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

Part 3:
System design

Industries du pétrole et du gaz naturel — Canalisations en plastique renforcé de verre (PRV) —

Partie 3: Conception des systèmes

Reference number
ISO 14692-3:2002(E)

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Foreword

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

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

ISO 14692-3 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*.

ISO 14692 consists of the following parts, under the general title *Petroleum and natural gas industries — Glass-reinforced plastics (GRP) piping*:

— *Part 1: Vocabulary, symbols, applications and materials*

— *Part 2: Qualification and manufacture*

— *Part 3: System design*

— *Part 4: Fabrication, installation and operation*

Introduction

The objective of this part of ISO 14692 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.

An explanation of the pressure terminology used in this part of ISO 14692 is given in ISO 14692-1.

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

Part 3: System design

1 Scope

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

2 Normative references

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

ISO 14692-1:2002, *Petroleum and natural gas industries — Glass-reinforced plastics (GRP) piping — Part 1: Vocabulary, symbols, applications and materials*

ISO 14692-2:2002, *Petroleum and natural gas industries — Glass-reinforced plastics (GRP) piping — Part 2: Qualification and manufacture*

ISO 14692-4:2002, *Petroleum and natural gas industries — Glass-reinforced plastics (GRP) piping — Part 4: Fabrication, installation and operation*

BS 7159:1989 *Code of practice for design and construction of glass-reinforced plastics (GRP) piping systems for individual plants or sites*

ASTM E1118, *Standard practice for acoustic emission examination of reinforced thermosetting resin pipe (RTRP)*

3 Terms and definitions

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

4 Symbols and abbreviated terms

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

5 Layout requirements

5.1 General

GRP products are proprietary, and the choice of component sizes, fittings and material types may 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 the following into consideration:

— 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 pipe systems available from manufacturers, including but not limited to:

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 component quality and 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 pipe system, when problems discovered at a late stage would have a negative effect on the overall project schedule.

Further guidance about GRP piping system layout is given in Annex A.

5.2 Space requirements

The designer shall take account of the larger space envelope of some GRP components compared to steel. Guidance on fitting sizes is given in Clause 7 of ISO 14692-2:2002. GRP fittings generally 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 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.

5.3 System supports

5.3.1 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 use of saddles and elastomeric pads may allow the use of standard-size supports.

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 should 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.

d) Valves or other heavy attached equipment shall be independently supported.

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

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

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

g) Consideration shall be given to the possible design requirements of the support to provide electrical earthing in accordance with the requirements of 5.8 and clause 10.

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

5.3.2 Pipe-support contact surface

5.3.2.1 Guidelines

The following guidelines to GRP piping support should be followed.

a) Supports in all cases should have sufficient width to support the piping without causing damage and should be lined with an elastomer or other suitable soft material. The minimum saddle width, in millimetres, should be $\sqrt{30D}$, where D is the mean diameter of the pipe, in millimetres.

b) Clamping forces, where applied, should 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.

c) Supports should be preferably located on plain-pipe sections rather than at fittings or joints.

d) Consideration shall be given to the support conditions of fire-protected GRP piping. Supports placed on the outside of fire protection could result in loads irregularly transmitted through the coating, which could result in shear/crushing damage and consequent loss of support integrity.

5.3.2.2 Supports permitting pipe movement

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

5.3.2.3 Supports anchoring pipe

The anchor support 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 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.

5.3.3 Support and guide spacing

The spanning capability of GRP piping spans is generally less than that for steel pipe, due to the lower modulus of the material. Supports shall be spaced to avoid sag (excessive displacement over time) and/or excessive vibration for the design life of the piping system.

GRP pipes, when filled with water, should be capable of spanning at least the distances specified in Table 1 while meeting the deflection criterion of 0,5 % of span or 12,5 mm centre, whichever is smaller. Spans are assumed to be simply supported. In some cases, bending stresses or support contact stresses may become a limiting factor (see 8.6), and the support spacing may have to be reduced.

Table 1 — Guidance to span lengths (simply supported)

Pipe nominal diameter mm	**Span** m
25	2,0
40	2,4
50	2,6
80	2,9
100	3,1
150	3,5
200	3,7
250	4,0
300	4,2
350	4,8
400	4,8
450	4,8
500	5,5
600 ⩾	6,0

Larger spans are possible, and the designer should verify that stresses are within allowable limits according to 8.6. The designer shall take into consideration the effect of buckling (8.7). The effect of temperature on the axial modulus of the GRP material shall also be considered.

5.4 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.

5.5 Vulnerability

5.5.1 Point loads

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

5.5.2 Abuse

The designer should 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:

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.

NOTE Further guidance on the design of gussets can be found in BS 4994 [1].

5.5.3 Dynamic excitation and interaction with adjacent equipment and piping

The designer should give consideration to the relative movement of fittings, which could 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 may be caused by transient pressure pulses, e.g. operation of pressure safety valves, valve closure etc.

5.5.4 Effect of external environment

5.5.4.1 Exposure to light and ultraviolet radiation (UV)

Where GRP pipe is exposed to the sun, the designer should consider whether additional 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.

5.5.4.2 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 pay particular attention to the freezing point of the internal liquid. For completely filled lines, solidification of the internal fluid may cause an expansion of the liquid volume, which could cause the GRP pipe to crack or fail. For water service, the volumetric expansion during solidification or freezing is more than sufficient to cause the GRP pipe to fail.

The pipe may require 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 pipe 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.

5.6 Joint selection

5.6.1 General

Various types of bonded and mechanical joints are available. These tend to be proprietary in nature but can generally be categorized into the following types:

— adhesive-bonded joints;

— laminated joints;

— elastomeric bell-and-spigot sealed joints (with/without locks);

— flanged joints;

— threaded joints;

— metallic/GRP interfaces;

— other mechanical joints.

A description and further guidance about the use of these joint types is given in Annex B. The designer should take into account the following factors when selecting the jointing method:

a) criticality;

b) reliability;

c) ease of joint assembly;

d) ease of repair, and future modifications and tie-ins.

5.6.2 Criticality and reliability

The designer should give consideration to the requirements for evaluating the performance of the joint during service.

The selection of the joint shall take into account the environmental conditions likely to be present during assembly, e.g. temperature and humidity.

The selection of the joint should take into account the presence of significant axial and in-plane axial bending stresses, which are more likely to expose the weakness of poorly made up joints than pressure alone.

The selection of joint shall take into account possible movement of the pipe caused by flexing of the hull, in the case of a floating offshore installation or flexing of the module during lifting operations.

5.6.3 Ease of joint assembly

The designer should give consideration to ensure the layout enables a site joint to be assembled to the correct dimensions and without the need to pull the joint into position such that the material is subject to overstress.

The selection of site joint should take into account the ease of access required by fitters to assemble the connection correctly. Site joints should be located in accessible locations away from supports and fittings.

The designer should give consideration to the preferred location of the last site joint in a piping loop to ensure the necessary access is available since this joint is often the most difficult to complete.

5.6.4 Ease of repair and access for future modifications and tie-ins

If bell-and-spigot joints are used in locations where future modifications are likely, the designer should consider the need for axial displacement of the pipe to enable the joints to be opened without the need to cut the pipe.

5.6.5 Metallic/GRP interfaces

Interfaces with metallic tanks, vessels, equipment or piping shall be by flanged (i.e. mechanical) connection.

In order to achieve reliable flange sealing, even with relatively low bolt-tensioning, steel-ring-reinforced elastomer gaskets should be used. Only soft type elastomers should be used, preferably with a hardness within the range Shore A 55 to A 75. The gasket material shall match the pressure, temperature and chemical resistance capabilities of the piping system. In general, PTFE envelope-type gaskets are not recommended and should not be used for pipes of large diameters (> 600 mm) and at high pressures (> 3,2 MPa).

The making of connections by other means, e.g. overwrapping of metallic pipe ends with GRP, is not acceptable unless qualified in accordance with 6.2.3.2 in ISO 14692-2:2002.

5.7 Fire and blast

5.7.1 General

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

a) blast;

b) fire protection of joints and supports;

c) interface with metal fixtures;

d) formation of steam traps;

e) jet fire;

f) heat release and spread of fire;

g) smoke emission, visibility and toxicity.

The methodology for assessing fire performance is given in Clause 9.

5.7.2 Blast

If components may be exposed to explosion hazards, the effect of blast overpressure, drag forces and projectile impacts should be considered (see 7.6.1), including the possible effect on support spacing.

5.7.3 Steam traps

Consideration should be given to the possibility of steam traps forming in pipe containing stagnant water, which would reduce the conduction of heat away by water.

5.7.4 Jet fires

Jet fires pose a significant threat to all types of piping systems because of the very high heat flux and erosive conditions that they produce. Whilst GRP pipe systems can be designed to withstand jet fires for a required period, the layout should be designed, if possible, to route piping away from areas which could be exposed to direct impingement by a jet fire.

5.7.5 Heat release and spread of fire

Consideration should be given to the contribution to the fire inventory and the risk of surface spread of flame to other areas, particularly if the pipes are empty and/or are no longer in service. The designer should consider the effect of the orientation of the piping and the possibility of thermal feedback from nearby reflective surfaces on the fire performance of the pipe.

5.7.6 Smoke emission, visibility and toxicity

Performance criteria for smoke and toxic emissions are primarily applied to the use of GRP piping in confined spaces, escape routes or areas with limited ventilation and where personnel are at risk. Consideration should be given to the risk of the spread of smoke and toxic emissions to other areas, particularly if the pipes are empty and/or are no longer in service.

5.7.7 Penetrations

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 pipework under consideration.

5.8 Control of electrostatic discharge

GRP piping and associated systems may be required to be electrically conductive/electrostatic dissipative and earthed, depending on service and location.

The location of the pipe determines the magnitude of external electrostatic charge-generation mechanisms to which the pipe may be exposed, and determines the consequences of an incendive discharge. For example, the effect of changing atmospheric electrical fields is mitigated by the shielding provided by metal walkways and decks located above the pipe.

In hazardous areas, the designer should be aware of the proximity of process pipe and other sources of high-pressure gas effluxes that may provide a strong external electrostatic-generation mechanism. The designer should also be aware of other potential sources of electrostatic-generation mechanisms, such as tribocharging and the presence of charged mists and soots produced in tank cleaning operations. In such locations and where practicable, the designer shall minimize the presence of unearthed metal objects attached to the pipe and take into account the proximity of nearby earthed metal objects when considering the risk analysis, see 10.1.

Further guidance for assessing the requirements for control of electrostatic discharge is given in Clause 10 and Annex G.

5.9 Galvanic corrosion

Galvanic corrosion is unlikely to be a concern at the interface of metal and GRP piping components if the GRP component incorporates small quantities of carbon fibre to provide electrical conductivity. This is because the exposed area of the carbon fibre (the cathode) is likely to be small compared to the adjacent metal component. The converse of a high cathode to anode ratio is usually needed to give rise to rapid corrosion.

However, if GRP components incorporate significant quantities of carbon or other cathodic material, e.g. for additional strengthening purposes, then precautions may be required to electrically isolate the carbon fibre at the interface with the metal component. Under such circumstances, the use of an impressed current from a cathodic protection system is not recommended.

6 Hydraulic design

6.1 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.

6.2 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. Guidance for the calculation of pressure losses is given in ISO 13703 [2]. The smooth surface of the GRP may result in lower pressure losses compared to metal pipe. Conversely the presence of excessive protruding adhesive beads will increase pressure losses.

6.3 General velocity limitations

Concerns that limit velocities in piping systems include:

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).

The designer shall take into account these concerns when selecting the flow velocity for the GRP piping system. 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.

6.4 Erosion

6.4.1 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.

6.4.2 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 [3].

6.4.3 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 pipe systems, the following should 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 bonded connections. Limits for the maximum size of adhesive beads are given in Table 4 of ISO 14692-4:2002.

6.4.4 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.

6.5 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 surge 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. Water hammer shall be defined as an occasional load, see 7.6.2.3.

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.

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

6.6 Cyclic conditions

The maximum pressure shall not exceed the design pressure. If the predicted number of pressure or other loading cycles exceeds 7 000 over the design life, then 7.4.4 shall apply.

7 Structural design

7.1 General

The aim of structural design for GRP piping systems is to ensure that they shall perform satisfactorily and sustain all stresses and deformations during construction/installation and throughout their service life. This clause identifies the service design criteria and the loads to which GRP may be subjected. The requirements for the stress analysis are given in Clause 8.

7.2 Manufacturer's pressure rating

The manufacturer's pressure rating provided in product literature is not the same as the qualified pressure, p_q, defined in 7.3 or the system design pressure. The manufacturer's pressure rating is defined as:

$$p_{NPR} = f_2 \cdot f_{3,man} \cdot p_q \tag{1}$$

where f_2 is defined as a load factor (see 7.6.2) and $f_{3,man}$ is a factor based on f_3, chosen by the manufacturer to account for the limited axial load capability of GRP, see 7.10.

f_3 is not a fixed parameter and is strongly dependent on application and p_q of the component. The value of f_3 for a component in a complex piping system, where significant non-pressure stresses can be produced, may be about 0,5. Conversely f_3 may have a value of 0,9 or more if the component is well supported and part of a long pipe run.

Use of the manufacturer's rating shall only be used for guidance purposes. Manufacturers should always provide the value of f_3 used to develop a purchase quotation.

NOTE For GRP pipes with a regression gradient less than 0,03 it may be required to de-rate, p_{qf}, in Equation (5). The derating factor is described in 7.6.2.1.

7.3 Qualified pressure

The qualified pressure, p_q, in megapascals[1)] for pipe and fittings shall be determined using the procedure described in 6.2.2 of ISO 14692-2:2002. The qualified pressure is based on a design life of 20 years. The qualified pressure for service lives other than 20 years shall be determined in accordance with 6.2.7 of ISO 14692-2:2002. The relationship between the qualified pressure and the design pressure for a component is defined in 7.5.

1) 1 bar = 0,1 (MPa).

7.4 Factored qualified pressure

7.4.1 General

The factored qualified pressure is defined as the pressure to be used in determining the safe operating envelope of the GRP pipe or piping system. It takes account of specific service conditions that could not be considered in the qualification programme.

The factored qualified pressure, p_{qf}, in megapascals, for pipe and fittings shall be calculated using Equation (2):

$$p_{qf} = A_1 \cdot A_2 \cdot A_3 \cdot p_q \qquad (2)$$

where

p_q is the qualifed pressure, in megapascals, given in 7.3;

A_1 is the partial factor for temperature, determined in accordance with 7.4.2;

A_2 is the partial factor for chemical resistance, determined in accordance with 7.4.3;

A_3 is the partial factor for cyclic service, determined from 7.4.4.

7.4.2 Design temperature

The effect of temperature on reduction of mechanical properties shall be accounted for by the partial factor A_1, which is determined according to Annex D in ISO 14692-2:2002.

The maximum operating temperature of the piping system shall not exceed the temperature used to calculate the partial factor A_1 of the GRP components. If the operating temperature is less than or equal to 65 °C, then A_1 will generally be equal to 1,0.

The effect of low temperatures on material properties and system performance shall be considered. For service temperatures below 0 °C, the principal should consider the need for additional testing, depending on the resin system. Both qualification as well as additional mechanical tests should be considered.

System components such as nylon locking strips may be susceptible to brittle fracture at low temperature.

NOTE GRP materials do not undergo ductile/brittle transition within the temperature range of this part of ISO 14692, hence, there is no significant abrupt change in mechanical properties at low temperatures. A concern is that at temperatures lower than −35 °C, internal residual stresses could become large enough to reduce the safe operating envelope of the piping system.

7.4.3 Chemical degradation

The effect of chemical degradation of all system components from either the transported medium or the external environment shall be considered on both the pressure and temperature ratings. System components shall include adhesive and elastomeric seals/locking rings, if used, as well as the basic glass fibre and resin materials.

The effect of chemical degradation shall be accounted for by the partial factor A_2 for chemical resistance, which is determined in accordance with Annex D in ISO 14692-2:2002. If the normal service fluid is water, then A_2=1. Reference shall be made to manufacturers' data if available.

NOTE 1 In general, the aqueous fluids specified in the qualification procedures of ISO 14692-2:2002 are amongst the more aggressive environments likely to be encountered. However, strong acids, alkalis, hypochlorite, glycol, aromatics and alcohol can also reduce the properties of GRP piping components; the effect depending on chemical concentration, temperature and resin type.

NOTE 2 The data from manufacturers' tables are based on experience and laboratory tests at atmospheric pressure, on published literature, raw material suppliers' data, etc. Chemical concentrations, wall stresses, type of reinforcement and resin have not always been taken into account. Therefore the tables can only give an indication of the suitability of the piping components to transport the listed chemicals. In addition, mixtures of chemicals may cause unexpectedly more severe situations.

7.4.4 Fatigue and cyclic loading

Cyclic loading is not necessarily limited to pressure loads. Thermal and other cyclic loads shall therefore be considered when assessing cyclic severity.

If the predicted number of pressure or other loading cycles is less than 7 000 over the design life, the service shall be considered static. If required, the limited cyclic capability of pipe system components can be demonstrated according to 6.4.5 of ISO 14692-2:2002.

If the predicted number of pressure or other loading cycles exceeds 7 000 over the design life, then the designer shall determine the design cyclic severity, R_c, of the piping system. R_c is defined as:

$$R_c = \frac{F_{min}}{F_{max}} \tag{3}$$

where F_{min} and F_{max} are the minimum and maximum loads (or stresses) of the load (or stress) cycle.

The partial factor, A_3, for cyclic service is given by:

$$A_3 = \sqrt{\left(R_c{}^2 + \frac{1}{16}(1 - R_c{}^2)\right)} \times \exp\left[(1 - R_c)\left(1 - \frac{N - 7000}{10^8}\right)\right] \tag{4}$$

where N is the total number of cycles during service life.

This equation is intended for cyclic internal pressure loading only, but may be applied with caution to axial loads provided they remain tensile, i.e. it is not applicable for reversible loading.

7.5 System design pressure

The system design pressure, p_d, shall be less than the maximum allowable pressure for a component given by Equation (5):

$$p_d \leqslant f_2 \cdot f_3 \cdot p_{qf} \tag{5}$$

where

f_2 is as defined in 7.6.2;

f_3 is as defined in 7.10;

p_{qf} is as defined in 7.4.

The system design pressure is limited by the component with the smallest value of f_3. Since the value of f_3 is dependent on the magnitude of axial stress, the component with the smallest f_3 cannot be determined until after the system stress analysis has been completed.

NOTE 1 It is not necessary to calculate the value of f_3 if the design stresses are compared to the failure envelope as described in 7.11.

NOTE 2 For GRP pipes with a regression gradient less than 0,03 it may be required to de-rate p_{qf} in Equation (5). The derating factor is described in 7.6.2.1.

7.6 Loading requirements

7.6.1 Applied loads

The design of piping systems shall represent the most severe anticipated conditions experienced during installation and within the service life of the system. Designers shall consider the loads given in Table 2 that can potentially be experienced by the piping system during the anticipated service life. Live loadings typically include, but are not limited to, the mass of the transported medium.

In some circumstances, changes in ambient temperature can be more important than temperature changes in the fluid. The mean temperature change of the pipe wall should then be taken as the full temperature difference between the applicable ambient temperature and the operating temperature. In addition, the effect of extreme transient temperatures, such as adiabatic cooling, shall also be considered.

The designer shall take account of possible mechanical and thermal loads that may be applied to GRP pipe by crude oil and ballast water during concrete pouring and setting construction activities of gravity-based structures.

The designer shall consider the effect of the predicted blast overpressures determined from the risk assessment. The effect of blast overpressure shall be determined using analytical techniques.

7.6.2 Part factor for loading

7.6.2.1 General

The purpose of the part factor f_2 is to define an acceptable margin of safety between the strength of the material and the operating stresses for the three load cases, occasional, sustained including and sustained excluding thermal loads. Table 3 provides default values for f_2 based on 7.6.2.2 and 7.6.2.3. For most GRP pipe systems an acceptable margin of safety is obtained by defining the long-term factored design envelope (Figure 1, Key item 7) as f_2 times the idealized long-term envelope (Figure 1, Key item 5). For GRP pipe systems that have a flat regression curve ($G < 0{,}03$), a further assessment of the margin of safety is recommended. For these systems the ratio of average short-term burst pressure to design pressure is less than 2,5. It shall be agreed between the principal and the manufacturer whether it is acceptable or not to allow this ratio to be less than 2,5. If this ratio is unacceptable, then the idealized long-term envelope shall be de-rated by the ratio $1{,}44 \cdot p_{\mathrm{LCL}}/p_{\mathrm{STHP}}$ (see 6.2.4 of ISO 14692-2:2002).

7.6.2.2 Part factor for sustained loading

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 pipe system. The value to be applied for specific piping systems shall be specified by the user. Because of the self-limiting nature of loads related to thermal expansion, the part factor f_2 to be used in the assessment of sustained loads including thermal effects could be larger than the factor for the assessment of sustained loads excluding thermal effects.

Table 2 — Loads experienced by a GRP piping system

Sustained loads	Occasional loads
Internal, external or vacuum pressure, hydrotest	Water hammer, transient equipment vibrations, pressure safety-valve releases
Piping self-mass, piping insulation mass, fire protection mass, transported medium mass, buoyancy, other system loads	Impact
Inertia loads due to motion during operation Displacement of supports caused by flexing of the hull during operations	Inertia loads due to motion during transportation Earthquake-induced horizontal and vertical forces, where appropriate Displacement of supports caused by flexing during lifting
Thermal induced loads, electric surface heating	Installation loads, lifting loads, transportation loads
Environmental loads, ice	Adiabatic cooling loads
Encapsulation in concrete	Earthquake, wind
Soil loads (burial depth)	Blast over-pressures
Soil subsidence	

Table 3 — Default values for f_2

Loading type	Load duration	f_2	Example of loading type
Occasional	Short-term	0,89	Hydrotest
Sustained including thermal loads	Long-term	0,83	Self-mass plus thermal expansion
Sustained excluding thermal loads	Long-term	0,67	Self-mass

Consequently the assessment of sustained loading shall be carried out in the following two stages:

a) assessment of sustained loading excluding thermal effects

Unless otherwise specified by the user, the part factor, f_2, used for the evaluation of sustained loads excluding thermal effects shall be taken as 0,67.

b) assessment of sustained loading including thermal effects.

Unless otherwise specified by the user, the part factor, f_2, used for the evaluation of sustained loads including thermal effects shall be taken as 0,83.

7.6.2.3 Part factor for occasional loads

The part factor f_2 to be used in the assessment of the combination of sustained loads such as pressure, and mass, and occasional loadings such as water hammer, wind or earthquake or blast loading shall be determined taking into account operating conditions and risk associated with the pipe system. The value to be applied for specific piping systems shall be specified by the user. Unless otherwise specified by the user, the part factor f_2 shall be taken as $1,33 \times 0,67 = 0,89$ for evaluation of this case.

Wind, earthquake, water hammer or blast loading need not be considered acting concurrently but shall be considered in combination with sustained loads excluding thermal effects. Hydrotesting shall be considered an occasional load.

7.6.3 External pressure/vacuum

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.

7.7 Allowable displacements

7.7.1 Deflection

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 should 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 Ovalization

Ovalization relative to pipe diameter shall not exceed 5 %.

7.8 Qualified stress

The pipe shall have been assigned a qualified stress, σ_{qs}, expressed in megapascals, by the manufacturer in accordance with Equation (6).

$$\sigma_{qs} = p_q \times \frac{D}{2t_r} \tag{6}$$

where

p_q is the qualified pressure, in megapascals;

D is the average diameter of the pipe, in millimetres;

t_r is the average reinforced wall thickness of the pipe, in millimetres.

The qualified stress, σ_{qs}, for fittings shall be calculated using Equation (7):

$$\left(\frac{\sigma_{qs}}{p_q}\right)_{\text{fitting}} = \left(\frac{\sigma_{qs}}{p_q}\right)_{\text{pipe}} \tag{7}$$

7.9 Factored stress

The factored stress, σ_{fs}, in megapascals, for plain pipe shall be calculated using either Equation (8) or Equation (9):

$$\sigma_{fs} = \sigma_{qs} \cdot A_1 \cdot A_2 \cdot A_3 \tag{8}$$

where

A_1 is the partial factor for temperature;

A_2 is the partial factor for chemical resistance;

A_3 is the partial factor for cyclic service;

σ_{qs} is the qualified stress, in megapascals.

$$\sigma_{fs} = \frac{p_{qf} \cdot D}{2t_r} \qquad (9)$$

where p_{qf} is the factored qualified pressure, in megapascals, determined from 7.4 and D and t_r are as defined in 7.8.

The factored stress, σ_{fs}, for fittings shall be calculated using Equation (10):

$$\left(\frac{\sigma_{fs}}{p_{qf}}\right)_{\text{fitting}} = \left(\frac{\sigma_{fs}}{p_{qf}}\right)_{\text{pipe}} \qquad (10)$$

7.10 Limits of calculated stresses due to loading

The general requirement is that the sum of all hoop stresses, $\sigma_{h,sum}$, and the sum of all axial stresses, $\sigma_{a,sum}$, in any component in a piping system due to pressure, mass and other sustained loadings, and of the stresses produced by occasional loads such as wind, blast or earthquake shall not exceed values defined by the factored long-term design envelope, see 7.11.

If the sum of these stresses lies outside the factored long-term design envelope, then the pipe of next higher rated pressure shall be chosen from the product family, and the stress calculation repeated until the sum of the stresses lies within the factored long-term design envelope. The procedure for determining the long-term design envelope is given in 7.11.

If the magnitude of non-pressure-induced axial stress is known, Equation (11) can be used to determine the allowable hoop stress, $\sigma_{h,sum}$, in megapascals.

$$\sigma_{h,sum} \leqslant f_2 \cdot f_3 \cdot \sigma_{fs} \qquad (11)$$

where

σ_{fs} is as defined in 7.9;

f_2 is the part factor for loading and shall be determined in accordance with 7.6.2;

f_3 is the part factor for axial load and shall be calculated using Equations (13) or (14).

Part factor f_3 is dependent on the value of the biaxial stress ratio r such that:

$$r = 2 \cdot \frac{\sigma_{sa(0:1)}}{\sigma_{sh(2:1)}} \qquad (12)$$

where

$\sigma_{sh(2:1)}$ is the short-term hoop strength, in megapascals, under 2:1 stress conditions;

$\sigma_{sa(0:1)}$ is the short-term axial strength, in megapascals, under axial loading only.

The biaxial stress ratio r is as defined in 6.2.6 of ISO 14692-2:2002. In the absence of data from the manufacturer, the default values given in 7.11.4 shall be used.

Part factor f_3 is defined according to whether r is greater than or less than 1.

if $r \leqslant 1$ then

$$f_3 = 1 - \frac{2\sigma_{ab}}{r \times f_2 \times \sigma_{fs}} \quad (13)$$

if $r > 1$ then

$$f_3 = r - \frac{2\sigma_{ab}}{f_2 \times \sigma_{fs}} \quad (14)$$

where σ_{ab} is the non-pressure-induced axial stress, in megapascals, see Figure 1.

The maximum allowable value of f_3 shall be unity. When the sustained axial stress, excluding that due to pressure, σ_{ab}, is compressive, f_3 is equal to 1.

The procedures for calculating part factor f_3 are applicable to both pipe and fittings. For the purposes of the calculation of part factor f_3 for fittings, an equivalent qualified stress, σ_{fs}, is determined using Equation (10).

7.11 Determination of failure envelope

7.11.1 General

This subclause describes how the failure envelope of the GRP pipe components can be determined to meet the requirements of 7.10. Two design options are defined, depending of the availability of measured data, which can be either a fully measured envelope, 7.11.2 or a simplified envelope, 7.11.3.

The fully measured envelope is generally only available for plain pipe. For all other component variants, the simplified envelope should be used. The least conservative procedure is the fully measured envelope.

NOTE For filament-wound GRP pipes, the design approach adopted by most manufacturers is to optimize performance for the 2:1 pressure condition (system with closed ends). Therefore the hoop strength is significantly greater than the axial strength.

7.11.2 Fully measured envelope

The long-term envelope is derived from a fully measured short-term envelope according to the procedures given in Annex C of ISO 14692-2:2002. The idealized long-term failure envelope, Figure 1, is geometrically similar to the short-term envelope, with all three data points being scaled according to f_{scale}, where;

$$f_{scale} = \frac{\sigma_{qs}}{\sigma_{sh(2:1)}} \quad (15)$$

where

σ_{qs} is the qualified stress, in megapascals;

$\sigma_{sh(2:1)}$ is the short-term hoop strength at 2:1 stress ratio, in megapascals.

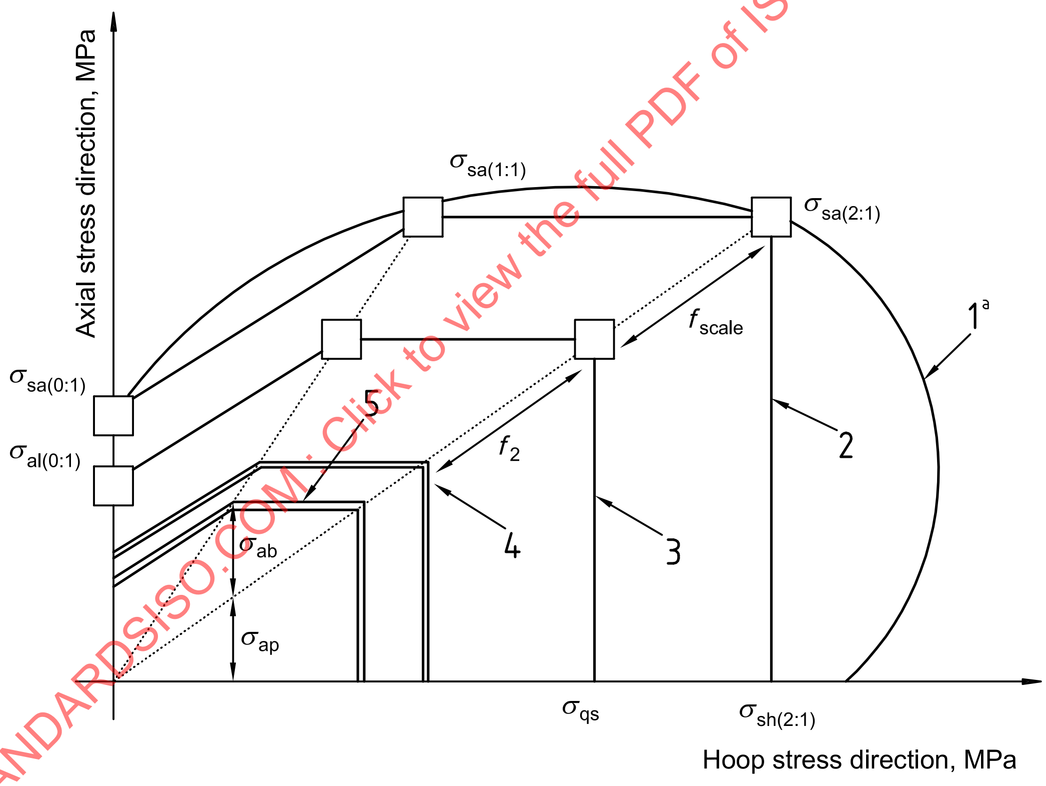
The non-factored long-term design envelope is based on this idealized long-term envelope multiplied by an appropriate part factor, f_2, 7.6.2, depending on loading type.

The factored long-term design envelope is defined according to Equation (16):

$$g_{long}(\sigma_{h,sum}, \sigma_{a,sum}) \leqslant f_2 \cdot f_{scale} \cdot A_1 \cdot A_2 \cdot A_3 \cdot g_{short}(\sigma_{sh(2:1)}, \sigma_{sa(0:1)}) \quad (16)$$

where

A_1	is the partial factor for temperature;
A_2	is the partial factor for chemical resistance;
A_3	is the partial factor for cyclic service;
σ_{ab}	is the non-pressure-induced axial stress;
σ_{ap}	is the axial stress due to internal pressure;
$\sigma_{a,sum}$	is the sum of all axial stresses, in megapascals;
$\sigma_{h,sum}$	is the sum of all hoop stresses, in megapascals, (pressure plus system design);
$g_{long}(\sigma_{h,sum}, \sigma_{a,sum})$	is the shape of the factored long-term design envelope;
$g_{short}(\sigma_{sh(2:1)}, \sigma_{sa(0:1)})$	is the shape of the idealized short-term envelope.



Key

1 schematic representation of the short-term failure envelope
2 idealized short-term envelope
3 idealized long-term envelope
4 non-factored long-term design envelope
5 factored long-term design envelope

[a] For design purposes, the shape should be based on actual measured data points.

Figure 1 — Idealized long-term envelope for a single wound angle ply GRP pipe with winding angles in the range of approximately 45° to 75°

7.11.3 Simplified envelope

7.11.3.1 General

This method makes use of the biaxial strength ratio r, which is the ratio of axial stresses at 0:1 and 2:1 stress ratios determined in 6.2.6 of ISO 14692-2:2002.

If a value of r for a component is unavailable, the default value given in 7.11.4 should be used.

7.11.3.2 Plain pipe

Figure 2 shows short- and long-term failure envelopes for a single wound angle ply GRP pipe with winding angle in the range ± 45° to 75° where the value of r can be expected to be less than 1. If r is greater than 1, e.g. hand lay-up pipe, 7.11.3.3 applies.

The idealized long-term failure envelope is geometrically similar to the short-term envelope and is derived according to Equation (17) or (18):

$$\sigma_{\text{al}(0:1)} = \sigma_{\text{sa}(0:1)} \times \frac{\sigma_{\text{qs}}}{\sigma_{\text{sh}(2:1)}} \tag{17}$$

or

$$\sigma_{\text{al}(0:1)} = r \times \frac{\sigma_{\text{qs}}}{2} \tag{18}$$

where

σ_{qs} is the qualified stress, in megapascals;

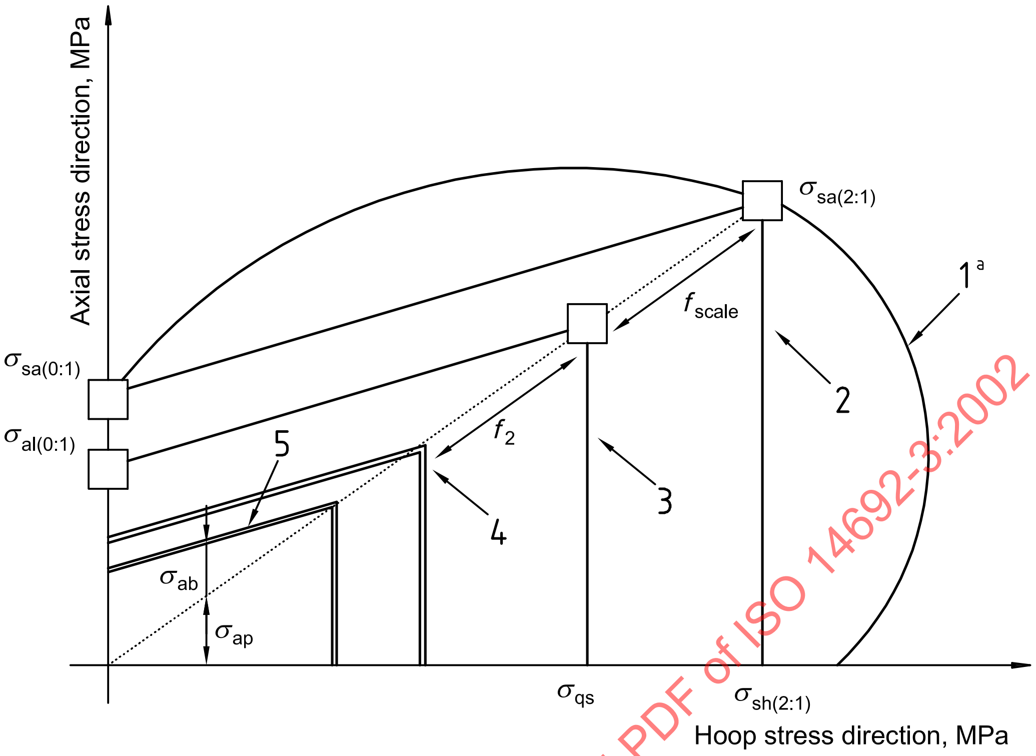
$\sigma_{\text{al}(0:1)}$ is the long-term axial (longitudinal) strength at 0:1 stress ratio, in megapascals;

$\sigma_{\text{sa}(0:1)}$ is the short-term axial strength at 0:1 stress ratio, in megapascals;

$\sigma_{\text{sh}(2:1)}$ is the short-term hoop strength at 2:1 stress ratio, in megapascals;

r is derived according to Equation (12).

The important feature of Figure 2 is that the axial tensile strength, $\sigma_{\text{al}(0:1)}$, is lower than the axial stress for the 2:1 internal pressure case, $\sigma_{\text{sa}(2:1)}$. The ratio of these strengths can range between 0,5 and 0,75 for plain pipe, depending on winding angle and specific pipe type. The non-factored long-term design envelope is based on this idealized envelope multiplied by an appropriate part factor, f_2, 7.6.2, depending on loading type.



Key

1 schematic representation of the short-term failure envelope

2 idealized short-term envelope

3 idealized long-term envelope

4 non-factored long-term design envelope

5 factored long-term design envelope

a For design purposes, the shape should be based on actual measured data points.

Figure 2 — Short and long-term idealized failure and design envelopes for a single wound angle ply GRP pipe with winding angles in the range of approximately 45° to 75°

The equations for defining the factored long-term design envelope for hoop and axial stress, respectively, are defined such that:

$$\sigma_{h,sum} \leqslant f_2 \cdot A_1 \cdot A_2 \cdot A_3 \cdot \sigma_{qs} \tag{19}$$

or

$$\sigma_{h,sum} \leqslant = f_2 \cdot \sigma_{fs} \tag{20}$$

and

$$\sigma_{a,sum} \leqslant f_2 \cdot A_1 \cdot A_2 \cdot A_3 \left[\left(\frac{\sigma_{qs}}{2} - \sigma_{al(0:1)} \right) \frac{\sigma_{h,sum}}{\sigma_{qs}} + \sigma_{al(0:1)} \right] \tag{21}$$

or

$$\sigma_{a,sum} \leqslant f_2 \cdot A_1 \cdot A_2 \cdot A_3 \left((1-r) \frac{\sigma_{h,sum}}{2} + \frac{r \cdot \sigma_{qs}}{2} \right) \text{ assuming } r \leqslant 1 \tag{22}$$

where

$\sigma_{a,sum}$ is the sum of all axial stresses, in megapascals;

$\sigma_{h,sum}$ is the sum of all hoop stresses, in megapascals, (pressure plus system design);

σ_{qs} is the qualified stress, in megapascals;

A_1 is the partial factor for temperature;

A_2 is the partial factor for chemical resistance;

A_3 is the partial factor for cyclic service;

σ_{fs} is defined in accordance with Equation (8).

NOTE Equation (19) or (20) and Equation (21) or (22) describe the limits of the factored long-term design envelope in terms of hoop and axial stresses respectively. Both criteria as described by these equations must be satisfied. There is no conflict between these combined equations and Equation (11). In fact, it is possible to demonstrate that by combining Equation (19) or (20) with Equation (21) or (22), Equation (11) results.

7.11.3.3 Pipe plus joint

The idealized long-term failure envelope is rectangular, with the edges determined by the σ_{qs} and the long-term axial strength of the joint, σ_a. The long-term idealized envelope may be either that shown in Figure 3 a) or Figure 3 b), where Figure 3 a) is representative of a joint with quasi-isotropic properties, e.g. laminated joint and Figure 3 b) represents an adhesive joint with anisotropic properties.

In both cases $\sigma_{al(0:1)}$ is defined in accordance with Equation (17).

The non-factored long-term design envelope is based on this idealized envelope multiplied by an appropriate part factor, f_2, 7.6.2, depending on loading type. The factored long-term design envelope is defined in accordance with Equations (19), (20), (21), (22), (23) and (24).

$$\sigma_{a,sum} \leqslant \frac{f_2 \cdot A_1 \cdot A_2 \cdot A_3 \cdot r \cdot \sigma_{qs}}{2} \text{ for } r \geqslant 1 \tag{23}$$

or

$$\sigma_{a,sum} \leqslant f_2 \cdot \sigma_{fs} \cdot \frac{r}{2} \text{ for } r \geqslant 1 \tag{24}$$

7.11.3.4 Fittings

7.11.3.4.1 Bends

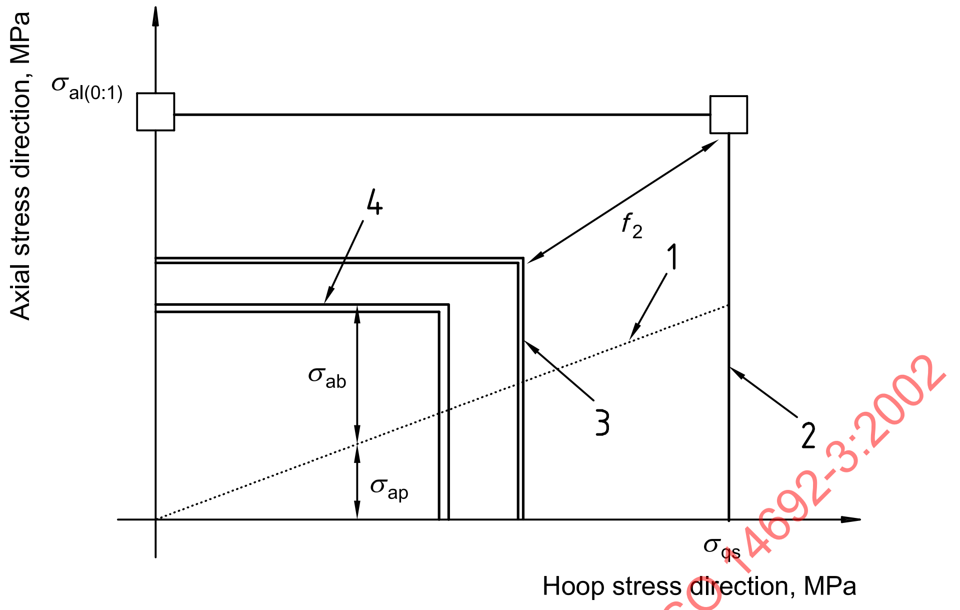
The response of bends to pressure-induced axial and bending loads is more complex than the equivalent loads on a straight pipe. Application of a bending moment causes ovalization, resulting in both induced axial and hoop stresses. The shape of the failure envelope depends on the layup configuration of the bend.

For filament-wound bends, the failure envelope is similar to the type shown in Figure 2, i.e. r is less than 1. The potential of applied pressure and bending loads to induce axial as well as hoop stresses results in a conservative approach to defining the long-term strength of a GRP bend.

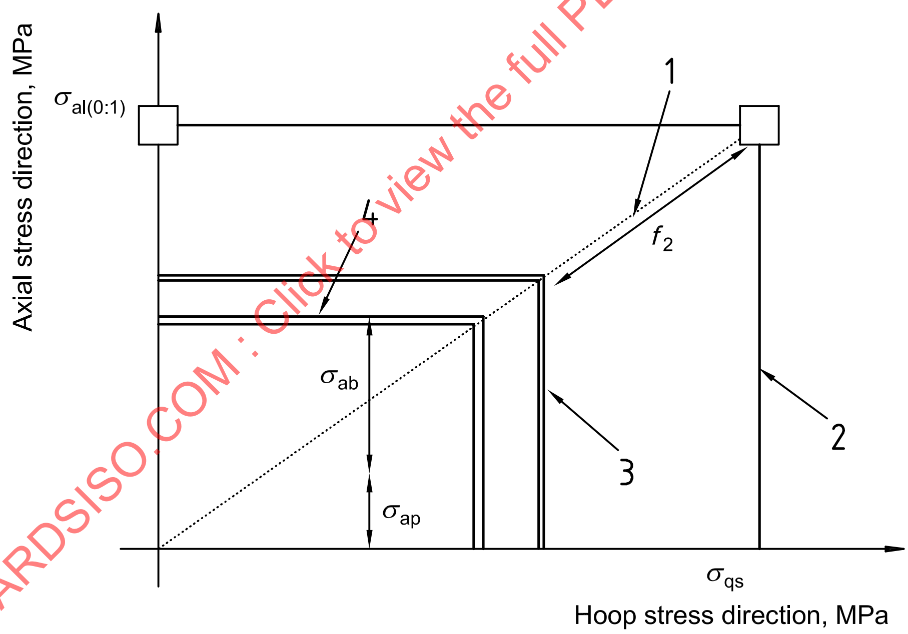
For bends that are constructed entirely from hand lay-up, the shape of the failure envelope can be considered to be rectangular, with r greater than 1 as shown in Figure 3 a).

The non-factored long-term design envelope is based on this idealized envelope multiplied by an appropriate part factor, f_2, 7.6.2, depending on loading type.

If data are unavailable from the manufacturer, the default values given in 7.11.4 shall be used.



a) Quasi-isotropic GRP joints



b) Adhesive joints

Key

1 2:1 pressure ratio

2 idealized long-term envelope

3 non-factored long-term design envelope

4 factored long-term design envelope

Figure 3 — Short and long-term idealized failure and design envelopes

7.11.3.4.2 Tees

At the intersection point of tee sections, stresses and their direction become complex and cannot easily be related to applied pressure and tensile loads. It is the intersection region which governs component performance, and therefore the design envelope for tees is similar to that for joints, 7.11.3.3. That is, failure under tensile load is dominated by axial “pull-out” at the intersection of the pipe and tee, and under pressure is dominated by weepage.

The failure envelope for tees can be considered to be rectangular, as shown in Figure 3 b).

If data are unavailable from the manufacturer, the default values given in 7.11.4 shall be used.

7.11.4 Default values for fittings and joints

The default values for the short-term biaxial strength ratio, r, for fittings and joints are given in Table 4.

NOTE 1 The value of r for plain pipe should always be available from the manufacturer. A typical value for 55° filament-wound glass epoxy pipe is about 0,4, but may be lower for other resin systems and wind angles.

If r is less than 1, the shape of the failure envelope is as shown in Figure 2.

If r is greater than 1, the shape of the failure envelope is rectangular, as shown in Figure 3 a) or Figure 3 b).

NOTE 2 If r is less than 2, e.g. adhesive bond, the joint is limited by axial tensile strength.

Table 4 — Values for the short-term biaxial strength ratio, r, for joints and fittings

Component	Short-term strength biaxial strength ratio r[a]
Fittings:	
Bends: filament-wound unidirectional 90° and $\pm\,\theta°$	0,45
Bends: filament-wound and hand lay	1
Bends: 100 % hand-lay	1,9
Tees: filament-wound and hand lay	1
Other hand-laminated: CSM/WR	1,9
Joints:	
Spigot/socket: adhesive or mechanical connection	1
Threaded	0,45
Flange	1
Laminated	2,0

[a] A higher factor may be used for r if justified by testing in accordance with 6.2.6 in ISO 14692-2:2002.

8 Stress analysis

8.1 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.

As the pipe diameter increases, the pipework tends to become less flexible and the stress intensification factors at bends and tees increase.

8.2 Analysis requirements

8.2.1 General

The designer shall evaluate the total piping system, inclusive of system criticality and risk of failure due to operating/material factors, in order to assess the need for flexibility/stress analysis. At large diameters, the design of the pipe may be determined more by the support conditions than the internal pressure conditions. Anchor (support) loading shall be checked for acceptability. The information listed in 8.2.2 and 8.2.3, as a minimum, shall be obtained before performing flexibility/stress analysis.

NOTE 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.

8.2.2 Installation and design parameters

These parameters include:

a) design and working pressure of the pipe;

b) design and working temperature of the pipe;

c) mass per unit length of pipe component contents;

d) valve types and masses of all valves and other in-line items;

e) routing dimensions;

f) environmental loadings;

g) magnitude of possible support displacement during lifting operations;

h) magnitude of support displacement caused by hull flexure of mobile facilities;

i) acceleration forces and displacements caused by motion of mobile facilities.

8.2.3 Component properties

These properties include:

a) diameter and wall thickness for all parts of the system;

b) mass per unit length of empty component;

c) axial and hoop expansion coefficient of pipe material;

d) axial and hoop modulus of elasticity of pipe material;

e) Poisson's ratio (axial and hoop);

f) stress intensity factors (S_f) of fittings and bends;

g) flexibility factors of fittings and bends;

h) pressure stress multipliers;

i) allowable stress(es) for the material.

Annex C gives further information about the material properties. The application of stress intensity factors (S_f), flexibility factors, and pressure stress multipliers shall be in accordance with Annex D, or in accordance with procedures agreed with the principal.

8.3 External pressure/vacuum

The designer shall ensure that, where possible, vacuum conditions can be sustained by the selected component.

The external collapse pressure, p_c, in megapascals, of GRP pipes shall be calculated by the following equation which assumes that the length of the pipe is significantly greater than the diameter:

$$p_c = 2\left(\frac{1}{F_e}\right) \cdot E_h \left(\frac{t_r}{D}\right)^3 \tag{25}$$

where

- D is the mean pipe diameter of reinforced wall, in millimetres, = $(D_i + 2t - t_r)$;
- t_r is the average reinforced wall thickness, in millimetres;
- t is the nominal wall thickness, in millimetres;
- D_i is the pipe inner diameter, in millimetres;
- E_h is the hoop modulus, in megapascals;
- F_e is the safety factor as defined in 7.6.3.

For thick and sandwich construction walls, the hoop bending modulus should be used in preference to the hoop tensile modulus.

The axial stresses, if compressive, shall be checked with the allowable stresses and checked with the axial buckling criteria given in 8.7.1 and 8.7.2.

8.4 Thermal loading

Thermally induced loads associated with the maximum operating or ambient temperature range shall be allowed for in the design.

When considering heating or cooling of the uninsulated pipe wall by the fluid contained within the pipe, the mean temperature change of the pipe wall to be used for stress analysis purposes should be calculated using Equation (26).

$$\Delta T_{\text{eff}} = k\,\Delta T_{\text{pa}} \tag{26}$$

where

ΔT_{eff} is the effective design temperature change to be used for stress analysis, in degrees Celsius;

ΔT_{pa} is the temperature difference between ambient temperature and the process design temperature, in degrees Celsius;

k is a factor to account for the low thermal conductivity of GRP (i.e. the average wall temperature of the pipe is always less than the design temperature because of GRP's low thermal conductivity). In the absence of further information, k should be taken as 0,85 for liquids and 0,8 for gases.

The axial stresses shall be checked with the allowable stresses and when the stress is compressive, the stresses shall be checked with the axial buckling criteria given in 8.7.1 and 8.7.2.

8.5 Stresses due to internal pressure

The hoop stress, in megapascals, due to internal pressure for plain pipe shall be calculated using Equation (27):

$$\sigma_{\text{hp}} = \frac{p \cdot D}{2 \cdot t_{\text{r}}} \tag{27}$$

where

p is the pressure, in megapascals;

D is the mean pipe diameter of reinforced wall, in millimetres, = $(D_{\text{i}} + 2t - t_{\text{r}})$;

D_{i} is the pipe inner diameter, in millimetres;

t is the nominal wall thickness, in millimetres;

t_{r} is the average reinforced wall thickness of the pipe, in millimetres.

The equivalent hoop stress, σ_{hp}, for fittings shall be calculated using Equation (28):

$$\left(\frac{\sigma_{\text{hp}}}{p}\right)_{\text{fitting}} = \left(\frac{\sigma_{\text{hp}}}{p}\right)_{\text{pipe}} \tag{28}$$

The axial stress, in megapascals, due to internal pressure for plain pipe shall be calculated using Equation (29):

$$\sigma_{\text{ap}} = \frac{p \cdot D}{4 \cdot t_{\text{r}}} \tag{29}$$

8.6 Stresses due to pipe support

The designer shall consider the effect of contact stresses at the support of large-diameter liquid-filled pipes, which become more significant with increasing diameter and D/t ratio. The calculation of axial stresses for pipes of diameter more than 0,6 m shall be in accordance with Annex E, or in accordance with procedures agreed with the principal. The magnitude of the stresses can be reduced by the application of local reinforcement at the supports and use of an elastomeric pad to reduce the rigidity of the support conditions.

For gas service and small- and medium-diameter pipes for liquid service, the support stresses are considered insignificant compared to the bending stresses at mid-span. The magnitude of the axial stresses shall be calculated in accordance with Equations (30) and (31) and checked with the appropriate allowable stresses. If the stress is compressive, the stresses shall be checked with the axial buckling criteria given in 8.7.1 and 8.7.2.

Considering a single span simply supported, the additional axial tensile stress due to self-mass induced through bending, σ_{ab} in megapascals, of the GRP pipe shall be calculated using Equation (30).

$$\sigma_{ab} = \frac{M_i\left[(D_i + 2t)/2\right]}{I_p \times 10^6} \tag{30}$$

where

I_p is the second moment of area about an axis through the centroid normal to the pipe axis, in metres^4 (m^4);

$= \frac{\pi}{64}\left[(D_i + 2t)^4 - D_i^4\right]$ which for thin-walled pipes $= \pi D^3 t_r / 8$

D is the mean pipe diameter of reinforced wall, in metres = ($D_i + 2t - t_r$);

D_i is the pipe inner diameter, in metres;

t is the nominal wall thickness, in metres;

t_r is the average reinforced wall thickness, in metres;

M is the bending moment due to dead weight, one- and two-span beam, in newton metres;

$= \rho_o \times 9{,}81 \times L_s^2 / 8$

where

L_s is the support span, in metres;

ρ_o is the combined pipe and fluid linear mass, in kilograms per metre = $\rho_{eff} \cdot \frac{\pi D_i^2}{4}$

where

ρ_{eff} is the effective density of the combined fluid pipe material, in kilograms per cubic metre = $\left(\rho_L + 4\frac{\rho_c t}{D_i}\right)$;

ρ_c is the density of GRP, in kilograms per cubic metre;

ρ_L is the density of fluid within the pipe, in kilograms per cubic metre (kg/m^3).

NOTE Equation (30) ignores the effect of the pressure profile produced by the head of fluid within the pipe.

The total axial stress, $\sigma_{a,bp}$, in megapascals, due to internal pressure and bending due to self-mass at the bottom and top of the pipe is given by Equation (31).

$$\sigma_{a,bp} = \frac{p \cdot D}{4 \cdot t_r} \pm \sigma_{ab} \tag{31}$$

The equations used for calculating the deflection due to dead weight (pipe and fluid mass) shall be

$$\delta = (5 \times \rho_o \times 9{,}81 \times L_s^4 \times 10^{-3})/(K_s \times E_a \times I_p) \tag{32}$$

where

δ is the deflection due to dead weight, in millimetres, one-and two-span beam and anchored beam;

K_s is the the support type factor, (dimensionless);

= 384 for single span beam (two supports);

= 925 for two span beam (three supports);

= 1 920 for anchored beam (two fixed supports built-in at both ends);

E_a = axial flexural (bending) modulus at design temperature, in megapascals.

8.7 Axial compressive load (buckling)

8.7.1 Shell buckling

The axial elastic buckling stress, σ_u, in megapascals, for a cylinder in pure bending may be taken as:

$$\sigma_u = 0{,}90 \times \beta \frac{E_{eff} t_r}{D} \tag{33}$$

where

D is the mean pipe diameter of reinforced wall, in metres = $(D_i + 2t - t_r)$;

D_i is the pipe inner diameter, in metres;

t is the nominal wall thickness, in metres;

t_r is the average reinforced wall thickness, in metres;

$E_{eff} = \sqrt{E_a \cdot E_h}$

E_a is the axial modulus, in megapascals;

E_h is the hoop modulus, in megapascals;

β = $0{,}188\,7 + 0{,}811\,3 \beta_0$

The value β_0 is obtained from:

$$\beta_0 = \frac{0{,}83}{\sqrt{0{,}1 + 0{,}005(D_i / t_r)}} \tag{34}$$

The ratio of the buckling stress to the maximum axial stress shall be greater than 3.

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

8.7.2 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 in metres, the axial compressive load should not exceed $F_{\mathrm{a,max}}$ in newtons, defined using the following formula where the moment of inertia has been approximated to $\pi D^3 t_\mathrm{r} / 8$.

$$F_{\mathrm{a,max}} = \frac{\pi^3 D^3 t_\mathrm{r}}{8L^2} E_\mathrm{a} \times 10^6 \qquad (35)$$

where

E_a is the axial modulus, in megapascals;

L is the length of unsupported pipe, in metres;

D is the mean pipe diameter of reinforced wall, in metres $= (D_\mathrm{i} + 2t - t_\mathrm{r})$;

D_i is the pipe inner diameter, in metres;

t is the nominal wall thickness, in metres;

t_r is the average reinforced wall thickness, in metres;

The equivalent buckling stress, in megapascals, is given by Equation (36).

$$\sigma_\mathrm{u} = \frac{F_{\mathrm{a,max}}}{\pi D \cdot t_\mathrm{r}} \times 10^{-6} \qquad (36)$$

The ratio of the buckling stress to the maximum axial stress shall be greater than 3.

9 Fire performance

9.1 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 pipe to reduce or eliminate the fire threat;

— use of alternative materials;

— 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.

Guidance on the influence of piping layout on the fire performance of the system is given in 5.7. The effect of blast overpressure is treated in 7.6.1.

9.2 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 pipe.

The fire endurance of GRP piping components shall be determined using the appropriate method in Annex E of ISO 14692-2:2002 as agreed between the principal and the authority having jurisdiction. Guidance on the quantification of appropriate fire endurance properties is given in Annex F.

The designer shall also take into consideration the following factors:

a) orientation of the piping and fittings;

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

c) possibility of the formation of steam traps within the pipe, 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 could subject the pipe to additional stresses;

g) length of support span compared to the length used to qualify the fire performance in Annex E of ISO 14692-2:2002. 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.

The designer shall assign the required fire performance of the piping system according to the fire resistance classification code designated by a three-field number given in Table 7 of ISO 14692-2:2002. Here, service function A, fire type B and performance C are assigned prescribed levels in decreasing order of severity. For completeness, the fire classification code includes service conditions which may be outside the scope of this part of ISO 14692. It is not necessary for the entire piping system to have the same fire classification. The designer may assign more than one fire classification code requirement according to location, etc. Examples of classification codes are given in F.7. The design of a GRP pipe system that has no fire-protective coating and which is intended to function in a fire shall include provision for loss of structural wall thickness.

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

For non-fire-protected water service pipe, 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 pipe. 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 pipes 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.

9.3 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.

Guidance on the quantification of appropriate fire reaction properties is given in Annex F. The designer shall assign the required fire performance of the piping system according to the classification code given in Table 8 of ISO 14692-2:2002. The fire reaction classification code is designated by a two-field number, where spread of fire and heat release D, and smoke and toxicity E are assigned prescribed levels in decreasing order of severity. It is not necessary for the entire piping system to have the same fire classification. The designer may assign more than one fire classification code requirement according to location etc.

9.4 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 should 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 should 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 pipe construction. On-site application of such material shall be limited to that required for installation purposes, e.g. field joints. If a fire-protective coating is used for the sole purpose of meeting the fire endurance requirements, the pipes may be coated on-site in accordance with the approved procedure for each combination, using the approved materials of both pipes and insulation, subject to on-site inspection and verification.

10 Static electricity

10.1 General

The presence of GRP, in common with all other insulating and non-earthed conducting materials, provides an enhanced risk for the generation and accumulation of electrostatic charge. However the risks from an insulating surface depend on its geometry, and the risk from a narrow cylinder is much less than that from a flat sheet of the same area. Cables, GRP handrails, etc. are of small diameter, whereas GRP pipes can be large and more sheet-like. Unlike structures, pipes made from GRP and other insulating materials are also capable of generating electrostatic charge on the inside of the pipe. Consequently electrostatic charges can be generated both on the inside and outside of GRP pipes and give rise to external discharges that could ignite a flammable atmosphere in the region surrounding the pipe. This is more likely if there are non-earthed conducting objects such as couplings present on the pipe. Energetic discharges can also occur inside insulating pipes, and care should be taken when operating a pipe that is only partially filled and may contain a flammable vapour. Sparks from subsequent discharging can also puncture pipe walls, produce shocks and affect the performance of personnel. Personnel coming into contact with highly charged GRP pipe can convey electrostatic charge into a hazardous area.

Consideration during design should therefore be given to these hazards, if GRP piping systems

a) are used to carry fluids capable of generating electrostatic charges;

b) come into rubbing contact with insulating materials;

c) are used in hazardous areas.

10.2 Classification code for control of electrostatic charge accumulation

Table 5 summarizes the electrical conductivity, electrostatic dissipative and resistance to earth performance requirements defined in 10.4. The X component of the X/Y classification code for the electrical properties of GRP piping components is given in Table 9 of ISO 14692-2:2002. The Y parameter has a value of either 1 or 0, depending on whether the requirements of continuity across the joint are satisfied, see 10.9.

GRP pipe system components that are designed to be electrically conductive should meet the classification code requirements of C1a, C2a, C3 or C4. Codes C5 and C6 provide performance parameters that could be used as input to a risk assessment and are intended for use with GRP pipe system components that were not designed to be electrically conductive. The classification codes C7 and C8 allow the use of pipe components that do not meet the requirements of C1 to C6 on a case-specific basis if agreed with the principal and authority having jurisdiction.

10.3 Mitigation options

If no significant electrostatic hazard is identified and the GRP piping does not pass through a hazardous area, there shall be no requirement for the GRP piping to be made electrically conductive, have electrostatic dissipative properties or to be earthed. There shall be no requirement to carry out 10.5 to 10.9.

If the piping passes through a hazardous area, the designer shall either

— require all GRP piping to be electrically conductive, codes C2a and C1a, regardless of the fluid being conveyed. The resistance to earth from any point in the piping system shall not exceed $1 \times 10^6\ \Omega$. There shall be no need to carry out the requirements in 10.5 to 10.9.

NOTE 1 The above reproduces the requirements of IMO Resolution A.753(18) [11], see G.1.

or

— apply the risk-based approach given in 10.5 to 10.9. This may result in more than one performance standard, depending on whether the source of electrostatic accumulation is due to charge-generation mechanisms inside or external to the pipe component. *Where this occurs, the more severe performance requirement shall apply.* Further guidance about the factors that determine the requirements for electrical conductivity and resistance to earth of GRP piping components is given in Annex G.

NOTE 2 The predominant source of electrostatic incendive discharge from GRP piping is likely to arise from electrically isolated unearthed metal objects attached to the GRP piping, rather than the GRP material itself.

NOTE 3 Where external electrostatic-generation mechanisms are of concern, the risk approach taken is no different to that which ought to be applied to all electrically isolated non-GRP piping components and structures located within the same vicinity.

NOTE 4 The risk of electrostatic discharge due to external charge-generation mechanisms is in many cases theoretical and may require a set of circumstances to coincide for an event to occur. Therefore the presence of GRP piping may not necessarily result in any significant enhanced risk of an incendive discharge beyond that which might normally be expected for the facility.

10.4 Design and documentation requirements

The designer shall identify and document the electrical conductivity, electrostatic dissipative and earth linkage requirements for the piping system located in hazardous areas as required in accordance with 10.3 and 10.10. The requirements shall apply to GRP pipes and GRP pipes that have a permanent outer coating. Other considerations may apply to GRP pipe that is clad with a removable covering material, e.g. insulation, see G.7.

This information shall be made available to the installer and operator. If pipe has been qualified according to its surface resistivity C5, charge shielding C3, or charge decay C6 properties, the designer shall identify whether these properties need to be verified during installation or operation.

Table 5 — Electrical conductivity, electrostatic dissipative and earthing requirements as a function of service conditions in hazardous areas

Service conditions	*X* parameter of *X/Y* conductivity code	Resistance to earth
Internal charge-generating mechanisms		
Pipe components that may contain a fluid with an electrical conductivity more than 10 000 pS/m and in which highly charged droplets are unlikely to form (see 10.5.3 and 10.5.4).	No conductivity requirement.	Fluid contents earthed to $10^6\ \Omega$ at a minimum of one point in the line.
Pipe components that may contain highly charged droplets of a fluid with an electrical conductivity more than 10 000 pS/m (see 10.5.2, 10.6.4 and 10.6.9).	C1a, C2a, or C3. See Note.	Fluid contents earthed to $10^6\ \Omega$ at a minimum of one point in the line. All isolated metal objects of significant size earthed to $10^6\ \Omega$.
Pipe components that may contain a flammable environment, i.e. only partially full, where the fluid has an electrical conductivity less than 10 000 pS/m (see 10.6.5 and 10.6.9).	C1a preferred but C2a and C3 acceptable. See Note.	Fluid contents earthed to $10^6\ \Omega$ at a minimum of one point in the line. All isolated metal objects of significant size earthed to $10^6\ \Omega$.
Pipe components that contain a flowing fluid with a velocity of more than 1 m/s and an electrical conductivity less than 10 000 pS/m (see 10.6.4 and 10.6.9).	C1a, C2a or C3. See Note.	Fluid contents earthed to $10^6\ \Omega$ at a minimum of one point in the line. All isolated metal objects of significant size earthed to $10^6\ \Omega$.
Pipe systems of less than 10 m length that contain a flowing fluid with a maximum flow velocity of less than or equal 1 m/s and an electrical conductivity less than 10 000 pS/m (see 10.6.7 and 10.6.8). Pipe systems more than 10 m long, particularly those that contain microfilters at the upstream end of the line, may be required to meet the requirements of 10.5.4, depending on the outcome of a risk analysis.	No conductivity requirement.	Fluid contents earthed to $10^6\ \Omega$ at a minimum of one point in the line. All isolated metal objects of significant size earthed to $10^8\ \Omega$.
External charge-generating mechanisms		
Pipe components that are at risk from weak external charging mechanisms but unlikely to have a covering of a conductive layer of significant size or to experience strong external charge generation during normal operations (see 10.7.3).	No conductivity requirement.	All isolated metal objects of significant size earthed to $10^8\ \Omega$.
Pipe components that are at risk of exposure to moderate charge-generation mechanisms and which could have a covering of a conductive layer of significant size (see 10.7.4).	C2a See Note.	All isolated metal objects of significant size earthed to $10^8\ \Omega$.
Pipe components that have an identified significant risk from strong external electrostatic charge generation mechanisms during normal operations (see 10.8.4 and 10.8.5).	C2a See Note.	All isolated metal objects of significant size earthed to $10^6\ \Omega$.
NOTE Alternative performance standards acceptable if agreed with the principal and authority having jurisdiction.		

10.5 Pipes that contain a fluid with an electrical conductivity more than 10 000 pS/m

10.5.1 Seawater and crude oil typically comply with these conditions.

10.5.2 If a charged mist can form inside the pipe, the requirements of 10.6 shall apply.

NOTE Conductive liquids cannot accumulate charge inside the pipe unless they are in the form of fine droplets like those a charged mist could form. This is considered extremely unlikely for the situations covered by this part of ISO 14692 and would require the velocity to be very high and/or the diameter of the pipe to be very large.

10.5.3 The inside of the pipe shall be connected to earth at a minimum of one exposed earthing point in the system. If the pipe may not always be completely filled with liquid, the inside of the pipe shall be earthed at the lowest point of the system and at locations where liquid may become trapped.

10.5.4 All isolated metal objects of significant size (see G.4) located on or attached to pipes should preferably have a maximum resistance to earth at any point of $10^6\ \Omega$. Priority should be given to objects that may be in close proximity to both fixed and mobile earthed objects, including personnel, during normal operations.

NOTE This requirement is a precaution to address situations where external charge-generation mechanisms are believed unlikely to occur, and have not been considered in the risk analysis.

10.6 Pipes that contain a fluid with an electrical conductivity less than 10 000 pS/m

10.6.1 Typical examples of such fluids include refined products such as diesel and kerosene.

NOTE See also Note in G.3.1.

10.6.2 The requirements of 10.6.3 to 10.6.6 should also be applied in non-hazardous areas if there is a risk of electric shock to personnel and the possibility of charge being accidentally transferred by personnel into a hazardous area.

10.6.3 The inside of the pipe shall be connected to earth at a minimum of one exposed earthing point in the system. If the pipe may not always be completely filled with liquid, the inside of the pipe shall be earthed at the lowest point of the system and at locations where liquid may become trapped.

10.6.4 GRP piping systems with a linear flow velocity exceeding 1 m/s shall be required to have C1a, C2a or C3 electrical conductivity properties. The use of components with C4 in conjunction with C5, C6 or C7 electrostatic dissipative properties shall be in agreement with the principal and authority having jurisdiction.

NOTE The C3 classification assumes that the maximum voltage generated inside the pipe is less than 50 kV. The designer shall give consideration to modifying the acceptance criterion if information is available to indicate that voltages greater than 50 kV are likely to be generated inside the pipe during service. Conversely it may be acceptable to relax the performance standard if information is available to indicate that voltages much lower than 50 kV are likely to be generated.

10.6.5 Pipes that may contain a flammable environment, i.e. only partially full, should preferably have a maximum value of resistance to earth at any point on the inside of the pipe of $10^6\ \Omega$ (C1a).

10.6.6 If the integrity of the inner layer is important for reasons other than safety, e.g. product quality, and the inner layers of the wall might be vulnerable to puncturing, then the maximum value of resistance to earth at any point on the inside of the pipe should be $10^6\ \Omega$ (C1a).

10.6.7 Pipe systems of less than 10 m length that contain a flowing fluid with a maximum linear velocity of less than or equal to 1 m/s and an electrical conductivity less than 10 000 pS/m shall not be required to be conductive, provided isolated metal components of significant size (see Annex G) have a maximum resistance to earth of less than $10^8\ \Omega$. Pipe systems more than 10 m long, particularly those that contain microfilters at the upstream end of the line, may have to meet the requirements of 10.6.4 depending on the outcome of a risk analysis.

10.6.8 Metal components in the pipeline that provide a direct electrical path between the inside and outside of the pipe shall have a maximum resistance to earth at any point of $10^6\ \Omega$. This resistance may be increased to $10^8\ \Omega$ for pipes satisfying the requirements of 10.6.7.

10.6.9 All isolated metal objects of significant size (see G.4) located on or attached to pipes should preferably have a maximum resistance to earth at any point of $10^6\ \Omega$. Priority should be given to objects that may be in close proximity to both fixed and mobile earthed objects, including personnel, during normal operations. See Note in 10.5.4.

10.7 Pipes exposed to weak/moderate external electrostatic-generation mechanisms

10.7.1 The requirements given in 10.7.3 and 10.7.4 should also apply in non-hazardous areas if there is a significant risk that charge accumulation could be transferred by personnel into a hazardous area.

10.7.2 GRP piping systems with removable cladding material that have exposed or covered isolated metal objects of significant size under the cladding shall also be subject to the requirements of this subclause, see G.7.

10.7.3 Pipe components that are unlikely to have a covering of a conductive layer of significant dimensions or unlikely to experience strong external charge generation during normal operations shall not be required to be conductive, provided they are exposed to only weak external charge-generation mechanisms, e.g. occasional tribocharging and proximity to small tank water wash. All isolated metal objects of significant size (see G.4) should have a maximum resistance to earth of less than $10^8\ \Omega$. Priority should be given to objects that may be in close proximity to both fixed and mobile earthed objects, including personnel, during normal operations.

NOTE Large pipes are more likely to have a sizeable covering of possible conductive material than small pipes.

10.7.4 Pipe components that may be covered with a conductive layer of significant dimensions during service but are unlikely to experience strong external charge generation during normal operations should be required to have electrostatic dissipative properties, classification C2a, provided they are exposed to only weak or moderate external charge-generation mechanisms, e.g. proximity to large tank washing, changing atmospheric fields, frequent tribocharging. If a pipe cannot achieve C2a, a classification of C5 or C6 may be acceptable where agreed with the principal and authority having jurisdiction. All isolated metal objects of significant dimensions (see G.4) located on or attached to pipes should have a maximum resistance to earth of less than $10^8\ \Omega$. Priority should be given to objects that may be in close proximity to both fixed and mobile earthed objects, including personnel, during normal operations.

10.8 Pipes exposed to strong external electrostatic generation mechanisms

10.8.1 GRP piping systems with removable cladding material that have exposed or covered isolated metal objects of significant size under the cladding shall also be subject to the requirements of this subclause, see G.7.

10.8.2 The principal mechanism of concern is the efflux past the pipe of a two-phase fluid, e.g. a gas with condensed droplets, for example from a nearby pipe leaking steam or hydrocarbon. The latter presents a potentially dangerous situation, since a hazardous atmosphere is always present.

10.8.3 As part of the risk assessment, the designer shall take into account the properties of the efflux fluid and its ability to enable charge separation, the pressure driving the efflux, the reliability of fittings and fixtures that could provide a source of leak, frequency of maintenance, the orientation and distance of the source of leak from the GRP pipe, the ventilation available, the distance to the nearest suitable earthed object for a potential incendive discharge and the proportion of time the facility is manned.

10.8.4 All isolated metal components of significant size (see G.4) located on or attached to the pipe at all locations likely to be affected should have a maximum resistance to earth of $10^6\ \Omega$. Priority should be given to objects that may be in close proximity to both fixed and mobile earthed objects, including personnel, during normal operations.

10.8.5 Pipe components that have an identified significant enhanced risk from strong external electrostatic generation mechanisms during normal operations should be electrically conducting classification C2a. If a pipe cannot achieve C2a, a classification of C5 or C6 may be acceptable where agreed with the principal and authority having jurisdiction.

NOTE There is an enhanced possibility of a propagating brush discharge from the GRP surface itself if the GRP pipe contains a conducting fluid and has a wall thickness less than 8 mm. Larger pipes are more likely to provide the capacitance for an incendive discharge than small pipes.

10.9 Continuity of electrical path within piping system

10.9.1 If piping is specified to be conductive, the designer shall consider the nature of the continuity path across the joint and determine the spacing of earth grounding straps accordingly. All components that cannot satisfy the continuity classification $Y = 1$ shall be independently earthed according to the manufacturer's recommendations.

10.9.2 If application of an external conductive paint is required, it is recommended that the coating be applied under factory conditions before the pipe is installed. It is recommended that conductive paint not be applied in the field in regions not readily accessible during service for inspection.

10.9.3 If an external conductive paint is applied, the operator shall be required to monitor the integrity of the coating during service life to ensure that regions of coating do not become isolated from earth.

10.9.4 The operator shall be required to monitor the performance of all earth bonding points during service.

10.9.5 The frequency and method used to assess the integrity of the coating, if applicable, and earth bonding points shall be commensurate with the results of the risk analysis.

10.10 Lightning strike

The use of GRP pipe to convey flammable or dangerous fluids in situations where it could be exposed to lightning strike shall be subject to the outcome of a risk analysis.

11 Installer and operator documentation

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

a) operating and design parameters;

1) design pressure;

2) design temperature;

3) T_g of the resin;

4) qualified pressure of each component;

5) minimum qualified pressure in each piping system;

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

7) chemical resistance limitations, if applicable;

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

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

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

11) 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;

e) inspection strategy.

The inspection strategy for installation and operations shall consider system criticality and accessibility for inspection. Guidance on the factors that need to be considered in the preparation of the inspection strategy is given in Annex H. Guidance on the choice of inspection methods is given in annex E of ISO 14692-4:2002. If acoustic emission testing is required, it shall be carried out in accordance with ASTM E1118. The assessment of the condition of the resin or adhesive should be carried out in accordance with 6.8.2 of ISO 14692-2:2002.

Annex A
(informative)

Guidance for design of GRP piping system layout

A.1 Support types

Supports allowing pipe to move with relative freedom include

a) hangers, which are free to move laterally or longitudinally with the pipe,

b) fixed supports over which the pipe may slide, allowing longitudinal movement and often lateral movement,

c) guides that permit longitudinal and rotational movement of the pipe but restrain lateral movement,

d) anchors, which restrict movements in all directions and divide the pipe system into individually expanding sections.

Hangers are free to move on their hanger rods and include band, ring, clevis or roller types. An orthodox pipe rack made of steel angle is a typical fixed support permitting both longitudinal and lateral movement.

A.2 Support spacing

Supports are designed into a piping system to prevent excessive deflection due to the pipe and fluid mass. When the mid-span deflection is limited to 12,5 mm or 0,5 % of span, the bending stress on the pipeline is normally below the allowable levels of the pipe and fittings. However, in more stringent designs, it may be necessary to use shorter spacing. This can be true if there are a number of heavy in-line components, such as valves, in the system, or if the design pressure or temperature is near the product limit. Once support spacing is calculated, the maximum stress levels should be determined.

A.3 Thermal expansion

The change in length due to thermal expansion for any above-ground piping system should be calculated. The thermal expansion of contact-moulded and filament-wound GRP pipe in the axial direction can vary greatly. The thermal expansion of GRP pipe is a function of the expansion coefficient and temperature change, as well as the total length of the piping system. Thermal expansion coefficients of GRP are approximately constant over their designed temperature use, thus making thermal expansion linear with temperature.

A.4 Pressure expansion

Although generally neglected, axial expansion due to internal pressure can sometimes be equal in magnitude to thermal expansion, due to the low modulus values of GRP pipe. The result is a significant pressure expansion which should be taken into account to achieve accurate results. The magnitude of pressure expansion depends upon the design pressure, the pipe size, wall thickness, and mechanical properties of the product. It is recommended to check the magnitude of pressure expansion and determine if it needs to be included as a factor in the design.

A.5 Controlling expansion with anchors

In the design of GRP piping systems, use should be made of their low axial modulus. One benefit of this mechanical property is the small end loads created from temperature and pressure effects, allowing lighter anchors to be used. For anchor-to-anchor conditions, it is normally not necessary to include pressure expansion in the design, as pressure effects only occur at direction changes. The pressure effects, however, should be evaluated for each design case.

A.6 Controlling expansion with guides

In the pipe wall, compressive forces from expansion may result in buckling, and in general, instability, unless the piping system is properly restrained with guides. Guides are rigidly fixed to the supporting structure to provide pipe support and prevent buckling due to expansion while still allowing the pipe to move in the axial direction. Under normal conditions, the linear expansion of the piping system between anchor points can be controlled without exceeding the allowable axial stress levels of the pipe and fittings.

Guides are recommended for lines that are subject to sideloads or uplift. Examples include lines subjected to pressure surges, lines emptied and filled during operation, and lines which can be lifted or moved (especially when empty) by wind or other external loads.

A.7 Controlling expansion with directional changes

Directional changes, as part of the geometry of the piping system, can alleviate the stresses created due to thermal and pressure expansion. However, the stress levels created in the GRP fittings, specifically elbows, at directional changes should be kept below the allowable bending stress level of the pipe and fittings. The stress level in the pipe and fittings depends on the total change in length and the distance to the first guide or hanger.

A.8 Controlling expansion with expansion loops

An expansion loop (loop of pipe usually C-shaped) is another method used to alleviate stresses due to length changes in the piping system. Expansion loops are generally employed between extremely long straight runs of pipe to alleviate the end loads and buckling between anchors. As with guide spacing for directional changes, the design is usually a simplified approach. Again, the design parameters include thermal and pressure expansions, not just temperature change. Decreasing the moduli to account for the effects of temperature leads to more conservative results, and should be considered in any detailed design.

A.9 Controlling expansion using bellows units

As far as possible, the use of bellows units (flexible pipe connectors) should be limited to applications in which the bellows accommodate expansion axially, i.e. in which they are only compressed/extended. Other methods, e.g. transverse displacement of a single bellows or an articulated bellows system, require special consideration.

Annex B
(informative)

Description and guidance on selection of jointing designs

B.1 General

Various types of bonded and mechanical joints are available for GRP piping. These tend to be proprietary in nature but can generally be categorized into the following types:

a) concentric adhesive-bonded joints;

b) laminated joints;

c) mechanical O-ring bell-and-spigot elastomeric seal joints (with/without locks);

d) flanged joints;

e) other mechanical joints;

f) metallic/GRP interfaces.

For most offshore applications, thrust-resistant types of joints are required, e.g. adhesive-bonded joint, elastomeric bell-and-spigot sealed joints (with locks), laminated joint or flanged joint.

However, for well-supported and anchored piping, non-thrust-resistant systems can be used, e.g. elastomeric bell-and-spigot sealed joints (without locks) or mechanically joined systems.

The designer should take into account the following factors when selecting the jointing method:

— criticality (reliability);

— performance under bending loads;

— installation environment (ease of inspection);

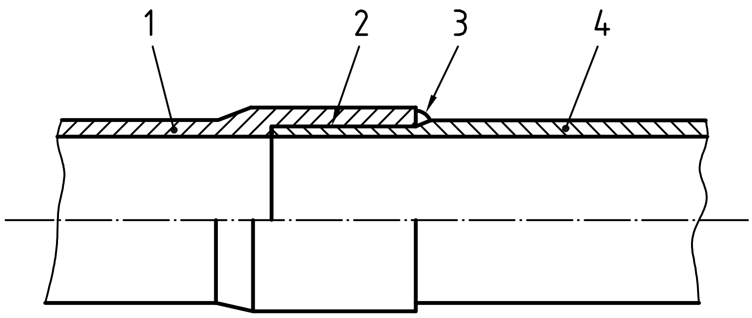
— ease of fabrication.

B.2 Adhesive-bonded joints

The adhesive-bonded joint is a rigid type of joint, which consists of a slightly conical (tapered) bell end and a machined (cylindrical or tapered) spigot end. Alternatively, the bell-and-spigot tapers may be threaded. A typical adhesive-bonded joint is shown in Figure B.1.

Adhesive joints have the lowest material cost of all joints, and are structurally efficient when made up correctly. If a cylindrical spigot is used, the joint is made up to a shoulder. The tapered bell and tapered spigot joint has two matching tapered surfaces and does not make up to a shoulder. The former has the advantage of enabling the position of final make-up to be readily determined. The latter (taper/taper joint) is a stronger joint but is more prone to positional errors if incorrectly assembled, which can weaken the joint.

Make-up of the adhesive joint tends to become more difficult for larger sizes, particularly for pipe above 450 mm diameter. A concern is the size of the adhesive bead that is created when the joint is made up and which could protrude into the bore of the pipe. This could create a substantial blockage factor as well as provide a source for erosion and cavitation damage.



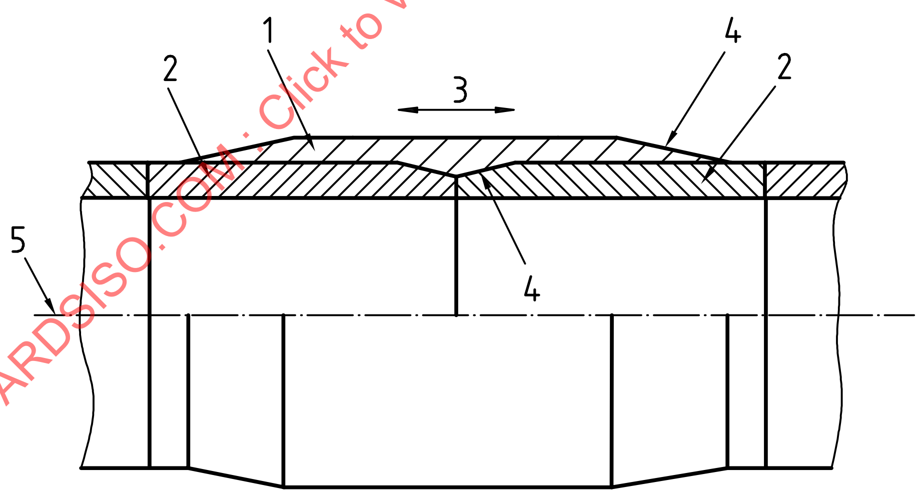
Key

1 pipe with integral socket end
2 adhesive
3 finishing fillet
4 pipe with spigot end

Figure B.1 — Typical adhesive-bonded joint

B.3 Laminated joints

The laminated joint consists of plain-ended pipe and fittings, prepared, aligned and laminated with reinforcing fibres and resin/hardener mixture as shown in Figure B.2. There are two types of laminated joint: the outer surface of the pipe can be either lightly abraded leaving a cylindrical surface, or else abraded to provide a taper. Laminated joints require a high degree of craftsmanship and their use on-site should be minimized. Lamination of pipes for a pipe spool assembly at a prefabrication shop or at a manufacturer's facility is recommended.



Key

1 laminate overlay
2 pipe laminate
3 laminate length
4 tapers not steeper than 1 in 6
5 pipe centreline

Figure B.2 — Typical laminated joint

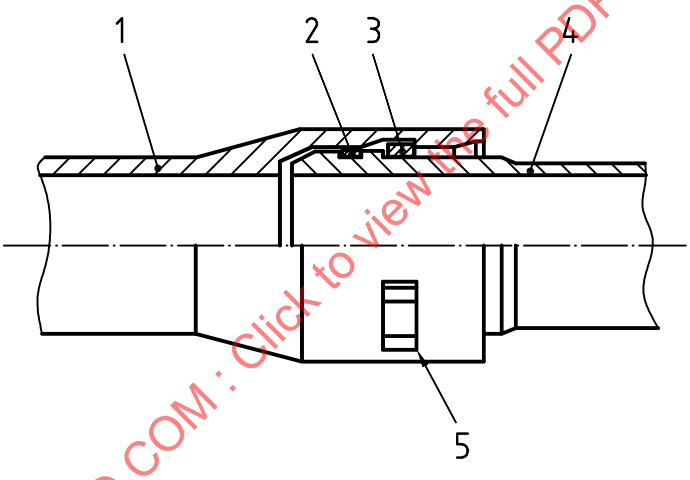
The joint has the advantage over adhesive joints that preparation of the joint is from the outside only and the relative positioning of the two butt ends is less critical. For field joints (hook-up joints), laminated joints should be considered due to their flexibility to accommodate minor misalignments.

B.4 Mechanical O-ring elastomeric bell-and-spigot seal lock joints

Elastomeric bell-and-spigot seal lock joints are made up of a spigot end and a socket end with O or lip sealing rings. The socket may either be an integrated part of the pipe (single socket), or a separate item (double socket). A double socket is used for joining two pipes both with spigot ends. Joints with two or more O-rings may be used. Elastomeric seal joints allow for some axial movement as well as a certain amount of angular deflection. If a tensile-resistant joint is required, a locking strip can be incorporated as shown in Figure B.3.

These are the simplest joints to assemble and they can be designed to enable a small amount of axial and angular movement within the joint. They are cheaper and generally structurally more efficient than flanged joints, but more expensive than adhesive joints. They are more bulky than adhesive joints, but have the advantage that they can be quickly assembled in poor working conditions and are the preferred joint for concrete gravity-base system piping and ballast transfer piping in ships.

The joint is also used for pump riser columns, where a keyway is added in the axial direction of the joint to enable the transfer of torque.



Key

1 pipe with integral socket end

2 elastomeric ring

3 locking strip

4 pipe with spigot end

5 insert hole for locking strip

Figure B.3 — Typical elastomeric bell-and-spigot sealed joints (locking type)

B.5 Flanged joints

Flanged joints facilitate connections with steel piping and allow easy assembly and disassembly of piping systems. The outside diameter and hole spacing of flanges should meet the requirements of either ISO 7005-3 [4] or, via ISO 15649 [5], of ASME B16.5 [6]. GRP flanges are always flat-faced and, accordingly, matching flanges should also be flat-faced.

Two types of flanges are commonly used:

— fixed-type flanges, adhesive-bonded or laminated to the pipe ends;

— loose ring-type flanges, with GRP collars adhesive-bonded or laminated to the pipe ends with loose backing flanges in GRP or steel.

Connecting bolts should always be used with washers on both flange faces, and consideration should also be given to the use of backing plates to avoid damage to the GRP on torquing the bolts.

Generally the use of flanged joints should be avoided if possible, since composite flanges are very sensitive to bad alignment and overtorquing of bolts. If possible, the use of heavy-duty flanges should also be avoided and should not be specified to compensate for the possibility of inadequate quality control during installation, since they significantly add to cost, mass and fitting length.

B.6 Threaded connections

Three types of threaded connection are available for both high- and medium-pressure GRP pipe systems:

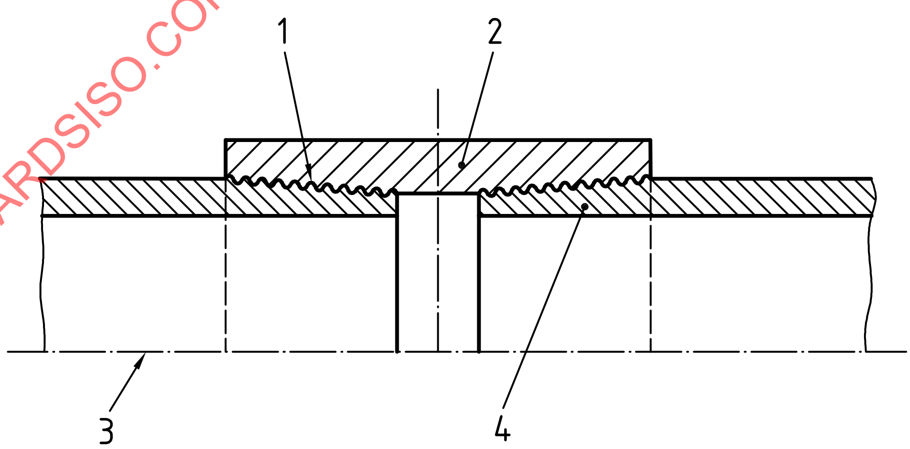
a) male/male joint, using a coupler with standard API threads (e.g. EUE 10RD, EUE 8RD, so-called round threads), see Figure B.4;

b) female/male threaded “integral” joint with standard API threads and sealing via the threads using PTFE tape and/or special compounds, as recommended by the manufacturer, see Figure B.5;

c) female/male coarse threaded “integral” joint, including O-ring for sealing, see Figure B.6.

To reduce friction and enhance sealing performance, thread fillers may be used, e.g. graphite and/or ceramic particles. PTFE-based lubricants may also be used to reduce friction, i.e. to facilitate low make-and-break torque.

Threaded end connections which conform to API standards should meet the requirements of API Spec 15HR [18]. Threaded end connections which are the design of the manufacturer should meet the specification, e.g. manufacturing quality, surface finish, etc., of the manufacturer.



Key

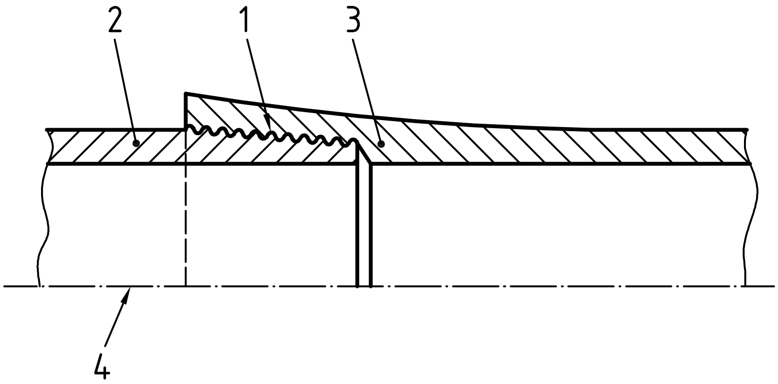
1 standard API threads

2 female thread connector

3 pipe centreline

4 pipe laminate

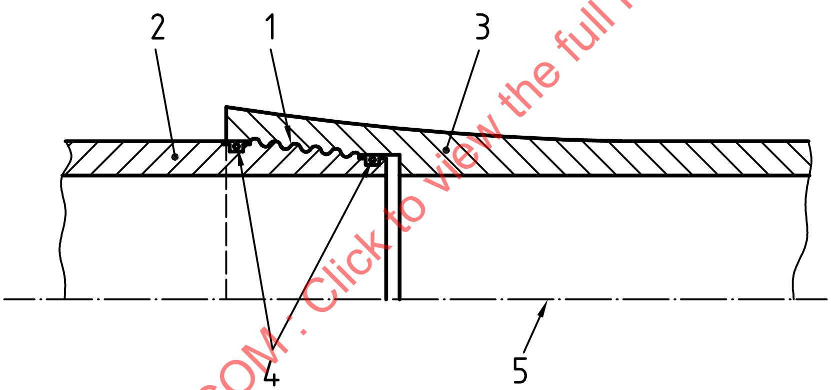
Figure B.4 — Standard API joint



Key

1 standard API threads
2 pipe body – male end
3 pipe body – female end
4 pipe centreline

Figure B.5 — Integral joint (API thread)



Key

1 coarse thread
2 pipe body – male end
3 pipe body – female end
4 O-ring seals
5 pipe centreline

Figure B.6 — Integral thread (coarse thread + O-ring seals)

B.7 Other mechanical joints

Various proprietary mechanical joints or couplers are available for GRP piping. Reference should be made to the manufacturer's data for guidance on use.

Annex C
(informative)

Guidance on material properties and stress/strain analysis

Manufacturers generally optimize the performance of GRP pipes for the internal pressure 2:1 hoop:axial stress ratio condition. This implies that the material behaviour is anisotropic and therefore the hoop modulus is greater than axial modulus.

The material properties, and their symbols, for GRP pipes/piping systems relevant for system design are:

Symbol	**Material property**
E_a	Young's modulus in the axial direction
E_h	Young's modulus in the hoop direction
ν_{ha}	Poisson's ratio, axial to hoop strain resulting from a stress in the hoop direction
ν_{ah}	Poisson's ratio, hoop to axial strain resulting from a stress in the axial direction
G_{shear}	Shear modulus
α_a	Coefficient of thermal expansion in the axial direction
α_h	Coefficient of thermal expansion in the hoop direction

where $\frac{\nu_{ha}}{E_h} = \frac{\nu_{ah}}{E_a}$

Typical values for the above-mentioned properties for 55° filament-wound glass-fibre-reinforced matrix pipe with a glass volume fraction of 55 % for epoxy, vinyl ester and polyester resins are given in Table C.1:

Table C.1 — Typical material properties

Material property	Value
E_a	12 000 MPa
E_h	22 000 MPa
ν_{ha}	0,55
ν_{ah}	0,30
G_{shear}	11 000 MPa
α_a	18 µm/m·°C
α_h	13 µm/m·°C

The relevant strains and stresses, and their symbols, for system design of GRP pipes/piping systems are:

Symbol	**Stress/strain**
ε_a	Strain in axial direction
ε_h	Strain in hoop direction
γ	Shear strain (in-plane)
σ_a	Stress in the axial direction
σ_h	Stress in the hoop direction
τ	Shear stress (in-plane)

The strains for a given applied stress are given by:

$$\varepsilon_a = \frac{\sigma_a}{E_a} - \nu_{ha}\frac{\sigma_h}{E_h}$$

$$\varepsilon_h = -\nu_{ah}\frac{\sigma_a}{E_a} + \frac{\sigma_h}{E_h}$$

$$\gamma = \frac{\tau}{G_{shear}}$$

Conversely, the stresses for a given applied strain are given by:

$$\sigma_a = \frac{E_a}{(1 - \nu_{ha}\nu_{ah})}(\varepsilon_a + \nu_{ha}\varepsilon_h)$$

$$\sigma_h = \frac{E_h}{(1 - \nu_{ha}\nu_{ah})}(\varepsilon_h + \nu_{ah}\varepsilon_a)$$

$$\tau = G_{shear} \cdot \gamma$$

Annex D
(normative)

Guidance on flexibility analysis

D.1 Overview and definitions

The following system design guidance provides an explicit means of deriving the imput parameters for the design allowances for filament-wound pipe and associated fittings. It is based on the use of the test data obtained by the vendor as part of the product qualification process and experience of how filament-wound laminates behave under combined loadings. The procedure involves the evaluation of allowed design envelopes for different load cases. A principle adopted during the development of the procedure was that it should not impose an additional test burden onto the component suppliers.

In the context of other codes, ISO 14692 should be regarded as a development of the UKOOA document[19]. The treatment and definition of system load cases, sustained, occasional, follows that used by ASME B31.3[20]. For system design parameters, flexibility factors, stress intensity factors and pressure stress multipliers, BS 7159 has been an important source of information. The fundamental difference between ISO 14692 and other documentation is that it specifies that products be offered and qualified on a performance basis.

This poses certain technical challenges when developing a method to establish parameters for design calculations, as the integrity of the components themselves has not been demonstrated by design but through testing.

For straight pipe, the procedure is conceptually straightforward, as there is normally sufficient data to construct a baseline short-term envelope for system stresses. Allowed design envelopes can then be developed by scaling from this baseline (it is the validity of this scaling which is the key technical assumption).

For fittings, however, the situation is less straightforward as explained by the following.

— The stress distribution for parts under pressure is complex and not limited to a simple membrane. For many components local bending will be the dominant component of stress. This issue is, for certain components, catered for in design by the use of a pressure stress multiplier (m_{psb}).

— The material of construction and manufacture method are different in fittings compared to straight pipe. The constraints of geometry mean that lay-ups will be different and, although the resin and glass reinforcement will be the same, the details of construction, winding angle, fibre fraction, etc. will vary. This means that mechanical properties such as strength and the degree of anisotropy will be different.

— The thickness of the laminate will vary markedly with position due to the application of material over $2D$ curvatures. For example, bends will be considerably thicker in the intrados compared to the extrados. This effect adds markedly to the complexity of the stress system.

The guidance adopted is to use the concept of “equivalent stress”. This is a means of equating fitting performance to that of straight pipe so that an allowed “equivalent” design stress may be developed. It is not a means of calculating the *actual* stress in the part, which in itself will be highly variable and not simple to compute. The “equivalent stress” is derived on the basis that qualification testing will have demonstrated that the fittings have a pressure rating at least as high as the associated straight pipe.

This guidance represents the state of the art at the time of publication and is based on empirical data obtained[7] on pipes up to 0,3 m diameter. However, the accuracy of the stress calculations obtained using the methods described in this annex cannot be guaranteed, and alternative calculation procedures shall be acceptable if agreed with the principal. These include for example the use of finite element analysis techniques and procedures based on experience.

For the purposes of this annex, the following terms and definitions apply.

D.1.1
stress intensification factor
S_f
ratio of the actual/effective stress in a component/fitting under external load to the nominal stress in that fitting as determined based on a straight pipe run with the same section modulus and Young's modulus

D.1.2
flexibility factor
κ
ratio of the flexibility in bending of a component/fitting to the flexibility of a straight pipe of the same lamination, Young's modulus and thickness with a length corresponding to the developed length of the fitting

D.1.3
pressure stress multiplier
m_{psb}
fractional increase in hoop stress loading due to applied internal pressure acting on the fitting

NOTE The above definitions relate the flexibility stress intensification factors of a bend or tee to the flexibility of a pipe made of the same material and with the same diameter and wall thickness. In a conventional steel pipe system, the pipe bend and the pipe are usually of the same material and dimension. In GRP systems, the pipe and bend are usually separate parts that are adhesively bonded or laminated together. Material, layup and dimensions can differ between the bend and the pipe; in particular, the bend walls are thicker. The factor of increase in thickness is typically in the range of two to five, depending on diameter and pressure rating.

For GRP, little experimental evidence is available to substantiate the definition of S_f values. Recent studies made by SINTEF [7] indicate that S_f values and flexibility values as indicated in BS 7159 do not comply with their experimental results for recent designs of filament-wound GRP piping.

Given the debate related to the S_f values as included in BS 7159 and the lack of other well-established data, the following information shall be used for the definition of the S_f and flexibility factors. These are based on figures that have been used in a large number of analyses and have proven to be satisfactory.

For piping systems made with non-filament-wound fittings and/or pipe, it is acceptable for the user of this part of ISO 14692 to refer directly to BS 7159 in preference to this annex.

Reference shall be made to BS 7159 for the specific factors of the flexibility analysis for diameters larger than 0,5 m.

D.2 Flexibility analysis

D.2.1 General

There are two areas of flexibility analysis that specifically require judgement by the design engineer. First, the model of the piping system should be conceived in such a way as to reflect the actual behaviour of the piping system. Many good modelling techniques are common to both isotropic and anisotropic piping systems, although some are unique to anisotropic systems.

The second area that requires judgement is the interpretation of the results obtained from a flexibility analysis. When steel pipe is used, there are well-defined allowable stress levels for the various grades of steel available. However, for GRP piping there is a wide range of laminates available and definition of the allowable stress is far more complex.

D.2.2 Bends

D.2.2.1 General

The response of bends to pressure and thermally induced axial and bending loads is more complex than the equivalent loads on a straight pipe. Application of a bending moment causes ovalization, resulting in both induced axial and hoop stresses. The ratio of the induced hoop to axial stresses resulting from bending can for example range between 2,1 and 2,8, depending on whether the direction of loading is in-plane or out-of-plane. Therefore, stresses within bends and their direction become complex and cannot easily be related to applied pressure and tensile loads.

The potential of applied pressure and bending loads to induce axial as well as hoop stresses results in a conservative approach to defining the long-term strength of a GRP bend. The long-term axial strength is taken as one-half the long-term strength at the 2:1 condition (axial stress). This is the same conservative approach to system design of straight pipes.

The following empirical relationships for flexibility factor, stress intensification factors and pressure stress multipliers are based on BS 7159. The assumptions and restrictions of the empirical formulae shall be considered when using these relationships in a piping system design. In particular, attention shall be paid to the wall thickness of the adjoining pipe. In the derivation of empirical correlations for flexibility factor, pressure stress multipliers and stress intensification factors, it is assumed that the maximum wall thickness of the bend is 1,75 times the wall thickness of the pipe.

NOTE In terms of laminate types as described in BS 7159, only type 3 filament-wound laminates are considered.

D.2.2.2 Flexibility factor (κ_b)

The calculations given below 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 pipe 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, κ_b, for GRP bends is based on the pipe factor, λ_b, and the axial pressure correction factor, δ_a, due to the effect of internal pressure.

λ_b is given by:

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

where

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

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

R_b is the mean pipe bend radius, in millimetres.

See Table D.1 for details.

NOTE 1 The wall thickness, t_b, of the reference laminate is defined as the wall thickness of the equivalent pipe section used for modelling purposes in the piping system design calculations.

δ_a is given by:

$$\delta_a = \frac{1}{\left[1 + \left(2{,}53\, p / (E_{h,bend}) \cdot (R_b / t_b)^{1/3} \cdot (D_i / 2t_b)^2\right)\right]} \tag{D.2}$$

where

p is the applied pressure, in megapascals;

$E_{h,bend}$ is the hoop modulus of the bend, in megapascals;

The flexibility factor for smooth bends is given as a function of λ_b, see Table D.1:

$$\kappa_b = \delta_a \cdot \frac{0{,}7}{\lambda_b} \cdot \frac{E_{a,pipe} \cdot t_{pipe}}{E_{a,bend} \cdot t_b} \tag{D.3}$$

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

The flexibility factor for mitred bends is given as a function of λ_b, see Table D.1:

$$\kappa_b = \delta_a \cdot \frac{0{,}64}{(\lambda_b)^{0{,}83}} \cdot \frac{E_{a,pipe} \cdot t_{pipe}}{E_{a,bend} \cdot t_b} \tag{D.4}$$

where

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

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

NOTE 2 Equations (D.3) and (D.4) are different to the corresponding equations in BS 7159. The SINTEF work [7] indicates that it is possible for the increased flexibility due to ovalization of the bend to be more than compensated for by a large increase in the wall thickness of the bend, with the result that the global flexibility factor could be less than 1, i.e. the bend is stiffer than the pipe.

NOTE 3 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 κ_b. For either smooth or mitred bends, it shall not be greater than 3.

D.2.2.3 Stress intensification factor (S_f)

For bends, smooth or mitred, four stress intensification factors are required to quantify the principal stresses. They are:

$S_{fa,ib}$ axial SIF under in-plane bending;

$S_{fa,ob}$ axial SIF under out-of-plane bending;

$S_{fh,ib}$ hoop SIF under in-plane bending;

$S_{fh,ob}$ hoop SIF under out-of-plane bending.

These S_f are functions of the pipe factor, λ_b, the axial pressure correction factor, δ_a, and the hoop pressure correction factor, δ_h where δ_h is given by:

$$\delta_{\text{h}} = \frac{1}{\left[1 + \left(1{,}1p/(E_{\text{h,bend}}) \cdot (R/t_{\text{b}})^{2/3} \cdot (D_{\text{i}}/2t_{\text{b}})^{11/6}\right)\right]} \quad \text{(D.5)}$$

The axial SIF under in-plane bending for a smooth bend, $S_{\text{fa,ib}}$, is given by (see Table D.1):

$$S_{\text{fa,ib}} = \delta_{\text{a}} \frac{0{,}76}{(\lambda_{\text{b}})^{2/3}} \quad \text{(D.6)}$$

For a hand-lay smooth bend, the factor 0,76 is replaced by 0,96.

The axial SIF under in-plane bending for a mitred bend, $S_{\text{fa,ib}}$, is given by (see Table D.1):

$$S_{\text{fa,ib}} = \delta_{\text{a}} \frac{0{,}5}{(\lambda_{\text{b}})^{2/3}} \quad \text{(D.7)}$$

The axial SIF under out-of-plane bending for a smooth bend, $S_{\text{fa,ob}}$, is given by (see Table D.1):

$$S_{\text{fa,ob}} = \delta_{\text{a}} \frac{0{,}56}{(\lambda_{\text{b}})^{2/3}} \quad \text{(D.8)}$$

For a hand-lay smooth bend, the factor 0,56 is replaced by 1,03.

The axial SIF under out-of-plane bending for a mitred bend, $S_{\text{fa,ob}}$, is given by (see Table D.1):

$$S_{\text{fa,ob}} = \delta_{\text{a}} \frac{0{,}51}{(\lambda_{\text{b}})^{2/3}} \quad \text{(D.9)}$$

The hoop SIF under in-plane bending for a smooth bend, $S_{\text{fh,ib}}$, is given by (see Table D.1):

$$S_{\text{fh,ib}} = \delta_{\text{h}} \frac{1{,}6}{(\lambda_{\text{b}})^{2/3}} \quad \text{(D.10)}$$

For a hand-lay smooth bend, the factor 1,6 is unchanged.

The hoop SIF under in-plane bending for a mitred bend, $S_{\text{fh,ib}}$, is given by (see Table D.1):

$$S_{\text{fh,ib}} = \delta_{\text{h}} \frac{1{,}2}{(\lambda_{\text{b}})^{2/3}} \quad \text{(D.11)}$$

The hoop SIF under out-of-plane bending for a smooth bend, $S_{\text{fh,ob}}$, is given by (see Table D.1):

$$S_{\text{fh,ob}} = \delta_{\text{h}} \frac{1{,}58}{(\lambda_{\text{b}})^{2/3}} \quad \text{(D.12)}$$

For a hand-lay bend, the factor 1,58 is replaced by 1,42.

The hoop SIF under out-of-plane bending for a mitred bend, $S_{\text{fh,ob}}$, is given by (see Table D.1):

$$S_{\text{fh,ob}} = \delta_{\text{h}} \frac{1{,}53}{(\lambda_{\text{b}})^{2/3}} \quad \text{(D.13)}$$

An upper limit, based on experience, is placed on all four S_{f} . No S_{f} shall be greater than 2.5.

D.2.2.4 Pressure stress multiplier (m_{psb})

The procedures given in ISO 14692-2 establish the qualified pressure for components within the pipe system. If Equation (7) is used to determine the qualified service stress for bends, then the stress concentrations within the component will already be taken into account. In these circumstances the pressure stress multiplier, m_{psb}, used in system design calculations shall be set to 1.

For bends that have not been qualified according to the procedures given in ISO 14692-2,the following values of pressure stress multiplier, m_{psb}, shall apply;

— for smooth bends, the pressure stress multiplier, m_{psb}, shall be 1;

— for mitred bends, the pressure stress multiplier, m_{psb} shall be 1,3.

D.2.2.5 Stress analysis

The purpose of the stress analysis is to calculate effective hoop and axial stresses which can then be used to assess whether the stress levels in the bend are within acceptable limits, i.e. within the factored long-term design envelope.

The effective hoop and axial stresses, $\sigma_{heff,b}$ and $\sigma_{aeff,b}$, in megapascals, are given by:

$$\begin{aligned} \sigma_{heff,b} &= \sqrt{\left(\sigma_{hp}+\sigma_{hb}\right)^2+4\xi^2} \\ \sigma_{aeff,b} &= \sqrt{\left(\sigma_{ap}+\sigma_{ab}\right)^2+4\xi^2} \end{aligned} \qquad \text{(D.14)}$$

where

σ_{hp} is the hoop pressure stress, in megapascals $= \dfrac{m_{psb}\cdot p\left(D_i+t_b\right)}{2t_b}$

σ_{ap} is the axial pressure stress, in megapascals $= \dfrac{p\left(D_i+t_b\right)}{4t_b}$

σ_{hb} is the hoop bending stress, in megapascals $= \dfrac{\left(D_i+2t_b\right)}{2I_b}\sqrt{\left(S_{fh,ib}M_i\right)^2+\left(S_{fh,ob}M_o\right)^2}$

σ_{ab} is the axial bending stress, in megapascals $= \dfrac{\left(D_i+2t_b\right)}{2I_b}\sqrt{\left(S_{fa,ib}M_i\right)^2+\left(S_{fa,ob}M_o\right)^2}$

ξ is the torsional stress, in megapascals $= 1{,}5\times\dfrac{M_T\left(D_i+2t_b\right)}{4I_b}$

NOTE 1,5 is a stress intensification factor.

p is the applied pressure, in bar (MPa)

M_i is the applied in-plane bending moment, in newton millimetres

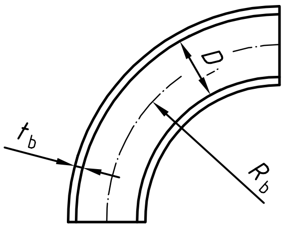
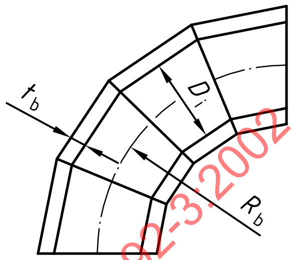
M_o is the applied out-of-plane bending moment, in newton millimetres

M_T is the applied torsional moment, in newton millimetres

I_b is the second moment of area, in millimetres^4 (mm^4) $= \dfrac{\pi}{64}\left(\left[D_i+2t_b\right]^4-D_i^4\right)$

If the stresses, $\sigma_{heff,b}$ and $\sigma_{aeff,b}$, lie inside the factored long-term design envelope, then the bend is designed within acceptable limits. If the stresses lie outside the this envelope, then a higher-rated bend, i.e. a thicker-walled bend, shall be chosen and the stress calculations repeated.

Table D.1 — Summary of piping design factors for bends

Bends	Smooth	Mitred
Diagram		
Pipe factor	$\lambda_b = \frac{4 t_b R_b}{D_i^2}$	
Axial pressure correction factor	$\delta_a = \frac{1}{\left(1+\left[2{,}53\, p/(E_{h,bend}) \cdot (R_b/t_b)^{1/3} \cdot (D_i/2t_b)^2\right]\right)}$	
Hoop pressure correction factor	$\delta_h = \frac{1}{\left(1+\left[1{,}1\, p/(E_{h,bend}) \cdot (R/t_b)^{2/3} \cdot (D_i/2t_b)^{11/6}\right]\right)}$	
Flexibility factor	$\kappa_b = \delta_a \cdot \frac{0{,}7}{\lambda_b} \cdot \frac{E_{a,pipe} \cdot t_{pipe}}{E_{a,bend} \cdot t_b}$	$\kappa_b = \delta_a \cdot \frac{0{,}64}{(\lambda_b)^{0{,}83}} \cdot \frac{E_{a,pipe} \cdot t_{pipe}}{E_{a,bend} \cdot t_b}$
SIF axial/in-plane	$S_{fa,ib} = \delta_a \frac{0{,}76}{(\lambda_b)^{2/3}}$ with $S_{fa,ib} \leqslant 2{,}5$	$S_{fa,ib} = \delta_a \cdot \frac{0{,}5}{(\lambda_b)^{2/3}}$ with $S_{fa,ib} \leqslant 2{,}5$
SIF axial/out-of-plane	$S_{fa,ob} = \delta_a \frac{0{,}56}{(\lambda_b)^{2/3}}$ with $S_{fa,ob} \leqslant 2{,}5$	$S_{fa,ob} = \delta_a \frac{0{,}51}{(\lambda_b)^{2/3}}$ with $S_{fa,ob} \leqslant 2{,}5$
SIF hoop/in-plane	$S_{fh,ib} = \delta_h \frac{1{,}6}{(\lambda_b)^{2/3}}$ with $S_{fh,ib} \leqslant 2{,}5$	$S_{fh,ib} = \delta_h \frac{1{,}2}{(\lambda_b)^{2/3}}$ with $S_{fh,ib} \leqslant 2{,}5$
SIF hoop/out-of-plane	$S_{fh,ob} = \delta_h \frac{1{,}58}{(\lambda_b)^{2/3}}$ with $S_{fh,ob} \leqslant 2{,}5$	$S_{fh,ob} = \delta_h \frac{1{,}53}{(\lambda_b)^{2/3}}$ with $S_{fh,ob} \leqslant 2{,}5$
Pressure stress multiplier	$m_{psb} = 1$	$m_{psb} = 1$ (see D.2.2.4 for conditions) or $m_{psb} = 1{,}3$
NOTE Modifications to these equations for smooth hand-lay components are given in the main text.		

D.2.3 Tees

D.2.3.1 General

At the intersection point of tee sections, stresses and their direction become complex and cannot easily be related to applied pressure and tensile loads. There are no analytical expressions that can be used to calculate stresses within tees and, as a consequence of this, relationships for pressure stress multipliers, stress intensification factors and flexibility factors available in piping codes are empirical.

From recent work within the Marinetech programme [8], where typical tee sections were loaded under combined bending and internal pressures, the following conclusions can be drawn.

a) Maximum stress intensification factors due to pressure are of the order of unity and are located in the intersection region.

b) Maximum stress intensification factors due to bending are also of the order of unity. Additional stresses due to bending can therefore be added to pressure stresses.

Therefore, it is the intersection region that governs component performance. Based on this conclusion, the design envelope for tees is therefore similar to that for joints. That is, failure under tensile load is dominated by axial “pull-out” at the intersection of the pipe and tee, and under pressure is dominated by weepage. This implies that the long-term failure envelope is rectangular.

The following empirical relationships for flexibility factor, stress intensification factors, and pressure stress multipliers are based on BS 7159. The assumptions and restrictions of the empirical formulae should be considered when using these relationships in a piping system design.

NOTE In terms of laminate types as described in BS 7159, only type 3 filament-wound laminates are considered.

D.2.3.2 Flexibility factor (κ_t)

The flexibility factor, κ_t, for GRP tees irrespective of whether the tee is equal or unequal, moulded or fabricated shall be 1, see Table D.2.

D.2.3.3 Stress intensification factor (S_{ft})

The stress intensification factor, S_{ft}, for tees is non-directional and is a function of the pipe factor, λ_t, where λ_t is given by:

$$\lambda_t = \frac{2t_t}{D_i} \text{ for equal tees}$$

$$\lambda_t = \frac{(2t_{br}/D_b)^2}{2t_t/D_i} \text{ for unequal tees} \tag{D.15}$$

where

t_{br} is the average wall thickness of the branch laminate of the tee, in millimetres;

D_b is the internal diameter of the branch of the tee, in millimetres (see Table D.2 for details).

NOTE The wall thickness of the reference laminate is defined as the wall thickness of the equivalent pipe section used for modelling purposes in the piping system design calculations.

The stress intensification factor is given as a function of λ_t:

$$S_{ft} = \frac{0{,}66}{(\lambda_t)^{0{,}5}} \tag{D.16}$$

An upper limit, based on experience, is placed on S_{ft}. It shall not be greater than 2,3.

D.2.3.4 Pressure stress multiplier (m_{pst})

The procedures given in ISO 14692-2 establish the qualified pressure for components within the pipe system. If Equation (7) is used to determine the qualified service stress for tees, then the stress concentrations within the component will already be taken into account. In these circumstances, the pressure stress multiplier, m_{pst}, used in system design calculations shall be set to 1.

For tees that have not been qualified according to the procedures given in ISO 14692-2, the value of the pressure stress multiplier, m_{pst}, shall be determined according to the following method.

The pressure stress multiplier, m_{pst}, for tees is non-directional and is a function of the pipe factor, λ_t, where λ_t is given by equation (D.15). The pressure stress multiplier, m_{pst}, is given as a function of λ_t:

$$m_{pst} = \frac{1{,}4}{(\lambda_t)^{0{,}25}} \tag{D.17}$$

An upper limit, based on experience, is placed on m_{pst} such that m_{pst} shall not be greater than 3.

D.2.3.5 Stress analysis

The effective hoop and axial stresses, $\sigma_{heff,t}$ and $\sigma_{aeff,t}$, in megapascals, are given by:

$$\begin{aligned} \sigma_{heff,t} &= \sqrt{(\sigma_{hp} + \sigma_{hb})^2 + 4\xi^2} \\ \sigma_{aeff,t} &= \sqrt{(\sigma_{ap} + \sigma_{ab})^2 + 4\xi^2} \end{aligned} \tag{D.18}$$

where

σ_{hp} is the hoop pressure stress, in megapascals $= \dfrac{m_{pst}\, p(D_i + t_t)}{2t_t}$

σ_{ap} is the axial pressure stress, in megapascals $= \dfrac{p(D_i + t_t)}{4t_t}$

σ_{hb} is the hoop bending stress, in megapascals $= 0$

σ_{ab} is the axial bending stress, in megapascals $= \dfrac{(D_i + 2t_t)}{2I_b} S_{ft} \sqrt{M_i^2 + M_o^2}$

ξ is the torsional stress, in megapascals $= \dfrac{1{,}5 \times M_T (D_i + 2t_t)}{4I_t}$

p is the applied pressure, in megapascals;

M_i is the applied in-plane bending moment, in newton millimetres;

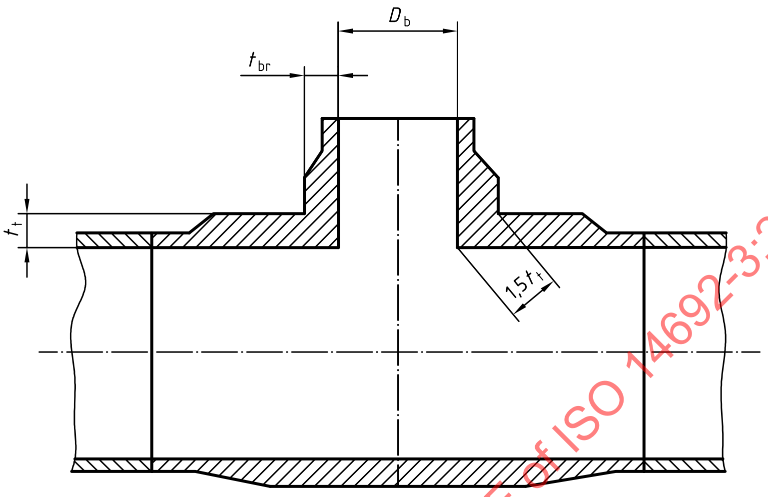
M_o is the applied out-of-plane bending moment, in newton millimetres;

M_T is the applied torsional moment, in newton millimetres;

I_t is the second moment of area of tee, in millimetres^4 (mm^4) $= \dfrac{\pi}{64}\left(\left[D_i + 2t_t \right]^4 - D_i^4 \right)$

If the stresses, $\sigma_{heff,t}$ and $\sigma_{aeff,t}$, lie inside the long-term factored design envelope, then the tee is designed within acceptable limits. If the stresses lie outside this envelope, then a higher-rated tee, i.e. a thicker-walled tee, shall be chosen and the stress calculations repeated.

Table D.2 — Summary of piping design factors for tees

Diagram		
Flexibility factor	$\kappa_t = 1$	
Stress intensification factor	$S_{ft} = \dfrac{0{,}66}{(\lambda_t)^{0{,}5}}$ with $S_{ft} \leqslant 2{,}3$	
Pipe factor	Equal tee	Unequal tee
	$\lambda_t = \dfrac{2t_t}{D_i}$	$\lambda_t = \dfrac{(2t_{br}/D_b)^2}{2t_t/D_i}$
Pressure stress multiplier	m_{pst} = 1 (see D.2.3.4 for conditions) or $m_{pst} = \dfrac{1{,}4}{(\lambda_t)^{0{,}25}}$ with $m_{pst} \leqslant 3{,}0$	

Annex E
(normative)

Calculation of support stresses for large-diameter liquid-filled pipe

E.1 General

The contact stresses at the support become significant for large-diameter liquid-filled pipes with large D/t ratio. This annex provides guidance on the calculation of the support stresses for large-diameter liquid-filled pipes using the following assumptions.

a) The mass of the GRP pipe is considered insignificant compared to the mass of the liquid contents.

b) The pipe material is considered isotropic, i.e. the hoop and axial modulus are the same.

NOTE 1 A conventional filament-wound GRP pipe has a hoop modulus about twice that in the axial direction.

c) The supports are flexible, for example they include an elastomeric pad.

d) The empirical coefficients are based on experimental data obtained on vessels of diameter 1 m and greater.

Alternative calculation procedures shall be acceptable if agreed with the principal. These include for example the use of finite element analysis techniques and procedures based on experience.

E.2 Axial stresses at mid-span

Consider a single span simply supported. The axial stresses at mid-span arise from the overall pressure, p, in megapascals, and the hydrostatic pressure head, together with the bending of the pipe between the span, L_s.

The axial stress, in megapascals, at the highest point of the cross-section is:

$$\sigma_{a,bp} = \frac{0{,}125}{t_r}\left[(2pD) + [\rho_L \times 9{,}81 \times (0{,}5D_i^2 - L_s^2)] \times 10^{-6}\right] \qquad \text{(E.1)}$$

where

p is the pressure, in megapascals;

D is the mean pipe diameter of reinforced wall, in metres = $(D_i + 2t - t_r)$;

D_i is the pipe inner diameter, in metres;

t is the nominal wall thickness, in metres;

t_r is the average reinforced wall thickness, in metres;

L_s is the support span, in metres;

ρ_L is the density of fluid within the pipe, in kilograms per cubic metre.

NOTE The mass of the GRP pipe is insignificant compared to the mass of the liquid contents.

The axial stress, in megapascals, at the lowest point of the cross-section is:

$$\sigma_{a,bp} = \frac{0{,}125}{t_r}\left[(2p \cdot D) + [\rho_L \times 9{,}81 \times (1{,}5 D_i^{\,2} + L_s^2)] \times 10^{-6}\right] \quad (E.2)$$

The mid-span vertical deflection, considering a single span simply supported, may be obtained from Equation (32).

E.3 Axial stresses at the pipe support

In this case, a section of the pipe is isolated on either side of the support (see Figure E.1).

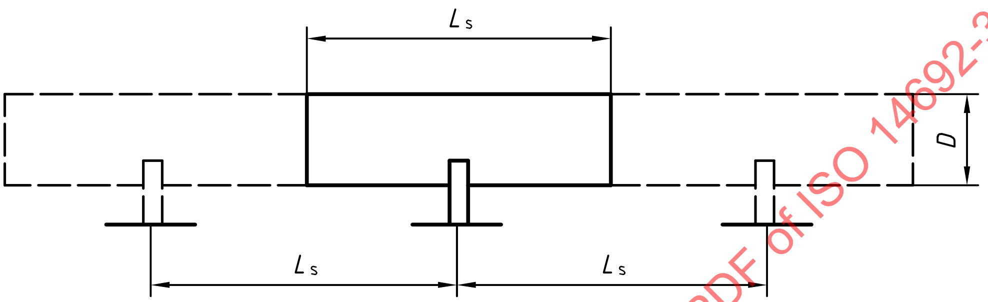


Figure E.1 — Section of the pipe isolated on either side of the support

The axial stress, in megapascals, at the point of greatest overall bending tensile stress is:

$$\sigma_{a,bp} = \frac{0{,}125}{t_r}\left[(2p \cdot D) + [\rho_L \times 9{,}81 \times D_i^{\,2} + \frac{\rho_L \times 9{,}81}{K_1}(L_s^2 - 0{,}5 D_i^{\,2})] \times 10^{-6}\right] \quad (E.3)$$

where the dimensions and parameters are the same as in E.2.

The axial stress, in megapascals, at the lowest point of the cross-section is:

$$\sigma_{a,bp} = \frac{0{,}125}{t_r}\left[(2p \cdot D) + [\rho_L \times 9{,}81 \times D_i^{\,2} - \frac{\rho_L \times 9{,}81}{K_2}(L_s^2 - 0{,}5 D_i^{\,2})] \times 10^{-6}\right] \quad (E.4)$$

The constants K_1 and K_2 for a range of total saddle angles, θ, are given in Table E.1.

Table E.1 — Values of constants K_1 and K_2

θ degrees	K_1	K_2
120	0,107	0,192
135	0,132	0,234
150	0,161	0,279
165	0,193	0,328
180	0,229	0,380

E.4 Shear stress in the pipe at the support

Using the isolated support concept employed above, the maximum shear stress, in megapascals, is given by:

$$\tau_{\text{max}} = K_3 \times \rho_{\text{eff}} \times 9{,}81 \times \left[\frac{\pi D}{4 t_\text{r}}\right] \times L_\text{s} / 10^6 \tag{E.5}$$

where the dimensions and parameters are the same as in 8.6.

NOTE This equation does not include the effect of internal pressure.

The constant K_3 for a range of total saddle angles, θ, is given in Table E.2:

Table E.2 — Values of constants K_3 for a range of total saddle angles, θ

θ degrees	120	135	150	165	180
K_3	1,171	0,958	0,799	0,675	0,577

The allowable shear stress, $\tau_{\text{allowable}}$, in megapascals, shall not be greater than $50/K$, where $K = 5$ for filament-wound pipes

Alternatively the value of K may be determined by experiment.

In all cases, $\tau_{\text{allowable}} > \tau_{\text{max}}$.

E.5 Hoop stresses at the pipe support

E.5.1 General

Hoop stresses, in megapascals, shall be determined at the lowest point of the support cross-section (the nadir) and at the uppermost point of the support (the saddle horn). Using again the isolated support concept, the following stress equations are obtained.

E.5.2 Hoop stress at the nadir

$$\sigma_\text{h} = -K_4 \times \frac{9{,}81 \times L_\text{s} \times \rho_0}{t_\text{r}(b_1 + 10 \cdot t_\text{r}) \times 10^6} \tag{E.6}$$

where

the dimensions and parameters are the same as in 8.6;

b_1 is the width of the saddle support, in metres.

NOTE This equation does not include the effect of internal pressure.

The constant K_4 for a range of total saddle angles, θ, is given in Table E.3:

Table E.3 — Values of constants K_4 for a range of total saddle angles, θ

θ degrees	120	135	150	165	180
K_4	0,750	0,711	0,673	0,645	0,624

If the pipe and support are fixed together, K_4 is 1/10th the value given in Table E.3.

If the pipe is not fixed to the support, the full value of K_4 shall be used.

E.5.3 Hoop stress at the saddle horn

$$\sigma_h = \left[\frac{9{,}81 \times L_s \times \rho_0}{4t_r(b_1 + 10t_r)} + \frac{3}{2} K_5 \left(\frac{9{,}81 \times L_s \times \rho_0}{t_r^{\ 2}} \right) \right] / 10^6 \qquad \text{(E.7)}$$

where

the dimensions and parameters are the same as in 8.6;

b_1 is the width of the saddle support, in metres.

NOTE This equation does not include the effect of internal pressure.

The constant K_5, for a range of total saddle angles, θ, is given in Table E.4:

Table E.4 — Values of constants K_5 for a range of total saddle angles, θ

θ degrees	120	135	150	165	180
K_5	0,0528	0,0413	0,0316	0,0238	0,0174

The hoop stresses given by Equations (E.6) and (E.7) shall be checked with the appropriate allowable values.

