping.

Reference should be made to API RP 2003 for further details on controlling the risk of static discharge.

## 9 Installer and operator documentation

The system designer shall provide design information for use by the installation and operation personnel. The information shall include, but not be limited to the following:

a) operating and design parameters;

   1) design pressure;

   2) design temperature;

   3) degree of cure properties;

   4) MPR of each component;

   5) mean and maximum velocity conditions in each piping system;

   6) chemical resistance limitations, if applicable;

   7) procedures to eliminate or control water hammer and cavitation, if applicable;

   8) fire classification and location of fire-rated pipe, if applicable;

   9) conductivity classification, location of conductive pipe, earth linkage/grounding requirements and location of earthing points;

   10) criticality;

b) system drawings and support requirements for heavy equipment;

c) preferred locations for connection of final joint in pipe loops, where appropriate;

d) guidance to enable early pressure-testing of piping sections, if appropriate.

# Annex A
(normative)

# Cyclic de-rating factor — $A_3$

## A.1 General

$A_3$ is the de-rating factor of the effects of cyclic variation in pressure. This annex outlines its derivation.

## A.2 Formulae for $A_3$

When determining $A_3$, the following formulae may be used in lieu of the graph.

$$f_c = \frac{\sigma_{\text{Static}\,100\ 000}}{\sigma_{\text{Cyclic}\,150\ 000\ 000}} \tag{A.1}$$

The cyclic long term strength factor, *fc*, is defined as the ratio of the projected stress values at 100 000 h (static loading) and 150 000 000 cycles (cyclic loading) respectively. These values shall be determined from regression analysis as defined in the ASTM D2992-96, Procedures A (cyclic) and B (static). In case no test data is available, *fc* shall be 4,0.

When $R_c > 0{,}4$:

$$\begin{aligned} A_3 &= \left(\frac{1-f_c}{0{,}6 f_c}\right)\left(\frac{1-R_c}{\log(150\times10^6)-\log(7\ 000)}\right)\log(N) \\ &+1-TAN\left[\left(\frac{1-f_c}{0{,}6 f_c}\right)\left(\frac{1-R_c}{\log(150\times10^6)-\log(7\ 000)}\right)\right](\log(7\ 000) \end{aligned} \tag{A.2}$$

When $R_c \le 0{,}4$:

$$\begin{aligned} A_3 &= \left(\frac{1-f_c}{f_c}\right)\left(\frac{1}{\log(150\times10^6)-\log(7\ 000)}\right)\log(N) \\ &+1-\left(\frac{1-f_c}{f_c}\right)\left(\frac{\log(7\ 000)}{\log(150\times10^6)-\log(7\ 000)}\right) \end{aligned} \tag{A.3}$$

$A_3$ shall be greater than or equal to $1/f_c$. $A_3$ shall be 1,0 if the calculated value is between 0,9 and 1,0. At 7 000 cycles or less, $A_3$ shall be 1,0. The minimum value for $A_3$ shall be 0,25.

## A.3 Theory and background

A review of Figure 2 will show a red line at $R = 0{,}4$. This line is the cyclic regression line from ASTM D2992 Procedure A, so there shall be no argument for using this line, since it is comes from “performance based testing” [critical concept in ISO 14692 (all parts)]. The default value of 4,0 for the ratio of static regression to cyclic regression is conservative based on actual test data. Using the ratio of cyclic regression at 150 000 000 cycles to static regression at 100 000 hours is necessary to superimpose cyclic on top of static regression (i.e. both have the same exposure time for chemical degradation). Note the values for cyclic regression have no safety factor (nominal regression line). The reason for this is $A_3$ superimposes the cyclic degradation factor on top of the static degradation and the static degradation value is a lower confidence limit value (LCL stress) and applies $f_2$ for design under different load cases. If this was not done, two safety factors would be applied to the design envelope.

If there are no cracks, there is nothing to propagate. The strain limit from cyclic testing establishes the strain limit for first crack. The very low strain limit will not intersect the static regression line, so the mechanism of resin matrix cracking from loads transverse to the fibres will continue for the 20 year service life.

### A.3.1 Uni-directional versus 54° laminates

Cyclic fatigue data for unidirectional laminates does show the potential for a strain limit in the resin, below which there is no further cyclic fatigue when testing in the fibre direction, so the issue of a strain limit for the resin needs further review. However, a 54° pipe is not stressed just in the fibre direction. Each ply is also stressed in the direction transverse to the fibres. This can be visualized by realizing that strain along the fibres in the plus ply direction produces strain transverse to the fibres in the adjacent minus ply direction and visa versa. Therefore, data for fatigue in unidirectional rods, tested in the direction of the fibres provides little guidance for fatigue or resin strain limits in a laminate that is bi-directionally loaded and produces strains and stresses transverse to the direction of the fibres.

### A.3.2 Fatigue limit

Data assembled by Battelle[17][18] from numerous pipe manufacturers indicated there was a fatigue limit between $10^8$ and $10^9$ cycles. Data from Talreja[19] also implies a fatigue limit for strain in the resin and the two values correlate fairly well. Based on this, a fatigue limit was arbitrarily set at 150 000 000 cycles, since this was the projected value from ASTM D2992 Procedure A.

### A.3.3 Cyclic regression rate versus load ratio, $R_c$

There is not a lot of data on the possibility of the cyclic regression rate changing as the load ratio ($R_c$) is increased. However, the Battelle data did indicate there was a slower regression rate (slope) as the load ratio increased. The current values are supported in the limited data that is available.

NOTE This is the weakest part of the proposed partial factor $A_3$ (i.e. how to interpret between full cyclic load and partial cyclic load). Any future data or theories may improve on the methodology for $A_3$, but the current values do have some support in the limited Battelle data.

# Annex B
(normative)

# Flexibility factors and stress intensification factors

## B.1 General

Flexibility factors shall be applied to bends and tees. Axial stress intensification factors (both in-plane and out-of-plane) shall be applied to bends and tees.

Since all components are subject to the qualification programme in ISO 14692-2, which includes the generation of hoop (and axial) stresses from an $R = 2$ test, hoop SIFs are not recommended for any components.

There are no SIFs for flanges nor reducers nor pipe joints.

Since all components are subject to the qualification programme in ISO 14692-2, pressure stress multipliers are not required.

## B.2 Flexibility factors

### B.2.1 General considerations

A flexibility factor describes the relationship between the axial flexural stiffness of a straight piece of or plain pipe and elbow (or tee), assuming that the plain pipe and elbow (or tee) have the same diameter and wall thickness and are subject to the same bending moment. A flexibility factor greater than 1,0 indicates the elbow (or tee) is not as stiff as the plain pipe (i.e. it is more flexible and will deflect/rotate more than the plain pipe). An alloy elbow or tee is typically less stiff than plain pipe. This is true because as bending occurs in an elbow or tee, the cross-section changes shape (i.e. it is no longer circular). This change in the cross-section reduces the moment of inertia, thus reduces the stiffness.

Standards such as ASME B31.3 and BS 7159 provide empirical formulae for flexibility factors for different pipe fittings. The formulae for flexibility factors are based only on the geometry of the fitting.

There are a number of issues with GRP bends and tees that shall be taken into account when determining the flexibility factors.

a) GRP, being an orthotropic material, typically has a hoop modulus that is higher than the axial modulus. Compared to isotropic materials, where the axial and hoop moduli are the same, the change in cross-section for GRP is typically less than the change in an isotropic material.

b) The thickness of the bend is typically larger than the thickness of plain pipe. This is typically amplified further at the intrados and extrados of the bend.

c) There is a stiffening effect from the overlap in material at the plain pipe/bend interface. These issues seem to be supported by the offshore composites Joint Industry Project by SINTEF (see Reference [11]) that showed the stiffness of bends to be much higher (i.e. the flexibility factor is much lower) than calculated by empirical formulae.

NOTE Incorrect flexibility factors can have a significant effect on the calculations of stress in a piping system. Unlike the stress intensification factor, a flexibility factor that is much higher than the actual value is not necessarily conservative.

### B.2.2 Flexibility factors for bends

The calculations given in Formula (B.1) to Formula (B.5) determine the flexibility factor for bends, first in terms of the component itself and then translated to a global flexibility factor that can be used in piping analysis computer programs. This is achieved by multiplying the local flexibility factor by the ratio of ${(E_a I_b)_{pipe}}/{(E_a I_b)_{bend}}$.

The flexibility factor, $\kappa_b$, for GRP bends is based on the pipe factor, $\lambda_b$, and the axial pressure correction factor, $\delta_a$, due to the effect of internal pressure.

$\lambda_b$ is given by Formula (B.1):

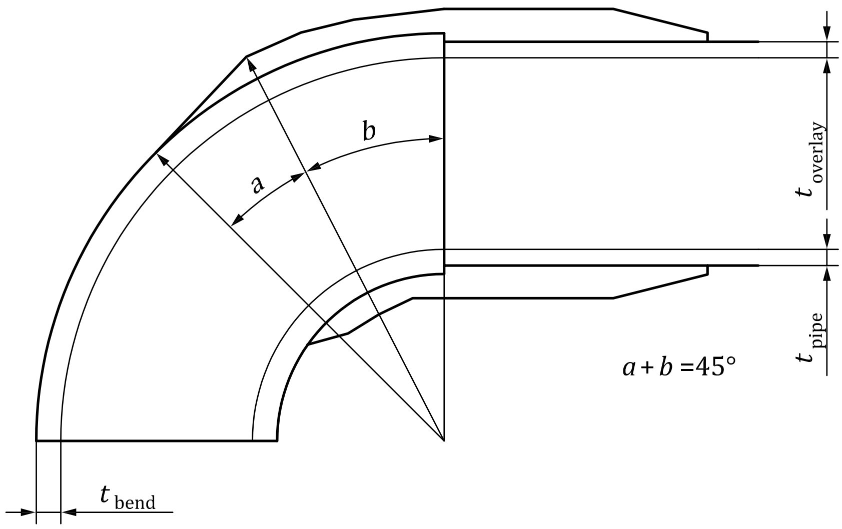
$$\lambda_b = \frac{4 t_b R_b}{D_i^2} \tag{B.1}$$

where

$t_b$ is the average wall thickness of the reference laminate of the bend, in mm;

$D_i$ is the internal diameter of the reinforced body of the bend, in mm;

$R_b$ is the mean pipe bend radius, in mm.




**Key**

$t_{bend}$ wall thickness of bend (mm)

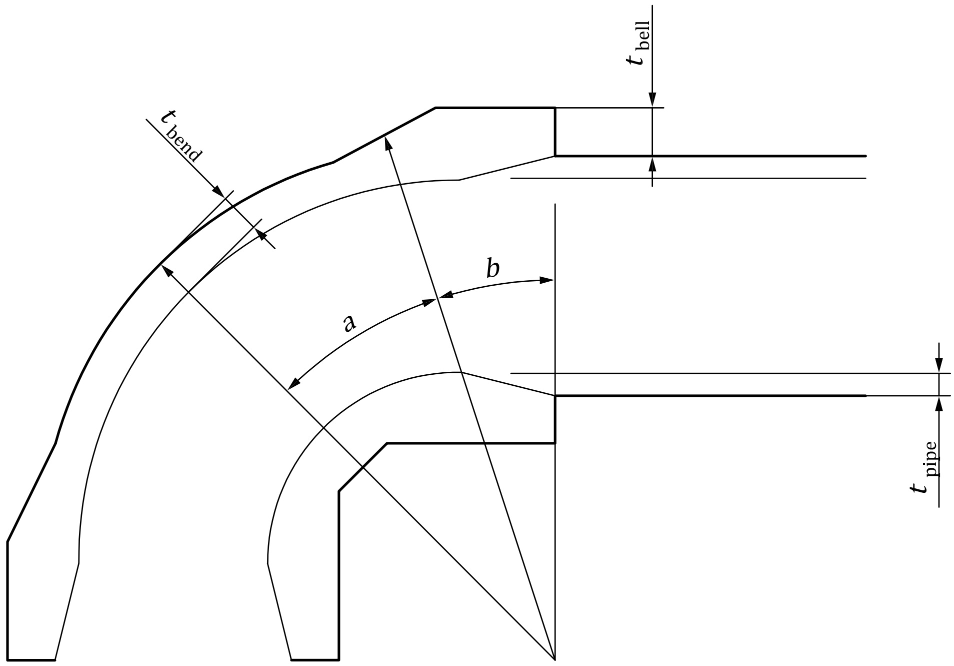
$t_{overlay}$ thickness of lamination (mm)

$t_{pipe}$ wall thickness of pipe (mm)

a angle subteded by taper length of lamination

b angle suntended by overlap length of lamination

**Figure B.1 — Terminology for calculating the flexibility factor of a bend using laminated joints**




**Key**

| | |
|---|---|
| $t_{\text{bend}}$ | wall thickness of bend (mm) |
| $t_{\text{bell}}$ | thickness of bell end of joint (mm) |
| $t_{\text{pipe}}$ | wall thickness of pipe (mm) |
| a | angle subteded by nominal thickness of bell end |
| b | angle suntended by end thickness of bell end |

**Figure B.2 — Terminology for calculating the flexibility factor of a bend using adhesive-bonded joints**

To determine $t_{\text{b}}$ for a bend, see Figure B.1 or Figure B.2 and Formula (B.2):

$$t_{\text{bend}} = \frac{b}{45} \times (t_{\text{bend}} + t_{\text{overlay}}) + (1 - \frac{b}{45}) \times t_{\text{bend}} \tag{B.2}$$

$\delta_{\text{a}}$ is given by Formula (B.3):

$$\delta_{\text{a}} = \frac{1}{\left[1 + \left(2{,}53 p / (E_{\text{h,bend}}) \cdot \left(R_{\text{b}} / t_{\text{b}}\right)^{1/3} \cdot (D_{\text{i}} / 2t_{\text{b}})^2\right)\right]} \tag{B.3}$$

where

$p$ is the applied pressure, in MPa;

$E_{\text{h,bend}}$ is the hoop modulus of the bend, in MPa.

The flexibility factor for smooth bends is given as a function of $\lambda_{\text{b}}$:

$$\kappa_{\text{b}} = \delta_{\text{a}} \cdot \frac{0{,}7}{\lambda_{\text{b}}} \cdot \frac{E_{\text{a,pipe}} \cdot t_{\text{pipe}}}{E_{\text{a,bend}} \cdot t_{\text{b}}} \tag{B.4}$$

For a hand-lay bend, the factor 0,7 is to be replaced by 1,0.

The flexibility factor for mitred bends is given as a function of $\lambda_b$:

$$\kappa_b = \delta_a \cdot \frac{0,64}{(\lambda_b)^{0,83}} \cdot \frac{E_{a,pipe} \cdot t_{pipe}}{E_{a,bend} \cdot t_b} \tag{B.5}$$

where

$E_{a,pipe}$ is the axial modulus of the attached pipe, in MPa;

$E_{a,bend}$ is the axial modulus of the bend, in MPa.

The ratio of the wall thicknesses is taken as an approximation of the ratio of the second moment of areas. The axial modulus of the pipe may be used in place of that for the bend if the modulus of the bend is not known.

An upper limit, based on experience, is placed on $\kappa_{b.}$ For either smooth or mitred bends, it shall not be greater than 3.

### B.2.3 Flexibility factors for tees

The flexibility factor for tees shall be 1,0.

## B.3 Stress intensification factors

Stress intensification factors, or SIFs, describe the relationship between the stress that would fail a plain pipe and that which would fail an elbow or tee. While flexibility factors affect the stiffness matrix in a beam based finite element analysis, SIFs are typically used to modify the computed stresses at the fittings. For alloys, SIFs are based on fatigue tests that were conducted on thin, steel pipe, elbows and tees, by Markl[12] using displacement controlled fatigue tests on piping components.

Since the fatigue behaviour of GRP is likely to be considerably different from that of steel, the SIFs from Markl's work has little value in the analysis of GRP.

Furthermore, the availability of SIF test data for GRP is limited due to the following.

a) The fabrication method of the elbow/tee changes (e.g. spiral/filament wound versus hand-lay/laminated) between products and between manufacturers.

b) The joint type will vary along with the fabrication method, thus resulting in different levels of stress concentration at the connections.

c) The material properties of the elbow/tee are not similar to those of the plain pipe to which they are attached.

d) The material properties of the elbow/tee are not uniform within the fitting.

e) The wall thickness of the fitting will vary from manufacturer to manufacturer and from one fabrication method to another. Furthermore, the wall thickness will vary within the fitting itself (e.g. the wall thickness at the intrados will be different than the wall thickness at the extrados).

The stress intensification factors in BS 7159 appear to be based on the work of Kitching and Bond[13]. SIFs are provided for bends, tees and reducing tees, both in-plane and out-of-plane. Correction factors for internal pressure are also provided. The SIFs are based on the pipe factor, which is a function of the geometry and dimensions of the bend/tee. Additional work has been conducted by the same authors as well as Hose and Myler after publication of BS 7159 in1989 (see Reference [12] to Reference [15]).

Care should be taken when using these factors because of the following.

a) Work carried out by the SINTEF offshore composites Joint Industry Project showed that some GRP bends may be substantially stiffer.

b) Some manufacturing processes have changed since 1989 resulting in a reduction in the wall of the plain pipe, but sometimes little to no change in the thickness of the fitting.

c) Much of the information about the stress intensification factors of bends and tees is related to the properties of its equivalent plain pipe, which may not be representative of the properties of the bend or tee.

One industry practice is to use an axial SIF of between 2.2 to 2.5 for all bends and tees for both in-plane and out-plane stress intensification factors (see Reference [16]). However, this philosophy was based on modelling the fitting wall thickness with its actual wall thickness, not that of the equivalent plain pipe. The philosophy in this document is to model the fitting wall thickness with its equivalent-rated plain pipe wall thickness. Thus, one cannot make a direct comparison between the default SIF in this document and other SIFs based on the actual wall thickness of the fitting.

## B.4 Modelling fittings

Design for pipe fittings will be primarily based on the fittings being stronger than the plain pipe to which they can be connected (i.e. pipe of similar materials and MPR).

NOTE For some applications, such as marine piping in the bottom of the tanker where the pipe wall is determined by external collapse pressure, the above statement will not be true and the MPR of the plain pipe thickness will be higher than the fittings.

It is expected that the effective failure and allowable stress envelope for fittings will be demonstrated to be everywhere (i.e. for all *R* ratios) equal to or larger than that of the associated plain pipe, where associated means the plain pipe (of similar MPR) which the fitting was tested against (the “reference” pipe).

Since fittings are to be (demonstrated) to be as strong or stronger than a (reference) pipe of the same MPR and typically pipe fittings will be attached to plain pipe of a lower or similar MPR, the fittings can safely be ignored in the strength design in the same way that pipe joints can be ignored.

In particular installations, such as in the bottom of shipboard tanks, additional pipe wall thickness may be utilized to increase free spans or to improve resistance to external pressure yet the MPR of the fittings does not need to be increased. In these instances the fitting may not be as strong as the plain pipe to which it is attached and cannot be ignored in the design.

It is proposed to carry out design for fittings based on the strength and properties of the reference plain pipe. Fittings would be modelled as short beam elements having the same ID and OD as the reference plain pipe (i.e. the plain pipe that the fitting was shown to be stronger than and not necessarily the plain pipe to which it is attached) and to have the same elastic properties and material strength as the reference plain pipe. At the fitting end nodes, the stress analysis model would transition from the real adjacent plain pipe section and properties to the reference pipe dimensions and properties.

The fittings can be installed into a library file using the ID, OD and elastic properties of the reference plain pipe (not the real fitting dimensions or properties) and the end to end dimensions of the fittings. Details of the allowable design envelope for the reference plain pipe will be provided (for use on the fittings). It is expected that pipe manufacturers would provide these library files for use by the designers.

SIFs (values to be determined) would be provided for factoring the stresses at the end nodes. It is likely that these SIFs would largely be based on the joint type rather than the fitting itself. Note that given the qualification criteria SIFs shall not be required for the fittings themselves.

The stress analysis software will calculate the associated reference pipe stresses (not the real stress in the fittings) at the intersection and end nodes. The compliance check for fittings will be carried out based on the reference pipe code stresses and the reference pipe allowable stress envelope.

The stress analysis software will calculate the adjacent pipe stresses at the end point nodes and apply the SIF. The compliance check for pipe will be carried out based on the adjacent pipe code stresses and the adjacent pipe allowable stress envelope.

This design method will deal correctly with situations where additional pipe wall thickness has been utilized to increase free spans or to improve resistance to external pressure.

See Figure B.3 for the proposed methodology for modelling bends and tees.

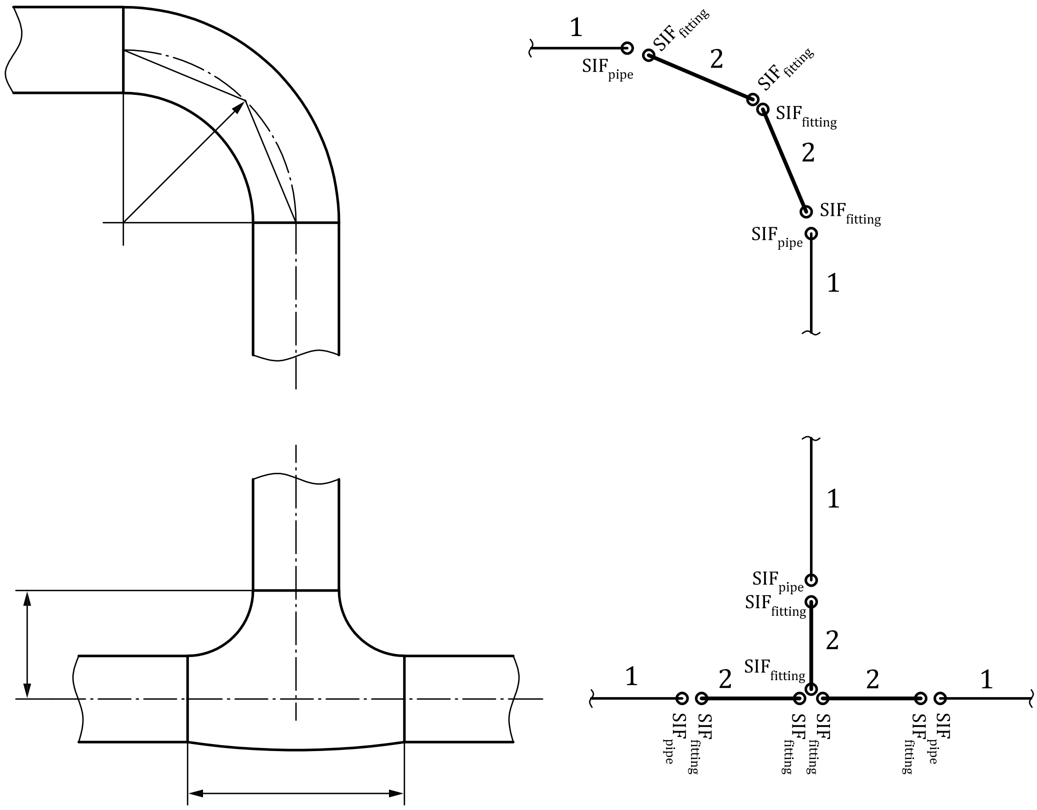



**Figure B.3 — Proposed design methodology for bends and tees**

## B.5 Optional combined loading test

Instead of using the default SIF values, the manufacturer has the option of conducting a combined loading test. The intention of the test is to subject a plain pipe and a bend or tee to a 1 000 h survival test with in-plane bending, so that $R$ is between 0,5 and 1,0.

As with the $R_{test}$ survival test in ISO 14692-2:2017, B.2.2, the hoop stress, $\sigma_{h,thr,SIF\text{-}test}$, and axial stress, $\sigma_{a,thr,SIF\text{-}test}$, components shall comply with Formula (B.6) and Formula (B.7), respectively.

$$\sigma_{h,thr,SIF\text{-}test} = \frac{\sigma_{h,thr,2:1}}{2} \tag{B.6}$$

$$\sigma_{a,thr,SIF\text{-}test} \geq \sigma_{a,thr,2:1} \tag{B.7}$$

This will generate an $R_{test}$ ratio of ≤1,0. The equivalent 1 000 h test pressure, $P_{T\ 1000,SIF\text{-}test}$, for the $R_{test}$ condition for GRE can then be calculated as the higher of the values in Formula (B.8) and Formula (B.9):

$$P_{T\ 1000,SIF\text{-}test} = 0,5 \times rd_{1\ 000,65} \times \frac{MPR_{65}}{0,67} \times \frac{t_{r,act} \times D_{r,min}}{t_{r,min} \times D_{r,act}} \tag{B.8}$$

$$P_{T\ 1000,SIF\text{-}test} = 0,5 \times rd_{1\ 000,65} \times \frac{MPR_{65}}{0,67} \tag{B.9}$$

NOTE Since both a plain pipe and a fitting (bend or tee) are being tested, the test pressure for both the plain pipe and the fitting is calculated. By using the higher of the two values, the minimum stress requirements for both components are satisfied.

In Formula (B.8), the actual dimensions of the test sample are required. For GRUP and GRVE, replace $rd_{1\,000,65}$ with $rd_{1\,000,21}$.

The temperature for this test shall be the same as the temperature in the $R_{test}$ survival test for the pipe in ISO 14692-2:2017, B.2.2.

The in-plane bending moment, $M$, for this test shall satisfy the requirement of Formula (B.7) and Formula (B.10):

$$\sigma_{a,thr,SIF\text{-}test} = \frac{1}{rd_{1\,000,65}} \times \left( \frac{P_{T1\,000,SIF\text{-}test} \times D_{r,min}}{4 \times t_{r,min}} + \frac{1\,000 \times M}{Z_r} \right) \quad \text{(B.10)}$$

where

$rd_{1\,000,65}$ is the 1 000 h to 20 a scaling ratio at 65 °C;

$rd_{1\,000,21}$ is the 1 000 h to 20 a scaling ratio at 21 °C;

$P_{T1\,000,SIF\text{-}test}$ is the pressure applied during the 1 000 h test, expressed in MPa;

$t_{r,min}$ is the minimum reinforced pipe wall thickness (of the reference pipe based on the fitting MPR), expressed in mm;

$D_{r,min}$ is the mean diameter of the minimum reinforced pipe wall (of the reference pipe based on the fitting MPR), expressed in mm;

$M$ is the in-plane bending moment applied to the test sample, expressed in Nm;

$Z_r$ is the actual reinforced section modulus of the pipe in the test sample, expressed in $mm^3$.

For GRUP and GRVE, replace $rd_{1\,000,65}$ with $rd_{1\,000,21}$.

If the plain pipe, fitting and joint survives this combined loading test, the SIF is 1,0. If any component fails this combined loading test, the manufacturer may repeat the test at a lower bending moment. If the plain pipe, fitting and joint passes at the lower bending moment, the manufacturer may then linearly interpolate a SIF between the default value of 1,5 and 1,0 based on the bending moment in the failed test and the bending moment in the test that passed.

The test is only applicable for the plain pipe/fitting combination used in the test. For example, if a 20 bar pipe and a 10 bar fitting is tested, these results may not necessarily extrapolate to a 20 bar pipe with a 16 bar fitting. Also, the requirements for representative products in ISO 14692-2:2017, Annex E and the requirements for scaling rules in ISO 14692-2:2017, Annex D apply.

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